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Performance Confirmation Plan

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CHANGE HISTORY

Revision Number	Interim Change No.	Effective Date	Description of Change
00	0	09/29/1997	Initial issue of Plan issued as Report No. B00000000-00841-4600-00002; this version served as basis for Viability Assessment Report.
01	0	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	01	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	02	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 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.	Effective Date	Description of Change
			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.

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The current revision of this report was prepared from work performed by Bechtel SAIC Company, LCC, under Contract Number DE-AC08-01RW12101, for the U.S. Department of Energy's Office of Civilian Radioactive Waste Management, Yucca Mountain Site Characterization Project. The assistance of a number of staff in preparing both the prior and current version of the plan is appreciated.

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EXECUTIVE SUMMARY

The *Performance Confirmation Plan* specifies monitoring, testing, and analysis activities to be conducted for evaluating the accuracy and adequacy of the information used in the License Application with regard to postclosure repository performance specified in Section 113(b) of the "Revised Interim Guidance Pending Issuance of New U.S. Nuclear Regulatory Commission (NRC) Regulations (Revision 01, July 22, 1999), for Yucca Mountain, Nevada" (Dyer 1999). The activities of the plan will focus on the processes (factors) important to postclosure safety and in compliance with the guidance and other applicable regulations and requirements.

This document is to be used as a basis for detailed planning of the performance confirmation program. It is also to be used as a basis for the identification of design requirements in system description documents for performance confirmation systems and for the development of total-system life-cycle cost estimates for the potential monitored geologic repository. In addition, a summary of the performance confirmation program will be included in the Site Recommendation report as part of the postclosure safety case.

The objectives for the program focus on compliance with regulatory requirements with an emphasis on postclosure sensitive items. The program is part of a reasonable assurance argument that postclosure conditions with long-term performance sensitivity will behave as expected. The program objectives are to: 1) provide data that subsurface conditions encountered and changes in those conditions during construction and waste emplacement operations are within the limits assumed in the licensing review, 2) provide data that natural and engineered systems and components that are required for repository operations and designed or assumed to operate as barriers after permanent closure are functioning as intended and anticipated, and 3) comply with U.S. Nuclear Regulatory Commission requirements for performance confirmation. Additionally, data obtained during performance confirmation will be used to support an evaluation of the repository's readiness for permanent closure.

The performance confirmation approach is comprised of eight major steps. The first step is to identify which processes are to be measured, the "key" performance confirmation factors. The second step is to define a performance confirmation database and predict performance. This includes identifying the processes and parameters important to postclosure performance and for which preclosure measurements can discern that pre- and postclosure values will be within predicted ranges. Part of this step is to predict values and variations of critical performance measures for the key parameters; these establish expectations during construction and operations. The third step is to establish tolerances or predicted limits or deviations from predicted values of the parameters. The fourth step is to identify completion criteria (which determine when data are sufficient) and guidelines for corrective actions to be applied when variances occur; this fourth step completes the definition of the performance confirmation baseline. The fifth step is to conduct detailed test planning of test and monitoring activities to measure the key parameters. The sixth step is to monitor performance, perform tests, and collect data. The seventh step is to analyze and evaluate the obtained data; these evaluations can include the use of process models, analyses, statistical tests, and total system performance assessments. The last step is to recommend and implement appropriate actions if there are deviations from what was predicted or assumed. If there are no deviations, or when the completion criteria of the activity are satisfied, the information will be used to support the evaluation of the repository's readiness for

permanent closure. The evaluation itself, however, is beyond the scope of performance confirmation.

Key performance confirmation factors for the program were identified based on: (1) factors that are important to repository safety based on the total system performance assessments and in accordance with the repository safety strategy, (2) other factors potentially important to postclosure safety such as additional data needs identified through the development of process models used to predict the repository performance, (3) factors or testing indicated by current regulatory guidance and repository requirements, and (4) factors due to licensing conditions. For the current version of the plan, identification of factors important to repository performance was based on the principal factors from the current safety strategy together with available performance sensitivity analyses.

Testing concepts for performance confirmation are also developed and described in this plan. This testing (when conducted) will focus on key parameters and will provide information to performance analyses to reduce uncertainty in the assessment of postclosure performance, as well as provide the data that will confirm the information used to determine that the postclosure objective will be met. The test concepts provide a general description of the methods that can be used in conducting performance confirmation testing and monitoring activities, and the description is extended to include the facilities needed to implement the concepts. Specific concepts in the plan are developed for subsurface geologic mapping, sample-based water and rock testing, seal testing, in-drift inspection of emplacement drifts, simulated postclosure drifts, and waste package materials testing together with facilities (such as dedicated observation drifts) required to monitor, collect, and analyze the data. These activities and concepts are integrated with the overall repository test and evaluation program to ensure the most effective and efficient use of limited resources.

Using the key performance confirmation factors and based on the identified test concepts, a preliminary set of test descriptions is developed in the plan as shown in Table ES-1. These test descriptions are to provide a brief definition of the activities to be performed with detailed planning to follow. The descriptions also serve as a basis for other related activities such as the project estimate of total-system life-cycle costs, and to serve as a basis for detailed test planning to follow. For each major test and monitoring activity, a test description is provided that defines the purpose, provides a description, identifies the parameters to be addressed, as well as identifying test interfaces and constraints and the period of performance.

It is important to note that the parameters and concepts identified for performance confirmation are based on the higher-temperature operating mode, the conceptual repository design, the current understanding of natural and engineered barrier processes, the mathematical models formulated for these processes, the computer codes that have been developed to simulate these processes, and the parameters required for these computer codes. Uncertainties still exist regarding many of these processes, such as rock matrix and fracture flow interactions and waste package corrosion. As new understanding is gained during licensing, construction, and operations, these concepts are expected to change which, in turn, could necessitate changes in the *Performance Confirmation Plan*.

Table ES-1. Identified Performance Confirmation Testing and Monitoring Activities

Test Category	Test Element	Test Number	Performance Confirmation Description
Core Performance Confirmation	Process Monitoring	PM-01	Seepage Monitoring
		PM-02	In Situ Waste Package Monitoring
		PM-03	Long-Term Materials Testing
		PM-04	Ventilation Monitoring
		PM-05	Rock Mass Monitoring
		PM-06	In-Drift Monitoring
		PM-07	Introduced Materials Monitoring
		PM-08	Recovered Material Coupon Testing
		PM-09	Dummy Waste Package Testing
		PM-10	Recovered Waste Package Testing
	Postclosure Simulation	PS-01	Postclosure Simulation Testing
Development Testing	Baseline Development	BD-01	Geologic Observations and Mapping
		BD-02	Subsurface Sampling and Index Testing
		BD-03	Baseline Analyses and Evaluations [1]
	Pre-Emplacement Testing	PE-01	Unsaturated Zone Testing
		PE-02	Near-Field Environment Testing
		PE-03	Waste Form Testing
		PE-04	Waste Package Testing
Prototype Testing	EBS[2] Testing and Verification	EB-01	Borehole Seal Testing
		EB-02	Ramp and Shaft Seal Testing
Technical Specifications and Monitoring	Environmental Monitoring	EM-01	Groundwater Quality Monitoring
	Disruptive Event Monitoring	DE-01	Groundwater Level and Temperature Monitoring
		DE-02	Surface Uplift Monitoring
		DE-03	Subsurface Seismic Monitoring

NOTE: [1] This activity supports all other performance confirmation activities and is included for completeness.
[2] EBS (engineered barrier system).

In addition, the current version of the *Performance Confirmation Plan* will require revision prior to the License Application in order to define and describe more fully the tests to be conducted, the parameters to be measured, the predicted values for those measurements, and the criteria for test completion. Conditions for changing or terminating tests to be described in the License Application must also be developed and documented. This is a consequence of the evolving nature of the design, anticipated changes in the reasonable assurance arguments for postclosure safety, and completion of more rigorous postclosure performance sensitivity analyses.

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ACRONYMS AND ABBREVIATIONS

Acronyms

AMR(s)	analysis model report(s)
CFR	Code of Federal Regulations
CHn	Calico Hills nonwelded tuff unit, Hydrogeologic Stratigraphy
CRWMS	Civilian Radioactive Waste Management System
CSNF	commercial spent nuclear fuel
DHLW	defense high-level waste
DOE	U.S. Department of Energy
Eh	oxidation-reduction potential
EPA	U.S. Environmental Protection Agency
ESF	Exploratory Studies Facility
GROA	geologic repository operations area
HLW	high-level waste
LA	License Application
M&O	Management and Operating Contractor
MGR	monitored geologic repository
MGR-PDD	Monitored Geologic Repository Project Description Document
NG	Nuclear Grade
NRC	U.S. Nuclear Regulatory Commission
pH	hydrogen ion concentration notation
PMR(s)	process model report(s)
QA	quality assurance
RSS	Repository Safety Strategy: Plan to Prepare the Safety Case to Support Yucca Mountain Site Recommendation and Licensing Considerations
ROV(s)	remotely operated vehicle(s) (same as remote inspection gantry)
SNF	spent nuclear fuel
SSCs	structures, systems, and components
SZ	saturated zone
TMH	thermal-mechanical-hydrological
TSPA(s)	total system performance assessment(s)
TSw	Topopah Spring welded tuff unit, Hydrogeologic Stratigraphy

ACRONYMS AND ABBREVIATIONS (Continued)

UNS	Unified Numbering System; classification system for metals and alloys, from American Society for Testing and Materials
UZ	unsaturated zone
VA	Viability Assessment
YMP	Yucca Mountain Site Characterization Project
YMP-RD	Yucca Mountain Site Characterization Project Requirements Document

Abbreviations

Bq	Becquerel, the SI measure of radioactivity, equal to 1 nuclear disintegration/second
cm	centimeter, 10^{-2} m
kgHM	kilograms of heavy metal
km	kilometer, 10^{+3} meters
kg	kilogram, 10^{+3} grams
kW	kilowatt, 10^{+3} Watts
m	meter, SI unit of distance
ml/g	milliliter/gram
mm	millimeter, 10^{-3} meters
mrem	millirem, 10^{-3} rems
mSv	milliSievert, 10^{-3} Sv
MT	metric ton, 10^{+3} kg
MTIHM	metric tons of initial heavy metal
MTHM	metric tons of heavy metal
picocuries	10^{-12} curies (1 curie equals that quantity of any radioactive isotope undergoing 3.7×10^{10} disintegrations/second)
rem	Roetgen equivalent man, a unit of dose equivalent
SI	System International; the international system of units
Sv	Sievert, the SI unit of measure of absorbed dose equivalent; 1 Sv equals 100 rem.
uSv	microSieverts, 10^{-6} Sv

1. INTRODUCTION

1.1 PLAN BASIS

1.1.1 Objective

The intent of this document is to provide a comprehensive plan for conducting performance confirmation. As defined in this context, performance confirmation is to evaluate the information used to determine with reasonable assurance that the performance objective (as stated in the governing regulations for the period after permanent repository closure) will be met. A performance confirmation program has been implemented under the repository program for this intent. The *Performance Confirmation Plan* specifies the monitoring, testing, and analysis activities to be conducted under the ongoing program.

1.1.2 Scope

The *Performance Confirmation Plan* identifies the monitoring and testing activities in the form of test descriptions. These test descriptions provide a brief synopsis of the testing and monitoring approach, as well as important parameters to be addressed by the test and the test constraints and interfaces.

The *Performance Confirmation Plan* also identifies the process of selecting parameters to be studied and the overall process to evaluate the data collected. All performance confirmation activities will be conducted as part of the U.S. Department of Energy's (DOE) strategy for developing and implementing the performance confirmation program. Fundamental elements of this strategy consist of the following:

- The performance confirmation program is to be clearly identifiable and traceable to the regulatory requirements.
- The program is to be further defined and focused by utilizing the safety strategy for the repository, total system performance assessments (TSPAs), and licensing commitments.
- The testing approach will define the necessary and sufficient set of requirements governing performance confirmation and will be integrated with the overall repository test and evaluation program objectives and planning strategy.

This strategy will be used to define an efficient, integrated, overall monitored geologic repository (MGR) test program.

Performance confirmation test and evaluation activities include test predictions, in situ testing, laboratory testing, test data analyses, and evaluations. The scope of tests and analyses are defined in the plan to ensure integration with repository design, design development testing, and other test and evaluation planning. The plan also establishes a basis for detailed performance confirmation planning activities.

The performance confirmation program was started during site characterization and will continue until permanent closure of the facility. During site characterization, the program addressed activities necessary for the development of the performance confirmation baseline and a transition of responsibilities for monitoring those parameters and natural processes pertaining to the geologic setting that were identified during site characterization.

In the future, the performance confirmation program will consist primarily of testing, monitoring, and evaluation activities. The transition from baseline development to monitoring and evaluation activities will occur after submittal of the Site Recommendation report and before the start of emplacement of waste in the repository. In the License Application (LA) for construction authorization, activities to address additional data or model validation needs will be described. The licensing data needs will be identified as a result of the presently ongoing process model report (PMR) development and will be addressed under the performance confirmation program.

Concurrent with the licensing data activities, ongoing monitoring and testing activities, as appropriate, will be transitioned and conducted under the performance confirmation program and described in the *Performance Confirmation Plan*. Only those activities related to postclosure performance, however, will be included in the plan. In addition, the performance confirmation baseline development will be completed in conjunction with subsurface construction and will identify, where appropriate, the expected limits and bounds for data to be used in performance evaluations for each test and monitoring activity under the performance confirmation program.

1.1.3 Plan Application

The *Performance Confirmation Plan* is to provide input into and an overview of the planning of performance confirmation testing and analyses. Specifically, the plan provides the framework for the preparation of detailed test plans for performance confirmation activities.

In addition, the *Performance Confirmation Plan* provides input to define requirements for the system description documents relative to performance confirmation related facilities and equipment. These facilities, in turn, will be incorporated into the design of subsurface facilities. The *Performance Confirmation Plan* is also used as a basis for annual and long-term planning and for the total-system life-cycle cost estimates for the potential repository.

1.1.4 Plan Revisions

This current version of the *Performance Confirmation Plan* was revised from an earlier document (CRWMS M&O 1997a), and used the *Performance Confirmation Concepts Study Report* (CRWMS M&O 1996a) to assist concept development. The plan was revised to address a new MGR configuration and to incorporate the revised regulatory guidance on proposed 10 CFR 63 (Dyer 1999). This version of the plan will be used as a support document in the preparation of the Site Recommendation report.

The *Performance Confirmation Plan* will continue to evolve consistent with the project's postclosure safety case, necessitating revision to the plan prior to the LA submittal and as a consequence of future postclosure safety case modifications. Such modifications may be prompted by additional information collected prior to waste emplacement, continued evolution or enhancement of the repository design and engineered barrier system, improved or alternative modeling approaches, or changes in anticipated postclosure sensitivities as indicated by subsequent TSPAs. Future revisions will also be better able to address issues such as prioritization of performance confirmation testing activities relative to the project's overall test program.

1.1.5 Outline of the Performance Confirmation Plan

The *Performance Confirmation Plan* is organized to reflect the development process of the performance confirmation program. Section 1 includes an introduction and background information, which is used as basis for the plan. Section 2 provides a summary description of the performance confirmation program, including objectives, the overall approach used for performance confirmation activities, and a concise program schedule. Section 3 describes the requirements and inputs applicable to the performance confirmation program, and identifies the processes (factors) that are important to postclosure safety and that should be tested and monitored by the performance confirmation program. Section 4 provides a description of the flow of the overall program, identifies the performance confirmation baseline components, and describes the predictions of performance as they relate to performance confirmation. Section 5 discusses concepts that can be used in conducting testing and monitoring (together with concepts for related test facilities). Section 6 describes data evaluations, possible corrective actions (if variances occur), and the reporting of the obtained data. Using the concepts in Section 5, Section 7 is to provide test descriptions for the planned activities to provide a basis for detailed test planning (this section is not finalized at this time). Section 8 presents the conclusions and recommendations of the plan, and Section 9 contains cited references.

Appendices of supporting information are also provided, including a glossary of terms (Appendix A), applicable regulatory guidance (Appendix B), a comparison of this guidance to existing regulations (Appendix C), a brief description of the repository design (Appendix D), requirements analysis for performance confirmation (Appendix E), a brief description of the test and evaluation program components (Appendix F), a preliminary set of test activities (Appendix G) and a description of the impacts to the program of differing thermal operating modes (Appendix H).

1.1.6 Quality Assurance

An activity evaluation was performed for the development of the *Performance Confirmation Plan*. It determined that the work performed to meet performance confirmation requirements and develop the associated plan is to be performed under the program quality assurance (QA) requirements (Sellers 1999). The basis for this determination is that the *Performance Confirmation Plan* identifies testing and analysis requirements for the MGR to determine with reasonable assurance whether the items important to waste isolation are functioning properly. This activity is related to testing items important to waste isolation.

In more detail, the *Q-List* (YMP 2001b) identifies the structures, systems, and components (SSCs) important to safety as part of the project's QA program. The *Q-List* includes certain engineered barriers such as the waste package and underground excavations addressed by the plan. The *Q-List* also includes certain natural barriers such as the Topopah Spring welded hydrogeologic unit (TSw) and the Calico Hills nonwelded hydrogeologic unit (CHn) (YMP 2001b, p. 3). The *Performance Confirmation Plan* describes sample and data collection, evaluations, and analyses of these geologic units.

The *Performance Confirmation Plan* was developed in accordance with AP-3.11Q, *Technical Reports*, and appropriate QA procedures were used in the preparation, review, approval, and revision of the plan. The interim revision of this plan (Revision 01, ICN 02) was prepared and accomplished in accordance with the *Technical Work Plan for: Performance Confirmation Program* (BSC 2001e), including the management of electronic data. The *Quality Assurance Requirements and Description* (DOE 2000) will apply to performance confirmation activities when implemented, such as test control (DOE 2000, Section 11). The appropriate QA controls will be applied to those activities.

The use of computer software for computations was not employed in the development of the *Performance Confirmation Plan*. Also, a determination of importance evaluation, in accordance with NLP-2-0, *Determination of Importance Evaluations*, is not required for the *Performance Confirmation Plan*, as the development of the plan is not a field activity.

1.2 BACKGROUND

1.2.1 Monitored Geologic Repository System

The mission of the MGR is to provide for the emplacement and isolation of commercial and DOE spent nuclear fuel (SNF), civilian SNF, and defense high-level waste (DHLW), such that the public health and safety and the environment are protected (*Yucca Mountain Site Characterization Project Requirements Document* [YMP-RD], YMP 2001a, p. 1.2-1). The MGR is defined by its architecture, and is divided into three systems (YMP 2001a, pp. 1.2-2 to 1.2-3):

1. Waste Handling System
2. Waste Isolation System
3. Operational Support System.

The Waste Handling System receives, prepares, temporarily stores, and (if necessary) retrieves the waste. The Waste Isolation System confines the waste in a disposal container, emplaces waste packages into drifts in the underground facility, and, by isolating the waste in a geologic natural barrier system, limits the release of radioactive materials. The Operational Support System provides operational, logistical, and administrative support for operating and maintaining the MGR.

Performance confirmation is a subsystem of the Waste Isolation System, as are the engineered barrier system and the natural barrier system (YMP 2001a, p. 1.2-4). The discussion of the MGR and the conceptual design of a repository for this version of the *Performance Confirmation Plan* assume the use of the potential Yucca Mountain location for a repository site. This is not meant to indicate that the potential site has been selected or to prejudge the actual site selection process. Upon selection of the actual repository site, the plan will be modified accordingly.

1.2.2 Regulatory Basis

As part of the licensing process, all repository activities (including performance confirmation) will comply with the U.S. Nuclear Regulatory Commission (NRC) regulations applicable to the project. The requirements of these regulations are identified in the project's technical baseline, including the YMP-RD (YMP 2001a, Section 2.3.2.04). NRC regulations defining these requirements are contained in the Code of Federal Regulations (CFR).

However, in review of these requirements, it should be noted that some of the NRC regulations are in the process of change. An existing regulation, 10 CFR 60, *Energy: Disposal of High-Level Radioactive Waste in Geologic Repositories*, defines a number of performance confirmation aspects. This regulation is to be superseded by a new regulation, 10 CFR 63, *Disposal of High-Level Radioactive Wastes in a Proposed Geologic Repository at Yucca Mountain, Nevada,* and a draft of this proposed rule was issued in 1999 (64 FR 8640).

To bridge the transition period between 10 CFR 60 and the draft 10 CFR 63, DOE provided interim regulatory guidance. This guidance is in the form of a modified version of the draft 10 CFR 63 that incorporates proposed changes in the regulation, "Revised Interim Guidance Pending Issuance of New U.S. Nuclear Regulatory Commission (NRC) Regulations (Revision 01, July 22, 1999), for Yucca Mountain, Nevada" (Dyer 1999). It is referenced in the plan as the "Interim Guidance."

In compliance with this requirement, the present version of the *Performance Confirmation Plan* uses DOE's Interim Guidance (Dyer 1999) to define the requirements for performance confirmation. This is of particular importance to the performance confirmation program, as Subpart F of both 10 CFR 60 and 10 CFR 63 (as presented in the Interim Guidance) define the specific requirements for performance confirmation activities.

For reference, Subpart F of DOE's Interim Guidance on performance confirmation is contained in Appendix B of this plan. To provide a perspective on the impact of using this guidance instead of 10 CFR 60, Subpart F of the DOE's Interim Guidance is compared to the same section in 10 CFR 60, and is provided in Appendix C of this plan. Note that the differences shown are due to both the changes made by the NRC in its proposed 10 CFR 63, and by the DOE in the Interim Guidance.

Concurrent with the preparation of the current version of the *Performance Confirmation Plan*, the NRC has recently published the final rule for 10 CFR 63 (66 FR 55732). The applicable sections of this final rule and impacts of the changes in this rule from the draft version are discussed in Appendix E.

1.2.3 Repository Conceptual Design

The importance of the repository design to the *Performance Confirmation Plan* is that the design provides a context for defining performance confirmation activities as well as providing a basis for the definition of performance requirements that may be applied to the performance confirmation program. Therefore, as the design changes, it is necessary to assess the influence of these changes on performance confirmation activities.

It should be noted that the repository conceptual design has continued to evolve since the Viability Assessment (VA) (DOE 1998a, Sections 4 and 5). Based on an evaluation of repository design concepts and design features, a revised conceptual design was recommended for the potential geologic repository at Yucca Mountain (CRWMS M&O 1999e, pp. v to viii). This revised design, Enhanced Design Alternative II, was, with minor modification, adopted by the Civilian Radioactive Waste Management System (CRWMS) in 1999 (Wilkins and Heath 1999). In turn, this design was used in developing the present version of the *Performance Confirmation Plan*, and eventually developed into the nominal scenario for the Site Recommendation (e.g. BSC 2001a). This design is presently designated as the higher-temperature operating mode (see Appendix D). Subsequently, the flexible design process has continued to refine the design configuration, and several alternative, lower-temperature operating modes are currently under study. The potential impact of these alternatives on the current definition of the program is briefly evaluated in Appendix H. When the design process eventually determines the appropriate operating mode for the LA, this design will be evaluated and appropriate revisions will be made to the *Performance Confirmation Plan*.

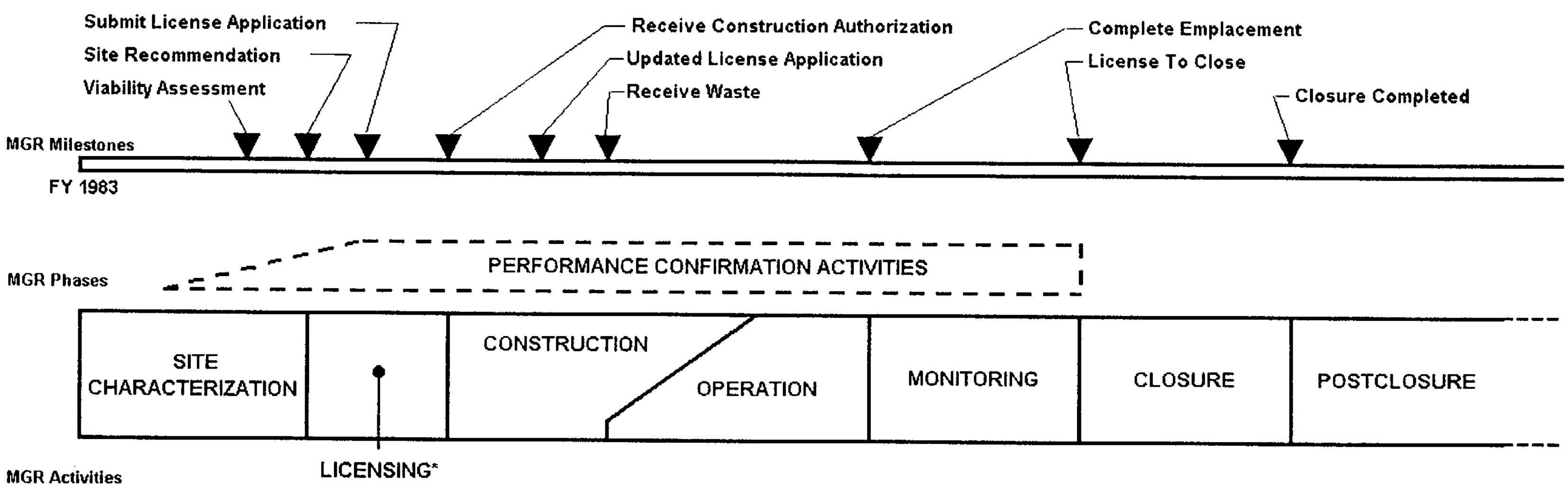
Some repository characteristics of importance to performance confirmation include:

- **The waste loading per area**–which influences the average thermal load across the subsurface area and affects the complexity of natural barrier response
- **The distance between drifts**–which influences the thermal flux field and the response of the near-field rock
- **The extent of ventilation**–during the preclosure period which influences the amount of heat that remains in the rock mass and influences the extent of the disturbed zone to be monitored
- **The waste package materials**–which influence the type and extent of performance confirmation testing
- **The inclusion of other engineered barriers**–the performance of which must be addressed by performance confirmation.

1.2.4 Repository Phases

The program to develop and operate the MGR can be divided into separate phases. A seven phase program is identified, as shown in Figure 1-1. These repository phases are:

1. Site characterization
2. Licensing
3. Construction
4. Operation
5. Monitoring
6. Closure
7. Postclosure.



SITE CHARACTERIZATION
- Surface-Based Tests
- ESF Construction
- ESF Testing & O&M
- Material Tests
- Process Model Development
- TSPA's
- Performance Confirmation

LICENSING
- Surface-Based Tests
- Development Testing
- Material Tests
- Process Model Development
- TSPA's
- Proof-of-Concept Testing
- Performance Confirmation

CONSTRUCTION
- Construct Surface Facilities & Equipment
- Construct Subsurface Facilities
- Disposal Container Fabrication
- Construction Testing
- Pre-Operational Testing
- Qualification Testing
- Performance Confirmation
- Mock-Up Activities

OPERATION
- Receive Waste
- Assemble Waste Package
- Underground Transport
- Emplace Waste Packages
- Maintain Safety/Security
- O&M
- Protect Retrieval
- Periodic Performance Testing
- Performance Confirmation
- Engineering Change Control
- Startup

MONITORING
- Maintain Safety/Security
- O&M
- Protect Retrieval
- Periodic Performance Testing
- Performance Confirmation

CLOSURE
- Place EBS Components Required for Closure
- Seal & Close Subsurface Facilities
- Decommission & Dismantle Surface Facilities
- Establish IBS
- Reclaim Site

POSTCLOSURE
- Confine Waste
- Isolate Waste

ABBREVIATIONS

ESF	Exploratory Studies Facility
EBS	Engineered Barrier System
IBS	Institutional Barrier System
O&M	Operations & Maintenance
TSPA	Total System Performance Assessment

* Modified from YMP (2001a); phases are modified to be consistent with the VA (see DOE 1998b, Figure 1-1; DOE 1998e, p. 2-1). A "Licensing Phase" is defined to occur between the Site Recommendation and the Construction Authorization milestones, and the "Caretaker Phase" has been retitled as "Monitoring Phase."

Figure 1-1. Repository Phases and Operations

The operational content of each phase is also briefly presented in Figure 1-1. As described in this plan, the performance confirmation period is shown starting during site characterization and extending to the start of the closure phase.

The phase titles and durations are taken from the Figure 1.2-5 of the YMP-RD (YMP 2001a), as modified by the VA report. Specifically, the figure was modified by the inclusion of the licensing phase (as identified in DOE 1998b, Figure 1-1) and the renaming of the caretaker phase to the monitoring phase (as identified in DOE 1998c, Section2.1.4, p. 2-1), together with adjustments to the activities list.

1.2.5 Monitored Geologic Repository Test and Evaluation Program

The *Performance Confirmation Plan* is a sub-tier document of the *Monitored Geologic Repository Test and Evaluation Plan* (Skorska 2001), and performance confirmation testing will be performed under the different categories of the MGR test and evaluation program. The objective of the MGR test and evaluation program is to define, design, and conduct testing for the MGR to: (1) support system design and development, (2) verify compliance with requirements, (3) evaluate the operational suitability and effectiveness of the system, (4) support the implementation of regulatory requirements (DOE 1995, p. 5) and compliance with quality controls, and (5) minimize cost/schedule impacts of test performance in meeting project milestones. The test and evaluation program is described in the *Monitored Geologic Repository Test and Evaluation Plan* (Skorska 2001), and additional information about the program can be found in the subject document.

The MGR test and evaluation program functions include:

- Evaluating the suitability of the Yucca Mountain site for housing a potential geologic repository by test and analysis
- Investigating design concepts to reduce risk
- Developing and testing models which are to support licensing and collecting baseline information pertinent to performance and design assumptions
- Performing testing to demonstrate design concepts and selected technologies and to evaluate potential design modifications, enhancements, and procedures
- Verifying SSCs compliance with design requirements and specifications
- Performing intermediate-level and system-level integration to validate compliance with MGR requirements; that includes the receipt, handling, retrieval, and disposal of waste
- Conducting periodic performance testing for continuing verification of preclosure requirements, to demonstrate safe and reliable MGR operation, and to comply with environmental monitoring
- Performing modeling, testing, and analysis to verify adherence to postclosure regulatory requirements.

To perform these functions, the *Monitored Geologic Repository Test and Evaluation Plan* (Skorska 2001) can conceptually be subdivided into major functional test categories (Figure 1-2). The test categories are as follows:

- Site Characterization Testing
- Development Testing
- Component Testing
- Prototype Testing
- Pre-operational and Startup Testing
- Periodic Performance Testing and Monitoring
- Core Performance Confirmation Testing
- Post-Permanent Closure Monitoring.

A more detailed description of each of these categories is presented in Appendix F.

The relationship of the performance confirmation program to these test categories takes advantage of testing that is performed for multiple reasons or objectives in order to make the most efficient use of limited test resources. Testing that is necessary to comply with regulatory requirements with particular emphasis on items important to the postclosure safety case are described by the *Performance Confirmation Plan*, while the remainder of the test program is to be captured by the *Monitored Geologic Repository Test and Evaluation Plan* (Skorska 2001) (see Figure 1-3).

The requirements of the performance confirmation program are satisfied by activities conducted under various test categories, some of which serve multiple purposes, and others that are conducted for the sole purpose of complying with performance confirmation requirements. This is indicated (by the different line styles) in Figure 1-2. Performance confirmation program testing is limited, however, to only those items necessary to comply with regulatory requirements or as a result of NRC licensing conditions, with a specific focus on items important to the postclosure safety. Performance confirmation will not address testing performed to address other regulatory requirements important to the preclosure safety case or testing conducted after the start of repository closure. These are instead addressed by the overall test program, as illustrated by Figure 1-3.

1.2.6 Repository Safety Strategy and Safety Case

The performance confirmation program is considered to be an important part of the strategy for the development of the postclosure safety case for the MGR. To document this strategy, a plan in support of the licensing strategy was developed by the CRWMS Management and Operating Contractor (M&O). The latest version of the document, *Repository Safety Strategy: Plan to Prepare the Safety Case to Support Yucca Mountain Site Recommendation and Licensing Considerations* (RSS) (CRWMS M&O 2001, Vol. 2), summarizes the current status of the safety case, identifies the processes important to postclosure safety, discusses the role of performance confirmation, and specifies the areas of work necessary to complete the regulatory case as needed to support site recommendation and initial LA decisions. In addition, the RSS is utilized

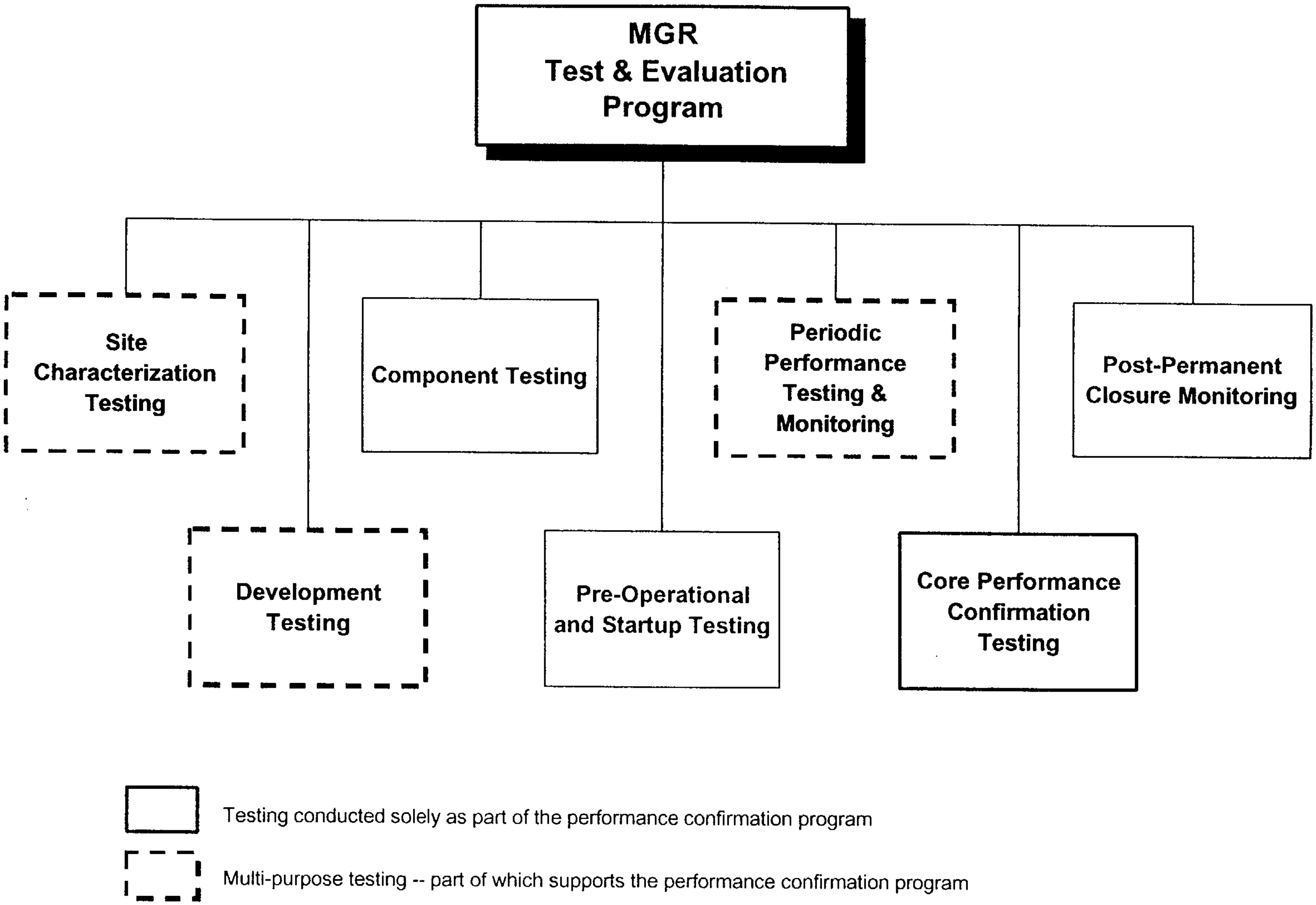
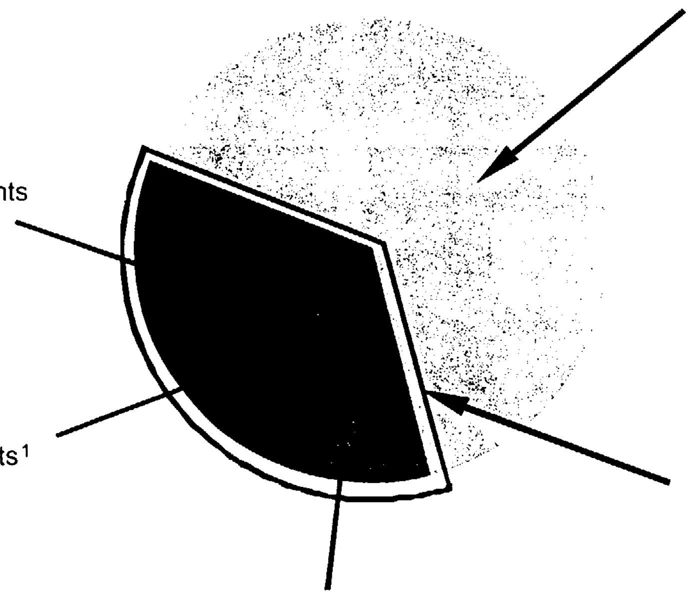


Figure 1-2. Test Categories of the Test and Evaluation Program



Notes:

[1] Included in Lieu of TSPA Sensitivity Analyses

[2] Tests Related to Preclosure Safety Requirements, MGR Operational Confidence, and Other Tests

Figure 1-3. Relationship of Performance Confirmation Program to the Test and Evaluation Program in this version of the *Performance Confirmation Plan* to assist in identifying performance confirmation factors as discussed in Section 3.

The postclosure safety case will utilize multiple lines of evidence regarding postclosure safety. Consequently, the strategy includes the following components (CRWMS M&O 2001, Vol. 2, p. 1-3):

- Performance assessment
- Safety margin and defense-in-depth
- Explicit consideration of potentially disruptive events
- Insights from natural analogues
- Performance confirmation.

The last component includes the performance of testing and monitoring activities together with evaluation of obtained data, as addressed by the *Performance Confirmation Plan.*

The interrelationship of these areas is integrated into the definition of the *Performance Confirmation Plan*.

2. OVERVIEW OF THE PERFORMANCE CONFIRMATION PROGRAM

2.1 PERFORMANCE CONFIRMATION PROCESS

2.1.1 Program Objectives

The performance confirmation program consists of tests, experiments, and analyses to evaluate the accuracy and adequacy of the information used to determine with reasonable assurance that the defined MGR postclosure objective is met. This objective is that the engineered barrier system shall be designed so that, working in combination with natural barriers, the expected annual dose to the average member of the critical group is less than 0.25 mSv (25 mrem) Total Effective Dose Equivalent during the first 10,000 years after closure, as a result of radioactive materials released from the geologic repository. This is defined in the "Revised Interim Guidance Pending Issuance of New U.S. Nuclear Regulatory Commission (NRC) Regulations (Revision 01, July 22, 1999), for Yucca Mountain, Nevada" (Dyer 1999, Section 2 and 113(b)).

The specific objectives of the program are:

- To provide data that indicate subsurface conditions and any changes during construction and waste emplacement fall within the limits assumed in the LA
- To provide data that indicate natural and engineered barrier systems and components required for repository operations (or designed or assumed to operate as barriers after permanent closure) are functioning as intended and anticipated
- To comply with NRC requirements for performance confirmation
- To provide information to support the authorization of permanent closure.

Data obtained during performance confirmation will be used to support an evaluation of the repository's readiness for permanent closure. In addition, these objectives will be pursued in a manner that does not adversely affect the ability of the natural and engineered barrier systems to meet the repository performance objectives as demonstrated in site performance protection analyses. The period of performance for the program extends from the site characterization phase to the start of the closure phase.

2.1.2 Concept of Operations

As part of the MGR program, the performance confirmation concept of operations is a process of data measurement and data evaluation. A major segment of this work is to obtain the appropriate data and evaluate these data against the performance confirmation baseline, as depicted in Figure 2-1. Schematically, sensors are installed, data is obtained and reduced (i.e., the electronic data are converted to engineering numbers), transmitted, and then evaluated by comparing the data to predicted bounds for confirmation. The bounds or tolerances vary with time to reflect construction and operation of the repository together with effects due to waste emplacement. In addition, as shown in Figure 2-1, a test-baseline period in general precedes the confirmation data to establish the ambient variability of the data acquisition process.

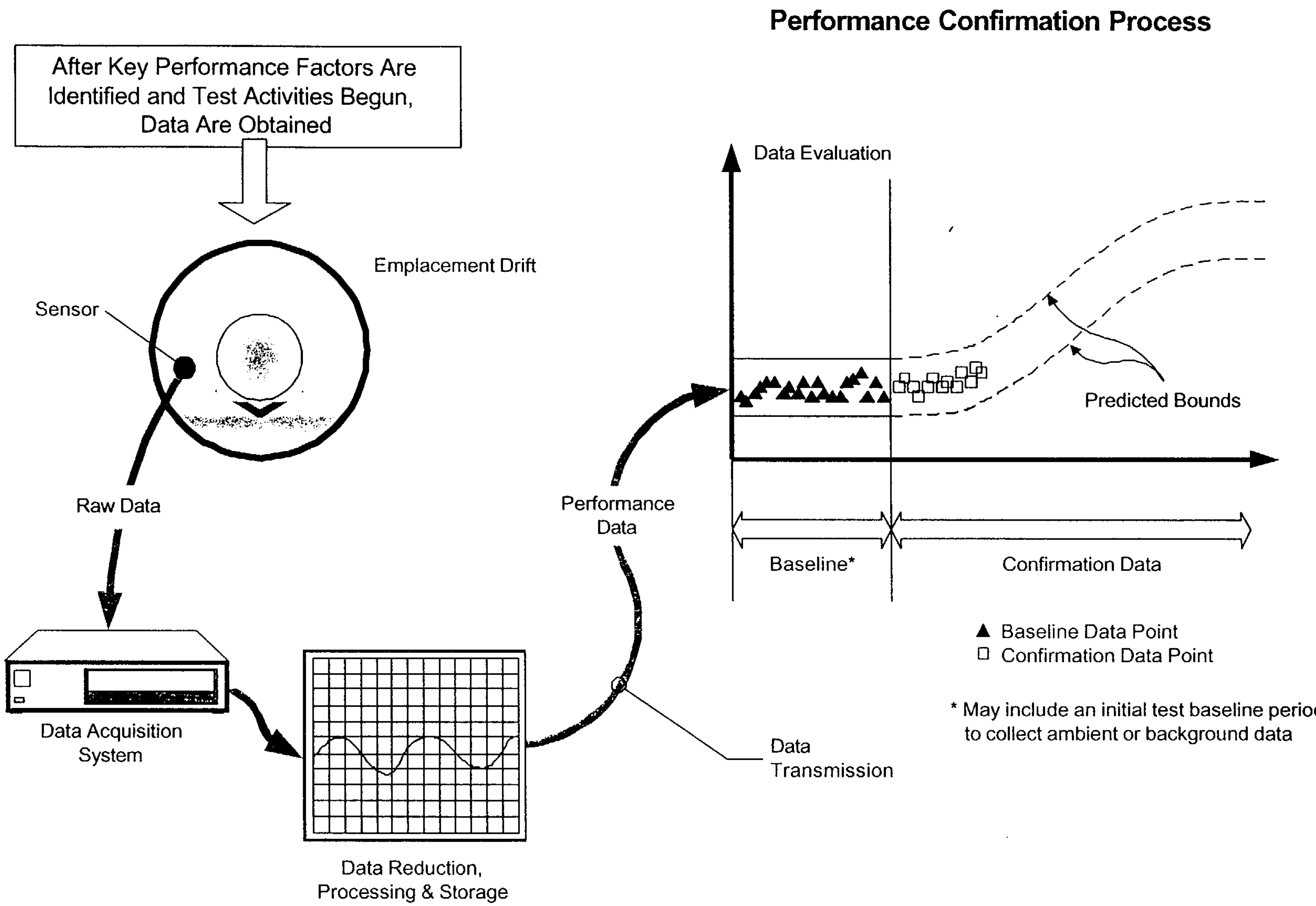


Figure 2-1. Schematic Diagram of Performance Confirmation Process From Testing to Data Evaluation

However, this simple schematic does not describe the entire process. In a more formal fashion, the concept of operations of performance confirmation can be summarized as a set of eight activities or steps (illustrated in Figure 2-2):

1. **Identify performance confirmation factors and parameters**–Identify the factors (processes) and related parameters important to postclosure safety that should be monitored as part of performance confirmation. The identification of factors important to safety for this version of the plan is based on the RSS (CRWMS M&O 2001) (which is derived from TSPA analyses), available TSPA analyses, and other inputs that have been used as described in Section 3. These factors will be documented as part of the LA.

2. **Establish the performance confirmation database and predict performance**–Establish the database from site characterization efforts and identify the analytical process models and performance assessment models to be used to predict and evaluate performance. Using this basis, predict the expected preclosure values and variations of these values. These predictions will be provided as part of the LA and are conducted as part of the TSPAs.

3. **Establish tolerances and bounds**–Establish tolerances or acceptable limits (screening levels) of deviations from predicted performance, including acceptable ranges of key parameter values, regulatory limits, and model validity or credibility limits. Analyses are to address expected changes as a result of construction, operations, and waste emplacement.

4. **Establish completion criteria and guidelines for corrective actions**–Establish criteria and guidelines for completing an activity and for evaluating conditions outside of tolerance, as well as identify and recommend corrective actions to be taken in these cases.

5. **Plan and set up the performance confirmation test and monitoring program**–Conduct detailed planning, construct the test/monitoring facilities, and set up the instrumentation necessary for the performance confirmation program, including the establishment of the ambient baseline if necessary.

6. **Monitor, test, and collect data**–Perform the testing and monitoring activities necessary to collect data in accordance with applicable regulations and QA requirements.

7. **Analyze, evaluate, and assess data**–Analyze and evaluate the obtained data against the performance confirmation baseline, including performing statistical tests and trend analyses. When changes occur in the predicted construction and operation sequencing, TSPAs will be conducted as necessary to assess the impact of these changes on the activity baseline.

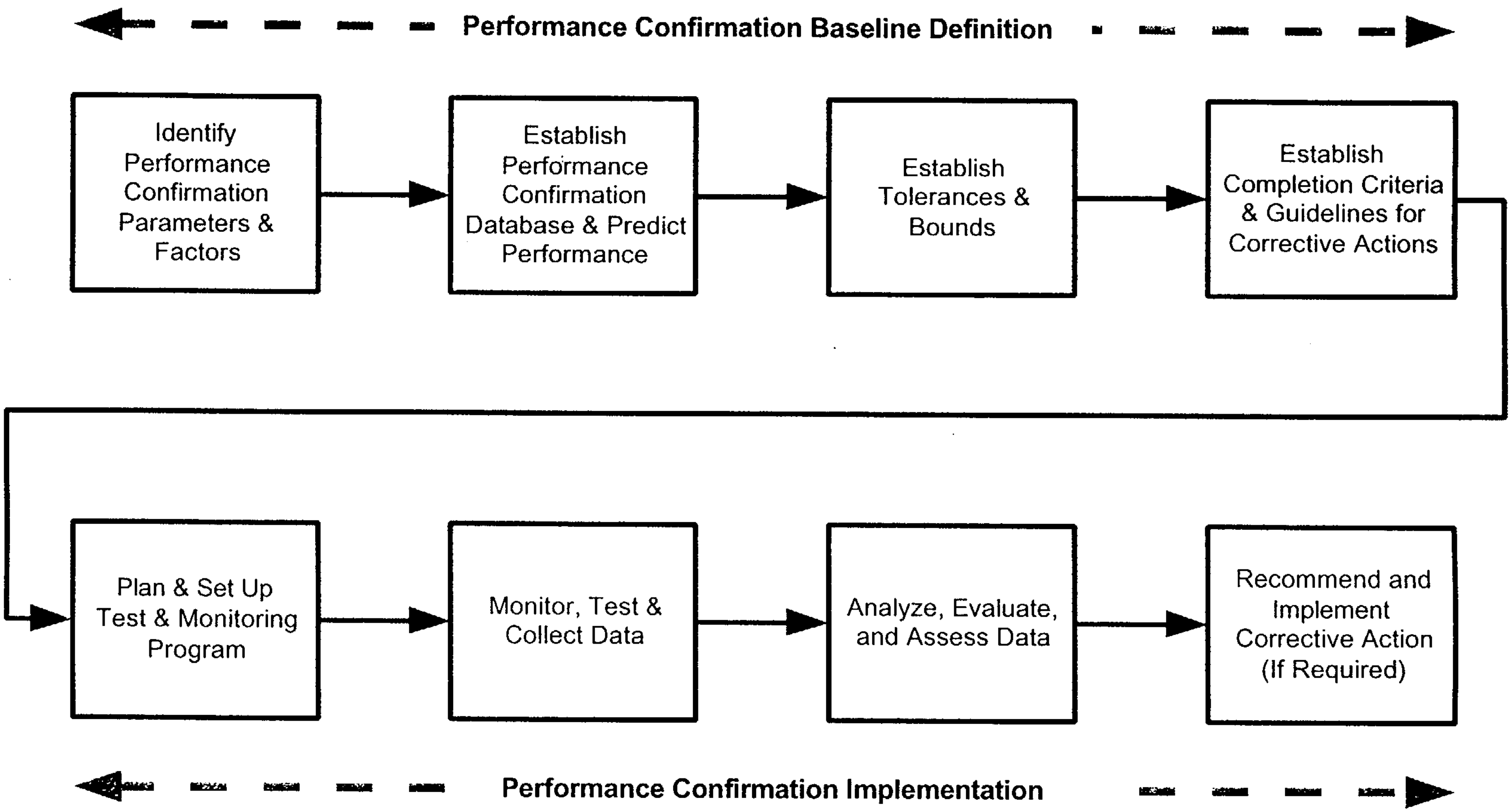


Figure 2-2. Performance Confirmation Program's Concept of Operations

8. **Recommend and implement corrective actions (if required)**–Identify, recommend, and (if necessary) implement corrective action if data or data trends exceed (or are expected to exceed) the prescribed bounds. If data stay within prescribed bounds, continue to perform periodic evaluations against completion criteria to determine whether to continue the test operation, or to stop the monitoring.

The first four steps of the process (from identifying factors to establishing completion criteria) define the performance confirmation baseline. The performance confirmation baseline includes the data obtained during site characterization as well as data obtained during the test-baseline period, together with the definition of tolerance and bounds for these data.

The performance confirmation concept of operations described in this plan is updated with regard to the description presented in the *Monitored Geologic Repository Concept of Operations* (CRWMS M&O 1999b, pp. 4-4 to 4-8).

2.1.3 Approach to Factor Selection

To define the performance confirmation program, it is necessary to identify those items that need to be measured (i.e., the "key" performance confirmation parameters. To identify these parameters, a staged approach has been adopted). First, the processes (factors) that need to be measured, termed "key performance confirmation factors," are identified. These factors are then examined to identify those parameters that are important to process behavior. These parameters are screened to identify the key parameters that are to be measured by performance confirmation. Finally, the test programs are identified that will measure the key parameters, focusing on the expected postclosure repository environment.

Factors that must be addressed by the performance confirmation program arise from four sources:

1. Principal factors important to postclosure repository performance
2. Other items with potential postclosure sensitivity, including data needs of the analyses and process models
3. Requirements documents
4. Factors arising from licensing conditions.

These sources have been analyzed along with their relationship to performance (based on the available information), and key performance confirmation factors have been identified.

The key focus of confirming performance is the identification of those items most important to postclosure safety, the "principal factors" (i.e., those factors or processes that have a substantial impact on the postclosure safety of the repository and retain a large degree of uncertainty in system performance assessments). The key performance confirmation factors, therefore, must also focus on these factors. This approach is in accordance with the underlying intent of the current NRC regulations.

For the present version, analyses in Section 3 of this plan to identify key performance confirmation factors use preliminary principal factors identified in the RSS (CRWMS M&O 2001, Vol. 2) and derived from TSPA analyses, which are:

- Seepage into emplacement drifts
- Performance of the drip shield/drift invert system
- Performance of the waste package
- Radionuclide concentration in water
- Radionuclide delay through the unsaturated zone (UZ)
- Radionuclide delay through the saturated zone (SZ)
- Probability of igneous activity.

These principal factors were analyzed to identify key performance confirmation factors as described further in Chapter 3.

A second source of factors to be considered is system requirements. Some requirement documents, in particular the YMP-RD (YMP 2001a), indicate the requirements that must be addressed by performance confirmation. Of primary importance are the regulatory requirements expressed in Subpart F of the "Revised Interim Guidance Pending Issuance of New U.S. Nuclear Regulatory Commission (NRC) Regulations (Revision 01, July 22, 1999), for Yucca Mountain, Nevada" (Dyer 1999) (see Appendix E). These requirements identify specific systems to be monitored. The key performance confirmation factors are identified directly from the regulatory text and incorporated into the performance confirmation program, as identified in Chapter 3.

The third source of factors relates to other items of potential postclosure safety significance, such as residual data needs identified through process model development. In lieu of TSPA sensitivity analyses or further maturation of the reasonable assurance argument for postclosure safety, factors relating to process models can be evaluated for potential postclosure safety significance. The process models used as a basis for TSPAs are currently being developed and may require additional data to support development or reduce uncertainty. Process models provide the computer-based simulations of individual processes that are abstracted to perform the TSPAs. Data needs for processes important to postclosure performance will drive performance confirmation testing activities during the preparation of the LA and may be needed to support licensing interactions. Data needs are driven by the degree to which models must accurately simulate certain natural processes and whether sufficient data to establish bounding values or tolerance limits are available. Data needs will be identified for each process model and documented in PMRs currently under development. Preliminary indications of potential data needs have been identified and will be discussed in Section 3. To the degree these data needs relate to processes and factors important to postclosure performance and to other factors specifically required by regulation, performance confirmation activities will address these needs.

The fourth source for factors or testing requirements may be identified during the licensing process as driven by NRC or DOE directives. For example, as part of the issue resolution process between the NRC and DOE, the NRC's issue resolution status reports identify areas of discussion, labeled key technical issues. Resolution of some key technical issues may require additional studies as part of performance confirmation. Future revisions of the plan will address acceptance criteria in the issue resolution status reports related to the performance confirmation program.

2.1.4 Parameter Screening

Upon identification of the processes that need to be examined, the underlying parameters for these processes must be evaluated to identify the essential set of parameters for examination. These key performance confirmation parameters are determined by a three-step screening process. The steps are:

1. The parameter must be relevant: the parameter must describe subsurface conditions, must be affected by construction or emplacement, or must be a time-dependent variable.

2. The parameter must be clearly defined: the parameter (or its basis) must be both measurable and predictable.

3. The parameter must be important to postclosure performance: the parameter has been shown (as determined by sensitivity analyses) to influence postclosure performance results.

In addition, parameters are excluded from consideration if the associated processes are not expected to occur in the preclosure phase and, consequently, cannot be monitored or tested. An illustrative example of this would be a surface temperature limit that is expected to occur thousands of years after emplacement; performance confirmation activities would not be used to address this parameter.

Performance confirmation parameters will be defined as part of detailed test planning, which is conducted separately from this plan.

2.1.5 Testing and Monitoring

Upon identification of the key performance confirmation parameters, testing and monitoring activities will be identified to evaluate these parameters. The performance confirmation program will include monitoring and testing activities for both the natural barrier system and the engineered barrier systems.

Detailed test plans will be prepared for each of the test and monitoring activities identified in Section 7 and Appendix G. Both in situ and laboratory testing and monitoring will be conducted in accordance with these detailed plans until completion criteria are met or the facility is approved for closure.

All performance confirmation testing and facility construction will be performed in a manner that does not adversely impact the postclosure safety of either the natural or engineered barrier systems of the repository and complies with applicable regulations and operational safety requirements. An initial set of test activities for the performance confirmation program is described under the synopsis of performance confirmation activity elements in Appendix G of this plan.

2.1.6 Requirements Development

Performance confirmation requirements have been and will continue to be established based on applicable regulations. Therefore, the requirements will focus on the following:

- Nonexceedance of critical performance measures
- Continued measurements indicating that conditions are remaining within ranges that will be documented in the LA
- Optimization of the number of measurements to achieve a required degree of confidence while minimizing cost.

2.1.7 Data Flow, Data Evaluation, and Reporting

Performance confirmation data obtained both in the subsurface and on the surface will be gathered and stored on site within surface facilities. Data from integrated instruments (i.e., instruments that are monitored by a data acquisition system) will be transmitted directly to the data control system, while data from non-integrated instruments will be entered into the system via an input station. Processed data (i.e., the data that have been converted into engineering units) will be available for onsite analysis and will be transmitted off site for data evaluation and expert review. As data are obtained as part of the performance confirmation program, they will be concurrently evaluated. Performance confirmation data evaluations will include:

- Comparison of newly obtained data with existing data and trend analyses
- Comparison of data with model predictions and specified tolerances
- Detection and prediction of data trends
- Evaluation of compliance with NRC performance confirmation requirements.

Emphasis will be placed on two types of possible variance: (1) the detection of deviations from expected trends and (2) data values exceeding specified tolerances. Depending on the nature and importance of any variances, corrective actions may be developed and recommended to the NRC.

Reporting of data is a fundamental part of the performance confirmation process. Processed data and data evaluations will be released to the public on a periodic basis via the Internet or in published format.

In addition, active communications will be maintained with NRC as defined in the LA. This basis may include the following:

- Timely assessment of variations from predicted performance and regulatory compliance and notification to the NRC when significant
- Timely recommendation and reporting of corrective actions, as appropriate

- Open discussions in technical meetings
- Reporting of technical findings.

2.2 PERFORMANCE CONFIRMATION ACTIVITIES

2.2.1 Activity Elements

Performance confirmation activities will be performed as part of the repository's overall test and evaluation program. As such, the test-related activities that address performance confirmation requirements will be contained under different test categories of the test and evaluation program. Tests categories identified as part of the performance confirmation program are described in the following sections.

2.2.2 Core Performance Confirmation

The performance confirmation monitoring and testing that is focused solely on the postclosure performance of the repository and performed during the operational phase of the project (i.e., prior to closure) is considered under core performance confirmation. Activities under this test category can be subdivided into three parts or elements:

Performance Confirmation Process Monitoring–This element includes the monitoring of factors and processes important to postclosure performance conducted during the preclosure phase of the repository. The activities of this element start with waste emplacement. Performance confirmation process monitoring activities include monitoring of key factors or processes that may change with time. Activities include monitoring of ambient seepage, monitoring of the waste package and in-drift conditions, and monitoring of the rock mass response immediately around the drift.

Performance Confirmation Postclosure Simulation–This element includes the testing activities necessary to confirm processes and process-interactions under near-postclosure conditions that are within the ranges specified in the LA. Testing will focus on important areas, in particular, such as the interface between the geologic and engineered barriers. Such testing includes the evaluation of various closure conditions and time-frames, and may include simulated failure conditions.

Performance Confirmation Evaluation and Operational Support–This element includes the evaluation and support activities necessary to efficiently conduct the testing of the performance confirmation program in accordance with procedures and quality requirements. These activities include:

- Data reduction and evaluation
- Distribution and reporting of performance confirmation test results
- Performance of TSPAs conducted after the LA (as necessary)
- Management and storage of rock and other samples
- Coordination and integration of test activities in the post performance plan
- Maintenance and coordination of the *Performance Confirmation Plan* and baseline.

2.2.3 Technical Specifications and Monitoring

Performance confirmation testing and other testing and evaluation activities will be conducted within the geologic repository operations area (GROA) and in the immediate region around the repository, as necessary, to address regulatory requirements and ascertain that systems are performing within specified limits. Performance confirmation testing under technical specification monitoring is comprised of two elements:

Environmental Monitoring–Monitoring of environmental factors will be conducted at the surface at the site and within the immediate region, as required to address performance confirmation requirements. Specific environmental testing activities related to performance confirmation may include groundwater monitoring.

Disruptive Event Monitoring–Activities within this element include testing and monitoring conducted to evaluate possible low-probability disruptive events in a cost-effective manner.

2.2.4 Development and Licensing Testing

Performance confirmation testing activities also include post-site characterization baseline testing through completion of the subsurface construction, in addition to pre-emplacement testing necessary to support the LA submittal, licensing interactions, and pre-emplacement licensing conditions. Performance confirmation testing under this test category can be subdivided into the following two elements:

Baseline Development and Monitoring–Baseline performance confirmation is the testing, monitoring, and analyses necessary to establish the baseline for performance confirmation predictions (as required for core performance confirmation activities) and to confirm that the subsurface conditions are as expected. The development of the performance confirmation baseline was started during site characterization and will continue until completion of subsurface construction. The performance confirmation baseline includes the expected response and defined tolerances of all key performance confirmation parameters. It also establishes the geologic conditions and site parameters.

Baseline development for all performance confirmation core activities will be performed under this category. In addition, laboratory testing of rock core and water samples will also be conducted under this element, involving index mechanical testing and thermal and hydrological property measurements.

Pre-Emplacement Testing–Testing in this element (appropriate for inclusion in the performance confirmation program) includes laboratory and field testing related to items important to postclosure safety as indicated through process model development as residual data needs. This testing will support the LA submittal, licensing interactions prior to construction, and will be used to satisfy pre-emplacement licensing conditions pertaining to postclosure significant items.

2.2.5 Prototype Testing

Performance confirmation testing activities will also be conducted to examine the performance of full-scale prototypes to demonstrate constructability and effectiveness of systems important to safety. These performance confirmation activities are included in the following element:

Engineered Barrier System Testing and Constructability–Testing in this element includes several performance confirmation activities that examine the performance of various subsystems of the engineered barrier, including drip shields. For example, the constructability of the closure configuration will be verified as part of performance confirmation activities.

2.2.6 Performance Confirmation Support Facilities and Equipment

As part of the performance confirmation elements discussed, a range of facilities and equipment will be required to support the performance confirmation program. Test support facilities and equipment will include:

- Performance assessment and process-level model computing codes (software), together with computer hardware required to implement these codes
- In situ testing equipment and instrumentation
- Subsurface test facilities including observation drifts and associated instrumentation alcoves, boreholes, and special test alcoves/niches
- In situ control and transmissions systems for environmental control
- Data acquisition systems
- Surface test and support facilities
- Information management equipment
- Offsite facilities including laboratory facilities and services.

2.3 PERFORMANCE CONFIRMATION PROGRAM MANAGEMENT AND ORGANIZATIONAL RESPONSIBILITIES

As stated in the *Monitored Geologic Repository Test and Evaluation Plan* (Skorska 2001, pp. 4-1 to 4-3), the CRWMS M&O will establish a test management organization to ensure the objectives of the test and evaluation plan are met and that all activities are performed under appropriate QA, management, and technical controls to ensure the validity of the work. The M&O test organization shall work with the DOE organization to facilitate coordination, oversight, and monitoring of all test activities.

The CRWMS M&O is responsible for the development, review, approval, and revision of the performance confirmation program as contained in the *Performance Confirmation Plan*. Performance confirmation activities were identified by a performance confirmation working group for the site characterization period (Skorska 2001, p. 2-3). This working group, perhaps better described as the performance confirmation team, was a special test and analysis group charged with the responsibility to define and conduct performance confirmation activities for the MGR. The team is composed of representatives of various technical components of the M&O and is presently coordinated and managed by the Performance Confirmation/Test Integration Section.

It is expected that the performance confirmation team will continue in its team form to coordinate the performance confirmation testing, monitoring, and analyses efforts undertaken by the M&O until the LA. This team is, however, expected to evolve into a more structured test organization before the start of construction, as described in the *Monitored Geologic Repository Test and Evaluation Plan* (Skorska 2001, pp. 4-1 to 4-3).

2.4 PROGRAM SCHEDULE

2.4.1 Performance Confirmation Activities by Monitored Geologic Repository Phase

The performance confirmation related activities for each of the MGR phases are briefly described as follows:

- **Site Characterization Phase**–Performance confirmation activities during this phase include:
  - Defining performance confirmation systems
  - Collecting relevant site characterization data in support of baseline development
  - Identifying major performance measures
  - Defining and developing the performance confirmation baseline
  - Developing and implementing the *Performance Confirmation Plan*.
- **Licensing Phase**–After the submittal of the LA for construction authorization and before the start of construction, performance confirmation activities include:
  - Performing detailed planning of performance confirmation activities
  - Updating baseline analysis and evaluation methods, as required
  - Continuing field and laboratory testing required for performance confirmation
  - Implementing performance monitoring activities in the *Performance Confirmation Plan*
  - Developing and acquiring long-lead instrumentation and equipment
  - Responding to DOE inquiries on performance confirmation
  - Updating and revising the *Performance Confirmation Plan*, and possibly updating the license, as necessary.

- **Construction Phase**–Performance confirmation activities during construction include:
  - Continuing construction tests and data acquisition
  - Acquiring and transmitting test data
  - Performing field tests and laboratory tests
  - Performing test data analyses and comparing data with predictions
  - Reporting data and evaluations
  - Recommending and ensuring the implementation of corrective actions, if necessary
  - Updating baseline analyses and tolerance bounds, if necessary
  - Updating and revising the *Performance Confirmation Plan,* and possibly updating the license, as necessary.
- **Operation Phase**–Performance confirmation activities conducted during waste emplacement include:
  - Continuing construction tests and data acquisition
  - Expanding monitoring and testing per plan
  - Acquiring and transmitting test data
  - Performing field tests and laboratory tests
  - Performing test data analysis and comparing data with predictions
  - Assessing and reporting performance
  - Recommending and ensuring the implementation of corrective actions, if necessary
  - Updating baseline analyses and tolerance, if necessary
  - Updating and revising the *Performance Confirmation Plan*, and possibly updating the license, as necessary.
- **Monitoring Phase**–Performance confirmation activities conducted during the monitoring phase include:
  - Maintaining the performance confirmation system
  - Continuing selected tests begun during the operation phase

- Monitoring and related data evaluation
- Assessing and reporting tasks
- Checking completion criteria
- Planning test and monitoring options for closure and postclosure phases, if required
- Updating and revising the *Performance Confirmation Plan*, and possibly updating the license, as necessary.

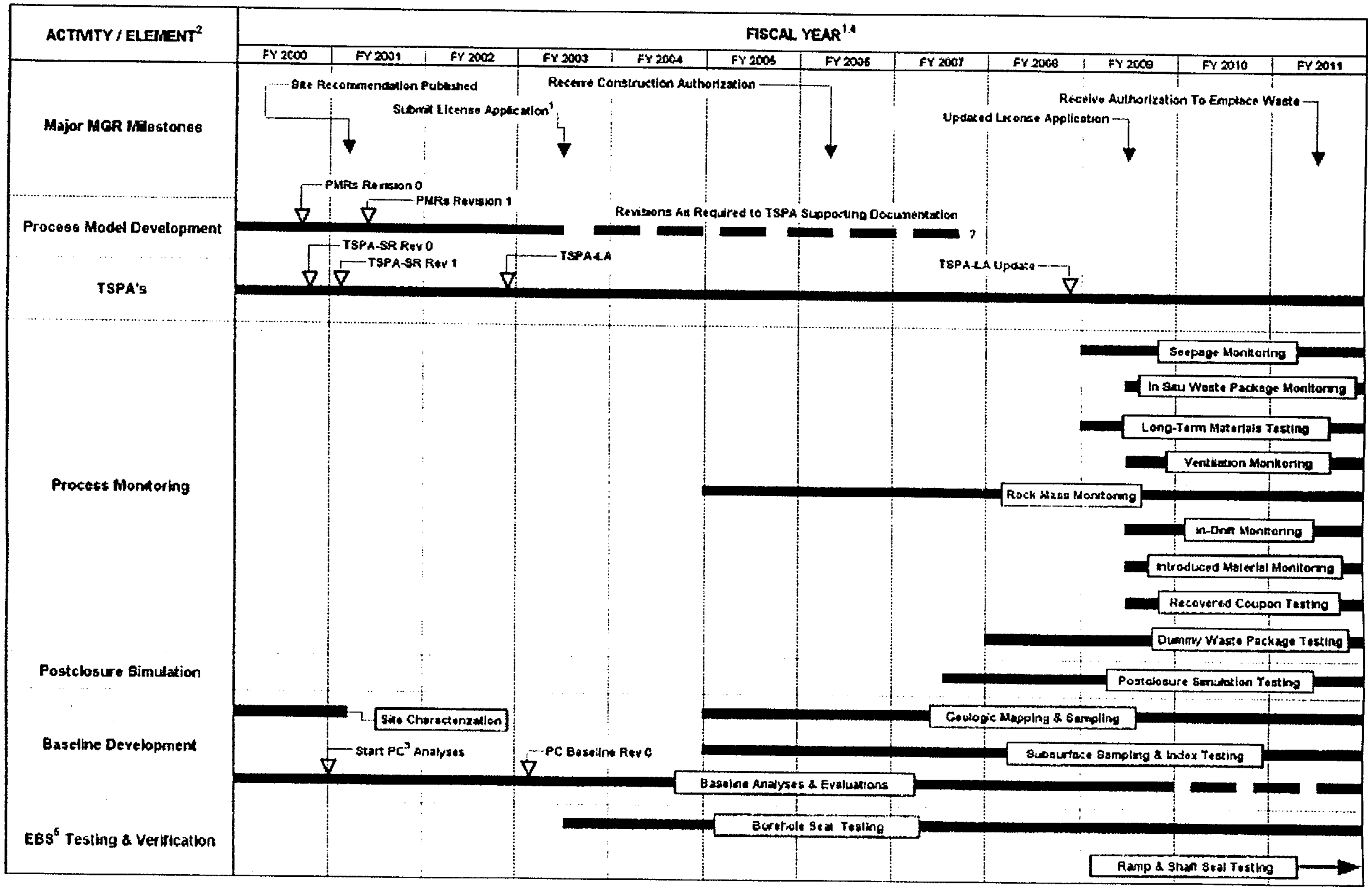
- **Closure Phase**–Performance confirmation activities have been concluded, and deactivation of the performance confirmation system and implementation of closure will occur at this time. If required, a program for permanent postclosure monitoring may be implemented.
- **Postclosure Phase**–Performance confirmation activities have ceased, and permanent postclosure monitoring activities (if any) are being performed.

2.4.2 Schedule of Performance Confirmation Activities

Performance confirmation activities were started during the site characterization and will continue over the construction, operations, and monitoring phases of the repository. A schedule of activities is shown for near-term performance confirmation activities in Figures 2-3 and 2-4 covering the period prior to the emplacement of waste (i.e., fiscal year 2011). It shows the relationship of the activities to major milestones of the project. The schedule reflects the present planning dates of the MGR and the performance confirmation activities as described in Appendix G of this document.

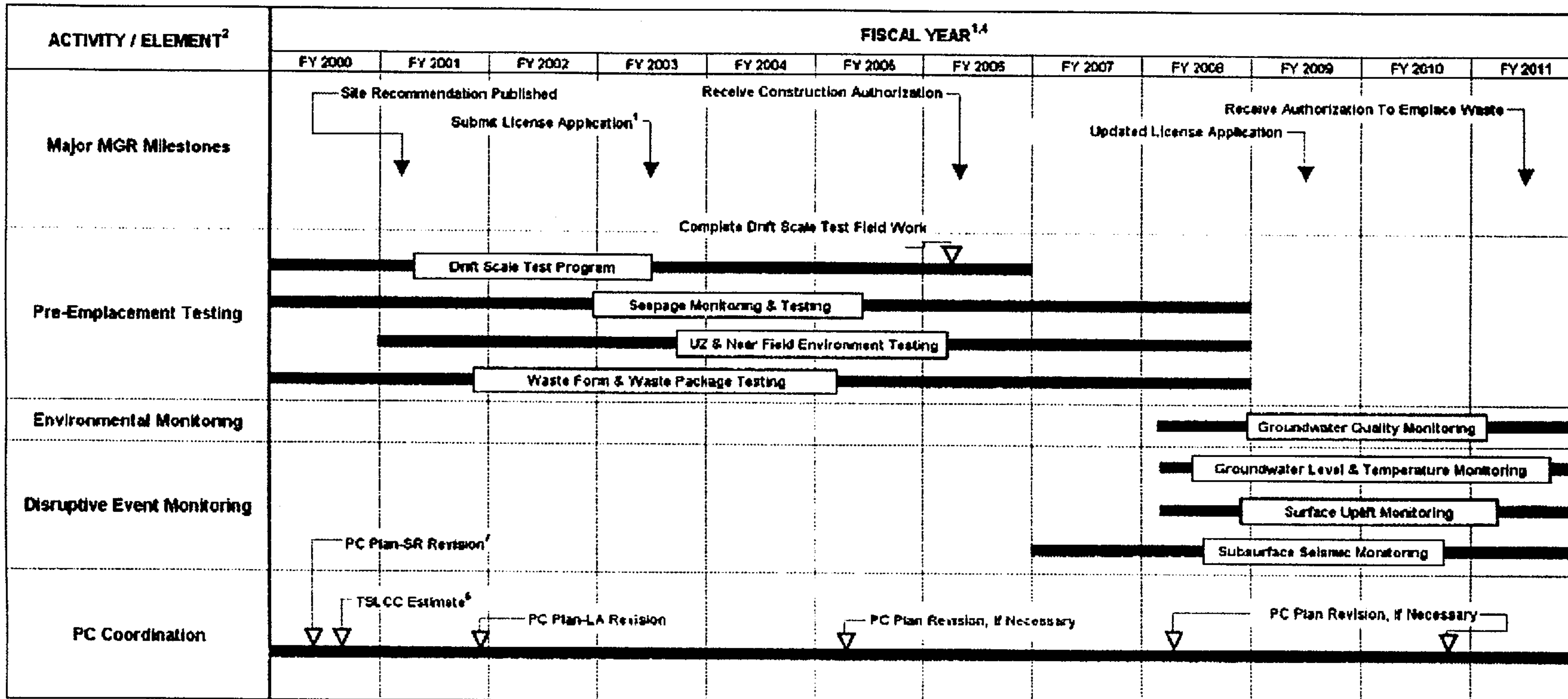
Significant planning of test activities for the performance confirmation program will commence in the near term prior to the LA submittal, with specific emphasis on near-term performance confirmation testing and baseline data collection. The schedule of some of these activities is directly linked to construction work (such as geologic mapping), making the schedule of these activities inflexible at points. Other testing activities such as the drift scale test have been initiated prior to this time and will be incorporated into the program. Ongoing performance confirmation operations and management are also required, including managing the performance confirmation program, and performing cost and schedule estimates of the performance confirmation activities.

A long-term performance confirmation schedule (shown in Figure 2-5) extends from the current fiscal year 2000 to 50 years after start of emplacement (i.e., to fiscal year 2061). This period describes the expected length of the performance confirmation period (Appendix D). It illustrates the major tasks to be accomplished over extended periods for the testing elements of the program, together with baseline development, data evaluations and reporting, and performance confirmation operations and management.



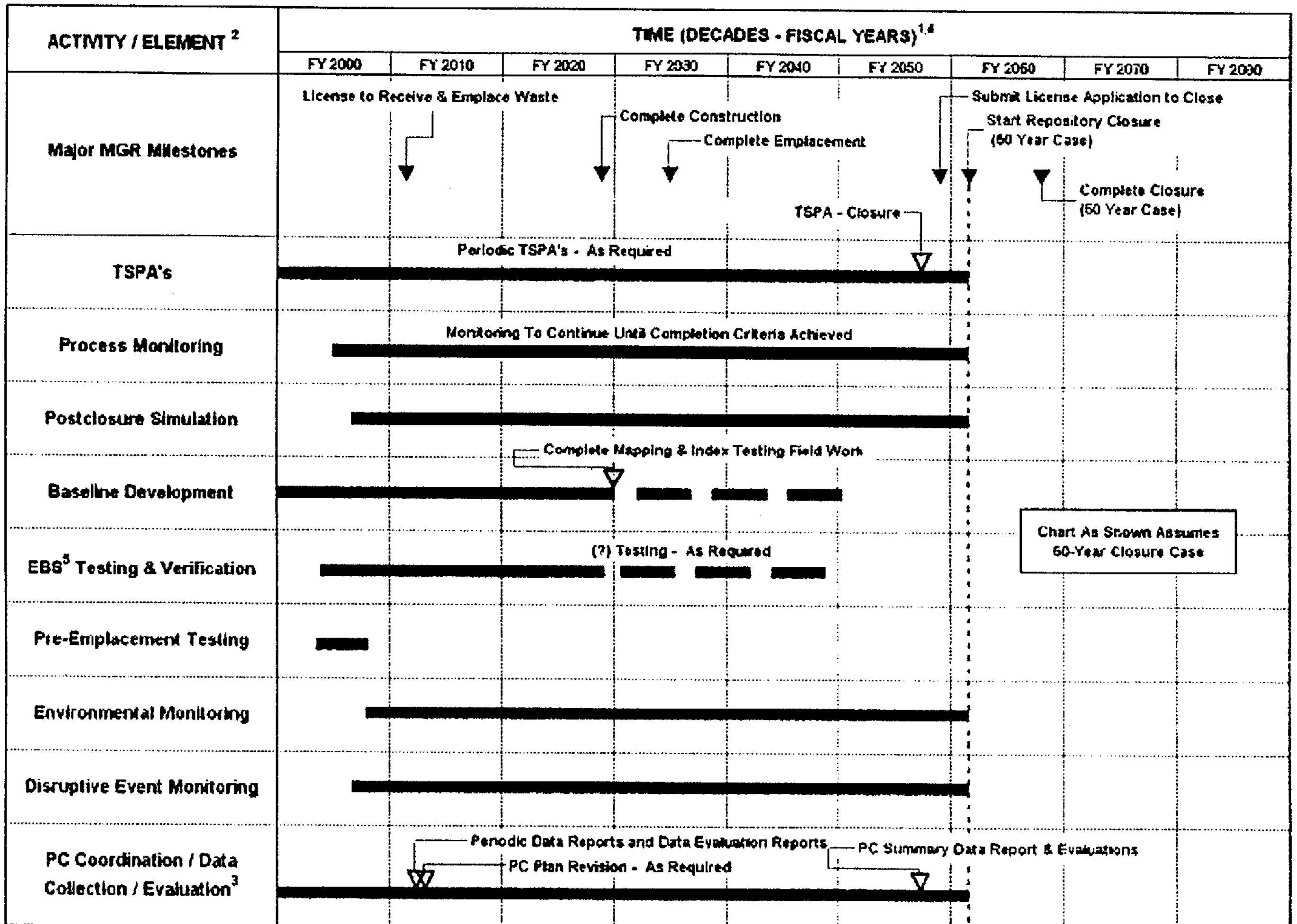
NOTE For definitions and notes, see Figure 2-4.

Figure 2-3. Short-Term Performance Confirmation Program Schedule (Part 1 of 2)



NOTE [1] Dates shown assume a 1-year delay in the submittal of the License Application.
[2] Activities include planning, procurement, and installation of instruments. Activities will be further defined in the TSLCC.
[3] PC (performance confirmation)
[4] FY (fiscal year)
[5] EBS (engineered barrier system)
[6] TSLCC (total system life-cycle cost)
[7] SR (Site Recommendation)

Figure 2-4. Short-Term Performance Confirmation Program Schedule (Part 2 of 2)



NOTE [1] Dates shown assume a 1-year delay in the submittal of the License Application
[2] Activities include planning, procurement, and installation of instruments; activities will be defined further in TSLCC
[3] PC (performance confirmation)
[4] FY (fiscal year)
[5] EBS (engineered barrier system)

Figure 2-5. Long-Term Performance Confirmation Program Schedule

In this context, the performance confirmation testing and monitoring is categorized with respect to the test categories and elements described in Section 2.2. Test activities for all elements will start detailed planning prior to the LA submittal, with an emphasis on near-term tests. The revision of the performance confirmation plan prior to the LA will describe the performance confirmation testing, the specific schedule for the testing, measurement predictions, completion criteria and other performance confirmation commitments necessary for inclusion in the LA. Performance confirmation testing is expected to peak with the monitoring of all elements during the operations phase of the repository and continue in these areas in a reduced fashion until closure of the facility.

Several of the activities will be started after the LA submission, as, for example, indicated under the process monitoring and disruptive event monitoring test categories. The program also includes activities that were started during site characterization and will continue into the performance confirmation period. These activities (such as the Drift Scale Test and waste form and waste package materials testing) are included under the pre-emplacement testing category (see Figure 2-4) as well as baseline development.

The performance confirmation baseline development is to establish the reference point and limits for performance confirmation evaluations. The baseline development activity will start with the set of baseline information available for the LA. Updates of this baseline information will be conducted throughout construction to support the amendment of the LA to receive and possess waste. After that time, updates of the baseline will be accommodated, as required, throughout the program.

Concurrent with the baseline development, performance predictions will also be conducted which support baseline development, detailed test planning, and the design and development of specifications for performance confirmation facilities and equipment. These predictions will be updated during construction and support the amendment of the LA to receive and possess waste. Periodic predictions and assessments of postclosure performance will also extend throughout the life of the program to address changes in data or regulatory concerns.

Performance confirmation program operations and management is active throughout the program and supports major licensing milestones by providing updates to the *Performance Confirmation Plan* and ensuring implementation of the program according to the plan. Activities will include distribution of data and evaluations to interested parties and response to technical questions from the NRC, the State of Nevada, and other review groups or boards.

3. PERFORMANCE CONFIRMATION REQUIREMENTS, MODELING, AND FACTOR IDENTIFICATION

3.1 REQUIREMENTS

Analyses of relevant requirements documents and regulations have been performed to provide a regulatory context for the performance confirmation, to identify performance confirmation requirements, and to provide a basis for the identification of testing prescribed by the requirements. These analyses are included in Appendix E of this document.

In general, the majority of requirements originate in Subpart F of the "Revised Interim Guidance Pending Issuance of New U.S. Nuclear Regulatory Commission (NRC) Regulations (Revision 01, July 22, 1999), for Yucca Mountain, Nevada" (Dyer 1999). Further, the source requirements have been recently updated based on the current status of the project and the MGR design (see Appendix D). The dynamic nature of the project may cause the current list of performance confirmation-related requirements to change, resulting in future updates or modifications. If significant changes occur, they will be incorporated into subsequent revisions of the *Performance Confirmation Plan.*

3.2 MEASURES OF EFFECTIVENESS OF POSTCLOSURE PERFORMANCE

3.2.1 Performance Objectives

The measure of effectiveness is based on demonstrating compliance with the postclosure performance objectives. The performance objectives for the MGR after permanent closure are specified in Section 113 of DOE's "Revised Interim Guidance Pending Issuance of New U.S. Nuclear Regulatory Commission (NRC) Regulations (Revision 01, July 22, 1999), for Yucca Mountain, Nevada" (Dyer 1999). These objectives indicate:

1. The geologic repository shall include multiple barriers consisting of both natural barriers and an engineered barrier system.

2. The engineered barrier system shall be designed so that, working in combination with the natural barriers, the expected annual dose to the average member of the critical group shall not exceed 25 mrem Total Effective Dose Equivalent at any time during the first 10,000 years after permanent closure, as a result of radioactive material released from the geologic repository.

3. The ability of the geologic repository to limit radiological exposures to an average member of the critical group shall be demonstrated through a performance assessment that excludes the effects of human intrusion.

4. The ability of the geologic repository to continue to isolate waste from the environment over the long-term in the event of limited human intrusion into the engineered barrier system shall be analyzed, and the results and bases of this analysis shall be included in the LA. This analysis shall be based on a separate performance assessment.

Section 102 (m) of this same guidance specifies that a performance confirmation program be conducted to verify the assumptions, data, and analyses that support the performance assessments called for in (3) and (4) above. The performance confirmation program will also verify that the natural and engineered barrier systems referenced in (1) and (2) continue to function as intended and anticipated. The performance confirmation program extends from the site characterization phase until the start of the closure phase of the repository (see Figure 1-1).

3.2.2 Multiple Barriers

As stated in Section 3.2.1, the current guidance requires that the geologic repository include multiple barriers, both natural and engineered. Employing multiple barriers ensures that the repository poses no significant risk to the public. As stated above, the DOE must demonstrate that the repository system would be capable of containing waste for thousands of years and preventing any significant exposure of radionuclides emplaced in the repository to a person living near the site. Section 102 (h) of the guidance (Dyer 1999) provides the regulatory framework for the use of multiple barriers to satisfy postclosure performance objectives.

The NRC has traditionally relied on independent, redundant barriers to provide assurance of safety when quantitative assessments of system performance include uncertainties. A principal advantage of a geological repository is the inherent defense-in-depth provided by the multiple natural and engineered barriers that work together to isolate waste from surface hazards, to prevent exposure of waste to water, and to inhibit or retard the mobilization and migration of radionuclides.

3.2.3 Repository System Performance Standards

The total system performance standards are in included in Section 113(b) of the "Revised Interim Guidance Pending Issuance of New U.S. Nuclear Regulatory Commission (NRC) Regulations (Revision 01, July 22, 1999), for Yucca Mountain, Nevada" (Dyer 1999). Because of the nature of uncertainties at the Yucca Mountain site, DOE believes that specifying standards for specific individual elements of the system (e.g., the waste package and the engineered barrier systems) would not provide any significant increase in the confidence of meeting total system performance. The NRC agrees with this conclusion and does not specify subsystem or component acceptance criteria in its postclosure performance objective in the draft of 10 CFR 63.113(b). The DOE believes that the margin between the estimate of postclosure performance and the regulatory limit in the draft 10 CFR 63.113(b) would increase confidence that the limit would be met.

The RSS (CRWMS M&O 2001, Vol. 2, pp. 5-2 to 5-3) alludes to safety margin goals for meeting this limit. The limit specified in Section 113(b) of the Interim Guidance (Dyer 1999) is that the expected annual dose to the average member of the critical group not exceed 25 mrem/year in the first 10,000 years after permanent closure. On the basis of this limit, the referenced strategy alludes to, but does not set a design goal of 2.5 mrem/year in the first 10,000 years after permanent closure and 25 mrem/year for 10,000 to 100,000 years. If these goals for margin were met, confidence that the regulatory performance would be met would be increased.

3.3 MODELING OF POSTCLOSURE PERFORMANCE ASSESSMENT

3.3.1 Regulatory Definition of Performance Assessment

The performance assessment to accomplish the performance measures of Sections 113(c) and (d) is defined in Section 2 of the "Revised Interim Guidance Pending Issuance of New U.S. Nuclear Regulatory Commission (NRC) Regulations (Revision 01, July 22, 1999), for Yucca Mountain, Nevada" (Dyer 1999):

> *"Performance assessment means a probabilistic analysis that: (1) Identifies the features, events and processes that might affect the performance of the geologic repository; and (2) Examines the effects of such features, events and processes on the performance of the geologic repository; and (3) Estimates the expected annual dose to the average member of the critical group as a result of releases from the geologic repository."*

The guidance also specifies in Section 114 that the performance assessment used to demonstrate quantitative compliance with the postclosure performance objective shall:

1. Include data related to the geology, hydrology, and geochemistry (including disruptive processes and events) of the Yucca Mountain site, and the surrounding region to the extent necessary, and information on the design of the engineered barrier system, used to define parameters and conceptual models used in the assessment.

2. Account for uncertainties and variabilities in parameter values and provide the technical basis for parameter ranges, probability distributions, or bounding values used in the performance assessment.

3. Consider alternative conceptual models of features and processes that are consistent with available data and current scientific understanding, and evaluate the effects that alternative conceptual models have on the performance of the geologic repository.

4. Consider only events that have at least one chance in 10,000 of occurring over 10,000 years.

5 Provide the technical basis for either inclusion or exclusion of specific features, events, and processes of the geologic setting in the performance assessment. Specific features, events, and processes of the geologic setting must be evaluated in detail if the magnitude and time of the resulting expected annual dose would be significantly changed by their omission.

6. Provide the technical basis for either inclusion or exclusion of degradation, deterioration, or alteration processes of engineered barriers in the performance assessment including those processes that would adversely affect the performance of natural barriers. Degradation, deterioration, or alteration processes of engineered barriers must be evaluated in detail if the magnitude and time of the resulting expected annual dose would be significantly changed by their omission.

7. Provide the technical basis for models used in the performance assessment such as comparisons made with outputs of detailed process-level models and/or empirical observations (e.g., laboratory testing, field investigations, and natural analogs).

8. Identify those design features of the engineered barrier system and natural features of the geologic setting that are considered barriers important to waste isolation.

9. Describe the capability of barriers, identified as important to waste isolation, to isolate waste, taking into account uncertainties in characterizing and modeling the barriers.

10. Provide the technical basis for the description of the capability of barriers, identified as important to waste isolation, to isolate waste.

11. Assume climate evolution consistent with the geologic record of natural climate change in the region surrounding the Yucca Mountain site.

12. Assume evolution of the geologic setting consistent with present knowledge of natural processes.

The TSPA is the method that will be used to make estimates of the expected postclosure performance and to evaluate compliance with Section 113(b) of the "Revised Interim Guidance Pending Issuance of New U.S. Nuclear Regulatory Commission (NRC) Regulations (Revision 01, July 22, 1999), for Yucca Mountain, Nevada" (Dyer 1999). The TSPA is consistent with the definition and requirements for performance assessment stated above. This methodology links models of the processes and components of the repository system into an analysis that provides an estimate of overall system performance. The performance computed is an annual dose to an average member of a critical group over a period of interest. The approach is probabilistic and calculates expected or mean annual dose, considers uncertainties, and will be used for the LA.

3.3.2 Total System Performance Assessment Overview

A TSPA is conducted using a hierarchy of models, data, and information that can be thought of as a pyramid. The base of the pyramid is composed of design and site data and other information needed in a performance assessment. The most complex and detailed models are near the base of the pyramid (the process models and the conceptual models that they contain) and the simplest models (the TSPA models) are at the apex (Figure 3-1). When a performance assessment is conducted, it begins at the base of the pyramid and continues progressively upward with the more complex models feeding results to the less complex models above them. The conceptual models and data are used to formulate and test the process models. Results from the process models are abstracted (simplified) and used in performance assessment models or are fed directly into the TSPA model. The results from abstracted models are compared to the results from the more complex models as a verification of the abstraction process. The performance assessment is conducted using the results from the process and performance assessment models in a TSPA model to analyze dose to an individual at a point down the hydraulic gradient from the repository. The TSPA model is also used to conduct sensitivity analyses to determine the major factors that influence dose.

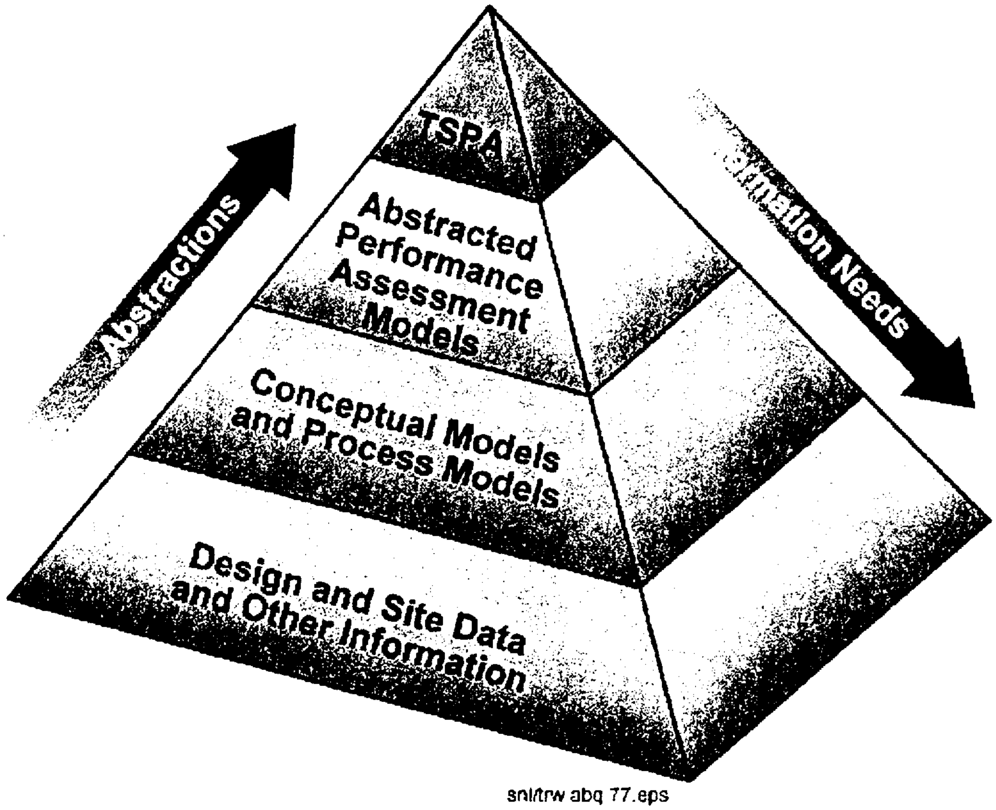


Figure 3-1. Hierarchy of Models, Data, and Information Used in Performance Assessment

Sensitivity results from the performance assessment can then be fed back down the pyramid to process models, and the process models can be used to calculate the expected range of results that can be compared to measurements made during performance confirmation.

For example, sensitivity analyses conducted for the TSPA-VA have shown that dose to humans is sensitive to flow, seepage into emplacement drifts, and waste package corrosion rate (DOE 1998d, pp. 4-71 through 4-77). If, during subsequent TSPA analyses, postclosure performance remained sufficiently sensitive to these factors, then the performance confirmation program would identify related parameters to these factors, and would conduct testing and monitoring activities as appropriate. Measurements obtained during performance confirmation would be compared to predictions to ensure that data fell within established bounds. Significant variations between measurements and predicted bounds established by the process model would suggest the need to revisit the test, the measurement methodology, or the underlying process model itself. For this reason, the performance confirmation process will proceed until there is reasonable assurance that measurements are consistent with the bounds established using the process models in order to provide reasonable assurance that both models and measurements are valid. Measurements, monitoring, observations, and test results will be compared with predictions of the performance of the natural and engineered barriers during the performance confirmation period (prior to permanent repository closure) to establish confidence that the natural and engineered barriers are performing as evaluated in the LA.

The site, design, and laboratory test data and information are used as input in the conceptual and process models. These data and information, the process models, and the abstractions of the models that feed the TSPA model are described in a series of nine PMRs. The flow of site and design information into these PMRs is shown in Figure 3-2. Each PMR contains descriptions of the process models and model abstractions that are contained in more detail in their supporting analysis reports. Following are brief summaries of the process-level models that are used to develop the detailed information needed for a performance assessment.

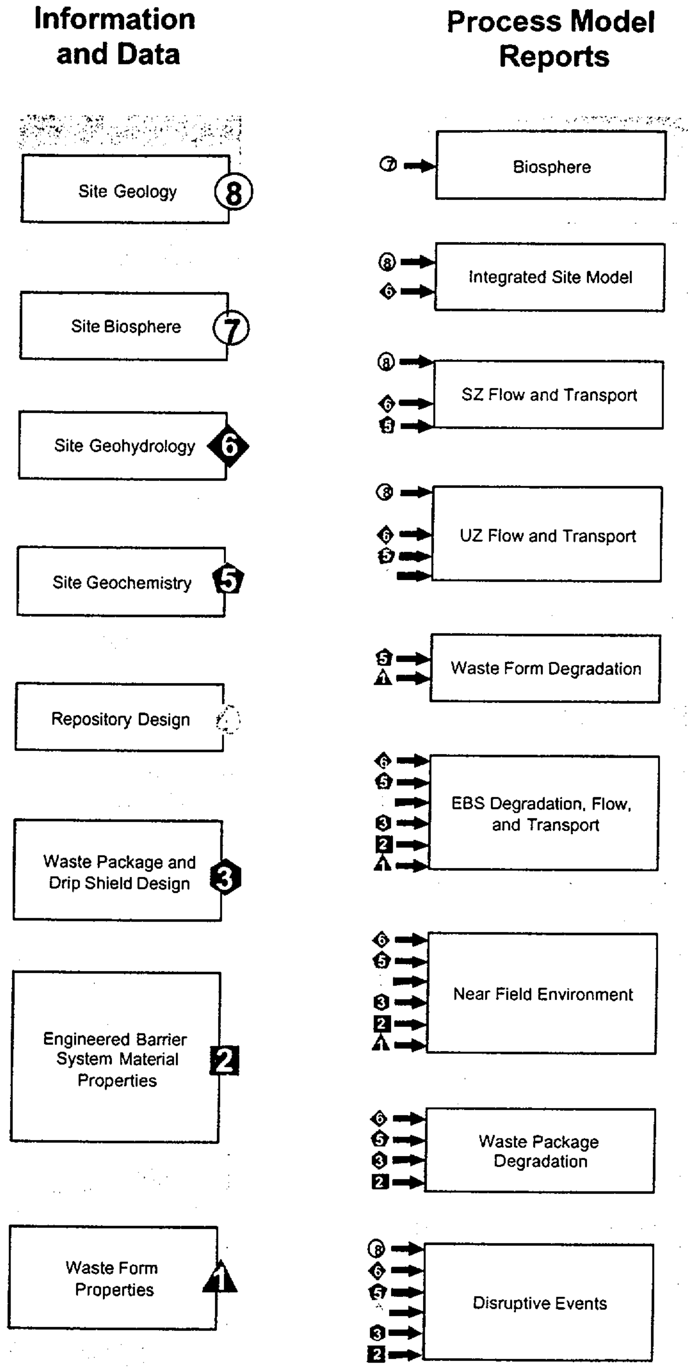
3.3.3 Biosphere Model

The biosphere model will be described in the Biosphere PMR (Figure 3-2). The process-level biosphere model GENII-S (Title: GENII S, Version 1.4.8.5, CSCI number 30034 V1.4.8.5) (CRWMS M&O 1998i) is used to generate probability distributions of the biosphere dose conversion factors for each radionuclide of interest. The dose conversion factor distributions calculated using this biosphere model are based on the input of the lifestyles of current residents of the Amargosa Valley region. The dose conversion factors are for the average person living in Amargosa Valley. This region is primarily rural agrarian in nature. Crop production includes livestock, livestock feed, gardens, dairy products, catfish, and minor amounts of pistachios and grapes. The dose pathways originate from contaminated groundwater from a well used for all human activities, including irrigation of crops, water for livestock, drinking water, and domestic use. The dose pathways analyzed are ingestion, inhalation, and external dose (CRWMS M&O 1998d, Chapter 9, Figure 9-2).

3.3.4 Saturated Zone Flowand Transport Model

The basis for the SZ flow and transport model will be described in the integrated site model and Saturated Zone Flow and Transport PMRs (Figure 3-2). The SZ flow and transport model describes the transport of radionuclides from the water table below the potential repository footprint to points of release in Amargosa Valley as described by biosphere inputs. The spatial distribution and temporal evolution of radionuclides at the water table, as derived from the UZ flow and transport models (Section 3.3.5), determines the entry points at the water table. This is imposed as the upper boundary condition for the SZ flow and transport model. The performance of the SZ has been evaluated by considering radionuclides that migrate 20 km downstream through the groundwater system in the volcanic aquifer and the alluvium to a hypothetical well where they could be a source of contamination of the biosphere (CRWMS M&O 1998d, Chapter 8, Figure 8-1).

Important processes that control the migration of radionuclides in the SZ include advection, dispersion, diffusion, sorption, and dilution. Diffusion of radionuclides from the fast flowing water in fractures into the slower moving flow in the rock matrix is an important mechanism for slowing the migration of radionuclides. Another retardation mechanism to the advective transport is the sorption of radionuclides on minerals along the flow path. Other processes that reduce the radionuclide concentration at a point of release to the biosphere include radioactive decay that occurs during the time of transport and dilution of the radionuclide plume at the exit point pumping well (CRWMS M&O 1998d, Chapter 8, Section 8.5.2, p. 8-62).



EBS = engineered barrier system
SZ = saturated zpne
UZ = unsaturated zone

Figure 3-2. Relationship Among Information and Data and Process Model Reports

3.3.5 Unsaturated Zone Flow and Transport Model

The UZ transport model and the UZ flow model will be described in the UZ Flow and Transport PMR and shown on Figure 3-2. The flow and transport models describe the spatial and temporal distributions of water flow and transport of radionuclides through the UZ, and of seepage into unventilated emplacement drifts of the potential repository. These models are built upon a wealth of site data, which allow for model calibration against field observations and validation using independent data sets or field tests. They summarize the current understanding of flow and transport in the UZ at Yucca Mountain and evaluate the pre- and postclosure performance of the UZ.

The UZ flow and transport models account for infiltration processes near and at the ground surface of the mountain. Because of the long time period considered in a performance assessment (up to a million years), the infiltration is expected to change because of changes in the climate. In the TSPA (DOE 1998d, Section 3.1.2, pp. 3-12 to 3-13), dry and wet climate cycles of duration of 10,000 and 90,000 years, respectively, were assumed to alternate over the time period modeled. The spatial and temporal variability in infiltration is specified as the main boundary conditions at the ground surface for the UZ flow and transport models. Percolating water derived from precipitation flows primarily in fractures in the welded tuff units and in the rock matrix in the nonwelded units.

As a result of the varied geology, flow and transport processes differ between the northern and southern parts of the potential repository. Below the horizon of the potential repository, perched water bodies have been found, primarily in the northern part of the potential repository area, where low permeability zeolitic rock units are abundant. The presence of the perched water bodies creates the potential for the lateral flow of water to nearby high permeability features, such as faults. The potential lateral flow and flow through faults have implications for radionuclide transport by allowing rapid advective transport from the potential repository to the water table, and bypassing the rock matrix where matrix diffusion and sorption could promote retardation. Larger-size colloids (e.g., plutonium colloids) that cannot diffuse into the matrix are particularly susceptible to rapid transport. Beneath the southern part of the potential repository, vitric nonwelded tuff is more abundant than zeolitic rocks; the vitric rocks potentially provide efficient sorption of some radionuclides. Technetium-99 and iodine-129 are non-sorbing and will provide the highest dose rate for the first 10,000 years of the potential repository's life span.

The rate of water seepage into unventilated drifts is expected to be considerably less than the prevailing percolation flux and may be zero for areas where the percolation flux is lower than the seepage threshold for that location. This is because the drifts act as capillary barriers which drive most of the flowing water around the drifts. The seepage threshold, defined as the critical percolation flux below which no seepage occurs (for a given location within a hydrogeological unit), depends upon various hydrological parameters of the fractures.

The UZ flow model also evaluates the effect of heat emitted from the radioactive waste with predictions that the drainage water flux will not greatly exceed the ambient percolation flux for most locations within the potential repository during the entire thermal period. In addition, coupled thermal-hydrological-chemical processes in the UZ rock mass are modeled to predict the chemistry of water and gases entering and occurring around the emplacement drifts, as well as the changes in hydrological properties expected from precipitation/dissolution processes.

3.3.6 Waste Form Degradation Model

The waste form degradation and mobilization of radionuclides will be described primarily in the Waste Form Degradation PMR, and the transport of radionuclides out of the failed waste package is described in the Engineered Barrier System Degradation, Flow, and Transport PMR (Figure 3-2). The waste forms in the repository are contained in and protected by the waste package. Upon failure of the package, the SNF assemblies and high level waste (HLW) canisters will be exposed to the drift environment including air, water vapor, and potentially dripping water. Radionuclides are not available for transport until the following has occurred: (1) failure of the fuel cladding (if any), the HLW canister, and breach of the drip shield, (2) degradation of the solid form of the waste, and (3) the mobilization of radionuclides into aqueous solution, aqueous particulate suspension colloids, or gaseous form. The mobile radionuclides would then potentially be transported through the degraded waste package and through the engineered barrier system to the UZ transport pathways (CRWMS M&O 1998d, Chapter 6, Section 6.5, p. 6-131).

The processes of waste form degradation and radionuclide mobilization depend heavily on design features and drift environment processes. The thermal history and waste package lifetime determine the temperature of the waste forms when they are exposed to degradation processes. The gas phase composition and aqueous chemistry of incoming water, along with the waste temperature, will control the rates of waste form degradation and radionuclide release. The waste form degradation and radionuclide mobilization modeling begin with the best current understanding of these processes and the most important interdependencies. It then abstracts them into a form simple enough to fit into the TSPA framework without excessive demand on computation time (CRWMS M&O 1998d, Chapter 6, Section 6.1.5, pp. 6-11 to 6-13).

The barrier system comprises all repository components within the drift. The overall waste form degradation, radionuclide mobilization, and transport of radionuclides within the barrier system are dependent on processes such as thermal hydrology, waste package degradation, and near-field geochemistry. Transport is influenced by the waste package degradation, the waste form degradation (including cladding degradation), the thermal hydrologic environment, the chemical environment, and the design of the barrier system. The radionuclides released from the barrier system are then transported through the natural system, the UZ, and the SZ (CRWMS M&O 1998d, Chapter 6, Section 6.1, p. 6-2).

3.3.7 Site- and Drift-Scale Thermal Hydrology Model

The site- and drift-scale thermal hydrology models will be described in the UZ Flow and Transport PMR and Engineered Barrier System PMR, respectively (Figure 3-2). The thermal hydrology analyses are conducted at two scales as input to the performance assessment, site or mountain scale, and drift scale. The site-scale model (one-, two-, or three-dimensional) includes surface topography, variations in stratigraphy, repository thermal loading (including edge effects), and natural development of large-scale buoyant gas-phase convection as a result of fluid density variations in a gravitational field. The site-scale model is used to capture the thermal effects on large-scale features of the mountain and to develop boundary conditions for the drift-scale models (CRWMS M&O 1998d, Chapter 3, Section 3.1.3, pp. 3-6 to 3-13).

The drift–scale model (one-, two-, or three-dimensional) describes the near-field thermal response that includes temperature, liquid saturation, and relativity humidity at the boundary of the waste package or drip shield. This information combined with the geochemistry in the near field is used as input to the waste package degradation model (CRWMS M&O 1998d, Chapter 3, Section 3.1.1.3, p. 3-4). The drift-scale model also accounts for differences in thermal loading of individual waste packages and the influence of a drip shield in the repository design (CRWMS M&O 1998d, Chapter 3, Section 3.1.1.3, p. 3-4, and DOE 1998d, pp. 4-104 to 4-106).

3.3.8 Near-Field Geochemistry Model

The development of the near-field geochemical environment models will be described in the Engineered Barrier System Degradation, Flow, and Transport PMR and the Near-Field Environment PMR (Figure 3-2). The near-field environment depends on the repository design: thermal load, backfill material (if employed), waste package and drip shield materials, and drift lining. Even though the ambient geochemical system at the Yucca Mountain site has a large capacity to moderate local system geochemistry, changes in the near-field have the potential to affect waste package corrosion, waste-form dissolution, radionuclide solubility, and transport through the engineered barrier system. The geochemical environment within the drift will be defined by complex interactions among the ambient and thermally perturbed water and gas flux, the masses of introduced waste and barrier system materials, and any microbial activity that may form in this environment. Additional factors that affect the near-field geochemical environment are the far-field percolation flux, the reaction and reflux of condensate water, and local seepage into the drift (CRWMS M&O 1998d, Chapter 4, Section 4.1.2, pp. 4-3 to 4-6).

3.3.9 Waste Package and Drip Shield Degradation Model

The waste package and drip shield degradation will be described in the Waste Package Degradation PMR (Figure 3-2). The corrosion of drip shield and waste package materials depends on the near–field environment. The failure rate of these barriers depends on the temperature, relative humidity, liquid saturation, and geochemistry at the surface of the barrier. Once the drip shield has failed, the waste package will be exposed to water when it returns as the near field cools. The purpose of the drip shield is to protect the waste package from flowing water for thousands of years past the peak heat pulse especially while the drift is hot and the corrosion rate of the waste package is higher (CRWMS M&O 1999a, p. 5-61).

The failure rate of both the drip shield and the waste package are predicted using the model WAPDEG (Title: WAPDEG, Version 3.09, CSCI number 30048 V3.09, CRWMS M&O 1998e). The model is used to develop failure distributions of drip shields and waste packages that are used as input to the TSPA analyses (CRWMS M&O 1999e, Sections 5.5 and 6.1, pp. 5-15 to 6-11). As indicated in the following sections, drip shield degradation analyses need to include the effects of potential seismic events and rockfalls on drip shield integrity.

3.3.10 Other Considerations

3.3.10.1 General

Other processes and events that could possibly effect the potential repository over the period of time considered in a performance assessment are igneous activity, seismicity, nuclear criticality, and human intrusion (CRWMS M&O 1998d, Chapter 10, Section 10.1, p. 10-1). The process considered for igneous activity and seismicity will be described in the Disruptive Events PMR and will be included in the base case performance assessment. The input from the Disruptive Events PMR will be used as the basis for incorporation of these processes into the TSPA model (Figure 3-2). The disruptive events, criticality, and human intrusion are not part of the base case model (the nominal case) (Figure 3-2). Human intrusion will be analyzed separately using a stylized intrusion scenario.

3.3.10.2 Igneous Activity

The possibility of future volcanic processes is considered in postclosure performance assessment if the probability of these processes occurring within some reasonable distance of the potential repository is greater than a specified limit on the order of 10^{-4} over 10^{4} years. The results of the *Probabilistic Volcanic Hazard Analysis for Yucca Mountain, Nevada* (CRWMS M&O 1996b, Section 4.3, p. 4-14) are that the expected annual frequency of intersection of the potential repository footprint by a volcanic event is 1.5×10^{-8}. Scenarios for basaltic igneous activity at the Yucca Mountain site have been formulated. Direct effects of volcanic processes imply the direct exhumation of a percentage of the waste. The direct effects are controlled by the geometric and physical properties of a future extrusive magma body. Indirect effects are related to changes in the ambient rock properties, including thermal, mechanical, hydrologic, and geochemical properties caused by a future intrusive magma body in the vicinity of the potential repository and by changes in the UZ and SZ. While it may be possible to predict the magnitude of such changes by perturbing the ambient process models, it is likely that other indirect effects will be controlled by the physical and chemical characteristics of the intruding body. The effects of igneous activity on the potential repository were evaluated as part of the technical basis for the TSPA (CRWMS M&O 1998d, Chapter 10, Section 10.4, pp. 10-15 to 10-57). These analyses found that there was little dose consequence of considering volcanic activity scenarios as part of performance assessment (CRWMS M&O 1998d, Chapter 10, Section 10.4.4.3, pp. 10-56 to 10-57).

3.3.10.3 Seismicity

Rockfall is expected to be the primary source of drip shield disturbance that results from a seismic event. The effects of rockfall on the waste package from seismic events were analyzed in the TSPA-VA (CRWMS M&O 1998d, Chapter 10, Section 10.5, pp. 10-57 and 10-67). The input information for these analyses included structural information for the degraded waste package (CRWMS M&O 1996c, Section 8, pp. 80 to 83) and information on the rock size that could cause a penetration of the waste package (CRWMS M&O 1996d, Chapter 8, Section 8, p. 26; CRWMS M&O 1996e, Section 8, p. 25). Analyses show that there is little dose consequence that can be attributed to rockfall (CRWMS M&O 1998d, Chapter 10, Section 10.5, p. 10-67).

Other indirect consequences of seismic activity are alteration of flow paths in the UZ or SZ or a change in water table elevation. Analyses show little dose consequences attributed to these events (CRWMS M&O 1998d, Chapter 10, Section 10.5, p. 10-68).

3.3.10.4 Nuclear Criticality

The potential for postclosure nuclear criticality must be considered because the waste contains fissile materials. The repository systems, particularly the waste package, have been engineered to ensure that criticality is impossible as long as the waste package has not failed. Once the waste package has failed, there is a very small (non-zero) probability of criticality to occur in, or external to, the failed package (CRWMS M&O 1998d, Chapter 10, Section 10.6, p. 10-69).

Criticality can have two potential effects on a repository after closure: (1) it changes the radionuclide inventory of the failed package, and (2) there is an increase in the thermal output of the failed package. The analyses conducted for the TSPA found that the dose consequences from in-package criticality to be small for the occurrence of criticality in a single waste package (CRWMS M&O 1998d, Chapter 10, Section 10.6, p. 10-81). In addition, the analyses found that there is extremely low probability of criticality external to the waste package because of the lack of deposits along the transport pathway that could accumulate significant amounts of fissile material (CRWMS M&O 1998d, Chapter 10, Section 10.6, p. 10-81).

Analyses of the effects of increased thermal load caused by a nuclear criticality show that the increase is small even when a steady-state criticality is considered. Steady-state criticality of a waste package is not considered to be a credible event in the potential repository environment (CRWMS M&O 1998d, Chapter 10, Section 10.6, p. 10-81).

3.3.10.5 Human Intrusion

The consequences of a stylized human intrusion scenario were analyzed in the TSPA to judge whether the repository system is inherently resilient to this class of disturbance. The stylized human intrusion scenario consisted of drilling from the surface into a single waste package with continued drilling to the water table. For the analyses, the dose to the drilling crew was not considered to be a measure of the quality of the design or the site (CRWMS M&O 1998d, Chapter 10, Section 10.7, pp. 10-81 and 10-82). The scenario was based on the following:

- Drilling techniques and drill size characteristic of groundwater exploration
- Waste package penetration at an early time after repository closure
- After package penetration drilling continues to the water table
- Waste from the damaged package falls down the hole to the water table
- As the waste degrades in the SZ, it is transported to the human environment.

The dose spike caused by carbon-14, technetium-99, and iodine-129 is approximately 150 times the dose from the base case for the potential repository, but the dose returns to near the base case at later times. Over 100,000 years, the effects of human intrusion are small (approximately a factor of four higher than the base case at 50,000 years) (CRWMS M&O 1998d, Chapter 10, Section 10.7, pp. 10-88 and 10-89).

3.3.11 Total System Performance Assessment

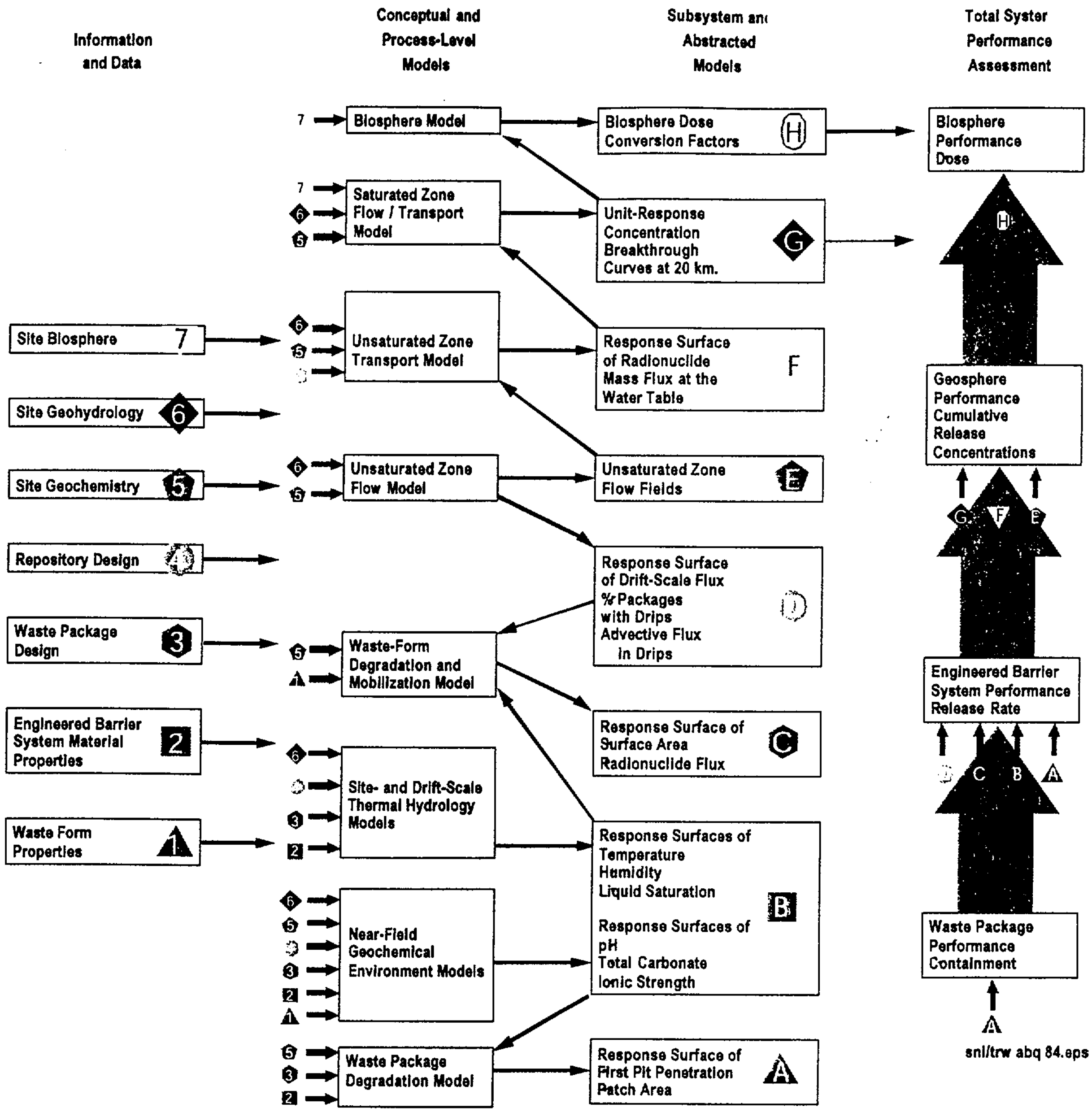
The TSPA for the site recommendation that will be revised for the LA begins with the site and design information that is used in the conceptual and process-level models that are an initial part of the assessment. Descriptions of the process models and their abstractions are contained in PMRs as delineated by Figure 3-2, and supported further by more detailed analysis model reports (AMRs). A simplified schematic of the flow of data through the TSPA is shown in Figure 3-3. The detailed models and abstractions contained in the reports of analysis models are used to develop input to the TSPA-site recommendation model. The model RIP (*Software Qualification Report (SQR) Repository Integration Program RIP*, *Version 5.19.01*, CRWMS M&O 1998b) is used to conduct the TSPA (Figure 3-3).

The results of the TSPA are in the form of waste package performance, engineered barrier system performance, geosphere performance, and biosphere performance (Figure 3-3). Waste package performance is reported as containment time, failure rate, or time of first package failure. Engineered barrier performance is reported as radionuclide release rate. Geosphere performance is reported as radionuclide concentration at a point as a function of time or cumulative release of radionuclides. Biosphere performance is reported in terms of dose to humans. The TSPA simulations are conducted for the time periods of interest that usually include 10,000, 100,000, or 1,000,000 years. The longer time periods are simulated to capture the peak dose from the potential repository.

3.4 IDENTIFICATION OF PERFORMANCE CONFIRMATION FACTORS

3.4.1 General

To define the performance confirmation program, it is necessary to identify the "key" performance confirmation factors. To identify these parameters, a staged approach is adopted. First, the processes or technical areas that need to be measured, termed "factors," are identified. Then, these factors are examined to identify those parameters that are important to process behavior; these factors and the associated parameters are then screened to identify the key factors that are to be measured by performance confirmation. Finally, the test programs are identified that will measure the key factors and associated parameters. It is important to note that the identification of key factors here is preliminary and will be updated prior to LA in response to TSPA sensitivity analyses and updates to the RSS (or successor document). As such, all performance confirmation factors identified here, and the performance confirmation activities associated with them, are subject to change.



Source: Modified from DOE 1998d, p. 2-28

Figure 3-3. Schematic of Information Flow in a Total System Performance Assessment Among Data, Process Models, and Abstracted Models

Factors that must be addressed by the performance confirmation program arise from four sources:

1. **Principal factors important to repository performance**–To correctly focus the resources of the project, the performance confirmation program needs to concentrate on those processes and parameters that are most important to repository postclosure safety. For the current version, the *Performance Confirmation Plan* employs the principal factors as identified in the RSS (CRWMS M&O 2001, Vol. 2, pp. 4-1 to 4-7) (which is derived from TSPA analyses) along with available performance analyses as a starting point. These preliminary "principal factors" important to repository safety have been assessed and used to identify candidate performance confirmation factors as presented in Section 3.4.2 of this document.

   It is important to note that continued sensitivity analyses and further evaluations of process models are expected to adjust the items that are identified as significant to postclosure safety. As a result, the *Performance Confirmation Plan*, which depends on these analyses and models, may require modification and revision.

2. **Data and validation needs of the analysis and process models**–With the completion of the site characterization phase of the MGR, it is expected that some additional data may be required to complete process development and validation efforts. These data needs will be identified in the PMRs, and addressing these needs may require additional testing efforts, which would be identified in the LA together with associated test plans in accordance with regulatory guidance. As these activities affect the assessment of postclosure safety, the data needs for licensing are addressed as part of the performance confirmation program and are described further in Section 3.4.3. Note that this listing of needs is tentative at present, as the PMRs are not available with this writing, and sensitivity analyses to identify that these data are important to postclosure safety are not yet available.

3. **Requirements documents**–The program also needs to address applicable regulatory requirements as part of the licensing process. As part of these requirements, particular factors and tests are specifically identified or prescribed for the performance confirmation program. These factors, while not of principal importance to safety, are prescribed in the regulations and therefore must be conducted to obtain a license and included in the *Performance Confirmation Plan*. These factors are described in Section 3.4.4.

4. **Licensing Conditions**–As part of the licensing process, requirements or issues needing additional testing may be identified by the NRC or the DOE and included in the license as a licensing condition or directive. Testing to address these conditions may be included as part of the performance confirmation program, if the issues are important to postclosure, or so indicated in the directive. To date, no licensing conditions have been identified for the performance confirmation, but may arise from considerations of the NRC issue status resolution reports.

Identification of the key performance confirmation factors is presented in the following sections.

3.4.2 Identification of Performance Confirmation Factors Based on Importance to Safety

3.4.2.1 General

As mentioned, the *Performance Confirmation Plan* will employ the preliminary identification of principal factors as described in the RSS (CRWMS M&O 2001, Vol. 2, Section 4.1, pp. 4-1 to 4-7) as a basis for the identification of performance confirmation factors together with other available performance analyses. The principal factors that are important to repository safety were first developed for the *Total System Performance Assessment,* Volume 3 of *Viability Assessment of a Repository at Yucca Mountain* (DOE 1998d, pp. 2-4 to 2-10). Since then, the principal factors have evolved due to changes in design and additional analyses.

The factors that are presented in Table 3-1 are from the current RSS (i.e., CRWMS M&O 2001, Vol. 2, p. 4-1) and are consistent with the repository design as described in Appendix D. These factors may change as the result of TSPA sensitivity analyses and will be modified as the RSS (CRWMS M&O 2001) (or successor document) is revised. A complete description of each of the principal factors may be found in the RSS (CRWMS M&O 2001, Vol. 2, Section 4.1, pp. 4-1 to 4-7). The following sections describe the factors as they relate to performance confirmation, provide a brief description of the selection of principal factors, and describe the approach to using the principal factors (identified in the RSS) to identify performance confirmation factors.

3.4.2.2 Repository Safety Strategy Principal Factors

The RSS (which is derived from TSPA analyses) is based on the identification of key attributes of the repository system that contribute significantly to repository postclosure safety. The key attributes are defined as those attributes encompassing the features, events, and processes important to postclosure performance of a potential repository system at Yucca Mountain. These specifically refer to performance of the system in which the dominant features, events, and processes are those related to mobilization of radionuclides by water followed by the migration of water-borne radionuclides away from the potential repository. The key attributes identified are (CRWMS M&O 2001, Vol. 2, Table 4-1):

- Limited water entering emplacement drifts
- Long-lived waste package and drip shield
- Limited release of radionuclides from the engineered barriers
- Delay and dilution of radionuclide concentrations provided by the natural barriers
- Low mean annual dose even considering potentially disruptive events.

The relationship of attributes of the safety strategy to the factors that control performance depends on the design of the repository system. The importance of these factors to performance is determined through performance assessment and related sensitivity analyses. The importance of these factors will be defined in detail by the TSPA site recommendation and the TSPA-LA. This plan will then be revised accordingly.

Table 3-1. Factors Important to Postclosure Safety

Key Attributes of the Repository System	Factors for the Enhanced Repository System[1]
Limited Water Entering Emplacement Drifts	Climate
	Infiltration
	Unsaturated Zone Flow (above Repository)
	Seepage into Drifts*
	Effects of Heat on Flow
Long-lived Waste Package and Drip Shield	Performance of Drip Shield/Drift Invert System*
	Environments in Emplacement Drifts
	Performance of Waste Package*
Limited Release of Radionuclides from the Engineered Barriers	Environments in Waste Packages
	Cladding Performance
	Waste Form Performance
	Radionuclide Concentration Limits in Water*
Delay and Dilution of Radionuclide Concentrations Provided by Natural Barriers	Unsaturated Zone Flow
	Radionuclide Delay Through the Unsaturated Zone*
	Saturated Zone Flow
	Radionuclide Delay Through the Saturated Zone*
	Effect of Wellhead on Radionuclide Concentrations
	Biosphere Transport and Uptake (Biosphere dose conversion factors)
Low Mean Dose Considering Potentially Disruptive Events	Probability of Igneous Activity*
	Repository Response to Igneous Intrusion*
	Additional Factors that Also Apply to Nominal Scenario: • Seepage into Emplacement Drifts* • Radionuclide Concentration Limits in Water* • Radionuclide Delay Through the Unsaturated Zone* • Radionuclide Delay Through the Saturated Zone*

NOTE: * Principal factor of the postclosure safety case.

[1] Based on text from CRWMS M&O (2001, Vol. 2, Sections 4.1 and 4.2).

For the RSS, principal processes (factors) were identified based on total system performance analyses, and on one or more of the following considerations (CRWMS M&O 2001, Vol. 2, p. 4-1):

1. They contribute substantially to expected postclosure performance.

2. They are a source of uncertainty sufficient to bring into question whether the postclosure performance objective is met.

3. They provide significant defense-in-depth.

Processes not identified (i.e., not included as "principal factors") are termed "other factors" for this discussion, but consideration of such other factors remains a required part of a detailed performance assessment.

The factors that affect repository performance are described in the PMRs that were developed in preparation for the TSPA site recommendation. The scope of each PMR is presented in Table 3-2, and the relationship of each of the factors to a particular PMR is presented in Table 3-3. Each PMR is a summary of more detailed reports called AMRs. The PMRs and the supporting AMRs are intended to fully describe current understanding of the factors that affect postclosure repository performance. The AMRs also contain the abstractions necessary for input into the TSPA site recommendation base case model. These reports provide the basis for the TSPA site recommendation and when revised (updated) will support the TSPA-LA. When the revised reports and the TSPA-LA are available, the *Performance Confirmation Plan* for the LA can be fully developed.

As this process moves forward, revisions of the *Performance Confirmation Plan* will be based on the current safety strategy and the TSPA.

3.4.2.3 Identification of Performance Confirmation Factors from the Repository Safety Strategy Principal Factors

A performance confirmation factor is defined as a factor of importance to postclosure safety that is to evaluate the adequacy of the information used to provide reasonable assurance that the performance objectives for the period after permanent repository closure will be met. For each RSS principal factor in Table 3-1, there is a corresponding evaluation to identify a potential performance confirmation factor, if possible (Table 3-4). This evaluation is discussed for each of the RSS principal factors (shown in Table 3-4) in the following sections. Some of the potential performance confirmation factors are eliminated in the identification of the actual performance confirmation factors to measure. The results of sensitivity analyses from the TSPA-VA were used to screen out principal factors related to dissolution of waste forms and dilution and retardation of radionuclides. Principal factors defined in the future versions of the RSS (which, in turn, will be based largely on the TSPA sensitivity results) will become key performance confirmation factors.

Table 3-3. Process Model Reports That Provide the Technical Basis for Principal and Other Factors

Categories	Factors for the Repository System	Associated Process Model Report (PMR)
Principal Factors (Nominal Scenario)	Seepage into emplacement drifts	Unsaturated Zone Flow and Transport
	Performance of the drip shield/drift invert system	Waste Package Degradation/Engineered Barrier System Degradation, Flow, and Transport
	Waste package performance	Waste Package Degradation
	Radionuclide concentration limits in water	Waste Form Degradation
	Radionuclide delay through the unsaturated zone	Unsaturated Zone Flow and Transport
	Radionuclide delay through the saturated zone	Saturated Zone Flow and Transport
Other Factors (Nominal Scenario)	Climate	Unsaturated Zone Flow and Transport
	Net infiltration into the mountain	Unsaturated Zone Flow and Transport
	Unsaturated zone flow above the repository	Unsaturated Zone Flow and Transport
	Effects of heat on flow	Unsaturated Zone Flow and Transport & Near Field Environment
	Environments in emplacement drifts	Engineered Barrier System Degradation, Flow, and Transport
	Environments in waste packages	Waste Form Degradation
	Cladding performance	Waste Form Degradation
	Waste form performance	Waste Form Degradation
	Unsaturated zone flow	Unsaturated Zone Flow and Transport
	Saturated zone flow	Saturated Zone Flow and Transport
	Effect of wellhead on radionuclide concentrations	Saturated Zone Flow and Transport
	Biosphere transport and uptake (biosphere dose conversion factors)	Biosphere
Factors for Disruptive Event Scenarios	Probability of igneous activity	Disruptive Events
	Repository response to igneous intrusion	Disruptive Events
	Additional factors that also apply to nominal scenario: • Seepage into emplacement drifts • Radionuclide concentration limits in water • Radionuclide delay through the unsaturated zone • Radionuclide delay through the saturated zone	(See Above)

Table 3-4. Performance Confirmation Factors and Type of Testing Based on Principal Factors

Key Attributes of the Repository System	Principal Factors for the Repository System	Performance Confirmation Key Factors	Type of Testing
Limited Water Entering Emplacement Drifts	Seepage into Emplacement Drifts	Ambient flow through the repository horizon and seepage into unventilated drifts	In situ testing during construction and operation
Long-lived Waste Package and Drip Shield	Performance of Drip Shield/Drift Invert System	Failure rate of drip shields [1]	Laboratory testing of drip shield materials over a range of expected repository conditions combined with process modeling of drip shield failure
	Performance of Waste Package	Corrosion rate of waste package materials and failure rate of waste packages	Laboratory testing of waste package materials over a range of expected repository conditions and process modeling of waste package failure, together with in situ monitoring/testing of waste package surfaces
Limited Release of Radionuclides from the Engineered Barriers	Radionuclide Concentration Limits in Water	Potential factor of solubility of actinides	Potential laboratory testing of solubility of actinides
Delay & Dilution of Radionuclide Concentrations Provided by Natural Barriers	Radionuclide Delay Through the Unsaturated Zone	None	None
	Radionuclide Delay Through the Saturated Zone	None	None
Low Mean Dose Considering Potentially Disruptive Events	Probability of Igneous Activity	In situ conditions which are possible precursors to igneous activity	Field monitoring of surface uplift and water level and water temperature of aquifer
	Repository Response to Igneous Intrusion	None	None
	Additional Factors that Also Apply to Nominal Scenario: • Seepage into Emplacement Drifts • Radionuclide Concentration Limits in Water • Radionuclide Delay Through the Unsaturated Zone • Radionuclide Delay Through the Saturated Zone	See Above	See Above

NOTE: [1] The determination of the need to test invert response by performance confirmation activities will be made in the next revision of this plan.

The present approach to identify performance confirmation factors is based upon principal factors of the current safety strategy. In the future, this program will update the identified performance confirmation factors as revisions of the RSS (and its successor documents), the PMRs, and the performance assessments become available. The current *Performance Confirmation Plan* is based on the following references (in toto): the RSS (CRWMS M&O 2001), the TSPA-VA (DOE 1998d and CRWMS M&O 1998d, Chapters 1-11), the *License Application Design Selection Report* (CRWMS M&O 1999a), and *Defense in Depth for Repository Postclosure Safety Case* (CRWMS M&O 1999c). More detail on the application of defense-in-depth concept can be found in *Example of Postclosure Defense in Depth Evaluation--The Viability Assessment Reference System* (CRWMS M&O 1999f).

These reports provide insight into the development the performance confirmation factors and into arguments that can be used to eliminate potential performance confirmation factors. Based on these reports, the factors that control repository performance can be simplified to provide a general premise that aids in the development of performance confirmation factors. This simplification yields the general premise that performance of the repository depends primarily on flow throughout the mountain and the failure rate of the waste packages.

3.4.2.4 Seepage into Emplacement Drifts

The seepage into unventilated emplacement drifts is directly related to the ambient flow through the repository horizon. The amount of seepage can be bounded, but the reasonable bound will require confirmation. In addition, the flux (seepage) is variable laterally so that data for confirmation will have to be obtained at several locations to determine whether the range of values is within the bound. The performance confirmation factor is defined as ambient flow through the repository horizon and seepage into unventilated drifts (Table 3-4).

3.4.2.5 Performance of Drip Shield/Drift Invert System

For this principal factor, the performance confirmation factor is defined as the failure rate of drip shields. Performance of the drip shield is predicted using the corrosion rates/mechanisms of materials and near-field conditions in a drip shield degradation model. The performance of the drip shield is related to the chemistry of the water contacting it and the mechanisms and rate of corrosion of the drip shield material.

The TSPA approach is to use a realistic representation of the corrosion mechanisms with uncertainty because bounding values are too conservative. Long-term corrosion rates and mechanisms will be determined through laboratory testing in the expected chemical environment that is predicted using process models. The process models used for these predictions are the drift-scale hydrothermal models and geochemical models. The temperature in the vicinity of the drip shield is a critical factor in these analyses. For example, if the temperature remains below boiling, the chemistry would remain near ambient by being influenced only by the materials used for the drift support. As the temperature increases, both the volume of rock and the duration of boiling influence the chemistry.

The uncertainty of geochemical processes at temperatures above boiling and the coupling of the chemistry, temperature, and water movement cause the failure rate of the drip shield or the waste package to be highly uncertain. Currently, the dissolution and precipitation of minerals during boiling is highly uncertain using geochemical models and will have to be determined through drift-scale testing. Because of the reliance on process models to establish the environment for the laboratory testing, the process models will have to be tested. Laboratory and in situ repository testing will be conducted to determine the geochemical conditions that are expected during heating and eventual return to ambient temperature, and these test data will be used for the comparison to model predictions. In situ testing will also be used to confirm conditions bounded by laboratory tests, as appropriate. The amount of water contacting the drip shield over time will also have to be measured or bounded.

The failure rate of drip shields caused by drift collapse will also have to be analyzed. In this analysis, rock mechanics models would be used to predict the severity of collapse. The analyses will include the effects of drip shield corrosion at the time of drift collapse.

3.4.2.6 Performance of the Waste Package

For this principal factor, the performance confirmation factor is defined as the corrosion rate of waste package materials and the failure rate of the waste packages (Table 3-4). The failure rate of the waste packages is predicted using material corrosion rates/mechanisms and near-field conditions in a waste package degradation model. The performance of the waste package is related to the chemistry of the water contacting it and the corrosion mechanisms and corrosion rate of the package materials. The TSPA approach is to use a realistic representation of the corrosion mechanisms with uncertainty because bounding values are too conservative. Long-term corrosion rates and mechanisms will be determined through laboratory testing in the expected chemical environment that is predicted using process models. The process models used for these environment predictions are the drift-scale hydrothermal models and geochemical models (as above). The temperature in the vicinity of the waste package is expected to be above boiling during the heating phase so that dissolution and re-precipitation of minerals is expected. Leaching of these minerals may have a significant effect on the chemistry of the water contacting the waste package once the drip shield has failed. Here, as in the case of drip shields, because of the reliance on process models to establish the environment for the laboratory testing, the models will have to be tested. Laboratory and in situ repository testing (as appropriate) will be conducted to determine the geochemical conditions that are expected (during the heating and return to ambient temperature) and these test data will be used for the model evaluations. In situ testing will also be used to confirm conditions bounded by laboratory tests. It is expected that a single in situ test can be developed to obtain data for evaluating the process models used to predict the near-field environment for both the drip shield and the waste package.

3.4.2.7 Radionuclide Concentration Limits in Water

Transport of radionuclides through the engineered barrier system depends on the solubility of the particular radionuclide. For example, the solubility of the actinides is important to the performance of the barrier system once the waste package has failed. A realistic representation based on existing data will be used, and sensitivity analyses will be conducted over a reasonable range to determine the effects of uncertainty on long-term dose. It is anticipated that existing data are adequate to confirm this principal factor. Should existing data prove inadequate, laboratory testing would be conducted to confirm actinide solubility, for those that contribute significantly to dose, under chemical conditions expected in the failed waste package. For this reason, a performance confirmation factor of solubility of actinides was defined (Table 3-4).

3.4.2.8 Radionuclide Delay through the Unsaturated Zone

Sorption coefficients and matrix diffusion can be realistically bounded using existing data and sensitivity analyses. Lower bound values should not cause repository releases to be higher than regulatory standards. For the UZ, changes in sorption coefficient over a range of 0 to 100 (CRWMS M&O 1998d, Chapter 7, Figures 7-47 and 7-48, p. F7-32) have little effect on the breakthrough curve from the UZ (CRWMS M&O 1998d, Chapter 7, Figure 7-54, p. F7-35). As sorption is increased, the dose peaks for sorbed radionuclides are moved farther out in time. Because of the small influence of sorption on the breakthrough curves, the dose peaks will be the same, and only the leading edge of the dose curve will change in shape as sorption is increased. The peak dose will not change because of the long half-lives of the radionuclides that contribute significantly to the dose (i.e., technicium-99, iodine-129, and neptunium-237). For this reason, no performance confirmation factor is included for this principal factor (Table 3-4). The importance of retardation of radionuclides in the UZ as a performance confirmation factor will be reassessed in a future revision of the plan when results of Revision 4 of the RSS and the analyses from the TSPA for the Site Recommendation report become available.

3.4.2.9 Radionuclide Delay through the Saturated Zone

Sorption coefficients and matrix diffusion can be realistically bounded using existing data and sensitivity analyses. The dose from the repository is caused primarily by three radionuclides, which are technicium-99, iodine-129, and neptunium-237. Of these radionuclides, only neptunium is sorbed significantly along the transport pathway between the point of release (from the engineered barrier system) and the point of potential water use (20 km down gradient from the repository). Its sorption coefficient ranges from 5 to 15 (ml/g) for the alluvium and 0 to 15 (ml/g) for the tuff (CRWMS M&O 1998d, Chapter 8, Table 8-19, p. T8-22). Sensitivity analyses show that dilution of radionuclides from all sources (sorption, matrix diffusion, and mixing caused by dispersion) is a factor of 10 (CRWMS M&O 1998d, Chapter 8, p. 8-88). Because of the small amount of retardation of neptunium, sorption would be expected to contribute little to the overall dilution. Bounding sorption with a coefficient of zero (retardation of 1.0) would be conservative and would be expected to have little effect on dose (similar to the effects on the breakthrough curves for the UZ discussed above). For these reasons, sorption of radionuclides in the SZ is not retained as a performance confirmation factor. Lower bound values of retardation (i.e., 1) should not cause repository releases to be higher than regulatory standards. For this reason, no performance confirmation factor is included for this principal factor (Table 3-4).

3.4.2.10 Performance Confirmation Factors Important to Performance

Table 3-4 shows the performance confirmation factors, type of testing, and ongoing laboratory testing that is discussed associated with principal factors. The testing for chemistry of water contacting the waste package is less important as cooler repository designs are considered. However, even for cool repository designs, some testing may still be required for validation of the process models associated with failure rate of the drip shields and waste packages. There is also the potential for additional laboratory testing of the solubility of the actinides (Table 3-4).

There is good agreement between the performance confirmation factors and the general premise of performance discussed earlier. The only one other factor with an effect on performance as great as the waste package failure rate and the groundwater flow through the mountain is the failure rate of the Zircaloy cladding on the commercial spent nuclear fuel (CSNF). If existing data is found inadequate to confirm the cladding failure rate, additional laboratory testing would be required (Table 3-4).

3.4.3 Identification of Performance Confirmation Factors for Licensing

With the completion of the site characterization phase of the MGR, it is expected that some additional data and model validation efforts may be required to support the LA submittal, with residual confirmatory data needs prior to the emplacement of waste at this facility. These data and model needs will be identified in future revisions of the PMRs. Any confirmatory testing driven from this source will be included in the LA. In lieu of TSPA sensitivity analyses, preliminary process model data needs serve to identify additional items that could be important to postclosure safety. Planned sensitivity analyses may eliminate some of these items prior to the next revision of the performance confirmation plan. For this version of the plan, these preliminary data needs are addressed as potential performance confirmation factors and are evaluated consistent with Section 3.4.2.3 to identify additional performance confirmation testing. Because of the preliminary nature of these information needs, adjustments to this portion of the program are likely in the LA version of this document. A listing of the nine process models associated with these data needs is shown in Table 3-5.

Since the PMRs are still being developed, draft versions of these documents are unavailable. Without these documents, direct identification of performance confirmation factors or related testing in support of the LA is not possible. As an interim measure, input transmittals from staff developing the PMRs have been obtained and coordinated with the appropriate licensing staff to tentatively identify areas of possible needs and to provide an input to the present version of the plan.

As shown in Table 3-5, no data needs were identified (at the present) for four process models: (1) Integrated Site, (2) Biosphere, (3) Disruptive Events, and (4) SZ Flow and Transport. For the Waste Form Degradation and the Waste Package Degradation models, long-term laboratory testing needs were identified, consistent with the requirements stated in Subpart F of DOE's Interim Guidance (see Appendix B) (Dyer 1999). Additional data needs were identified for the remaining factors, some of which are encompassed in the foregoing analysis (and shown in Table 3-4). Factors already screened in Sections 3.4.2.4 through 3.4.2.9 using the process described in Section 3.4.2.3 are eliminated as potential performance confirmation factors. This includes CSNF degradation and HLW glass degradation. Another potential factor, the validation of UZ Model by continuing investigations at analogue sites, was deleted from this list as it will be considered under insights from analogues, another component of the safety strategy (see Section 1.2.6). The remaining factors and tests are included in the test descriptions presented in Appendix G of the *Performance Confirmation Plan.*

Table 3-5. Potential Performance Confirmation Factors Based on Preliminary LA Data Needs

Process Model	Potential Performance Confirmation Factors	Type of Testing
Integrated Site Model	None identified at this time	--
Unsaturated Zone Flow and Transport[1]	Effects of construction on the ambient moisture and seepage conditions including drainage characteristics below drifts as affected by construction	Testing and monitoring of hydrological conductivity below repository during construction, and seepage testing and monitoring
	Sorptive properties of the CHn immediately below the repository	Sampling and laboratory testing of sorptive properties of the CHn
	Unsaturated flow and transport within the CHn formation to validate conceptual models	Sampling, laboratory and field testing
	Validation of UZ Model (by continued investigations at analogue sites)	---[3]
Near-Field Environment[1]	Rock mass response to cooling	Monitoring of rock mass thermal-hydrological-mechanical response as in cooling of Drift Scale Test
	Coupled thermal-mechanical-hydrological-chemical processes	Field testing
	Geochemical interactions as part of coupled processes	Laboratory testing
Engineered Barrier System Degradation, Flow, and Transport	None identified at this time	---
Waste Package Degradation[2]	Stress corrosion cracking of barrier materials: Nickel-Alloy (UNS N06022), Titanium Grade 7 (UNS R52400) and 316 stainless steel (UNS S31603) Long-term phase stability of Nickel-Alloy (UNS N06022) and 316 NG stainless steel (UNS S31603) Long-term stability of passive film on barrier materials	Laboratory materials testing
Waste Form Degradation[2]	Dissolved radionuclide concentration limits Colloidal radionuclide concentration and transportation limits Clad performance In-package chemistry CSNF degradation and high-level waste glass degradation.[4]	Laboratory materials testing
Saturated Zone Flow and Transport	None identified at this time	--
Biosphere	None identified at this time	--
Disruptive Events	None identified at this time	--

NOTE: [1] Source: CRWMS M&O 2000b

[2] Source: CRWMS M&O 1999d

[3] No testing was identified for the performance confirmation program to address this need, as analogue studies are a separate component of the safety strategy (see Section 1.2.6).

[4] No testing identified at this time.

3.4.4 Prescribed Performance Confirmation Factors

Requirement documents, as described earlier, indicate the requirements that must be addressed by performance confirmation. Some of these requirements directly prescribe specific factors or elements of the repository system to be investigated or specify specific testing categories or types. Of primary importance are the prescribed regulatory requirements expressed in Subpart F of DOE's revised Interim Guidance (see Appendix B) (Dyer 1999) which includes prescribed specific testing of both geologic and engineering systems.

Based on present performance confirmation requirements (identified and evaluated in Appendix E), prescribed performance confirmation factors and/or tests are presented in Table 3-6, together with the requirement source. The test type required for each factor is also identified. These prescribed factors are included in the identified testing descriptions in Section 7 and Appendix G of the *Performance Confirmation Plan.*

3.4.5 Parameter Screening

Upon identification of the processes that need to be examined (i.e., key performance confirmation factors), the underlying parameters for these processes must be evaluated to identify the essential set of parameters to be examined. A three-step screening process determines these essential or "key" performance confirmation parameters. The steps are:

1. The parameter must be relevant and describe either subsurface conditions, is affected by construction or emplacement, or is a time-dependent variable.

2. The parameter (or its basis) must be clearly defined and must be both measurable and predictable.

3. The parameter must be important to postclosure performance so that when measured it will reduce uncertainty of the repository system.

Postclosure performance parameters that are not included if the associated processes are not expected to occur in the preclosure phase and, consequently, cannot be monitored or tested. Examples are radionuclide concentrations in the ground water, future populations that would be affected by postclosure radionuclide releases, and radiation doses to these populations. Key performance confirmation parameters are initially identified as part of the test descriptions in Section 7 and Appendix G and will be defined in detail in subsequent performance confirmation detail test plans, which follow the development of the *Performance Confirmation Plan.*

Table 3-6. Prescribed Confirmation Factors and Testing Based on Requirements

Prescribed Performance Confirmation Factors & Testing	Required Testing/Monitoring	Requirement Source
Monitor waste package surface temperature to assess condition of cladding and verify that surface temperature is below 85°C	Monitoring of waste package surface	YMP-RD requirement[1] 2.3.2.04.38 MGR-PDD[2] requirements 5.1.1.2 and 5.1.1.3
Observation of the encountered subsurface (geologic) conditions of the repository horizon	Geologic observation mapping and index laboratory testing	YMP-RD requirements 2.3.2.04.08 and 2.3.2.04.16 Interim Guidance[3] Sec. 131(a)(1) and 132(a)
Monitoring of in situ rock mass response due to repository construction and waste emplacement	Rock mass monitoring (temperature and displacement) near emplacement drifts	YMP-RD requirements 2.3.2.04.08, 2.3.2.04.17, and 2.3.2.04.20 Interim Guidance Sec. 131(a)(1), 132(b), and 132(e)
Performance and constructability of borehole, ramp and shaft seals	Field testing of borehole, ramp and shaft seals	YMP-RD requirement 2.3.2.04.21 Interim Guidance Sec. 133(a)
Engineered barrier system interaction response of waste packages, backfill (if used), rock, and groundwater	Field testing of engineered barrier system postclosure configuration	YMP-RD requirement 2.3.2.04.21 Interim Guidance Sec. 133(a)
In situ monitoring of representative waste packages, at representative conditions and for as long as practical	Remote monitoring of waste package in emplacement drifts	YMP-RD requirements 2.3.2.04.25, 2.3.3.04.26 and 2.3.3.04.28 Interim Guidance Sec. 134(a), 134(b) and 134(d), MGR-PDD-Item 5.1.1.3
Laboratory investigations of internal waste package materials and waste form at representative conditions	Laboratory materials testing	YMP-RD requirement 2.3.2.04.27 Interim Guidance Sec. 134(c)
Water quality monitoring conducted at the boundary of the controlled area	Well monitoring, both downgradient and upgradient, at boundary of controlled area	Final EPA rule[4] Section 197.4
Disruptive event monitoring	Precise leveling surveys over repository Water level & temperature Monitoring -Subsurface seismic monitoring	YMP-RD requirement 2.3.2.04.10 Interim Guidance Sec. 131(a)(2)

NOTE: [1] *Yucca Mountain Site Characterization Project Requirements Document* (YMP 2001a).

[2] *Monitored Geologic Repository Project Description Document* (Curry 2001).

[3] "Revised Interim Guidance Pending Issuance of New U.S. Nuclear Regulatory Commission (NRC) Regulations (Revision 01, July 22, 1999), for Yucca Mountain, Nevada" (Dyer 1999). Cited sections are under Subpart F, included in Appendix B.

[4] *Public Health and Environmental Radiation Protection Standards for Yucca Mountain (40 CFR Part 197)*

4. PROGRAM FLOW, BASELINE COMPONENTS, AND PREDICTIONS

4.1 PROGRAM FLOW

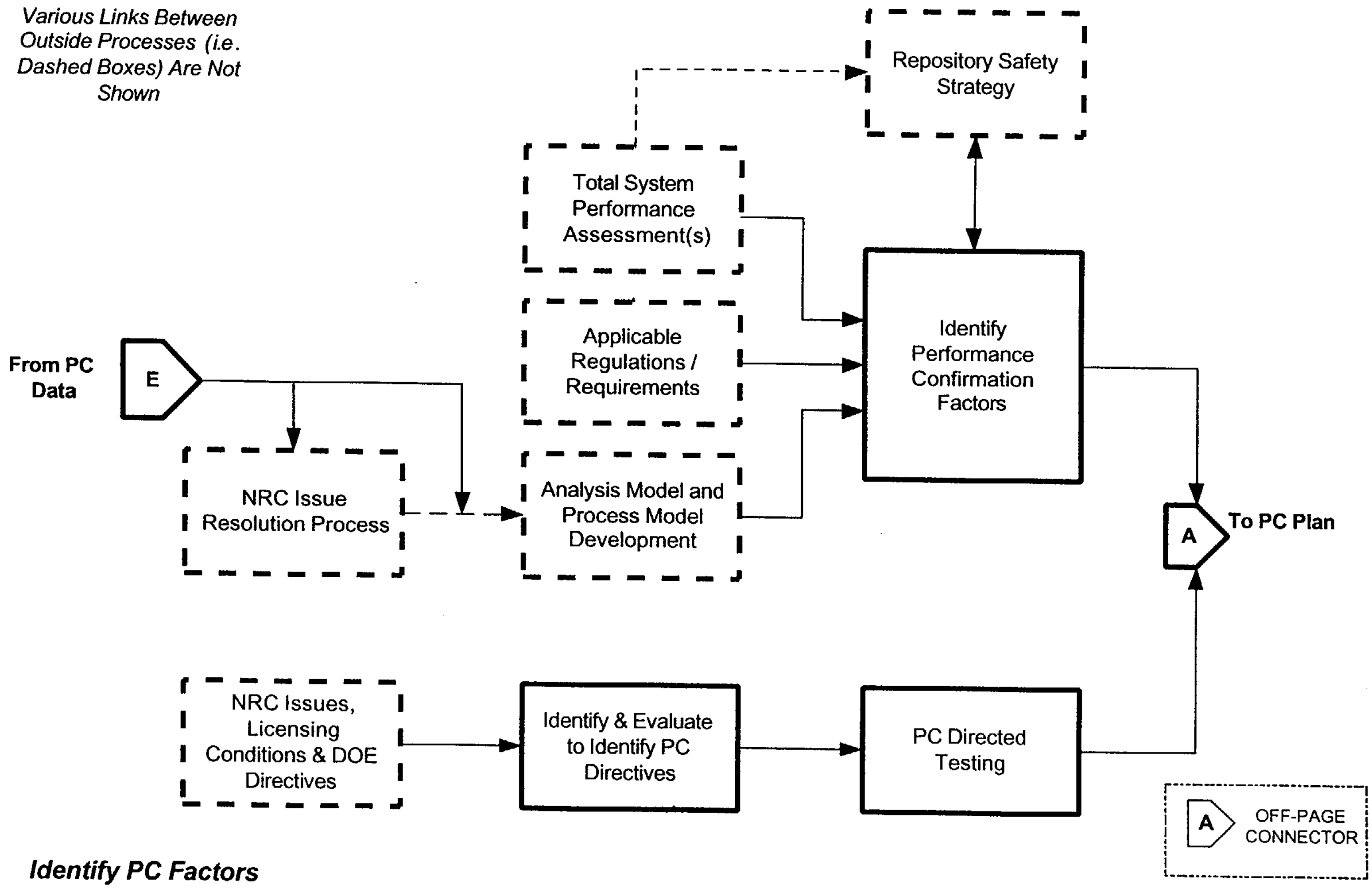
As described in Chapter 2, the performance confirmation concept of operations is a process of data measurement and data evaluation. The concept of operations can be divided into eight steps:

1. Identify performance confirmation factors
2. Establish the performance confirmation database and predict performance
3. Establish tolerance and bounds
4. Establish completion criteria and guidelines for corrective actions
5. Plan and set up the performance confirmation test and monitoring program
6. Monitor, test, and collect data
7. Analyze, evaluate, and assess data
8. Recommend and implement corrective actions (if required).

To conduct these steps, a logic flow is identified that describes the inputs and outputs of the performance confirmation process. In brief, the logic for performance confirmation activities can be represented by a set of four diagrams, as shown in Figures 4-1 through 4-4. These diagrams represent the interaction and complexity of the performance confirmation process.

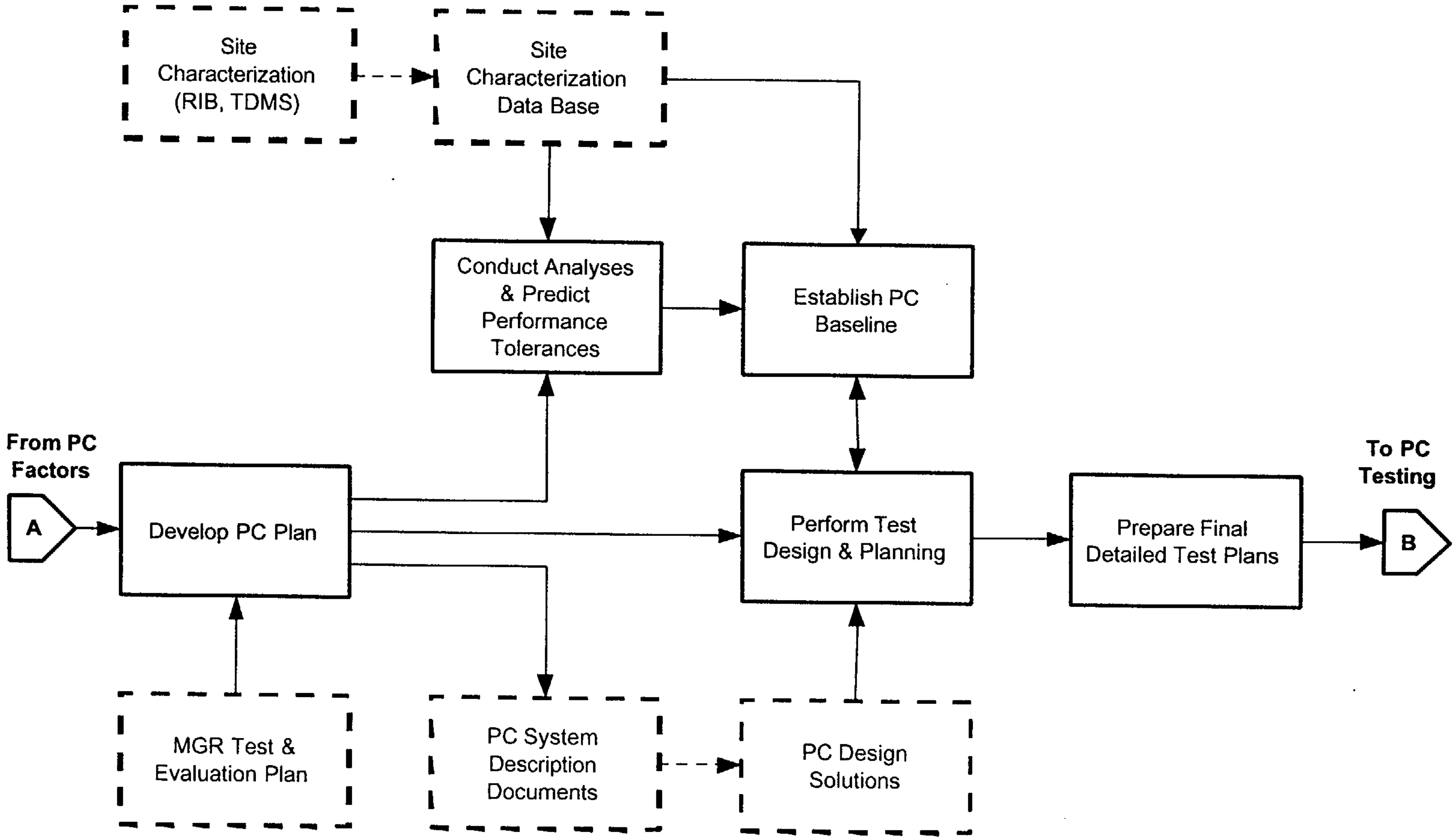
The first diagram (Figure 4-1) focuses on the identification of performance confirmation factors and inputs for this version of the *Performance Confirmation Plan*. It includes the identification of the performance confirmation requirements and key performance confirmation factors, including: (1) the factors important to safety identified by the TSPA, (2) the requirements identified directly in applicable regulations, and (3) other factors potentially important to postclosure safety such as data and model validation needs from the PMRs. The RSS uses the TSPAs to establish principal factors, which in turn influences the identification of performance confirmation key factors. Another input for the performance confirmation program is the set of test/data requirements as required by the NRC for licensing or as indicated by directives by DOE (termed "directed testing").

The second diagram (Figure 4-2) encompasses activities needed to plan performance confirmation activities. The identification of the performance confirmation factors in the first chart allows the development of the *Performance Confirmation Plan*, which is prepared in accordance with the overall *Monitored Geologic Repository Test and Evaluation Plan* (Skorska 2001). Given the *Performance Confirmation Plan*, analyses can be performed to establish the test baselines as well as provide input in the system description documents. The system description documents in turn provide guidance to develop design solutions, which are used in performance confirmation testing. At the conclusion of the process, detailed test plans are constructed to describe the testing/monitoring to be conducted, the facilities to be utilized, and the data to be collected (together with completion criteria).



PC (performance confirmation)

Figure 4-1. Process: Identification of Performance Confirmation Factors



Develop PC Plan & Plan Tests

PC (performance confirmation)
RIB (reference information base)
TDMS (Technical Data Management System)

Figure 4-2. Process: Development of the Performance Confirmation Plan

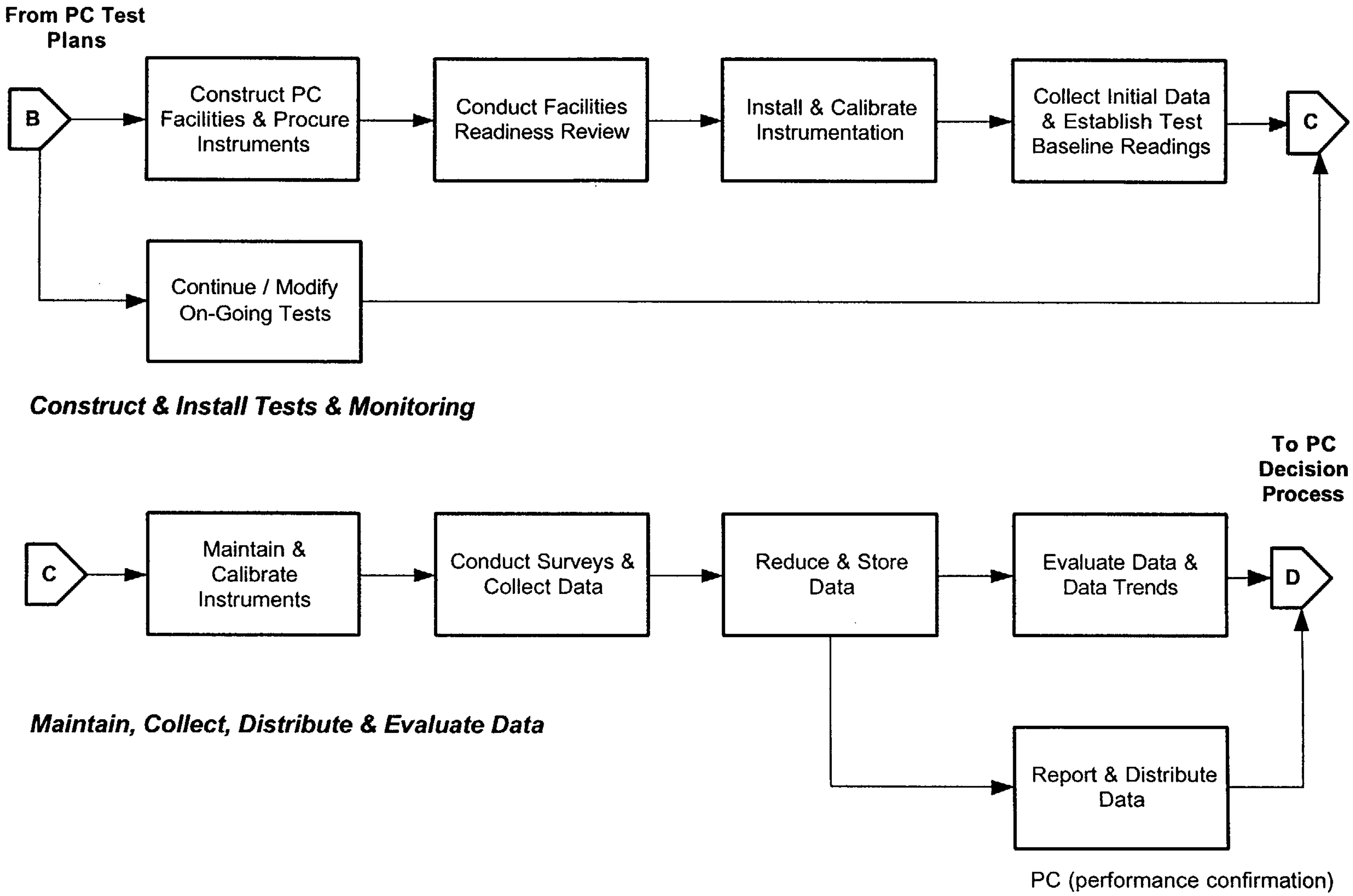
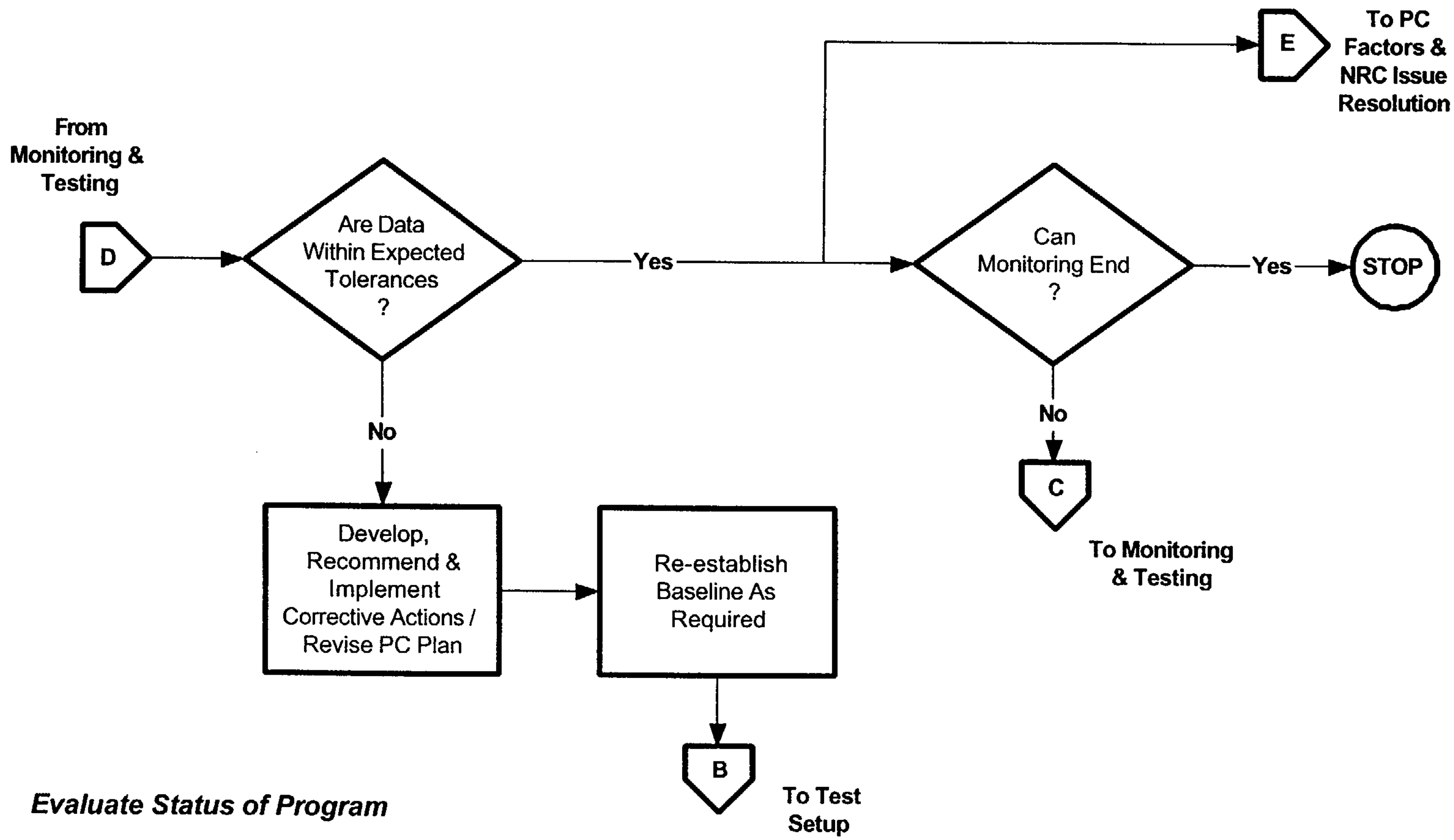


Figure 4-3. Process: Performance Confirmation Facilities and Data Collection



PC (performance confirmation)

Figure 4-4. Process: Performance Confirmation Data Evaluation

The third diagram (Figure 4-3) identifies the steps to implement the detailed test plans; it includes the activities to monitor, test, and collect data and then analyze, evaluate, and assess these data. The first activity of the diagram is to construct and establish a performance confirmation test facility. Included under the process are installation and calibration of instruments and the establishment of an initial baseline (i.e., reference basis for ambient variation such as monitoring ambient rock movements prior to construction).

Also in Figure 4-3, ongoing testing and activities utilizing prior test facilities, a second alternative path is indicated between points B and C. After the test facility is established (at Point C), data are collected, reduced, and stored. Data are then reported to the public, evaluated for trends, and compared to the performance confirmation baseline (completing the activities at Point D).

The fourth diagram (Figure 4-4) describes (in simplified form) the final decision process that occurs after the data have been evaluated. This decision process includes addressing data variations outside the baseline and implementing corrective actions, if required. If corrective action is required, it may also require modification of an ongoing performance confirmation activity or require construction of new performance confirmation facilities, as indicated by the directive to return to the previous diagram (to Point B). The second decision point is to evaluate if the activity needs to continue or has satisfied its completion criteria and can be concluded with the approval of the NRC. If not, the activity continues (returning to data collection at Point C). Concurrently, obtained data are transmitted to other portions of the project or other stakeholders (Point E), and these data in turn can affect the overall performance confirmation process.

4.2 PROGRAM BASELINE

4.2.1 Overview

The performance confirmation baseline will incorporate information on subsurface conditions and natural systems important to postclosure performance. The performance confirmation baseline will be established for natural conditions prior to construction of the repository and as necessary before conducting other activities of the test and monitoring program. Activities during the performance confirmation period will verify that actual subsurface conditions and changes resulting from construction and/or operation are within acceptable performance limits, and that the natural and engineered systems and components are functioning as required. This information will be used to support the LA submittal to the NRC requesting amendments to receive and possess waste and to close the repository.

The performance confirmation baseline will include the following:

- **Reference Information**–Reference information on each key performance confirmation parameters will be identified, including specific data tracking numbers, if applicable.
- **Predictions**–Predictions of expected values of the specific parameters and associated uncertainties will also be established for each key performance confirmation parameter.

- **Test Criteria or Tolerances**–The tolerances and confidence levels for determining significance of deviations will also be part of the performance confirmation baseline.
- **Completion Criteria**–The criteria used to determine when an activity could be concluded will also be part of the baseline.

These items are described in more detail in the following sections.

4.2.2 Reference Information

The performance confirmation baseline will contain information that establishes the state of a system, subsystem, component, or condition, such as the geologic setting, that may change as a result of construction and/or emplacement activities. The information collected during site characterization will be included as part of the performance confirmation baseline. This information may include parameter sample means, observed ranges, standard deviations, or description of parameter distributions. This reference information will be established for each performance confirmation parameter.

4.2.3 Predictions

The performance and uncertainties for each performance confirmation parameter will be predicted. These predictions will define the expected state of a system, subsystem, component, or condition that may change as a result of site characterization, construction, or emplacement activities. Uncertainties in the prediction of the parameter state will be established. This information may include estimates of parameter expected value, variance, or a description of the parameter distribution. These data may be both temporally or spatially variable. This information will be developed prior to construction and emplacement activities. Later, observations of the parameter will be made and an evaluation will be performed to compare observed values with the predicted values.

4.2.4 Test Criteria or Tolerances

Test criteria for each parameter, which could be stated in the form of a confidence or significance level for statistical tests, in the form of parameter tolerance limits or ranges, or screening levels, will be established. Since uncertainty is a part of many of the parameters, the test criteria will establish (1) the required level of statistical significance, or (2) if the deviations between measured and predicted values are statistically significant. These criteria or limits will be established so that from observations of the parameters, predictions can be confirmed and deviations from the acceptable test criteria can be evaluated. If the test criteria are not met, appropriate analyses will be conducted, and corrective action will be recommended.

4.2.5 Completion Criteria

The criteria for completing each performance confirmation activity will be specified as part of the performance confirmation baseline. Completion criteria are necessary to ensure that the *Performance Confirmation Plan* is sufficient to provide information to support the evaluation of the repository's readiness for permanent closure. Performance confirmation is the program of tests, experiments, and analyses which is conducted to evaluate the accuracy and adequacy of the information used to determine that the performance objectives for the period after permanent closure will be met with reasonable assurance. The completion criteria may specify the level of accuracy and adequacy needed and the duration of time in which additional information is obtained. The additional information obtained through the conduct of the performance confirmation program will support evaluation of the postclosure performance objectives, or the results of this program will identify information in the LA that was unexpected, resulting in the implementation of a corrective action(s).

4.3 PREDICTIONS OF PERFORMANCE

4.3.1 Overview

Confirmation of the performance of the natural and engineered barrier systems of the MGR will include comparisons of model predictions with measured data. These comparisons will involve:

- Establishing a baseline of preclosure and postclosure performance predictions before the submittal of the LA
- Comparing data obtained to model predictions to confirm the validity of the models used for prediction of postclosure performance after the submittal of the LA
- Assessing any changes in predicted compliance with regulatory requirements
- Recommending corrective actions and updating the performance confirmation baseline, if necessary.

This section describes the performance predictions that in conjunction with performance confirmation data will form the basis for these comparisons. The comparisons, evaluations, and corrective actions are described in Section 6.1.

4.3.2 Pre- and Post-License Application Predictions

4.3.2.1 General

Comparisons of measurements and analyses during the performance confirmation period to predicted bounds of limits included in the LA help provide reasonable assurance that postclosure conditions with long-term performance sensitivity will behave as expected. The modeling predictions described in the following sections will be developed as a prerequisite to tests and conducted during the performance confirmation period. Information from performance confirmation tests will be used to make direct comparisons to these predictions, or to support analyses that provide information suitable for comparisons to predictions.

The following sets of performance predictions will be made:

1. Pre-LA performance predictions of the natural and engineered barriers for the performance confirmation period using the LA database

2. Post-LA performance predictions of the natural and engineered barriers for the performance confirmation period using performance confirmation data in addition to the LA database (These analyses will be used to determine if there are changes in expected performance because of changes in data or corrective actions.)

3. Post-LA predictions of the expected postclosure performance of the natural and engineered barriers and the overall MGR using the performance confirmation data in addition to the LA database (These analyses will be used to evaluate if there are any changes in compliance with regulatory requirements through comparison of these predictions to those in the LA.).

The first two activities involve modeling of specific processes for predicting parameter values that are to be measured in the site monitoring and test activities of the performance confirmation program. The specific analyses for the first two activities and their relevance to site monitoring and test activities are described in the following sections. The third activity involves modeling the processes important for overall MGR postclosure performance as described in Section 3.3.

The interrelationship of these activities with respect to timing and scope are shown in Table 4-1. Table 4-1 lists the performance predictions as described in this section and data used for the prediction. The first activity, as defined, precedes the submittal of the LA and uses the same database as the LA. It will provide guidance to the specifications for the performance confirmation site monitoring and testing. The second and third activities are performed after the submittal of the LA and could be performed together as the normal output of the predictive models. These activities will be performed as necessary to facilitate comparisons of measurements and data to the predictions and bounds contained in the LA. Consequently, if significant changes are warranted, these activities could lead to model improvements, changes in the performance confirmation program, or changes in the MGR design, construction, and operation (see Section 6.1).

The overall prediction process will evolve with time. Additional performance confirmation data, the advance of general knowledge, or an increased understanding of natural and engineered systems and component processes could indicate the need for new conceptual and mathematical models. Predictions using improved models when compared to those in the LA could change the results of the performance assessment even if all other aspects, such as parameter values, repository layout, and waste emplacement remain unchanged. Performance confirmation will incorporate, as necessary, the effects of significant mathematical model and computer code changes associated with demonstrating compliance with regulatory standards. Although the actual improvement of mathematical models and computer codes is not within the scope of performance confirmation, the results will include recommendations for model improvements as needed.

Similarly, new data and the advance of general knowledge and understanding of natural and engineered systems and component processes may indicate the need for changes in the performance confirmation program. These changes could involve additional measurement points, additional tests, or reduced scope of the planned measurements or tests. The results of the predictions and associated comparisons could also indicate the need for a change in the MGR design, construction, and operation. These changes, while viewed as unlikely, would be implemented to bring the MGR back into compliance with regulations.

Table 4-1. Timing, Scope, and Data Used for Performance Predictions

Activity	Timing	Scope of Predictions	Data Used
Pre-LA Performance Predictions for the Performance Confirmation Period	Once or twice before submittal of LA	Predictions of natural and engineered system performance during the performance confirmation period	Site characterization data and pre-LA performance confirmation data
		Recommendations for model improvements, performance confirmation program changes, and MGR design, construction and operation changes, if needed	
Post-LA Performance Predictions for the Performance Confirmation Period	As necessary after submittal of LA	Predictions of natural and engineered system performance for the performance confirmation period	Site characterization data and pre- and post-LA performance confirmation data
		Comparisons with pre-LA performance predictions for the performance confirmation period	
		Evaluation of process models	
		Recommendations for model improvements, performance confirmation program changes, and MGR design, construction, and operation changes, if needed	
Post-LA Predictions of Postclosure Performance	As necessary after submittal of LA	Predictions of postclosure natural and engineered system and overall system performance	Site characterization data and pre- and post-LA performance confirmation data
		Comparisons with LA postclosure performance predictions	
		Evaluation of changes in regulatory compliance	
		Recommendations for model improvements, performance confirmation program changes, and MGR design, construction, and operation changes	

4.3.2.2 Pre-License Application Performance Predictions for the Performance Confirmation Period

The confirmation of postclosure performance relies on preclosure measurements and testing to demonstrate compliance with the postclosure performance objectives and standards of the "Revised Interim Guidance Pending Issuance of New U.S. Nuclear Regulatory Commission (NRC) Regulations (Revision 01, July 22, 1999), for Yucca Mountain, Nevada" (Dyer 1999). Performance assessment predictions are required to establish the baseline for the expected behavior of the natural and engineered barriers from the beginning of construction, through waste emplacement and the monitoring period, to permanent repository closure. Sensitivity and uncertainty analyses will be used to establish the expected range of parameters at measurement locations for the planned time of the measurement. These analyses will provide feedback to the development of detailed test and measurement specifications that could result in revision of the planned tests and measurements.

To date, performance assessments have concentrated on the preclosure radiological safety of the workers and the general public (CRWMS M&O 1996f) and on the postclosure performance of the natural and engineered barriers (CRWMS M&O 1995; CRWMS M&O 1998d; DOE 1998d).

In addition, design analyses and operational safety analyses have included waste package, drift stability, and ventilation analyses (CRWMS M&O 1996f).

The simulation period of previous postclosure performance assessments usually started with the permanent closure of the repository, assuming the final radioactive waste inventory at the beginning of the simulation period as the initial condition for the predictions. For performance predictions for the performance confirmation period, however, the planned progression of construction, waste emplacement, and ventilation will be considered. In addition, predictions will include the effects of ventilation on testing because the enhanced repository design (shown in Appendix D) relies on ventilation to reduce the volume of rock in which boiling will occur after closure.

Complete analyses have not yet been performed that would predict the preclosure response of the natural and engineered system and components important for postclosure performance. However, pretest analyses of thermal hydrologic conditions for heater tests have been conducted (Birkholzer and Tsang 1997, pp. 1 to 3, and 42 to 47; Buscheck et al. 1997a, p. iii; Buscheck et al. 1997b, pp. ii and 5-1; and Buscheck et al. 1997c, pp. 8-1 to 8-4). These analyses included geochemical predictions (Sonnenthal et al. 1998, pp. 1, 4, 5, and 70 to 72), evaluation of air permeability (Nitao 1997, pp. 7 to 8), and evaluations of seepage into drifts (Tsang and Cook 1997, pp. 15 to 16). These analyses are representative of the type of analyses that would be conducted prior to testing for performance confirmation.

Pre-LA performance predictions for the performance confirmation period will be conducted as part of the TSPA for the LA. These analyses are expected to include all of the evaluations described in this section and are included in the *Performance Confirmation Plan* for completeness. Predictions will be made for all processes to be evaluated and performance confirmation parameters to be measured in order to confirm the factors described in Chapter 3.

These predictions of the performance of the natural and engineered barriers during the performance confirmation period will provide the basis for the comparison with performance confirmation data. The predictions will consider the planned progression of repository construction and waste emplacement, including the planned types and locations of wastes to be emplaced. The modeling analyses will include predictions of both in situ and laboratory measurements as defined in the *Performance Confirmation Plan*. The analyses will not predict the full three-dimensional transient state of the natural and engineered barriers, but will be tailored to predict the parameters to be measured only at the locations and times of the planned performance confirmation activities. The analyses will demonstrate that the limited test analyses and measurements will sufficiently represent the total system behavior. The specific modeling analyses planned and their relationships to the planned performance confirmation site monitoring and testing concepts are described in Section 4.3.3.

4.3.2.3 Post-License Application Performance Predictions for the Performance Confirmation Period

The modeling analyses for the performance confirmation period performance of the natural and engineered barriers will be performed before the submittal of the LA and will be updated periodically after its submittal, as necessary. These predictions will use the LA database supplemented with the parameter values obtained by the performance confirmation site monitoring and testing. The purpose of these analyses will be to evaluate the adequacy of the conceptual and mathematical models for predicting natural and engineered barrier performance, i.e., to test the validity and accuracy of the models.

When conducted, these predictions will consider not only the new data collected after the submittal of the LA, but also the as-built conditions, the actual progression of repository construction, waste emplacement, and ventilation, and they will include the actual types and locations of wastes emplaced. The predictions will consider the constructed repository layout, actual waste emplacement, and ventilation configuration. This includes any changes during construction as a result of underground conditions encountered that are different from the assumptions in the LA. The predictions will consider the time of actual waste receipt at the repository and the characteristics of the waste emplaced, such as the category of waste, radionuclide inventory, burnup rate, age at emplacement, and waste package barrier design. The specific modeling analyses planned and relationships to the planned performance confirmation site monitoring and testing concepts are described in Section 4.3.3.

4.3.2.4 Post-License Application Predictions of Postclosure Performance

The modeling analyses of the expected postclosure performance of the natural and engineered barriers and of the overall MGR that will be performed for the LA will be periodically repeated after its submittal, as necessary. These predictions will use the LA database supplemented by the parameter values obtained by the performance confirmation site monitoring and testing. The purpose of these analyses is to evaluate the effects of changes, including site data, conceptual and mathematical models, and as-built waste package and repository conditions on the predictions and, consequently, on the expected ability to comply with the regulatory standards in the "Revised Interim Guidance Pending Issuance of New U.S. Nuclear Regulatory Commission (NRC) Regulations (Revision 01, July 22, 1999), for Yucca Mountain, Nevada" (Dyer 1999, Sections 111, 112, and 113).

When conducted, these predictions will consider not only the new data collected after the submittal of the LA, but also the as-built conditions at the time of the repository closure. These new data will include the actual repository layout; the actual locations, types, and characteristics of wastes emplaced; ventilation history; and any unexpected changes, such as rock falls and waste package recovery, before repository closure. The predictions will consider the time of actual waste receipt at the repository and the characteristics of the waste emplaced, such as the category of waste, radionuclide inventory, burnup rate, age at emplacement, and waste package barrier design. These predictions could be performed in response to unexpected or unanticipated findings when comparing measured values with limits identified in the LA. Additional predictions may also be required to provide more refined estimates for the postclosure simulation portion of the performance confirmation program.

4.3.3 Specific Process Modeling for Preclosure Analyses

4.3.3.1 General

Establishment of the baseline for the *Performance Confirmation Plan* involves interpolating and extrapolating site parameter values measured at discrete points, such as in surface-based boreholes, the Exploratory Studies Facility (ESF), and the Cross Drift, to obtain values for the entire potential repository horizon. These interpolations and extrapolations may be accomplished by simple arithmetic calculations, by calibration of mathematical process models, and by inverse process modeling. The process models used in the evaluation are described in Section 3.3 and the key performance confirmation factors that require testing are described in Section 3.4.2.

All testing conducted under the performance confirmation program will require pre-test predictions, including predictions for tests to be performed for baseline purposes. To illustrate the types of modeling that may be required to predict baseline conditions that will be confirmed, the following sections focus on the predictions associated with performance confirmation factors derived from the RSS as described in Section 3.4.2. Additional baseline predictions beyond the types identified here will be required if TSPA sensitivities indicate that the potential performance confirmation factors derived from the preliminary PMR data needs (Section 3.4.3) remain in the program, or if other factors are identified prior to the LA submittal for inclusion in the program because of their postclosure safety significance. For this version of the *Performance Confirmation Plan*, the specific modeling and prediction discussions to follow are provided for illustrative purposes only.

4.3.3.2 Unsaturated Zone Flow and Transport

The primary performance confirmation factor for the UZ flow and transport is ambient flow through the repository horizon and seepage into unventilated drifts. Existing UZ flow and transport models, built upon and calibrated against a wealth of site characterization data, contain both pre- and postclosure predictions of the performance of the UZ, specifically with regard to percolation flux and seepage into unventilated drifts. These models can be utilized to conduct performance confirmation baseline modeling of the planned performance confirmation testing and monitoring as described in Section 5.3. The testing outcomes will be used to compare with UZ flow and transport model predictions.

4.3.3.3 Waste Form Degradation

Currently ongoing laboratory testing will continue to completion during construction of the underground facility. For Zircaloy-clad CSNF, the release is controlled by the cladding failure rate after waste package failure. For this reason, there is the potential of long-term testing of Zircaloy if the data available at the time of the LA proves inadequate to justify the cladding model. The release of neptunium-237 from the failed waste package is controlled by its solubility in the water in the transport pathway. Whether the pathway is diffusion or advection dominated depends on the degree of failure of the waste package (i.e., diffusion out of small openings as opposed to flow through larger openings). For this reason, there is a potential data need to be addressed by performance confirmation to confirm a limited set of information on actinide solubility in the TSPA-LA.

4.3.3.4 Site- and Drift-Scale Thermal Hydrology

The near-field factors (geochemistry, drip shield failure, and waste package failure) are related directly to drift-scale thermal hydrology. The drift-scale thermal hydrology model will be used to evaluate temperature, humidity, and saturation at the surface of the drip shield during the thermal pulse and the amount of water contacting these barriers as the drift cools. The drift-scale thermal hydrology model, therefore, may require additional testing for comparisons to model predictions.

4.3.3.5 Near-Field Geochemistry

The failure rates of the drip shields and waste packages are directly tied to the near-field geochemistry. The duration of boiling that occurs and the volume of rock that is boiled affects the near-field geochemistry. For repository designs that have temperatures (after closure) that are below boiling, geochemical models would be used to predict the changes in ambient chemistry caused by the dissolution and reprecipitation of minerals at temperatures below boiling. If the repository thermal design boils a significant volume of rock, a drift-scale thermal test of long duration may be required. This testing would evaluate whether the range of geochemical conditions bound the conditions that will exist at the surface of the drip shield and waste package after the thermal pulse.

4.3.3.6 Waste Package and Drip Shield Degradation

Waste package and drip shield degradation will be predicted using the waste package degradation model that also includes the drip shield. The degradation of these barriers depends on the corrosion rate and corrosion mechanisms that are incorporated into the model for the waste package and drip shield materials. The corrosion mechanisms and long-term corrosion rates of these materials will be determined by laboratory testing under chemical conditions that bound the expected near-field geochemistry (discussed in the previous section). In addition to laboratory testing, waste packages and drip shields at selected locations within the repository would also be monitored. Thermal and moisture conditions would be predicted using the drift-scale thermal hydrology model.

Drip shield and waste package failure resulting from drift collapse will also be analyzed using geomechanics models. These analyses have been conducted with drifts that did not have backfill (CRWMS M&O 1996c, 1996d, 1996e) and the results indicated that there was little effect on waste packages. Similar analyses will have to be repeated for drip shields and waste packages for the current repository design (Appendix D). If the effects of drift collapse are significant to postclosure performance, the geomechanics models would require evaluation. These models could be evaluated using a combination of monitoring of drift geomechanics data and results from drift-scale heater tests.

4.3.4 Postclosure Performance Modeling

The same models used to predict performance of the repository during the performance confirmation period are the same models used to make predictions for postclosure performance for inclusion in the LA. Model prediction updates may be performed in response to unanticipated results from comparisons of measured data to predictions contained in the LA, or as a consequence of changes to the LA and the performance confirmation program.

The TSPA will combine the effects of all individual and coupled modeling and predict the performance of the overall waste isolation system with respect to the total system performance standards. The TSPA includes the modeling of radionuclide release from the engineered barrier system, radionuclide transport from the potential repository to the accessible environment, and radiation doses to the public. Because none of that is expected to occur during the preclosure period, comparisons with measured data will not be possible. Any postclosure predictions performed during the performance confirmation period will be compared with the LA predictions, including any changed in the assessment of compliance with the overall system postclosure performance standards. Some of the fundamental processes, however can be evaluated with laboratory tests and field tests using surrogates for radionuclide release. Also, postclosure performance predictions will be used to predict results for the postclosure simulation portion of the performance confirmation program, which will provide a limited opportunity to evaluate expected postclosure conditions for some of the key processes at the engineered to natural system interface.

The modeling predictions described in the previous sections will be developed as part of the performance confirmation program for testing described in the program as a prerequisite to tests conducted later in the program. Information from performance confirmation tests will be used to make direct comparisons to these predictions or to support analyses that provide information suitable for comparisons to predictions.

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5. PERFORMANCE CONFIRMATION CONCEPT DEVELOPMENT

5.1 OVERVIEW

Using the key performance confirmation factors identified in Section 3, monitoring concepts are developed for each of the major categories of the performance confirmation program. These categories include core performance confirmation tests for process monitoring and postclosure simulation. Concepts are also provided for other categories of performance confirmation testing including pre-emplacement tests and baseline tests under development testing, engineered barrier system testing and constructability (including testing required by regulations), and environmental groundwater quality monitoring and disruptive event monitoring under technical specifications and monitoring (see Table 5-1).

Sections 5.2, 5.3, and 5.4 describe the performance confirmation concepts for measuring, monitoring, observing, and testing the performance confirmation factors and parameters. This includes the general concepts necessary to conduct performance confirmation activities (Table 5-1), as well as for performance confirmation facilities and support (Table 5-2). Each concept is defined, as applicable, in terms of the activity and/or the facilities and equipment to be used. These concepts will be used to define the test program in Section 7. The concepts do not identify specifics of testing and monitoring. Specifics such as locations of tests, monitoring frequencies, instrumentation to be installed, and procedures will be defined in separate detailed test plans, design specifications, and activity plans.

The description of performance confirmation concepts will be divided into three sections: (1) elements common to various concepts (Section 5.2), (2) monitoring and testing (Section 5.3), and (3) test facilities and support (Section 5.4). The description of the monitoring and testing concepts will be discussed along the lines of test categories and test elements as listed in Table 5-1. Test facilities and support are discussed based on physical location (i.e., on site in the subsurface, on site at the surface, or off site [see Table 5-2]).

Monitoring and testing concepts describe the methods to measure the key performance confirmation factors identified in Chapter 3. The discussion is subdivided into seven elements: (1) process monitoring, (2) postclosure simulation, (3) baseline development, (4) pre-emplacement testing, (5) engineered barrier system testing and verification, (6) environmental monitoring, and (7) disruptive events monitoring (see column two in Table 5-1). The majority of the test concept discussion focuses on the process monitoring concepts, those concepts that are used to monitor conditions within the emplacement drifts (in the surrounding rock mass), and to evaluate the long-term material response of the waste package and drip shield.

The test facilities and support concepts are divided into three elements (Table 5-2): (1) subsurface test facilities and support, (2) surface (onsite) test facilities and support, and (3) offsite test facilities and support. Subsurface test facilities and support concepts consist of permanent observation/monitoring drift(s) and alcoves, monitoring within emplacement drifts, testing in alcoves in nonemplacement areas, and data transmission and control system. The surface test facilities and support concepts include the performance confirmation support area

Table 5-1. Performance Confirmation Concepts for Monitoring and Testing Activities

Test Category	Performance Confirmation Element	Performance Confirmation Test Concepts	Related Performance Confirmation Test Activities
Core Performance Confirmation	Performance Confirmation Process Monitoring	UZ Hydrology and Seepage	Seepage Testing and Monitoring
		Remote Observation and Inspection of Emplacement Drifts	Remote Inspection In Situ Waste Package Monitoring
		Emplacement Drift Ventilation Monitoring	Ventilation Monitoring
		Rock Response Monitoring	Rock Mass Monitoring
		In-Drift Instrumentation	In-Drift Monitoring
		Impact of Introduced Materials	Introduced Materials Monitoring
		Waste Package Monitoring and Testing	Long-Term, Waste Form, Waste Package, and Drip Shield Materials Testing
	Performance Confirmation Postclosure Simulation	Postclosure Simulation	Performance Confirmation Postclosure Simulation Testing
Development and License Testing	Baseline Development	Geologic Mapping	Geologic Mapping
		Geologic Sampling and Testing	Subsurface Sampling Index Testing
	Pre-Emplacement Testing	Pre-emplacement Testing	Unsaturated Zone Testing Near-Field Environment Waste Form Waste Package
Prototype Testing	Engineered Barrier System Testing and Verification	Ramp and Shaft Seal Testing Borehole Seal Testing Drip Shield and Backfill Testing	Seal Constructability Drip Shield Testing
Technical Specifications and Monitoring	Environmental Monitoring	Groundwater Quality	Groundwater Quality
	Disruptive Event Monitoring	Groundwater Level and Temperature Monitoring	Groundwater Level and Temperature Monitoring
		Precise Leveling	Surface Uplift Monitoring
		Seismic Monitoring	Seismic Monitoring

Table 5-2. Test Facilities and Support Concepts

Test Category	Performance Confirmation Element	Overall Test Concept
Test Facilities and Support Concepts	Subsurface Test Facilities and Support	Permanent Observation Drifts and Alcoves Special Test Alcoves Stationary Control and Monitoring Systems Mobile Vehicle Operations Control System
	Surface Test Facilities and Support	Performance Confirmation Support Area (Sample Storage and Transfer Facility, Performance Confirmation Data Collection, Storage and Management System, Index Testing Laboratory, Instrument and Calibration Facility, and Administrative Support)
	Offsite Test Facilities and Support	Special Waste Package and Engineered Barrier System Material Testing Facilities Performance Confirmation Data Evaluation Facilities Performance Assessment Facilities

which includes sample storage and laboratory facilities. Offsite facilities and support concepts include special laboratory facilities (located at national laboratories and other locations), data analysis and evaluation facilities required to conduct core analysis, and reporting functions.

5.2 ELEMENTS COMMON TO VARIOUS CONCEPTS

To define the performance confirmation program, several elemental concepts are adopted which apply to various testing concepts described later in this section. The elements are consistent with relevant project assumptions (see Appendix E) and affect access, monitoring instrumentation, and schedule aspects of performance confirmation. Briefly, these elements are:

Remote Inspection–In monitoring environmental conditions within emplacement drifts, the radiation and thermal hazards within the drifts make entry arduous, time consuming, and could expose personnel to potential hazards. In contrast, field instrumentation typically requires periodic maintenance and calibration; for borehole surveys or borehole-installed instruments, access is required to the borehole collar. To eliminate the exposure of personnel to such hazards to maintain instrumentation, the performance confirmation program will restrict direct personnel access into the emplacement drifts after the emplacement of waste. This will require the use of remote technology such as instrument boreholes extending from adjacent monitoring drifts and the use of robotic devices or vehicles for direct entry.

Continuous and Periodic Inspection–To monitor environmental conditions over the entire repository area in a cost-effective fashion, a combined inspection approach is adopted. To assure that the entire system is performing as expected, periodic observations and monitoring will be performed of the overall (spatial) system. These inspections, such as using a robot or remotely operated vehicle (ROV), will be performed to define spatial variation across the repository.

To assure the system is performing as expected during the intervening time between inspections, continuous observations and measurements will be performed using methods that measure the average response of segments of the system. Examples of such measurements (termed average areal measurements) could include monitoring the temperature of the exhaust air of an entire emplacement drift or using acoustic monitoring to measure rock deformations over large rock mass volumes. As a supplement to these areal measurements, continuous measurements are performed in a limited portion of the system to provide a complete record of the key performance confirmation parameters with time.

Borehole Penetrations into an Emplacement Drift–To provide access for survey instruments, video cameras, and removable sensors into the emplacement drift environment, the use of through-going boreholes from adjacent observation drifts, alcoves, and/or contingency drifts shall be considered a viable approach using appropriate personnel safety measures to be defined during detailed test planning.

Replaceable In-Drift Instrumentation–The regulatory importance of instruments to monitor conditions within emplacement drifts dictate the need (in most cases) that such instrumentation can, at specific intervals or times, be replaced. When possible, replaceable instruments will be employed for monitoring conditions. Instruments may be remotely placed through boreholes from adjacent excavations or by the use of instrument packages placed within emplacement drifts and later retrieved by remote means. The use of non-replaceable ("throw-away") instrumentation is not precluded for use by performance confirmation and such instrumentation will be employed when situations dictate.

Access for replaceable instruments is to be sufficient to replace the electronic or moveable component sensors for recalibration or replacement and does not include the replacement of the entire mechanism or instrument. An example would be the ability to replace the displacement sensor of a multipoint borehole extensometer but leaving the anchor system and measurement rods in place.

Redundancy–Underground environmental conditions for in situ sensors and instrumentation are far from ideal. Factors such as humidity, dust, and temperature variations together with impacts from installation and handling methods can damage or eventually destroy sensors. In the design of test and monitoring areas, redundancy of instrumentation will be employed to provide backup when a specific sensor fails. In addition, some attrition of instruments is anticipated during the performance of a test. During the performance confirmation program, the option of replacing instruments shall be maintained, when possible, to address situations where sensor failure has led to data gaps or questions regarding data accuracy.

Flexibility in Design–During the performance of long-term testing and monitoring, it will be necessary, at times, to change or refocus the test program and/or methods. Therefore, performance confirmation testing and monitoring will be defined to allow flexibility in test design and execution so as to perform changes as needed in accordance with applicable QA procedures.

In addition, other parts of the test and evaluation program may supplement this monitoring with large-scale seismic simulators and testbeds, which can be used to evaluate the effects of seismic events on subsurface structures and components.

Sample Control and Storage–As part of the performance confirmation program, both rock and water samples will be collected at various times. To store, ship, and control the distribution of these samples, a sample control and storage facility will be maintained as part of the performance confirmation surface facility. Performance confirmation samples, if shipped to offsite facilities for special testing, will be tracked and returned after this testing program is completed.

The accessibility and staffing of the core facility will be on a full-time basis during construction and operation (when most samples will be taken and tested), but facilities will be staffed only on an as-needed basis thereafter. Samples obtained by performance confirmation activities and samples obtained during site characterization from within the bounds of the site (i.e., within the preclosure controlled area) will be maintained during the performance confirmation period and thereafter decommissioned with the closure of the surface facilities. All other samples will be maintained based on available space and cost considerations.

Data Acquisition and Frequency–To provide a comprehensive record of the data obtained for the program, all monitored data will be collected, transmitted, integrated, and stored by an integrated performance confirmation data acquisition system. Non-integrated data (data not recorded electronically by the system) will be entered into this system either by manual input using computer stations or by the use of scanned images. Frequency of measurements will vary as appropriate for each test; frequency may also vary for a specific test over time in order to record initial and quickly changing processes which later stabilize (and change little) with time, allowing longer durations between measurements.

Postclosure Monitoring–As indicated by the requirements analysis in Appendix E, performance confirmation activities will end with the closure of the repository. In addition, specific requirements have not been identified for continuing similar activities during the postclosure period at this time. Therefore, all performance confirmation activities described in the present plan are to be completed upon the approval and start of repository closure, and post-permanent closure activities will be described in a separate test plan to be prepared when required for the MGR.

5.3 TESTING AND MONITORING CONCEPTS

5.3.1 Performance Confirmation Process Monitoring Concepts

5.3.1.1 General

Long-term testing for the process confirmation portion of the performance confirmation program currently focuses on the principal factors from the RSS that remains after evaluation for postclosure sensitivity. The results of sensitivity analyses from TSPA-VA were used to screen out principal factors related to dissolution of waste forms and dilution and retardation of radionuclides. As the RSS (CRWMS M&O 2001) is revised and sensitivity analyses are conducted for the TSPA-Site Recommendation, these factors may reappear based on more detailed results from the process models that are included in the PMRs.

Factors that are screened out from inclusion in the *Performance Confirmation Plan* could become factors for consideration as defense-in-depth (i.e., factors where additional margin could be gained using a less conservative approach). These factors, based on importance, would be included in the *MGR Test and Evaluation Plan*, which describes the overall MGR test program.

Prior to the completion of the revised RSS (CRWMS M&O 2001) and a TSPA for the site recommendation, data needs for the PMRs are being used to capture additional potential principal factors. Potential performance confirmation factors were identified by evaluating residual PMR data needs in anticipation that some of these will remain in the program following the completion of site recommendation sensitivity evaluations and would be incorporated into a revision of this plan. These data needs are being used to help define near-term pre-emplacement tests (concepts for these have not yet been described). Some of these involve testing away from the emplacement drifts as indicated in the test description sheets (Appendix G). The potential for pre-emplacement testing to extend into the post-emplacement period has not yet been fully evaluated beyond those tests already identified in the process confirmation portion of the program. Test concepts beyond those described in the current plan will be included in a subsequent revision of the plan either as pre-emplacement test concepts or as added to other appropriate test categories.

5.3.1.2 Unsaturated Zone Hydrology and Seepage

Based on the analysis of principal factors in the RSS, a key performance confirmation parameter is seepage into unventilated emplacement drifts. To confirm seepage, it is necessary to monitor the UZ hydrology in the rock that eventually enters the emplacement drift as seepage. The general objective of this monitoring and testing of the UZ hydrology is to confirm the current understandings of water seepage into and around the emplacement drifts. To satisfy this objective, subsurface monitoring of water potential, water content, seepage, and measurements of the hydraulic properties of fractures will be performed.

Hydrologic testing and monitoring will be performed in closed alcoves located in the ambient access or monitoring drifts. The location of the alcoves will be determined by applying criteria such as areas of relatively high and low infiltration, overlying bedrock/alluvium contact, faults and fracture zones, geographic variation (north to south in the ESF), and presence of extreme (high or low) lithophysal cavity densities and welded/nonwelded rock units. The number of these seepage alcoves will be used to provide coverage of these differing conditions. Alcoves developed during site characterization that are isolated from ventilation effects, such as Alcove 7, will also be used in the program.

Seepage monitoring and testing also includes confirmation of the seepage threshold concept arising from capillary barrier mechanism. Additional testing of this seepage concept is planned at niche sites and in different tuff units, including the TSw lower lithophysal unit and the TSw lower non-lithophysal unit. These tests are intended to be similar to site characterization tests at an ESF niche site (Niche 3650) in the middle nonlithophysal unit of TSw tuff and will be of longer duration and involve a larger volume of water.

To determine the spatial distribution of percolation flux through the repository horizon, heat dissipation and neutron probes will continue to be used to measure water potential and water content. Thermocouple psychrometers may be added during the performance confirmation period to verify and improve upon the quality of the information provided by the heat dissipation probes.

A passive system to detect direct seepage from the host rock has been in place and operating during the site characterization period. Seepage collection mats that are pH (hydrogen ion concentration) sensitive have been installed in an alcove (Alcove 7) that is isolated from the effects of ventilation. Although no direct evidence of seepage has been found, this passive system will continue to be monitored for purposes of performance confirmation. In addition to this passive system, heat dissipation probes and time domain reflectometry will be used to more actively determine whether seepage is likely to occur prior to and during thermal loading of the repository. The use of these passive and active methods coupled with the locations of the alcoves will confirm that seepage is occurring within expected bounds and assumptions important to postclosure performance.

UZ hydraulic conductivity measurements will be made to evaluate UZ parameters that could affect seepage. Tension infiltrometers will be established at various locations throughout the ESF and monitoring drifts to characterize geohydrological units and provide further seepage characterization of the potential repository horizon host rock.

As part of monitoring and testing activities, rock cores will be collected for analysis in offsite laboratories in conjunction with construction. Analyses will be performed to determine rock hydrologic properties such as hydraulic conductivity, effective porosity, moisture content, hydraulic potential-moisture content relationship, and moisture content-hydraulic content conductivity relationship.

5.3.1.3 Remote Observation and Inspection of Emplacement Drifts

5.3.1.3.1 General Concepts

Several concepts will be used to perform observations and inspections within emplacement drifts. Observation and monitoring via boreholes will provide a limited amount of access. Also, a limited amount of information can be obtained via indirect observations, such as drift ventilation monitoring. But the primary access concept is the general purpose use of remotely operated systems.

Several performance confirmation data collection activities will be utilizing telerobotic or remotely operated systems, which will be designed to withstand limited exposure to the elevated temperatures and radiation levels expected within the post-emplacement drift environment. The remotely operated systems or vehicles will be general-purpose mobile platforms outfitted with instrument packages providing visual, thermal, and radiological inspection capabilities. The vehicles will also be equipped with telerobotic manipulators with end-of-arm tool attachments like grippers, cameras, and lighting for recovery of waste package test specimens or coupons. These remote systems will be observed and controlled continuously by human operators at a control station located above ground.

The ROVs will be required to conduct visual, thermal, and radiological monitoring and collect and distribute coupons as described in the following sections. The ROVs will perform these functions within a harsh environment. Preliminary calculations indicate that postemplacement temperatures inside the drifts may reach 215°C under certain circumstances (CRWMS M&O 1999e, Figure 2-2). Other calculations indicate that radiological conditions inside the emplacement drifts may have dose equivalents of 35 rem/hr or more at the surface of some waste packages (CRWMS M&O 1997f, Figure 7.3-2). These radiation levels are much too high to realistically permit human entry, but are manageable for remote equipment.

5.3.1.3.2 Remote Visual Inspection

A remotely operated visual inspection system will be used to obtain visual records of the waste package surface, drift inverts, and ground support systems in the waste emplacement drifts following emplacement for both performance confirmation and preclosure drift maintenance. In off-normal events such as drift collapse or rock fall, the ROV systems will be used to assess the situation. This process will require the development of the vision and delivery system by adapting well-established technology for the parameters to be monitored in the expected emplacement drift environments. Being able to remotely view objects and conditions within the emplacement drifts will be a fundamental capability needed for performance confirmation observations to satisfy regulatory requirements and support long-term repository operations.

Following emplacement of waste packages, remote vision systems will be used to record the conditions of the emplaced waste packages, the drift excavation, and the surrounding rock walls. Initially, these video records will establish baseline data of the initial emplacement conditions and future scans will provide data for evaluating potential planned and unplanned events and conditions. It will be used to inspect areas of concern, such as checking the performance of the invert floor material for thermally induced cracks or premature deterioration. This inspection system will also check and monitor the integrity of the drift walls, rock falls, and unstable areas. In addition, the ROVs will check for signs of cracking or deterioration of ground supports and for visible signs of waste package corrosion.

5.3.1.3.3 Remote Thermal Inspection

A remotely-operated thermal inspection system will be used to measure waste package wall temperature, rock temperature on the emplacement drift wall, and drift air temperature following waste emplacement. While in situ exhaust air monitoring will provide good bulk or average temperature information about the emplacement drifts, it will not provide direct, detailed, thermal data about specific waste packages or specific areas within the drift. Monitoring only exhaust air or localized areas of heat concentration (such as hot spots) does not ensure that the thermal limits on the waste package or within the engineered barrier system are met (see Section 3). In addition, information about thermal variation and distribution across the emplacement drifts would not be provided by ventilation monitoring alone.

Remotely operated thermal inspection systems can be used to observe close-up thermal response and to correlate this information over a long period. While the prior testing has provided some level of understanding and confidence about the thermal models being developed, they will not replace the need to observe the thermal performance directly.

A mobile remote means for obtaining thermal data will be preferred over in situ monitoring because it permits the periodic calibration of instruments. The remotely operated thermal inspection system will be equipped to monitor both air and surface temperatures. The inspection system may consist of technologies as simple as thermocouple temperature probes or as advanced as a real-time thermal imaging infrared camera that can provide color-coded images and thermally map entire surfaces of a waste package and the surrounding drift wall.

5.3.1.3.4 Remote Radiological Inspection

A remotely operated radiological inspection system will be used to monitor radiation levels in the emplacement drifts following waste emplacement to establish initial radiological conditions and to detect potential waste package failure and radionuclide release. The exhaust air from each emplacement drift will be continually monitored for radioactive gases. If radioactive particles or gases are detected, it will indicate that a waste package has developed a leak. Detection of radionuclides in the exhaust air, however, only provides the first alert that there is a problem. A mobile remote radiological inspection system will then be deployed to enter the affected drift and identify which waste package is leaking and the extent of contamination.

Remote radiological inspection systems can range in sophistication from simple passive dosimeter monitoring sensors to teleoperated radiation imaging systems that provide remote, real-time, color-coded radiological images over an entire field of view. The latter would permit radiation mapping of individual waste packages and would detect the exact location of the leak on a waste package.

5.3.1.3.5 Remote Manipulation

Remote manipulation will be employed to place and to recover sample coupons of waste package materials and other materials placed at key points of interest within the emplacement drifts. Remote manipulation will also be used to collect dust samples (e.g., by using swipes of the waste package surface) and check for particulate contamination by obtaining wiped swatch samples from surfaces of interest. In the event of a rock fall or other anomaly, remote manipulation will be able to remove small rocks or debris that could otherwise impair the complete inspection of an emplacement drift. Telerobotic arms will be used to hold and position other sensor systems, such as cameras or probes, which will allow operators to inspect around or behind objects.

5.3.1.3.6 Design Strategies and Technologies for Elevated Thermal and Radiation Environments

The technical details for the remote data acquisition system in waste emplacement drifts have not yet been finalized. General concepts and considerations that need to be addressed in the design of such a system can be presented, however, based on existing technology.

From the nuclear industry, technologies and effective design techniques exist that will permit remotely operated equipment to be used in radiation environments many times higher than expected inside the emplacement drifts. For the dose rates expected, the principal strategies for minimizing the effects of radiation will be the judicious use of radiation shielding materials, the use of rad-hardened electronic components, the monitoring of the total accumulated dose, and replacing sensitive components at periodic intervals. The latter will be possible because each employment of a ROV inside the emplacement drifts will be for short periods only.

The major challenge facing designers will be to build systems that can tolerate the elevated temperatures. A review of design strategies and heat compatible technologies indicates that it may be feasible to develop heat tolerant vehicles that can operate for limited periods of time within the emplacement drifts. For much of the design, it will not be difficult to select appropriate mechanical components, such as gears and bearings, and structural materials that are suitable for use at elevated temperatures. A key concern, however, will be the use of heat-sensitive on-board electronics and actuators. Typically, commercial grade electronics and components have maximum operating temperatures in the range of 50°C to 85°C. If available, military grade components may allow operation of some components up to 100°C (CRWMS M&O 1999i, pp. 44 to 45). Calculations have demonstrated that the equipment and instrumentation within the insulated ROV will not exceed 50°C during the preclosure period if they do not remain in an emplacement drift longer than 58 minutes without on-board active cooling and up to 180 minutes with active cooling systems using the VA emplacement drift conditions (CRWMS M&O 1997e, Figure 7.6-10). This period is considered sufficient for performing the planned measurements and sample collection and represents a bounding case since the evolving layout concepts involve a substantially greater ventilation rate in the emplacement drift.

Beyond selecting the most suitable electronic components, there are several design strategies and technologies that may enable the use of ROV technologies inside the emplacement drifts. These include:

- Limited time of exposure
- Thermal insulation/heat rejection technologies and strategies
- Active and passive cooling systems for internally generated heat
- Thermally robust power and communication technologies
- Limited or alternated duty cycle of power intensive components
- Low power electronics and components
- High temperature tolerant electronics and hardware
- Prudent layout of thermal conduction paths for high heat components.

Heat from external sources can be rejected by the use of the appropriate shielding and insulating materials. The primary concern is removing or dissipating heat internally generated by the ROV. The principal source of internal heat generation is the consumption and conversion of electric power. Two subsystems that are critical to the successful design of heat tolerant vehicles are power and communications technologies.

Electric Power Alternatives–An analysis was completed that reviewed several alternative power system design concepts (CRWMS M&O 1997g). Electric batteries are typically used to power conventional ROV designs; standard battery designs, however, generate considerable heat and do not operate well at temperatures above 50°C. One promising concept, which appears to be fairly immune to elevated temperatures, is the use of conductor bar technology. This technology is well-proven and used in the transit industry to power trains and trolleys. It involves mounting an electrically conductive bar alongside the rail system to which a small riding unit, or shoe, is attached, providing electrical power across a sliding brush contact.

A conductor bar installed in the emplacement drifts would be durable, robust, and essentially maintenance free. It is a totally passive system and housed in a protective insulator cover. One advantage of this technology is that the primary power source would be external to the ROV and thereby significantly reduce internally generated heat. If a segment of conductor bar becomes unusable, it could be replaced with a new segment using ROVs.

Remote Communication Alternatives–Existing communications technologies have been previously reviewed for ROV operation within the emplacement drifts (CRWMS M&O 1997e, pp. 95-105; CRWMS M&O 1997k, pp. 25 to 68). Radio control is used extensively in underground remote mining applications; in underground applications, however, care must be taken when designing the system to avoid a phenomenon called multipathing, where radio signals reflecting off rock walls can be distorted and interfere with clear radio communication.

Another promising remotely-operated vehicle communications technology that appears to be fairly immune to elevated temperature environments is the use of wave-guide technology, similar to that used in the rail transit industry. This technology entails the use of a small slotted wave guide, a hollow metallic conduit installed along the length of each drift. A small microwave transceiver antenna rides along the slot in the wave-guide and provides very high bandwidth communication between the vehicle and the transmitting/receiving station located near the entrance to the emplacement drift. It is a well-proven, existing technology and requires essentially no maintenance.

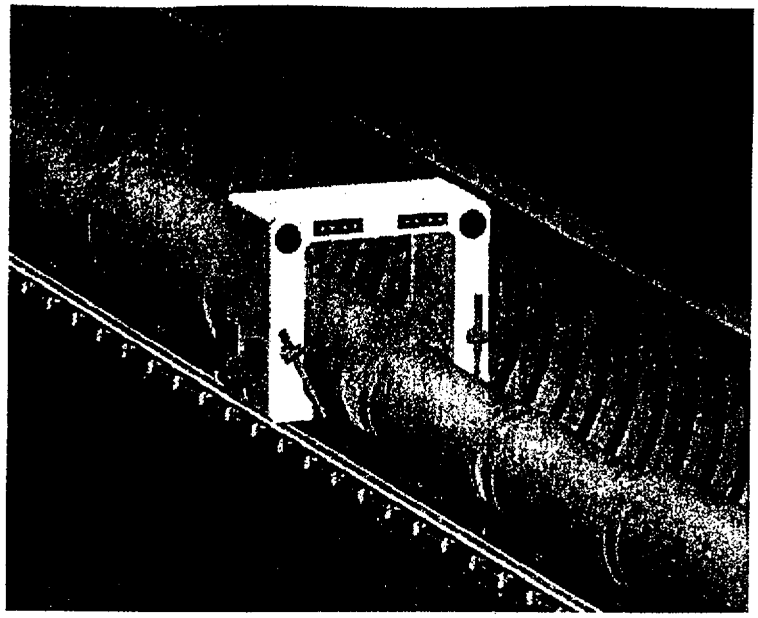
Electronic Component Technology–In the past several years, there have been many advances in the area of low-power, high-capacity, electronic components for the portable computer industry. Special 3-volt logic components, hardware sleep modes, and other techniques have been developed that considerably reduce the amount of energy required. The advantage of these components is that they consume much less power and therefore generate much less heat internal to the system.

The automotive, aerospace, and oil and gas industries are currently developing a new breed of electronic components that operate uncooled (without active cooling), in ambient temperatures above 200°C. Using new silicon carbide and other technologies, whole new families of heat-tolerant integrated circuits are being developed.

5.3.1.3.7 Remote Operated Vehicle Inspection System

Incorporating the foregoing discussions, a concept of a rail-based ROV gantry inspection system has been developed; this inspection system would ride the same rail system which is installed and used by waste package handling equipment (e.g., CRWMS M&O 1997i; DOE 1998a, p. 4-60 to 4-61). As mentioned, the ROV gantry would serve as a general-purpose instrumentation platform and would provide ample support for remote visual, thermal, and radiological inspection activities. It would also provide an excellent platform onto which remote manipulators could be mounted for sample/coupon recovery activities.

As presently conceived, the ROV would arch over and straddle the emplaced waste packages in a kind of horseshoe-shaped configuration (see Figure 5-1). A radial three-axis carriage riding on



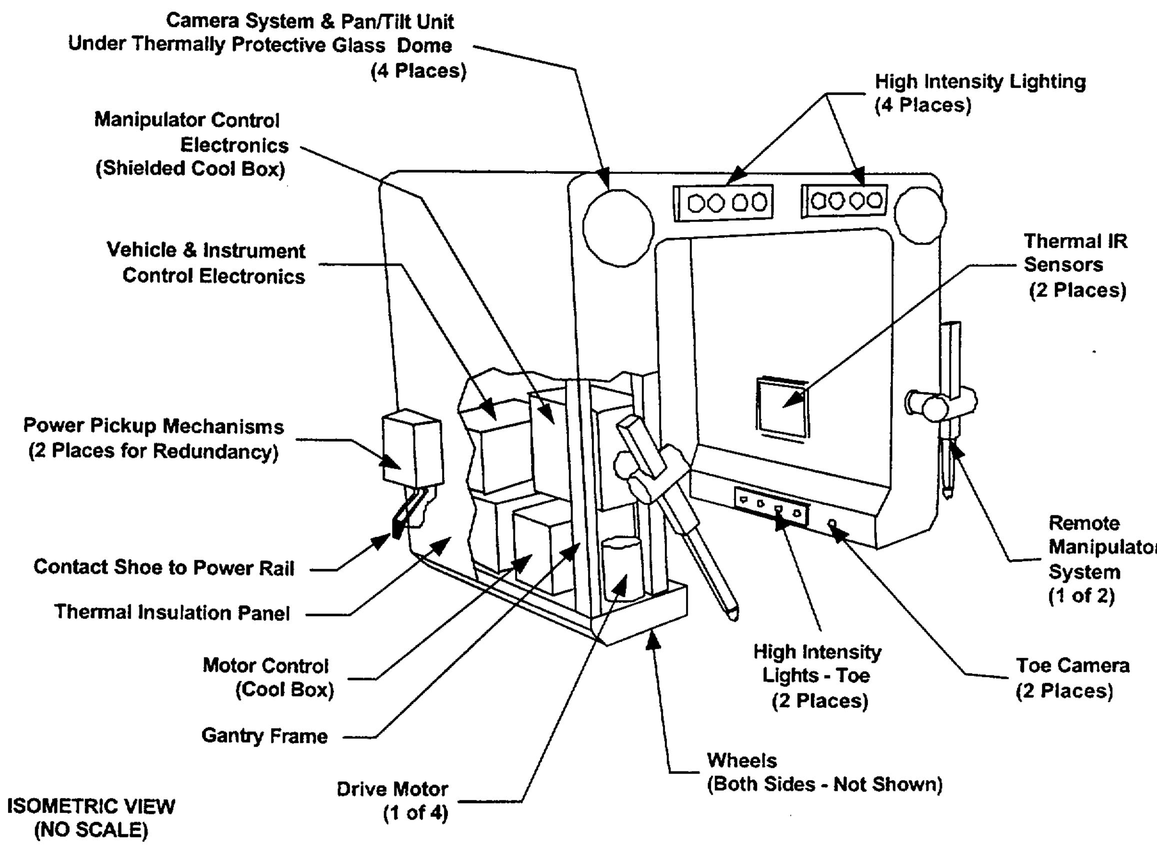


Figure 5-1. Conceptual Illustration – Remote Inspection Gantry

the arched structure permits instrumentation packages to be driven around the waste packages and provides visibility to either side and on top. This gantry vehicle can also provide close-up and detailed inspection coverage of the surrounding drift walls and infrastructure.

Features of the ROV concept include the following:

- Large payload
- Capable of carrying multiple and larger instruments and manipulators
- Accommodation for heat tolerant power and communication technologies
- Accommodation for alternative power sources such as batteries
- Benefits from existing rail infrastructure
- Provision for overall coverage and close-up detailed inspection
- Ease in insulation from external heat and dissipation of internally generated heat
- Sturdiness and ruggedness of construction suitable for some infrastructure maintenance
- Flexibility in system configuration for varied task assignments and off-normal applications.

Some concerns and limitations related to the use of a gantry-style ROV are the difficulty in extrication should the system and backup systems fail and difficulty or impossibility of the gantry traversing around or over even small obstacles. Some of these concerns have been further addressed in a report (CRWMS M&O 1997e).

5.3.1.4 Emplacement Drift Ventilation Monitoring

The emplacement drift environment can also be monitored during preclosure by sampling the ventilation air that goes into and comes out of the emplacement drift. Conceptually, monitoring instruments can be installed within the air regulator at the isolation door and within the exhaust main ducts (e.g., see CRWMS M&O 1997l, Figure 7.4.1.3). Some parameters that can be measured as part of ventilation monitoring are:

- Dry bulb temperature
- Wet bulb temperature
- Relative humidity
- Radioactivity
- Radon
- Percentage of oxygen and carbon dioxide
- Dust.

Some of these parameters are also measured during construction and operations to address preclosure requirements (e.g., CRWMS M&O 1997l, p. 28).

These parameters will allow computations and inference of other parameters. An approximation of the rock wall temperature in the drift can be made by measuring the intake and exhaust air temperatures. The amount of moisture being removed from the drifts can be evaluated by monitoring the relative humidity at both the intake and exhaust ends of the emplacement drifts. Monitoring at the exhaust end of the emplacement drifts also allows measurement of gases indicative of a waste package leak (e.g., krypton-85), including introduced tracers. Additionally, dust measurements of the ventilated air can also be conducted.

Additional design description of emplacement drift ventilation monitoring for the VA design is provided in the following analyses: *Subsurface Repository Performance Confirmation Facilities* (CRWMS M&O 1997b), *Performance Confirmation Data Acquisition System* (CRWMS M&O 1997e) and *Emplacement Drift Air Control System* (CRWMS M&O 1997m).

5.3.1.5 Rock Response Monitoring

In response to the requirements identified in Chapter 3, a program for monitoring the coupled thermal-mechanical-hydrological (TMH) response of the rock around emplacement drifts will be initiated and maintained through the performance confirmation period. This monitoring is to confirm the conceptual understandings and numerical simulations of TMH processes considered in performance assessments.

To confirm this understanding, TMH testing and monitoring is to be conducted at appropriate locations or areas to provide sufficient coverage of the emplacement horizon. Measurements would be focused on the near-field preclosure response of the rock around typical emplacement drifts. Conceptually, this could entail measurement at three locations across the upper block of the potential repository horizon (i.e., at the northern, central, and southern reaches of the horizon). Locations would also be selected in the lower block if this horizon were also used for emplacement.

In these monitoring areas, hydrologic response to thermal effects will be determined by monitoring temperature, moisture potential, and moisture content through the use of electrical resistivity tomography, neutron logging, and cross-borehole radar techniques. These devices are briefly described as follows:

Electrical resistivity tomography–An electrical resistivity tomography allows the measurement of changes in liquid saturation distribution in rock over a relatively large plane. Based on temperature information and assuming that rock/water chemistry remains stable, changes in liquid saturation can be inferred from electrical resistivity tomography images taken over time. It is proposed to deploy electrodes in an array of vertical, coplanar boreholes aligned perpendicular to the emplacement drifts of interest. In this way it will be possible to estimate the distribution of condensate formation as the boiling point propagates outward from the emplacement drifts and to assess the extent to which gravity influences condensate flow.

Acoustic and seismic tomography–Acoustic and seismic energy travels through different material types with different levels of attenuation and velocity. These waves travel more quickly through denser materials and more slowly through low-density materials. Seismic tomography utilizes this principle to produce a three-dimensional image of the interior structure of rock masses. The energy put into the rock mass may be from natural or man-made sources such as from blast detonations, air gun blasts, or even from sounds produced by construction and excavation equipment. The energy waves travel through the rock mass and are detected by an array of monitoring stations. Advanced computer software programs are used to analyze and map the energy propagated through the ground volume. A network of microseismic sensors can be installed within the subsurface repository to collect data on rock mass properties and characteristics.

Neutron logging–Neutron logging provides relatively precise measurements of rock liquid saturation, but only to distances of a few tens of centimeters. Boreholes suitable for accepting neutron-logging equipment will be deployed where changes in liquid saturation are expected from heating of the emplacement drifts. The boreholes will be situated such that logging can observe gravity shedding of condensate from locations above the emplacement drifts to locations below the drifts.

Cross-borehole radar–This technology is proposed to provide images of changes in the liquid saturation of the host rock. Boreholes will be deployed at locations that will allow observation of condensate accumulation and drainage in the vicinity of the emplacement drifts.

Temperature measurements, which will locate the boundary between "dry" and partially saturated rock, will be obtained by deploying temperature gages within boreholes at varying distances from emplacement drifts. The gages will be sealed to prevent intra-borehole fluid flows from corrupting the measurements. Mechanical response could be measured through the use of multi-point borehole displacement gages and with the use of acoustic monitoring.

Measurement or estimation of TMH processes has been attempted in both the single heater test and drift scale tests. These tests have included direct measurement of the mechanical response of the rock mass to temperature changes and measurement of the moisture movement and air permeability changes during and after the test(s) but have only provided an indirect comparison of hydrologic changes in the rock mass to the thermal-mechanical responses.

To ascertain coupled TMH effects, temperature, fracture displacements, and transmissivities will be measured in a series of boreholes placed near the emplacement drifts. Downhole packer-displacement gages, which are capable of measuring the displacements of a single fracture in a borehole, will be positioned in boreholes to straddle a fracture or fracture zone. The gages will be attached to anchors on either side of the zone of interest and will measure normal and shear displacements. After initial transmissivity of the zone is determined, displacements and transmissivities will be measured periodically thereafter. In this way, an understanding of the initial and changed conditions of the fractures or zones due to temperature changes and thermal displacements can be determined.

Rock cores will be collected from the TMH boreholes for laboratory testing of mechanical and thermal properties. These properties include unconfined compressive strength, thermal conductivity, and the coefficient of thermal expansion. These samples will allow for the evaluation of property variation across the repository horizon.

5.3.1.6 In-Drift Instruments

To monitor the conditions within emplacement drifts on a continual basis, a limited number of in-drift instrument areas are included as part of the performance confirmation monitoring. These instruments would provide readings on a continuous basis at specific locations, at times between the monitoring of the drifts by ROVs and as a supplement to the indirect monitoring of the drifts as through ventilation monitoring. The sensors would be similar to those used for the ROV. For each area, several stations would be located along the emplacement drift axis to provide an estimate of the change in values with distance along the drift.

To provide access to this instrumentation, boreholes from adjacent observation drifts or cross-block drifts would extend into the emplacement drifts to provide access (Figure 5-2). Instruments would be placed on the end of metal tubular rods or "strings" that would extend through the boreholes and position the instruments at various locations within the drift. Periodically, for maintenance and calibration or when questionable readings are detected, the instruments would be retrieved by using the strings.

Conceptually, in-drift instrumentation would be located in close proximity to instrument stations monitoring the adjacent rock mass to provide a complete picture of the behavior both within the drift and in the adjacent rock.

5.3.1.7 Impact of Introduced Materials

In response to the requirement (discussed in Section 3) to monitor and analyze changes from the baseline condition of parameters that could affect the performance of a geologic repository, it is necessary to monitor fluids and other materials introduced into the repository horizon as a result of construction and operations. This monitoring is to evaluate the impact that introduced materials (e.g., water from construction activities, fire suppression, hydrocarbons, concrete, steel, ground support, and railcars) will have on the postclosure performance of the repository if these materials remain in the repository after closure.

A tracking system will be established to monitor the fluids and materials used for repository construction and operation and to evaluate potentially adverse effects.

To determine the pH and the Eh (oxidation-reduction potential) of the water and hydrocarbons introduced into the repository that will remain after closure, data will be collected at several locations within the repository lithostratigraphic units during the performance confirmation program. The tests will be conducted in the alcoves excavated from the emplacement drifts and the main access drifts. To determine the chemical composition of the water, hydrocarbons, and the other materials that will be left behind after closure, field samples will be collected and delivered to the surface for chemical analysis at offsite laboratories. A record keeping system (similar to the present Tracers, Fluids, and Materials program) will be adopted for this program to track spills across the site.

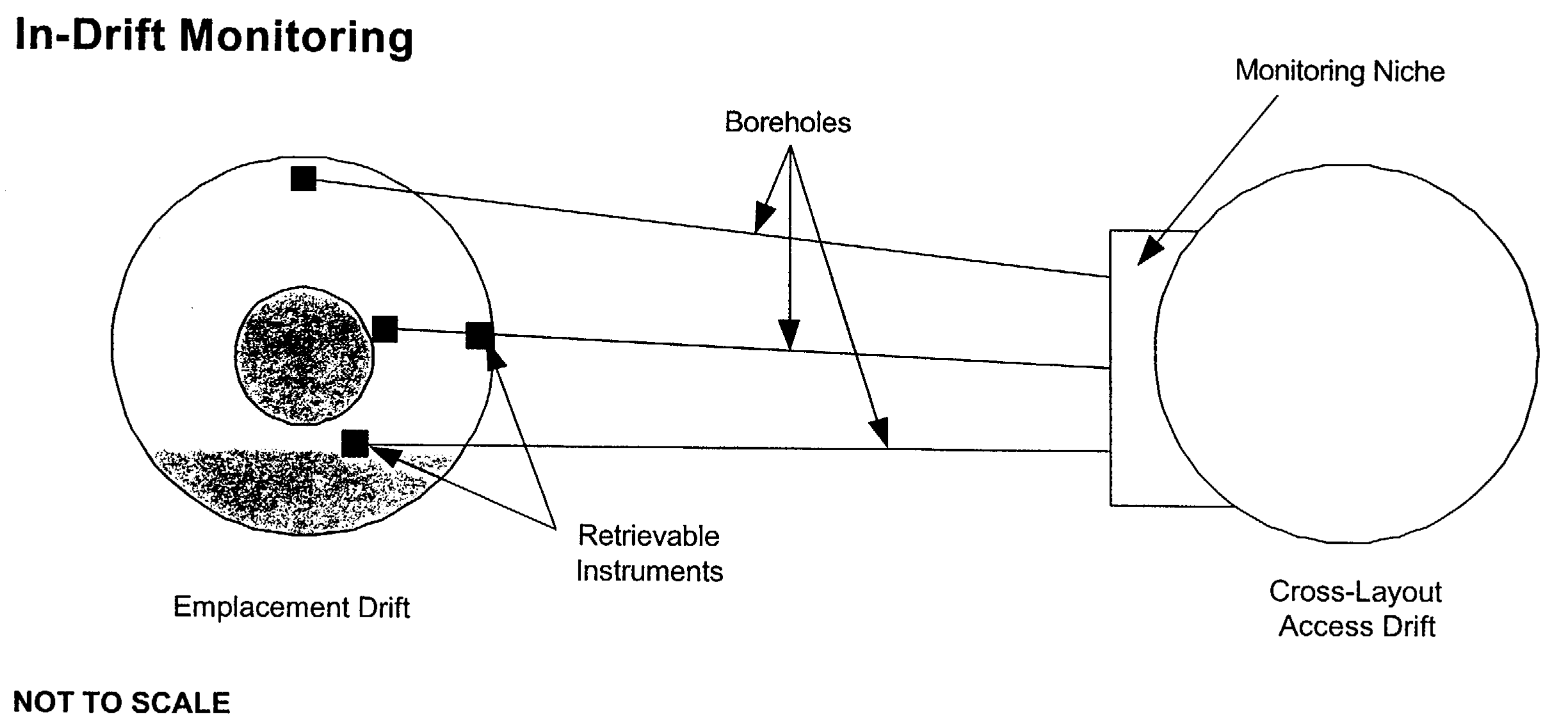


Figure 5-2. Schematic of Emplacement Drift Monitoring Using In-Drift Instruments

5.3.1.8 Waste Package Monitoring and Testing

5.3.1.8.1 Types of Monitoring and Testing

Waste package and drip shield monitoring and testing concepts consist of offsite testing and experiments, in situ monitoring, and the recovery of various types of waste package samples. The recovery of waste package samples includes the option to recover emplaced waste packages, dummy waste packages (if utilized, which are full size but do not contain actual waste), and waste package specimens or coupons. Each of these concepts is described in the following sections.

5.3.1.8.2 Laboratory Waste Package and Drip Shield Materials Testing

This concept mostly entails the continuation into the performance confirmation period of long-term laboratory studies of the waste form, waste package, and drip shield materials that will support the site recommendation and the LA. An example of this testing is the work being performed at the Yucca Mountain Site Characterization Project's (YMP) Atlas Facility (CRWMS M&O 1999g), which provides a controlled environment in which to test and evaluate key barrier system parameters and configurations. It is desirable in several instances to continue obtaining data for various degradation phenomena that will affect the long-term performance of the drip shield, disposal container, the waste form, and internal elements of the waste package. The major advantage of laboratory testing compared to in situ repository testing is the economy of testing and the greater range of conditions that can be studied. Also, environmental conditions can be maintained in the laboratory that simulate repository conditions at some future time; the laboratory testing complements the in situ repository testing which will occur under environmental conditions representative of the initial stages of repository operations. Another advantage of laboratory testing for performance confirmation is that test conditions can be maintained to accelerate the degradation. Because laboratory testing is oriented toward making hypotheses and understanding fundamental mechanisms, it provides a framework for observations made in the in situ performance confirmation testing.

The key parameters affecting drip shield and waste package container performance that can be measured in laboratory testing include all of those associated with oxidation and aqueous corrosion. All of the corrosion degradation modes that have been identified as important to the drip shield, outer barrier, inner liner, and other metallic components will be measured in long-term corrosion tests. This testing will include those under immersed conditions and in humid atmospheres. The interactions between materials, such as the degree of galvanic interaction, are readily measurable in a laboratory setting. Several corrosion degradation phenomena, such as pitting corrosion, crevice corrosion, stress corrosion cracking, and hydrogen embrittlement, often exhibit long incubation times before discernible initiation occurs. Another aspect in characterizing corrosion degradation is that a pit or crack may initiate, but the propagation rate may increase, decrease, or remain steady with time. Long-term testing can confirm material performance. This testing can include characterization of oxidation and corrosion products and evaluation of parameters associated with phase stability in the metal and weld integrity.

The long-term testing is already underway, having been initiated in 1996 and 1997, and several more tests will be initiated during the next 2 to 3 years. Depending on the finalization of the LA waste package design and results of the material testing work, a limited number of laboratory based tests are expected to continue for perhaps 10 to 20 or more years to provide greater confidence in the selected design, the selected container materials, and the performance models. The degree of confidence will increase with the longevity of the test. Continuation of the testing can provide continuing confirmation of performance prediction models and allow for any needed model modifications. Similarly, unresolved safety questions regarding the internal waste package degradation, criticality control materials such as basket materials, and others can be addressed by the long-term laboratory testing.

Additionally, studies begun in 1998 on the long-term thermal aging behavior of the candidate materials under repository relevant conditions will continue; certain phases forming readily at high temperatures in short time periods are known to degrade the performance of materials currently proposed for the outer barrier of the waste package. Both nonwelded and welded samples will be aged. The extent to which these phases form at the more relevant repository temperatures will be confirmed to be within the limits defined in the LA.

Much of the laboratory testing to date has been (and will continue to be) focused on phenomena that will occur in the latter part of the containment period and into the controlled release period. This period is when the temperature has decreased so that aqueous conditions can occur to first breach the container and then degrade the internals. The key parameters in this time frame are the dissolution kinetics of spent fuel, which species enter the water, and in what form (ions or colloids). Transport phenomena involving these ions and colloids are also studied. Similarly, for glass waste forms, the dissolution rates can be monitored over time as can any tendency for the glass to devitrify. Another important effect, which can realistically only be measured in a laboratory setting, is the interaction between the corroding disposal container and the release of radionuclides. Some of the particularly long-lived actinides may preferentially sorb onto metal oxides; the extent of this reaction is amenable to quantification in the laboratory.

Much of the effort in setting up the laboratory testing is expected to be completed before the LA, so the testing during the performance confirmation period would mainly consist of continuing the operation and periodically characterizing the SNF and glass specimens. Except for the characterization of an emplaced waste package that has failed or been damaged in the repository, laboratory testing may be the only way to comply with regulatory requirements and provide sufficient basis for evaluating postclosure performance.

5.3.1.8.3 Dummy Waste Package and Drip Shield Testing

This concept for performance confirmation entails the manufacture and emplacement of a dummy waste package of the same dimensions and configuration as the real waste package but not containing any radioactive waste. Instead of the waste, the package will house an electrical heater. The dummy waste package would be included in test drifts under simulated, postclosure conditions or in emplacement drifts. The concept also extends to the emplacement of a drip shield to evaluate its long-term behavior prior to closure.

The dummy package(s) will be used to study thermally induced changes in the container material and the surrounding environment. The full scale dummy waste package will also permit the same fit between the inner and outer container material as the real waste package, which will accurately reflect the state of stress existing in the real package. The dummy waste package will be fabricated and welded just like the radioactive waste packages; examination of the exposed surfaces and welds will be as close as possible to studying an actual waste package.

The dummy drip shields will be used to study their ease of emplacement, the potential response to rock falls, and the possible interaction with the rock and backfill material (if employed). The drip shield will be fabricated by the process expected to be used for drip shields when they are to be emplaced just prior to closure of the repository.

Most testing of the materials will be performed on the surface and perhaps off site as well. While some measurements can be made by observation of the drip shield and dummy waste package surfaces during exposure in the repository, most measurements will be made by withdrawing the drip shield and dummy waste package and examining them destructively either in the surface facility, depending on the kinds of available equipment and instrumentation, or at an offsite laboratory.

Important parameters to be determined by examination of the dummy waste package include the dry oxidation rate, corrosion rate in humid atmospheres, and aqueous general corrosion rate, as well as the threshold humidity level for transition from dry oxidation to aqueous corrosion. Evidence of pitting or other localized attack, including any microbiologically influenced corrosion on the container surface, will be examined. Penetration of the container section by general corrosion, pitting, stress corrosion cracking, or other localized attack will be quantified. The nature and composition of oxidation and corrosion products will be determined during examination of the exposed surfaces of the container. Instrumenting the dummy containers with strain gages will allow monitoring the stresses at various locations and changes in the stress with the time of exposure in the repository. Non-destructive examination of welds will support investigations of weld integrity while destructive sectioning of the container will support investigation of potentially damaging embrittling phases plus any evidence of penetration by corrosive attack. Similar examination(s) will be performed for the drip shield.

5.3.1.8.4 Recovered Material Specimens/Coupons

This concept involves placing non-radioactive waste container material specimens at different locations within emplacement drifts where they are expected to experience different environmental conditions and then retrieving them for laboratory examination at surface or offsite facilities. This approach complements the laboratory testing concept by providing exposure to the more realistic environment instead of a simulated one and acts as an oversight in case some factor has been neglected or cannot be reproduced in laboratory test environments. Specimens will be placed in a variety of exposure locations to cover a reasonable range of the geological and geochemical variations expected to occur in the repository. Some specimens will be placed in the hotter and drier locations alongside the waste packages in the emplacement drifts or the electrically heated dummy waste packages, if utilized, in test alcoves. These specimens will witness the same thermal and humidity conditions that the real, radioactive waste package containers are to experience during the operational period. Other specimens will be placed in test alcoves located away from the emplacement drifts in the cooler and more moist locations in the repository to simulate the conditions that would be representative at a future time when the heat source inside the waste package will have decayed.

Specimen testing will be largely restricted to the container and cladding materials because, while the exposure conditions in the repository represents the external environment of the waste package, it does not represent the internal environment of the waste package. The specimens will range from small coupon-size pieces like those used in laboratory testing to panel-size pieces approaching the dimensions of a waste package. Some of the test specimens will contain welds because the integrity of the welds on the waste package is an important technical issue during the repository operational period. Depending on the nature of the measurement or characterization, the specimens may be analyzed on site at the underground exposure location, at the repository surface facility, or at an offsite laboratory. Compared to testing the dummy waste packages and destructive examination of sacrificial waste packages, these specimens are relatively inexpensive. The major expense will be in accessing the specimens located in the emplacement drifts, but several measurements can be taken by remotely controlled cameras and instrumentation on the ROVs to minimize the need for physical withdrawal of the specimens.

The key parameters to be determined by the specimen tests will be corrosion and other degradation characteristics of the drip shield and waste package barrier. These include the dry oxidation rate and the different phenomena occurring in humid atmospheres and under aqueous conditions such as threshold humidity level, humid air general corrosion rate, aqueous general corrosion rate, pitting corrosion characteristics in humid air and in aqueous conditions, and microbial corrosion characteristics. Evidence of galvanic effects, such as galvanic interaction, between the metal components of the waste package will be noted. The nature and characteristics of oxidation and corrosion products will be determined by examining the surfaces of the retrieved specimens. Embrittlement in the container materials and the integrity of the welds will also be determined by analyses of retrieved specimens.

5.3.1.8.5 Recovery of Actual Waste Packages

This concept involves the transport of a previously emplaced waste package to the surface for testing and measurements in support of performance confirmation. This concept will not be implemented for performance confirmation except as a contingency. Instead, waste package performance will be confirmed through other waste package testing.

The ability to remove any or all of the waste packages after emplacement is a basic requirement of the repository program. This capability will be maintained throughout the preclosure retrievability period. Such activity could yield information on corrosion, behavior of welds, or early changes in the basket or the fuel itself; however, the activities required to recover one or more waste packages are not trivial. While the exact impacts of this activity are not well defined, it will not be desirable to perform this action repeatedly or as a planned activity for the following reasons:

- Additional material stress on the waste package due to handling and cooling/re-heating. The process of the removal of the waste package from elevated temperature conditions in the emplacement drifts and the mechanical stresses possibly incurred by transport up to surface and down again to re-emplace a canister could increase the risk of juvenile failure of the canister.

- The emplacement drifts (after temperatures exceed 50°C) would need to be blast-cooled to permit access to the emplacement drifts with retrieval equipment, possibly affecting drift stability and incurring significant costs. The temperature surge may also adversely affect monitoring equipment likely to be located within emplacement drifts and in the main exhaust drift.

- During the operations phase after emplacement is complete, the surface facility will be mothballed. If any activity were required in the surface facility in conjunction with waste package recovery and handling during the monitoring period, the facility would have to be re-activated at substantial cost. However, based on the *Retrievability Strategy Report* (CRWMS M&O 1998h, pp. 5-2, 6-1 to 6-9), there is a potential for waste package movement and recovery from accidents during operations that may require the surface facility to remain active during this period.

5.3.2 Performance Confirmation Postclosure Simulation Concepts

As part of the performance confirmation program, testing of the postclosure environment will be conducted. This testing will confirm that the measured conditions within a simulated postclosure drift are within the ranges consistent with the LA. It will also provide an opportunity to evaluate possible design options, which are beyond the scope of the performance confirmation program. This testing addresses the requirement in the DOE's revised Interim Guidance (see Appendix B, Section 133) (Dyer 1999) which requires "... a program for in situ testing of ... thermal interaction effects of the waste packages, backfill, rock, and groundwater ...". Also, similar testing has been considered previously (e.g., the large-scale/long-duration test in the *Updated In Situ Thermal Testing Program Strategy* [CRWMS M&O 1997j, p. 19 and 21]).

The testing would be conducted after the start of waste emplacement, allowing for the use of actual waste (if identified in the detailed test plan). Conceptually, a single test drift will be employed for this testing, as illustrated in Figure 5-3. The drift will have the dimensions of an actual emplacement drift and could be located at the edge of the emplacement horizon to facilitate the use of actual rail and other subsurface systems for testing.

The test drift will be separated into test sections allowing for the simulation of several different test cases within the overall test drift. Within a specific test section, heaters or actual waste packages will be emplaced for sufficient time to allow for an impact on the adjacent rock mass (i.e., to heat up and dry out the rock). After a prescribed time, the postclosure configuration will be constructed in the section with dummy (or actual) waste packages, drip shield, backfill (if employed), and employing expected postclosure technology and equipment.

Instrumentation will be emplaced within the drift to measure the in-drift environments, including seepage. Instrumentation access will also be provided via an adjacent test alcove. The test alcove is (conceptually) constructed below the test section to minimize any potential impact on the water flow around the opening (i.e., the near-field geohydrology), and to permit monitoring

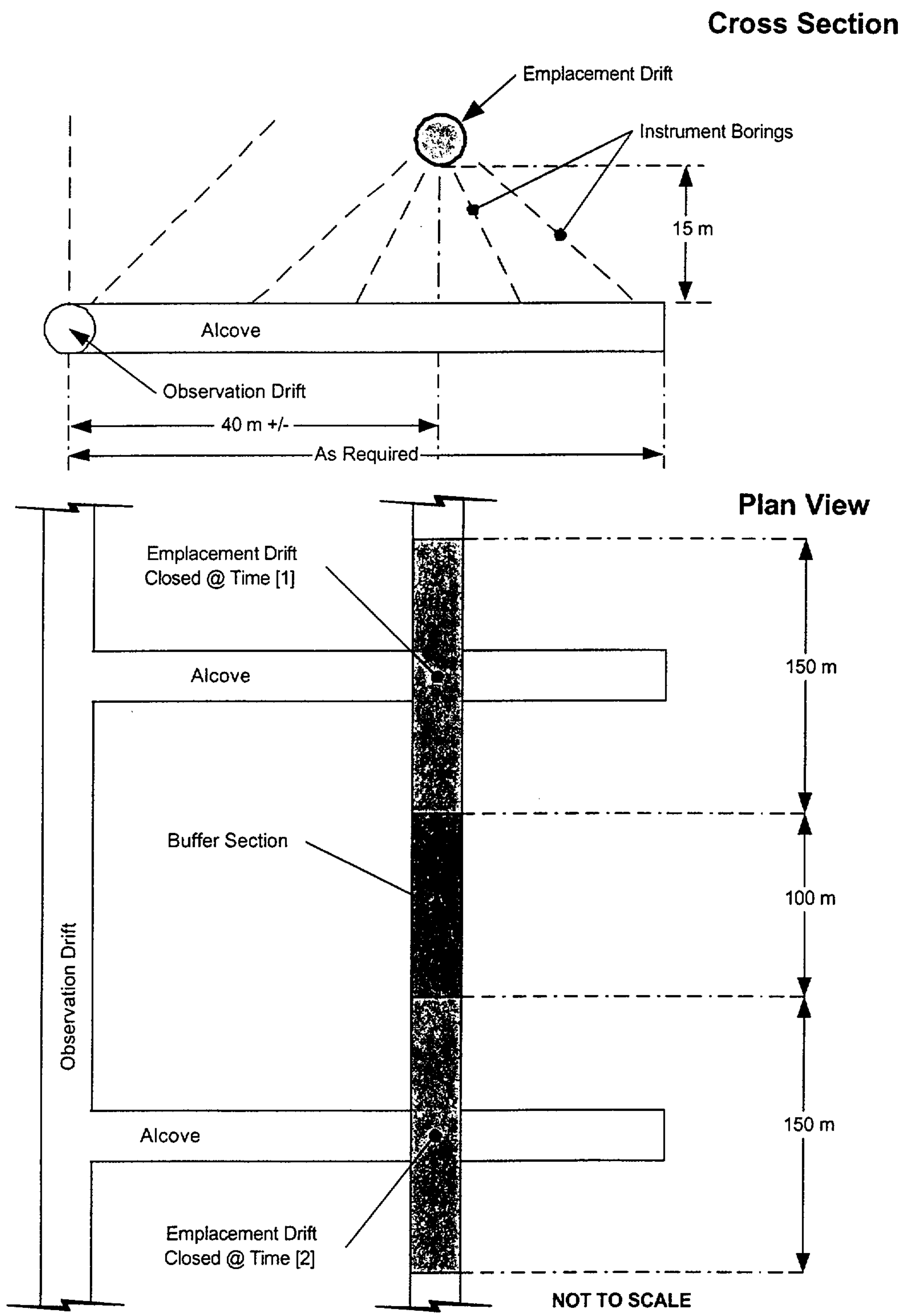


Figure 5-3. Conceptual Configuration for Postclosure Simulation Test Sections

of the rock mass response below the drift where greater temperature and response may be expected. Seepage measurements or testing below the drift can also be conducted.

Testing in this section would be conducted for a long period of time (in excess of 10 years) to obtain sufficient data on the response of the engineered barrier system and natural barrier systems. The test section will be isolated from adjacent test sections by placement of a barrier seal between the sections. Also, conditions in the test section (including gas content) will be similar to postclosure drifts by using bulkheads, buffer sections, or by other means. Construction of additional sections will follow a similar process. Upon completion of testing, each section will also be "deconstructed" (i.e., carefully disassembled to examine the engineered barrier system components for a detectable change in processes or parameters that could influence long-term performance such as corrosion or microbial growth). The sections can be deconstructed from either end, but the sequencing of the sectional tests would require careful, detailed planning. Additional specifics of the test configuration will be further defined in the detailed test plan.

5.3.3 Performance Confirmation Baseline Development and Monitoring

5.3.3.1 Geologic Mapping

Based on the requirement analysis in Appendix E, geologic mapping of repository underground openings conducted during construction was identified as a required performance confirmation activity. This program will provide information on stratigraphy of the emplacement horizon, such as lateral extent, depth, thickness, rock type, mineralogy, and fracture density; it will also provide information on the characteristics of major fracture sets and faults (including location, width, length, aperture, orientation, and displacement of the features). This mapping will be conducted in accordance with applicable standard engineering practices such as ASTM D4879-89 (Reapproved 1996), *Standard Guide for Geotechnical Mapping of Large Underground Openings in Rock*.

Stereoscopic imaging combined with digital mapping and onsite geologic proofing will be conducted to obtain peripheral coverage of the subsurface excavations. During construction, continuous observations will be made of the drift walls for determination of anomalous conditions. The digital imaging system will produce high-resolution, color stereoscopic images capable of discerning structural objects in cm range length, with onsite image evaluation capability. Onsite geologists will evaluate the accuracy and detail of the digital images as they are produced.

Mapping will also include detailed full-periphery geologic mapping and the localized collection of discontinuity statistics using a detailed line survey sampling technique. Rock mass classification data will be developed from the mapping and discontinuity data in accordance with ASTM D5878-95, *Standard Guide for Using Rock Mass Classification Systems for Engineering Purposes*.

This mapping strategy will provide a baseline of the as-excavated conditions. Mapping will be conducted at a to-be-determined distance behind the advancing tunnel boring machine. The distance shall be determined based on limiting vibration interference from the tunnel boring machine to the stereoscopic imaging system. The use of stereoscopic imaging technology should minimize the extent to which mapping activities may interfere with tunneling and drift ground support installation. Requirements on the extent and level of detail of mapping will be coordinated with observations required for ground support determinations and feature observations.

The objectives of geologic mapping include:

Supplemental Ground Support and Rock Stabilization Requirements–Continuous geologic mapping will provide identification of zones or areas that may require modification of the initial support system installed in the drifts. The mapping will help provide locations of unstabilized keyblocks, zones of raveling, or zones of intense fracturing that may require additional attention for long-term stabilization.

Design Confirmation–During the LA, a specific design based on certain geologic assumptions will be presented. During construction of the repository, these assumptions will need to be verified in accordance with regulatory requirements. Mapping will provide statistical discontinuity data to support the verification of rock mass classification for engineering purposes in accordance with ASTM D5878-95.

Anomalous Conditions Identification–Geologic mapping data will ensure documentation of the presence and extent of any anomalous conditions such as significant unexpected faults and shears, significant and unexpected variations in lithostratigraphy, the presence of unusual fracture characteristics or sets, and zones where the designed ground support may not be adequate.

Repository Baseline Conditions–Geologic mapping of emplacement drifts ensures that the conditions encountered in each drift scheduled to receive waste are fully documented. Photographic imaging, derivative mapping, and line survey data collection will serve as a baseline for future analysis of each drift after emplacement and initial start-up. Maintenance and service problems can be analyzed in light of the geologic conditions at any given drift. A consistent and continuous record of the encountered geologic conditions will enhance and assist in remote interpretations of the drift behavior during repository operation.

5.3.3.2 Geologic Sampling and Testing

In accordance with DOE's revised Interim Guidance (see Appendix B, Section 132) (Dyer 1999), a sampling and offsite laboratory testing program to confirm subsurface conditions will be undertaken. This sampling and testing program will support UZ hydrology and seepage testing and thermal testing and monitoring. Rock samples will be collected at locations corresponding to UZ hydrology and seepage testing and instrumentation locations, including alcoves and monitoring drifts. Parameters to be tested include rock hydrologic properties such as saturated hydraulic conductivity, effective porosity, moisture content, water potential-moisture content relationship, and moisture content-hydraulic conductivity.

To support thermal testing and monitoring, rock cores collected from the instrumentation boreholes at the three thermal test locations will be analyzed. Testing will determine rock chemistry and hydrologic properties such as mineralogy, saturated hydraulic conductivity, effective porosity, moisture content, hydraulic potential-moisture content relationship, and moisture content-hydraulic conductivity relationship. These tests will be performed before and after the alcove thermal test and before and during the emplacement drift monitoring. Mechanical and thermal properties testing will include unconfined compressive strength, thermal conductivity, and thermal expansion.

5.3.4 Pre-Emplacement Testing

Definition of the requirements for this category of testing is still in progress, and no testing concepts have been specifically identified for testing at this time. Preliminary test scope sheets for this testing (presented in Appendix G) identify tasks only at a summary level. However, it is expected that many of the test techniques that will be used for this testing will be highly similar to those employed for site characterization and will include both field and laboratory testing methods.

5.3.5 Engineered Barrier System Testing and Constructability

5.3.5.1 General

As identified under performance confirmation requirements, and as required for repository development, prototype testing of specific engineered barrier system components, such as seals, drip shield, and backfill (if employed) will be performed under the performance confirmation program. This prototype development is discussed in the following sections under three areas: (1) ramp and shaft seals, (2) borehole seals and (3) backfill and drip shield testing. Drip shield material testing and development is discussed under waste package materials testing in Section 5.3.1.8. Other related testing involving laboratory and bench scale tests to establish design alternatives and design data is defined under the test and evaluation plan and is not part of the performance confirmation program.

5.3.5.2 Ramp and Shaft Seal Testing

Prototype ramp and shaft seal tests are identified to address performance confirmation requirements discussed in Appendix E. The tests are to examine seal performance and to resolve design issues associated with large-scale construction not previously addressed by laboratory or small-scale in situ testing. This testing will evaluate performance against established requirements; initial requirements have been identified in the *Repository Seals Requirements and Concepts* (CRWMS M&O 1998f, pp. 2 to 3).

Construction of full-scale prototypes of both ramp and shaft seals are to be conducted and consistent with expected needs for both seal types identified in conceptual studies (e.g., CRWMS M&O 1997c, Figure 5-9). Due to the influence of both rock conditions and construction techniques on seal development, these tests are to be performed within representative geologic units and using construction techniques identified for repository closure. These prototype facilities will be developed in the early stages of repository development and remain consistent with identified requirements.

5.3.5.3 Borehole Seal Testing

Prototype testing of borehole seal tests is also identified to address performance confirmation requirements identified from applicable regulations (Appendix E). It is expected that this testing will be performed in surface boreholes using appropriate drilling technology to install and test the seals. This testing will involve representative prototype seals emplaced in shallow boreholes to allow for seal recovery and ease of testing. Seals will be installed into representative rock conditions and tested using available borehole testing technology. After testing, the seals will be removed from in situ by the use of large core bits (significantly larger than the original boreholes) which would drill over the seal sections and recover the seals and the adjacent rock (termed "overcoring"). The recovered seals would then be transported to the laboratory for additional testing and examination. Specialized test facilities are not identified for this testing.

5.3.5.4 Backfill and Drip Shield Testing

As identified by the applicable regulatory requirements (Appendix E), both backfill constructability and backfill performance testing are prescribed to be included under the performance confirmation program. However, as backfill within the emplacement drifts is not identified as a design option for the repository at this time, backfill testing is not identified as part of the current performance confirmation program.

As described earlier under Section 5.3.1.7, dummy drip shields will be used to study their ease of emplacement, the potential response to rock falls, and the possible interaction with the rock and backfill material (if employed). If backfill were identified in the future as a design option, the constructability of the drip shield and backfill configuration would be studied together, while backfill performance testing would be addressed as a separate concern. As both drip shield and backfill placement and backfill compaction procedures are scale-sensitive, drip shield/backfill constructability testing would be conducted as a full-scale prototype under repository spatial constraints and using full-scale, available construction technology. As the placement technology for both barriers is insensitive to rock-type, the prototype facility can be located at the surface for ease of access and reduced cost.

To evaluate backfill performance, other areas of testing could examine the properties and response of backfill under representative field conditions. As discussed earlier (under postclosure simulation testing), the postclosure configuration will be constructed and tested. If backfill is identified as a barrier, the performance of the backfill can be examined under representative postclosure conditions as part of this testing. Therefore, additional in situ testing to examine backfill performance alone would not be required, but rather existing tests would be modified to assess backfill performance.

5.3.6 Groundwater Quality Monitoring

In addition to environmental monitoring required for preclosure considerations, SZ testing will be performed as indicated by present draft regulations (see Appendix E). To perform this testing, a set of monitoring wells will be installed, as required, to provide sufficient coverage of the SZ at the point-of-compliance downgradient of the repository. These downgradient wells will be supplemented by a limited number of wells upgradient from the repository. The upgradient wells will allow the determination of the water quality before passing under the site and being potentially affected by the repository. By conducting both measurements, the upgradient wells can establish the ambient water quality flowing into the site, and the downgradient wells will identify changes (if any) from the upgradient wells.

Periodic water samples will be taken from each of the monitoring wells to determine the chemistry of the sample, with a focus on nuclear waste-related parameters (i.e., radium content, gross alpha activity, and content of beta and photon-emitting radionuclides) as well as potential contaminants due to repository construction and operation. Sampling will be performed under applicable environmental standards and stored and carefully transported off site for chemical analyses. The sampling process will be coordinated with other performance confirmation activities so as not to adversely impact other testing such as water level or water temperature measurements (if performed).

5.3.7 Disruptive Event Monitoring

5.3.7.1 Groundwater Level Monitoring

To address the low-probability occurrence of a geologic process that could perturb the level of the SZ near the repository, groundwater-level and groundwater temperature measurements will be performed. These measurements will be conducted within the same monitoring well network installed for groundwater quality measurements and will incur minimal additional costs. Groundwater-level measurements will be conducted in relation to the well collars, which will be surveyed periodically as part of the precise leveling network (see Section 5.3.7.3).

5.3.7.2 Seismic Monitoring

To address the low-probability occurrence of a seismic event greater than the seismic design basis event for the facility, subsurface seismic monitoring will be conducted as part of the performance confirmation program. Seismic response of the subsurface can be expected to be less than that at the surface, but subsurface monitoring will be compared to surface monitoring to define the correlation between the two. Measurements will be taken at the repository horizon to obtain a representative correlation but will be located outside the influence of the expected disturbed zone around the emplacement area. In addition, other parts of the test and evaluation program may supplement this monitoring with large-scale seismic simulators and testbeds, which can be used to evaluate the effects of seismic events on subsurface structures and components.

5.3.7.3 Precise Leveling

To address the low-probability occurrence of major geologic processes (such as volcanism) occurring at the site, surface uplift above the site will be measured periodically. A grid of survey stations will be established across the site with elevations (and attendant survey error) baselined prior to the first emplacement of waste at the site. Precision surveys will be conducted between these stations allowing elevations to be determined to high accuracy, on the order of detecting 1 cm of displacement between surveys (the exact precision will be defined in a detailed test plan). Existing surveying technology can be employed, or when it becomes available, high-precision global positioning satellite technology could be used to measure these elevation changes with respect to a reference point(s) located at some distance from the site. This will allow the determination of any localized elevation changes at the site.

5.4 TEST FACILITIES AND SUPPORT CONCEPTS

5.4.1 Subsurface Test Facilities and Support

5.4.1.1 General

In addition to laboratory testing at surface facilities, several test facilities and support concepts will be utilized to gather the information needed to execute the performance confirmation program. These facilities and concepts are described in this section. One such concept involves TMH monitoring of representative areas of the emplacement horizon extensively and continuously (termed observation drifts). Excavations stemming off these observation drifts, or other access points (termed alcoves) are to be employed for the monitoring or testing of emplacement areas as well as in nonemplacement areas with instruments typically installed in boreholes. Alcoves dedicated to specific testing types are termed in this context as "special test alcoves."

To conduct the test and monitoring detailed in Section 5.3, a preliminary subsurface monitoring facility layout can be constructed using a conceptual layout (CRWMS M&O 2000c), as illustrated in Figure 5-4. The configuration illustrates the location of various special test alcoves and observation drifts that could be utilized (alcoves off the observation drifts are not shown for clarity). However, this layout is expected to be extensively modified in the LA, as additional analysis and detailed planning is necessary to provide specifications for a final performance confirmation configuration. Not shown in this diagram are support concepts for systems to collect and transmit data for performance confirmation, which are discussed in the following subsections. Initial design analyses of performance confirmation support facilities for performance confirmation have been conducted for the prior VA design as documented in *Subsurface Repository Performance Confirmation Facilities* (CRWMS M&O 1997b) and *Performance Confirmation Subsurface Facilities Design Analysis* (CRWMS M&O 1998g).

5.4.1.2 Observation Drifts

As discussed earlier, access to emplacement drifts will be restricted for performance confirmation activities (Section 5.2) To provide access to conduct TMH monitoring of the rock mass around emplacement drifts, observation drifts will be excavated adjacent to emplacement drifts. Alcoves will be developed off the observation drifts to permit a larger drilling coverage of the thermally perturbed UZ. Drill holes drilled from the observation drift toward the adjacent emplacement drifts will contain instrumentation for long-term, in situ data collection. Such a concept would likely resemble the ESF thermal tests where the heated drift is not accessible but is monitored via borehole instruments.

In this concept, it may be possible to allow selected drill holes to penetrate the emplacement drift wall, allowing instrumentation to be inserted directly into the emplacement drift and then withdrawn. Instrumentation would be installed in the drill holes from the observation drifts and, if repair or re-calibration is needed, would be removed and reinserted from the observation drift. In the case of instruments that must be grouted in place, additional holes may have to be drilled in the event of an instrument failure.

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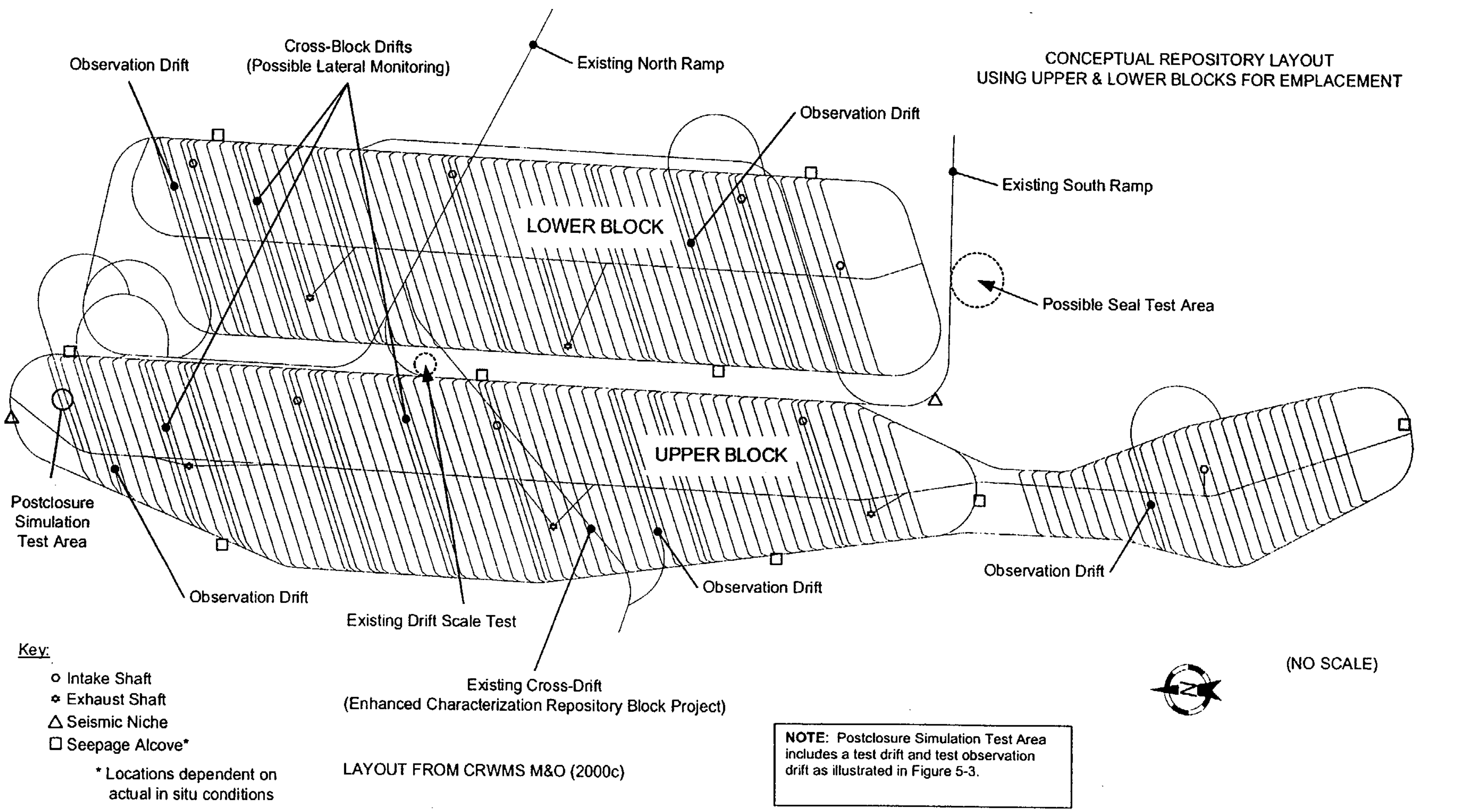

Figure 5-4. Conceptual Subsurface Layout with Performance Confirmation Facilities

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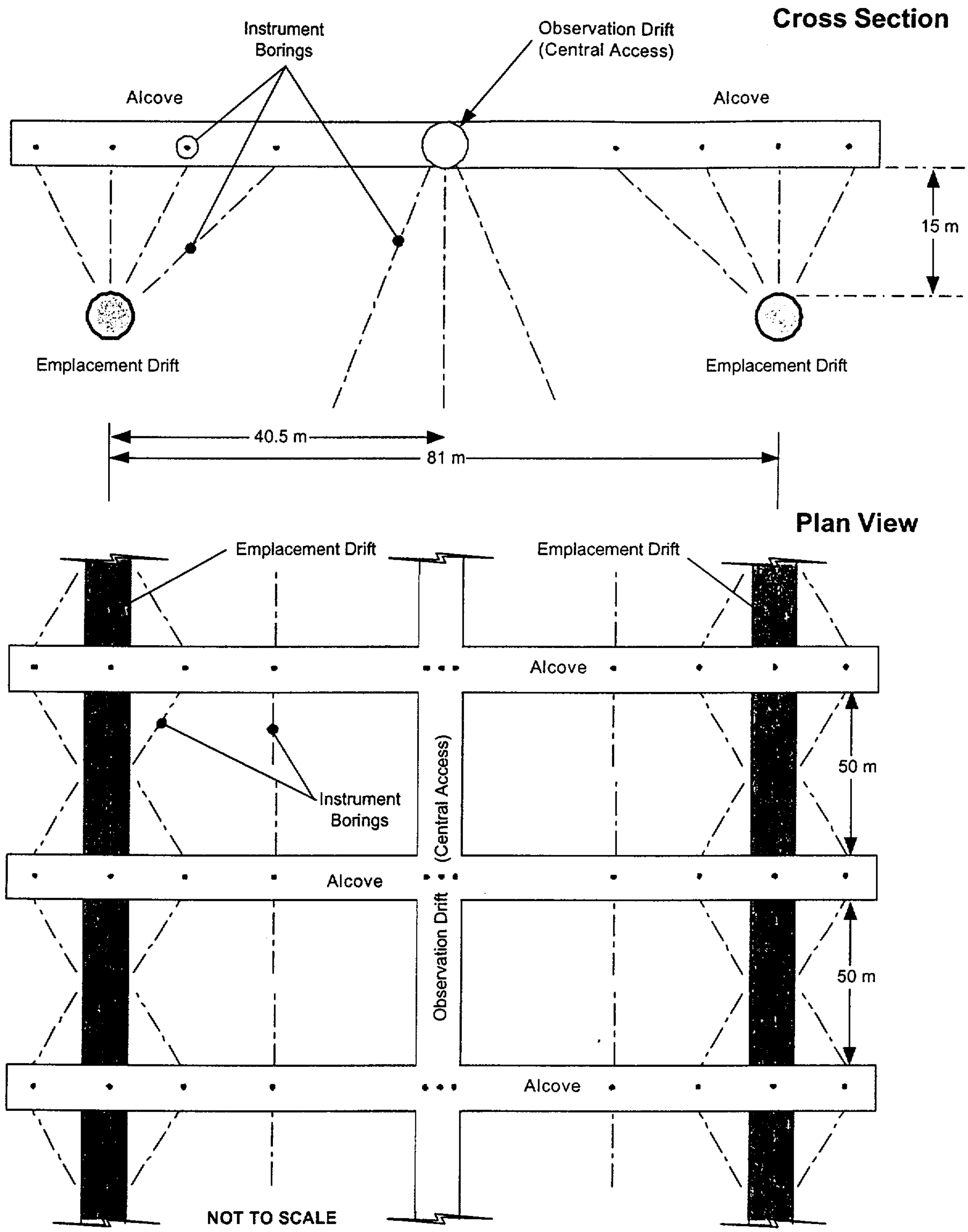
For the present design concept, observation drifts are (in general) to be located above and parallel to the emplacement drifts for a number of reasons. During the preclosure phase, the expected rock mass response around the opening (i.e., in the near field) will be relatively symmetrical with respect to the center of the opening; this conceptually permits observation drifts to be located above, below, and aside the repository emplacement areas. However, from a configuration viewpoint, locating observation drifts above the repository horizon provides for the most flexibility. With the observation drift in a plane above the emplacement drifts, boreholes can be drilled down to the emplacement drifts for monitoring ground movement at the tunnel crown. Monitoring for ground movement may be possible from below, but it is not the preferred configuration. Observation drifts located below the horizon and that intersect with the exhaust mains (located below the repository horizon by design) will create access problems due to elevated temperatures within the exhaust mains. Locating an observation drift aside emplacement drifts within the repository horizon will be constrained due to the need to maintain a certain distance from the emplacement drifts, restricting these observation drifts to a narrow section within the pillar region between emplacement drifts.

A typical observation drift/alcove configuration for monitoring preclosure TMH response is shown in Figure 5-5. The number of observation drifts will ultimately depend on the amount of coverage that is required to monitor a representative volume. The amount of areal coverage would vary with the number of observation drifts and the spacing of the alcoves and instrumentation stations. In the current design, three observation drifts are designated for performance confirmation of the upper block and two for the lower block (see Figure 5-4). Measurements in a few observation drifts and associated boreholes are expected to provide acceptable statistical distributions of the performance confirmation parameters and to provide adequate coverage of spatial heterogeneity across the repository block. Performance analyses planned in support of the performance confirmation program design will establish the actual number and location of the observation drifts for the LA.

The size of the observation drifts will be determined by the required equipment operating envelopes, but will approximate the 5.5 m tunnel boring machine diameter employed for emplacement drift construction (CRWMS M&O 1999e, p. 2-4, Figure 2-3). This allows the use of the same tunnel boring machine as employed for emplacement drift construction. Ventilation raises will be excavated between the observation drifts and the east, west, and exhaust main(s). Actual location and configuration of the observation drift ventilation raises or their connections to the mains have yet to be determined.

The configuration of alcoves and boreholes off the observation drifts has yet to be determined. Performance analyses planned in support of the performance confirmation design will establish the actual number and location of the alcoves and boreholes.

The first observation drift will be excavated during the pre-emplacement development construction period to obtain baseline data prior to the emplacement of the first waste packages. Subsequent observation drifts would be constructed during the normal development operations but prior to construction of the corresponding waste emplacement drifts. This is necessary to obtain the initial rock mass response due to excavation.



NOTE: Layout shown is conceptual and requirements for observation placement (i.e., above, at, or below the emplacement drift horizon) have not yet been determined.

Figure 5-5. Conceptual Observation Drift Configuration for Monitoring

Boreholes drilled from the exhaust main, ventilation drift, and perimeter mains that are appropriately oriented can be used to monitor parameters in regions above, below, and between emplacement drifts (at least on the periphery of the emplacement drifts). These boreholes alone cannot provide sufficient coverage of the thermally perturbed UZ for thermal monitoring, but may augment the observation drift instrumentation. Boreholes from the perimeter main can also monitor conditions between emplacement drifts.

5.4.1.3 Special Testing Alcoves

5.4.1.3.1 General

As identified in the requirements section, several testing programs are to be initiated during the early or developmental stages of construction. Included in this suite of testing are seepage monitoring and testing of potential sealing systems (for boreholes, ramps, and shafts). In addition, subsurface seismic monitoring has been identified as part of performance confirmation and will be performed during the operations and monitoring phases of the MGR. Specific subsurface locations and support of these testing activities will be established in the design and accommodated in the operational concept. An illustration of possible locations of these facilities is shown in Figure 5-4.

As many of these activities as possible will be carried out in an area of the subsurface layout which is removed from the high temperature and radiation environment of the emplacement areas. Personnel access to the emplacement side of the repository will be limited because administrative controls, including strict access limitations, will be enforced to keep radiation doses as low as reasonably achievable. The development side of the repository will provide the best accessibility for testing, and for this reason, it is assumed for this activity that the seals testing will be carried out in the development side of the ventilation system. While access for testing the development side will be not be unlimited even on the development side, it should be sufficient to construct, install, and monitor the tests. However, some access to the emplacement side will be required for ongoing monitoring such as seismic monitoring.

5.4.1.3.2 Seepage Alcoves

In situ monitoring of seepage will require short alcoves, which are hermetically sealed from the ventilation system using a bulkhead. The sealed alcoves will require access through the bulkhead seal to access instrumentation in the isolated section. Conceptually, the alcoves will be approximately 20 m in total length, with an exterior area for housing data acquisition systems and staging for entry into the isolated sections. The exact number of alcoves will be determined during detailed test planning.

5.4.1.3.3 In Situ Seal Testing Alcoves

To address the regulatory requirements for in situ testing of seals, the development of ramp and shaft seals may require full-scale prototypes to be constructed and tested under representative subsurface conditions. The seals would be installed and tested away from the emplacement area and would require access to both ends of the seals and placement of instruments into the seals from the side. For study of a shaft seal, a short stub "shaft" would be required with alcoves leading to both ends and an intermediate level from which to install instruments. For the ramp seal, two parallel alcoves would be required, one for the seal, and the other for instrument installation and observations. However, given appropriate circumstances, the instrument/observation alcove could be replaced by the enlargement of an adjacent access way parallel to the seal alcove or the excavation of a short niche (to provide for a separate work area), to reduce total excavation costs.

Based on these configuration requirements, one test facility would be required for each type of seal for a total of two test areas. These areas may be directly adjacent to efficiently utilize resources. Conceptually, these seal test facilities would be located along the south ramp, providing access to various geologic units from the surface to the repository horizon. The location would also have a minor impact on subsurface operations, although activities along the south ramp may be limited by initial subsurface construction activities.

5.4.1.3.4 Niches for Seismic Monitoring

As part of seismic monitoring of the site, seismic monitoring will monitor the subsurface response of the repository horizon, in addition to the existing surface-based network. The subsurface seismic monitoring will require short alcoves, or "niches," to house and protect a surface-mounted data acquisition system, which is mounted adjacent to the borehole collar. The instruments themselves will be installed in short boreholes within the niches; the instruments are integrated with the data acquisition system to provide continuous digital logs in the event of a seismic event. To provide minimum coverage of the repository horizon and redundancy in the event of system failure, two seismic niches are identified; they will possibly be located at the northern and southern end of the subsurface facility.

5.4.1.4 Stationary Control and Monitoring System

To collect data periodically underground, instruments will be connected to a data acquisition system when appropriate. Instruments connected this way are termed "integrated." The data acquisition system will collect data at set intervals (via the use of an input/output board) from integrated instruments and will store the data locally (CRWMS M&O 1997e, p. 90).

As part of the performance confirmation activities, there will be a number of in situ instruments and data collection devices installed at various locations throughout the subsurface repository. The data collected from these devices will be transmitted to a surface-based control center via a data highway (fiber optic transmission line) that is part of the MGR operations monitoring and control system. Based on current design concepts, the data highway will utilize high-speed fiber optic communication technology. The fiber optic data highway will be installed throughout the subsurface main perimeter drifts and along performance confirmation observation drifts. The data acquisition systems will then be able to transmit data via controller boards to the surface data control/facilities network in the performance confirmation support area (CRWMS M&O 1997e, pp. 94 and 97).

5.4.1.5 Mobile Vehicle Operations Control System

In addition to the stationary control system, it is necessary to collect data from mobile performance confirmation systems (such as the ROVs) and control the equipment remotely from the surface-based or underground control station. A mobile vehicle operations control and associated transmission system is required to collect data from both mobile and static instruments and provide real-time data to accurately and safely control moving platforms. Based on present technology, microwave or radio wave transmissions from the ROV could be collected by in-drift wires and transmitted via a subsurface network to an operator control station at the surface (e.g., CRWMS M&O 1997e, p. 97). The operator control station would control and oversee a variety of systems in addition to the mobile control function, across the repository horizon. This data flow is presented schematically as part of the general data flow shown in Figure 5-6.

5.4.2 Surface Test Facilities and Support

5.4.2.1 General

The surface test facilities and support concepts include a performance confirmation support area. This concept is briefly described in the following section.

5.4.2.2 Performance Confirmation Support Area

Onsite support for performance confirmation activities will require specialized facilities to maintain testing and monitoring activities. Conceptually, this onsite support will be contained in a performance confirmation support building area. The performance confirmation support building area will be located outside the radiologically controlled area of the MGR to permit free access of personnel to both surface and subsurface activities. Its main purpose will be to act as the hub for the acquisition, storage, distribution, and monitoring of all scientific data and samples required for the performance confirmation. This area will also house the administration of the performance confirmation programs required for the day-to-day management of performance confirmation activities and required laboratory facilities. Table 5-3 lists the features of this area.

Table 5-3. Performance Confirmation Support Building Concept

Feature	Conceptual Description[1,2]
Location and Type of Structure	Located On Site Either Metal Frame or Block Structure
Contents and Functional Areas	Offices (Administrative, Onsite Operations and Management, Procurement, Logistics, Information Management, Maintenance, Safety, etc.) Performance Confirmation Computer Facilities (Storage, Evaluation, and Transmission) Instrumentation/Calibration Laboratory Index Testing Laboratory Performance Confirmation Surface-Monitoring Support (Well Monitoring, Precision Leveling, etc.) Instrument and Spare Parts Storage Sample Storage Sample Packaging, Preparation, and Shipping Records Management and Storage Mechanical Shop

NOTES: [1]Central control facility to operate ROVs is located in other surface facilities.
[2]Environmental monitoring facilities are located in other surface facilities.

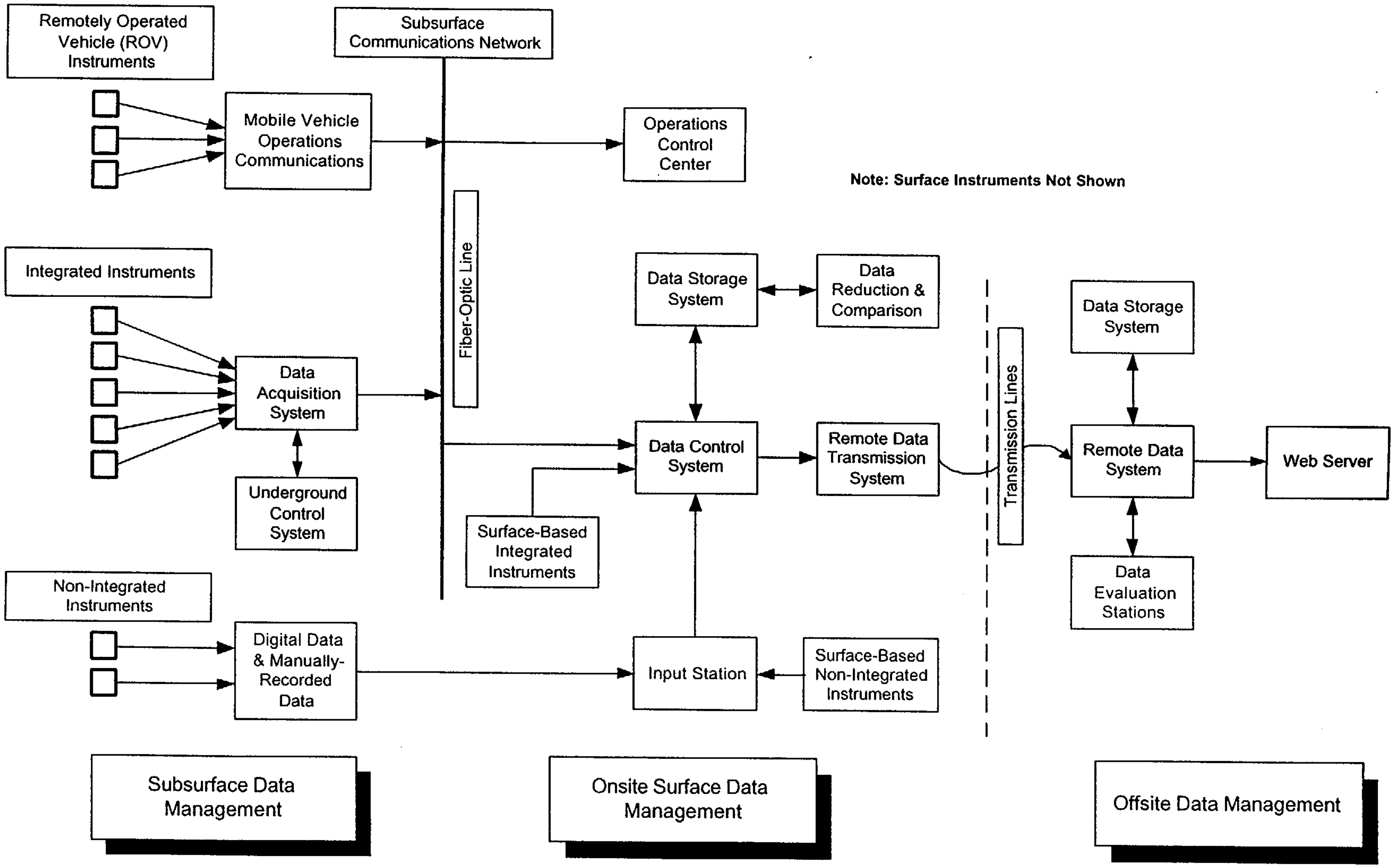


Figure 5-6. Performance Confirmation Program Data Flow

5.4.3 Offsite Facilities and Support

Offsite facilities are required to support long-term laboratory testing activities and the performance confirmation data evaluation activities. Offsite laboratory facilities will be required to investigate the long-term response of engineering materials. Conceptually, these facilities will continue to be located at various national laboratories as they are at the present, due to the existing investment in instrumentation, equipment, and trained personnel. Locating these facilities onsite would incur undue expense.

Onsite performance confirmation data evaluation facilities are also required to process performance confirmation data in an effective and timely fashion. These facilities will support a core-group of technical experts who will be responsible for the day-to-day evaluation and reporting of performance confirmation .data as transmitted from the site. Given present technologies, this core group can be located in the Las Vegas, Nevada area at a DOE facility, or elsewhere, as required by the project. However, some proximity to the site should be maintained to allow for interactions with onsite personnel. The core group will maintain communications with experts and periodically report data either in the form of published reports or in the maintenance of a data reporting system on the world-wide-web.

It is also envisioned that process model and TSPA analyses will be performed by a core group of staff. This group would be located in offsite facilities as well and co-located with the performance confirmation data evaluation facilities to permit staff interaction and reduce overlapping administrative support. Given present technologies, the performance assessment facilities can be located in the Las Vegas, Nevada area at a DOE facility, or elsewhere, as required by the project. Sophisticated computer hardware and software would be required at these facilities to support the complex analyses conducted by the group. In addition, the group would require consultant support on an as-needed basis to conduct special analyses or to modify or extend existing computer models.

5.4.4 Operations and Management

Performance confirmation operation and management activities include the following functional areas:

- Performance confirmation data management
- Sample management
- Performance confirmation emplacement drift monitoring system operation
- Performance confirmation data acquisition system operation
- Nonintegrated testing support
- Performance confirmation planning management
- Training
- Quality control.

Performance confirmation data management encompasses both onsite and offsite activities. For data acquired during performance confirmation, management activities include onsite transmittal, collection, reduction, and storage of data. These operations are performed using onsite computer and office facilities. In addition, data management activities will include the transmittal of performance confirmation data to offsite data-evaluation facilities, where data are stored, analyzed, reported and distributed to the public. This is illustrated in Figure 5-6.

As mentioned earlier, rock and water samples from performance confirmation efforts will be maintained. This requires sample management (i.e., the cataloging, handling, and storage of samples, performed on site, together with the packing and shipment of samples to offsite laboratory facilities). The process also requires the storage of core descriptions (core logs) and the tracking of sample status using of a computer database. Storage facilities will be temperature controlled, as appropriate, to preserve samples until repository closure.

To monitor conditions within emplacement drifts, a multicomponent performance confirmation emplacement drift monitoring system is employed, including, as appropriate, remote inspection vehicles, in-drift instruments, sample coupons, and ventilation monitoring. Operation of these subsystems requires maintenance, periodic calibration, and replacement of instruments and parts. For remote inspection vehicles, a shop facility is required to replace major components and to test subsystems. For ventilation instruments, brief, periodic shutdowns of the ventilation system are also required.

The performance confirmation data acquisition system monitors field instruments that are connected directly to the subsurface data acquisition systems and controllers. These integrated instruments can be sampled on a variable schedule as required, and the data can be transmitted to a control center on the surface via the MGR operations monitoring and control system and stored in performance confirmation data systems. Maintenance will require replacement and repair of data transmission components, such as input/output boards, controls, periodic replacement of instruments, and maintenance of information facilities such as periodic updating of operating software.

For instruments, borehole surveys, sampling, and tests which are not integrated into the performance confirmation data acquisition system (e.g., borehole camera surveys or laboratory porosity determinations), management and operations support is also required. The equipment for this system includes drilling equipment, borehole placement equipment, portable readouts, and laboratory test equipment. Operational support, therefore, will include instrument calibration, laboratory testing, drill rig repair, instrument and spare parts storage and control, and associated computer operations for data reduction and analysis.

Performance confirmation planning management supports the planning of performance confirmation activities including preparation and revision of the detailed test plans, revision of the *Performance Confirmation Plan* (as necessary), development of performance confirmation records, baseline change control, and administrative support activities.

To assure that personnel are conducting performance confirmation activities in accordance with the requirements of the *Quality Assurance Requirements and Description* (DOE 2000), training of all personnel will be performed. Each staff member will be required to attend the appropriate QA indoctrination and complete training prior to performing work subject to QA requirements. Management will be required to monitor staff performance and work scope to determine the need for additional training, retraining, or deletion of training.

Performance confirmation testing and monitoring activities will be conducted in accordance with appropriate procedures and audited by the QA and safety staff. Each activity will be evaluated to assess relevance to potential waste isolation impacts (due to construction and/or performance confirmation activities), potential interactions between independent performance confirmation activities, and/or potential interactions between construction activities and performance confirmation activities. Management will select personnel with appropriate qualifications for conducting those activities, ensure that personnel have completed QA indoctrination and training, and ensure that personnel conduct the activities in accordance with the procedures necessary to 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.

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6. DATA EVALUATIONS, CORRECTIVE ACTIONS, AND REPORTING

6.1 EVALUATIONS AND CORRECTIVE ACTIONS

6.1.1 Approach

A fundamental performance confirmation function is to compare the results of the measurements, monitoring, and testing against the performance confirmation baseline. This function will require evaluations of data, especially for the identification of data variance from the baseline, and for regulatory compliance with provisions and commitments of the repository license. New data may result in changes in the expected postclosure performance of the natural and engineered barrier systems and the overall MGR compared to the predictions included in the LA. The results of these comparisons may require corrective actions in terms of model improvements, changes in the performance confirmation program, and changes to the MGR design, construction, and operation.

A variety of techniques are planned for evaluating the results of performance confirmation site monitoring and testing. These techniques include statistical tests, natural and engineered barrier process modeling, and TSPA. The planned process modeling and TSPAs are described in Sections 3.3 and 4.3. The specific statistical tests to be used will be selected when the analyses are needed. Examples of common tests are null-hypothesis testing, the signed-rank test, the paired t-test, the rank-sum test, and the two-sample t-test (Hirsch et al. 1993, pp. 17.12, 17.13, 17.18 through 17.23). The choice of tests will depend on the nature of the parameter comparison, such as comparing pairs of single-value distributions of parameters, and on the statistical distributions of the parameter values (such as normal or log normal). The statistical tests will determine the statistical significance of any differences. These tests are planned for comparing:

- Site characterization data (performance confirmation baseline) with performance confirmation data
- Successive stages of performance confirmation data
- Model predictions of each performance confirmation parameter with the baseline values
- Pre- and post-LA performance predictions.

The planned comparisons are described in the following sections.

6.1.2 Data Comparisons

Evaluations of the collected performance confirmation data are to confirm that the measured values, observed features, and natural and engineered barrier processes are as expected. These evaluations will involve comparisons of performance confirmation data with the site characterization data (without process modeling). However, this comparison will include mathematical analyses for raw data reduction, numerical interpolations, numerical extrapolations, and statistical interpretations. The interpolations and extrapolations may be accomplished by simple arithmetic calculations, calibration of mathematical process models, and by inverse process modeling (that could involve some process modeling). Not all performance confirmation activities will involve modeling. For example, the confirmation that subsurface geologic conditions are as expected is based on comparing observations without the need for modeling other than the interpolations and extrapolations.

Some parameters can be measured directly (e.g., air temperature by using a thermometer) but many measurements, especially if acquired through remote means, require the conversion of the measured data into the parameters of interest. For some parameters, the conversion of electrical currents or voltages into the physical values of interest, like mechanical stress, is involved (termed "data reduction"). For others, analyses are necessary to convert measured data into the parameters of interest. An example is the derivation of saturated hydraulic conductivity from groundwater pumping rates and well drawdown measurements as a function of time. This involves the assumption of a mathematical model for the relationship between these data. The hydraulic conductivity is then calculated from the measured data using that mathematical model.

Other analyses involve the interpolation and extrapolation of point values in space and time to obtain (1) spatial distributions as functions of time, (2) the calculation of statistical distributions of uncertainty for the direct data comparisons, and (3) input to the performance assessment models. This could include the derivation of a normal distribution for rock matrix porosity and a log normal distribution for saturated hydraulic conductivity from spatially distributed measurements of a given hydrogeologic unit. Because differences can be expected, statistical analyses will be performed to evaluate the statistical significance of the differences. Because these comparisons use the site properties defined by the various conceptual site models, this aspect of the performance confirmation constitutes an additional test of these conceptual models. At present, these models include the geologic framework model (CRWMS M&O 1997d, pp. ii to vi, and 42), the UZ flow model (Bodvarsson et al. 1997, pp. 1-2 to 1-12), the UZ transport model (CRWMS M&O 1997n, pp. 1-1 to 1-16), the SZ flow model (Czarnecki et al. 1997, pp. 1, 2, and 108 to 111), and the SZ transport model (Zyvoloski et al. 1997, pp. 1-1 to 1-10). In addition, the near-field thermal hydraulic model (Nitao 1998, pp. 1 and 2) that is used for drift-scale analyses will be used for measurement comparisons.

The direct comparisons between parameter values measured before and after the submittal of the LA will indicate the statistical significance of any data differences. Because of the interrelationships of parameters, including associated nonlinearities, intuition with respect to the effects of data differences on predicted postclosure performance might be misleading. Consequently, only postclosure performance predictions can demonstrate the significance of data differences with respect to effects on compliance with NRC regulations.

6.1.3 Comparisons of Measured Data with Model Predictions

The statistical tests evaluating the differences between the LA baseline values and the values measured following the submittal of the LA provide only a partial picture of the differences. Although the tests determine the statistical significance of the differences, they do not define the technical and scientific significance of the differences with respect to the natural and engineered barrier processes and the overall system performance. Each data comparison looks at only one or two parameters for a given analysis; independent of other parameters, the comparison neglects the combined, often nonlinear, effects of all parameters determining the performance of a system or component. Consequently, the modeling of the important natural and engineered barrier processes and of the overall system will reveal the technical and scientific significance of the data differences with respect to performance predictions.

The results of the performance predictions made for the performance confirmation period prior to the submittal of the LA will be compared with the performance confirmation data. Comparisons will also be made between iterations of the post-LA preclosure performance predictions for the performance confirmation period when performed. This includes tests to evaluate the statistical significance of differences.

6.1.4 Comparisons of Model Predictions

The results of the performance predictions made prior to submittal of the LA will be compared with the results of the predictions made after the submittal of the LA, when these predictions are performed. Comparisons will also be made between iterations of the post-LA performance predictions. Statistical tests will be performed to evaluate the statistical significance of differences. More important, however, will be interpretations of the technical and scientific significance of differences regarding the fundamental concepts of natural and engineered barrier system processes and the overall MGR performance.

6.1.5 Accuracy and Validity of Performance Assessment Models

The comparisons identified in the preceding sections provide insights into the validity of the conceptual models and the accuracy of the mathematical models for predicting performance of the natural and engineered barrier systems and of the overall MGR. Obtained data that correspond, both in magnitude and trend, to model predictions helps substantiate the ability of the models to predict long-term response. These insights can be used to infer the validity and accuracy of the models when used to predict the postclosure performance of the natural and engineered barrier systems of the MGR. These inferences based on comparison of predictions with performance confirmation tests will be key results of the performance confirmation program.

6.1.6 Evaluation of Compliance with Nuclear Regulatory Commission Postclosure Performance Requirements

The ultimate test of the results of performance confirmation will be to evaluate whether the postclosure performance predicted in support of the LA changes as a result of changes in parameter values, conceptual and mathematical models, repository layout, waste inventory, and events during the preclosure phase. The critical performance confirmation issue will be to demonstrate compliance with the NRC and the EPA requirements in consideration of these changes.

Consequently, postclosure performance assessments after the submittal of the LA will form the basis for demonstrating compliance with NRC postclosure performance requirements. The timing of these assessments will depend on the results of the performance confirmation site monitoring and testing, including the data and model comparisons. The postclosure performance assessments will be performed whenever the statistical comparisons between parameter values and performance predictions show significant differences or if other observations allude to potential problems or significant changes regarding the expected repository performance.

6.1.7 Trend Detection

The described comparisons and evaluations will be analyzed to identify any trends between the measured and predicted performance of the natural and engineered barrier systems and the overall MGR regarding the LA baseline. If trends are significant, based on both statistical analyses and expert interpretations, then corrective actions will be recommended as identified in the following sections.

6.1.8 Recommended Corrective Actions

Commitments to execute specific corrective actions are outside the scope of the *Performance Confirmation Plan,* but the types of corrective actions that could be implemented are described in this section and the following sections.

A process for assessing the trends and recommending corrective actions will be developed under the performance confirmation program. The type of corrective action recommended depends on the nature and significance of the variations and their trends. The following corrective actions may be recommended:

- Revisions and additions to the YMP technical database
- Revisions or improvements of the conceptual process models
- Revisions or improvements of the mathematical models and associated computer codes of these processes
- Changes in the performance confirmation site monitoring and testing program
- Changes in the performance confirmation test facilities and support systems
- Changes in the design, construction, and operation of the MGR
- Selective waste retrieval
- Complete waste retrieval and site abandonment
- Interactions with the NRC and stakeholder organizations.

6.1.9 Corrective Action Implementation

The implementation of the corrective actions will be the responsibility of the following organizations:

- YMP Technical database: Technical Data Management
- Conceptual and mathematical process models and associated computer codes, depending on process: Science & Analysis
- TSPA mathematical model and computer software: TSPA
- Performance confirmation program coordination: Science & Engineering Testing
- Performance confirmation test facilities and support system design: Science & Engineering Testing and Repository Design
- MGR design: Repository Design
- Performance confirmation test facilities, support system, and repository construction and operation, including waste emplacement and retrieval: Site Operations
- Interactions with the NRC and stakeholder organizations: NRC Regulatory Coordination
- File abandonment or MGR closure: Site Operations and Regulatory and License Application.

In addition, Science & Engineering Testing has the responsibility to monitor the implementation of these changes and to revise the *Performance Confirmation Plan* accordingly.

6.1.10 Baseline Change Control

Baseline change control will assure that the above changes are baselined and controlled in accordance with QA procedures to ensure that the same up-to-date data and information will be used by personnel for activities described under evaluations and corrective actions, including the implementation of the corrective actions. Baseline and change control will cover:

- Performance confirmation data
- Technical, process and TSPA, computer codes
- Monitoring and testing plans and specifications
- AMRs and PMRs, or other appropriate model documentation
- Test facilities and support plans and specifications
- Monitoring and testing reports
- Performance assessment reports
- MGR design drawings and specifications
- MGR as-built reporting

- *Performance Confirmation Plan.*

Responsibilities for baselining and control for each of the above items will be spelled out in future procedures.

6.2 REPORTING

6.2.1 General

In addition to the *Performance Confirmation Plan*, a series of reports will be generated as performance confirmation activities are conducted. Such reports will include test plans, testing/monitoring reports, database reports, comparison reports, assessment reports, and prediction reports. Preparation, review, and approval of these reports will be conducted in accordance with applicable procedures. Each report will include a list of cited references, a glossary of important terms, and a list of acronyms and abbreviations. Most documents listed may be revised periodically to reflect corrective actions resulting from the performance confirmation evaluations.

Reports, processed data and data evaluations will be released to the public on a periodic basis via the internet or in published format. As part of this process, technical reports on performance confirmation will be issued including the following:

- Monitoring and testing plans and specifications
- Test facilities and support requirements
- Monitoring and testing reports
- Technical database reports
- Data comparison reports
- Data and model comparison reports
- Performance assessment reports
- Updates to the *Performance Confirmation Plan.*

6.2.2 Monitoring and Testing Plans and Specifications

These documents will identify the planned activities in sufficient detail to execute the activities, including:

- Specifications for the instrumentation, equipment, materials, and supplies
- Identification of the facilities and support systems needed (including conceptual drawings)
- Planned locations and duration
- Frequency of measurements
- Technical testing procedures

- Data acquisition system(s) to be used
- Determination of importance
- QA requirements
- Names of responsible organizations, principal investigators, and key staff
- Testing and evaluation reports to be generated.

6.2.3 Test Facilities and Support Requirements Documents

These documents will identify the performance confirmation requirements for the facilities and support systems in sufficient detail for construction and operation, including specifications for the testing facilities, support systems, and planned locations. The performance confirmation related system description documents will be updated as required.

6.2.4 Monitoring and Testing Reports

These reports will document the design of each site monitoring and testing activity, the conduct of the activity, and the results of the activity, which will include as appropriate:

- Description of the activity
- Identification of the test facilities and support systems used
- Identification of the location, time and duration of the activity
- Instrumentation used
- Measured data
- Calculated data (from raw data conversions, interpolations, and extrapolations)
- Problems encountered and actions taken to resolve the problem(s).

6.2.5 Technical Database Reports

Periodic reports on the status of the project technical database and changes during the reporting period, since the last periodic report, will be prepared, and will include as appropriate:

- List of site monitoring and testing reports data that have been added
- List of parameter names that have been added and reasons for addition
- List of parameter names that have been removed and reasons for removal
- List of parameter names that had values added
- List of parameter names that had values deleted
- List of parameter names whose values were revised.

6.2.6 Data Comparison Reports

These reports will be prepared for each iteration of the data comparisons. They may include:

- Comparisons of the measured performance confirmation parameter values with the site characterization and LA baseline
- Statistical analyses to determine the statistical significance of any differences
- Technical/scientific significance of the differences
- Trends and trend analysis
- Recommendations for corrective actions (see Section 6.1.8 for list of potential actions).

Evaluations of postclosure performance and regulatory implications will be included in separate reports.

6.2.7 Data/Model Comparison Reports

These reports will be prepared for each iteration of the comparisons of performance confirmation data with pre-LA performance predictions for the performance confirmation period described earlier. They will include as appropriate:

- Comparisons of the measured performance confirmation parameter values with the pre-LA performance predictions
- Comparisons of the measured performance confirmation parameter values with post-LA performance predictions of a previous iteration
- Statistical analyses to determine the statistical significance of differences
- Technical/scientific significance of the differences
- Conclusions with respect to the validity of the conceptual models and accuracy of the mathematical models
- Identification of any trends with respect to previous evaluations
- Recommendations for corrective actions (see Section 6.1.8 for list of potential actions).

Evaluations of postclosure performance and regulatory implications will be included in separate reports.

6.2.8 Updated Model Reports

Prior to updating the TSPA to incorporate changes in measurement, monitoring, or testing data, any necessary changes would be incorporated in appropriate model documentation (including user manuals) to provide a documented basis for the update.

6.2.9 Performance Assessment Reports Updates

6.2.9.1 Type and Frequency of Reports

Three types of performance predictions will be reported:

1. Pre-LA predictions of the performance of the natural and engineered barrier systems during the performance confirmation period

2. Post-LA predictions of the performance of the natural and engineered barrier systems during the performance confirmation period

3. Post-LA predictions of the postclosure performance of the natural and engineered barrier systems.

A single report may be prepared for each performance assessment iteration, or separate topical reports may prepared for specific aspects of process modeling or TSPAs. The following sections list the content for each of these three types of predictions.

6.2.9.2 Pre-License Application Performance Predictions for the Performance Confirmation Period

These reports will include:

- Summary descriptions of the conceptual and mathematical models and computer codes used

- Descriptions and listings (or references) to the data to be used for the predictions, which will include site characterization data, pre-LA performance confirmation data, and the LA MGR design

- Predictions of parameter values for the locations and times of planned in situ and field measurements of natural and engineered barrier performance

- Predictions of expected results of laboratory testing and experiments.

6.2.9.3 Post-License Application Performance Predictions for the Performance Confirmation Period

These reports will include:

- Descriptions and listings (or references) to the data to be used for the predictions, which will include site characterization data, pre- and post-LA performance confirmation data, and as-built MGR conditions
- Predictions of parameter values for the locations and times of planned in situ and field measurements of natural and engineered barrier performance
- Predictions of expected results of laboratory testing and experiments
- Comparisons with the pre-LA performance predictions for the performance confirmation period
- Comparisons with previous iterations of post-LA performance for the performance confirmation period
- Statistical analyses to evaluate the statistical significance of differences
- Interpretations of the technical/scientific significance of differences
- Conclusions with respect to the validity of the conceptual models and the accuracy of the mathematical models
- Identification of trends with respect to previous evaluations
- Recommendations for corrective actions (see Section 6.1.8 for list of potential actions).

6.2.9.4 Post-License Application Predictions of Postclosure Performance

These reports will include:

- Descriptions and listings (or references) to the data to be used for the predictions, which will include site characterization data, pre- and post-LA performance confirmation data, and as-built MGR conditions
- Predictions of postclosure natural and engineered barrier system and overall MGR performance
- Comparisons with the LA performance predictions of postclosure performance
- Comparisons with previous iterations of post-LA performance predictions for the performance confirmation period
- Statistical analyses to evaluate the statistical significance of differences

- Interpretations of the technical/scientific significance of differences
- Identification of trends with respect to previous evaluations
- Recommendations for corrective actions (see Section 6.1.8 for list of potential actions).

6.2.10 Performance Confirmation Plan

The *Performance Confirmation Plan* will be revised, as necessary, to reflect recommended adjustments to the plan, if any, as indicated by the previously listed evaluations and reporting.

6.2.11 Other Documentation

As identified in various places of this plan, other activities will interface with and will be affected by the performance confirmation program. Documentation of these activities is outside the scope of this plan. This documentation will include:

- MGR design, construction, and operation, including waste emplacement and potential retrieval
- Conceptual models of natural and engineered barrier processes, their mathematical models and computer codes, and TSPA software, including software qualification
- Interactions with the NRC and stakeholder organizations
- Documentation in compliance with specific steps of appropriate procedures, including mathematical model validation and computer software verification
- Documentation in support of the LA amendment for repository closure and other regulatory compliance documentation.

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7. TEST DESCRIPTIONS

7.1 GENERAL

The *Performance Confirmation Plan* identifies the current and expected regulatory requirements for performance confirmation and the activities planned to satisfy these requirements. These activities are based on the higher-temperature operating mode repository concept, understanding of natural and engineered barrier processes, and conceptual and mathematical models and computer codes. Assumptions are necessary regarding the state of knowledge expected to exist at the time of the submittal of the LA. Changes in the planned activities can, therefore, be expected as the repository design, the PMRs, and the performance confirmation program are developed and as regulations change.

Tests identified in this section follow from the performance factors that are identified in Section 3 and are based on the conceptual testing framework described in Section 5. The performance confirmation factors and conceptual framework are preliminary and subject to change as TSPA sensitivity analyses are completed and the RSS (CRWMS M&O 2001) is updated. Consequently, the specific testing strategy discussed in this section is preliminary. A revision of this document prior to the LA will include necessary adjustments to the testing strategies contained herein.

7.2 IDENTIFIED TESTING

Appendix G contains a preliminary description of the testing and monitoring activities for the performance confirmation program, in the form of test description sheets. The test description sheets identify the test name and the test category under the overall test and evaluation plan, as well as to provide the purpose of the activity, a brief description of the scope, a list of parameters to be addressed, test interfaces and constraints, and a period of performance.

7.3 DETAILED TEST PLANNING

Detailed planning of performance confirmation activities and tests will be implemented based on this plan. Detailed planning requirements are established to ensure that sufficient information is included in the planning and the work is properly controlled. These requirements are based on the *Quality Assurance Requirements and Description*, Section 11.2.1 (DOE 2000). A portion of these requirements will be addressed in the description sheets, which follow in Appendix G. The other requirements must be addressed throughout detailed performance confirmation activity planning. The *Monitored Geologic Repository Test and Evaluation Plan* (Skorska 2001) will provide the methodology for implementing tests and evaluations on the project. This methodology will be followed for detailed activity planning.

Detailed performance confirmation test planning must include identification of test procedures to be developed to control and perform testing and monitoring. In this context, the "term" test is used to describe the array of performance confirmation activities. Applicable existing procedures will be modified, as appropriate, to conduct performance confirmation activities. The detailed test planning will use the performance confirmation baseline information to identify test requirements and acceptance limits (including required levels of precision and accuracy). The detailed test planning will identify test methods to be employed and instructions for performing the test or activity. The scope sheets will identify prerequisites that address what needs to be tested or monitored; the detailed plans will identify calibrated instrumentation; appropriate, adequate test equipment and instrumentation; trained personnel; the condition of test equipment; suitably controlled environmental conditions; and provisions for data acquisition. The detailed test planning will identify mandatory hold points. Scope sheets will identify reporting requirements. Detailed test planning will identify methods to record data and results. Provisions for ensuring that prerequisites for the given test/activity have been met will be identified in the detailed test planning. The selection and identification of the measuring and test equipment to be used to perform the test will be done during detailed planning to ensure that the equipment is of the proper type, range, accuracy, and tolerance to accomplish the intended function. Detailed test planning will identify the functional qualification level of personnel performing the activities.

8. CONCLUSIONS AND RECOMMENDATIONS

As described, the purpose of the *Performance Confirmation Plan* is to specify monitoring, testing , and analysis activities for evaluating the accuracy and adequacy of the information used to determine that performance objectives for postclosure will be met. This plan defines a number of specific performance confirmation activities and associated test concepts in support of the MGR that will be implemented to fulfill this purpose. In doing so, the plan defines an approach to identify key factors and processes, predict performance, establish tolerances and test criteria, collect data (through monitoring, testing, and experiments), analyze these data, and recommend appropriate action.

The process of defining which factors to address under performance confirmation incorporates input from several areas. In all cases, key performance confirmation factors are those factors which are: (1) important to safety, (2) measurable and predictable, and (3) relevant to the program (i.e., a factor that is affected by construction, emplacement, or is a time-dependent variable). For the present version of the plan, performance confirmation factors important to safety are identified using the principal factors from the RSS (CRWMS M&O 2001) (which is derived from TSPA analyses) together with other available performance assessment analyses. With this basis, key performance confirmation factors have been identified, and test concepts and test descriptions have been developed in the plan.

Other activities are also incorporated into the performance confirmation program outside of these key factors. Additional activities and tests have been incorporated when they are prescribed by requirements and regulations or are necessary to address data needs and model validation requirements relevant to postclosure safety. These other activities have been included with identified factors to construct the overall performance confirmation program.

Given a set of key factors, test concepts necessary to conduct performance confirmation activities are analyzed in the plan, relying largely on the work from the initial version of the *Performance Confirmation Plan*. Extrapolating from this basis, the present version of the plan describes the test and monitoring concepts needed to conduct the performance activities (as part of Section 5) and also defines a discrete set of performance confirmation activities (in Section 7 and Appendix G). This set of activities is considered to be sufficient to address postclosure safety requirements and meet the applicable requirements for the LA.

However, one limitation of the current version of the *Performance Confirmation Plan* is that the definition of the activities in the plan relies on a number of concepts and documents, all of which are expected to evolve. Specifically, performance confirmation activities are based on the higher-temperature operating mode conceptual design together with the present understanding of natural and engineered barrier processes. The understanding of these barriers is contained in conceptual and mathematical models and computer codes, which are in the process of being documented in the AMRs and PMRs. The current plan is also based on the regulatory requirements contained in the "Revised Interim Guidance Pending Issuance of New U.S. Nuclear Regulatory Commission (NRC) Regulations (Revision 01, July 22, 1999), for Yucca Mountain, Nevada" (Dyer 1999) which is a transition document in use until the regulations (i.e., 10 CFR 63) are finalized. Further, the requirements analysis for the performance confirmation program are based on the system requirements of the MGR, which are in the process of revision.

The implication of this limitation is that assumptions were necessary in the preparation of the *Performance Confirmation Plan* regarding the state of knowledge expected at the time of the submittal of the LA. Changes in the defined *Performance Confirmation Plan* and associated activities can therefore be anticipated as the MGR design is further developed and the applicable regulations and requirements are finalized. Consequently, revisions to this *Performance Confirmation Plan* will be required to reflect these changes.

As for recommendations, it is suggested that system description documents associated with performance confirmation and the design analyses required to implement the performance confirmation program should be updated and revised as a result of this plan revision. This updating will provide a consistent basis for subsequent reports and other analyses for the MGR. Additional development of the performance confirmation baseline is also recommended. Completion of the baseline will be useful in establishing and identifying the specific site characterization information to be used in performance confirmation. This will also be useful in performing performance predictions for the performance confirmation period and associated model analyses, reports, and design analyses.

It is also recommended that the plan be revised to: (1) re-examine testing required to address data and code-validation needs after the LA and (2) fully include the regulatory guidance of the final 10 CFR 63. In addition, the plan may require modification as the result of the future revision of RSS (or similar guidance document) and updated TSPA sensitivity analyses. This subsequent revision of the *Performance Confirmation Plan* would serve as supporting documentation for the LA.

Finally, it is recommended that the *Performance Confirmation Plan* be used as the guiding document for multi-year planning until such time detailed plans for the identified activities are developed. Additional planning of near-term performance confirmation activities is recommended, in particular for the transition period between the initial submittal of the LA and the submittal of the license for construction authorization.

9. REFERENCES

9.1 REFERENCE FORMAT

Section 9.2 contains general references cited in the report, while cited codes and standards are presented in Section 9.3. The sequence of numbers at the end of each reference is the tracking number for the document from the Office of Civilian Radioactive Waste Management. References preceded by "ACC:" are available through the online Record Information System (RISWeb). Items preceded by "TIC:" are maintained by the Office and listed on-line at the Technical Information Centers (TICWeb).

9.2 DOCUMENTS CITED

Birkholzer, J.T. and Tsang, Y.W. 1997. *Pretest Analysis of the Thermal-Hydrological Conditions of the ESF Drift Scale Test*. Milestone SP9322M4. Berkeley, California: Lawrence Berkeley National Laboratory. ACC: MOL.19971201.0810.

Bodvarsson, G.S.; Bandurraga, T.M.; and Wu, Y.S., eds. 1997. *The Site-Scale Unsaturated Zone Model of Yucca Mountain, Nevada, for the Viability Assessment*. LBNL-40376. Berkeley, California: Lawrence Berkeley National Laboratory. ACC: MOL.19971014.0232.

Buscheck, T.A.; Gansemer, J.; Delorenzo, T.; Nitao, J.J.; Shaffer, R.J.; Cordery, M.J.; and Lee, K.H. 1997a. *Thermal-Hydrological Models of the Distribution of Temperature, Relative Humidity, and Gas-Phase Air-Mass Fraction in Repository Drifts.* Deliverables SPLD1M4, SPLD2M4. Livermore, California: Lawrence Livermore National Laboratory. ACC: MOL.19980109.0248.

Buscheck, T.A.; Shaffer, R.J.; Lee, K.H.; and Nitao, J.J. 1997b. *Analysis of Thermal-Hydrological Behavior During the Heating Phase of the Single-Heater Test at Yucca Mountain.* Supplemental Submission to Deliverable SP9266M4. Livermore, California: Lawrence Livermore National Laboratory. ACC: MOL.19980109.0241.

Buscheck, T.A.; Shaffer, R.J.; and Nitao, J.J. 1997c. *Pretest Thermal-Hydrological Analysis of the Drift-Scale Thermal Test at Yucca Mountain.* Livermore, California: Lawrence Livermore National Laboratory. ACC: MOL.19980507.0359.

BSC (Bechtel SAIC Company, LLC) 2001a. *Site Recommendation Subsurface Layout.* ANL-SFS-MG-000001 REV 00 ICN 02. Las Vegas, Nevada: Bechtel SAIC Company. ACC: MOL.20010411.0131.

BSC 2001b. *Lower-Temperature Subsurface Layout and Ventilation Concepts.* ANL-WER-MD-000002 REV 00. Las Vegas, Nevada: Bechtel SAIC Company. ACC: MOL.20010718.0225.

BSC 2001c. *FY01 Supplemental Science and Performance Analyses, Volume 1: Scientific Bases and Analyses.* TDR-MGR-MD-000007 REV 00 ICN 01. Las Vegas, Nevada: Bechtel SAIC Company. ACC: MOL.20010801.0404; MOL.20010712.0062; MOL.20010815.0001.

BSC 2001d. *FY01 Supplemental Science and Performance Analyses, Volume 2: Performance Analyses.* TDR-MGR-PA-000001 REV 00. Las Vegas, Nevada: Bechtel SAIC Company. ACC: MOL.20010724.0110.

BSC 2001e. *Technical Work Plan For: Performance Confirmation Program.* TWP-PCS-SE-000001 REV 01. Las Vegas, Nevada: Bechtel SAIC Company. ACC: MOL.20011212.0189.

CRWMS M&O (Civilian Radioactive Waste Management System Management and Operating Contractor) 1995. *Total System Performance Assessment - 1995: An Evaluation of the Potential Yucca Mountain Repository.* B00000000-01717-2200-00136 REV 01. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.19960724.0188.

CRWMS M&O 1996a. *Performance Confirmation Concepts Study Report.* B00000000-01717-5705-00035 REV 01. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.19971105.0425.

CRWMS M&O 1996b. *Probabilistic Volcanic Hazard Analysis for Yucca Mountain, Nevada.* BA0000000-01717-2200-00082 REV 0. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.19971201.0221.

CRWMS M&O 1996c. *Static Structural Analyses of Waste Packages in Degraded States.* BBAA00000-01717-0200-00014 REV 00. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.19970402.0069.

CRWMS M&O 1996d. *Rock Size Required to Breach Barriers at Different Corrosion Levels.* BBAA00000-01717-0200-00012 REV 00. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.19961106.0042.

CRWMS M&O 1996e. *Rock Size Required to Cause a Through Crack in Containment Barriers.* BBAA00000-01717-0200-00015 REV 00. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.19961217.0318.

CRWMS M&O 1996f. *Mined Geologic Disposal System Advanced Conceptual Design Report.* B00000000-01717-5705-00027 REV 00. Four volumes. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.19960826.0094; MOL.19960826.0095; MOL.19960826.0096; MOL.19960826.0097.

CRWMS M&O 1997a. *Performance Confirmation Plan.* B00000000-00841-4600-00002 REV 00. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.19980204.1022.

CRWMS M&O 1997b. *Subsurface Repository Performance Confirmation Facilities.* BCA000000-01717-0200-00011 REV 00. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.19970723.0142.

CRWMS M&O 1997c. *Repository Seals Requirements Study.* BC0000000-01717-5705-00018 REV 00/DCN 1. Las Vegas, Nevada: CRWMS M&O. ACC: MOL19980224.0346.

CRWMS M&O 1997d. *ISM2.0: A 3D Geologic Framework and Integrated Site Model of Yucca Mountain*. B00000000-01717-5700-00004 REV 00. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.19970625.0119.

CRWMS M&O 1997e. *Performance Confirmation Data Acquisition System*. BCAI00000-01717-0200-00002 REV 00. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.19990720.0197.

CRWMS M&O 1997f. *MGDS Subsurface Radiation Shielding Analysis*. BCAE00000-01717-0200-00001 REV 00. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.19971204.0497.

CRWMS M&O 1997g. *Repository Rail Electrification Analysis*. BCAC00000-01717-0200-00002 REV 00. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.19980122.0462.

CRWMS M&O 1997h. [Not used]

CRWMS M&O 1997i. *Preliminary Waste Package Transport and Emplacement Equipment Design*. BCA000000-01717-0200-00012 REV 00. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.19980511.0131.

CRWMS M&O 1997j. *Updated In Situ Thermal Testing Program Strategy*. B00000000-01717-5705-00065 REV 01. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.19990526.0296.

CRWMS M&O 1997k. *Subsurface Waste Package Handling - Remote Control and Data Communication Analysis*. BCA000000-01717-0200-00004 REV 00. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.19970714.0655.

CRWMS M&O 1997l. *Overall Development and Emplacement Ventilation Systems*. BCA000000-01717-0200-00015 REV 00. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.19980123.0661.

CRWMS M&O 1997m. *Emplacement Drift Air Control System*. BCAD00000-01717-0200-00005 REV 00. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.19980102.0034.

CRWMS M&O 1997n. *The Site-Scale Unsaturated Zone Transport Model of Yucca Mountain*. Milestone SP25BM3, Rev. 1. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.19980224.0314.

CRWMS M&O 1998a. [Not used]

CRWMS M&O 1998b. *Software Qualification Report (SQR) Repository Integration Program RIP Version 5.19.01*. CSCI: 30055 V.5.19.01. DI: 30047-2003, Rev. 02. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.19980916.0337.

CRWMS M&O 1998c. *Controlled Design Assumptions Document*. B00000000-01717-4600-00032 REV 05. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.19980804.0481.

CRWMS M&O 1998d. *Total System Performance Assessment-Viability Assessment (TSPA-VA) Analyses Technical Basis Document*. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.19981008.0001; MOL.19981008.0002; MOL.19981008.0003; MOL.19981008.0004; MOL.19981008.0005; MOL.19981008.0006; MOL.19981008.0007; MOL.19981008.0008; MOL.19981008.0009; MOL.19981008.0010; MOL.19981008.0011.

CRWMS M&O 1998e. *Software Routine Report for WAPDEG (Version 3.09)*. CSCI: 30048 v 3.09. DI: 30048-2999, Rev 02. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.19981012.0224.

CRWMS M&O 1998f. *Repository Seals Requirements and Concepts*. SE9240M3. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.19981123.0124.

CRWMS M&O 1998g. *Performance Confirmation Subsurface Facilities Design Analysis*. BCAI00000-01717-0200-00004 REV 00. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.19981116.0450.

CRWMS M&O 1998h. *Retrievability Strategy Report*. B00000000-01717-5705-00061 REV 01. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.19980723.0039.

CRWMS M&O 1998i. *Software Qualification Report (SQR) GENII-S 1.485 Environmental Radiation Dosimetry Software System Version 1.485*. CSCI: 30034 V1.4.8.5. DI: 30034-2003, Rev. 0. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.19980715.0029.

CRWMS M&O 1999a. *License Application Design Selection Report*. B00000000-01717-4600-00123 REV 01 ICN 01. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.19990908.0319.

CRWMS M&O 1999b. *Monitored Geologic Repository Concept of Operations*. B00000000-01717-4200-00004 REV 03. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.19990916.0104.

CRWMS M&O 1999c. *Defense in Depth for Repository Postclosure Safety Case*. BC0000000-01717-5705-00024 REV 01. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.19990407.0083.

CRWMS M&O 1999d. *Input for Performance Confirmation Plan - Waste Form & Waste Package Process Model Reports*. Input Transmittal RSO-WP-99270.Ta. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.19990927.0358.

CRWMS M&O 1999e. *Enhanced Design Alternative II Report*. B00000000-01717-5705-00131 REV 00. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.19990712.0194.

CRWMS M&O 1999f. *Example of Postclosure Defense in Depth Evaluation -- The Viability Assessment Reference System*. BC0000000-01717-5705-00025 REV 01. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.19990407.0084.

CRWMS M&O 1999g. *Strategy for Integrated Engineered Barrier System Testing Program.* TDR-EBS-ND-000001 REV 00. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.20000103.0342.

CRWMS M&O 1999h. *License Application Design Selection Feature Report: Waste Package Corrosion Resistant Materials (Metal and Ceramic) (Design Feature #14).* B00000000-01717-2200-00216 REV 01. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.19990319.0409.

CRWMS M&O 1999i. *Preliminary Analysis of Remote Monitoring & Robotic Concepts for Performance Confirmation.* BCAI00000-01717-0200-00001 REV 00. Las Vegas, Nevada: CRWMS M&O. TIC: 240458; 240461; 240462; 204464; 240466. ACC: MOL.19990802.0325.

CRWMS M&O 2000a. *Design Analysis for the Ex-Container Components.* ANL-XCS-ME-000001 REV 00. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.20000525.0374.

CRWMS M&O 2000b. *Input for Performance Confirmation Plan - Natural Barrier System Process Model Reports.* Input Transmittal RSO-NEP-99268.T. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.20000125.0165.

CRWMS M&O 2000c. *Input for Performance Confirmation Plan - Figures of Layout and Repository-Level Geometry.* Input Transmittal RSO-SSR-99316.T. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.20000216.0306.

CRWMS M&O 2001. *Repository Safety Strategy: Plan to Prepare the Safety Case to Support Yucca Mountain Site Recommendation and Licensing Considerations.* TDR-WIS-RL-000001 REV 04 ICN 01. Two volumes. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.20010329.0825.

Curry, P.M. 2001. *Monitored Geologic Repository Project Description Document.* TDR-MGR-SE-000004 REV 02 ICN 02. Las Vegas, Nevada: Bechtel SAIC Company. ACC: MOL.20010628.0224.

Czarnecki, J.B.; Faunt, C.C.; Gable, C.W.; and Zyvoloski, G.A. 1997. *Hydrogeology and Preliminary Calibration of a Preliminary Three-Dimensional Finite-Element Ground-Water Flow Model of the Site Saturated Zone, Yucca Mountain, Nevada.* Administrative Report. Denver, Colorado: U.S. Geological Survey. ACC: MOL.19980204.0519.

DOE (U.S. Department of Energy) 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.

DOE 1995. *OCRWM Test and Evaluation Master Plan (TEMP), Revision 00.* DOE/RW-0478. Washington, D.C.: U.S. Department of Energy, Office of Civilian Radioactive Waste Management. ACC: MOV.19970203.0017.

DOE 1998a. *Preliminary Design Concept for the Repository and Waste Package.* Volume 2 of *Viability Assessment of a Repository at Yucca Mountain.* DOE/RW-0508. Washington, D.C.: U.S. Department of Energy, Office of Civilian Radioactive Waste Management. ACC: MOL.19981007.0029.

DOE 1998b. *Introduction and Site Characteristics.* Volume 1 of *Viability Assessment of a Repository at Yucca Mountain.* DOE/RW-0508. Washington, D.C.: U.S. Department of Energy, Office of Civilian Radioactive Waste Management. ACC: MOL.19981007.0028.

DOE 1998c. *Costs to Construct and Operate the Repository.* Volume 5 of *Viability Assessment of a Repository at Yucca Mountain.* DOE/RW-0508. Washington, D.C.: U.S. Department of Energy, Office of Civilian Radioactive Waste Management. ACC: MOL.19981007.0032.

DOE 1998d. *Total System Performance Assessment.* Volume 3 of *Viability Assessment of a Repository at Yucca Mountain.* DOE/RW-0508. Washington, D.C.: U.S. Department of Energy, Office of Civilian Radioactive Waste Management. ACC: MOL.19981007.0030.

DOE 2000. *Quality Assurance Requirements and Description.* DOE/RW-0333P, Rev. 10. Washington, D.C.: U.S. Department of Energy, Office of Civilian Radioactive Waste Management. ACC: MOL.20000427.0422.

DOE 2001. *Civilian Radioactive Waste Management System Requirements Document.* DOE/RW-0406, Rev. 5, DCN 04. Washington, D.C.: U.S. Department of Energy, Office of Civilian Radioactive Waste Management. ACC: MOL.20010628.0243.

Dyer, J.R. 1999. "Revised Interim Guidance Pending Issuance of New U.S. Nuclear Regulatory Commission (NRC) Regulations (Revision 01, July 22, 1999), for Yucca Mountain, Nevada." Letter from Dr. J.R. Dyer (DOE/Yucca Mountain Site Characterization Office [YMSCO]) to Dr. D.R. Wilkins (CRWMS M&O), September 3, 1999, OL&RC:SB-1714, with enclosure, "Interim Guidance Pending Issuance of New NRC Regulations for Yucca Mountain (Revision 01)." ACC: MOL.19990910.0079.

Dyer, Dr. J.R. 2000. "Direction to Prepare Change Request to Delete Backfill from Design Basis for Site Recommendation." Letter from Dr. J.R. Dyer (DOE/YMSCO) to Dr. D.R. Wilkins (CRWMS M&O), January 24, 2000, OPE:PGH-0559. ACC: MOL.20000128.0238.

Hirsch, R.M.; Helsel, D.R.; Cohn, T.A.; and Gilroy, E.J. 1993. "Statistical Analysis of Hydrologic Data." Chapter 17 *of Handbook of Hydrology*. Maidment, D.R., ed. New York, New York: McGraw-Hill. TIC: 236568.

Lindner, E. 2001a. "Historical Commitment ID: 00143." E-mail from E. Lindner to M. Skorska, August 2, 2001. ACC: MOL.20010822.0230.

Lindner, E. 2001b. "Historical Commitment ID: 00362." E-mail from E. Lindner to M. Skorska, August 1, 2001. ACC: MOL.20010822.0183.

Lindner, E. 2001c. "Historical Commitment ID: 01567." E-mail from E. Lindner to M. Skorska, August 1, 2001. ACC: MOL.20010822.0466.

Lindner, E. 2001d. "Historical Commitment ID: 01603." E-mail from E. Lindner to M. Skorska, August 1, 2001. ACC: MOL.20010822.0470.

Nitao, J.J. 1997. *Preliminary Bounds for the Drift-Scale Distribution of Percolation and Seepage at the Repository Level Under Pre-Emplacement Conditions.* Deliverable No. SPLB1M4. Livermore, California: Lawrence Livermore National Laboratory. ACC: MOL.19980115.0873.

Nitao, J.J. 1998. *Reference Manual for the NUFT Flow and Transport Code, Version 2.0.* UCRL-MA-130651. Livermore, California: Lawrence Livermore National Laboratory. ACC: MOL.19980810.0391.

Sellers, M.D. 1999. "QAP-2-0 Evaluations for Activities Within Work Package 16012250M1, 16012121M1 and 16012154M1." Interoffice correspondence from M.D. Sellers (CRWMS M&O) to R.A. Morgan (CRWMS M&O), October 14, 1999, LV.SES.BHT. 10/99-072, with enclosures. ACC: MOL.19991105.0085.

Skorska. M.B. 2001. *Monitored Geologic Repository Test & Evaluation Plan.* TDR-MGR-SE-000010 REV 03 ICN 01. Las Vegas, Nevada: Bechtel SAIC Company. ACC: MOL.20020102.0203.

Sonnenthal, E.; Spycher, N.; Apps, J.; and Simmons, A. 1998. *Thermo-Hydro-Chemical Predictive Analysis for the Drift-Scale Heater Test.* Milestone SPY289M4. Version 1.1. Berkeley, California: Lawrence Berkeley National Laboratory. ACC: MOL.19981130.0132.

Stroupe, E.P. 2000. "Approach to Implementing the Site Recommendation Design Baseline." Interoffice correspondence from E.P. Stroupe (CRWMS M&O) to Dr. D.R. Wilkins, January 26, 2000, LV.RSO.EPS.1/00-004, with attachment. ACC: MOL.20000214.0480.

Tsang, Y.W. and Cook, P. 1997. *Ambient Characterization of the ESF Drift Scale Test Area by Field Air Permeability Measurements.* Milestone SP9512M4. Berkeley, California: Lawrence Berkeley National Laboratory. ACC: MOL.19971201.0829.

Wilkins, D.R. and Heath, C.A. 1999. "Direction to Transition to Enhanced Design Alternative II." Letter from Dr. D.R. Wilkins (CRWMS M&O) and Dr. C.A. Heath (CRWMS M&O) to Distribution, June 15, 1999, LV.NS.JLY.06/99-026, with enclosures, "Strategy for Baselining EDA II Requirements" and "Guidelines for Implementation of EDA II." ACC: MOL.19990622.0126; MOL.19990622.0127; MOL.19990622.0128.

YMP (Yucca Mountain Site Characterization Project) 2001a. *Yucca Mountain Site Characterization Project Requirements Document (YMP-RD).* YMP/CM-0025, Rev. 4, DCN 02. Las Vegas, Nevada: Yucca Mountain Site Characterization Office. ACC: MOL.20010322.0491; MOL.20011107.0002.

YMP 2001b. *Q-List.* YMP/90-55Q, Rev. 7. Las Vegas, Nevada: Yucca Mountain Site Characterization Office. ACC: MOL.20010409.0366.

Zyvoloski, G.A.; Robinson, B.A.; Birdsell, K.H.; Gable, C.W.; Czarnecki, J.; Bower, K.M.; and Faunt, C. 1997. *Saturated Zone Radionuclide Transport Model.* Milestone SP25CM3A. Los Alamos, New Mexico: Los Alamos National Laboratory. ACC: MOL.19980127.0089.

9.3 CODES, STANDARDS, REGULATIONS, AND PROCEDURES

10 CFR (Code of Federal Regulations) 20. Energy: Standards for Protection Against Radiation. Readily available.

10 CFR 60. Energy: Disposal of High-Level Radioactive Wastes in Geologic Repositories. Readily available.

29 CFR 1910. Labor: Occupational Safety and Health Standards. Readily available.

29 CFR 1926. Labor: Safety and Health Regulations for Construction. Readily available.

40 CFR 191. Protection of Environment: Environmental Radiation Protection Standards for Management and Disposal of Spent Nuclear Fuel, High-Level and Transuranic Radioactive Wastes. Readily available.

40 CFR 197. Protection of Environment: Public Health and Environmental Radiation Protection Standards for Yucca Mountain, Nevada. Readily available.

64 FR (Federal Register) 8640. Disposal of High-Level Radioactive Wastes in a Proposed Geologic Repository at Yucca Mountain, Nevada Proposed rule 10 CFR 63. Readily available.

64 FR 46976. Environmental Radiation Protection Standards for Yucca Mountain, Nevada; Proposed rule 40 CFR 197. Readily available.

66 FR 32074. 40 CFR 197, Public Health and Environmental Radiation Protection Standards for Yucca Mountain, NV; Final rule. Readily available.

66 FR 55732. Disposal of High-Level Radioactive Wastes in a Proposed Geologic Repository at Yucca Mountain, Nevada; Final rule 10 CFR 63. Readily available.

AP-3.11Q, Rev. 3. *Technical Reports.* Washington, D.C.: U.S. Department of Energy, Office of Civilian Radioactive Waste Management. ACC: MOL.20020102.0338.

ASTM D 4879-89 (Reapproved 1996). 1989. *Standard Guide for Geotechnical Mapping of Large Underground Openings in Rock*. West Conshohocken, Pennsylvania: American Society for Testing and Materials. TIC: 246997.

ASTM D 5878-95. 1996. *Standard Guide for Using Rock Mass Classification Systems for Engineering Purposes.* West Conshohocken, Pennsylvania: American Society for Testing and Materials. TIC: 246996.

Energy Policy Act of 1992. Public Law No. 102-486. 106 Stat. 2776. Readily available.

NLP-2-0, Rev. 5, ICN 4. *Determination of Importance Evaluations.* Las Vegas, Nevada: Bechtel SAIC Company. ACC: MOL.20010801.0317.

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