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Performance Confirmation Concepts Study Report

Civilian Radioactive Waste Management System

Management & Operating Contractor

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Prepared for:
U.S. Department of Energy
Office of Civilian Radioactive Waste
Management
1000 Independence Avenue, S.W.
Washington, D.C. 20565

– Part 1

102.8

WBS: 1.2.1.5
SCPB: 8.3.5.16
QA: L

**Civilian Radioactive Waste Management System
Management and Operating Contractor**

Performance Confirmation Concepts Study Report

B00000000-01717-5705-00035 REV 01

November 22, 1996

Prepared for:

U.S. Department of Energy
Yucca Mountain Site Characterization Project
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102.8

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Under Contract Number
DE-AC01-91RW00134

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Civilian Radioactive Waste Management System
Management and Operating Contractor

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Document Identifier Number

B00000000-01717-5705-00035 REV 01

November 22, 1996

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ACKNOWLEDGMENTS

The following individuals are acknowledged for the support and participation in the integrated product team, the performance confirmation concepts study team, that was organized to conduct this study:

James A. Blink, MGDS Project Engineering;
Albin Brandstetter, Performance Assessment;
Mark Fortsch, Repository Design Surface;
Phillip D. Gehner, Systems Analysis and Modeling;
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Ovadia Lev, Requirements;
Douglas McAffee, Repository Design Subsurface;
J. Kevin McCoy, Waste Package Development;
R. Daniel McCright, Waste Package Materials;
Daniel G. McKenzie, Repository Design Subsurface;
Prasad Nair, formerly with System Engineering;
Mark T. Peters, Scientific Program Operations;
Mark D. Sellers, MGDS Project Engineering;
David Stahl, Waste Package Materials.

These team members participated in many meetings which supported the study. Those individuals that provided input to the report are in bold type above and are considered as co-authors of the report. The support of all these individuals and organizations is appreciated by the lead document preparer and is gratefully acknowledged.

Additional support for the study was provided by the following individuals in the contributions made by the authors of certain areas of the report: Darren Jolley, Derick McWilliams, Thomas Scotese.

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EXECUTIVE SUMMARY

This report documents the work performed to conduct the Fiscal Year 1996 Performance Confirmation Concepts Study. The report also documents the study conclusions and recommendations. The objective of the study was to develop technically based recommendations, regarding the extent and content of the Performance Confirmation Program as required by Title 10 Code of Federal Regulations (CFR) Part 60, Subpart F. The scope of the FY96 study was to focus on the Performance Confirmation requirements and concepts with potential impact on repository/waste package design and/or operation.

Performance Confirmation is defined in 10 CFR Part 60.2 as "the program of tests, experiments, and analyses which is conducted to evaluate the accuracy and adequacy of the information used to determine with reasonable assurance that the performance objectives for the period after permanent closure will be met." Subpart F of 10 CFR Part 60 provides general requirements for a Performance Confirmation program, as well as more specific requirements related to confirmation of geotechnical and design parameters, design testing, and monitoring and testing of waste packages. This study began with these requirements as regulatory constraints and expanded them to a lower level of detail so that they could be implemented in the repository design. If a regulatory constraint became overly restrictive in terms of design solutions then that constraint was noted for potential discussion with the NRC.

The first step in developing requirements and concepts for the Performance Confirmation program was to identify candidate parameters related to Performance Confirmation that may need to be tested or analyzed to confirm that the post closure performance objectives will be met. These parameters were identified by considering key post-closure performance objectives (e.g., limiting 10,000 year peak dose, achieving substantially complete containment, etc.) and identifying the models used to evaluate these post closure objectives together with the process-level models used to support these evaluations. Once the process models and model abstractions were identified, the parameters used in these models were identified, resulting in a list of approximately 480 different parameters. A complete list of these parameters is provided in Appendix B. Screening criteria (e.g., time dependent parameter, important to waste isolation calculations, affected by construction, etc.) were then developed to identify a subset of these parameters as performance confirmation parameters. A final screening of the parameters was conducted to identify key parameters whose observation, monitoring, or testing could have a potentially significant influence on the design of the repository or engineered barrier system. This screening resulted in a smaller list of about 90 parameters. These parameters are listed in full in Appendix D, but include items such as saturated hydraulic conductivity, rock temperature, fracture and fault zone characteristics, groundwater chemical characteristics, etc.

The next step in the process was to develop concepts for collecting performance confirmation information for each of the key parameters. These concepts were then organized into three major areas. These areas were monitoring and testing concepts (including site, repository, and waste package concepts), test facilities and support concepts (including subsurface and surface concepts), and evaluation and reporting concepts. Options within each of the concepts were then developed so that a nominal case and an enhanced case could be developed for each of the concepts. The nominal option consists of a set of performance confirmation tests and functions that, in the study team's judgement, would provide adequate confidence in the ability of the performance confirmation process to meet regulatory requirements and to support accurate assessment of subsurface conditions, changes in those conditions, and proper functioning of the natural and engineered barriers. The enhanced option consists of a set of performance confirmation tests and functions that potentially would provide a higher level of confidence than would the nominal case. The level of confidence required will be established through additional quantitative, statistical bases in conjunction with regulatory interaction and policy direction.

The final steps in the process were to develop evaluation criteria and then evaluate the options against those criteria. The quantitative evaluation criteria used to develop a recommendation between the enhanced and nominal options was the absolute cost of each option and the delta cost between the options. The potential impact of the testing concepts on waste isolation was also considered in evaluating and recommending the test them.

The costs for the suite of enhanced options was estimated to be approximately $2.2 billion, while the cost of the nominal options was $0.7 billion. This is compared to the $0.6 billion estimate for the Advanced Conceptual Design reference case. Additionally, no difference between the options, in terms of impact on waste isolation, was identified presuming that effective borehole and excavation seals can be developed and installed. It was also determined that adequate controls will be possible for either of the options to prevent significant long-term impacts on waste isolation.

Given the above evaluation, it is the recommendation of this study to pursue and establish the specific requirements for the nominal case. The following is a partial list (paraphrased in some cases) of the requirements derived for the nominal option. The full list of recommended design requirements can be found in Section 8.

Performance Confirmation Monitoring and Testing Requirements

> At least five surface-based boreholes shall be provided for monitoring unsaturated zone hydrology and shall avoid underground excavations.
>
> Monitoring of at least two percent of the thermal rock mass behavior shall be performed with a portion of the rock mass monitored near the first emplacement drifts to contain waste.

Subsurface Test Facilities and Support Requirements

> The Repository Subsurface Facilities shall provide underground openings (drifts, alcoves, boreholes, and ancillary excavations), access, data acquisition, and test support to implement performance confirmation monitoring and test recommendations including interface and coordination with Site Investigation Testing, Repository Testing, Waste Package Testing, and Surface Support.
>
> > Any ground support system (i.e., shotcrete or concrete) that covers the emplacement drift rock wall surface shall not be installed until after any necessary rock mapping is complete.

Placement and recovery of material coupons or specimens in the emplacement drift or other underground locations shall be performed at least once every ten years.

Recovery of selected waste packages shall be performed on a non-routine basis.

The design, excavation, and ground support of emplacement drifts shall permit installation of and access to test/monitoring instrumentation, and observation drift instrumentation, and provide access for remotely operated vehicles or mobile inspection platforms to obtain measurements.

Excavation of at least one permanent observation drift above the repository horizon shall be developed in support of thermal monitoring.

The air temperature, relative humidity, and gaseous radioactive emissions of all emplacement drifts shall be monitored through the drift ventilation.

The provision and use of remotely operated vehicles or movable inspection platform for monitoring emplacement drift environments and effects shall be considered to permit remote inspections of emplacement drifts.

Surface Facility Requirements

The Repository Surface Facilities shall have the capability to support Performance Confirmation surface operations, equipment, and tests including, but not limited to:

The capability to receive, handle, store, examine, test, and return to the underground waste packages, material coupons, and other specimens recovered from underground emplacement. This capability is to be exercised on a non-routine basis, for malfunctioning radioactive waste packages or as required.

The facilities and equipment to support Performance Confirmation operations such as test monitoring and control, data processing, record management and communication, limited laboratory tests, analysis and evaluations.

It is important to note that the parameters and concepts leading to the above requirements are based on the current understanding of natural and engineered barrier processes, the mathematical models that have been formulated for these processes, the computer codes that have been developed to simulate these processes and the parameters that are required for these computer codes. Uncertainties still exist with respect to many of these processes (e.g., rock matrix and fracture flow interactions, waste package corrosion, etc.). As new understanding is gained during site characterization, construction, and operations, the process models and simulations of the processes may change. These changes could necessitate changes in the list of performance confirmation parameters which could, in turn, necessitate changes in the performance confirmation requirements.

In addition to identifying Performance Confirmation requirements, the study team also developed a draft Performance Confirmation Plan, located in Appendix A. The purpose of the plan is to provide an overview of the performance confirmation approach, performance confirmation objectives, responsibilities, a concept of operations, and schedules. The draft version of the plan contains an annotated outline of its proposed contents. The final version of the plan will contain a definition of the test and evaluation program for confirming the confinement and waste isolation performance of the MGDS. The test and evaluations covered will include process modeling, performance predictions, site monitoring and testing, waste package monitoring and testing, repository monitoring and testing, test data analysis evaluation, and performance. The plan will also contain test and analysis requirements for each performance confirmation test and analysis, a brief description of test/analysis objectives, and responsibilities and requirements for facilities, equipment data acquisition, evaluation, and reporting.

Finally, two top level schedules, included in the draft Performance Confirmation Plan, were developed in order to show the recommended timing for phasing site characterization activities into the performance confirmation activities. The first schedule, Figure ES-1, separates the complete set of testing activities into three categories. The first category consists of those tests conducted as part of the site characterization program in order to support the development of a waste isolation reasonable assurance argument and the development of the performance confirmation baseline. This category is shown to be ongoing and will phase out as the development of the performance confirmation program becomes complete. The second category consists of other testing, including site characterization testing in support of a site recommendation, testing to show conformance of the design to the requirements, preclosure safety testing, etc. This category of tests is also ongoing, and certain aspects of this testing activity are expected to continue through the waste emplacement time period. The third category consists of testing conducted in support of the performance confirmation program. This activity is shown to begin at the time of Viability Assessment, prior to the end of site characterization, and phases into a full program at about the time of License Application. The second schedule, Figure ES-2, provides a top level view of the data flow between the waste isolation reasonable assurance testing, the performance confirmation testing activities, TSPA, and the activities required to plan and develop the performance confirmation program.

Transition to Performance Confirmation Program Testing

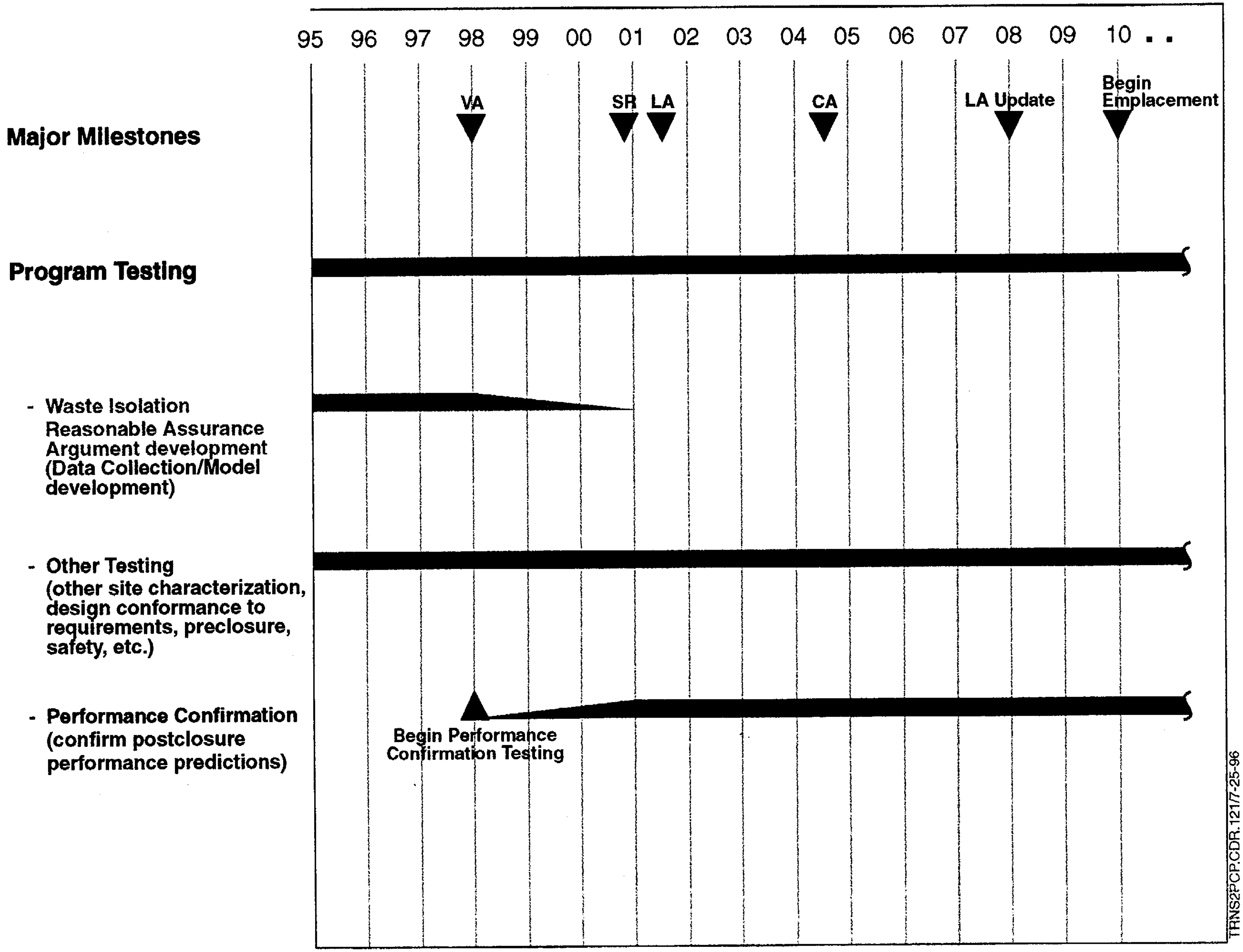

Figure ES-1. Transition To Performance Confirmation Program Testing

Development and Conduct Approach Performance Confirmation Program

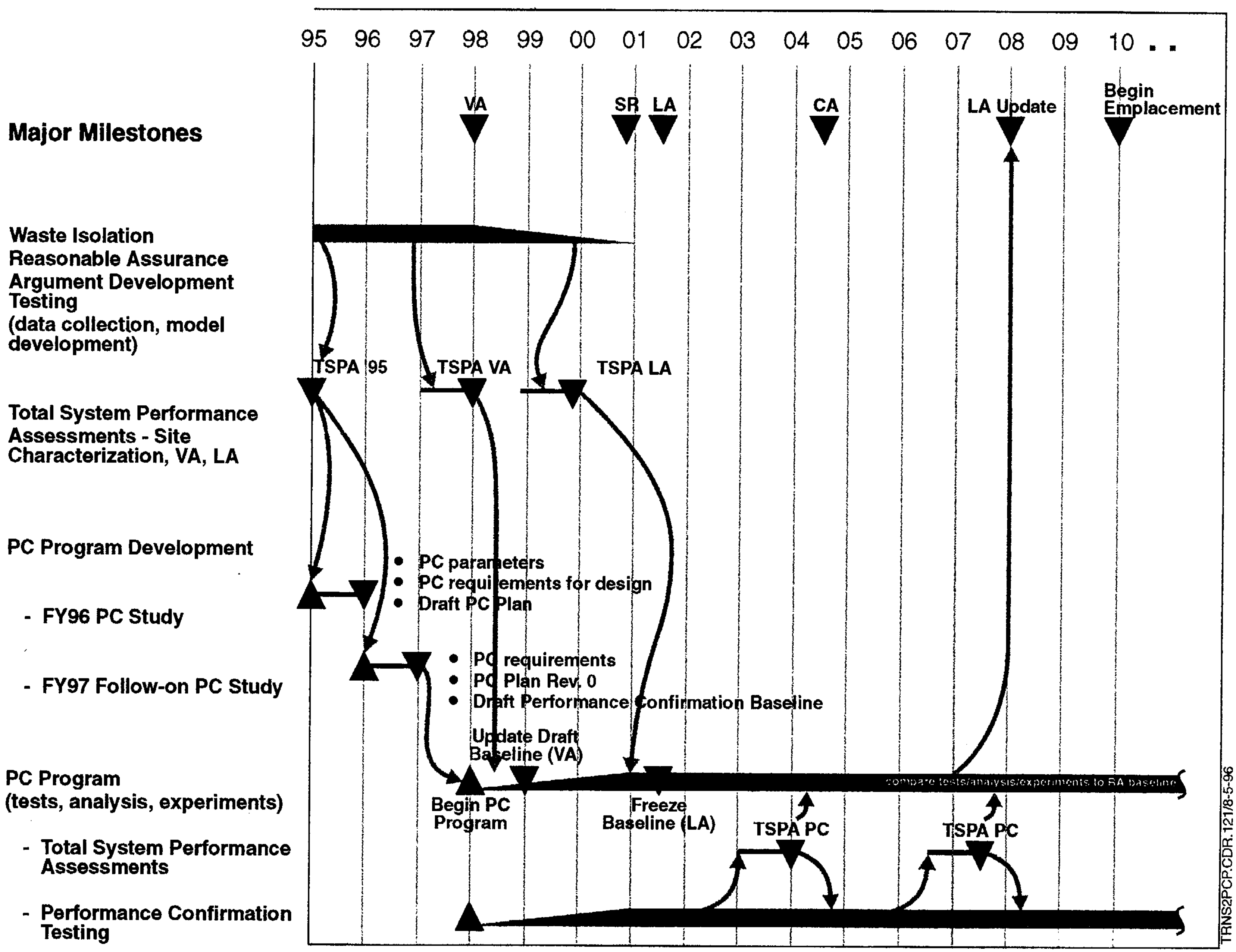

Figure ES-2. Development and Conduct Approach - Performance Confirmation Program

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FIGURES

TABLES

ACRONYMS

ACD	Advanced Conceptual Design
AE	Accessible Environment
CDA	Controlled Design Assumptions
CFR	Code of Federal Regulations
CI	Configuration Item
CRD	Civilian Radioactive Waste Management System Requirements Document
CRWMS	Civilian Radioactive Waste Management System
DCN	Document Change Notice
DI	Document Identifier
DIE	Determination of Importance Evaluation
DOC	dissolved organic carbon
DOE	U.S. Department of Energy
DRD	Design Requirements Document
EBDRD	Engineered Barrier Design Requirements Document
EBS	Engineered Barrier System
EPA	U.S. Environmental Protection Agency
ESF	Exploratory Studies Facility
FAD	Functional Analysis Document
FY	Fiscal Year
GROA	Geologic Repository Operations Area
HLW	High Level Waste
ITS	important to safety
MGDS	Mined Geologic Disposal System
M&O	Management and Operating Contractor
MPC	Multi-purpose Canister
MTU	Metric Tons of Uranium
NAS	National Academy of Sciences
NRC	U.S. Nuclear Regulatory Commission
NWPA	Nuclear Waste Policy Act of 1982
PC	Performance Confirmation
OCRWM	Office of Civilian Radioactive Waste Management
QA	Quality Assurance
QAP	Quality Assurance Procedure
RDRD	Repository Design Requirements Document
RD	Requirements Document
SBTF	Surface Based Test Facilities
SCP	Site Characterization Plan
SCPB	Site Characterization Plan Baseline
SD&TRD	Site Design and Test Requirements Document
SSC	Structures, Systems and Components
T&E	Test and Evaluation
TBD	To Be Determined
TBV	To Be Verified
TDPP	Technical Document Preparation Plan

ACRONYMS (continued)

TEMP	Test and Evaluation Master Plan
TFM	tracers, fluids, and materials
TSPA	Total System Performance Assessment
WBS	Work Breakdown Structure
WP	Waste Package
YMP	Yucca Mountain Site Characterization Project
YMSCO	Yucca Mountain Site Characterization Office

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1. INTRODUCTION

A Performance Confirmation Concepts Study was conducted during fiscal year 1996 to initiate the formulation of the detailed content and extent of the Performance Confirmation Program for the Yucca Mountain Site Characterization Project (YMP). A Performance Confirmation Program is required by Subpart F of Title 10 Code of Federal Regulations (CFR) Part 60, *Disposal of High-Level Radioactive Wastes in Geologic Repositories*. The study was needed at this time to ensure that the requirements of the performance confirmation program are considered in the design of the Mined Geologic Disposal System (MGDS) for the Viability Assessment.

1.1 STUDY OBJECTIVES

The primary objective of the performance confirmation concept study was to provide the technical basis for recommending performance confirmation program related requirement updates to the YMP requirements documents. During this fiscal year, the primary emphasis was on the identification of the performance confirmation needs that have to be considered in the MGDS design to ensure that the associated data acquisition will be possible. These recommendations, if accepted by DOE, will be incorporated into the technical baseline and will establish criteria for the design of the repository and engineered barrier systems that include the needs of the performance confirmation program.

The report provides general guidance for the development of the entire Performance Confirmation Program. This guidance should be sufficient to facilitate development of an MGDS design for the Viability Assessment that will incorporate performance confirmation requirements. The report also contains an overview of the total performance confirmation approach in the form of a draft Performance Confirmation Plan (Appendix A). This approach focuses on emplacement and post-emplacement monitoring activities, but implications on site characterization and pre-emplacement and construction activities are also identified.

The study has a number of secondary objectives. The report contains the identification of specific concepts for measurements, monitoring, observations, and testing necessary to execute the performance confirmation program. These concepts constitute a continuation of portions of the site characterization program. The report also identifies the data evaluations and the postclosure performance assessment predictions that are necessary before and after the license application to confirm that the postclosure performance requirements of 10 CFR Part 60 can be met. This may require modifications of conceptual and mathematical models and of associated computer codes of natural and engineered barrier processes on the basis of any new understanding gained from the new data acquisition.

1.2 STUDY SCOPE

In general, the content and extent of the Performance Confirmation Program needs to be defined as required by 10 CFR Part 60, Subpart F. During this fiscal year, the performance confirmation concept study emphasized the identification of the key performance confirmation drivers for natural and engineered barrier system design with respect to defining detailed performance confirmation concepts for data acquisition. The study identified activities and the information important for performance confirmation for the reference thermal loading range of 80 to 100 metric tons of uranium (MTU) per acre (CRWMS M&O 1995e). Due to the current uncertainties in the environmental standards for radioactivity for a potential geologic repository located at Yucca Mountain, Nevada, the study considered the following potential total system postclosure performance standards: (1) limiting the cumulative releases of radionuclides to the accessible environment for 10,000 years after repository closure, which was required by the remanded 40 CFR Part 191 *Environmental Radiation Protection Standards for Management and Disposal of Spent Nuclear Fuel, High-Level and Transuranic Radioactive Wastes* of the Environmental Protection Agency; (2) limiting the risk to individuals of adverse radiological health effects from radioactive releases from the potential repository for up to one million years, which is based on the National Academy of Sciences (NAS) recommendations in the report *Technical Bases for Yucca Mountain Standards* (NAS 1995), and (3) limiting peak dose to individuals from releases from the repository for 10,000 years, as identified in DOE planning guidance (YMSCO 1996) and in the DOE recommendations to the National Academy of Sciences (Dreyfus 1994).

The performance confirmation concept study estimated sample sizes, sampling frequencies, sample locations, and required observation precision only to the extent necessary to identify MGDS design drivers and to support repository and waste package designs related to performance confirmation program activities. The study focused on repository construction, waste emplacement, and post-emplacement monitoring and the activities that can be most influenced by the longer time frames and larger spatial scales available in testing and experiments conducted prior to repository closure.

The *Office of Civilian Radioactive Waste Management, Test and Evaluation Master Plan (TEMP)* (DOE 1995a) describes the Test and Evaluation (T&E) policy, objectives, requirements, general methodology, responsibilities, and scheduling of test phases for the Civilian Radioactive Waste Management System (CRWMS). The Performance Confirmation Program is a portion of the entire T&E activities and is considered a part of the operational effectiveness tests of the operational T&E phase for the CRWMS. Thus, the Performance Confirmation Program is governed by the TEMP. Given this, this fiscal year's activities were limited to refining the requirements on a portion of the T&E activities, while permitting integration with the higher-level T&E documents.

The wastes considered in the report include commercial spent fuel and high-level waste glass. Shortly before the study was concluded, DOE spent nuclear fuel was added to the CRWMS baseline. The effect of these wastes on performance confirmation has not been determined, but future studies will address this.

The study was managed by the CRWMS Management and Operating Contractor (M&O) Systems Analysis and Modeling department and interfaced with the following CRWMS M&O organizations who also participated in the study: MGDS Project Engineering, Performance Assessment, Repository Design Subsurface, Repository Design Surface, Requirements, Scientific Program Operations, Waste Package Development, Waste Package Materials.

1.3 BACKGROUND

Background information for the performance confirmation program is provided by (1) 10 CFR Part 60 requirements for the performance confirmation program, (2) performance confirmation plans included in the *Site Characterization Plan* (SCP) (DOE 1988), (3) NRC comments on the SCP's performance confirmation program and DOE's responses to these comments, (4) a survey of performance confirmation aspects of foreign repository programs, and (5) the performance confirmation approach of this report.

1.3.1 Performance Confirmation Requirements of 10 CFR Part 60

Performance confirmation is defined in 10 CFR Part 60.2 as "the program of tests, experiments, and analyses which is conducted to evaluate the accuracy and adequacy of the information used to determine with reasonable assurance that the performance objectives for the period after permanent closure will be met."

The overall system performance objective for the period after permanent closure is stated in 10 CFR 60.112, which refers to "such generally applicable environmental standards for radioactivity as may have been established by the Environmental Protection Agency...." The previous EPA standard for high-level waste disposal, 40 CFR Part 191, was remanded and subsequently reissued with the statement that the standard is inapplicable to repositories to be licensed in accordance with the Nuclear Waste Policy Act of 1982. Therefore, there is no EPA standard currently applicable to Yucca Mountain. The remanded standard included a limit on the cumulative release of radionuclides to the accessible environment in the first 10,000 years following repository closure and of limits on radionuclide concentrations in ground-water and on radiation doses to people drinking that water during the first 1,000 years after repository closure. The National Academy of Sciences (NAS), in its report *Technical Bases for Yucca Mountain Standards* (NAS 1995), recommends the use of a standard that sets a limit on the risk of adverse health effects to individuals from radioactive releases from the potential repository and compliance with the standard measured at the time of peak risk (out to about one million years). The EPA is considering the NAS recommendations and will issue revised standards. The NRC will then revise 10 CFR Part 60 to be consistent with the EPA standard. The exact forms of the new standard and the subsequently issued revised regulations are not known.

The performance objectives of particular barriers after permanent repository closure are stated in 10 CFR 60.113 and cover the waste containment time within waste packages, the rate of release of radionuclides from the engineered barrier system, and the pre-waste emplacement ground-water travel time. The NAS does not recommend subsystem performance requirements.

Thus, the Performance Confirmation Program should provide further confidence and reasonable assurance that the MGDS will comply with these postclosure performance requirements. This confidence and assurance are obtained by establishing a baseline set of information before the submittal of the License Application, which will include predictions of expected conditions, then observing those conditions after the submittal of the License Application, and finally comparing the new observations with the previous observations and predictions.

The requirements in 10 CFR Part 60, Subpart F, have been identified and discussed in Chapter 2.

1.3.2 Performance Confirmation Described in the Site Characterization Plan

The SCP describes preliminary plans for a Performance Confirmation Program in Section 8.3.5.16. According to the SCP, the Performance Confirmation Program is divided into two major phases: (1) the Baseline phase and (2) the Confirmation phase. The submittal of the License Application marks the division between the two phases.

The Baseline phase consists of information acquired and developed during site characterization. It includes (1) developing information on subsurface conditions and natural systems important to the performance assessment to be provided in the License Application and those aspects of design integral to the assessment; and (2) monitoring and analyzing changes in this baseline information as a result of site characterization and predicting changes resulting from construction and operation.

The Confirmation phase consists of in situ monitoring, laboratory and field testing, and associated analyses required to confirm (1) assumptions regarding the actual subsurface conditions at the site, and (2) the functioning of the engineered and natural systems and components as predicted by the performance assessment calculations presented in the License Application.

In Tables 8.3.5.16-1 and 8.3.5.16-2, the SCP lists specific monitoring and testing activities that were planned during site characterization and testing activities that were planned to be continued for performance confirmation. These activities were not intended to be complete, but rather to indicate the monitoring and testing that were tentatively identified at that time as being useful for performance confirmation. Portions of these tables relevant to the performance confirmation concept study are included in Appendix I. There is little difference between the performance confirmation concepts identified in the current report and the activities listed in the SCP. Some differences exist because the SCP planned an Exploratory Shaft Facility in contrast to the Exploratory Studies Facility being built. Most of the parameters and most of the monitoring and testing activities listed in the SCP are identified as performance confirmation parameters and concepts in the current study. A complete comparison of specific activities is not yet possible, however, because the current study was limited to identifying concepts that affect the MGDS design. Other concepts, such as surface-based monitoring that does not influence the MGDS design, will be identified in a follow-up of the current study.

1.3.3 NRC Comments on SCP Performance Confirmation Program

Following publication of the SCP, the Nuclear Regulatory Commission (NRC) provided formal comments on the SCP in NUREG-1347 (NRC 1989). These comments included concerns that the SCP's performance confirmation program does not provide sufficient information on detailed technical aspects of the planned monitoring and testing (e.g., provisions for underground testing of sealing concepts) and on the timing of the monitoring and testing (e.g., with respect to activities before and after the submittal of the construction authorization application). The DOE response to the NRC comments stated that it was premature to provide the requested information, but that it will be developed in conjunction with the Advanced Conceptual Design (ACD) of the MGDS.[1] The

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[1] DOE letter, Dwight Shelor to John Linehan. December 14, 1990. Enclosed DOE responses to NRC comments and Questions.

timing of the current study conforms with this response. The NRC agreed with much of the DOE response, but maintained that some of the testing should be started during site characterization as such, DOE should provide detailed plans earlier.

The current study adds additional detail and begins the development of the Performance Confirmation Plan. The commencement of the study is consistent with the statement in the DOE's response. After completion of the study report and approval by the DOE, the NRC-DOE interactions mentioned in the NRC comments and DOE response are recommended. The interactions would be intended to facilitate the NRC's understanding of the DOE's proposed performance confirmation program, to provide the NRC an opportunity to comment on that program, and to enhance communications between the two agencies on performance confirmation issues.

It is again noted that the current study focus is the identification of performance confirmation needs for the repository construction, waste emplacement, and post-emplacement periods and not the development of baseline information prior to the submittal of the license application. This was necessary to support the current MGDS design effort and to ensure that specific performance confirmation requirements are developed and addressed in the design to be used for the Viability Assessment. The requirements provided in 10 CFR Part 60, Subpart F, without additional details, are not sufficient to facilitate development of design concepts to support performance confirmation nor sufficient to facilitate development of life cycle costs related to performance confirmation in support of the Viability Assessment. Thus, additional development of requirements and design criteria is necessary. This study will provide a recommended set of requirements sufficient for this level of design engineering and the technical basis for the recommendations. It also provides a preliminary approach for performance confirmation in the form of a draft Performance Confirmation Plan.

1.3.4 Foreign Approaches to Performance Confirmation

In an effort to take advantage of previous work and to minimize any unnecessary work, a survey was conducted to determine what requirements and concepts for a performance confirmation program have been identified by foreign countries. The survey covered eight countries that have geological repository programs. A detailed listing of the findings is included in Appendix E.

Most foreign geologic disposal programs are in the proof-of-concept, site selection, or site characterization phase. Confirmatory studies, whether through active additional characterization or through more passive monitoring of key components of the disposal system and its environment, have not been contemplated in most foreign programs.

Two exceptions are the Canadian program, which is still in the proof-of concept and pre-site selection phase, and the Swedish program, which is actively attempting to select a site for characterization. In both of these programs, pre- and postclosure monitoring have been discussed in general terms. Although the geologic media (i.e., saturated crystalline rocks) and disposal concepts (i.e., waste package and repository designs) of these two programs are different from the potential geologic repository at Yucca Mountain, some of the identified parameters and testing are also applicable to this study. Differences occur mainly because of the additional needs for monitoring and testing unsaturated geologic media at Yucca Mountain and different regulatory environments.

At present, however, sufficient detail for specific monitoring and testing activities has not yet been developed by these programs to be used by the YMP. Also, although basic concepts for a portion of the YMP Performance Confirmation Program have been developed by this study, detailed designs with respect to specific locations, durations, instrumentation, etc. have to be developed yet. Consequently, technology transfer in either direction appears to be premature. As additional details are developed by all programs, the YMP should share its monitoring and testing plans and experience internationally and stay abreast of similar international developments in order to take advantage of technology transfer and exchange opportunities as they may arise.

1.3.5 YMP Performance Confirmation Approach

As described above, the YMP approach for performance confirmation is based on 10 CFR Part 60 and as elaborated by the SCP. It starts during the site characterization phase and continues through all subsequent phases until the repository closure. The performance confirmation activities must provide data (via testing) that show that subsurface conditions during repository construction, waste emplacement operation, and the caretaker period following waste emplacement until permanent repository closure are within the limits established in the License Application. They must also show (by performing evaluations) that natural and engineered systems and components are functioning as intended. The performance confirmation approach is divided into a baseline period and a confirmation period.

Activities during the baseline period will develop information on subsurface conditions and natural systems important to postclosure performance. They will also monitor and analyze changes in this baseline information as a result of site characterization activities. This information will be used to predict changes resulting from construction and operation. These baseline period activities will begin during the site characterization phase.

Activities during the confirmation period will verify that actual subsurface conditions and changes resulting from construction and operation are within predicted limits. They will also verify that the natural and engineered systems and components are functioning as intended and anticipated. This information will be used to support the application sent to the NRC requesting a repository license amendment to permanently close the repository.

Figure 1-1 depicts the general process of collecting performance confirmation data, using a waste package emplaced in a repository drift as the example. Characteristics of the waste package, the drift, and the mountain itself (e.g., temperatures of the waste package surface, the drift air, and the surrounding rock) are measured with appropriate instruments. The raw data from these instruments (e.g., electrical currents) are then converted to obtain the performance confirmation data of interest (e.g., degrees centigrade).

As depicted by Figure 1-2, measurements of these parameters would have been made during site characterization and predictions would have been made prior to repository construction of how the parameter values (e.g., temperatures) would change as a function of time because of the repository construction and waste emplacement. The measurements would reflect heterogeneities in geologic properties and the predictions would include uncertainties in the predictions, resulting in a band of possible parameter values.

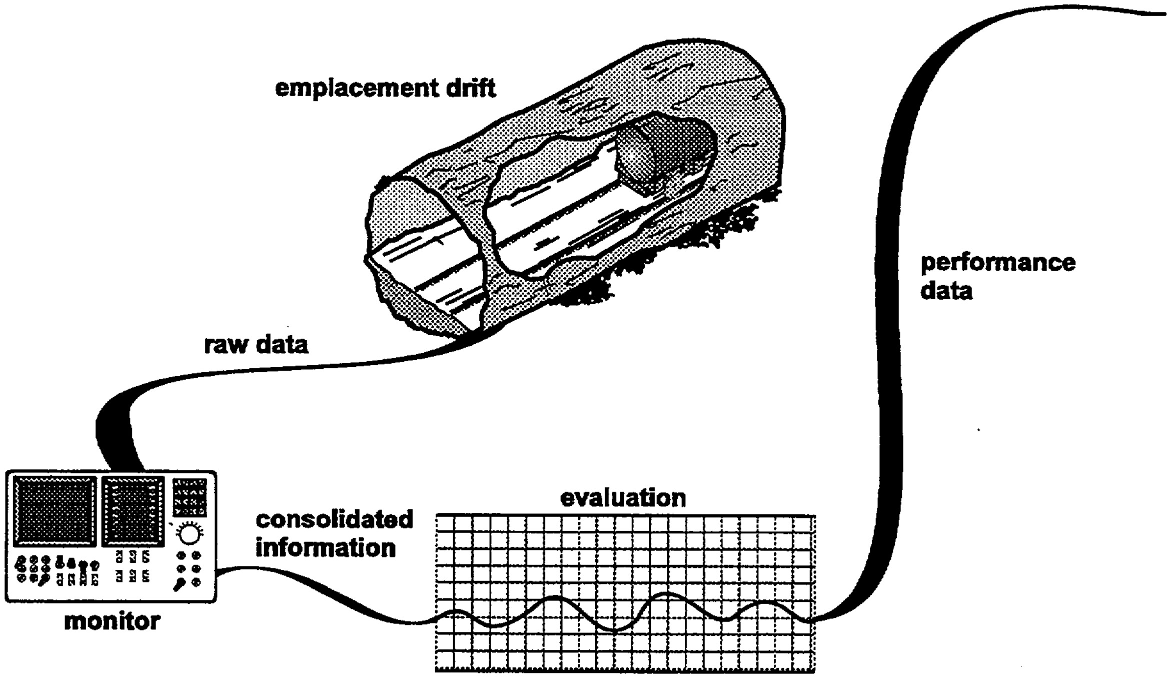

Figure 1-1. Performance confirmation involves gathering data on the waste package, drifts and mountain. The data will be evaluated and used to predict how the repository will perform.

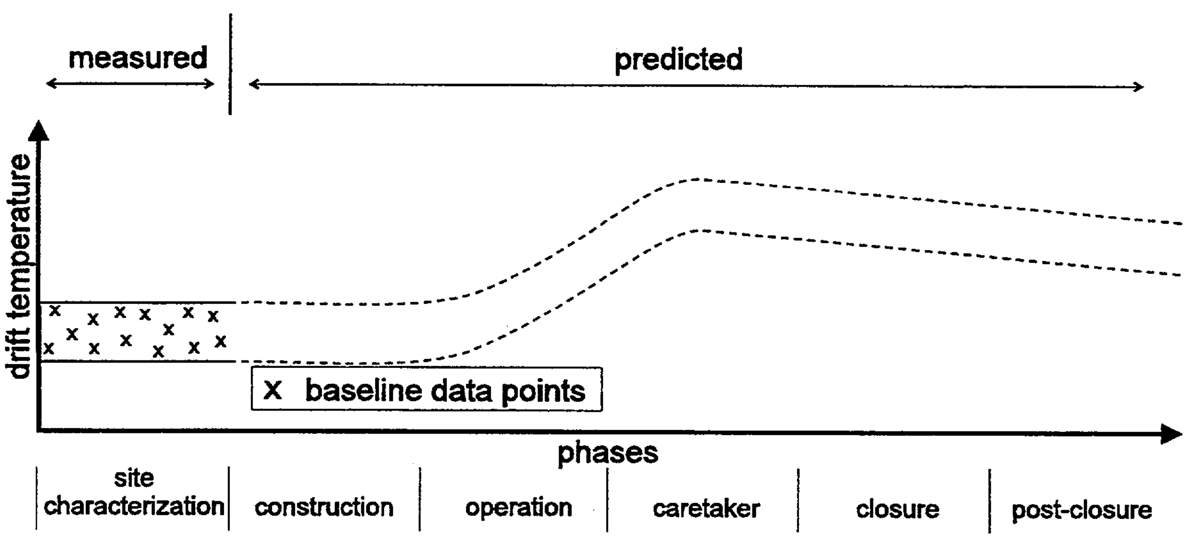

Figure 1-2. Baseline Period—Early Predictions at Time of Construction.

During performance confirmation, the new measurements (i.e., performance confirmation data— drift air temperatures in the example) would be expected to be within these uncertainty bands, as shown by Figure 1-3. If they are not, performance assessments would evaluate the potential effects of any deviations on the postclosure performance of the repository and compliance with regulatory requirements (e.g., radionuclide releases to the accessible environment and radiation doses to the public). If the deviations are considered significant, they would be reported to the NRC and could affect repository operations.

1.4 TECHNICAL APPROACH

The overall technical approach used for the conduct of the study is described in the following paragraphs. Specific approaches used in the development of a particular report section or study are discussed in each section.

1.4.1 Regulatory Requirements and Relevant Background

The fundamental basis for the Performance Confirmation Program is the regulatory requirements contained in 10 CFR Part 60, paragraphs 60.112 and 60.113, and Subpart F, and recent developments that may change some requirements. Relevant backgrounds that need to be considered for the study include the performance confirmation plan in the SCP, comments by the NRC on that plan, related foreign radioactive waste repository programs, and the general YMP approach for performance confirmation. (Section 1)

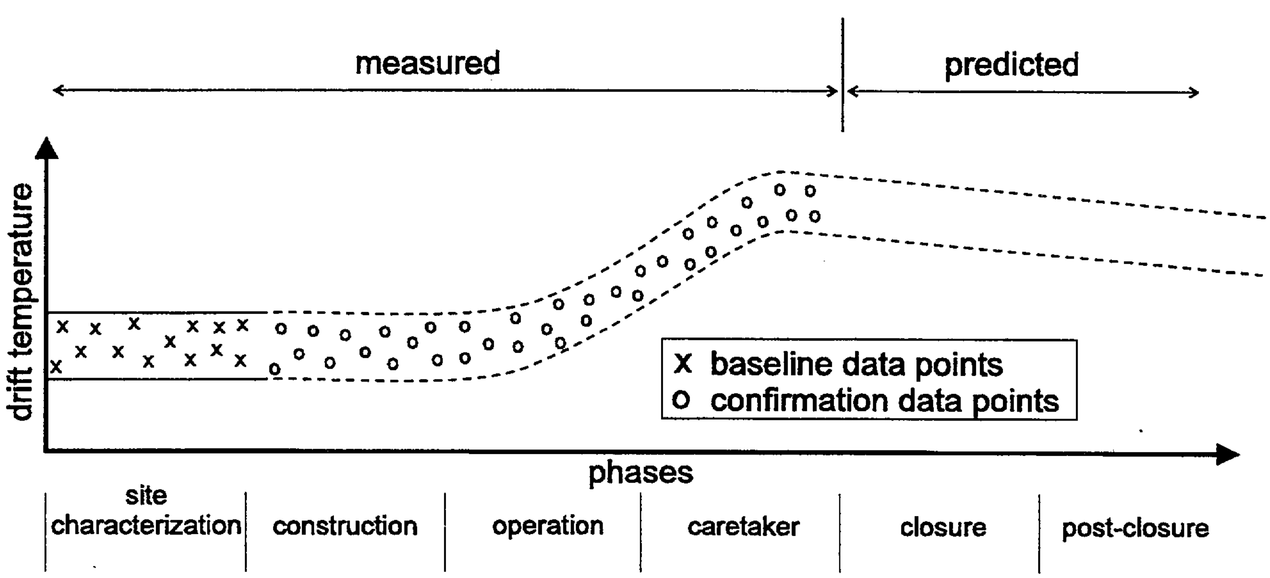

Figure 1-3. Confirmation Period—High Confidence at Time of Closure.

1.4.2 Relevant CRWMS Requirements and Study Inputs and Assumptions

On the basis of the regulatory and related functional requirements, CRWMS requirements documents exist that need to be considered for the Performance Confirmation Program and that may have to incorporate the requirements arising from the Performance Confirmation Program. These documents include the *Mined Geologic Disposal System Requirements Document* (DOE 1996a), *Repository Design Requirements Document* (DOE 1994a), *Engineered Barrier Design Requirements Document* (DOE 1994b), and *Site Design and Test Requirement Document* (DOE 1995c). Study inputs are derived from requirements in these documents. Other relevant inputs and assumptions are identified (Section 2).

1.4.3 Identification of Activities

Also on the basis of the regulatory requirements, functional analyses were performed to refine the test and evaluate function and to identify the specific confine and isolate waste functions that need to be addressed by the CRWMS (CRWMS M&O 1996i). The relationship of the functional analyses with the Performance Confirmation Program is identified to ensure that the performance confirmation activities and data acquisition for specific parameters meet the needs identified by the functional analysis. (Section 3)

1.4.4 Identification of Processes, Models, and Parameters

On the basis of the regulatory requirements and the functional analyses, the natural and engineered barrier processes are identified, described, and analyzed to demonstrate compliance with the regulatory requirements. These processes then determine which conceptual and mathematical models are needed and which computer codes are available for the analyses. These in turn determine the specific parameters that are needed for the analyses. Parameter selection criteria are then identified that consider regulatory, functional, measurement, modeling, and uncertainty aspects in order to select those parameters (called performance confirmation parameters) that need to be measured, monitored, observed, or tested during performance confirmation. A subset of these parameters (called key performance confirmation parameters for design) whose data acquisition needs to be considered in the MGDS design is then identified (Section 4).

1.4.5 Development of Performance Confirmation Concepts

As the next step, performance confirmation concepts are identified and described that are needed for measuring, monitoring, observing, or testing the key performance confirmation parameters and for performing the required analyses. These concepts include specific in situ and laboratory activities, related facilities, data analyses, modeling predictions, and evaluations and reporting (Section 5).

1.4.6 Development of Performance Confirmation Requirements

The combination of regulatory requirements, CRWMS requirement documents, functional analysis definitions, performance confirmation concepts, and key performance confirmation parameters then leads to the formulation of general performance confirmation requirements. These requirements are recommended for incorporation into the appropriate CRWMS requirements documents. Observance of these requirements is intended to ensure that the performance confirmation concepts can be implemented for the data acquisition of the key performance confirmation parameters (Section 6).

1.4.7 Performance Confirmation System Analysis

A performance confirmation system analysis is then performed to develop a recommendation for specific performance confirmation requirements regarding accuracy, quantity of samples and testing, location, and frequency. The approach for developing alternatives for the specific requirements is proposed, and alternative requirements are developed. A reference case is discussed to establish the current state of the design. Alternative concepts meeting the general performance confirmation requirements and alternative specific requirements are developed. Alternative concept selection criteria, which include cost, scientific confidence, and potential impact on waste isolation, are established to discriminate between the reference case and the alternatives. Finally, an evaluation of the concepts is performed for each criterion and the results are analyzed (Section 7).

1.4.8 Conclusions and Recommendations

On the basis of the entire study, conclusions and recommendations have been formulated with respect to external interactions (e.g., the NRC and international programs), internal interfaces (e.g., MGDS design, functional analysis, and performance assessment) and future work (including the completion of the Performance Confirmation Plan) (Section 8).

2. INPUTS AND ASSUMPTIONS

The inputs and assumptions used in conducting this study are documented in this section. The types of inputs include quality assurance requirements and controls, regulatory guidance, and requirements contained in the technical document hierarchy. The requirements are documented in the program level requirements documents. Major assumptions used in the study are included in this section of the report. Other minor assumptions, for example, those used in performing the cost evaluations, are included in the appropriate areas of the report.

2.1 QUALITY ASSURANCE REQUIREMENTS AND CONTROLS

The Quality Assurance program applies to the development of this technical document. The Civilian Radioactive Waste Management System (CRWMS) Management and Operating Contractor (M&O) Quality Administrative Procedure QAP-2-0 activity evaluation, *Perform System Studies*, (CRWMS M&O 1995b) was completed. Although a QAP-2-3 classification analysis has not yet been performed, the QAP-2-0 activity evaluation determined that the work performed to develop a system study report is quality affecting because it impacts items that are on the Q-List (DOE 1994c) by direct inclusion. There are no applicable determination of importance evaluations in accordance with Nevada Line Procedure, NLP-2-0, *Determination of Importance Evaluations*. This study report, as appropriate, will provide recommendations for requirements to be included in the project design requirements documents. Appropriate QAP procedures, QAP-3-5 in particular, were used in the preparation, review, approval and, if necessary, the revision of the report. Accordingly, a Technical Document Preparation Plan, *Technical Document Preparation Plan for the Performance Confirmation Concepts Study Report* (CRWMS M&O 1996b) for this document was developed, issued, and utilized to guide its preparation. Other applicable procedural controls not specifically discussed in the Technical Document Preparation Plan are listed in the above mentioned QAP-2-0 activity evaluation.

A portion of the existing site data were collected or developed prior to the approval of a quality assurance program. Also, current scoping results from total system performance assessments are used in this study. Any unqualified data is identified as such in the report. Data developed in accordance with an approved quality assurance program is utilized when available. As such, as additional data are obtained under quality affecting procedures, it may be necessary to review these results to determine what impact the new data might have and if any changes may be warranted in the conclusions.

Data and assumptions that are identified in this document are for preliminary design and shall be treated as unqualified; these data and assumptions will require subsequent qualification (or superseding data and assumptions) as the testing and design efforts proceed. This document will not directly support any construction, fabrication, or procurement activity and therefore is not required to be procedurally controlled as TBV (to be verified). In addition, the data and assumptions associated with this report are not required to be procedurally controlled as TBV. However, use of any data from this report for input into documents supporting procurement, fabrication, or construction is required to be controlled as TBV in accordance with the appropriate procedures.

2.2 REQUIREMENTS ON PERFORMANCE CONFIRMATION

The CRWMS technical baseline is undergoing a change which will affect the hierarchy of technical documents, but at the time of development of the study these issues were not resolved. The CRWMS currently controls the *Mined Geologic Disposal System Requirements Document* (MGDS-RD) (CRWMS M&O 1996j) as a part of the Program Baseline. The MGDS-RD was selected as the source for inputs into this study.

The Yucca Mountain Site Characterization Project technical document hierarchy consists of design requirement documents such as the *Engineered Barrier Design Requirements Document* (EBDRD) (DOE 1994b), *Repository Design Requirements Document* (RDRD) (DOE 1994a), and the *Site Design and Test Requirements Document* (SD&TRD) (DOE 1995c). The EBDRD and RDRD were developed in July of 1993 and have not been completely revised since they were originally published. In September 1994, a document change notice provided a status of the documents and indicated to potential users of the document the need to be aware that changes may occur in derived requirements and some inputs may be identified as unqualified. Thus, the project baseline documents have not incorporated subsequent changes made in the MGDS-RD. The *Controlled Design Assumptions* document (CDA) (CRWMS M&O 1996c) has been used to document assumptions and design bases consistent with the technical and programmatic changes made in MGDS-RD and to complement the baseline versions of the EBDRD and RDRD. The assumptions from the CDA related to performance confirmation are discussed in section 2.3.1 below.

2.2.1 MGDS-RD Requirements on Performance Confirmation

The requirements listed below are taken from the MGDS-RD. They were included if they mention the performance confirmation program, refer to 10 CFR Part 60.137 or any section of Subpart F, which includes sections 60.140 through 60.143. After each requirement or group of requirements, an assessment of its applicability in the study is provided with an indication as to whether it is considered an input to the study.

> "**3.2.1 Performance Characteristics**
>
> C. (R, E)[1] An objective of the GROA [Geologic Repository Operations Area] is to preserve the option of waste retrieval throughout the period during which wastes are being emplaced and, thereafter, until the completion of a performance confirmation program and NRC [Nuclear Regulatory Commission] review of the information obtained from such a program. To satisfy this objective, the GROA shall be designed so that any or all of the emplaced waste could be retrieved during an appropriate period of operation of the facility on a reasonable schedule starting at any time up to 100 years after waste emplacement operations are initiated. A reasonable schedule for retrieval would be equal in length to the time required for the construction of the repository and the emplacement of the waste. [10CFR60.111(b)(1), (3)] [NWPA[2] 42USC10142] [CRD 3.7.4.2.M]"

[1] The parenthetic notation preceding this requirement designates the MGDS segment to which the requirement is allocated. "R" indicates Repository Segment; "E" represents the Engineered Barrier Segment.

[2] NWPA = Nuclear Waste Policy Act

Assessment of MGDS-RD 3.2.1.C: This is a system-level requirement on the MGDS and the waste retrieval capability of the GROA, but it implies that the completion of a performance confirmation program and NRC review of the information obtained from such a program should be completed within 100 years after waste emplacement operations are initiated. For this requirement to be met, the criteria for completion of the performance confirmation program must be established and the content of the program established consistent with the 100-year requirement considering the time needed for NRC review of the information established. Thus, this requirement is an input to the study.

"**3.7.1.3 Site Characterization Requirements**

... **B.** Requirements. The requirements listed below apply to design of site characterization systems and facilities, as appropriate (some are not applicable to the SBTF [Surface Based Testing Facilities]).

1. Site characterization facilities and systems are to be designed and constructed in accordance with applicable design requirements derived from the 10CFR60 regulations listed below such that they do not preclude the ability of the Repository and Engineered Barrier Segments to meet the requirements in this MGDS-RD. ...

az. The requirements of 10CFR60.137 shall be imposed on the design of permanent components of the Site Segment, unless non-applicability is justified in writing. [NUREG 1439 App C] [CRD 3.7.4.2.K.8][3]

ba. The requirements of 10CFR60.140(b) shall be imposed on the design of permanent components of the Site Segment, unless non-applicability is justified in writing. [NUREG 1439 App C] [CRD 3.7.4.2.K.8]

bb. The requirements of 10CFR60.140(c) shall be imposed on the design of permanent components of the Site Segment, unless non-applicability is justified in writing. [NUREG 1439 App C] [CRD 3.7.4.2.K.8]

bc. The requirements of 10CFR60.140(d)(1) shall be imposed on the design of permanent components of the Site Segment, unless non-applicability is justified in writing. [NUREG 1439 App C] [CRD 3.7.4.2.K.8]

bd. The requirements of 10CFR60.141(a) shall be imposed on the design of permanent components of the Site Segment, unless non-applicability is justified in writing. [NUREG 1439 App C] [CRD 3.7.4.2.K.8]

[3] CRD = Civilian Radioactive Waste Management System Requirements Document (DOE 1995e) NUREG 1439 = NRC 1991

be. The requirements of 10CFR60.141(b) shall be imposed on the design of permanent components of the Site Segment, unless non-applicability is justified in writing. [NUREG 1439 App C] [CRD 3.7.4.2.K.8]

bf. The requirements of 10CFR60.141(c) shall be imposed on the design of permanent components of the Site Segment, unless non-applicability is justified in writing. [NUREG 1439 App C] [CRD 3.7.4.2.K.8]

bg. The requirements of 10CFR60.141(d) shall be imposed on the design of permanent components of the Site Segment, unless non-applicability is justified in writing. [NUREG 1439 App C] [CRD 3.7.4.2.K.8]

bh. The requirements of 10CFR60.141(e) shall be imposed on the design of permanent components of the Site Segment, unless non-applicability is justified in writing. [NUREG 1439 App C] [CRD 3.7.4.2.K.8]

bi. The requirements of 10CFR60.142(a) shall be imposed on the design of permanent components of the Site Segment, unless non-applicability is justified in writing. [NUREG 1439 App C] [CRD 3.7.4.2.K.8]

bj. The requirements of 10CFR60.142(b) shall be imposed on the design of permanent components of the Site Segment, unless non-applicability is justified in writing. [NUREG 1439 App C] [CRD 3.7.4.2.K.8]

bk. The requirements of 10CFR60.142(c) shall be imposed on the design of permanent components of the Site Segment, unless non-applicability is justified in writing. [NUREG 1439 App C] [CRD 3.7.4.2.K.8]

bl. The requirements of 10CFR60.142(d) shall be imposed on the design of permanent components of the Site Segment, unless non-applicability is justified in writing. [NUREG 1439 App C] [CRD 3.7.4.2.K.8]

bm. The requirements of 10CFR60.143(a) shall be imposed on the design of permanent components of the Site Segment, unless non-applicability is justified in writing. [NUREG 1439 App C] [CRD 3.7.4.2.K.8]

bn. The requirements of 10CFR60.143(b) shall be imposed on the design of permanent components of the Site Segment, unless non-applicability is justified in writing. [NUREG 1439 App C] [CRD 3.7.4.2.K.8]

bo. The requirements of 10CFR60.143(c) shall be imposed on the design of permanent components of the Site Segment, unless non-applicability is justified in writing. [NUREG 1439 App C] [CRD 3.7.4.2.K.8]

bp. The requirements of 10CFR60.143(d) shall be imposed on the design of permanent components of the Site Segment, unless non-applicability is justified in writing. [NUREG 1439 App C] [CRD 3.7.4.2.K.8]"

Assessment of MGDS-RD 3.7.1.3.B.1. az. through bp.: These requirements are imposed on the design of permanent components of the Site Segment. The focus of this study is on design requirements on the Repository and Engineered Barrier System, but if any specific requirements on the Site are identified they will be so noted and appropriate traceability noted. Thus, these requirements may not be specifically used as input to the study.

"3.7.2.7 Performance Confirmation Requirements

A. General Requirements

1. The GROA shall be designed to include the capability to support tests appropriate or necessary for the administration of the regulations of 10CFR60. These tests may include tests of (1) radioactive waste, (2) the geologic repository including its structures, systems, and components, (3) radiation detection and monitoring instruments, and (4) other equipment and devices used in connection with the receipt, handling, or storage of radioactive waste. [10CFR60.74(a)] [CRD 3.3.1.1.B]"

Assessment of MGDS-RD 3.7.2.7.A.1.: All requirements in sections 3.7.2.7 have been allocated to the Repository Segment. This requirement is on the GROA to have the capability to support tests. Because of MGDS-RD 3.7.2.7.A.2, below, this requirement includes performance confirmation tests. The tests that are specifically listed in this requirement are not necessarily performance confirmation tests. Performance confirmation tests are conducted to evaluate the accuracy and adequacy of the information used to determine with reasonable assurance that the performance objectives for the period after permanent closure will be met. The capability to test the items listed is required to insure that the performance of the GROA through permanent closure is met. Therefore, the four type of tests are not considered inputs to this study, unless the tests are determined to also be needed for performance confirmation.

"2. The tests required in section 3.7.2.7.A.1 shall include a performance confirmation program carried out in accordance with Subpart F of 10CFR60. [10CFR60.74(b)] [10CFR60.137] [CRD 3.7.4.2.L]"

Assessment of MGDS-RD 3.7.2.7.A.2.: The combination of this requirement and the first sentence in 3.7.2.7.A.1 is a requirement on the GROA to have the capability to support performance confirmation tests and is an input to the study.

"3. The performance confirmation program shall provide data that indicates, where practical, whether: (1) Actual underground conditions encountered and changes in those conditions during construction and waste emplacement operations are within limits assumed in the licensing review; and (2) Natural and engineered systems and components required for repository operation, or that are designed or assumed to operate as barriers after permanent closure, are functioning as intended and anticipated. [10CFR60.140(a)] [CRD 3.7.4.2.L]"

Assessment of MGDS-RD 3.7.2.7.A.3.: This requirement states the primary objectives of the performance confirmation program and is based on 10CFR60 Subpart F and therefore is an input to the study.

"4. The program shall include in situ monitoring, laboratory and field testing, and in situ experiments, as appropriate, to accomplish the objectives stated in 10CFR60.140(a) (3.7.2.7.A.3) above. [10CFR60.140(c)] [CRD 3.7.4.2.L]"

Assessment of MGDS-RD 3.7.2.7.A.4.: This requirement states testing concepts to be used in the program (unless they are determined to be inappropriate in meeting the objectives of the performance confirmation program) and is based on 10CFR60 Subpart F and therefore is an input to the study.

"5. The program shall:

a. Not adversely affect the ability of the natural and engineered elements of the geologic repository to meet the performance objectives (as specified in 3.7.2.2.B, 3.7.2.6.J.3, and 3.7.3.2).

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

c. Monitor and analyze changes from the baseline condition of performance of the geologic repository.

d. Provide an established plan for feedback and analysis of data, and implementation of appropriate action. [10CFR60.140(d)] [CRD 3.7.4.2.K.5] [CRD 3.7.4.2.L]"

Assessment of MGDS-RD 3.7.2.7.A.5.: This requirement puts a constraint on the program to not adversely affect the ability to isolate waste. The specific requirements that are referred to as containing the performance objectives may be in error. MGDS-RD 3.7.2.2.B is vacant. It is a reserved requirement in the section for geologic setting requirements. MGDS-RD 3.7.2.6.J.3 is a requirement on seals to contribute to meeting the Environmental Protection Agency requirement which is referred to in 10 CFR60.112. MGDS-RD 3.7.3.2 contains all the general requirements on the Engineered Barriers Segment including the Environmental Protection Agency requirement which is referred to in 10 CFR60.112, substantially complete containment, and controlled release from 10CFR60.113. It also provides other objectives of the performance confirmation program and is based on 10CFR60 Subpart F and therefore is an input to the study.

"6. The repository shall be capable of monitoring underground conditions and evaluating them against design assumptions. [10CFR60 141(b)] [CRD 3.7.4.2.L]"

Assessment of MGDS-RD 3.7.2.7.A.6.: This requirement is allocated to the repository to have a capability to monitor underground conditions and a requirement on the performance confirmation program to evaluate the underground conditions against design assumptions. It is based on 10CFR60 Subpart F and therefore is an input to the study.

"**B.** Testing. During the early developmental stages of construction, the Repository Segment shall be capable of supporting in situ testing of such features as borehole and access seals, backfill, and the thermal interaction effects of the waste packages, backfill, rock, and groundwater. [10CFR60 142(a)] [CRD 3.7.4.2.L]"

Assessment of MGDS-RD 3.7.2.7.B.: This requirement is allocated to the repository to have a capability to support in situ testing of several features. It is a specific constraint on the timing of certain types of tests. It is based on 10CFR60 Subpart F and therefore is an input to the study.

"**C.** Rock Measurements. The Repository Segment shall be capable of measuring, as a minimum, rock deformations and displacement, changes in rock stress and strain, rate and location of water inflow into underground areas, changes in groundwater conditions, rock pore water pressures, including those along fractures and joints, and the thermal and thermomechanical response of the rock mass as a result of development and operations of the geologic repository.
[10CFR60.141(c)] [CRD 3.7.4.2.L]"

Assessment of MGDS-RD 3.7.2.7.C.: This requirement is allocated to the repository to have a capability to measure specific rock conditions. It is a constraint on specific types of measurements and when they need to be measured. It is based on 10CFR60 Subpart F and therefore is an input to the study.

"**D.** Thermomechanical Response. The Repository Segment shall be capable of in situ monitoring of the thermomechanical response of the underground facility until permanent closure to ensure that the performance of the natural and engineering features are within design limits. [10CFR60.141(e)] [CRD 3.7.4.2.L]"

Assessment of MGDS-RD 3.7.2.7.D.: This requirement is allocated to the repository to have a capability to perform in situ monitoring of the thermomechanical response. It is a specific constraint on the type of parameters to be measured and the duration of monitoring. It is based on 10CFR60 Subpart F and therefore is an input to the study.

"**E.** Laboratory Experiments.

1. To support the waste package monitoring program required by 10CFR60.143(a) and (b), the GROA shall be designed to include facilities (to the extent appropriate for on-site work) capable of supporting laboratory experiments that focus on the internal condition of the waste packages. [10CFR60.143(c)] [CRD 3.7.4.2.L]"

Assessment of MGDS-RD 3.7.2.7.E.1.: This requirement is allocated to the repository to have facilities, if appropriate, to support laboratory experiments in support of the waste package monitoring. A constraint on the repository would need to be applied if this type of lab work is determined to be performed on site. It is based on 10CFR60 Subpart F and therefore is an input to the study.

"2. To the extent practical, the environment experienced by the emplaced waste packages within the underground facility during the waste package monitoring program shall be duplicated in the laboratory experiments. [10CFR60.143(c)] [CRD 3.7.4.2.L]"

Assessment of MGDS-RD 3.7.2.7.E.2.: This requirement is on the representativeness of the waste package monitoring program laboratory experiments. It is a constraint on the laboratory experiments. It is based on 10CFR60 Subpart F and therefore is an input to the study.

"**F.** Backfill Test. A backfill test section shall be constructed to test the effectiveness of backfill placement and compaction procedures against design requirements before permanent backfill placement is begun. [10CFR60.142(c)] [CRD 3.7.4.2.L]"

Assessment of MGDS-RD 3.7.2.7.F.: This requirement is placed on the repository to allow space for a backfill test section which focuses on constructability and timing of the test. It is a constraint on the repository design regarding space to perform this test. It is based on 10CFR60 Subpart F and therefore is an input to the study.

"**G.** Borehole and Access Seal Tests. Test sections shall be established to test the effectiveness of borehole and access seals before full-scale operation proceeds to seal boreholes and accesses. [10CFR60.142(d)] [CRD 3.7.4.2.L]"

Assessment of MGDS-RD 3.7.2.7.G.: This requirement is placed on the repository to allow space for test sections for boreholes and access seals and the objective and timing of the test. It is a constraint on the repository design to provide space for this test. It is based on 10CFR60 Subpart F and therefore is an input to the study.

"**H.** A program of in situ testing shall begin as early as practicable after construction authorization to meet the requirements of 10CFR60.142 (section 3.7.2.7 in the MGDS-RD document). [10CFR60 142(b)] [CRD 3.7.4.2.L]"

Assessment of MGDS-RD 3.7.2.7.H.: This requirement is on timing of the in situ testing. It is a constraint on the timing of these tests and that may influence the design. It is based on 10CFR60 Subpart F and therefore is an input to the study.

As can be seen from the requirements listed in the previous section and their assessment, the majority of the design inputs selected are either directly from 10 CFR 60 Subpart F or are slight variations from them. The program-level document provides well-traced inputs from 10 CFR 60 Subpart F. The design organizations have requested additional guidance and specific inputs for the development of the design to accommodate the Performance Confirmation Program. This request is one of the primary reasons for conducting this study. Since the technical document hierarchy is expected to change, it is recommended that requirements related to performance confirmation that currently exist at the level of the MGDS-RD remain fixed with the possible exception of MGDS-RD, 3.7.2.7.A.5. The resulting design requirements and criteria from this study should be placed in the CDA document until the structure of the technical document hierarchy is established.

2.2.2 Selected Design Inputs Related to Performance Confirmation

Additional inputs to the report are listed below:

1. *Total System Performance Assessment—1995: An Evaluation of the Potential Yucca Mountain Repository* (CRWMS M&O 1995a).

2. *Office Civilian Radioactive Waste Management Test and Evaluation Master Plan* (DOE 1995a).

3. *Mined Geologic Disposal System Functional Analysis Document* (CRWMS M&O 1996i).

The *Total System Performance Assessment* document is used in the study to determine the importance of parameters for inclusion in the performance confirmation program. The *Total System Performance Assessment* document was not developed under quality affecting procedures and thus is considered as unqualified data, but it represents the best available information for the intended purpose. A general knowledge of the results from the TSPA is needed to complete the parameter selection process. The *Test and Evaluation Master Plan* is the program level management document that directs all test and evaluation activities. It is used as input and general guidance in developing an understanding of the overall test and evaluation master plan. The performance confirmation program is just one of several elements of this master plan. Finally, the *MGDS Functional Analysis Document* was developed under quality affecting procedures. Specific sections related to the Evaluate System Performance function and the confine and isolate waste functions of the *MGDS Functional Analysis Document* are used as inputs to develop performance confirmation functions.

2.3 ASSUMPTIONS

Section 2.3.1 lists assumptions made concerning performance confirmation in the *Controlled Design Assumptions Document* (CRWMS M&O 1996c). Specific assumptions made for this study are documented in the section that follows the CDA document assumptions.

2.3.1 Controlled Design Assumptions Related to Performance Confirmation

The CDA document contains several assumptions that, although not directly attributed to performance confirmation, represent current design assumptions related to performance confirmation. These assumptions are listed below and are followed with a discussion of their applicability to this study:

Assumption Identifier: Key 053 **Subject**: Off-Normal Waste Handling Building Capability "The MGDS shall have the capability to handle any [Multi-Purpose Canisters] MPCs and other canistered waste forms that require remedial processing. Such processing includes opening the canister, removing the waste form, discarding the canister, and repacking the waste form in a Disposal Container or Waste Package. *The MGDS shall have the capability to open an MPC and remove the contents without damaging the SNF [Spent Nuclear Fuel].*"

In the rationale for this assumption, the following is stated:

> "It is assumed that, until better defined, the probable equipment and systems (such as cutter, welder, and bare fuel handler) in the special operations cell for uncanistered fuel assembly casks and performance confirmation will accommodate the mitigation needs of an off-normal MPC. This special operations cell will need to be adaptable to multiple functional roles for one-time or low-volume events. Probable events and best remedial methodology will need to be investigated before operations and equipment can be defined for this area."

Applicability of the assumption to this study: The ability to perform special types of handling and operations on a waste package or waste form are assumed and it is assumed the frequency of their occurrence is rare. These operations were assumed to be similar to those required for performance confirmation. This study will establish requirements on these type and frequency of operations, but the assumption listed above is also used. Since the Waste Handling Building will have some capability to perform similar functions, the requirements and design concepts developed will redefine the specific hot cell needs and will not result in large deviations of the advanced conceptual design for the Waste Handling Building.

Assumption Identifier: EBDRD 3.2.5.1.2.B.1 **Subject:** EBS Reliability
"Reliability of the EBS shall be as follows:

1. Waste Package - The probability of failure (breach) of an individual waste package during the preclosure phase should be demonstrated to be less than 10^{-6} per year based on credible hazards."

Applicability of the assumption to this study: The likelihood of a waste package breach during the preclosure phase is roughly 10^{-4} over the 100 year period. Thus, the expected number of waste packages to breach is 1.2, assuming approximately 12,000 waste packages (Key Assumption 003 of the CDA). This information is used as rationale for why monitoring for aqueous radionuclide releases is not needed. It is assumed that if a gaseous radionuclide release is detected in the subsurface at any time prior to closure, then the source of the release will be determined. If the origin of the release is from the breach of a waste package, then the breached waste package will be recovered, the reason for breach determined, and remediation of the failure will be performed, including remediation of any significant amount of radionuclides released from the waste package. Therefore, coupled with the assumption listed above, during the preclosure time frame it is expected that about one waste package breach would occur and then a release of gaseous radionuclides would occur. There also is no credible mechanism for aqueous transport even if a waste package breaches in the preclosure time frame and its breach is undetected. This one expected release, even if undetected, does not justify monitoring for aqueous releases from the engineered barrier system or in the natural barrier.

2.3.2 Specific Study Assumptions

Several assumptions have been made to allow continuation of the study. These assumptions are listed below:

A. Due to uncertainty in the form of the final Environmental Protection Agency standard, three possible standards were considered: 1) limiting the cumulative releases of radionuclides to the accessible environment for 10,000 years after disposal which is the current MGDS requirement based on the 1985 issue of 40 CFR Part 191; 2) limiting the risk to individuals of adverse health effects from releases from the repository for a time out to about one million years, which is based the National Academy of Sciences recommendations on *Technical Bases for Yucca Mountain Standards* (NAS 1995); and 3) limiting peak dose to individuals from releases from the repository for 10,000 years, as identified in DOE planning guidance (YMSCO 1996) and in the DOE recommendations to the National Academy of Sciences (Dreyfus 1994). This was so that the study would not have to be redone when the standard is set or if design drivers from the use of only one standard would be missed.

B. It is assumed that the list of candidate parameters in the Performance Confirmation Data Matrices, which is described below, is sufficiently complete to include the key performance confirmation parameters or the drivers of the Performance Confirmation Program.

C. It is assumed that underground instrumentation will be retrievable and replaceable to allow for recalibration and maintenance.

D. It is assumed certain parameters and processes that are important to performance will be sufficiently known at the time of license application that additional characterization will not be necessary. This is based on the fact that at the time of construction authorization there will be reasonable assurance that the postclosure performance objectives will be met. This will establish that many of the processes and associated parameters are sufficiently known due to site characterization activities.

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3. IDENTIFICATION OF KEY ACTIVITIES

The functional analysis of performance confirmation is done to identify the key activities necessary to conduct the program. The following sections define the approach that was used, the primary functions, definitions of the functions, and an introduction to lower level functions.

The establishment of performance confirmation functions is necessary for the definition of requirements and allocation of these requirements to design elements for implementation. In defining the performance confirmation functions, considerations were given to:

1. Confirmation of the Confine and Isolate Waste function of the Mined Geologic Disposal System (MGDS).

2. Program requirements related to performance confirmation listed in Section 2. These primarily refer to 10 CFR 60, Subpart F requirements to verify natural and engineered barrier functions and evaluate their effectiveness.

3. Performance confirmation as a test function and an evaluate function which is both an element of the *Test and Evaluation Master Plan* (DOE 1995a) and MGDS Evaluate System Performance function.

The Confine and Isolate Waste function is one of the key functions of MGDS. It is described in the *MGDS Functional Analysis Document* (CRWMS M&O 1996i) as follows (Function 1.4.5):

> *The Confine and Isolate Waste function confines the waste in the disposal container and inhibits the transport of radioactive material to the accessible environment. This function begins when the waste is sealed in the disposal container and continues until the MGDS and the accessible environment return to acceptable levels.*

Since performance confirmation focuses on postclosure performance of the repository, i.e., on the containment and isolation of the waste, its principal function may be defined as the confirmation of the Confine and Isolate Waste function.

In 10 CFR 60, Subpart F, it is required to verify the functions of the natural and engineered systems and to collect data on subsurface conditions including geotechnical conditions, design performance functions, waste package, backfill, and seals. In the *Site Characterization Plan* (DOE 1988) and the *License Application Annotated Outline* (YMP 1995), it is also stipulated that Performance Confirmation will confirm baseline conditions and barrier performance.

The *Test and Evaluation Master Plan* (DOE 1995a) specifies two types of testing; Developmental Test and Evaluation and Operational Test and Evaluation. Performance Confirmation is considered to be the "operational effectiveness" phase of Operational Test and Evaluation.

It is noted that performance confirmation must also address analyses and tests that integrate the various conformance verification requirements specified in the design requirement documents.

In summary, the performance confirmation functions to be defined were required to:

1. Have a direct correspondence to and cover all the primary subfunctions of the Confine and Isolate Waste function of the MGDS.

2. Reflect compliance with 10 CFR 60, Subpart F.

3. Permit integration/differentiation of test and evaluation planning.

3.1 PERFORMANCE CONFIRMATION AS A FUNCTION OF MGDS

The *MGDS Functional Analysis Document* (FAD) (CRWMS M&O 1996i) identifies the top-level functions of the CRWMS and defines five subfunctions under the MGDS Dispose of Waste function, as shown in Figure 3-1 (Function 1.4). These five principal subfunctions include Evaluate System Performance (1.4.4) and Confine and Isolate Waste (1.4.5).

Functions preceding Performance Confirmation in the MGDS functional hierarchy have not been completely defined in the Functional Analysis Document, but proposed definitions are provided that are expected to be included in the next revision of the document. For the purpose of this study, it was necessary to assume that the Functional Analysis Document will include Confirm Waste Isolation as a subfunction (1.4.4.3) of Evaluate System Performance (1.4.4), together with two other subfunctions: Evaluate System Design and Development (1.4.4.1) and Evaluate System Operation (1.4.4.2). This Evaluate System Performance function is shown in Figure 3-2. Tentative definitions for the functions in this figure are proposed below. Additional details including input, output and interfaces for all proposed functions are provided in Appendix G.

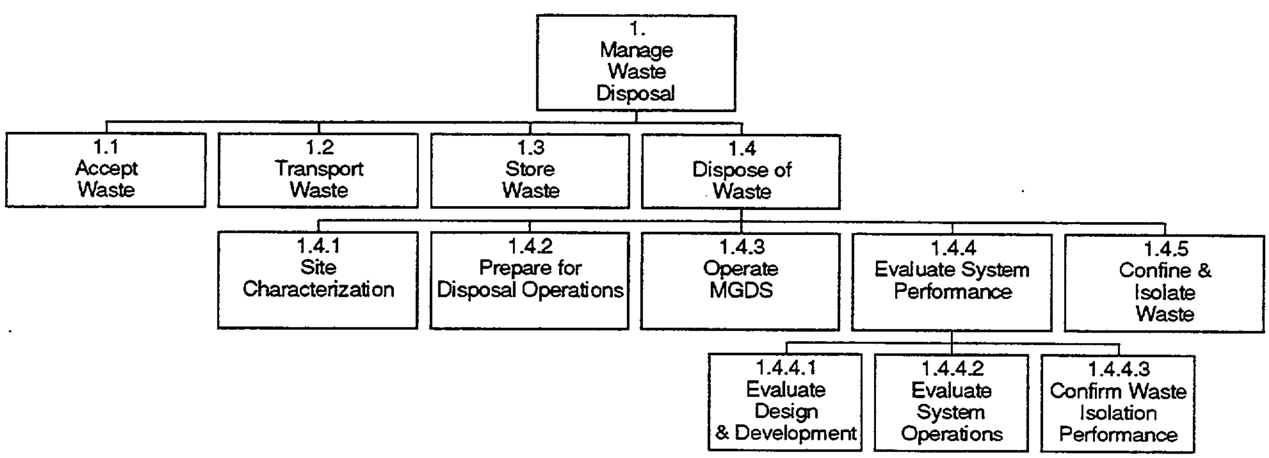

Figure 3-1. Performance Confirmation as a Function of MGDS

1.4.4 Evaluate System Performance

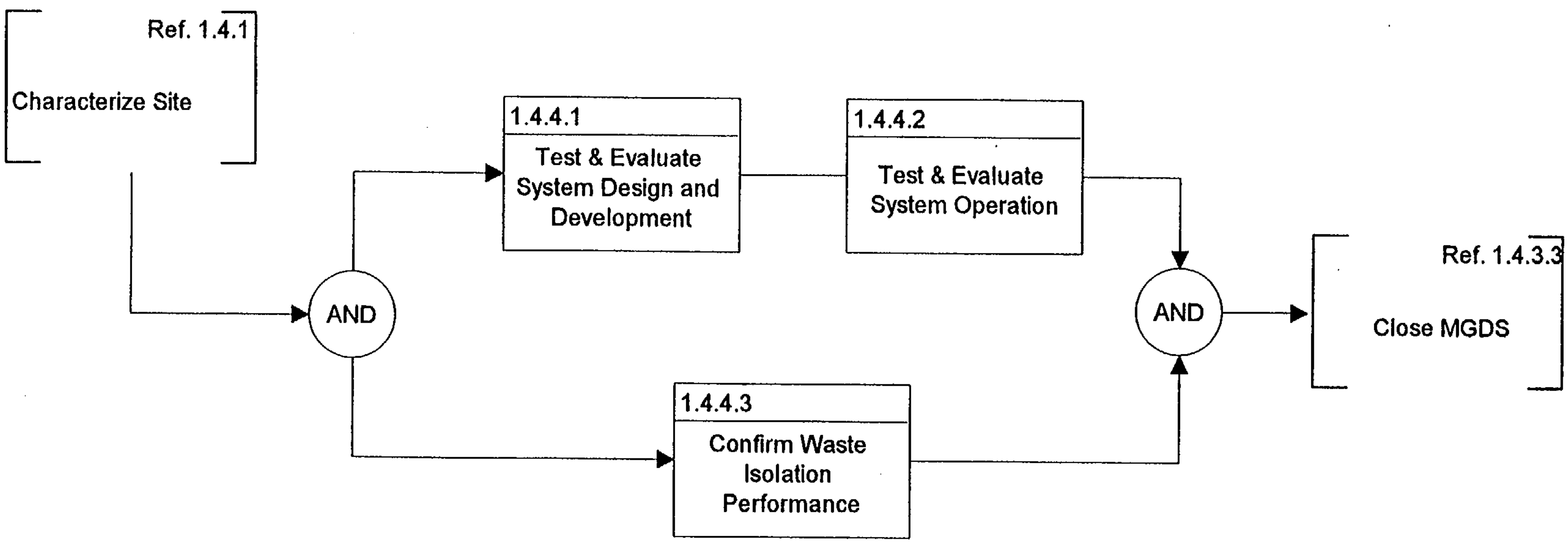

Figure 3-2. MGDS Evaluate System Performance Function

1.4.4 Evaluate System Performance (Proposed Definition)

The evaluate system performance function tests and evaluates the design, development and operational performance of the repository for the purpose of verifying design requirements and specifications; evaluating compliance with government regulations; and assessing environmental impact. The function interfaces with all MGDS functions, estimates the ability of the repository system to comply with regulations governing preclosure and postclosure performance objectives and its effect on the environment and uses the estimates in updates to compliance documents and in support of the continuing development of the system. It includes the conduct of performance confirmation and environmental monitoring programs and the planning for postclosure monitoring. The function is initiated during site characterization and ends with termination of the MGDS closure license.

1.4.4.1 Evaluate System Design and Development (Proposed Definition)

The evaluate system design and development function tests and evaluates the performance of the repository for the purpose of verifying design, regulatory, and license requirements. The function is comprised of system and subsystem development and qualifications tests, demonstrations, analyses, assessments, and predictions. The function began with Exploratory Studies Facility and waste package material testing during Site Characterization and ends when the license to operate is received and all repository elements are fully operational.

1.4.4.2 Evaluate System Operation (Proposed Definition)

The evaluate system operation function tests and evaluates the operational performance of the repository, its compliance with government regulations, its impact on the environment while operational, and its compliance with the licensing requirements. The function includes system and subsystem Operational Test and Evaluation activities beginning with the authorization to construct the repository and ends when all operational requirements have successfully been met.

1.4.4.3 Confirm Waste Isolation Performance (Proposed Definition)

The confirm waste isolation function confirms the Confine and Isolate Waste function of MGDS. This includes confirming that actual subsurface conditions encountered and changes in those conditions during construction and waste emplacement operations are within performance limits identified in the license, and confirming the natural and engineered systems for repository operation are within performance limits and consistent with the postclosure performance analytical predictions. The function begins with the collection of critical data during site characterization and ends with the confirmation that the waste isolation system meets required long term performance requirements.

3.2 DEFINITION OF PERFORMANCE CONFIRMATION FUNCTIONS

Figure 3-3 shows six performance confirmation functions which are referred to as Confirm Waste Isolation Performance (function 1.4.4.3). These functions are described below:

1.4.4.3.1 Develop and Validate Computer Models

The develop and validate computer models function defines those activities related to the development of computer modeling software which predicts the system performance of the Waste Isolation System. This function also includes the necessary steps to validate the software per *Quality Assurance Requirements and Description* (DOE 1996b) requirements. This function begins with results from Site Characterization and ends with the ability to predict Waste Isolation System performance.

1.4.4.3.2 Predict Waste Isolation Performance

The predict waste isolation system performance function consists of utilizing approved modeling software to predict the Waste Isolation System performance. The predicted results establish the performance baseline to be utilized in the license application. This function begins with validated computer models available for usage and ends with predicted results available for license application.

1.4.4.3.3 Test Waste Isolation Performance

The test waste isolation performance function will test critical parameters associated with the natural environments, induced environments, and effects on the design elements of the engineered barrier system. The function begins with waste emplacement and ends with the acquisition of data needed for waste isolation performance assessment.

1.4.4.3.4 Evaluate Waste Isolation Performance

The evaluate waste isolation performance function analyzes the critical processes of the natural barrier system and engineered system performance elements and provides a predicted performance calculation as to the performance of the waste isolation system. The function evaluates waste package performance, engineered barrier effectiveness, natural barrier effectiveness, human intrusion, and effects of the natural and induced environments. The function begins with the receipt of critical performance test data and ends with evaluation of the data to confirm the limits defined in the license.

1.4.4.3.5 Implement Corrective Action

The implement corrective action function defines the actions necessary to resolve discrepancies between the test data collected and the analytical evaluation of the modeled processes. The function could involve revision to the process models, updates/revisions to the software coding, enhancement in the test program, or revision to the waste isolation system design. The function begins when discrepancies are identified between the results from the performance confirmation test program and the process modeling and ends when the corrective action is implemented.

1.4.4.3 Confirm Waste Isolation Performance

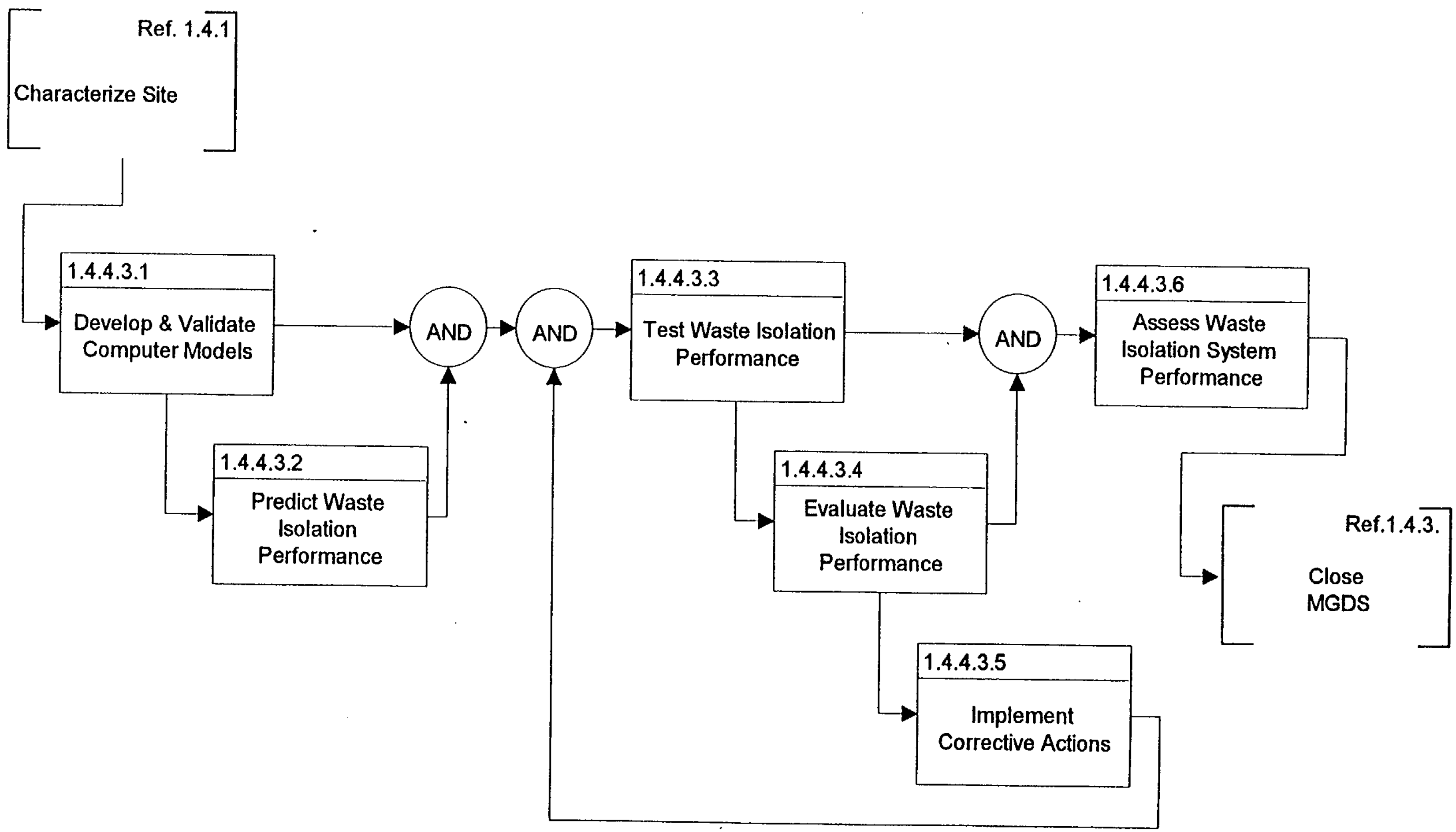

Figure 3-3. Performance Confirmation Functions

1.4.4.3.6 Assess Waste Isolation System Performance

The assess waste isolation system performance function is the analytical execution of verifying the waste isolation system meets or exceeds the required limits. The assessment will utilize qualified software and qualified supporting test data. The function begins with the completion of gathering all applicable test data , resolution of modeling parameters, and final concurrence on the predicted environmental and waste degradation process and ends when the final analytical results are approved and a recommendation for closure is obtained.

This section defines the primary functions of performance confirmation. The test (1.4.4.3.3) function and the evaluate (1.4.4.3.4) function, shown in Figures 3-4 and 3-5, respectively. The remaining Performance Confirmation functions (1.4.4.3.1, 2, 5, 6) are related to performance confirmation operations and are addressed in Appendix A, the Draft Performance Confirmation Plan.

Figure 3-6 shows the relationship between the test functions and the evaluate functions of performance confirmation. The latter (1.4.4.3.4.x), shown in Figure 3-5, correspond one-to-one to the subfunctions of Confine and Isolate Waste function (1.4.5) of MGDS, as defined in the Functional Analysis Document. The test functions (1.4.4.3.3.x), shown in Figure 2-4, provide test data, based on measurements that are required for evaluation. The test and evaluate functions are defined below.

1.4.4.3.4.1 Evaluate Waste Package Performance

This function confirms the Confine Waste function (1.4.5.1) of the MGDS. It evaluates the capability of the waste package to contain the waste and limit the release of radionuclides from the waste package boundary.

1.4.4.3.4.2 Evaluate Engineered Barrier Performance

This function confirms the Limit Radionuclide Release to the Natural Barrier function (1.4.5.2) of MGDS. It evaluates a) the rate of radionuclide transport from the WP to the Natural Barrier (after WP breach); b) the effects that the underground environments have on radionuclide transport; c) external criticality; and d) the effectiveness of the total Engineered Barrier System.

1.4.4.3.4.3 Evaluate Natural Barrier Performance

This function confirms the Limit Release of Radionuclides to the Accessible Environments function (1.4.5.3) of MGDS. It evaluates: a) the rate of radionuclide transport from the Engineered Barrier, through the Natural Barrier, to the Accessible Environments; and b) the potential dose to which the population may be exposed to as a result of the radionuclide release.

1.4.4.3.3 Test Waste Isolation Performance

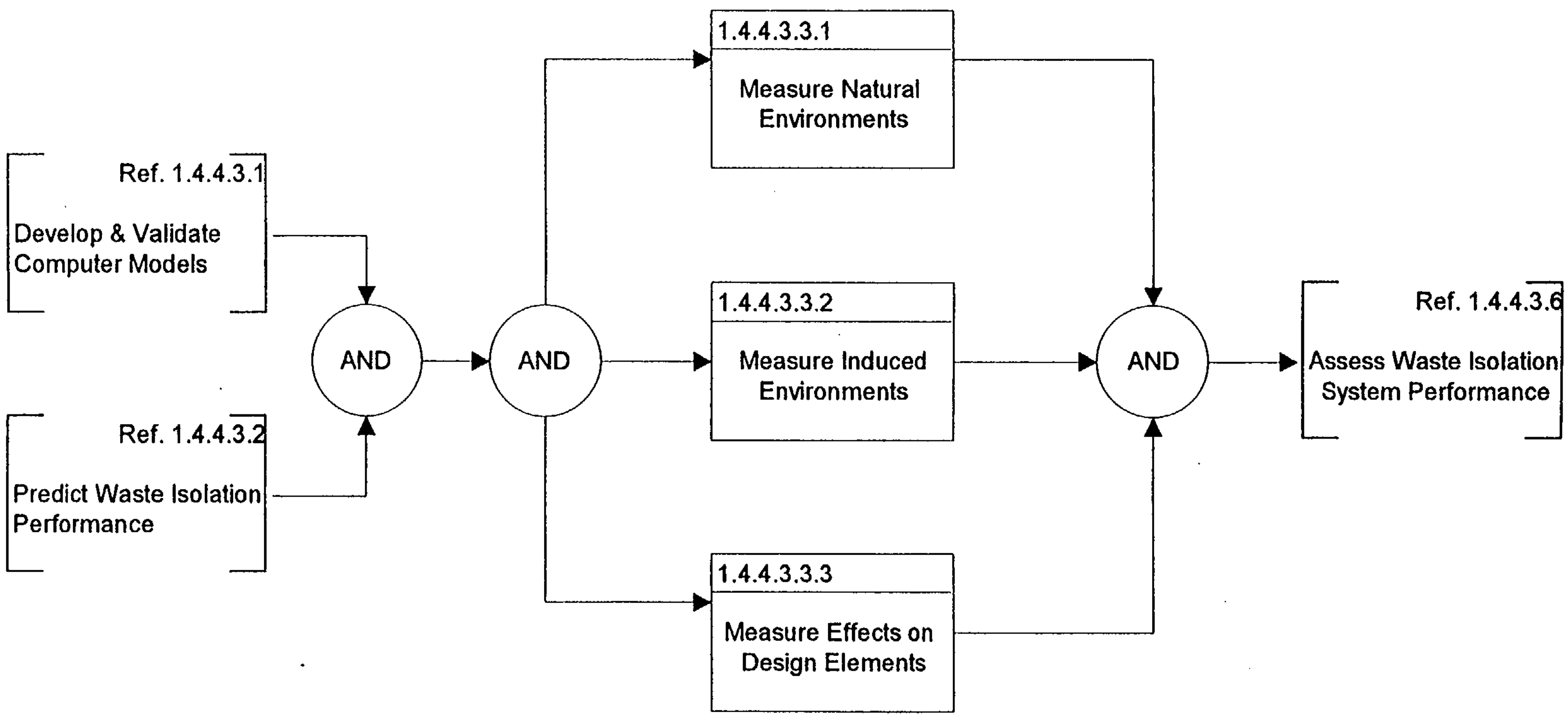

Figure 3-4. Performance Confirmation Test Functions

1.4.4.3.4 Evaluate Waste Isolation Performance

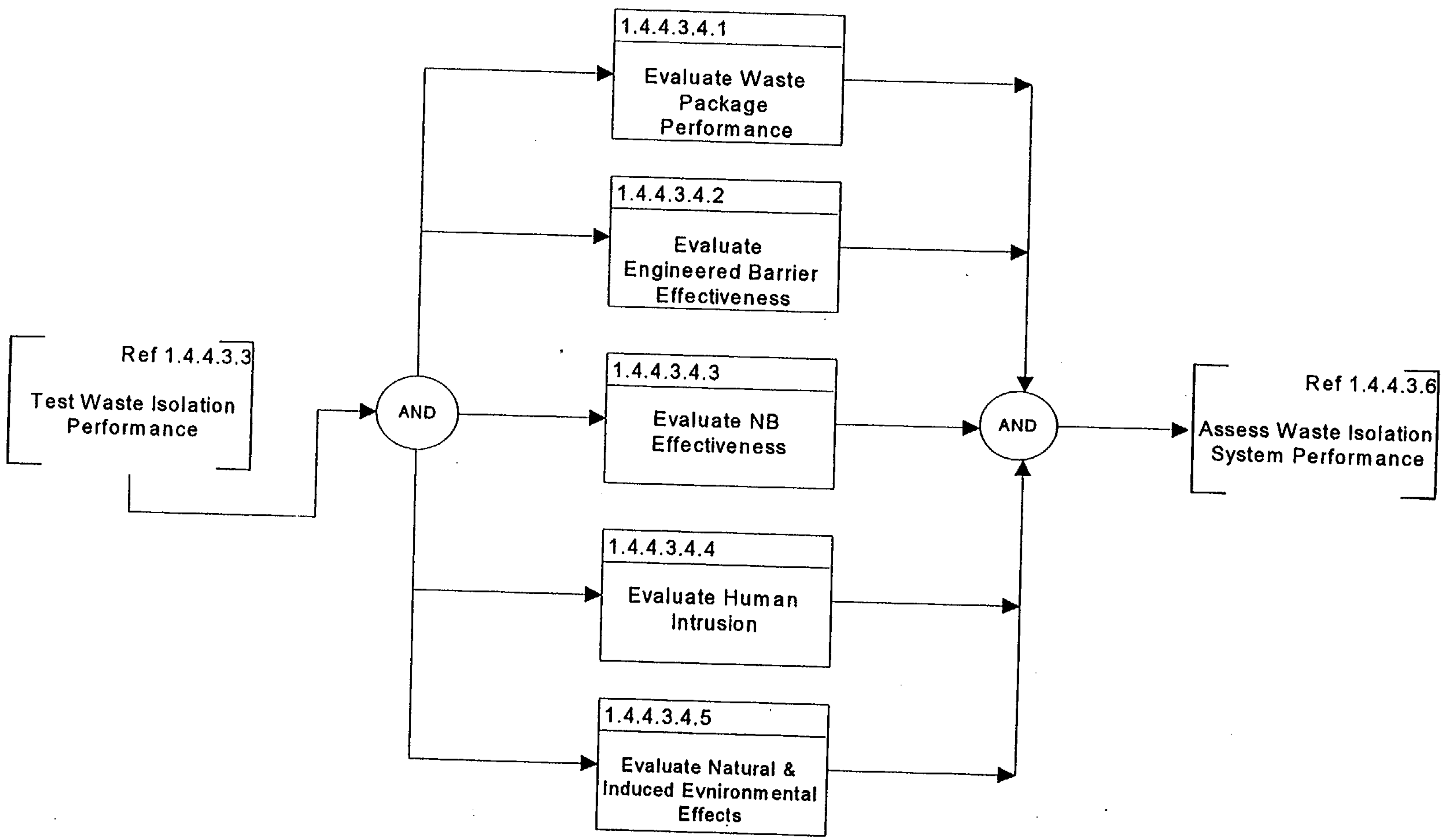

Figure 3-5. Performance Confirmation Evaluation Functions

PERFORMANCE CONFIRMATION TEST & EVALUATION FUNCTIONAL FLOW DIAGRAM

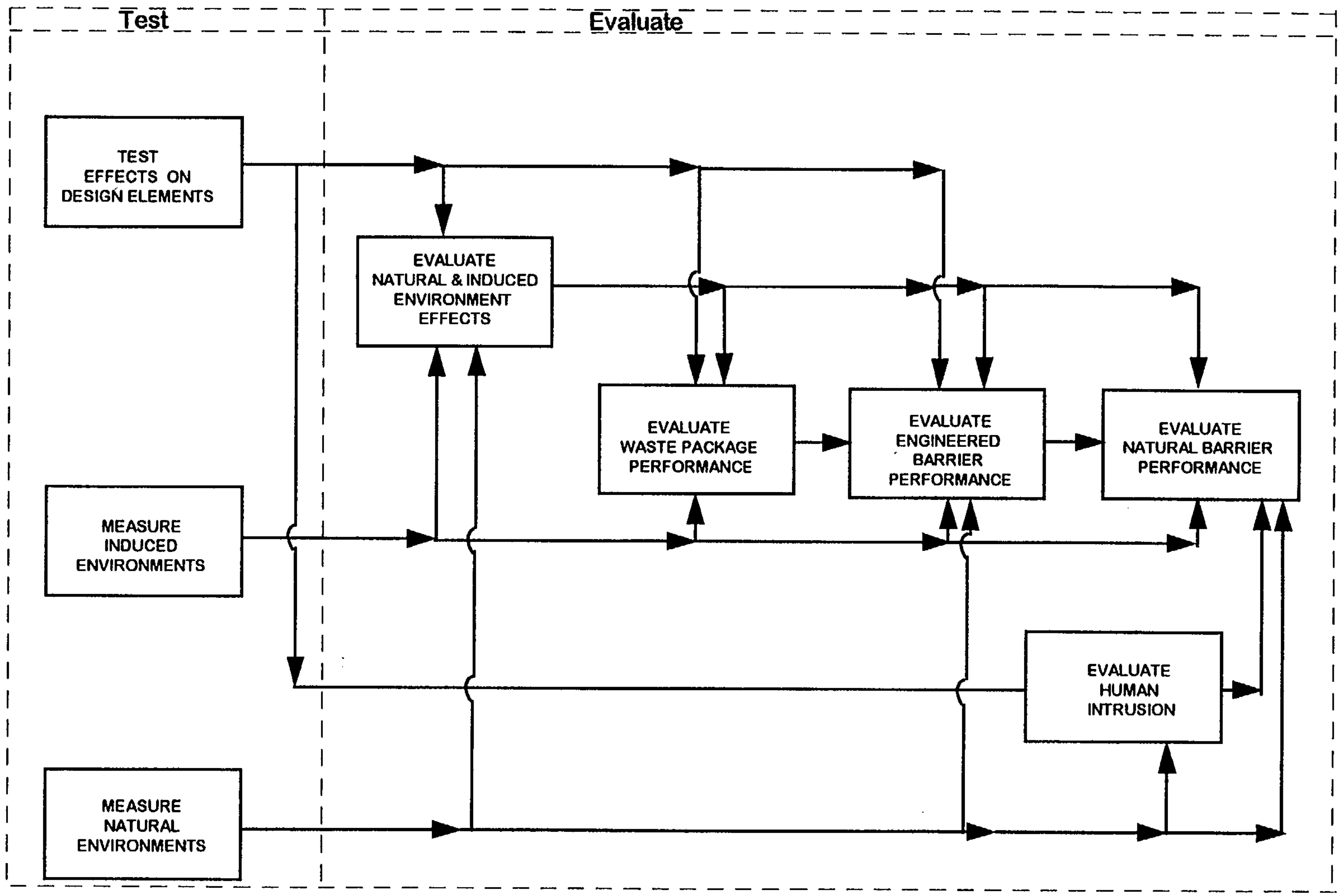

Figure 3-6. Relationships Among Performance Confirmation Test and Evaluation Functions

1.4.4.3.4.4 Evaluate Human Intrusion

This function confirms the Limit Human Intrusion function (1.4.5.4) of the MGDS. It evaluates changes in human population data and measures for preventing access to the underground repository.

1.4.4.3.4.5 Evaluate Natural and Induced Environment Effects

This function confirms the Limit Natural and Induced Environments function (1.4.5.5) of MGDS. It evaluates the impact of the natural environments on the engineered system and the effects of the system performance on the natural environments.

1.4.4.3.3.1 Measure Natural Environments

This function a) provides test data that extends the site characterization baseline (natural phenomena and rock characteristics), and b) monitors the effects on the site as a result of waste emplacement. The function starts when construction starts and ends with closure.

1.4.4.3.3.2 Measure Induced Environments

This function provides test and monitoring data of the surface and subsurface environments induces by the disposal of waste. These environments include thermal, thermo-hydrologic, structural-mechanical, thermo-chemical and radiation environments. The function starts with waste emplacement and ends with closure.

1.4.4.3.3.3 Test Effects on Design Elements

This function provides tests of the effects that the natural and induced environments produce on various design elements of the repository. These elements include the Waste Package, the emplacement drifts construction, backfill and seals. In-situ and laboratory testing and experimentation related to these elements is also included. The function starts with waste emplacement and ends with closure.

3.3 PERFORMANCE CONFIRMATION TEST AND EVALUATION LOWER-LEVEL FUNCTIONS

For each of test and evaluate functions lower-level subfunctions were identified. The subfunctions for the five functions in the evaluate group correspond, in general, to their counterparts in the MGDS Confine and Isolate Waste function (1.4.5.x).

The subfunctions for the three functions in the test group were organized based on the types, functions and objectives of the various tests. Figure 3-7 shows the organization of all performance confirmation functions.

PERFORMANCE CONFIRMATION TEST & EVALUATION FUNCTIONS

Performance Confirmation

Test Functions

Measure Natural Environments
- CLIMATIC EFFECTS
  - -Precipitation
  - -Wind
  - -Temperature
- NATURAL PROCESSES
  - -Erosion
  - -Tectonics
  - -Volcanism
- HUMAN POPULATION
  - -Access
  - -Economics
- SITE GEOLOGY
- SITE HYDROLOGY
- SITE GEOCHEMISTRY

Measure Induced Environments
- THERMAL
  - -Rock Temp
  - -Air Temp
  - -Waste Package Temperature
  - -Humidity
- THERMO-HYDRO
  - -Water Inflow
  - -Water Outflow
  - -Moisture Content
- STRUCTURAL/ MECHANICAL
  - -Rockfall
  - -Convergence
  - -Strain/Stress
  - -Seismic
- THERMO-CHEMICAL
- RADIATION

Measure Effects on Design Elements
- WASTE PACKAGE
  - -Disposal Container
  - -Emplacement Car
  - -Emplacement Drift Backfill
  - -Invert
- EMPL DRIFT CONSTRUCTION
  - -Metal
  - -Concrete
  - -Rockbolt
- ACCESS DRIFT BACKFILL
- SEALS

Evaluation Functions

Evaluate WastePackage Performance
- WASTE STABILITY
  - - Internal Criticality
  - - Internal Mobilization
- WASTE CONTAINMENT
  - -Structure Integrity
  - -Material Integrity

Evaluate Engineere Barrier Effectiveness
- RN TRANSPORT
  - -Water Out Flow/ Engineered Barrier
  - -Colloid Effects
  - -Sorbing/ Engineered Barrier
  - -Radionuclide Concentration
- EXTERNAL CRITICALITY
- EXTERNAL MOBILIZ
  - -Waste Dissolution
  - -Waste Oxidation

Evaluate Natural Barrier Effectiveness
- UNSATURATED ZONE
  - -Sorbing/Unsaturated Zone
  - -Dilution/Uusaturated Zone
  - - Time for Decay/ Unsaturated Zone
- SATURATED ZONE
  - -Sorbing/Saturated Zone
  - -Dilution/Saturated Zone
  - -Time for Decay/Saturated Zone
- GASEOUS RELEASE
- DOSE POTENTIAL

Evaluate Human Intrusion
- ACCESS CONTROL
- ECOMIC DESIRABILITY

Evaluate Natural & Induced Enviromental Effects
- ROCKFALL & CONVERGENCE
- FAST PATHWAYS TO ENGINEERED BARRIER
- EXPOSURE OF WASTE
- WATER FLOW INTO ENGINEERED BARRIER
- VENTILATION EFFECTS
- THERMAL IMPACT TO ENVIRONMENT
- INDUCED MATERIAL EFFECTS

Figure 3-7. Performance Confirmation Test and Evaluate Lower-Level Functions.

4. IDENTIFICATION OF PERFORMANCE CONFIRMATION PARAMETERS

A key step in identifying performance confirmation parameters to be confirmed is the identification of natural and engineered barrier processes to be analyzed to demonstrate compliance with the postclosure performance standards of 10 CFR Part 60 *Disposal of High-Level Radioactive Wastes in Geologic Repositories*. The processes are evaluated in performance assessments using key measures of effectiveness of the postclosure performance objectives. The next step was to identify process models and computer codes that are being used or may be used in the future for postclosure performance assessments. Parameters were then identified on the basis of the data needs of these process models and computer codes and the outputs generated by them. The linkage between the process models and the parameters is shown in a set of six tables in Appendix B. This chapter briefly describes the mathematical models and computer codes. The parameters are described in Section 4.2.6 below. The major steps in the approach to determine performance confirmation parameters are listed below along with an example at each step:

1) Identify the key measures of effectiveness for the post-closure performance objectives (e.g., 10,000 yr total peak dose at accessible environment (AE), substantially complete containment, etc.)

2) Identify models used to evaluate these measures of effectiveness and key process-level models that support the evaluations - the model used to develop predictions of performance (e.g., RIP, Unsaturated Zone (UZ) hydrology, near field hydrology, waste package degradation, etc.)

3) Identify parameters used in these models including data from site characterization and MGDS design (e.g., rock matrix effective porosity, temperature, moisture content, waste inventory, thermal loading, etc.)

4) Establish selection criteria to determine performance confirmation parameters (e.g., affected by construction or emplacement, time dependent variable, important to performance assessment, etc.)

5) Determine key parameters for design, that is, those parameters whose acquisition has a significant influence on the design of the repository or engineered barriers system (e.g., altered zone rock temperature, in situ fluid potential, moisture content, etc.)

Each of these major steps is discussed in the sections 4.2.1 through 4.2.5. In section 4.2.6, a description of the key performance confirmation parameters for design is provided.

4.1 IDENTIFICATION OF KEY MEASURES OF EFFECTIVENESS

The key measures of effectiveness are based on showing compliance with postclosure performance standards. Postclosure performance assessments are required to demonstrate compliance with the numerical standards of 10 CFR Part 60. These standards apply to the disposal system as a whole and separately to individual barriers or subsystems.

4.1.1 Total System Performance Standards

Total system performance standards are included in 10 CFR Part 60 issued by the Nuclear Regulatory Commission, which references environmental (i.e., radiological health) standards in 40 CFR Part 191 issued by the Environmental Protection Agency. The latter regulation was remanded by a court order, however, and new standards are currently being developed that consider recommendations of the National Academy of Sciences (NAS 1995). These recommendations by the NAS are more restrictive than the 10,000 year peak dose limits as identified in DOE planning guidance (YMSCO 1996) and in the DOE recommendations to the National Academy of Sciences (Dreyfus 1994), therefore the 10,000 year peak dose limits are not specifically discussed in this section of the report, but can be found in the identified references. Following is the text of the relevant regulations, supplemented with explanatory notes.

Nuclear Regulatory Commission

10 CFR 60.112 Overall System Performance Objective for the Geologic Repository after Permanent Closure. "The geologic setting shall be selected and the engineered barrier system and the shafts, boreholes and their seals shall be designed to assure that releases of radioactive materials to the accessible environment following permanent closure conform to such generally applicable environmental standards for radioactivity as may have been established by the Environmental Protection Agency with respect to both anticipated processes and events and unanticipated processes and events."

Environmental Protection Agency

The environmental standards of the U.S. Environmental Protection Agency (EPA) referenced above were set by 40 CFR Part 191 *Environmental Standards for the Management and Disposal of Spent Nuclear Fuel, High-Level and Transuranic Radioactive Wastes*. A court decision, however, remanded this regulation and directed the EPA to develop and the NRC to implement a site-specific standard to protect the public from radioactive wastes in a potential repository at the Yucca Mountain site. Following were the key provisions of 40 CFR 191, which covered radionuclide releases to the accessible environment, radiation doses to members of the public from drinking radioactive ground-water, and radionuclide concentrations in ground-water:

40 CFR 191.13 Containment Requirements. " (a) Disposal systems for spent nuclear fuel or high-level or transuranic radioactive wastes shall be designed to provide a reasonable expectation, based upon performance assessments, that the cumulative releases of radionuclides to the accessible environment for 10,000 years after disposal from all significant processes and events that may affect the disposal system shall: (1) have a likelihood of less than one chance in 10 of exceeding the quantities calculated according to Table 1 (Appendix A)[1]; and (2) have a likelihood of less than one chance in 1,000 of exceeding ten times the quantities calculated according to Table 1 (Appendix A)."

[1] Table 1 (Appendix A)" refers to the information contained in 40 CFR Part 191, not Appendix A of this report. Similarly for the reference to Note 6 and Appendix B in the following paragraph.

Table 1 in Appendix A of 40 CFR Part 191 lists release limits for specific radionuclides and in Note 6, provides a formula for calculating normalized releases. The formula requires that the sum of the individual radionuclide releases divided by their release limits has to be equal to or less than 1. Appendix B of 40 CFR Part 191 suggests that the results of total system performance assessments be presented as complementary cumulative distribution functions that indicate the probability of exceeding various levels of cumulative release. This function can include all the uncertainties, including the probabilities of processes and events as defined for (1) and (2) above.

40 CFR 191.15 Individual Protection Requirements. "Disposal systems for spent nuclear fuel or high-level or transuranic radioactive wastes shall be designed to provide a reasonable expectation that, for 1,000 years after disposal, undisturbed performance of the disposal system shall not cause the annual dose equivalent from the disposal system to any member of the public in the accessible environment to exceed 25 millirems to the whole body or 75 millirems to any critical organ. All potential pathways (associated with undisturbed performance) from the disposal system to people shall be considered, including the assumption that individuals consume 2 liters per day of drinking water from any significant source of ground water outside of the controlled area."

40 CFR 191.16 Ground-Water Protection Requirements. "(a) Disposal systems for spent nuclear fuel or high-level or transuranic radioactive wastes shall be designed to provide a reasonable expectation that, for 1,000 years after disposal, undisturbed performance of the disposal system shall not cause the radionuclide concentrations averaged over any year in water withdrawn from any portion of a special source of ground water to exceed: (1) 5 picocuries per liter of radium-226 and radium-228;(2) 15 picocuries per liter of alpha-emitting radionuclides (including radium-226 and radium-228 but excluding radon); or (3) the combined concentrations of radionuclides that emit either beta or gamma radiation that would produce an annual dose equivalent to the total body or any internal organ greater than 4 millirems per year if an individual consumed 2 liters per day drinking water from such a source of ground water. (b) If any of the average annual radionuclide concentrations existing in a special source of ground water before construction of the disposal system already exceed the limits in Sec. 191.16(a), the disposal system shall be designed to provide a reasonable expectation that, for 1,000 years after disposal, undisturbed performance of the disposal system shall not increase the existing average annual radionuclide concentrations in water withdrawn from that special source of ground water by more than the limits established in Sec. 191.16(a)."

National Academy of Sciences

Following the court order mentioned above, and as required by the Energy Policy Act of 1992, NAS prepared recommendations to the EPA on public health and safety standards for Yucca Mountain (NAS 1995). These recommendations include:

- use a standard that sets limits on the risk to individuals of adverse health effects from radioactive releases from the repository (a radionuclide release limit, as in 40 CFR Part 191, was not recommended);

- measure compliance with the standard at the time of peak risk, whenever it occurs (within the limits imposed by the long-term stability of the geologic environment, which the Committee believes to be on the order of one million years); and

- assess the consequences of future human intrusion into the repository, but do not include a risk-based calculation of the adverse effects of it.

The report also addresses other issues, including the use of a critical population group for assessing radiological risk and the application of individual barrier performance requirements. A public rulemaking is recommended to resolve these issues, which the EPA has started.

As a result of these recommendations, recent total system performance assessments have included the calculation of radiation doses an individual obtaining drinking water from a contaminated source five kilometers from the repository boundary for periods of up to one million years following permanent repository closure might receive.

4.1.2 Individual Barrier Performance Standards

The individual barrier performance standards apply to subsystems of the MGDS, including two for the engineered barrier system and one for the natural barrier, and are contained in 10 CFR 60.113 *Performance of Particular Barriers after Permanent Closure, (a) General Provisions*. The National Academy of Sciences (NAS 1995) has expressed concern about the use of subsystem performance objectives; they may not appear in the revision of 10 CFR Part 60 that will incorporate the EPA's expected new regulations for Yucca Mountain.

Waste Package Performance Standard

The first part of the engineered barrier system performance standard applies to waste containment within the waste packages as follows:

10 CFR 60.113(a)(1)(i)(A). "(i) The engineered barrier system shall be designed so that assuming anticipated processes and events, (A) containment of high-level waste will be substantially complete during the period when radiation and thermal conditions in the engineered barrier system are dominated by fission product decay."

10 CFR 60.113(a)(1)(ii)(A). "(ii) In satisfying the preceding requirement, the engineered barrier system shall be designed, assuming anticipated processes and events, so that (A) containment of high level waste (HLW) within the waste packages will be substantially complete for a period to be determined by the Commission taking into account the factors specified in Sec. 60.113(b) provided, that such period shall be not less than 300 years nor more than 1,000 years after permanent closure of the geologic repository."

Engineered Barrier System Performance Standards

The second part of the engineered barrier system performance standard applies to the barrier as a whole as follows:

10 CFR 60.113(a)(1)(i)(B). "(i) The engineered barrier system shall be designed so that, assuming anticipated processes and events, (B) any release of radionuclides from the engineered barrier system

shall be a gradual process which results in small fractional releases to the geologic setting over long times."

10 CFR 60.113(a)(1)(ii)(B). "(ii) In satisfying the preceding requirement, the engineered barrier system shall be designed, assuming anticipated processes and events, so that the release rate of any radionuclide from the engineered barrier system following the containment period shall not exceed one part in 100,000 per year of the inventory of that radionuclide calculated to be present at 1,000 years following permanent closure, or such other fraction of the inventory as may be approved or specified by the Commission; provided, that this requirement does not apply to any radionuclide which is released at a rate less than 0.1% of the calculated total release rate limit. The calculated total release rate limit shall be taken to be one part in 100,000 per year of the inventory of radioactive waste, originally emplaced in the underground facility, that remains after 1,000 years of radioactive decay."

Natural Barrier Performance Standard

The natural barrier performance standard establishes a minimum limit on the ground-water travel time as follows:

10 CFR 60.113(a)(2) Geologic Setting. "The geologic repository shall be located so that pre-waste-emplacement ground-water travel time along the fastest path of likely radionuclide travel from the disturbed zone to the accessible environment shall be at least 1,000 years or such other travel time as may be approved or specified by the Commission."

Potential Modifications of Requirements

Modifications of the above requirements are possible:

10 CFR 60.113(b). "On a case-by-case basis, the Commission may approve or specify some other radionuclide release rate, designed containment period or pre-waste-emplacement ground-water travel time, provided that the overall system performance objective, as it relates to anticipated processes and events, is satisfied."

That paragraph then lists five factors that the Commission may take into account to relax these requirements.

10 CFR 60.113(c). "Additional requirements may be found to be necessary to satisfy the overall system performance objective as it relates to unanticipated processes and events."

4.2 IDENTIFICATION OF MODELS

Postclosure performance assessment includes conceptual and mathematical modeling of natural and engineered barrier processes that may affect the postclosure performance, or waste isolation, of the Mined Geologic Disposal System (MGDS). It consists of a hierarchy of modeling of individual processes, coupled processes, and the total system as part of the evaluation of expected compliance with the regulatory standards. Figure 4-1 depicts a simplified performance assessment flow diagram of the individual processes listing the major inputs and outputs of that modeling. The figure shows that major inputs are derived from site characterization and waste package and repository design. Major outputs are the parameters required by the regulatory postclosure performance standards described in Section 4.1.

Following are brief descriptions of the major processes, in the same sequence as in the flow diagram of Figure 4-1 and in the parameter matrices in Appendix B. Appendix B shows the parameters that are used in the process and the computer codes that have been developed for the computer simulation of the process. Some of the processes are also simulated by total system performance assessment software, which is described after the discussion of the process models. The parameters include data provided by site characterization and MGDS design.

A summary of the computer codes that are being used or could be used for postclosure performance assessments is provided in Appendix H. Included are mathematical models and computer codes that may need to be modified as new site information becomes available, as the engineered system design develops, and as new understanding of natural and engineered barrier characteristics and processes is gained. The listed models and codes may need additional verification and validation before they can be qualified for use in a license application for a MGDS at the Yucca Mountain site.

Some of the listed computer codes are being used in support of MGDS design and Yucca Mountain site characterization and are not yet used in performance assessments. They are listed because they could be used to support future performance assessments. Some of the computer codes are not being used and funded at present. And because of the evolution of our understanding of natural and engineered barrier processes and computer technology, not all of the listed computer codes are expected to be used in support of the license application.

The performance confirmation concepts and parameters selected by this study are based on the current understanding of natural and engineered barrier processes, the mathematical models that have been formulated for these processes, the computer codes that have been developed to simulate these processes, and the parameters that are required for these computer codes. Uncertainties still exist with respect to these processes (e.g., rock matrix and fracture flow interactions, waste package barrier corrosion, and emplacement drift deformation and collapse). As new understanding is gained during site characterization (including research on engineered component behavior), the models and computer codes may change. The same may occur during performance confirmation. Consequently, changes in both site characterization and performance confirmation may be necessary to reflect any new understanding, models, computer codes, and parameter needs.

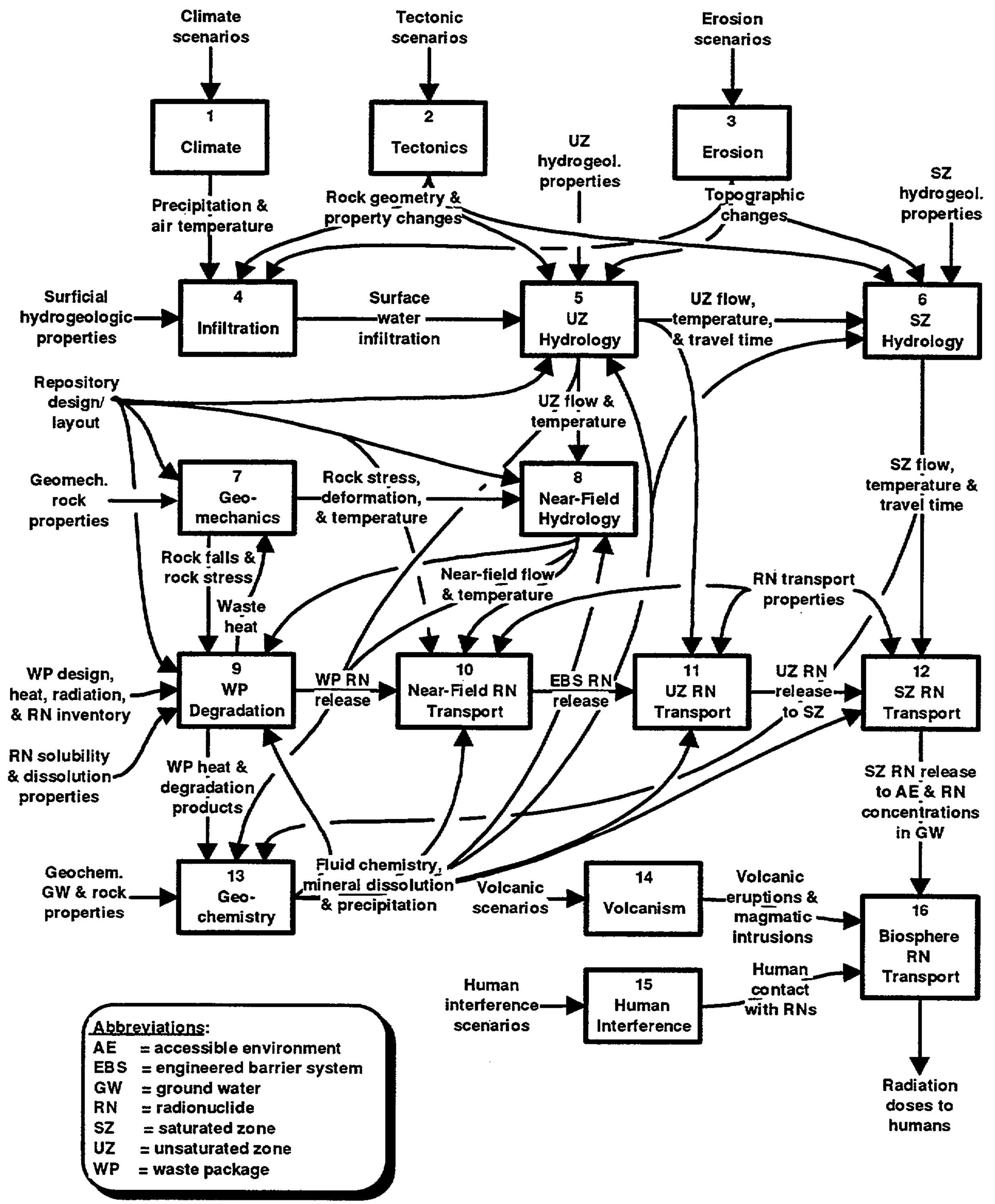

Figure 4-1. Simplified Flow Diagram for Postclosure Performance Assessment. (only major processes, linkages, and parameters are shown)

4.2.1 Climate

Climate affects the surface water infiltration rate, which affects the percolation flux at depth in the unsaturated zone, ground-water flow in the saturated zone, and the water table elevation. Climate modeling predicts principally future precipitation and air temperatures as input to estimating the surface water infiltration over the one-million year time frame of potential regulatory concern. Major inputs to climate modeling are scenarios with respect to future climatic changes, principally the cycles of arid and humid periods, including ice ages. Commonly, sinusoidal relationships are assumed for these long-term climatic variations. Different approaches are possible, including direct modeling of climatic changes on the basis of the paleoclimatic record to compute precipitation and air temperatures, or embedding sinusoidal relationships for infiltration directly into the ground-water flow models themselves without explicitly modeling precipitation and air temperatures. Specific mathematical models and computer codes have not yet been selected for the first approach, while the second approach has been employed in *Total System Performance Assessment - 1995* (TSPA) (CRWMS M&O, 1995a).

4.2.2 Tectonics

Tectonic activity (earthquakes, faulting, folding, and local and regional uplift and subsidence) resulting from continental drift, plate tetonics, and tectonic stress fields may change the geometry and hydrological and geomechanical characteristics of the natural barriers. This may include changing the relative elevations of recharge and discharge locations and thus water table elevations and aquifer gradients. Earthquakes may also result in short-duration fluctuations of the water table without associated changes in ground surface elevations and the geologic structure. Tectonic activity associated with fault movement may affect the hydrological and geomechanical characteristics of fracture zones. Tectonic deformation and earthquake activity may result in disruptions and re-arrangements of surface-water systems (e.g., warping, landslides, lateral offset of stream alignments along faults with associated effects on ground-water recharge and discharge areas). This could also change the local distribution of infiltration into the Yucca Mountain unsaturate zone. Mathematical models and computer codes have not yet been selected (Barr et al. in prep.). Computer codes have been used, however, for special studies, e.g., ELFPOINT, in support of a seismic ground-water pumping analysis, to compute seismically induced elastic rock deformations resulting from shear and tensile faulting (Arnold 1996).

4.2.3 Erosion

Erosion of the ground surface by wind and water and associated deposition of materials on the ground surface could reduce or increase the depth of a potential repository and also affect surface features that influence surface water infiltration. Erosion and deposition could affect a potentially favorable condition as defined by 10 CFR 60.122 (b)(5). Extreme erosion such as during the quaternary period, when continental Glaciation caused very heavy precipitation. could be a potentially adverse condition per 10 CFR 60.122 (c)(16). Because evaluations to date indicate that erosion is not a problem at Yucca Mountain (DOE 1993), development of a mathematical model and computer code for erosion and deposition is not planned.

4.2.4 Infiltration

For present climatic conditions, infiltration is derived from measurements of present climatic variables (principally precipitation, air temperatures, solar radiation, and potential evapotranspiration), soil/alluvial/colluvial moisture measurements in shallow boreholes, vegetative cover, and the surface geology (including areal distribution of the alluvium, colluvium, rock exposures, and known and suspected fracture zones). For postclosure predictions, spatially distributed annual precipitation may be sufficient, while seasonal variations may have to be considered for predicting unsaturated zone moisture conditions, especially if ground-water age dating indicates the existence of fast flow paths. Because of the potential for fast pathways of ground-water from the ground-surface to the repository horizon, individual rainstorm events may have to be analyzed as well to evaluate whether, how fast and how much percolation from individual rainstorm events could reach the repository.

4.2.5 Far-Field Unsaturated Zone Hydrology

The far-field unsaturated zone hydrology includes hydrologic processes within the three-dimensional site-scale unsaturated zone model defined by Wittwer et al. (1995) and any lateral extensions of that model that may be considered in the future. It is covered by the site-scale unsaturated zone hydrologic model in Chapter 10 of the TSPA - 1995 report. It does not include the effects of the waste heat and repository excavation on the unsaturated zone hydrology (this is covered by the near-field unsaturated zone hydrology). Far-field unsaturated-zone hydrologic processes include (a) percolation of water through the unsaturated zone resulting from surface water infiltration (including the effects of climate changes), and (b) flow of air and gases through the unsaturated zone. Isothermal conditions are usually assumed (that is, any effects of geothermal gradients and of the waste heat are not considered).

The principal output parameters of the site-scale unsaturated zone hydrologic modeling are (a) fluid potentials (including air pressure), (b) rock moisture content (including relative humidity), and (c) flow rates and velocities of water, air and gas (including their directions, flow paths, and flow times). The output includes the unsaturated-zone component of the pre-waste emplacement ground-water travel time as required by 10 CFR 60.113(a)(2) and initial conditions for the post-emplacement non-isothermal modeling (described for the near-field unsaturated zone hydrology).

Mathematical models and computer codes have been developed using different assumptions with respect to the coupling of fracture flow with porous matrix flow, numerical solution techniques, and other considerations. The principal computer codes being used in the Yucca Mountain Site Characterization Project (YMP) at present are FEHM/ FEHMN, NUFT, TOUGH2, and V-TOUGH. Other computer codes have been used for special purposes, e.g., GWRAND for unsaturated zone ground-water travel time analyses, LYNX for representing the geometry of excavations and hydrostratographic units and for performing related analyses, and WEEPTSA for probabilistic analysis of interactions of discrete fracture flow with waste containers.

4.2.6 Saturated Zone Hydrology

The saturated zone hydrology includes hydrologic processes within the three-dimensional regional and site-scale saturated zone models being developed. It is identified as the regional and site-scale saturated zone flow model in Chapter 10 of the TSPA - 1995 report. Far-field unsaturated-zone hydrologic processes include (a) recharge of the saturated zone resulting from surface water infiltration (including the effects of climate changes), (b) flow of water through the saturated zone, (c) discharge of water at natural discharge locations (springs and evaporation), and (d) ground-water pumping from wells. On the regional scale, isothermal conditions are usually assumed (that is, any effects of geothermal gradients and of the waste heat are not considered). On the site-scale, thermal effects of the waste heat need to be considered if they reach below the water table.

The principal output parameters of regional-scale saturated zone hydrologic modeling are (a) fluid potentials (including water table elevations) and (b) ground-water flow rates (including directions, flow paths, and flow times). The regional-scale output includes the initial and boundary conditions for the site-scale saturated zone modeling. The same output parameters result from the site-scale saturated zone hydrologic modeling, but with the consideration of heat, other outputs may be (a) rock and water temperatures, (b) rock moisture content (including relative humidity), and (c) flow rates and velocities of water vapor/steam, air and gas (including directions, flow paths, and flow times). The site-scale output includes the saturated-zone component of the pre-waste emplacement ground-water travel time as required by 10 CFR 60.113(a)(2).

Mathematical models and computer codes have been developed using different assumptions with respect to the coupling of fracture flow with porous matrix flow, coupling of fluid and heat flow, numerical solution techniques, and other considerations. The principal computer codes being used in the YMP at present are FEHM/FEHMN, MODFLOW, NUFT, TOUGH2, and V-TOUGH. Other computer codes have been used for special purposes, e.g., SATTRAK for saturated zone ground-water travel time analyses and MLAEM and SLAEM for regional saturated ground-water flow analyses to establish boundary conditions for site-scale saturated zone modeling.

4.2.7 Geomechanics

Geomechanics include thermal and thermal-mechanical processes within the thermally affected zone of the repository. Thermal and thermal-mechanical processes include (a) heat conduction and diffusion through the rock, (b) deformation and displacement of the rock (including excavation collapse and rock falls in excavations); and (c) thermal-mechanical effects on near-field hydraulic characteristics of the rocks. The principal output parameters of thermal-mechanical modeling are rock stress and strain and geometric changes (i.e., deformation, displacement, and rock falls).

Numerous thermal and thermal-mechanical models have been developed for the construction and mining industry for different assumptions with respect to the nature of the stresses and deformations. Thermal-mechanical analyses are just starting for postclosure performance assessment. The main use of these analyses has been to support Exploratory Studies Facility (ESF) and repository design. The heat conduction and diffusion code COYOTE has been used extensively in the YMP. Thermal-mechanical computer codes being used in the YMP for design purposes at present are 3DEC, ABAQUS, ANSYS, FLAC/FLAC3D, UDEC, and UNWEDGE.

4.2.8 Near-Field Unsaturated Zone Hydrology

The near-field unsaturated zone hydrology includes hydrologic processes within that portion of Yucca Mountain whose temperatures will be affected by the waste heat. It includes both the drift-scale and repository-scale unsaturated zone thermal-hydrologic model identified in Chapter 10 of the TSPA - 1995 report. Near-field unsaturated-zone hydrologic processes include (a) percolation of water through the unsaturated zone resulting from surface water infiltration, (b) flow of air and gases through the unsaturated zone, (c) perturbation of the water, air and gas flow by the waste heat of a potential repository, including the creation of water vapor/steam; and (d) effects of the waste heat and repository excavation on rock hydraulic characteristics.

The principal output parameters of near-field unsaturated zone hydrologic modeling are (a) rock and ground-water temperatures, (b) fluid potentials (including air pressures),(c) rock moisture content (including relative humidity), and (d) flow rates and velocities of water, water vapor/steam, air and gases (including their directions, flow paths, and flow times). Modeling is generally at a finer scale than for the far-field hydrology in order to more accurately represent the greater fluid and thermal gradients expected in the vicinity of the engineered barrier system.

Mathematical models and computer codes have been developed using different assumptions with respect to the coupling of fracture flow with porous matrix flow, coupling of fluid and heat flow, numerical solution techniques, and other considerations. The principal computer codes being used at present are the same as for the far-field modeling, namely FEHM/FEHMN, NUFT, TOUGH2, and V-TOUGH. Other computer codes have been used for special purposes, e.g., A-TOUGH and CLIMATE to compute the moisture removal from the excavations by the underground ventilation system, MPSalsa for thermal-hydrological modeling of unsaturated zone air and water flow, and STAFF3D for hydrothermal analyses in support of site characterization.

4.2.9 Waste Package Degradation

Waste package degradation covers the changes with time of the waste itself and of the barriers protecting the waste. It includes both the waste form dissolution model and the waste package degradation model in Chapter 10 of the TSPA - 1995 report. Waste package processes include (a) radioactive decay, (b) generation of heat,(c) radiation, (d) thermal-mechanical deformation, (e) waste package barrier corrosion by different mechanisms, (f) galvanic protection of the inner barrier by the outer barrier, (g) fluid flow (liquid, water vapor/steam, air and gases) within the waste package, (h) waste form dissolution, (i) aqueous and gaseous radionuclide release from the waste package into the emplacement drift (including diffusive and advective transport), (j) waste form and waste package barrier-related geochemical reactions, and (k) internal and external criticality. The performance of the cladding may be included, if it is decided to take credit for its performance or if its degradation may adversely affect the performance of other waste package components.

The principal output parameters are (a) the initial time of radionuclide release as required for the determination of the containment time in accordance with 10 CFR 60.113(a)(1)(i)(A) and 10 CFR 60.113(a)(1)(ii)(A), (b) temperatures of the waste package components (including at the waste form center and on the exterior walls),(c) stresses, strains and deformations of the waste package barriers, (d) crack formation as a result of mechanical stress and corrosion, (e) reduction of barrier thickness as a result of the different corrosion mechanisms, (f) radionuclide dissolution rates, (g) aqueous and gaseous radionuclide release rates from the waste package into the emplacement drift, and (i) conditions conducive to or preventing internal and external criticality.

Mathematical models and computer codes have been developed in the YMP for different waste package processes and using different assumptions. They include AREST, AREST-CT, PIGS, WPADEG, and YMIM. MCNP and SCALE are being used for criticality calculations. In addition, ORIGEN2 should be mentioned here, which provides the radionuclide inventory, radiation output, and heat output of spent fuel as a function of time; these data are required as input to the waste package degradation modeling.

4.2.10 Near-Field Radionuclide Transport

Near-field radionuclide transport includes the movement of aqueous and gaseous radionuclides from the waste package into the host rock and within the thermally altered zone. It is covered by the drift-scale radionuclide transport model in Chapter 10 of the TSPA - 1995 report.

Near-field radionuclide transport processes include (a) radioactive decay, (b) diffusive (molecular), dispersive (hydrodynamic), and advective transport of aqueous and gaseous radionuclides from the waste package through the emplacement drift (including through any backfill materials and through any rock materials resulting from rock falls and drift collapse); (c) diffusive and advective transport of aqueous and gaseous radionuclides through the altered zone, (d) formation and effects of colloids on radionuclide transport, (e) sorption of radionuclides on any backfill and rock materials in the emplacement drifts, (f) sorption of radionuclides on the rock in the altered zone, and (g) thermal-chemical effects on radionuclide transport and sorption.

The principal output parameters are (a) aqueous and gaseous radionuclide concentrations in any backfill and rock materials in the drifts, (b) aqueous and gaseous radionuclide concentrations in the rock within the altered zone, and (c) the radionuclide release rate from the engineered barrier system as required by 10 CFR 60.113(a)(1)(i)(B) and 10 CFR 60.113(a)(1)(ii)(B).

Mathematical models and computer codes have been developed using different assumptions with respect to radionuclide transport mechanisms, coupling with fluid flow and geochemical calculations, numerical solution techniques, and other considerations. The principal computer codes being used in the YMP at present are FEHM/FEHMN, NUFT, and TRACR3D/TRACRN. WEEPTSA is being developed for probabilistic analyses of the interaction of water flowing in discrete fractures with waste containers, radionuclide release from the waste containers, and radionuclide transport to the water table.

4.2.11 Far-Field Unsaturated-Zone Radionuclide Transport

Far-field unsaturated-zone radionuclide transport includes the movement of aqueous radionuclides from the thermally altered zone to the water table (if and when the altered zone does not extend to the water table) and of gaseous radionuclides from the thermally altered zone to the ground surface (if and when the altered zone does not extend to the ground surface). It is covered by the site-scale unsaturated zone radionuclide transport model in Chapter 10 of the TSPA - 1995 report.

Far-field radionuclide transport processes include (a) diffusive (molecular), dispersive (hydrodynamic), and advective transport of aqueous and gaseous radionuclides from the altered zone through the unsaturated zone to the water table (aqueous radionuclides) and ground surface (gaseous radionuclides), (b) formation and effects of colloids on radionuclide transport, and (c)sorption of radionuclides on the rock in the unsaturated zone.

The principal output parameters are (a) aqueous and gaseous radionuclide concentrations in the rock within the unsaturated zone, and (b) the aqueous and gaseous radionuclide release rate from the unsaturated zone to the water table and ground surface.

Mathematical models and computer codes have been developed using different assumptions with respect to radionuclide transport mechanisms, coupling with fluid flow and geochemical calculations, numerical solution techniques, and other considerations. The principal computer codes being used in the YMP at present are the same as for the near-field unsaturated zone radionuclide transport, namely FEHM/FEHMN, NUFT, and TRACR3D/TRACRN. As for the near-field radionuclide transport, WEEPTSA could be used for probabilistic analyses of the interaction of water flowing in discrete fractures with waste containers, radionuclide release from the waste containers, and radionuclide transport to the water table.

4.2.12 Saturated Zone Radionuclide Transport

Saturated zone radionuclide transport includes the movement of aqueous radionuclides from the water table below the potential repository to the accessible environment (or where ever required by any new regulations). It is covered by the site-scale saturated zone radionuclide transport model in Chapter 10 of the TSPA - 1995 report.

Saturated zone radionuclide transport processes include (a) radioactive decay, (b) diffusive (molecular), dispersive (hydrodynamic), and advective transport of aqueous radionuclides from the water table below the potential repository to the accessible environment;(c) formation and effects of colloids on radionuclide transport, and (d) sorption of radionuclides on the rock in the saturated zone. An important aspect, and uncertainty, is the mixing of radionuclides with depth below the water table, and thus the dilution of radionuclides in the saturated zone.

The principal output parameters are (a) aqueous radionuclide concentrations in the saturated zone (previously required by 40 CFR 191.16), and (b) the aqueous radionuclide release rate to the accessible environment (if and where ever required by any new regulation replacing 40 CFR 191.13).

Mathematical models and computer codes have been developed using different assumptions with respect to radionuclide transport mechanisms, coupling with fluid flow and geochemical calculations, numerical solution techniques, and other considerations. The principal computer codes being used in the YMP at present are the same as for the near-field and far-field unsaturated zone radionuclide transport, namely FEHM/FEHMN, NUFT, and TRACR3D/TRACRN.

4.2.13 Geochemistry

Geochemistry includes the effects of geochemical processes on all other processes. For the purposes of this report, it was not split into the categories listed in Chapter 10 of the TSPA - 1995 progress report, namely waste-package thermal-chemical model, drift-scale thermal-chemical model, and site-scale unsaturated zone geochemical model.

Waste package and drift-scale thermal-chemical processes include (a) the waste form dissolution itself (also listed under waste package degradation), (b) chemical aspects of waste package barrier degradation,(c) the generation of waste package degradation products, (e) interactions of the latter with any backfill, rock fall, and man-made materials in the emplacement drifts, and (f) any thermal-chemical reactions in the surrounding rock (including thermal-hydrological-mechanical changes as a result of the excavations and waste heat, effects of the thermal-chemical regime in the emplacement drifts, mineral dissolution and precipitation). Site-scale geochemical processes include geochemical changes resulting from (a) changes in hydraulic characteristics of the rocks (e.g., because of faulting, seismic fracturing, and other tectonic deformations), (b) surface water infiltration,(c) changes in water table elevations, and (d) future human activities.

The principal output parameters of geochemical and thermal-chemical modeling are the chemical concentrations, Eh and pH, of the fluids and solids in drifts, backfill materials, and rock pores and fractures.

At present, the principal geochemical model and computer code in the YMP is EQ3/6. Geochemical aspects are also being considered in computer codes for other processes, such as AREST-CT for waste package degradation modeling and OS3D/GIMRT for multicomponent reactive mass transport. The computer code VNETPC has been used to compute the removal of construction equipment exhaust gases by the underground ventilation system.

4.2.14 Volcanism

The possibility of future volcanic processes needs to be 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). Scenarios for basaltic igneous activity at Yucca Mountain have been formulated (Barr et al., 1993). 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 (reflected by the volcanism box in the flowchart). Indirect effects are related to changes in the ambient rock properties (thermal, mechanical, hydrologic, and geochemical) caused by a future intrusive magma body in the vicinity of the potential repository (not shown in the flowchart). 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/chemical attributes of the intruding body itself. One approach to addressing the indirect effects uses natural analogs of similar intrusive bodies in similar geologic and hydrogeologic settings.

Specific mathematical models and computer codes have not yet been selected. Preliminary analyses of magmatic intrusion into a potential repository are included in TSPA - 1991 (Barnard et al., 1992) and TSPA - 1993 (Eslinger et al., 1993; Wilson et al., 1994). These studies use existing process models to analyze the effects of the assumed intrusion on rock and ground-water conditions and radionuclide release.

4.2.15 Human Interference

Human interference includes all activities by people following permanent repository closure that could affect waste containment and isolation. It includes postclosure (a) direct drilling of boreholes into and through the repository, (b) hydrocarbon (oil, gas and coal) and mineral exploration and extraction within and near the repository boundary, (c) ground-water use (e.g., industrial and irrigation) and liquid and solid waste disposal within the area affecting ground-water flow and radionuclide transport with respect to the potential Yucca Mountain repository.

Direct drilling into the repository could result in a drill penetrating a waste package or contaminated rocks between or below the waste packages, resulting in immediate radiological exposures of the drillers. Hydrocarbon and mineral exploration would have the same consequences as the direct drilling if boreholes are involved. It could also entail excavation of tunnels and shafts, with radiological consequences to the miners and other workers. In addition, the use of any extracted hydrocarbons or minerals by people could expose them to radiation because of the potentially contaminated hydrocarbons or minerals. Drilling and excavations could also alter the hydrogeologic conditions at Yucca Mountain. Ground-water use and liquid waste disposal could change the moisture content of the unsaturated zone and the water table elevation, and thus the hydraulic gradients of the saturated zone. Both liquid and solid waste disposal could change the geochemistry of the unsaturated and saturated zone. Ground-water use and liquid and solid waste disposal could therefore change ground-water travel times, radionuclide dilution and sorption, and radionuclide concentrations in the ground-waters.

Mathematical models and computer codes have not been developed specifically for human interference. They are not needed because the processes involved, that is, ground-water flow, geochemical reactions, geosphere and biosphere radionuclide transport, and radiological exposures, can be simulated with existing mathematical models and computer codes for these processes. The principal output parameters are determined by the process models that are needed for a particular type of human interference.

4.2.16 Biosphere Radionuclide Transport

For the purposes of this report, biosphere radionuclide transport includes direct radiation, the movement of radionuclides above the ground surface, and radiological exposures of people following the permanent repository closure. Direct radiation exposures occur from contaminated air, soils, and surface water bodies (e.g., lakes, reservoirs, rivers) when a person is located (a) in contaminated air, (b) on contaminated ground, (c) on shores of water bodies, or (d) in water craft on the water bodies. Biosphere radionuclide transport includes (a) advection and dispersion of gaseous and solid radionuclides by wind, (b) advection and dispersion of dissolved radionuclides by surface water bodies, (c) plant uptake of radionuclides from contaminated soils or through irrigation with contaminated water, and (d) movement of radionuclides through the animal food chain. Radiological exposures from these mechanisms include inhalation of contaminated air and dust, absorption of radionuclides through the skin, drinking of contaminated ground or surface water, eating of contaminated crops and animal products, and swimming in contaminated surface water bodies.

The principal output parameters of the biosphere radionuclide transport modeling is the radiation doses received by members of the public. For current simulations, exposures have been calculated for an individual obtaining drinking water from a contaminated source five kilometers from the repository boundary as a function of time for up to one million years. The calculation of exposure to a representative or critical population group may be necessary if adopted by any new regulations.

Mathematical models and computer codes have been developed for different transport and exposure mechanisms. The principal computer codes being used in the YMP at present are GENII and MACCS.

4.2.17 Total System Performance Assessment Models

Total system performance assessment involves the simulation of all major processes that potentially affect postclosure performance of the potential repository in order to compute system and major subsystem performance measures. The system and subsystem performance measures are defined by regulatory requirements; they are summarized in Section 4.1. Past and present total-system performance assessments involved the computation (for up to one million years) of (a) the waste package containment time, (b) the annual radionuclide release rate from the engineered barrier system, (c)the radionuclide concentrations in the saturated zone, (d) the cumulative radionuclide release to the accessible environment with its associated cumulative complementary distribution function, and (e) radiation doses to an individual obtaining drinking water from a contaminated source five kilometers from the repository boundary .

These computations can be accomplished either with a single computer code, like RIP, or an assembly of individual process codes that are connected through common inputs and outputs, like TSA. In total system performance assessments, the effects of input parameter uncertainties on output parameter uncertainties are generally simulated as well. This is generally accomplished through repeated simulations, where each simulation selects different parameter values from the range of expected values. In RIP, this is accomplished automatically by randomly selecting parameter values from probability density functions of the uncertain parameters. As many as 1000 simulations (also called realizations) may be necessary to obtain valid statistics on the uncertainties of the computed outputs. The multiple simulations require simplifications for modeling the individual processes because of computer hardware limitations and to attain reasonable simulation times.

4.3 IDENTIFICATION OF CANDIDATE PERFORMANCE CONFIRMATION PARAMETERS

A process was developed for selecting key performance confirmation parameters whose measurement, monitoring, observation, or testing needs to be considered in the MGDS design. This process involved the following four steps:

1. preparation of a set of five tables listing all parameters and relating them to major process models,

2. development of criteria for selecting key performance confirmation parameters,
3. preparation of a new set of five tables for selecting performance confirmation parameters, and
4. extracting the key parameters from these five tables into a single table.

This last table formed the basis for developing the performance confirmation concepts for their measurement, monitoring, observation, or testing that are described in Chapter 5.

Following are descriptions of the four steps involved in the selection of the key parameters.

As the first step in the selection of performance confirmation parameters, a set of five tables was prepared that list in the left column all parameters that are required as (a) input to waste package and repository design, (b) input to postclosure performance assessments, (c)the result of waste package and repository design, and (d) the output of postclosure performance assessments. Because of the large number of parameters, the lists were split in accordance with the following five major subsystems of the natural and engineered barrier system:

1. general site parameters,
2. saturated zone parameters,
3. unsaturated zone parameters,
4. repository parameters, and
5. waste package parameters.

The other columns of these tables show which major performance assessment process model requires them as input or produces them as output. These tables are included in Appendix B. The processes themselves are described in Section 4.2.2 above.

Within each table, the parameters are organized by category. For instance, the saturated zone parameter table includes the categories alluvium/colluvium and rock matrix, rock fracture zones (including faults), ground-water, etc.

Within each category, the parameters are grouped by subcategory. For instance, in the saturated zone parameter table, the alluvium/colluvium and rock matrix category includes the subcategories stratigraphy, biological characteristics, chemical/mineralogical characteristics, hydraulic characteristics, etc.

A matrix of backfill and seal related parameters is still needed, but because the specific requirements on backfill and seals have not been set, specific parameters in this area were not further considered.

4.4 CRITERIA FOR SELECTION OF PERFORMANCE CONFIRMATION PARAMETERS

A selection process was formulated for identifying performance confirmation parameters, including key performance confirmation parameters whose data acquisition needs to be considered in the MGDS design. The process consider regulatory requirements, natural and engineered barrier processes, and the associated parameters. More specifically, the process considered the following factors in order to arrive at performance confirmation parameter selection criteria:

1. regulatory requirements or expectations by 10 CFR Part 60, Subpart F, specifically as reflected in Program level requirements documents and listed in the design inputs section 2.2.1 above;

2. functional requirements as reflected in the MGDS *Functional Analysis Document* (FAD) (CRWMS M&O 1996i).

3. analysis needs by the Waste Isolation and Containment Strategy (DOE 1996d); The waste isolation and containment strategy is still evolving (Draft Document). Thus, it was not used as part of the final screening process in the preparation of this study, but it should be considered in the final screen when the strategy is approved.

4. performance assessment needs as reflected by TSPA - 1995 (CRWMS M&O, 1995a), recent performance assessment (PA) process modeling, and expected future TSPA and PA process modeling;

5. the expected variability of parameters as a result of construction and waste emplacement;

6. the measurability and predictability of parameters;

7. the need and ability to reduce the uncertainty of parameters; and

8. the effect of the performance confirmation of parameters on MGDS design.

On that basis, the following twelve selection criteria were formulated (reasons are listed in italic):

1. The parameter is required to be measured, monitored, observed, or tested by 10 CFR Part 60, Subpart F. A list of specific parameters or parameter categories is provided below along with the referenced requirement and the regulatory source:

   a. Radioactive waste, the geologic repository including its structures, systems and components, radiation detection and monitoring instruments, and other equipment and devices used in connection with the receipt, handling, or storage of radioactive waste. from MGDSRD 3.7.2.7.A.1 which cites the regulatory source as [10 CFR 60.74(a)]

   b. Borehole and access seals, backfill, and the thermal interaction effects of the waste packages, backfill, rock, and ground water; from MGDSRD 3.7.2.7.B which cites the regulatory source as [10 CFR 60.142(a)].

   c. Rock deformations and displacement, changes in stress and strain, rate and location of water inflow into underground areas, changes in ground-water conditions, rock pore water pressures, including those along fractures and joints, and the thermal and thermomechanical response of the rock mass; from MGDSRD 3.7.2.7.C, which cites the regulatory source as [10 CFR 60.141(c)].

d. Thermomechanical response; from MGDSRD 3.7.2.7.D which cites the regulatory source as [10 CFR 60.141(e)].

e. Waste package monitoring, internal condition; from , MGDSRD 3.7.2.7.E, which cites the regulatory source as [10 CFR 60.143(c)].

f. Backfill placement and compaction; from MGDSRD 3.7.2.7.F, which cites the regulatory source as [10 CFR 60.142(c)].

g. Borehole and access seals; from , MGDSRD 3.7.2.7.G, which cites the regulatory source as [10 CFR 60.142(d)].
The requirements of 10 CFR Part 60, Subpart F, are the main reasons for the performance confirmation program and thus a key selection criterion. Included in this criterion are several requirements, as listed above.

2. The parameter is a determinant of the proper functioning of a structure, system, or component that has been allocated performance requirements relating to a confine and isolate waste function.
The confine and isolation waste function and its subfunctions, defined by the functional analysis, have to be addressed to assure that the data are available for demonstrating compliance with the regulatory requirements of 10 CFR 60.112 and 60.113.

3. The parameter is required to test the hypotheses of the waste containment and isolation strategy document (DOE 1996d).
Parameter needs of the waste containment and isolation strategy need to be considered to assure that its hypotheses can be tested and confirmed.

4. The parameter was used in TSPA - 1995 and is expected to be used in the TSPA for the site viability assessment and MGDS license application or the parameter is currently and/or planned to be used in design and performance assessment process level models of the MGDS.
All parameters needed for postclosure performance assessments, including for detailed natural and engineered barrier process modeling and for total system performance assessments, have to be considered.

5. The parameter needs to be measured, monitored, observed, or tested to confirm that actual subsurface conditions encountered are within the limits assumed in the licensing review [10 CFR 60.140(a)(1)].
Because site characterization measurements will be at a limited number of locations and depths, interpolations and extrapolations are required for MGDS design and performance assessments in support of the License Application. The assumptions involved may need to be confirmed as subsurface repository construction proceeds.

6. The parameter is appreciably affected by the subsurface construction process or by the emplacement of waste.
An important aspect of the confirmation of subsurface conditions is whether the parameter values are affected by the repository construction and waste emplacement. Because these changes may affect postclosure performance, confirmation of the changes predicted prior to submittal of the License Application may be needed.

7. The parameter is a variable (e.g., moisture content, rock temperature) that varies with time (note that material properties, e.g., hydraulic conductivity, that vary with time are not considered for this criterion).
A parameter may change with time even if it is not affected by repository construction and waste emplacement, for instance, because of climatic changes, earthquakes, and magmatic intrusions. Assumptions used in the License Application in this regard may therefore need to be confirmed. This criterion is not applied to material properties because their prediction is implicit in the modeling of the variables.

8. The parameter can be directly measured or derived from the results of analyses of measurements, tests or experiments.
A parameter cannot be a performance confirmation parameter if it cannot be directly measured or derived from the results of analyses of other measurements, tests, or experiments (e.g., lifestyles of future populations and radiation doses to people resulting from radioactive releases from the repository).

9. Spatial interpolation and/or future values of the parameter and tolerance or uncertainty bands for the parameter values can be predicted or estimated.
A parameter must be predictable and it must be possible to estimate the uncertainties in the predictions. Unless predictions can be made, performance confirmation is not necessary.

10. The parameter is a significant qualifier, disqualifier, or determinant of overall postclosure system performance (considering 10,000-year cumulative radionuclide release, 10,000-year total peak radiation dose, and 1,000,000-year total peak radiation dose), the postclosure performance of particular barriers (e.g., substantially complete containment and controlled release) as documented in TSPA - 1995 and/or process model analyses reports, and/or is expected to be a significant qualifier, disqualifier, or determinant in future analyses. [10CFR 60.140 (a) (2)].
Even if all other screens are passed, if the parameter is not important as a qualifier, disqualifier, or determinant of postclosure subsystem or system performance, its performance confirmation is superfluous.

11. The parameter has a reasonable amount of uncertainty, the uncertainty can be reduced by performance confirmation, and the consequence is large if the parameter is found to deviate from tolerance bounds.
If the parameter is well known (e.g., radionuclide half lives or design parameters), it does not need to be confirmed. If the nature of its measurement is such that any existing uncertainty cannot be reduced, it does not need to be confirmed. And even if the

uncertainty is large, if the consequence of that uncertainty with respect to postclosure performance predictions is not significant, the parameter does not need to be confirmed. If a parameter passes all previous screens and this criterion applies, the parameter is a performance confirmation parameter.

12. The acquisition of the parameter significantly influences the design, construction, operations, cost, or schedule of the repository segment or engineered barriers segment. *The above considerations have to apply in order for a performance confirmation parameter to be selected as a key performance confirmation parameter.*

Cost and schedule are not considered as criteria for selecting performance confirmation parameters because technical factors were considered sufficiently important that they should not be influenced by cost and schedule considerations. Cost and schedule, however, influence the MGDS design and hence were factored into deciding if an performance confirmation parameter should be a key performance confirmation parameter. Cost is primarily a factor in evaluating alternative performance confirmation concepts with respect to locations, frequency, and duration of the performance confirmation data acquisition.

4.5 DETERMINATION OF KEY PARAMETERS FOR DESIGN

A new set of five tables was then prepared that lists the same parameters as the first set of tables in the left column and the selection criteria listed above, in abbreviated form, as additional columns. These tables are included in Appendix C.

The twelve selection criteria were then grouped into four sequential screens on the basis of their interrelationships and entered as columns in those six tables, using abbreviated titles. A parameter had to pass each screen in order to be considered for the next screen. Finally a parameter selected as a performance confirmation parameter would become a key performance confirmation parameter if its data acquisition would affect MGDS design. This screening process, using the abbreviated forms for the twelve selection criteria, is depicted in Table 4-1 and in the flowchart in Figure 4-2.

Because the intent of the screening process is to identify performance confirmation on technical grounds, a parameter required by 10 CFR Part 60, Subpart F, may not be selected as a performance confirmation parameter. If this is the case, resolution with the U. S. Nuclear Regulatory Commission (NRC) would be needed. This is indicated in the flowchart as an additional question following Screen 4. In general, Subpart F concentrates on identifying conditions, processes, and general changes that need to be confirmed. It does not identify specific parameters for most requirements with the exception of 10 CFR 60.141(c). As it turned out, all of the parameters listed in that paragraph were selected as performance confirmation parameters because they passed the entire screening process on technical grounds.

Table 4-1. Performance Confirmation Parameter Selection Process

Screen 1: 1. 10 CFR 60 Subpart F 2. Confine & isolate waste function 3. Containment & isolation strategy 4. TSPA & PA process models	A parameter had to pass only one of these criteria in order to move to the next screen because confirmation may be needed if any one of them would apply
Screen 2: 5. Subsurface conditions 6. Affected by construction/emplacement 7. Time dependent variable	A parameter had to pass only one of these criteria in order to move to the next screen because confirmation may be needed if any one of them would apply
Screen 3: 8. Can be measured or derived 9. Can be predicted or estimated 10. Important to performance	A parameter had to pass all three of these criteria in order to move to the next screen, because if anyone of them did not apply, the parameter could not be or would not have to be confirmed
Screen 4: 11. Reduce uncertainty 10 CFR Part 60 Subpart F	A parameter had to pass this screen because it would not have to be confirmed if its uncertainty was acceptable or irreducible; if a parameter required by Subpart F would not be selected, resolution with the NRC would be required
Screening results: Performance confirmation parameter 12. Key parameter for design	A parameter passing screen 4 would be a performance confirmation parameter; a performance confirmation parameter affecting design would be a key parameter for design

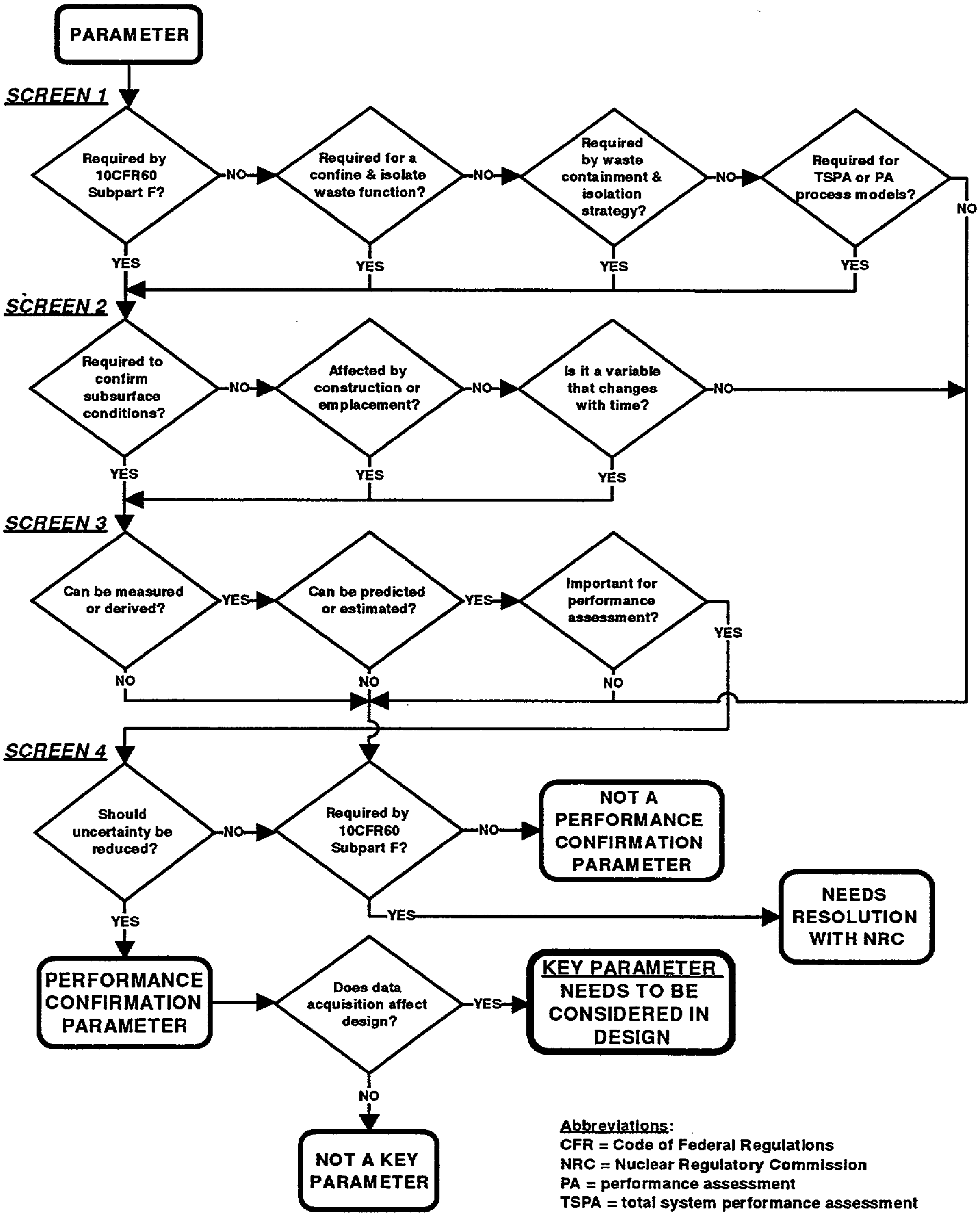

Figure 4-2. Selection Process for Key Performance Confirmation Parameters.

The screening was performed by a team representing systems engineering, repository design, waste package design, site characterization, and performance assessment. The tables in Appendix C show the results of that screening. From these tables, a new table was created that lists only the key performance confirmation parameters, because only those are of interest for the current report. This table is in Appendix D.

From a total of 435 parameters listed in the five tables in Appendix C, 126 were selected as performance confirmation parameters and 94 of these as key performance confirmation parameters (the actual number will be greater because some parameters consist of several different measurements, for instance, geochemical compositions). Many parameters were not selected because they are expected to be sufficiently known from site characterization by the time a License Application will be submitted. This assumption may not be correct because of uncertainties in the remainder of the site characterization program. Consequently, it is recommended that the parameter selection process is revisited on an annual basis to ensure that no parameters are overlooked in the performance confirmation program.

As mentioned in previous sections, the emphasis of the performance confirmation program is to confirm that subsurface conditions encountered during repository construction and waste emplacement and changes in the natural and engineered barrier system with respect to postclosure performance resulting from repository construction and waste emplacement will be as assumed in the License Application. Although the *Site Characterization Plan* (DOE 1998) indicates in Section 8.3.5.16 that some of the performance confirmation activities are expected to be continuations of site characterization activities, many of the site characterization activities will be terminated, while new activities, primarily with respect to natural and engineered system performance prior to repository closure, will be entirely new. Details are provided in the description of recommended performance confirmation concepts in Section 5 of this report.

4.6 DESCRIPTIONS OF KEY PERFORMANCE CONFIRMATION PARAMETERS FOR DESIGN

Performance confirmation activities need to confirm three major aspects of most parameters:

1. that the spatial interpolation and extrapolation of point measurements is within acceptable bounds of error;

2. that the temporal changes in parameter values resulting from the excavation and waste emplacement are within acceptable bounds of error; and

3. that compliance with the regulatory postclosure performance standards of 10 CFR Part 60 can still be demonstrated, in spite of any changes in parameter values.

The first two aspects are the key considerations for the data acquisition aspects of the performance confirmation program. The first aspect needs to be confirmed as subsurface excavation proceeds in order to obtain data that are not affected by the excavation and waste emplacement. The second aspect needs to be confirmed over longer time periods following excavation and waste emplacement (for some parameters until permanent repository closure) in order to measure the excavation and waste emplacement effects as functions of space and time. The third relates to the evaluation of the collected data for predictive purposes.

Following are descriptions of the key performance confirmation parameters that need to be considered in the design of the engineered barrier system in order to assure that the planned performance confirmation activities can be performed. The other parameters, including performance confirmation parameters that do not influence design, will be described in a future update of this report. The descriptions are by category and subcategory, in the same sequence as in the parameter tables, parameter selection tables, and key parameter table in Appendix D.

4.6.1 General Site Parameters

The list of general site parameters (Appendix D) includes those site characteristics that apply to both the unsaturated and saturated zones or to the site in general. It covers features of the site and vicinity approximately bounded by Crater Flat in the west, Rainier Mesa in the north, Jackass Flats in the east, and the Amargosa Valley in the south. Extension to Death Valley may be necessary depending on evidence with respect to the connectivity of the Yucca Mountain saturated-zone ground-water system with the groundwater in Death Valley.

The general site parameters are organized into the following four categories: (1) physiography, (2) future geologic events and processes, (3) postclosure human interference, and (4) postclosure demography, lifestyles, and public exposure mechanisms.

Physiography includes the subcategories topography, vegetation, climate and meteorology, and surface hydrology. Future geologic events and processes include the subcategories future erosion and deposition, future uplift and subsidence, future volcanic eruptions and magmatic intrusions, and future seismicity. Postclosure human intrusion includes the subcategories postclosure borehole drilling (directly into the engineered barrier system), postclosure hydrocarbon (coal, oil, and gas) and mineral exploration and extraction, postclosure ground-water use (e.g., for industrial and irrigation purposes) and liquid waste disposal, and postclosure solid waste disposal. Postclosure demography, lifestyles and public exposure mechanisms include the subcategories postclosure population, postclosure crops, livestock and food, other postclosure exposure mechanisms (e.g., swimming and boating), and postclosure public health risk. The latter subcategory includes potential postclosure radiological performance standards for peak radiation dose to the maximally exposed individual and to a representative population group. Although these would be important postclosure performance assessment parameters, they were not selected as performance confirmation parameters because no radiation doses to the public are expected from potential postclosure processes before repository closure.

From the general site parameter list, only two parameters, namely (1) future seismicity and (2) postclosure hydrocarbon and mineral exploration and extraction, were selected as key performance confirmation parameters. These parameters are briefly described below.

Future Seismicity

A surface-based monitoring network exists at present that records seismic activity at the site and surrounding areas. Continuation of the surface-based monitoring and measurements of subsurface acceleration/ground motion are recommended (a) to confirm that facility and excavation design assumptions are correct, (b) to have a record of earthquakes should any damage occur,(c) as a basis for evaluating any subsurface rock falls, rock deformations, and fault movement, (d) as a basis for any above ground changes (including topographic), and (e) to confirm damping or reduction of acceleration/ground motion with depth. The measurements to be taken and/or derived from the monitoring include the location and depth of epicenters, the earthquake magnitude, and the acceleration/ground motion. The monitoring program is needed to evaluate potentially adverse conditions in accordance with 10 CFR 60.122(c)(12), (13), and (14) with respect to the repetition of historic earthquakes or a potential increase in the frequency and magnitude of earthquakes that are typical for the area.

Postclosure Hydrocarbon (Coal, Oil, and Gas) and Mineral Resource Exploration and Extraction

Current site information indicates that no recoverable hydrocarbons and minerals (other than common construction materials) exist at the Yucca Mountain site. Geologic mapping and associated laboratory analyses of rock samples are recommended if any indications of hydrocarbon and mineral resources (other than common construction materials) are found during the subsurface excavation process. The location of the sampling needs to be recorded, and if any hydrocarbons or minerals are found, the type of coal, oil, gas, or mineral has to be determined and the potential recoverable quantity estimated because it could be a potentially adverse condition in accordance with 10 CFR 60.122(c)(17).

4.6.2 Unsaturated Zone Parameters

The list of unsaturated zone parameters (Appendix D) includes those site characteristics that apply specifically to the unsaturated zone. At present, the unsaturated zone at the Yucca Mountain site is defined by the preliminary three-dimensional site-scale model of the unsaturated zone (Wittwer et al., 1995). It includes all hydrogeologic units between the ground surface and the water table. It covers an area of about 34 km^2 that is bounded by straight lines along the Solitario Canyon fault to the west, Yucca Wash to the north, the Bow Ridge fault to the east, and by an west-east line about 2.5 km to the south of the potential repository boundary. The lateral extent of this model may be extended depending on new site information and conceptual designs for the subsurface repository. This may affect activities related to performance confirmation parameters in general, but not key performance confirmation parameters whose data acquisition is restricted to the waste package, subsurface repository, and associated laboratory activities.

The unsaturated zone parameters are organized into the following four categories: (1) alluvium/colluvium and rock matrix, (2) rock fracture zones (including faults), (3) ground water (in the rock matrix, fractures, fault zones, and other discontinuities), and (4) subsurface air and gases (in the rock matrix, fractures, fault zones, and other discontinuities).

The first two categories include properties of the rocks themselves, while the latter two categories include properties of the subsurface fluids (i.e., water, water vapor/steam, air, and other gases). Subcategories within these categories include stratigraphy of the alluvium/colluvium and rock matrix, geometry of fracture zones, biological, chemical/mineralogical, hydraulic, pneumatic, mechanical, and thermal characteristics, naturally occurring radon, and aqueous and gaseous radionuclide transport. The pre-waste-emplacement ground-water travel time requirement of 10 CFR 60.113(a)(2) is one of the parameters in the unsaturated zone parameter list, but not a key performance confirmation parameter.

From the unsaturated zone parameter list, 36 parameters were selected as key performance confirmation parameters. Some of these parameters, like ground-water chemical composition, include more detailed characteristics, so that the actual number of key performance confirmation parameters is larger. The selected parameters are briefly described below.

Alluvium/Colluvium and Rock Matrix

The alluvium/colluvium and rock matrix includes porous rocks within the unsaturated zone whose fractures, if any, can be represented as an equivalent porous medium for ground-water flow, radionuclide transport, and rock stability/deformation/displacement modeling. The applicability of the equivalent porous medium assumption depends on the spatial scale of the model selected and the objectives of the analyses, thus may vary between different analyses.

<u>Stratigraphy of Alluvium/Colluvium and Rock Matrix</u>. The stratigraphy of the hydrogeologic units is essential information for MGDS design and performance assessments. Confirmation of the rock types and mineralogy encountered during subsurface excavation will confirm the design and performance assessment assumptions made for the license application. Rock types and mineralogy are basic information for spatial extrapolations of point measurements of other rock characteristics, such as hydraulic conductivity, radionuclide sorption coefficients, and geochemical reaction analyses.

<u>Hydraulic Characteristics of Alluvium/Colluvium and Rock Matrix of Altered Zone</u>. Hydraulic characteristics of the unsaturated zone are required for ground-water flow and radionuclide transport modeling. The flow modeling requires the saturated hydraulic conductivity and relationships between (a) the hydraulic potential (also called soil moisture tension) and moisture content and (b) the moisture content and unsaturated hydraulic conductivity. These relationships, named after the researchers who developed them, are based on experimental evidence (e.g., Van Genuchten, 1980). The transport modeling requires the effective porosity and the dispersivity or dispersion coefficient. These measurements are typically obtained through laboratory testing of rock samples from a limited number of locations. Extrapolation and interpolation is then used to derive their initial values (prior to excavation and waste emplacement) for the entire model domain and modeling is used to predict their changes with time resulting from the excavation and waste emplacement. Performance confirmation is recommended only for the thermally altered zone.

Pneumatic Characteristics of Alluvium/Colluvium and Rock Matrix of Altered Zone. Among the various pneumatic rock characteristics, only the air permeability in the altered zone was selected as a key parameter because of its importance in modeling two-phase ground-water flow (i.e., liquid water and water vapor/steam) resulting from the waste heat.

Mechanical Characteristics of Alluvium/Colluvium and Rock Matrix of Altered Zone. In situ rock stress, strain (i.e., the change of rock length per unit length of rock or of rock volume per unit volume of rock), deformation, and displacement may affect the hydraulic characteristics (e.g., hydraulic conductivity and porosity) of the rocks, and thus ground-water flow. They are needed for thermal-mechanical analyses to predict potential rock falls and emplacement drift collapse that may deform waste packages, change the stress distribution in waste packages (which may have an effect on waste package barrier corrosion), and directly fracture waste packages. They are also needed for thermal-mechanical-hydrological analyses to predict the changes in the hydraulic characteristics of the thermally altered zone.

Thermal Characteristics of Alluvium/Colluvium and Rock Matrix of Altered Zone. The rock temperature will change as a result of the waste heat, and in turn, affect ground-water flow (both liquid and water vapor/steam), which are important processes for waste package performance. Consequently, the accuracy of the rock temperature predictions in the license application are crucial for confirming the waste package and TSPA predictions.

Rock Fracture Zones (Including Faults)

Rock fracture zones, including faults, are those parts of the unsaturated zone whose fracture characteristics need to be considered in ground-water flow, radionuclide transport, and rock stability/deformation/displacement calculations, that is, cannot be adequately represented by an equivalent porous medium assumption. The need for considering the fracture characteristics separately from the porous rock matrix characteristics depends on the spatial scale of the model selected and on the objectives of the analyses; thus, they may vary between different analyses.

Geometry, Including Future Displacements of Rock Fracture Zones (Including Faults). Rock fracture zones (including faults), depending on their characteristics, can be conduits or barriers to ground-water flow and radionuclide transport. They affect the mechanical stability/deformation/displacement of the rocks induced by the excavations and the waste heat. A basic component of fracture zone (including fault) characterization is their geometry, that is their location, orientation, length, and width, and for faults, their displacement. Important with respect to ground-water flow and radionuclide transport are the apertures of the fractures and the fracture density (the number of fractures per unit width of rock) because they determine the permeability of the fracture zones to ground-water flow and the pore and fracture space available for radionuclide transport. Although not listed, the connectivity of the fractures needs to be inferred from the other measurements because of its importance with respect to potentially fast flow and transport pathways.

Biological Characteristics of Rock Fracture Zones (Including Faults). Biological activity, including microorganisms, may affect the ground-water chemistry and thus waste package corrosion, waste dissolution, and radionuclide transport. Sampling and laboratory analysis will be needed when fracture zones are encountered during the emplacement drift excavation and as a function of time following waste emplacement.

Chemical/Mineralogical Characteristics of Infillings of Rock Fracture Zones (Including Faults). The chemical and mineralogical characteristics of infillings, including the apparent age of the minerals, provide information with respect to the evolution of the fractures, including their hydraulic characteristics, which can then be used to predict any future changes that may affect water, water vapor/steam, air, and gas flow (including through the repository excavations), and aqueous and gaseous radionuclide transport through the fracture zones.

Hydraulic Characteristics of Rock Fracture Zones (Including Faults). The same hydraulic parameters described above for the rock matrix are also needed for rock fracture zones (including faults), and for the same reasons.

Pneumatic Characteristics of Rock Fracture Zones (Including Faults) of Altered Zone. The fracture air permeability for the altered zone is needed for the same reasons as for the rock matrix. In addition, the gaseous dispersion coefficient is a key parameter because of its importance to gaseous radionuclide transport.

Thermal Characteristics of Rock Fracture Zones (Including Faults) of Altered Zone. The same reasons apply as for the rock matrix.

Ground Water (In Rock Matrix, Fractures, Fault Zones, and Other Discontinuities)

The ground water in the unsaturated zone includes all water and water vapor/steam in the pores and fractures between the ground surface and the water table.

Chemical Characteristics of Ground Water (in the rock matrix, fractures, fault zones, and other discontinuities). The chemical characteristics of ground water affect the corrosion of waste packages, waste dissolution, rock permeability and porosity (through precipitation and dissolution of minerals), and radionuclide sorption on the rocks. Performance confirmation is recommended for the altered zone to confirm chemical changes resulting from the waste heat and associated ground-water flow effects. Chemical characteristics include the concentrations of anions and cations, the pH, the Eh, and several other parameters. Typical parameters measured in the past in two wells in the saturated zone are listed in Table 1 of Section 1.612e in the YMP Reference Information Base (RIB) (DOE, 1995d). Following is a list of the RIB parameters, plus a few others that may have to be measured for the unsaturated zone:

Cations: aluminum (Al^{+++}), calcium (Ca^{++}), iron (Fe^{++}), lithium (Li^{+}), magnesium (Mg^{++}), manganese (Mn^{++}), potassium (K^{+}), sodium (Na^{+}), strontium (Sr^{++}), tritium ($^{3}H^{+}$), and zinc (Zn^{++}).

Anions: chloride (Cl^{-}), bicarbonate (HCO_3^{-}), fluoride (F^{-}), nitrate (NO_3^{-}), phosphate (PO_4^{---}), and sulfate (SO_4^{--}).

Other: Eh (not included in the RIB) -- a measure of the oxidation potential, also called redox potential; (expressed in volts or millivolts);
p H -- a measure of the acidity or alkalinity; the reciprocal of the logarithm of (the hydrogen-ion concentration; neutral water has a hydrogen-ion concentration of 10^{-7} g/L and thus a pH of 7);
aqueous silica (SiO_2);
dissolved organic carbon (DOC);
specific conductance/conductivity (a measure of the total dissolved ionic solid concentration); and
various measures related to age dating.

Additional constituents may need to be added on the basis of new research and performance assessment results with respect to their importance for natural and engineered barrier postclosure performance.

Hydraulic Characteristics of Ground Water (in the rock matrix, fractures, fault zones, and other discontinuities). The in situ fluid potential (also called moisture tension) constitutes the driving force for ground-water flow. In the unsaturated zone, it is related to moisture content, which in turn determines the unsaturated hydraulic conductivity (see description of hydraulic rock characteristics for the unsaturated rock matrix). The adequacy of the prediction of its spatial distribution in the entire unsaturated portion of the natural barrier, especially the effects of the waste heat in the thermally altered zone, is an important aspect of performance confirmation because of its importance to ground-water flow (liquid and water vapor/steam), waste package performance, and radionuclide transport.

Thermal Characteristics of Ground Water of Altered Zone (in the rock matrix, fractures, fault zones, and other discontinuities). The ground-water temperature as affected by the waste heat is a key output of the performance assessments and needs to be confirmed because of its importance to ground-water flow, geochemical processes, waste package performance, and radionuclide transport.

Pneumatic Characteristics of Subsurface Air and Gases (in the rock matrix, fractures, fault zones, and other discontinuities). The air pressure is the key parameter driving air, gas, and water vapor/steam flow. It will be predicted by performance assessments and therefore needs to be confirmed for the same reasons as the fluid potential of ground water.

4.6.3 Saturated Zone Parameters

The list of saturated zone parameters (Appendix D) includes those site characteristics that apply specifically to the saturated zone. For the purposes of this report, it is assumed to be bounded by Crater Flat in the west, Rainier Mesa in the north, Jackass Flats in the east, and the Amargosa Valley in the south. Extension to Death Valley may be necessary depending on evidence with respect to the connectivity of the Yucca Mountain saturated-zone ground-water system with the ground-water in Death Valley. On the other hand, the area of the saturated zone that needs to be considered may be reduced after completion of the three-dimensional saturated zone model being developed at present.

The saturated zone parameters are organized into the following three categories: (1) alluvium/colluvium and rock matrix, (2) rock fracture zones (including faults), and (3) ground water (in the rock matrix, fractures, fault zones, and other discontinuities).

The first two categories include properties of the rocks themselves, while the last category includes properties of the ground water. Subcategories within these categories include stratigraphy of the alluvium/colluvium and rock matrix, geometry of fracture zones, biological, chemical/mineralogical, hydraulic, mechanical, and thermal characteristics, and aqueous radionuclide transport. The latter subcategory includes potential postclosure performance standards for radionuclide concentrations in the ground-water and the aqueous radionuclide release rate to the accessible environment. Although these would be important postclosure performance assessment parameters, they were not selected as performance confirmation parameters because no radionuclide releases to the saturated zone are expected before repository closure.

No saturated zone parameter was selected as a key performance confirmation parameter because data acquisition for the selected performance confirmation parameters would not affect MGDS design.

4.6.4 Repository Excavation and Borehole Parameters

The list of repository excavation and borehole parameters (Appendix D) includes characteristics within the excavations and boreholes themselves. Characteristics in the rock adjacent to the excavations and boreholes are included either in the general site, unsaturated zone, or saturated zone parameter tables, depending on the location of the characteristic within the natural barrier system and the parameter itself.

The repository excavation and borehole parameters are organized into the following five categories: (1) excavation geometry, (2) subsurface repository excavation environment (inside ramps, shafts, alcoves, and emplacement and other drifts), (3) waste emplacement (for each waste type and waste package design), (4) ESF and repository construction fluids and materials remaining after repository closure (other than backfills and seals), and (5) engineered barrier system radionuclide release. Note that the characteristics of the waste packages and wastes themselves are included in the waste package parameter table.

The excavation geometry category includes the geometry of ramps, shafts, alcoves, transportation drifts, waste emplacement drifts, and surface-based and underground boreholes. This includes potential geometry changes with time, such as caused by excavation deformation and convergence, by rock falls, and by excavation and borehole collapse. The subsurface repository excavation environment category includes physical, chemical, and radiological characteristics inside the excavations. The waste emplacement category covers the number of waste packages for each waste type and waste package design, the location of waste packages within the repository and drifts, and the thermal and areal mass loading. The construction fluids and materials category includes quantities and chemical composition/alteration of construction and fire water (including accidental spills), hydrocarbons (including accidental spills), concrete, steel, ground support, railcars, and any other fluids and materials remaining in the repository after closure. The EBS radionuclide release category includes aqueous and gaseous radionuclide release rates to the host rock and concentrations in the emplacement drift walls. It also includes the postclosure performance standard of 10 CFR

60.113(a)(1)(ii)(B) with respect to the fractional annual EBS radionuclide release, following the containment period, relative to the 1,000-year inventory. Although this is a postclosure performance standard, it was not selected as a key performance confirmation parameter because no radionuclide releases from the EBS are expected before repository closure. Waste package recovery would be considered if any radionuclides escape from the waste packages, as detected by repository ventilation air monitoring.

From the repository excavation and borehole parameter list, 16 parameters were selected as key performance confirmation parameters. Some of these parameters, like the chemical composition of fluids and materials remaining permanently in the repository, include more detailed characteristics, so that the actual number of key performance confirmation parameters is larger. The selected parameters are briefly described below.

Excavation Geometry

The excavation geometry includes the geometry of subsurface repository excavations and of both surface-based and underground boreholes. Only the geometry of excavations was selected as a key performance confirmation parameter. For boreholes, inspection of any deformation prior to sealing as part of the sealing program was considered sufficient.

<u>Geometry of Waste Emplacement Drifts</u>. Although the initial geometry of the waste emplacement drifts is defined by the repository design, any changes resulting after the excavation need to be monitored because of the potential impacts of drift deformation and convergence, rock falls, and drift collapse on waste package performance.

Subsurface Repository Excavation Environment (Ramps, Shafts, Alcoves, and Emplacement Drifts)

The subsurface repository excavation environment includes characteristics within the excavations themselves and some parameters defined at the excavation walls.

<u>Physical Characteristics of Excavation Environment</u> (ramps, shafts, alcoves, and emplacement drifts). The air temperature and relative humidity in the drifts and any ground-water inflow (including rate and temperature) directly affect waste package performance. Because of the heterogeneity of the Yucca Mountain hydrogeologic units, locations and rates of ground-water inflow cannot be predicted with any precision. Consequently, it is important to detect and monitor any inflow that is encountered during the repository excavation and following waste emplacement. The drift-averaged air temperature and relative humidity can be predicted with fair accuracy, but random effects by ground-water inflows and other natural barrier heterogeneities require that the accuracy of these predictions be confirmed.

<u>Chemical Characteristics of Excavation Environment</u> (ramps, shafts, alcoves, and emplacement drifts). The same parameters listed under chemical characteristics of the ground-water in the unsaturated zone need to be measured for the same reasons for any ground-water inflow into the repository drifts.

ESF and Repository Construction Fluids and Materials Remaining after Repository Closure (Other than Backfill and Seals)

Tracers, fluids, and materials (TFMs) introduced by the ESF and repository construction and operation, including waste emplacement, may affect the postclosure performance of the natural and engineered system barriers. This can occur because of changes that they induce to these barriers prior to repository closure, and because of effects of any TFMs remaining in the repository after closure. See section 5.3 for a description of potential effects of the planned performance confirmation program, including the subsurface introduction of TFMs, on postclosure waste isolation performance. It is assumed that record keeping of TFMs used and remaining in the subsurface excavations is part of the construction and operation activities. Performance confirmation is required only with respect to the TFMs that are expected to remain permanently in the subsurface. This includes determining the quantities remaining and confirming expected chemical alterations during the preclosure period.

Construction and Fire Water, Including Accidental Spills. Water is used during the excavation of ramps and drifts as part of the tunnel boring operation, for drilling of rock bolt holes, for muck conveyor dust suppression, for washing of excavation walls prior to geologic mapping, and perhaps for fire fighting. Part of the introduced water is removed with the muck and part with the ventilation air. The water remaining in the rock could affect ground-water flow and associated waste package performance and radionuclide transport. Although records of water use and potential spills are required when they occur, confirmation of the quantities and chemical composition remaining in the rock is recommended.

Hydrocarbons, Including Accidental Spills (each type that may affect postclosure performance). Hydrocarbons are used in construction equipment, such as coolants, lubricants, and internal combustion engine fuel. A large part of gaseous hydrocarbons are expected to be removed by the ventilation air. Records of direct and indirect hydrocarbon use, including accidental spills, their locations and chemical compositions will be part of the construction and operation record. Confirmation of the quantities remaining and their chemical composition are recommended.

Concrete. Inverts that form the base for rail transport of the waste packages to be emplaced will be made of precast concrete, and lining of the emplacement drifts with precast concrete segments is being contemplated. The amount, chemical composition, and locations of concrete used will be part of the design and construction record. Performance confirmation is recommended for the chemical composition and alteration of the concrete as a function of time.

Steel. Steel will be used for the rails, railcars, and ground support. As with concrete, the amount, type, and locations of steel will be part of the design and construction record. Performance confirmation is recommended for the chemical composition and alteration of the steel as a function of time.

Ground Support. Ground support consists of steel sets, rock bolts, shotcrete, and other materials to make the excavations safe following excavation and during waste emplacement. The materials used may include concrete, steel, and plastics. As before, design and construction records will be the basis for the initial quantities, chemical compositions, and locations. Performance confirmation is recommended for the chemical alteration and composition of the materials remaining in the repository as a function of time.

Railcars. Railcars are planned to be used for transporting waste packages to the emplacement locations and they are planned to remain in place. Their principal component will be steel. Design and emplacement records will be the basis for the number, chemical compositions of constituent materials, and locations. Performance confirmation is recommended for the chemical alteration and composition of the materials remaining in the repository as a function of time.

Other Fluids and Materials Remaining in Repository after Closure, if Required (each type that may affect postclosure performance). Numerous other fluids and materials are expected to be used for the construction and operation of materials. The Determination of Importance Evaluation for Subsurface Exploratory Studies Facility(CRWMS M&O 1995h) can be used as an initial indication of the types of fluids and materials and their potential impact, if any, on waste isolation. Design, construction, and emplacement records will keep track of those that may have a waste isolation impact. Performance confirmation is recommended for the chemical alteration and composition of any fluids and materials to be identified by future DIEs or performance assessments.

4.6.5 Waste Package Parameters

The list of waste package parameters (Appendix D) includes characteristics of the waste packages themselves and of the wastes contained within them. Waste emplacement characteristics, that is the locations of the waste packages within the repository and emplacement drifts and associated thermal and areal mass loadings are included in the repository excavation and borehole parameter table.

The waste package parameters are organized into the following nine categories: (1) waste form characteristics (e.g., of spent fuel and glass defense high-level waste), (2) radionuclide characteristics, (3) waste package geometry, (4) corrosion and other degradation characteristics of each waste package barrier, (5) chemistry of each waste package barrier (including of degradation products), (6 through 8) hydraulic, mechanical, and thermal characteristics of each waste package barrier, and (9) waste package radionuclide containment and release (for each waste form, waste package design, and important radionuclide). These categories were not further divided into subcategories.

Waste package characteristics include data on the individual radionuclides in the wastes themselves, including half life, chain-decay relationships, radioactivity, and weight. For postclosure performance assessments, data and simulations are needed only for those radionuclides that are important with respect to demonstrating compliance with postclosure regulatory standards for radionuclide releases and radiation doses. The following 39 radionuclides were included in TSPA - 1995: actinium-227, americium-241, -242M, and -243, carbon-14 (gaseous), cesium-135, chlorine-36 (gaseous), curium-244, -245, and -246, iodine-129 (gaseous), lead-210, neptunium-237, nickel-59 and -63, niobium-93M and -94, palladium-107, plutonium-238, -239, -240, -241, and -242, protactinium-231, radium-226 and -228, samarium-151, selenium-79, technetium-99, thorium-229, -230, and -232, tin-126, uranium-233, -234, -235, -236, and -238, and zirconium-93. Because radionuclide characteristics are well known, however, they were not selected as performance confirmation parameters.

From the waste package parameter list, 28 parameters were selected as key performance confirmation parameters. Some of these parameters, like the chemical composition of waste package barrier corrosion products, include more detailed characteristics, so that the actual number of key performance confirmation parameters is larger. The selected parameters are briefly described below.

Waste Form Characteristics (e.g., of Spent Fuel and Glass Defense High-level Waste)

Waste form characteristics include parameters for all potential waste forms that may be considered for emplacement in a potential Yucca Mountain repository. This would include spent fuel, distinguishing between boiling water and pressurized water reactor fuel, burnup rates, and any other differences in the geometry and radiological composition of the spent fuel that are important from a postclosure performance standpoint. It would include defense high-level waste glass, again distinguishing between different types as necessary for postclosure performance assessment. Also needed would be characteristics of other wastes to be emplaced (e.g., foreign radioactive waste), as authorized by any new national nuclear waste policy act.

Since the waste containers will be sealed and the environment inside them will be chemically inert, it is expected that confirmation of the parameters in this section will not be necessary unless there is a waste package breach. Accordingly, confirmation of these parameters, which will require retrieval and analysis of a waste package, will only be undertaken if a breach is suspected or detected.

Geometry/Dimensions of Waste Form. For high-level waste glass or intact spent fuel, the initial geometry and dimensions of the total waste form within the waste package will be known from the specifications for the waste form and from studies of test materials. For failed fuel, additional information on the nature of the failures will presumably be collected at the time of waste acceptance. The geometry of the waste form is needed principally for analyzing ground-water and humid air contact, waste dissolution, and potential internal waste package criticality.

Because the inside of a waste package will be an inert environment, significant changes to the geometry and dimensions are not expected in an intact waste package. Accordingly, measurements should be undertaken only if containment failures are detected. If such failures are detected, changes to the geometry and dimensions should be determined by opening the disposal container and examining the waste. The waste should be examined first by nondestructive methods, then by destructive methods if that is warranted. Nondestructive methods would include inspection of accessible cladding surfaces to estimate the amount of cladding oxidation that has occurred and to determine the sizes and locations of any cladding breaches. To detect cladding breaches on interior fuel rods, the fuel assembly could be immersed in water and the water analyzed for actinides and fission products. If nondestructive methods prove to be inadequate, destructive tests should be considered. Destructive testing would require removal of end fittings and cutting of spacer grids so that each fuel rod would be accessible for inspection.

Geometry/Dimensions of Waste Pellets/Particles. As with the total waste form geometry, the geometry of the waste pellets or particles is needed principally for analyzing ground-water and humid air contact, waste dissolution, and potential internal waste package criticality. The performance confirmation efforts for this parameter should be dependent on measures taken to confirm the geometry and dimensions of the waste form as discussed above. Since fuel pellets or particles are encased in cladding, no degradation of the fuel is expected if the cladding is intact. However, the cladding also renders ineffective the methods described in the previous section, so additional destructive tests would be necessary. These could include sectioning of fuel rods and microscopy to determine the volume of fuel that has been oxidized, and x-ray diffraction to identify the oxidized phases and their quantities. Sectioning of fuel rods would also allow determination of the thickness of the remaining cladding.

Surface Area of Waste Pellets or Particles. The surface area of the waste pellets or particles is one of the more important parameters for calculating waste dissolution. This parameter will change as the result of both oxidation of the fuel and dissolution. As for the parameter geometry/dimensions of waste pellets/particles discussed above, the performance confirmation efforts for this parameter should be dependent on measures taken to confirm the geometry and dimensions of the waste form. Because the cladding encases the fuel, destructive testing is necessary. The fuel rods would be sectioned and samples taken for surface area determination. Appropriate methods include quantitative microscopy and the Brunauer-Emmett-Teller adsorption method. Mercury porosimetry would produce a mixed waste and should be avoided if possible.

Weight and Radioactivity of Each Radionuclide. The weight and radioactivity of each radionuclide are needed to determine radiation in the vicinity of the waste package and radionuclide release from the waste form. Because the two are interrelated through well-established physical ratios, only one or the other needs to be defined as a design parameter. The weight and activity change with time because of radioactive decay, waste dissolution, and radionuclide transport from the waste form into the repository excavation. With the possible exception of failed spent fuel, the initial weight of each radionuclide in the waste form will be known from waste characterization or neutronic calculations. For failed spent fuel, the weights for intact spent fuel will provide an upper bound on the weight of each radionuclide.

While the waste containers remain intact, changes in the weights will be readily predicted by decay calculations, and no performance confirmation effort is needed. If waste container failures are detected during the performance confirmation period, the containers should be retrieved and inspected or tested, as discussed in the previous three sections. As needed, additional tests or measurements may be performed to determine the amount of release. Possible measurements include sampling of emplacement drift surfaces to measure the level of contamination.

Gas Composition Inside Fuel Element. The isotopic composition and quantity or activity of radioactive gases within the spent fuel elements are needed for calculating radioactive gas release from the waste packages and potential internal criticality. The principal radioactive gases from a radiological risk perspective include carbon-14, chlorine-36, and iodine-129. The same thoughts covered above for other waste form parameters apply here with respect to confirming internal spent fuel element gas compositions.

Geometry of Waste Package (Excluding Backfill)

The initial geometry of the waste packages is defined by the waste package design, which is expected to be verified for the actual waste packages at the time of waste acceptance. The geometry is expected to change with time because of thermal-mechanical stresses (from the waste heat itself and from potential rock falls and emplacement drift collapse) and waste package barrier corrosion.

Corrosion Effects on Barrier Thickness and Shape. Corrosion is expected to thin and roughen the containment barriers over time, which affects the mechanical integrity of the barriers and corrosion itself. This potentially will lead to weakening and eventually failure of the barriers. Because of its importance in waste package degradation, a significant amount of effort has been expended on corrosion research and additional effort during performance confirmation is appropriate.

During the preclosure period, the spent-fuel and high-level radioactive waste containers will be hot and, with few exceptions, are expected to remain dry, so there will be little corrosion of the containers. As a result, there is little to be gained by measuring changes in barrier thickness by retrieving and inspecting or testing actual waste containers. Alternative methods must be used.

One alternative method is to develop a section of the repository for performance confirmation. This section might be left unheated to simulate the low temperatures and high humidities that will prevail at long times. These conditions are expected to increase the aggressiveness of the environment and thus make measurement of corrosion rates and depths more practical. Monitoring and retrieval of samples from the performance confirmation section would be straightforward because there would be no radiation field and the temperature would be low.

A second alternative method is to use laboratory tests. These could simulate anticipated conditions, or they could impose more severe conditions to accelerate corrosion or account for conditions that are unexpectedly severe.

Except in an accelerated laboratory test, the amount of corrosion that occurs during the preclosure period is unlikely to be sufficient to cause a waste container to fail. Accordingly, experiments must be supplemented by structural analysis. Structural analyses of degraded waste containers are already in progress and should be completed before the license application. Little additional analysis should be needed during performance confirmation.

Mechanical Effects on Barrier Thickness and Shape. Ground support for the emplacement drifts may eventually degrade to the point that rocks fall from the crown of the drifts. Fallen rocks could eventually fill the drifts. One of the largest uncertainties regarding this parameter is the size of the rocks that will fall and the time of occurrence and frequency of rock falls. Because these reflect the properties of the host rock, laboratory measurements are not particularly helpful, and in situ monitoring is required.

During the preclosure period, it is expected that there will be little degradation of the waste containers and only modest degradation of the ground support. The performance confirmation effort should accordingly be fairly small. For waste packages that are subjected to large rock falls and for which significant mechanical damage is suspected, retrieval should be retained as a possible contingency measure.

Because of the mechanical strength of the waste containers, it is unlikely that any rock falls will cause mechanical damage of the containers during the preclosure period. However, characterizing any debris found in the emplacement drifts will provide data that could be used to develop a distribution of rock sizes and fall frequencies. Such a distribution could be combined with structural analyses of degraded waste containers to predict the rate of mechanical failures.

Location and Geometry of Criticality Control Materials. Current waste package designs call for criticality control by a "basket" of borated stainless steel. The basket is an assembly of slotted, interlocking plates that form a set of square cells inside the disposal container. The plates separate each fuel assembly from its neighbors. The boron in the plates is a strong neutron absorber and will effectively prevent nuclear chain reactions.

Because of the inert environment inside an intact waste package, no degradation of the basket is expected before the containment barriers are breached. At that time, humid air and even liquid water may begin to enter the package. The rate of filling is expected to be quite slow. However, it is conceivable that the waste package will fill with water and that there will be corrosion of the basket materials. If that occurs, the rate of corrosion and the transport of boron from its original location will have significant effects on the control of criticality.

Because of the long waste package containment lifetime and the small rate of filling, it is not possible to study degradation of the basket materials in actual waste packages. Instead, the basket materials may be exposed directly to air in unheated drifts to simulate degradation in a breached package at times long after emplacement. Corrosion rates may also be measured for samples immersed in a suitable corrodent, possibly in the presence of a radiation field.

Damage to the criticality control materials could conceivably occur as a result of rock fall and mechanical damage to an unbreached waste package. As with mechanical effects on barrier thickness and shape, retrieval should be retained as a possible contingency measure to be used for waste packages that are subjected to large rock falls and for which significant mechanical damage is suspected.

Corrosion and Other Degradation Characteristics of Each Waste Package Barrier (Excluding Backfill)

Characteristics of waste package barrier degradation address various forms of corrosion resulting from dry and humid air and from water.

The performance confirmation methods for these parameters rely on retrievable samples (coupons) rather than on retrieval of entire waste packages. (An exception is cladding failure rate, which is discussed below and for which performance confirmation relies on laboratory tests.) Samples tested in a laboratory could be exposed to whatever environment is deemed appropriate. Retrievable samples placed in the repository could be either clamped to actual waste packages or exposed to ambient conditions in a performance confirmation section of the repository. The former location closely replicates the environment of the actual waste package materials; the latter may approximate the conditions that will prevail at long times. Because of the substantial thermal conductivity of the containment barriers, the outer surface of the waste package will be essentially isothermal, and the position of a sample on the waste package will be immaterial. To determine the effects of welding, some of the samples would presumably include weld joints.

Threshold Humidity For Humid-Air Corrosion. The value of this parameter defines at what relative humidity humid-air corrosion of a waste package barrier will commence. It is therefore an important parameter for predicting the containment period for the waste and the eventual release of radionuclides from the waste packages. The relative humidity of the emplacement drifts is expected to drop during construction and emplacement as a result of ventilation. After emplacement, the humidity is expected to drop further because of heating by the waste packages. The humidity in the emplacement drifts during the preclosure period is therefore expected to be below the threshold for humid-air corrosion.

The threshold humidity will depend on the type and amount of contamination that is present on the waste package surface. Contaminants may include oils, salts, and dust. It would be appropriate to place coupons of the outer barrier materials in a few selected emplacement drifts. The coupons would be retrieved after several years and used in experiments to determine the threshold humidity for the contamination that had accumulated.

Dry Oxidation Rate. This parameter represents the rate of uniform waste package barrier corrosion caused by dry emplacement drift air. It is expressed as the change in barrier thickness as a function of time. Dry oxidation is expected to be negligible for the corrosion resistant materials, which form a thin, highly protective oxide coating upon exposure to air. The depth of dry oxidation is also expected to be small for the corrosion allowance materials because of the modest surface temperature of the waste packages. Dry oxidation might be studied by the methods used for humid-air general corrosion, as discussed below. To determine how much damage is due to each mechanism, however, laboratory tests in dry air would probably be necessary.

Humid-Air General Corrosion Rate. This parameter represents the rate of uniform waste package barrier corrosion caused by the moisture in the emplacement drift air. It is expressed as the change in barrier thickness as a function of time. As discussed before, the relative humidity in the emplacement drifts is expected to be below the threshold for humid-air corrosion during the preclosure period, so measuring the general corrosion rate by inspecting filled waste containers would be ineffective. Two effective approaches would be to expose coupons in a performance confirmation drift and to continue laboratory studies on humid-air corrosion. Both of these are discussed in the paragraph corrosion effects on barrier thickness and shape above.

Aqueous General Corrosion Rate. This parameter represents the rate of uniform waste package barrier corrosion caused by liquid water contacting a waste package barrier. It is expressed as the change in barrier thickness as a function of time. No aqueous general corrosion is expected during the preclosure period. In contrast to humid-air corrosion, aqueous corrosion is also not expected if samples are exposed in a performance confirmation drift. Information on aqueous general corrosion can therefore be obtained only by laboratory tests.

Preparation is nearly complete for tests to determine general corrosion rates in a variety of aqueous environments. A large number of samples will be exposed for several years. It is expected that many of these tests, particularly those in aggressive environments, can be discontinued after a few years because the corrosion rates will be shown to be unacceptably high. A smaller number of experiments might be continued through the performance confirmation period to demonstrate that the corrosion rate continues to be acceptably low.

Humid-Air Pit Corrosion Rate. This parameter represents the rate of pit initiation, spatial distribution, and growth on a waste package barrier caused by the moisture in the emplacement drift air. It is usually expressed as the change in pit depth as a function of time. If pitting in humid air occurs, the pit depth and pit density (number of pits per unit surface area of the waste package barrier) can be measured from samples intended for measurement of humid-air general corrosion. See the paragraph on humid-air general corrosion rate above.

Aqueous Pit Corrosion Rate. This parameter represents the rate of pit initiation, spatial distribution, and growth on a waste package barrier caused by liquid water contacting a waste package barrier. It is usually expressed as the change in pit depth as a function of time. Like aqueous general corrosion, aqueous pitting corrosion rates can only be measured effectively in the laboratory. However, experiments on pitting are more difficult than those on general corrosion because pitting often requires a long initiation time. Because the corrosion rate accelerates upon pit initiation, simply monitoring a sample with no pits is apt to produce severe underestimates of the degradation rate.

A possible method for overcoming this difficulty is to study pit repassivation. By imposing an anodic potential on the sample, pits would be forced to initiate. The potential would then be removed and the sample allowed to reach its free corrosion potential. If the pits stop growing (repassivate), pitting does not occur for the environment under test.

If the chemistry of water for a waste package exposed to dripping water can be determined, only a few samples need be used to determine pitting behavior.

Microbial Corrosion Rate. Many metals are subject to microbially influenced corrosion. For actual waste packages, the surfaces are expected to be hot and dry, and therefore hostile to microbial growth, during the preclosure period. As a result, microbial corrosion tests must be performed in the laboratory. Water chemistries should be relevant to repository conditions, and nutrient supplies (other than the metal itself) should be severely limited. Although the emplacement drifts may be sterilized by heat and radiation during the preclosure period, it is expected that microbes will eventually be transported to the drifts by water flow in fractures. Accordingly, the metal samples should be tested with various microbes, or mixtures of microbes, that are typical of Yucca Mountain.

Cladding Failure Rate.
Fuel cladding is subject to degradation by a variety of mechanisms. For fuel in an intact or perforated waste package, perhaps the most important degradation mechanisms are creep rupture of the cladding, oxidation of the cladding, and oxidation of the uranium dioxide fuel. All three mechanisms are thermally activated. Creep rupture is driven by the pressure of gas inside the cladding. This mechanism can proceed in an inert environment, but it is expected to produce only tiny breaches in the cladding. Oxidation of he cladding and fuel both require an oxidizing environment, so they will not occur in a waste package while at least one containment barrier is intact. In addition to the mechanisms listed above, the cladding may fail as a result of mechanical stress if the container is degraded to the point of losing its own mechanical integrity.

Disposal containers are being designed to control all three types of degradation, so retrieval of waste packages is not expected to provide significant new insights. Instead, laboratory studies are suggested if current understanding is inadequate for confident prediction of future performance. Studies of fuel oxidation are in progress. Studies of oxidation, creep rupture, and mechanical properties of irradiated cladding may also be required.

Chemistry of Each Waste Package Barrier (Including Degradation Products but Excluding Backfill)

The initial composition of the containment barriers will be set by specifications for the materials and compliance of the compositions with the specifications will be verified as part of the quality assurance program for manufacturing. The composition of the metallic part of the barriers will not vary with time, but the composition of the corrosion products may depend on the conditions under which corrosion occurs. The composition may be significant in revealing the mechanisms of corrosion.

An appropriate performance confirmation effort is to analyze the composition and structure of products of corrosion observed on coupons retrieved from the performance confirmation section of the repository. If corrosion is observed on actual waste containers, it may also be worthwhile to collect samples of these for analysis.

Gas Composition Inside Waste Container. The current advanced conceptual waste package design includes the injection of helium into the waste container during waste package fabrication (CRWMS M&O, 1996l). When the containment barriers are breached, the helium will gradually be replaced by air. Air in a hot waste package could result in oxidation of the fuel and cladding. If waste packages are retrieved from the repository, it would be appropriate to determine the composition of the fill gas and estimate the rate of leakage. No change in the gas composition inside the waste container is expected while the containment barriers are intact, so confirmation of this parameter will only be undertaken if a container breach is suspected or detected.

No change in the gas composition inside the waste container is expected while the containment barriers are intact, so confirmation of this parameter will only be undertaken if a container breach is suspected or detected.

Chemical Composition of Criticality Control Materials. Degradation of criticality control materials is discussed above. However, corrosion of these materials does not, in itself, reduce their ability to control criticality if the neutron absorbing nuclides remain in place, trapped in the products of corrosion. Through laboratory experiments, this performance confirmation effort can clarify the amount of boron that will remain in the corrosion products. This effort will be integrated with the effort described above.

No change in the composition of the criticality control materials is expected while the containment barriers are intact, so waste package retrieval will not be used to confirm this parameter unless a container breach is suspected or detected.

The borides in the criticality control materials are distributed as discrete particles, not as a continuous phase. Accordingly, there will be no chemical attack on a given boride particle until the surrounding matrix is removed and the particle is exposed to the corrodent.

Oxidation Product Composition. Efforts to determine the composition of the products of dry oxidation will be integrated with measurements of the dry oxidation rate as described above. Samples of the products of oxidation from laboratory tests will be examined by x-ray diffraction and scanning electron microscopy. The examinations are expected to show which oxide phases are present, what their compositions are, and whether their structure is compact or porous. Information on the oxides and their structure will be helpful in understanding the oxidation mechanisms. Like dry oxidation rate, oxidation product composition can be confirmed by retrieving samples. This is discussed above in the section Corrosion and Other Degradation Characteristics of Each Waste Package Barrier (Excluding Backfill).

Aqueous Corrosion Product Composition. As with the determination of oxide product composition, efforts to determine the composition of the products of aqueous corrosion will be integrated with measurements of aqueous corrosion rates as described above. Samples of the products of oxidation from laboratory tests will be examined by x-ray diffraction and scanning electron microscopy. As for dry oxidation, the examinations are expected to show which oxide phases are present, what their compositions are, and whether their structure is compact or porous. Information on the oxides and their structure will be helpful in understanding the corrosion mechanisms. Like aqueous general corrosion rate, aqueous corrosion product composition can be confirmed by retrieving samples. This is discussed in the section Corrosion and Other Degradation Characteristics of Each Waste Package Barrier (Excluding Backfill).

Physical/Chemical Degree of Embrittlement. Particularly for the corrosion resistant materials, long exposures to moderately elevated temperatures can lead to ordering and formation of brittle phases. For the container materials, these reactions are expected to be extremely slow even at the highest expected temperatures. Significant embrittlement of the container materials is not expected if the emplacement drifts are not backfilled. Somewhat greater embrittlement of fuel basket materials may occur, because they reach higher temperatures than do the container materials. Thermal embrittlement of both basket and container materials would be increased if the waste packages are covered with backfill. Confirmatory tests on basket materials may be appropriate. The tests would expose sample of the basket material to elevated temperatures for long periods of time. After exposures, the samples would be mechanically tested. If significant changes in mechanical properties are observed, microscopy and x-ray or electron diffraction might be used to determine which phases are present.

Embrittlement of metals can also occur upon exposure to gaseous hydrogen. Hydrogen gas can be generated by aqueous corrosion, particularly under acidic conditions. However, the expected rates of corrosion are so low that any hydrogen concentration will be low and hydrogen embrittlement will not be significant.

Thermal embrittlement can be studied by laboratory testing and by retrieving samples that are clamped to waste packages. Thermal embrittlement is extremely slow at ambient temperature, so no samples should be placed in an unheated performance confirmation section of the repository. As is discussed in the section Corrosion and Other Degradation Characteristics of Each Waste Package Barrier (Excluding Backfill), samples of container materials that are clamped to the surface of a waste package will experience conditions that closely replicate those of actual waste package materials. Accelerated tests can be performed in the laboratory by increasing the temperature.

Basket materials also will be subject to thermal embrittlement, but they will be at temperatures well above that of the waste package surface. For these materials, long-term laboratory tests can reproduce the conditions inside a waste package. Waste package retrieval could also be used, but it would probably be more expensive because each new sample would require retrieval of another package.

Physical/Chemical Weld Integrity. Because of nonuniformities in heating and cooling, the closure weld of the waste container is expected to produce stresses in the surrounding material. To some extent, these can be reduced by using a narrow groove geometry and vibratory stress relief. The ideal approach would be to heat treat the weld, but this maybe precluded by temperature limits that are intended to protect the fuel cladding. In any case, the initial stresses near the closure weld will be measured as part of the manufacturing development program. Chemical analysis of the weld and microstructural analysis of the weld and heat-affected zone will also aid in determining how the weld will affect container performance.

It is expected that one or more waste package mockups would be built and the closure welds thoroughly characterized by nondestructive and destructive testing. Such mockups would not contain waste and would never be emplaced. If additional confirmation of weld performance is desired, scale-model rings or rings and lids could be clamped to actual waste packages and later retrieved.

Mechanical Characteristics of Each Waste Package Barrier (Excluding Backfill)

Mechanical characteristics cover the physical properties of waste package barrier materials and stress, strain, and deformation.

In Situ Stress and Strain. The initial mechanical stress and resulting strain in the waste package barriers are caused by the manufacturing, including the closure welding process. They change with time because of the decay of waste heat, and after emplacement, because of potential rock falls, drift collapse, and corrosion.

During the period of performance confirmation, thermal effects are expected to be the most significant cause of changes in stress. Rock falls should be rare, and corrosion will not cause significant loss of material. As a result, the best way to confirm thermal stresses is to instrument and electrically heat a waste package mockup. In contrast to an actual waste package, a mockup would allow instrumentation of both internal and external components. The tests could be performed in a laboratory. Because of the relatively large thermal diffusivity of waste package materials, the gradual reduction in decay heating could be accelerated without significantly disturbing the steady state heat flows in the mockup.

Thermal Characteristics of Each Waste Package Barrier (Excluding Backfill)

Thermal characteristics of the waste package barriers include the waste package center and exterior wall temperatures, and the thermal conductivity, thermal expansion coefficient, and heat capacity of each barrier material. These characteristics are important for predicting mechanical stress/strain/deformation of the waste package barriers, barrier corrosion, and waste dissolution. They also affect the thermal environment in the drifts and surrounding rocks. Only the barrier wall temperature was selected as a key performance confirmation parameter.

Barrier Wall Temperature. The waste package center temperature cannot be measured directly without violating the integrity of the containment barriers. It can be derived from measurements of waste package surface temperature using heat transfer models. Current models could be validated by putting electrical heaters or even actual spent nuclear fuel into an instrumented disposal container, or by comparison with data from dry cask storage demonstration projects.

The primary reason for monitoring waste package center temperature would be to determine the amount of degradation of spent fuel cladding. However, that effort is justified only if credit is taken for the cladding, and the current containment and isolation strategy does not take such credit. See related paragraph above on cladding failure rate.

If it is decided to monitor the surface temperature of actual waste containers, thermocouples could be attached to the surface of the containers. Thermal calculations indicate that the surface of the waste container is practically isothermal, so it is not necessary to determine a temperature distribution. Except during the initial heating phase, the temperatures are not expected to change rapidly, so an alternative method would be to measure temperatures periodically with temperature sensors on a remotely operated vehicle.

Waste Package Radionuclide Containment and Release for Each Waste Form, Waste Package Design, and Important Radionuclide

This category includes parameters that define the radiological performance of the waste forms and waste package. No waste package failure, and thus radionuclide release from the waste packages, is expected before repository closure. Radiation monitoring of the emplacement drift air, which is required as part of the environmental, health, and safety program, is expected to be sufficient to detect any radionuclide leakage from waste packages. Although none is expected to be detected, if it should occur, recovery of the defective waste package(s) may be required.

Waste Package Life or Time of Initial Radionuclide Release. The calculation of waste package life or time to initial radionuclide release, also called waste package containment period, is required by 10 CFR 60.113(a)(1)(ii)(A). Although no radionuclide release from waste packages is expected before repository closure, this is a key performance confirmation parameter because waste package recovery may be required if there should be a waste package failure before repository closure.

Radionuclide Release Rate from Waste Form. This parameter is an important input to the calculation of radionuclide release from the waste packages. This is a key performance confirmation parameter for the same reason as given for waste package life above.

Radionuclide Release Rate from Waste Packages. This parameter is an important input to the calculation of radionuclide release from the engineered barrier system, which has to comply with 10 CFR 60.113(a)(1)(ii)(B). This is a key performance confirmation parameter for the same reason as given for waste package life above.

4.6.6 Backfill and Seal Parameters

Backfill and seal parameters) include characteristics of any backfills and seals that may be emplaced in the excavations and boreholes. A selection of key performance confirmation parameters has not yet been made pending completion of the Engineered Barriers System Performance Requirements Study and the Seals System Study.

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5. PERFORMANCE CONFIRMATION CONCEPTS

The Performance Confirmation Concepts have been organized in three major areas:

- Monitoring and Testing Concepts (Section 5.1)
- Test Facilities and Support Concepts (Section 5.2)
- Evaluation and Reporting Concept (Section 5.3)

The specific concepts for each of these areas are listed in Table 5-1.

Table 5-1. Candidate Performance Confirmation Concepts.

- Monitoring and Testing Concept
  - Site Monitoring and Testing Concept
    - Subsurface Geologic Mapping package
    - Surface Based Unsaturated Zone Package
    - Underground Fault Zone Package
    - Thermal Testing Package
  - Repository Monitoring and Testing Concept
    - In Situ Seals Test
    - Backfill Test
    - Follow-On Drift Heater Test
    - Seismic Monitoring
    - Remote Observation of Emplacement Drifts
  - Waste Package Monitoring and Testing Concept
    - Off-Site Lab
    - In Situ Monitoring
    - Pull Waste Package
    - Pull Dummy Waste Package
    - Pull Specimen
- Test Facilities and Support Concept
  - Subsurface Test Facilities and Support Concept
    - Permanent Observation Drift
    - Emplacement Drift Ventilation
    - Waste Package Recovery
    - Alcoves
    - Remotely Operated Vehicle (ROV)
  - Surface Test Facilities and Support Concept
    - Performance Confirmation Multi-Purpose Hot Cell
    - Performance Confirmation Support Building
- Evaluation and Reporting Concept

The monitoring and testing concepts have been further subdivided into three areas: Site, Repository, and Waste Package. This breakout of monitoring concepts is based on the initial categorization of parameters and the Key Performance Confirmation Parameters for Design matrix (Appendix D). Each parameter in the matrix was considered in the development of the concepts. The parameters were organized into logical groupings for the types of instrumentation needed, the locations where information is needed, and the reasons for monitoring and testing the parameters. Each of these areas is supported by a Test Facilities and Support Concept.

The Site Performance Confirmation Monitoring and Testing Concept is composed of a number of testing "packages" including subsurface geologic mapping, surface based unsaturated zone hydrology, underground fault zone hydrology, and thermal testing. There are other site related performance confirmation testing activities but they are not addressed in this study since they are not design drivers. The Test Facilities and Support interface with these concepts by providing facilities for testing and support, which includes data and sample collection and handling.

The Repository Performance Confirmation Monitoring and Testing Concept consists of backfill testing, in situ seal testing, subsurface seismic monitoring, rockfall/drift collapse monitoring, emplacement drift monitoring, and radiation monitoring.

The Waste Package Performance Confirmation Monitoring and Testing Experiment Concepts include off-site lab testing, in situ waste package monitoring, and testing of recovered waste package materials, including waste packages, "dummy" waste packages, and materials specimen and coupons.

These Monitoring and Testing Concepts are located in the repository subsurface, on the surface and at off-site test facilities.

The Test Facilities and Support Concept have been divided into two areas: Repository Subsurface and Repository Surface. Repository Subsurface Performance Confirmation Test Facilities and Support consist of permanent observation/monitoring drift(s), emplacement drift ventilation, recovery of waste packages, recovery of "dummy" waste packages, recovery of non-radioactive specimens, remotely operated vehicles, and alcove concepts and interfaces with drift construction. The underground handling and data and samples are also considered, including interfaces with the subsurface testing and monitoring concepts.

Repository Surface Performance Confirmation Test Facilities and Support consist of performance confirmation and a multi-purpose hot cell (which is located in the Waste Handling Building), and a performance confirmation support building. Surface based handling of samples and data is also considered and includes interfacing with subsurface Test Facilities and Support, surface based testing and monitoring concepts, off-site testing, and any off-site analysis work.

The final concept is the Performance Confirmation Evaluation and Reporting Concept. The Performance Confirmation Baseline information will be used in this concept. Baseline information consists of existing data (site characterization), process models, abstraction models, analyses, predicted parameter values, and established limits. The evaluation and reporting of acquired performance confirmation information is composed of monitoring observations/data, test results/data, and experiment results/data. Information feedback and appropriate action involve evaluation of the accuracy and adequacy of the baseline ; identification, recording, and control of changes affecting performance; and recommendation of appropriate action.

The Performance Confirmation Concept chart (Figure 5-1) shows an overview of the concepts and indicates the flow of data and samples throughout the concepts. Data and samples are collected from the monitoring and testing concepts. An indication of the types of concepts and the specific parameters are shown on the figure.

If the output from the subsurface is samples there are two main options:

(1) If a "dummy" waste package or waste package is recovered from the subsurface it goes to the Waste Handling Building (performance confirmation and multi-purpose hot cell). The output is data going to the Performance Confirmation Support Building, and/or samples, if required, going to an off-site laboratory. This data could be analyzed on-site or could be further evaluated by off-site evaluation and reporting personnel, and the findings, as data, returned to the Performance Confirmation Support Building which is the central location for all Performance Confirmation information.

(2) If samples are rocks or waste package specimens (non-radioactive), the destination is the Performance Confirmation Support Building. The samples, if required, are sent to an off-site laboratory and then the data is returned. The data could be evaluated on-site or could be sent off-site for evaluation and reporting and then results as data are returned to the Performance Confirmation Support Building.

If the output is data from subsurface, surface, off-site laboratory, or off-site evaluation and reporting, the data is sent to the Performance Confirmation Support Building. Any data could be analyzed on-site or followed by off-site evaluation and reporting.

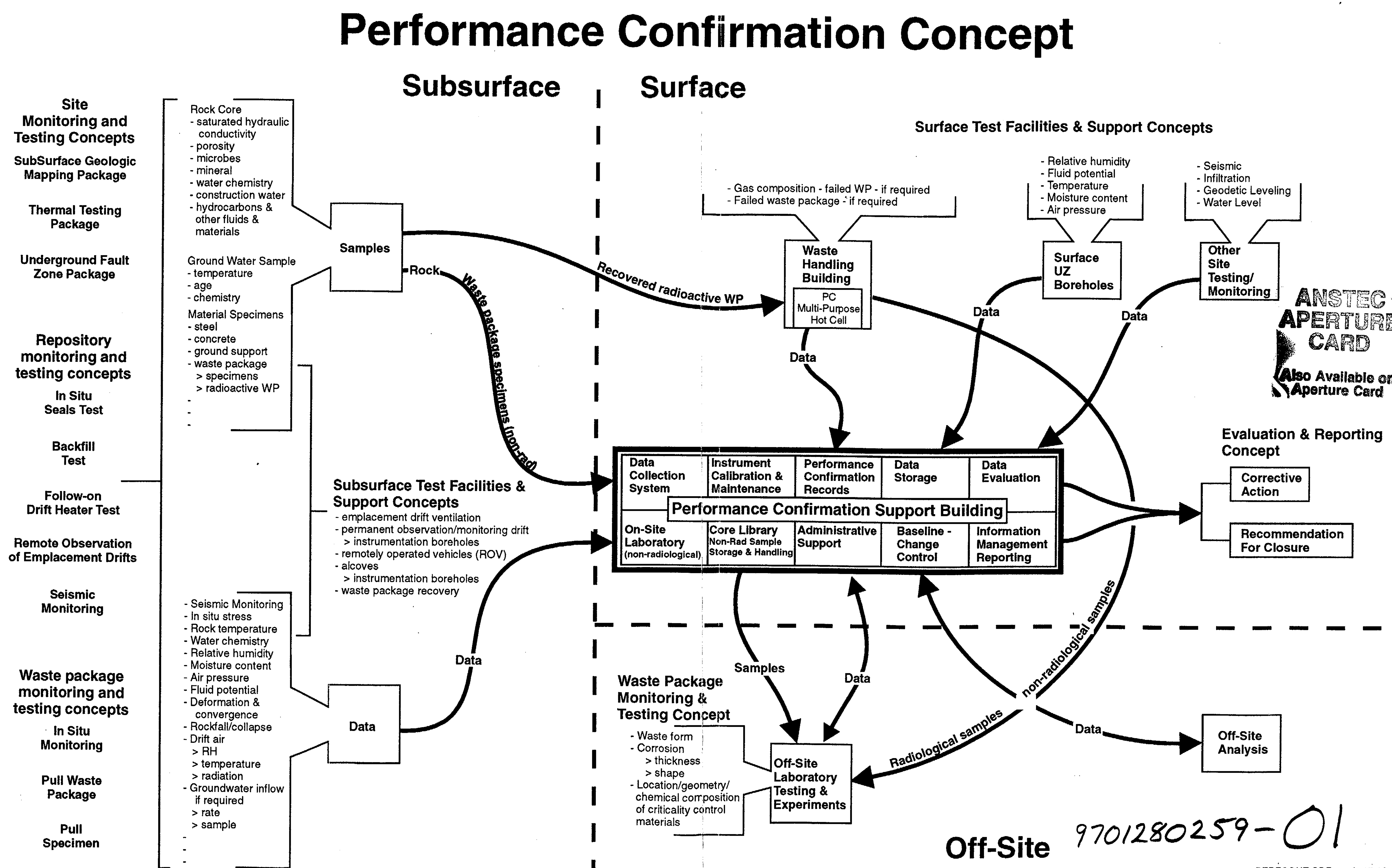

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Figure 5 -1. Performance Confirmation Concept.

5.1 PERFORMANCE CONFIRMATION MONITORING AND TESTING CONCEPTS

The performance confirmation monitoring and testing concepts have been grouped based on the identified parameters. Generally, the site monitoring and testing concepts will cover the site related key parameters for design, similarly for the repository and waste package concepts. Minor exceptions to this occur in the descriptions below, but this is typically due to the flexibility in the specific concept being described.

5.1.1 Site Performance Confirmation Monitoring and Testing Concepts

The key performance confirmation parameters for design related to the site and natural barrier have been grouped according to four testing packages or concepts. This was done to simplify the presentation of the details on personnel, instrumentation, drilling, coring, sampling, laboratory analyses, and requirements on the repository operator needed to conduct the post-License Application performance confirmation program. The associated costs have also been compiled to assist in cost/benefit analyses and a high-level total life cycle cost estimate. The four packages are described below. It is important to note that the details on number of boreholes, instruments, etc. were selected because this information was used in developing cost estimates, and are not meant to be design or testing requirements (see also discussion of basis of cost estimates in Section 7). Future efforts will be needed within the testing community to develop detailed testing requirements. In addition, the monitoring and testing concepts are closely linked to the test and support facilities concepts developed by the repository design group for this study (see Section 5.2).

5.1.1.1 Subsurface Geologic Mapping Package

Performance confirmation parameters to be studied by geologic mapping include stratigraphy (lateral extent, depth, thickness, rock type, mineralogy, fracture density) and characteristics of major fracture sets and faults (location, width, length, aperture, orientation, displacement, and mineralogy of in-fillings). A sampling and off-site laboratory program to confirm subsurface conditions would be undertaken for performance confirmation parameters related to rock hydrologic properties (i.e., saturated hydraulic conductivity, effective porosity, moisture content, hydraulic potential-moisture content relationship, and moisture content-hydraulic conductivity relationship) and biological characteristics of fractures and faults. In addition, if unanticipated geologic conditions are encountered, it may become necessary to address issues related to percolation flux through the repository horizon, such as apparent ages of fracture minerals and apparent age of unsaturated zone water by environmental isotope measurements (e.g., 36Cl and 3H). The performance confirmation parameters related to postclosure hydrocarbon and mineral resource exploration and extraction may also need to be addressed if unanticipated geologic conditions are encountered. These contingencies require sampling and off-site laboratory analyses, the number of which depends on the situation(s) encountered.

Subsurface mapping would take place during repository construction. This could be done in a similar fashion to that being done in the Exploratory Studies Facility (ESF), where the mapping follows the tunnel boring machine (TBM). However, for greater efficiency, the mapping should be lagged behind the excavation headings. An alternative mapping technique might be to use photogrammetry, which may be more compatible with the proposed use of precast concrete as ground support throughout the repository. (A form of photogrammetry has been tested successfully in the ESF.) The photographs could be taken remotely, and the mapping and interpretation done by geologists at the surface. However, the resolution capability of photogrammetric mapping may be insufficient for certain data collection, such as rock mass classifications. If the results of rock mass classification are used to optimize tunnel support requirements (not required if precast concrete is used throughout the repository), this portion of the mapping program would have to be conducted immediately behind the tunnel boring machine(s).

Sampling would require short intact core to obtain hydrologic data undisturbed by excavation processes. Other sampling could be done by chipping off hand samples of varying size following excavation. The personnel collecting samples would need to have an understanding of the purpose of the sample. The laboratory facilities are not required to be in close proximity to the repository itself, and samples could be shipped to the appropriate facilities.

5.1.1.2 Surface-Based Unsaturated Zone Hydrology Package

Performance confirmation parameters to be monitored include rock and water temperature, gas pressure, moisture content, and in situ fluid potential (derived from thermocouple psychrometer measurements of temperature and relative humidity). The instrumentation needs to be retrievable for recalibration and/or replacement because monitoring may take place up to closure of the repository. Two systems that currently provide some of these capabilities are SEAMIST and Westbay systems. Instrumentation required for this package includes: gas pressure - 2 borehole transducers per interval; in situ fluid potential (includes temperature and relative humidity) - 2 borehole thermocouple psychrometers / interval; moisture content - periodic borehole geophysical logging (neutron log).

In most cases, the instrumentation currently used in boreholes for site characterization is not ideal for long-term monitoring. In addition, it is not retrievable since it is frequently grouted in place. For this reason, new boreholes would need to be drilled. Ideally, the new boreholes would be located near existing, well-characterized boreholes (using the same pad), which would make coring and direct measurement of geologic and hydrologic properties unnecessary. The nearby existing boreholes would have to be sealed to ensure that measurements in the instrumented new boreholes are representative of undisturbed rock mass conditions. If boreholes were drilled away from existing boreholes, lithologic and hydrologic data could be provided by geophysical logging, as opposed to collecting core and conducting laboratory analyses. There should be multiple intervals packed off within each borehole, and ideally, each of the major units would be monitored (e.g., TCw, PTn, TSw, and CHn). The SEAMIST Pneumatic System currently being used by the United States Geologic Survey has this capability. The number of boreholes to be monitored depends on several factors, including the repository configuration and thermal load.

5.1.1.3 Underground Fault Zone Hydrology Package

Performance confirmation parameters to be monitored include rock and water temperature, gas pressure, moisture content, and in situ fluid potential (derived from thermocouple psychrometer measurements of temperature and relative humidity). The instrumentation (same as described above) needs to be retrievable for recalibration and/or replacement purposes since monitoring may take place up to closure of the repository (see discussion of Surface-Based Unsaturated zone Hydrology

Package). Monitoring will be done in existing alcove(s), in order to continue to monitor transient conditions in the Ghost Dance Fault after emplacement of waste.

In addition, if other major faults (anticipated or unanticipated) are encountered in the subsurface during construction, we may choose to characterize and monitor these in a manner similar to what is planned for the Ghost Dance Fault studies in the ESF. (One concept being explored in this study is to take advantage of the close proximity of the western edge of the repository to the Solitario Canyon Fault). If we need to characterize other faults, there will be a need to perform other measurements , in addition to those above. These would include in-hole and/or cross-hole air permeability, and coring and off-site laboratory work to determine hydrologic properties (i.e., saturated hydraulic conductivity, effective porosity, moisture content, hydraulic potential-moisture content relationship, and moisture content-hydraulic conductivity relationship).

The activities related to faults encountered during construction may be accommodated by drilling into the fault zone on a later encounter or from an observation drift above the main repository. The current assumption is that the configuration and number of boreholes required is similar to that used in ESF activities for the Ghost Dance Fault studies. The key to this activity (as well as other activities described here) is to develop testing, monitoring, and experiment concepts which minimize interference with repository construction and emplacement operations, but still supply adequate information about the encountered fault.

5.1.1.4 Thermal Testing Package

Performance confirmation parameters to be monitored include rock and water temperature, gas pressure, moisture content, relative humidity, water chemistry, in situ stress, and deformation/convergence. Instrumentation required for this package would include:

- gas pressure - borehole transducers
- temperature - borehole thermocouples and/or resistance temperature detectors, as well as infrared thermal imaging of rock surface
- relative humidity - humicaps and/or psychrometers
- moisture content - periodic borehole geophysical logging (neutron log) and/or electrical resistivity tomography
- water chemistry - SEAMIST sensors and/or periodic sampling by SEAMIST and off-site laboratory analysis
- in situ stress - borehole stress meters; deformation/convergence - multiple point borehole extensometer.

It is assumed that all instrumentation must be retrievable and/or replaceable. To be retrievable and/or replaceable the instrumented boreholes must be drilled from a long observation drift above the emplacement horizon. In-hole and cross-hole air permeability would be measured before and after the alcove thermal test and before and during the emplacement drift monitoring, (see discussion of repository subsurface test and support facilities concepts in Section 5.2).

In addition, off-site laboratory work related to rock chemistry and hydrologic properties, such as saturated hydraulic conductivity, effective porosity, moisture content, hydraulic potential-moisture content relationship, and moisture content-hydraulic conductivity relationship, would be done on core before and after the alcove thermal test and before and during the emplacement drift monitoring; (see discussion below). The instrumentation, monitoring, coring, sampling, and laboratory work described above are similar to that planned for the ESF drift-scale heater test. To provide early data acquisition and to allow design adjustments, the thermal testing should be conducted either entirely or primarily in the early stages of repository operations.

This testing package is related to two Test Facilities and Support, which are described in more detail in the discussions on data acquisition and basis for cost estimates. Briefly, these include (1) Thermal Testing in an alcove setting using heaters, possibly inside "dummy" waste packages, and (2) Permanent Monitoring/Observation Drifts above and parallel to a subset of emplacement drifts.

5.1.2 Repository Performance Confirmation Monitoring and Testing Concepts

Code of Federal Regulations 10 Part 60 describes several testing programs that are to be initiated "During the early or developmental stages of construction...". Included in this suite of testing are tests of potential sealing systems for boreholes and shafts, backfill testing, and heater testing. In addition, subsurface seismic monitoring has been identified as a performance confirmation activity that should be performed during repository operations. Also, capabilities to observe or monitor emplacement drift environments will be discussed.

5.1.2.1 In Situ Seal Testing

There are currently no specific requirements in place for the performance of seals. A seals systems study is planned for fiscal year 1997 to determine these requirements. Therefore, only a limited amount of information was developed and existing information was used regarding the in situ seal testing and related repository acquisition concepts. In situ testing of seal designs and materials may require multiple test locations. Each geologic unit which is required to contain seals at closure would be tested.

The *Preliminary Test Planning Package for Support of Pre-Title II Design Studies* (YMP 1992) contains a description of an in situ seal testing program originally planned for the ESF. Six subsurface test locations are discussed, however, two are in the Calico Hills unit. The other four locations are the Tiva Canyon member, the non-welded Paintbrush Tuff, and two locations in the repository horizon. For the purposes of this system study, three test areas, one in each of the units described above, are assumed. A description of the seal testing plan is contained in the above referenced document and was used in developing the subsurface acquisition concept described below.

5.1.2.2 Backfill Testing

10 CFR 60.142 , "Design Testing" section (a) describes an in situ testing program to assess the effects of backfill. This test is prescribed to start "During the early or developmental stages of construction...". Subsequently, section (b) describes a "backfill test section" which is intended to "... test the effectiveness of backfill placement and compaction procedures...". This test, however, must only be completed "...before permanent backfill placement is begun." Two backfill tests are described, which may occur 90 years or so apart. The earlier test is likely to be conducted on a reasonably small scale (tens of meters) in a test alcove-type environment.

Backfill between seals, and in mains, ramps, and shafts is likely to be required . Backfill of emplacement drifts, however, is not currently in the reference Advance Conceptual Design. The need or requirements related to this topic are being addressed in this year's *Engineered Barrier System Performance Requirements System Study* (CRWMS M&O 1996m). If the repository is ultimately licensed without emplacement drift backfill, then the early, heated backfill test would likely not be required. If emplacement drift backfill is required the specific functions and parameters to be tested and observed are dependent on the results of this referenced study. Therefore, only a limited amount of information was developed regarding the early, heated backfill test and related repository acquisition concepts.

The second test is more for constructability, and will likely be conducted on something approaching an emplacement drift scale (hundreds of meters). As noted, it does not need to be conducted until just prior to backfill placement. This test will be used to test the viability of the backfill process and equipment, and to gather information on productivity, availability, and the condition and uniformity of the emplaced backfill.

5.1.2.3 Follow-on Drift Heater Testing

Although there will be ample opportunity during repository operations to examine the heating of the emplacement drifts and surrounding rock, there will be no cool-down experienced during the pre-closure period. Predicted drift temperatures at closure, 100 years after emplacement, are within a degree or two of the peak temperatures which occur in the 40 to 60 year range. For this reason, a follow-on drift heater test is envisioned which can run for a sufficient duration to heat up a significant amount of the surrounding rock so that, when the heat is turned off, the thermo-hydrologic activity associated with repository cool-down can be examined. Such a test is alluded to in 10 CFR 60.142(a) "...a program for in situ testing of...thermal interaction effects of the waste packages, backfill, rock, and groundwater...".

There are a number of issues as to whether this particular heater test is actually required. There is a planned series of thermal tests that has been identified in the long range plan. In situ testing will occur in the Single Element Heater Test and the Drift Scale Heater Test which the YMP may attempt to use to demonstrate compliance with the intent of 10 CFR 60.142(a). Some of the issues that need resolution are:

1) What information can be obtained from this testing that does not already exist for the License Application and cannot be obtained by other means, ignoring the timing?

2) Is the timing of the testing important? Does the NRC want this testing done "again" prior to the License Application update to Receive and Possess, but on a larger scale and with a better idea of the final design?

These issues have not been resolved but the requirements for the nominal case do not require the test and requirements for the enhanced case do require the test. This was done so that cost comparisons could be made and included in the evaluation. While it may ultimately be possible to combine the backfill test above with the heater test, it is assumed for this evaluation that separate tests are required.

The heater test is assumed to resemble the heater test shown in the *In Situ Thermal Testing Program Strategy* (DOE 1995b). In this reference, the test is referred to as the "Emplacement Drift Thermal Test."

5.1.2.4 Seismic Monitoring

Subsurface seismic activity monitoring, specifically acceleration/ground motion, will provide information on seismic events which may occur during the pre-closure period. Such information collected at the repository horizon, when used in conjunction with data from the same event collected from surface monitoring stations, could provide important information regarding the attenuation with depth of seismic activity. Although, this parameter was considered a site parameter due to the similarity to other repository activities, it was included in the repository testing section of the report.

5.1.2.5 Remote Observation and Inspection of Emplacement Drifts

The remote observation and inspection of emplacement drifts will be discussed in this section. A number of mechanisms may be used for performing these observations. Access to the emplacement drifts in order to perform the observations is a key to these concepts. A mechanism for observation via borehole which will be discussed below provides some limited amount of access. Also, a limited amount of information can be obtained via indirect observations, e.g., ventilation drift monitoring. But, the primary access concept that will be discussed is the general purpose use of ROVs. These ROVs could serve as the mobile base platforms for carrying several different types of inspection packages into the emplacement drifts for observation and data collection. The instruments could provide repository personnel with real-time and highly detailed visual, thermal, radiological and geotechnical feedback on the existing conditions related to the waste packages and emplacement drift infrastructure. The ROVs could also be equipped with telerobotic manipulators that would provide the capability of emplacing and retrieving small test coupons or specimens.

5.1.2.5.1 Remote Visual Inspection

Being able to remotely view objects and conditions within the emplacement drifts appears to be a fundamental capability needed for performance confirmation observations, satisfying regulatory requirements, and general long-term repository operations. The key performance confirmation parameters that have been identified that require remote visual inspection include: rockfall/collapse size and groundwater inflow rate. For the waste package, remote visual inspection would be required for corrosion effects on barrier thickness and shape, and mechanical effects on barrier thickness and shape.

The technology of using remotely operated vision systems in hostile environments is a proven and well established application. There is little question that a robust vision system could be developed for use in the emplacement drifts provided appropriate design strategies are followed. The larger challenge is in developing the delivery system, i.e., developing a robust and reliable means of getting a vision system into and out of the emplacement drift (as discussed in the following section on ROVs). But, remotely operated vision systems can certainly be built that provide high resolution color images from virtually anywhere within the underground repository.

Following emplacement of waste packages, remote vision systems could be used to record and document the exact conditions of the emplacement or drift and the surrounding area of the repository. These video records would be invaluable for confirming and verifying original operating conditions and future scans of the area would allow for before and after comparisons to be made. A remotely controlled vision system would provide an extremely flexible inspection capability for monitoring and surveying planned, as well as unplanned events and conditions. It could be used to inspect areas of concern such as the performance of the invert floor material, possibly checking for thermally induced cracks or premature deterioration. This inspection system could also check and monitor the integrity of the drift and wall structures, check for rock falls or unstable areas. It could check for signs of cracking or deterioration of any areas where ground support structures such as rock bolts and shotcrete were installed. It could check for signs of water, moisture and corrosion. It could be used to enhance or substantiate off-line photogrammetry and geologic mapping databases. An in-drift inspection capability of this nature would be a vital tool in substantiating engineering methods, approaches and techniques as the repository construction and emplacement modes continue to progress over the years.

5.1.2.5.2 Remote Thermal Inspection

The key performance confirmation parameters identified that would require remote thermal inspection include the waste package barrier wall temperature and the rock (emplacement drift wall) temperature; the drift air temperature may also be included. Thermal inspection is an important application area for the use of remote systems and ROVs. The emplacement drifts will be completely off limits to human personnel and the only direct means for obtaining specific thermal conditions will be by remote systems. 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. Using only exhaust air monitoring it would be possible for localized areas of heat concentration (i.e., hot spots), which may exceed the 200°C assumed thermal limit (CRWMS M&O 1996c), to go undetected. It will also not provide information about thermal variation and distribution across the emplacement drifts. Using a remotely operated thermal inspection system will allow for data to be collected that can be obtained in no other way.

Remotely operated thermal inspection systems can be used to observe thermal response parameters close-up and correlate this information over a long period of time. While the heated drift tests will provide some level of understanding and confidence about the thermal models being developed, they will not replace the need to observe the performance directly and over the entire 100 year window for performance confirmation observation.

A mobile remote means for obtaining thermal data is generally preferred over in situ monitoring because it permits for the periodic re-calibration of instruments. Concepts for general purpose ROV platforms were discussed previously. A remotely operated thermal inspection system would be equipped to monitor both air and surface temperatures. The inspection system might consist of technologies as simple as thermocouple temperature probes, or as advanced as a real-time thermal imaging infrared camera that can provide vivid color coded images and thermally map entire surfaces of a waste package or monitor temperature changes on the surrounding geologic surfaces.

The thermal inspection systems would be operated in conjunction with a vision system and provide human operators, located in a control room at the surface, with specific, detailed feedback about the thermal performance of waste packages; structures, systems, and components; and the subsurface infrastructures. These teleoperated thermal inspection systems could be deployed periodically within the emplacement drifts to document and catalog changes to the thermal profiles and verify those findings with previous expectations. Should anomalies arise or unexpected changes occur, the remote thermal inspection system will be an important means for obtaining more information.

5.1.2.5.3 Remote Radiological Inspection

The key performance confirmation parameter that have been identified that may require remote radiological inspection are the waste package life or time of initial radionuclide release. Remote radiological inspection is another important application area for the use of remote systems and ROVs. Due to the radiation emitted by the waste packages, the emplacement drifts during performance confirmation will be completely off limits to humans. A principle means for obtaining direct information regarding specific radiological conditions within drifts will be by remote systems.

The exhaust air from each emplacement drift will be continually monitored for radioactive gases. If any radioactive particles or gases are detected it would 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 may then be needed to enter the appropriate drift, identify which specific waste package is leaking and the extent of contamination.

Remote radiological inspection systems may be important for other reasons. 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. This would permit radiation mapping of individual waste packages and their surrounding environments. These systems provide the capability of monitoring and mapping specific radiological conditions in any specified drift.

5.1.2.5.4 Remote Geological Inspection

The key performance confirmation parameters identified that require remote geological inspection fall under the category of ESF and repository construction fluids and materials remaining after repository closure. The collection is needed to insure chemical composition and alteration is as predicted. It is possible that additional inspection of geologic materials will be desired at some time after the initial emplacement process has begun. A mobile teleoperated or telerobotic device might be equipped to drill, core and manipulate samples from within the emplacement drifts. It is conceivable that a remote geologic inspection system could be used to setup or support rock stress and movement experiments and assist in measuring drift convergence.

It may also be important to check the status of certain hydrologic parameters at specific locations within the drifts. This type of teleoperated device would be useful for monitoring water in-flow (if any), measuring drift moisture or humidity levels and other key parameters. It is also interesting to consider that there may be many such geotechnical and hydrologic measurements to be made and therefore an automated or semi-automated capacity to process them seems worthwhile to consider.

5.1.2.5.5 Remote Manipulation

Remote manipulation may be an important capability for recovery of sample specimens and test coupons placed at key points of interest within the emplacement drifts. Remote manipulation may also be useful in collecting dust samples and checking for particulate contamination by obtaining wiped swatch samples from surfaces of interest. In the event of a rock fall or other anomaly, remote manipulation would provide the system flexibility to clear the path of small rocks or debris that could otherwise impair the complete inspection of an emplacement drift. Telerobotic arms could be used to hold and position other sensor systems such as cameras or probes which would allow operators to inspect around or behind objects. A robotic manipulator arm might also be used to inspect and probe structural components of the repository. The robotic manipulator arm could check the integrity of rock walls and ground support structures much in the same way a human inspector may push or tap on these structures to check their integrity.

If in situ monitoring instruments are necessary , they could be designed to be easily retrievable, replaceable or serviceable by a remote maintenance system. It is emphasized that within the emplacement drifts even minor tasks, like adding or replacing relatively inexpensive sensors, or other components, will still require a remote system.

It is possible to develop a mobile telerobotic manipulation system that would allow for remote dexterous manipulation (manipulation involving several degrees of freedom simultaneously) with handling capacities on the order of a few grams to 50 kg. The control of these robotic manipulators would be by tele-operation from a surface-based control station. The manipulator system could consist of a single or dual arm configuration. The manipulators would be able to accommodate a wide variety of quick-change end-of-arm tooling, including grippers, cameras, lighting, proximity sensors, gas sensors, eddy-current crack detectors, scoops, shovels, impact hammers, saws, cutters, etc.

5.1.3 Waste Package Performance Confirmation Monitoring and Testing Concepts

Waste package performance confirmation monitoring and testing concepts consists of off-site testing and experiments, in situ monitoring, and 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, which are full size but do not contain actual waste, and waste package specimens or coupons. Each of these concepts is described below.

5.1.3.1 Laboratory Measurements Performed "Off-Site"

This concept mostly entails the continuation into the performance confirmation period of long-term laboratory studies that have supported viability assessment and license application. It is desirable in several instances to obtain data for various degradation phenomena that will affect the long term performance of the 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 multiplicity of conditions that can be studied. Also, environmental conditions can be maintained in the laboratory that simulate repository conditions at some future time so that the laboratory testing complements the in situ repository testing, which will occur under environmental conditions representative of the initial stages of repository operations. Another great advantage of laboratory testing for performance confirmation is that test conditions can be maintained to "accelerate" the degradation. Accelerated testing cannot usually be accomplished in the repository setting. 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 concepts.

The key parameters affecting 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 either the outer barrier or the inner barrier can be measured in long-term corrosion tests. This includes testing under immersed conditions and in humid atmospheres. The interactions between barriers, such as the degree of galvanic protection, 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. Only by doing the long term testing can a high degree of confidence be obtained in predicting performance. Characterization of oxidation and corrosion products is performed. Also, parameters associated with phase stability in the metal and weld integrity are measured in laboratory investigations.

Some of the long term testing is already underway (in 1996), and several more tests will be initiated in the next 2 to 3 years. Depending on the outcome of the license application waste package design and results of the material testing work, it is expected that a limited number of laboratory based tests will continue indefinitely 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 increases with the longevity of the test. Continuation of the testing provides continuing confirmation of performance prediction models and allows for any needed modification. Similarly, degradation concerns with waste package "internals," such as criticality control materials (basket materials, neutron flux traps, and others) are resolved by the long term laboratory testing. In most instances, the test specimens and equipment will already have been purchased before the performance confirmation period, so that the major expense will be to keep the testing operational and maintained and to perform specimen characterization on a periodic basis.

Waste form testing and characterization is best served in continuation of testing, now underway, well past the license application period. Key parameters characterizing spent fuel (overall geometry/dimension, geometry/surface area of UO_2 pellets, as well as the starting inventory of radionuclides) are measured. In this instance, laboratory testing is in a "hot cell." Study of the kinetics and mechanism of dry oxidation of spent fuel is important to understanding a possible early waste package failure mode (a breached container admits oxygen that rapidly oxidizes the warm UO_2 and ruptures the cladding to expose more fuel). Much of the laboratory testing emphasis is on phenomena that will occur in the later part of the containment period and into the controlled release period; that 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 will be 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 and specification can be monitored over time, as can any tendency for the glass to devitrify. Another important effect that can realistically only be measured in a laboratory setting is the interaction between the corroding disposal container and the release of radionuclides. It has been proposed that some of the particularly long-lived actinides will preferentially sorb onto metal oxides, and the extent of this reaction is amenable to quantification in the laboratory.

Much of the cost in setting up the laboratory testing will have been incurred before license application, so the costs of maintaining the appropriate parts of the testing during the performance confirmation period will be mainly those of continuing the operation and periodically characterizing the spent fuel and glass specimens. Continuation of the "hot cell" tests into the performance confirmation period adds confidence to the performance models. Except for the characterization of an emplaced waste package that has failed or been damaged in the repository, laboratory testing is about the only way that waste form characterization can continue in order to increase confidence in performance predictions.

5.1.3.2 In Situ Monitoring

This concept provides a wealth of background information that is essential for understanding and interpreting results from all of the other in situ performance confirmation concepts. In situ monitoring also provides a "reality check" on the continuing laboratory investigations. Some of the parameters that will be monitored are also obvious indicators of operational safety in the repository. Foremost among the parameters to be monitored are gaseous radionuclides whose presence would indicate an early leak, such as the scenario in which a cracked weld breaches the waste package and exposes very warm spent fuel to oxygen. Sniffers to detect Kr-85, tritium, possibly C-14 (as CO_2), and perhaps other radionuclides in the exit ventilation atmosphere would be used. Specific tracer gases may be used so that the location of the leaking container can be determined. Cameras and closed circuit television will monitor waste package container surfaces for evidence of corrosion or other penetrating attack.

In situ monitoring of the container surface temperature on radioactive waste packages and on "dummy" waste packages is planned. The humidity will be measured at many locations in the repository—in the emplacement drifts, in access drifts, wherever dummy waste packages and test alcoves are located, since an important strategy element in waste containment is maintaining "dry" conditions. Other chemical sensors may be emplaced in the repository, depending on the outcome of laboratory investigations on what are the important parameters determining waste package performance. One possibility would be detection of certain sulfur containing species, indicating microbial activity. More equipment for monitoring environmental parameters can be used outside the emplacement drifts, for instance in specially constructed test alcoves where dummy waste packages and pull specimens are placed. "Dummy" waste packages will be instrumented with strain gages to measure stress at different locations on the container. In order to capture as much information as possible, it is proposed to instrument as many diverse kinds of locations in the repository as possible, for example, in faulted or heavily fractured areas (where waste packages would not be emplaced), but which could provide information about ""what-if" scenarios). Analysis of any in-leaking groundwater would be particularly appropriate for determination of disposal container and waste form performance in later time periods, when the "thermal blanket" has collapsed, and aqueous conditions are more probable.

5.1.3.3 Pull Radioactive Waste Package—Perform Measurements On-Site or Off-Site

This concept involves the characterization of real, radioactive waste packages while they are exposed to repository conditions, including the high thermal field that close spacing of the packages will produce. This concept of performance confirmation is by far the most costly and is proposed on a contingency basis; that is in case a breached, damaged, or malfunctioning waste package is detected, and the waste package is retrieved and brought back to the surface facility for re-work. From a performance confirmation point of view, such an occurrence is looked upon as a "target of opportunity."

Meaningful in situ measurements on most of the internal elements of the waste package — the waste form, the spent fuel cladding, the basket or criticality control structure can only be made from this concept, since it is not possible to produce the combination of radiation field and internal (to the waste package) environment in any of the other in situ performance confirmation concepts. Depending on equipment that will be available at the surface facilities, it is expected that most of the examination of radioactive waste packages will be performed there, with perhaps some specialized kind of analyses (if needed) performed in a laboratory. Several of the analyses that will be performed on the retrieved waste package will complement analyses being performed off-site in long term laboratory investigations on the waste form, "basket" material (for criticality control), spent fuel cladding, and any other internal waste package structure (e.g., glass pour canister, spent fuel interim storage container, even if that item is not intended to be one of the engineered barriers).

The key parameters that will be examined in this concept include many of the waste form characterization parameters. For spent fuel, changes in the geometry and surface area of the UO_2 pellets plus any evidence of oxidation are noted. For glass waste form, any evidence of devitrification is noted. For all the waste forms, analyses of the radionuclides indicate if predictions of the inventory are accurate. The condition of the spent fuel criticality control structure is assessed, as well as the condition of the spent fuel cladding and any other internal elements in the package. The condition of the fill gas in spent fuel packages is assessed. Because the expected conditions are hot and dry during the operational period, none of the aqueous processes (such as dissolution) are expected to be observed, so that only the continuing laboratory work will provide any performance confirmation for these parameters.

5.1.3.4 Pull Dummy Waste Package — Perform Measurements On-Site or Off-Site

This concept for performance confirmation entails manufacture of a "dummy" waste package of the same dimensions and configuration as the real waste package, but not containing any radioactive waste. Instead, the package houses an electrical heater. The "dummy" package will be used to study thermally induced changes in the container material and in the surrounding environment. The full scale dummy waste package also permits exactly the same fit of the inner and outer barrier material, reflecting accurately the state of stress existing in the real package. The dummy waste package will also be fabricated and welded just like the radioactive waste packages, so that examination of the exposed surfaces and welds will be very much like examination of the real thing.

Obviously, the cost of pulling dummy packages is less than that of pulling radioactive waste packages; however, the measurements are largely confined to those affecting the disposal container, while pulling radioactive waste packages yields information about the waste form and other internal elements of the waste package. The dummy waste packages would be emplaced in a specially designed alcove where recovery would not present as many obstacles. However, to keep the dummy packages powered will require installation and maintenance of an infrastructure, with frequent access to the location of this test alcove. Because the repository design is one of close emplacement of radioactive waste packages to achieve a high thermal output, considerable effort (and expense) will be required in the design of a repository "wing" to achieve thermal results similar to the emplacement drift. An additional variation in using dummy waste packages is to reduce electrical power to some of them in order to simulate later time periods in the repository, when the surface temperature has decreased so that aqueous conditions may occur around the waste package.

While some measurements can be made by observation of the surface during exposure, most measurements will be made by withdrawing the dummy waste package and examining it destructively either in the surface facility (depending on the kinds of equipment and instrumentation available) or at an off-site laboratory.

Key parameters supported by this concept 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 oxidation to corrosion. Evidence of pitting or other localized attack (including any microbially influenced corrosion) on the container surface is examined. Penetration of the container section by general corrosion, pitting, stress corrosion cracking, or other localized attack is quantified. The nature and characterization of oxidation and corrosion products are made during examination of the exposed surfaces of the container. Instrumenting the dummy containers with strain gauges allows monitoring the stresses at various locations and changes in the stress with the time of exposure in the repository. Non-destructive examination of welds supports investigations of weld integrity while destructive sectioning of the container supports investigation of potentially damaging embrittling phases plus any evidence of any penetration by corrosive attack.

5.1.3.5 Pull Specimens — Perform Measurements On-Site or Off-Site

This concept 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 the laboratory test environments. It is assumed that "pull specimens" can be placed at different locations in the repository, where the specimens will experience different sets of environmental conditions. Some specimens should be placed in the hotter and drier locations, either alongside the waste packages in the emplacement drifts or alongside of electrically heated dummy waste packages in test alcoves. These specimens will thus witness the same thermal and humidity conditions that the real (i.e., radioactive) waste package containers are experiencing during the operational period. Other pull specimens should be placed in test alcoves located away from the emplacement drifts in the cooler and moister locations in the repository in order to simulate the conditions that would be representative for the waste package at a future time when the heat source inside the waste package has decayed. It is desirable from a testing point of view, to put specimens in a variety of exposure locations in order to cover a reasonable range of the geological and geochemical variations occurring across the repository "imprint." It is even desirable to locate pull specimens in faulted or heavily fractured areas (where waste packages would not intentionally be emplaced) so that exposure data can be collected under "off-normal" conditions.

"Pull specimen" testing is largely restricted to the container materials, since the exposure conditions in the repository can only duplicate the "external" environment of the waste package. The specimens themselves 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 "pull 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 pull specimens may be analyzed "on site"—with the measurement performed at the exposure location or the specimen withdrawn and then measured and examined at the repository surface facility, or "off site"— measurement performed at a laboratory site. Compared to testing the "dummy" waste packages and destructive examination of "sacrificial" waste packages, pull specimens are relatively inexpensive. The major expense will be in accessing the pull specimens located in the emplacement drifts, but it is believed that several measurements can be taken by remotely controlled cameras and instrumentation to minimize the need for physical withdrawal of the specimens.

The key parameters supported by the pull specimen tests are those dealing with corrosion and other degradation characteristics of each waste package barrier. These include the dry oxidation rate, and the different phenomena occurring in humid atmospheres and under aqueous conditions (threshold humidity level, humid air general corrosion rate, aqueous general corrosion rate, pitting corrosion in humid air and in aqueous conditions, microbial attack). Evidence of galvanic effects, such as galvanic protection, between the two metals comprising the waste package is noted. The nature and characteristics of oxidation and corrosion products can be determined from examining the surfaces of the "pull specimens." Also, determination of the embrittlement in the container materials, and integrity of the welds are supported by "pull specimens."

The "pull specimen" concept increases the confidence goals because many specimens can be placed in locations selected to represent different sets of environmental conditions.

5.2 PERFORMANCE CONFIRMATION TEST FACILITIES AND SUPPORT CONCEPTS

The performance confirmation concepts described in this section support data acquisition performed via monitoring, testing, or experiments. The concepts include both subsurface and surface facilities that provide access to locations needed to perform tests and monitoring, plus support of these activites. Data and sample handling are included in the concepts and the descriptions that follow. This includes interfaces with off-site testing or analysis and a central facility for all performance confirmation related information.

5.2.1 Repository Subsurface Performance Confirmation Test Facilities and Support Concepts

It is likely that a combination of several different Test Facilities and Support will be utilized in order to gather the information needed to execute the Performance Confirmation Program. One such concept is envisioned in which certain localized, representative areas of the repository would be extensively and continuously monitored via observation drifts with instrumented boreholes. Other data would be gathered continuously over the entire repository by monitoring a small airflow volume passing through each emplacement drift. The recovery of emplaced waste packages for performance confirmation is possible. Alcoves for monitoring or testing in non-emplacement areas will be provided. There are certain concerns regarding subsurface geologic mapping interface with construction that will be discussed. Sample collection and handling during repository construction is a fundamental part of the concept. Another method would be intermittent remote excursions into the emplacement drifts, which could involve physical recovery of "dummy" waste packages and/or samples (e.g., waste package material "coupons") left in the emplacement drifts. The ACD report (CRWMS M&O, 1996a), which contains unqualified data, was used as the reference. Each of these potential concepts and areas is discussed in more detail below.

5.2.1.1 Permanent Observation Drifts

Drifts which ramp up (or down) could be excavated off the main perimeter drifts and out over the repository emplacement areas to provide a permanent monitoring facility which will remain accessible throughout the pre-closure period. Figures 5-2, 5-3, and 5-4 show a concept for these "Observation drifts." Drillholes from the observation drift toward the adjacent emplacement drifts would contain instrumentation for long-term, in situ data gathering activities. Such a concept would likely resemble the current plans for the ESF thermal test where the heated drift is not accessible, but is monitored via borehole instruments. Selected drillholes could penetrate the emplacement drift wall, allowing instrumentation to be inserted directly into the emplacement drift, and then withdrawn. Instrumentation would be installed in the drillholes 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 which must be grouted in place, additional holes may have to be drilled in the event of an instrument failure.

There are a variety of observation drift arrangements, that could be utilized to provide access for monitoring for example above, below, or at the same level parallel, perpendicular, or at an angle to an emplacement. The two permanent observation drift concepts are shown and discussed in this section and represent very preliminary evaluations of obtaining data near emplacement drifts. Other possibilities are not listed or discussed. The first concept shown in this evaluation is one in which a drift is driven across the repository block approximately 25 m above the emplacement drifts on an alignment parallel to the underlying drifts. This drift would lie directly over an emplacement drift. By drilling holes from the observation drift down and to the sides, three underlying emplacement drifts could be instrumented for continuous pre-closure monitoring. See Figures 5-2, 5-3, and 5-4 for the observation drift concept.

The number of observation drifts will ultimately depend on the amount of coverage which is required. The amount of areal coverage would vary with the number of observation drifts and the spacing of the instrumentation stations. A single observation drift spanning the upper block would provide coverage of three emplacement drifts (approximately 2,700 m of emplaced drift), or up to about 2% of the total inventory. If six observation drifts were employed, up to about 10% coverage could be achieved.

The observation drift can be a relatively small drift. The size will be driven by required equipment operating envelopes. For this evaluation, it is assumed that a 3 m by 3 m "horseshoe" configuration is adequate. The drift could be driven by roadheader or drill and blast. While tunnel boring machine development would be feasible, the small total length of this size drift required would likely mean that it would not be worthwhile mobilizing a tunnel boring machine to perform the job. An alternative could be to drive the observation drift with the emplacement drift tunnel boring machine. This would make it larger than it needs to be but would likely speed up the development process. A 3x3 m horseshoe drift of the length needed to serve as an observation drift would require the excavation listed below:

- 10% ramp - 500 meters
- 0.5% observation drift - 1,080 meters[1]

The excavated volume would be approximately 8 m^3 per meter of drift, or about 12,640 m^3 per observation drift. For comparison, a 5 m diameter emplacement drift will have an excavated volume of about 21,200 m^3.

The first observation drift would likely be excavated during the pre-emplacement development construction period so that it could be ready to begin data acquisition with the emplacement of the first waste packages. Subsequent observation drifts would be constructed during the normal development operations.

A second option for permanent in situ monitoring from accessible drifts would be to utilize the unemplaced drifts intended for operational use. In the *Mined Geologic Disposal System Advanced Conceptual Design Report* (MGDS ACD) (CRWMS M&O 1996a), the 40th, 80th, and 120th drifts (counting from the north end of the upper block) were shown as developed but not emplaced. Dual use (operations and performance confirmation) should be compatible since the primary operational use of the unemplaced drifts is to allow ambient temperature air to pass unheated through the emplacement area and into the emplacement exhaust drift in order to moderate the exhaust drift temperature. These drifts may also serve as an emergency pathway for personnel to move between

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[1] The width of the upper block varies, and this length would vary with the width of the block.

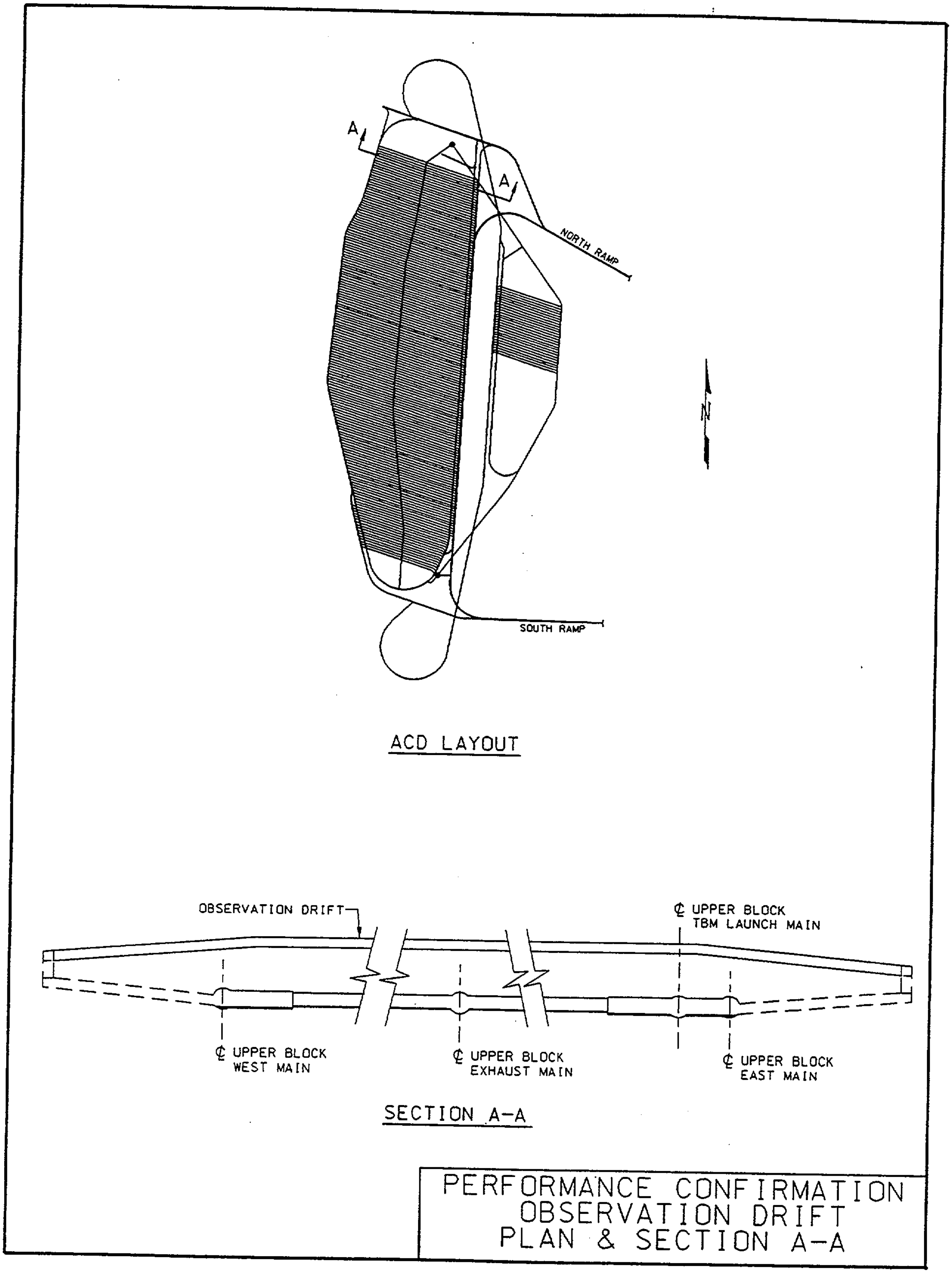

Figure 5-2. Performance Confirmation Observation Drift - Plan & Section A-A.

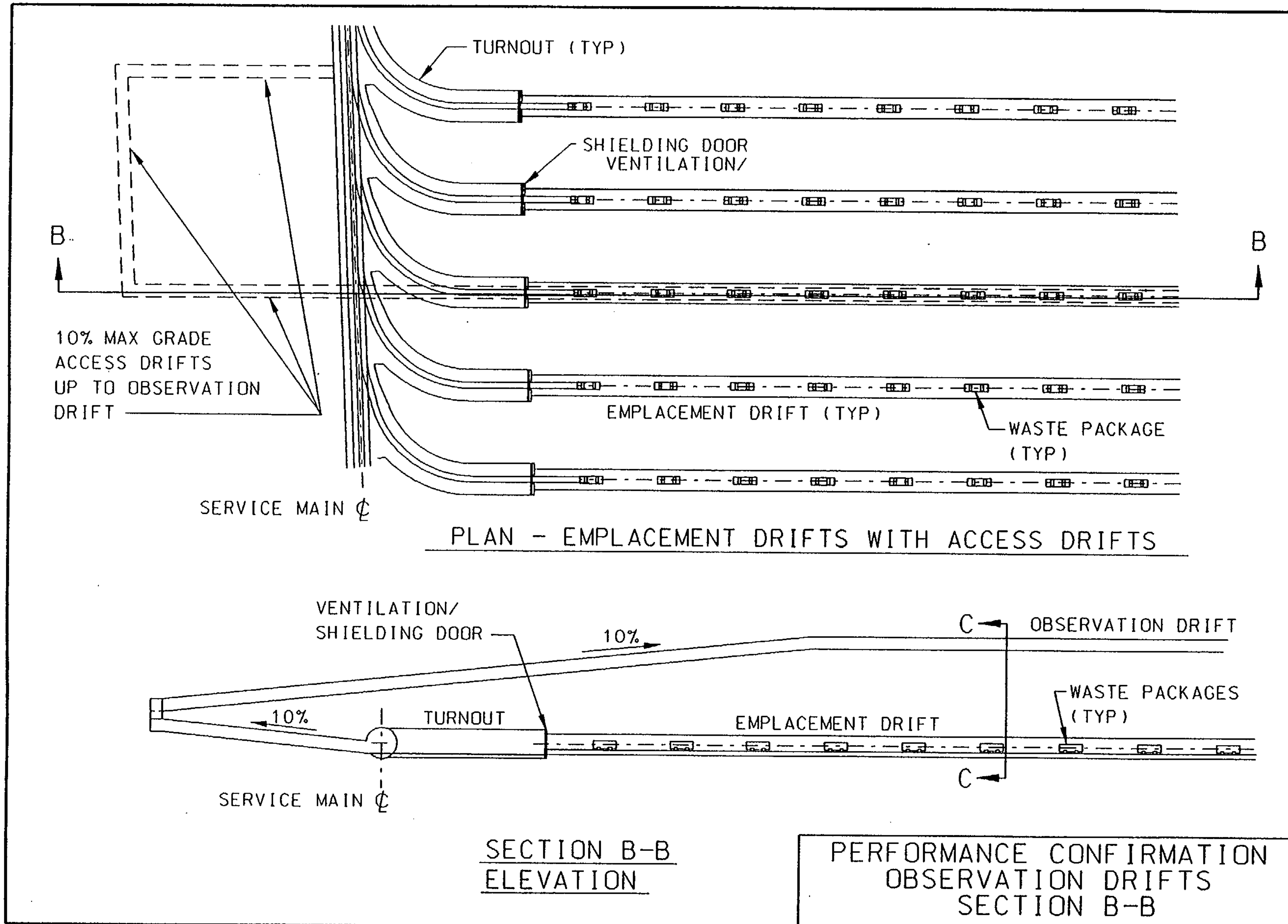

Figure 5-3. Performance Confirmation Observation Drifts - Section B-B.

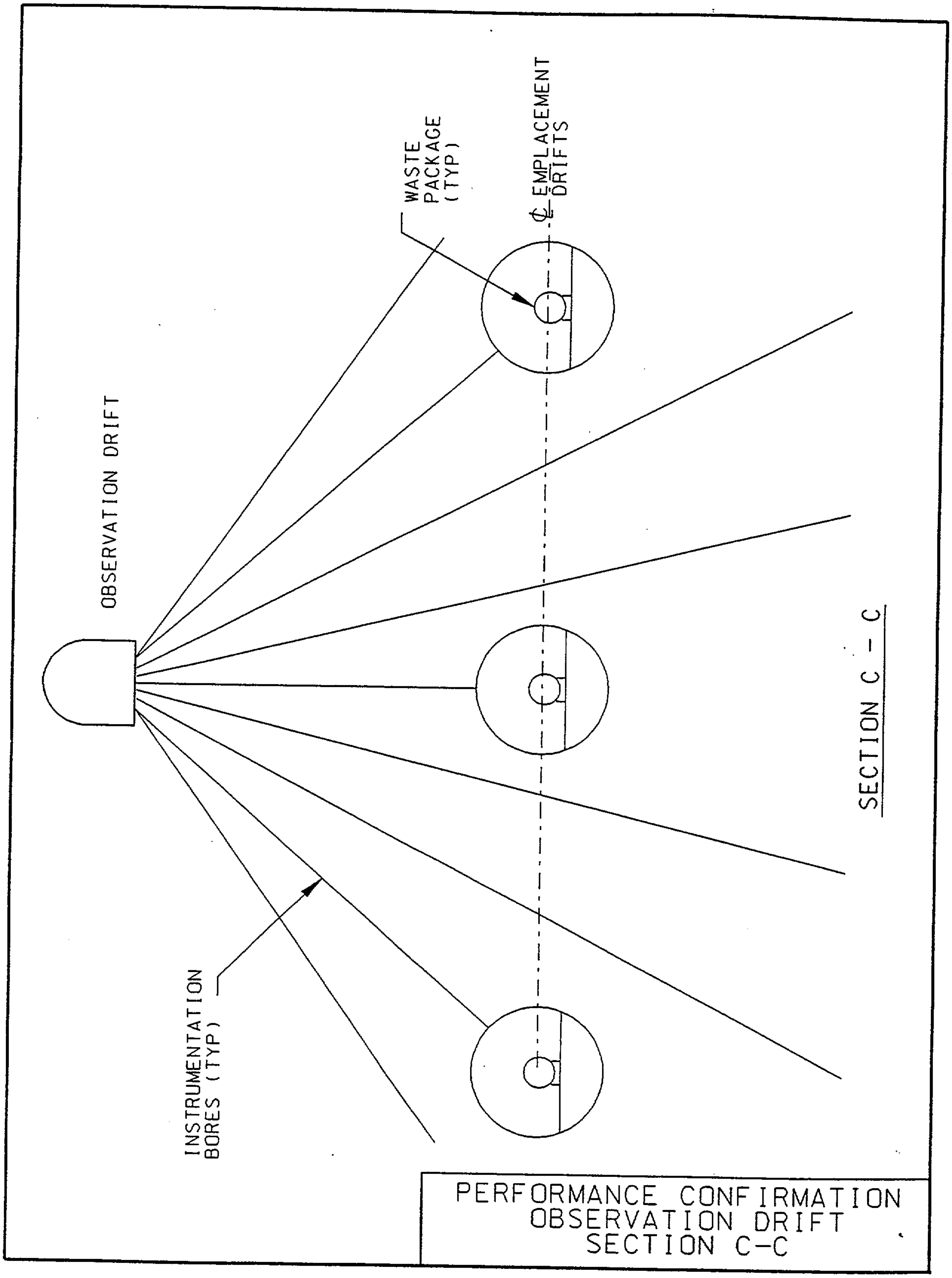

Figure 5-4. Performance Confirmation Observation Drift - Section C-C.

the emplacement exhaust drift and the east or west service mains. The presence of instrumentation in the drift should not hinder the passage of air or personnel on foot.

There are several differences between using of the operational drifts for performance confirmation and using the dedicated observation drifts discussed above. Figure 5-5 shows a potential arrangement for monitoring from an empty emplacement drift. When compared to Figure 5-4, it can be seen that the dedicated observation drift ("option 1") can provide coverage of three drifts as opposed to two for monitoring from an empty emplacement drift ("option 2"). As noted above, there are currently three operational drifts planned, which would result in a maximum coverage of six emplacement drifts. In addition, it would be more difficult to acquire information from the area directly between two adjacent heated drifts with option 2 because it is not possible to drill a hole directly into this area from a drift located in the plane of the emplacement drifts.

Reasonably large airflows would be coursed through the option 2 drift since one of its operational functions is to allow passage of ambient temperature air into the emplacement exhaust for dilution of heated emplacement drift exhaust air. Volumes of 15-30 m^3/s would be normal, with a possibility of higher flows on a temporary basis if emplacement drift cooling for re-entry is required. A flow of 30 m^3/s in a 5 m diameter drift results in an air velocity of about 1.5 m/s, or about 300 ft/min. (3.4 mph). The airflow in a dedicated observation drift (option 1) would be set at whatever was needed to support the operations and personnel planned for the drift, and would likely be much lower than for option 2.

The advantages of option 2 lie in its lower cost. No additional excavation cost would be incurred, as the operational drifts are already planned. A potential disadvantage of option 2 is that only three cross-block drifts are currently planned. Option 1 drifts are purely for the purpose of performance confirmation, and as many as are needed could be developed. Additionally, the first option 2 drift would not be developed until several years after the start of emplacement. An option 1 drift would likely be built during pre-emplacement construction so that it could be operational by the start of waste emplacement operations.

5.2.1.2 Emplacement Drift Ventilation Monitoring

The reference design described in the MGDS ACD Report does not include ventilation of emplacement drifts after waste emplacement is completed in the drift. It was assumed that a minimal, but undefined, amount of leakage would pass through the closed drifts. Alternatively, in order to give some insight into emplacement drift conditions, a small amount of ventilation (0.05 m^3/sec, about 100 ft^3/min) could be supplied through each drift without unreasonably impacting the reference design. Ventilation at this level would not lower the peak temperature significantly, but, if monitored at the exhaust end of the emplacement drifts, would allow measurement of:

- gasses indicative of WP leak (^{85}Kr, etc.)
- dry bulb temperature
- wet bulb temperature
- Relative Humidity (either by using the dry bulb and wet bulb temperatures, or by direct measurement).

Coupled with monitoring at the intake end of the drifts, this information would yield the amount of moisture being removed from the drifts, an approximation of the rock wall temperature in the drift, and give rapid indication of leakage of gaseous radionuclides due to a waste package breach. It would also tend to distribute the heat in the drifts, reducing the magnitude of the disparity in temperature between hotter and cooler zones along the drifts. In the ACD waste package arrangement, assuming no air movement, there is an approximate 15°C difference between the drift wall temperature adjacent to the center of a 21 pressurized water reactor waste package, and the drift wall temperature at the mid-point between waste packages.

The precise balancing, distribution, and regulation of several hundred different air "splits" will require a significant design and operations effort. Considerations would include the small unit quantity of airflow, seasonal and diurnal atmospheric changes, and, during the active emplacement period, a constantly changing fan pressure/quantity situation. It is likely, however, that this approach will be found feasible.

In order to prevent the central exhaust drift from becoming uninhabitable due to the high temperature air bleeding from the emplacement drifts, reasonably large quantities of ambient temperature air will have to be directed into the central exhaust via unemplaced drifts. This ambient temperature airflow will help to dilute and cool the overall airmass in the central exhaust and maintain accessibility for radiation monitor repair and drift inspection and repair.

An estimate of the dilution airflow needed is given below:

> If the average air temperature exiting the emplacement drifts were 155°C, and the average dilution (unheated) air temperature is 27°C, a dilution ratio of about 5:1 of unheated to heated air would be needed to maintain average temperatures in the exhaust main at or below 50°C. The worst case from a volume standpoint would occur close to the end of active emplacement operations, when nearly the maximum number of filled emplacement drifts exist, but normal emplacement operations are still occurring in the last two or three drifts in the lower block. The bleed quantity would total 17.2 m^3/sec (343 emplacement drift splits at .05 m^3/sec each). The dilution quantity would be 5 times this amount, or about 85.8 m^3/sec. It can be seen that this concept would add about 103 m^3/sec to the required emplacement ventilation system quantity.

The maximum flow rate that can be supplied by the emplacement ventilation system is defined by the maximum allowable velocity in the waste ramp. This peak allowable velocity is 7.62 m/sec (CRWMS M&O 1996c). If it is assumed that 80% of the 7.62 m diameter waste ramp is free of obstruction and able to pass airflow, then the maximum flow rate sustainable in the ramp is 80% of the cross-sectional area times the maximum velocity. This value is 278 m^3/sec. The normal emplacement operations require only about 20 m^3/sec per active drift (CRWMS M&O 1996a). Even if four drifts are maintained in the active mode simultaneously, there is significant excess flow capacity available because there are no other large air quantity needs, under normal conditions, in the emplacement system. The current flow network could support four active emplacement drifts (two are assumed in the ACD), at the bleed/dilution quantity described above, with simultaneous cooling of a selected emplacement drift for re-entry (at 60 m^3/sec), and 10-15% leakage before the velocity limit would be approached.

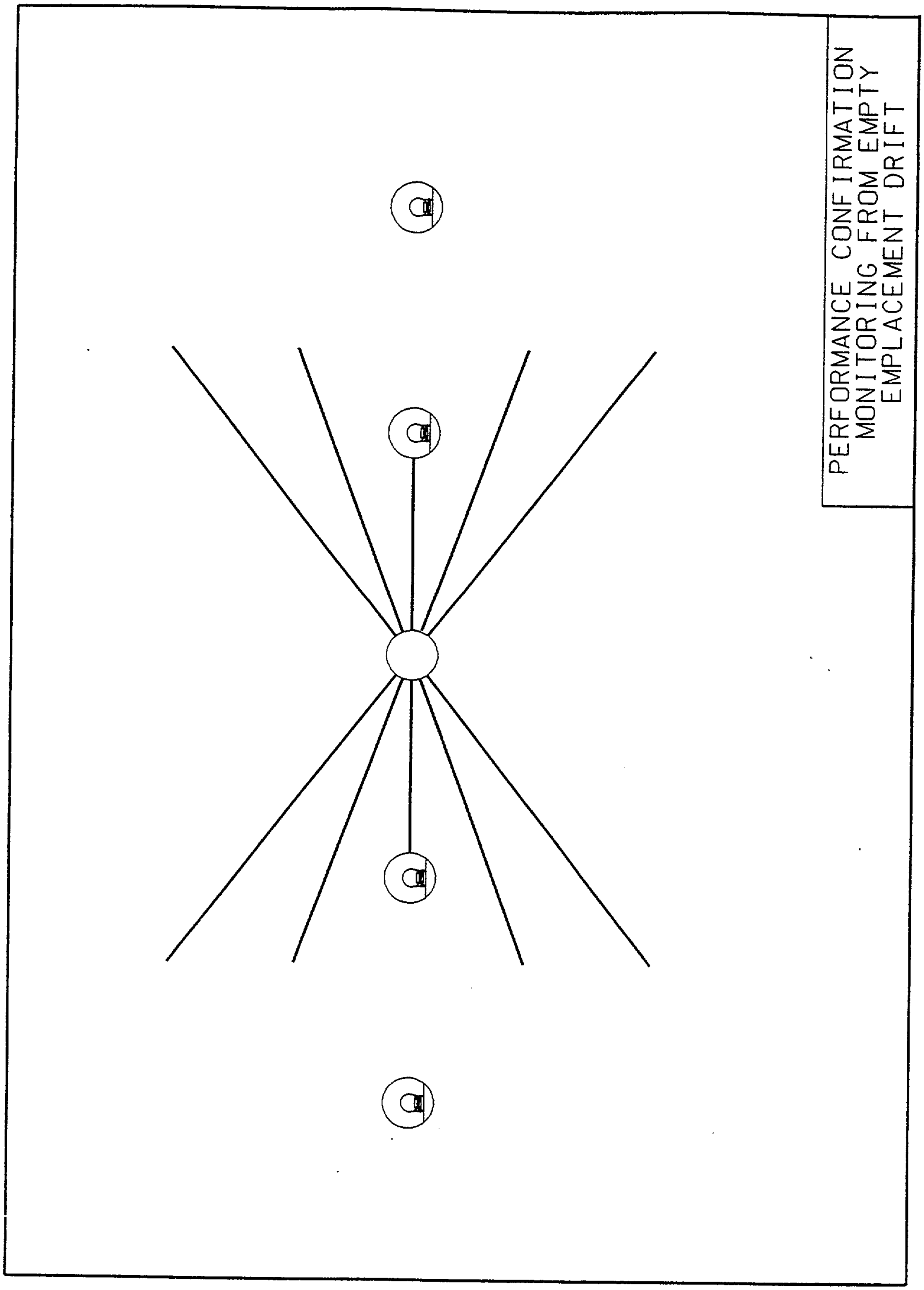

Figure 5-5. Performance Confirmation Monitoring From Empty Emplacement Drift.

5.2.1.3 Recovery of Waste Packages for Performance Confirmation

The ability to remove any (or all) of the waste packages after emplacement is a basic requirement of the repository program, and this capability will be maintained throughout the pre-closure 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 WPs are not trivial. While the exact impacts of this activity are not well defined, it will not be desirable to perform this action repeatedly for the following reasons:

- Cooling of an emplacement drift from a temperature in the range of 140 to 160°C to less than 50°C will cause large changes in the stresses around the opening, both in the rock and in the installed ground support components. The heating/cooling/reheating will induce strain cycles in the emplacement drift rock and ground support components which would otherwise not occur.

- The air mass which is pushed out of the emplacement drift and into the main exhaust drift at the onset of drift cooling will make the main exhaust drift temporarily inaccessible. The temperature surge may also adversely affect monitoring equipment likely to be located in the main exhaust drift.

- Unless the WP to be recovered is the one closest to the drift entrance, other WPs would have to be removed, transported, and re-emplaced prior to recovery of the target WP. This means that at least some additional emplacement drifting beyond what is needed for the initial emplacement will be required.

- During the Caretaker phase after emplacement is complete, the surface facility will be "mothballed." If any activity is required in the surface facility in conjunction with caretaker period WP recovery and handling, the facility would have to be re-activated at some cost.

5.2.1.4 Alcove Concepts for Performance Confirmation Program Testing in Non-Emplacement Areas

As described in section 5.1.2 above, 10 CFR 60 describes several testing programs which are to be initiated "During the early or developmental stages of construction...". Included in this suite of testing are tests of potential sealing systems for boreholes and shafts, backfill testing, and heater testing. In addition, subsurface seismic monitoring has been identified as a performance confirmation activity which should be carried during repository operations. Specific subsurface locations and support of these testing activities needs to be established in the design and accommodated in the operational concept.

These activities would 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 it is assumed for this activity that the early backfill, seal, and thermal testing will be carried out in the development side ventilation system. While access for testing will be not be unlimited even on the development side, it should be sufficient to construct, install, and monitor the tests. Testing activities are assumed to take place primarily in the area south of the upper emplacement block adjacent to the South Ramp Extension (See Figure 5-6). Each of these locations for these testing activities is discussed below.

5.2.1.4.1 In Situ Seal Testing Alcove

In situ testing of seal designs and materials may require multiple test locations. Each geologic unit which is expected to contain seals at closure would be tested. Access to all units from the surface to the repository horizon is provided in the south ramp. Alcoves can be developed off the south ramp in each unit of interest.

For the purposes of this system study, three test areas, one in the Tina Canyon member, one in the non-welded Paintbrush Tuff, and one location in the repository horizon, are assumed. A description of the seal testing plan is contained in the above referenced document. Each of these test areas is estimated (YMP 1992), to require approximately 300 m of drifting. The test locations would include one near the south portal for the Tina Canyon unit, one about halfway down the south ramp in the bedded Tuff, and one along the south ramp extension in the repository horizon.

5.2.1.4.2 Alcoves or Drifts for Backfill Testing

The initial heated backfill test, if required, could be conducted in an alcove along the south ramp extension. It is assumed that an arrangement similar to that being used for the ESF heated drift would suffice for this testing activity. A "U" shaped alcove layout with one leg of the "U" serving as the backfilled drift and the other leg as the observation area should be adequate for the test. Heaters to simulate emplaced waste would be covered with backfill material. Instrumentation for data acquisition would be placed in the backfill and in boreholes drilled from the observation drift.

It is noted that the configuration and size of the testing areas described in this section are estimates made only for purposes of developing a feel for their associated construction costs and operational impacts. Additional input will be needed to produce complete testing configurations.

An estimate of the excavation required for this test area is approximately 100 to 130 meters of drift. The backfill test area will likely be driven to resemble the emplacement drift size and shape, while the balance of the drifting could be very similar to the ESF heated drift test access.

Data acquisition could be handled by either a local data logger which is downloaded on a regular basis, or by a permanently installed data acquisition, transfer and storage system. In either case, the information would be acquired and stored on-site and subsequently retrieved and transferred to the appropriate scientific personnel located off-site.

On-site scientific presence would be needed to monitor the test, and construction support would be needed to install the test equipment and to assist with maintenance over the test duration.

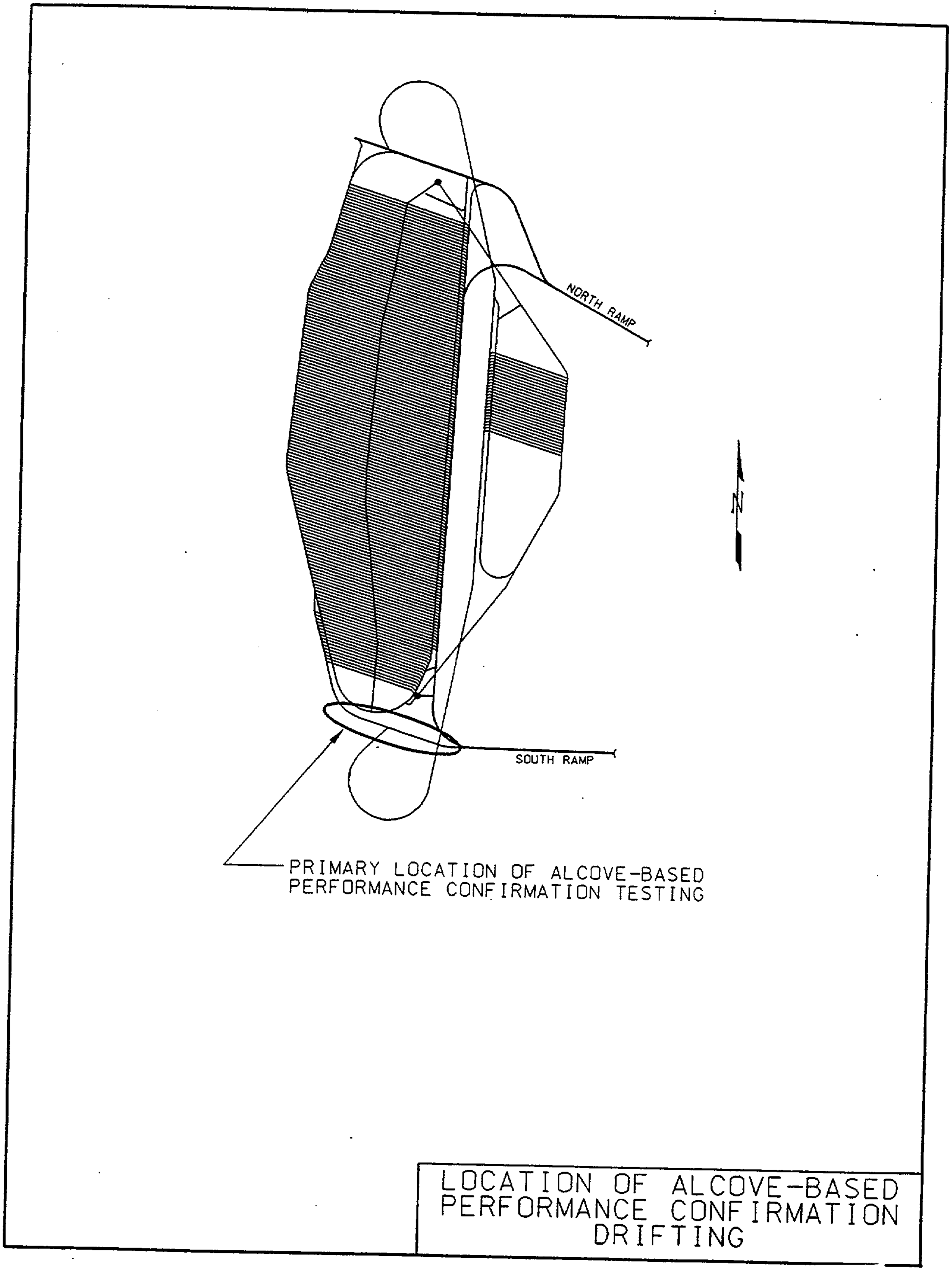

Figure 5-6. Location of Alcove-Based Performance Confirmation Drifting.

The second backfill test is more for constructability, and will likely be conducted more on something approaching an emplacement drift scale (hundreds of meters). As noted above, it does not need to be conducted until just prior to backfill placement. If emplacement drift backfill is utilized in the MGDS, it would not be emplaced until just prior to closure. This test would likely involve filling all or part of an empty emplacement drift to test the material handling equipment and concept.

As described above, the constructability test would occur very late in the preclosure period. An empty emplacement drift, which had been excavated during the normal development operation as a reserve emplacement area, would be backfilled to test the viability of the backfill process and equipment, and to gather information on productivity, availability, and the condition and uniformity of the emplaced backfill.

5.2.1.4.3 Follow-on Drift Heater Test Arrangement

The heater test arrangement is assumed to resemble the heater test shown in the *In Situ Thermal Testing Program Strategy* (DOE 1995b). In this reference, the test is referred to as the "Emplacement Drift Thermal Test." The test arrangement as shown in the reference would require a relatively intricate, lengthy drifting arrangement with drifts on three distinct levels. It is likely that a simpler arrangement would ultimately be selected.

5.2.1.4.4 Seismic Monitoring Alcove

Seismic monitoring can be accommodated in the repository operational area by providing a small alcove with appropriate utilities and access. Equipment vibration and dust must be accounted for in the selection and installation of the equipment. Data acquisition, as noted above, could be handled by a local data logger or by connection into a subsurface-wide data transmission network and storage system. A single alcove is assumed, and is located along the south ramp extension in the same general area as the backfill test described earlier. This alcove is assumed to be an "L" shape with a total length of 20 to 30 m.

5.2.1.5 Subsurface Geologic Mapping or Unexpected Geologic Conditions and Their Interface with Repository Construction

10 CFR 60.72(b)(3) and 60.141(a) both require that a program of geologic mapping be carried out during the construction of the repository. The scope and coverage of the mapping is not specified. The ESF tunnel is being mapped continuously by personnel stationed on a gantry which is an integral part of the tunnel boring machine trailing gear. The ESF ground support system varies according to the ground conditions as they are seen at the working face.

The degree to which mapping is required during repository construction is closely tied to the selection of the emplacement drift ground support concept. Robust, continuous liner systems are being considered in order to reduce the inherent uncertainty of maintaining access for monitoring and retrieval for the extended preclosure period. The use of such lining systems, especially if installed in a close-coupled process with excavation, will present challenges in the acquisition of comprehensive mapping information. The requirement to acquire mapping information will have to be factored into the development of the final construction process.

Scheduling will be critical to the successful collection of an unexpected fault zone hydrologic information without adverse impact to repository construction. Because of the large number of emplacement drifts to be excavated, a fault which is encountered in one drift is likely to be encountered in several drifts. This implies that, once an unexpected fault is discovered, a plan could be devised to gather fault hydrology data in conjunction with a subsequent intercept of the same fault. Also, if the fault is of sufficient length, it could be examined from the closest observation drift. Long-term alcove-based fault hydrology testing would best be done either off the main drift, or in Observation Drifts dedicated to performance confirmation. Alcove-based testing off emplacement drifts would be disruptive to the repository construction and operation sequence and should only be considered if an extensive, completely unexpected major feature is found which calls into question the viability of the site.

5.2.1.6 Sample Collection and Handling During Repository Construction

It is assumed that geologic samples will be collected on a regular basis during the development of the repository. This sampling must be coordinated with repository drift excavation to minimize impact to the construction operation while still obtaining the required information. Ideally, sampling would not be closely coupled to the excavation operation. The two functions should be reasonably independent. Sample acquisition would have the least impact if carried out in conjunction with TBM maintenance activities.

The selection of an emplacement drift ground control concept may have a significant impact on the sequence, and possibly the number, of samples taken. Full lining of emplacement drifts, particularly if installed as part of the primary excavation operation, may limit sampling opportunities and require sampling to be closely tied to excavation. As noted above, this may not be desirable, but could be necessary.

For this evaluation, about 200 to 1,000 sampling sites are assured. This amounts to one to five sites per emplacement drift. An average of approximately eight emplacement drifts are used per year during full operations, so 8 to 40 sampling sites per year, or about one sample per week if 1,000 sites are selected or about one sample every six weeks if 200 sites are selected.

The handling of the samples would depend on any special requirements placed on the sampling by the nature of the testing to be done on the particular sample. Samples can be taken, bagged, boxed, or sealed, and transported to the surface by the normal personnel and supply transportation system. At the south portal surface facility, the samples would be off-loaded and either stored on-site or transported to a sample management facility.

5.2.1.7 Remotely Operated Systems for Temporary In-Drift Monitoring

There are performance confirmation data collection activities that may best be acquired by telerobotic or remotely operated systems. It is feasible that ROVs could be designed to withstand limited exposure to the elevated temperatures and radiation levels expected within the post-emplacement drift environment. The ROV systems would be general purpose mobile platforms that could be outfitted with a variety of instrument packages providing visual, thermal, radiological, or geotechnical inspection capabilities. The ROVs could also be equipped with telerobotic manipulators with end-of-arm tooling attachments like grippers, cameras and lighting for recovery of sample test specimens or coupons. These remote systems would be under continuous observation and control by human operators at a control station located above ground.

Controlled design assumptions specify that maximum temperatures inside the post-emplacement drifts will be limited to 200°C (CRWMS M&O 1996c). Based on current design concepts, preliminary calculations indicate that temperatures inside the post-emplacement drifts may actually only reach the 150-165°C range (CRWMS M&O 1996a, Vol. II, p. 8-26). Other calculations indicate that radiological conditions inside the emplacement drifts may have dose equivalents of 28,900 millirem/hr near the surface of some waste packages (CRWMS M&O 1996a, Vol. III, p. 6.3-167). These radiation levels are much too high to realistically permit human entry, but they are not exceptionally high for remote equipment.

5.2.1.7.1 Design Strategies and Technologies for Elevated Thermal and Radiation Environments

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 that which is expected inside the emplacement drifts. For the dose rates expected, the principal strategies for minimizing the effects of radiation will be a) the judicious use of radiation shielding materials, b) use of "rad-hardened" electronic components, and c) since the ROVs will be employed inside the emplacement drifts for only limited periods of time, the total accumulated dose can be monitored and sensitive components can be swapped-out at periodic intervals.

The major challenge facing ROV designers is building 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 ROVs which 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 (gears, bearings, etc.) and structural materials that are suitable for use at elevated temperatures. A key area of concern, however, is the use of on-board electronics and actuators which may be heat sensitive. 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.

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 thermal conduction paths for high heat components.

Heat from external sources can be rejected by use of appropriate shielding and insulating materials. The primary concern is removing or dissipating heat generated internally to 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 ROVs are power and communications technologies.

Electric batteries are typically used to power conventional ROV designs, however standard battery designs generate considerable waste heat and do not operate well at temperatures above 50°C. An analysis was completed recently (CRWMS M&O 1996e) that reviewed several alternative power system design concepts. One very promising concept that appears to be fairly immune to elevated temperatures is the use of "conductor bar" technology. Conductor bar technology is well proven and used in the transit industry to power trains and trolleys. It involves mounting an electrically conductive bar along side 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 very important advantage of this technology is that the primary power source would be external to the ROV and thereby significantly reduce internally generated heat. There are questions about whether this system, or any like it, could be expected to last the full 100 years of performance confirmation. However, if for some reason a segment of conductor bar became unusable, it would be feasible to install a new bar segment using ROVs.

Another recent analysis describes existing communications technologies for ROV operation within the emplacement drifts (CRWMS M&O 1996f). Radio control is used extensively in underground remote mining applications, however, in underground applications, 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 ROV communications technology that looks promising, and one that also 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 ROV 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.

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 since they consume much less power, they also 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 un-cooled (i.e., 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.

The design of the general purpose ROV base platform is seen as being more critical than design of the add-on instrumentation packages. A heavy focus of the design effort will be on developing reliable and robust ROV platforms such that no single mechanical or electrical failure could jeopardize getting the system back out of the emplacement drift. By using an ROV concept, all servicing, calibration, upgrading or replacement of inspection instruments can be performed either in the field from man-rated drifts or at surface-based maintenance shops and laboratories.

5.2.1.7.2 ROV Concepts for Performance Confirmation

There has been a great deal of research performed in the area of developing ROV technologies for hazardous environments. ROV technologies have been developed by the military, public utility companies, universities and by nuclear, aerospace, and factory automation industries. They have been successfully used in the air, in space, on land and in the oceans. ROVs are currently used for nuclear remediation and clean-up applications, in battlefield training, in factories and industries, by police departments, fire departments, bomb squads, and by hazardous material and emergency response teams.

It is envisioned that ROVs can be developed for use inside the emplacement drifts. Conceptual designs for three different performance confirmation ROVs were recently presented in a preliminary analysis document (CRWMS M&O 1996g). These ROVs will serve as general purpose platforms that provide mobility and basic electrical, mechanical and computational interfaces needed by a wide variety of remote monitoring and inspection instruments. The preliminary ROV concepts include the following basic approaches:

- Rail-Based Gantry ROV Inspection System
- Mini-Rover ROV Inspection System
- Overhead Mono-Rail Inspection System

5.2.1.7.3 Rail-Based Gantry ROV Inspection System

One current waste package emplacement concept calls for the use of a rail-based gantry system to emplace waste packages on pedestals along the center of the emplacement drifts (CRWMS M&O 1996e). It is conceivable that, if such a concept is used, a gantry-style ROV inspection system could also be developed that would ride on the same rail system used for emplacement. This gantry ROV could serve as a general purpose instrumentation platform and would provide ample support for remote visual, thermal, radiological and geotechnical inspection activities. It would also provide an excellent platform on to which remote manipulators could be mounted for maintenance activities or sample/coupon recovery activities. The inspection gantry would be controlled from a control station located at the surface.

A remotely operated gantry system could be designed that would arch over and straddle the emplaced waste packages in a kind of horseshoe-shaped configuration. A radial three-axis carriage riding on the arched structure would permit instrumentation packages to be driven around the waste packages providing visibility to either side and on top. The gantry ROV would also provide close-up and detailed inspection coverage of surrounding drift walls and infrastructure.

Features of a gantry-style ROV include the following:

- Large payload, capable of carrying multiple, larger instruments, manipulators, and fully redundant backup systems.
- Accommodates heat tolerant power and communication technologies.
- Could readily accommodate alternative power sources such as batteries.
- Benefits from existing rail infrastructure.
- Provides good overall coverage and close-up detailed inspection.
- Larger size easier to insulate from external heat and dissipate internally generated heat.
- Sturdy, rugged construction suitable for some infrastructure maintenance.
- Flexible system configuration suitable for varied tasks assignments and for off-normal applications.

Some of the concerns and limitations related to the use of a gantry-style ROV are that it may be more difficult to extricate should the ROV system and backup systems ever fail, and the size of the gantry may make traversing around or over even small obstacles difficult or impossible.

5.2.1.7.4 Mini-Rover ROV Inspection System

Both the center-in-drift-on-pedestal emplacement concept and the center-in-drift-on-rail concept, which are described in the ACD Report (CRWMS M&O 1996a, Vol. II, p. 8-198 to 8-199), leave only a limited amount of space on either side of the waste packages. In a 5 meter diameter emplacement drift the space between the waste package and the drift wall ground support is quite limited and may be only about a meter. Although the space in the emplacement drifts is limited, the current trend in ROV design is toward much smaller and much higher capacity vehicles. Micro-electronic and micro-fabrication techniques are enabling the development of many sophisticated instruments, such as cameras, accelerometers, and even seismometers, in instrument package volumes the size of a dime. Mini-robotic manipulators, with payloads up to 10 kg, have been developed that could provide additional capabilities. It is possible to conceive of a small, half meter wide by half meter high, wheeled ROV that could be developed to provide sufficient payload capacity for carrying miniaturized remote instrumentation for visual, thermal, radiological and geotechnical inspection. A set of small telerobotic manipulators would allow recovery of test coupons and specimens.

Its mobility would allow the mini-rover to access areas on either side and at both ends of the waste packages. On-board robotic actuators would allow cameras or other instruments to be elevated high enough to survey the top of each waste package.

A critical design challenge for mini-rovers is supplying a source of power. It may be possible to use on-board batteries; however, a battery of sufficient size to power an ROV over a 1200 m round trip inspection survey of an emplacement drift would have to be relatively massive. Standard battery designs are also sensitive to elevated temperatures and would necessitate using active cooling systems, which would in-turn would require more power and cooling. A better solution may be the use of an in-drift conductor bar concept, described above, as the main source of power. A short umbilical cable connecting the mini-rover ROV to the conductor bar would be adequate to allow mobility. It might also be possible to develop a combination conductor bar battery concept where a smaller ROV battery would periodically hook up to the conductor bar for recharging.

Features of a mini-rover ROV include the following:

- Accommodate either on-pedestal or on-rail emplacement methods.
- High mobility, maneuverability and freedom of motion.
- Traverse uneven or irregular surfaces and small obstacles.
- Light mass requires less power.
- Easy to relocate and deploy.
- Easy to retrieve should failure occur.
- High Development Costs but lower replication costs.
- Could be used to retrieve small samples or test coupons.
- Benefits from current research and development efforts and focus.

In developing a mini-rover ROV there are definitely technical challenges to overcome (i.e., developing a robust power source). Some of the other concerns and limitations are that it may not provide all the functionality of a larger system, that is, it may not be able to deploy larger instruments and manipulate larger tools or objects. Its smaller size will require more engineering and design effort to package instruments into a smaller profile. It would be more difficult to add redundant systems. There are concerns as to whether the smaller package could be appropriately insulated and thermally controlled.

5.2.1.7.5 Mono-Rail ROV Inspection System

A fairly simple system of I-beams could be installed in each emplacement drift that would serve as a rail system for a mono-rail based inspection system. The mono-rail system could be mounted either overhead or against one side of the drift. A general purpose mono-rail ROV could be developed that would provide basic support for visual, thermal, radiological and geotechnical inspection capabilities. The ROV platform could be designed to fit in a fairly small area above or to the side of the waste packages. A single ROV platform would be transferred from one drift to the next as needed. The mono-rail inspection system would be controlled from a control room on the surface.

A unique feature of this concept is that the ROV mono-rail car could either be self-powered or be driven by actuators located external to the drift. The ROV platform could be driven from one end of the drift to the other by means of a mechanical cable and pulley actuation system. The system would be powered by motors located outside the entrance to the emplacement drift. This would minimize a key design concern because drive motors are a principle source of internally generated heat in ROV concepts. Another key advantage of this concept is that maintenance or replacement of drive motors, cables and pulleys could be performed from human-rated main drifts.

Features of a mono-rail ROV inspection system include the following:

- Accommodates either on-pedestal or on-rail emplacement configurations.
- Could possibly attain much higher speeds, resulting in shorter inspection cycles, and less heat build-up.
- Can be actuated by externally mounted actuators.
- Drive system components easily accessible for maintenance or replacement
- A pan-tilt capability would provide good overall drift visibility and coverage.

Some of the concerns and limitations related to the use of a mono-rail ROV system are the increased costs associated with mounting a secondary rail system in all the drifts. It adds to the permanently installed infrastructure inside the drifts and may require periodic cleaning or maintenance. It may be inoperable in some off-normal situations and prone to damage by rock falls. It relies on more moving components and has significant areas of sliding contact. And it is limited in its payload and its ability to accommodate manipulation systems.

5.2.2 Repository Surface Performance Confirmation Test Facilities and Support Concepts

A certain amount of background is needed before the repository surface performance confirmation Test Facilities and Support are described. This background information will describe the evolution from the SCP-CDR (SNL 1987) design concept need reference to the current concepts developed for this study. Following this background, a description of the specific repository surface concepts is presented.

5.2.2.1 Background on Repository Surface Facilities Related to Performance Confirmation

Performance Confirmation activities at the MGDS will require that the Surface Facilities provide certain systems, equipment, facilities, and operations for supporting and executing these activities. The Performance Confirmation Concepts Study has generated information that defines, in part, many of the Performance Confirmation requirements that must be addressed in the Viability Assessment and License Application designs of the Surface Facilities. This has been accomplished by identifying, coordinating and documenting the many Performance Confirmation parameters amongst many of the impacted disciplines in the program. This information, much of which is qualitative at this point, suggests that the assumption made in the ACD Report by the Surface Design group that a stand-alone Performance Confirmation Building was not required is valid. The Performance Confirmation function, as defined in the Functional Analysis required that the Surface Facilities must be able to support the Performance Confirmation function by providing the necessary facilities and services. Viability Assessment design will use the results of this study when the requirements are prepared and approved to ensure that all known and predicted Performance Confirmation needs are accommodated.

Performance Confirmation has been recognized as an important function at the repository since the beginning of the waste isolation studies. The role that would be provided at the Surface Facilities has never been very well defined. For example, the SCP-CDR provided an entire facility in the Surface Facility design concepts; however, there was very little dis cussed regarding what this facility would actually do to support the Performance Confirmation program. It was originally thought that a sampling of waste packages would be routinely recovered from the subsurface and that various, but unknown, examinations would be conducted on them in order to be able to demonstrate that the predictions for the engineered barrier system were being met. As time passed and the design changed, the waste packages became larger, heavier, and more robust. No requirements emerged that would seem to support the need to provide an entire Performance Confirmation Building as suggested in the SCP-CDR and, in fact, no requirement clearly emerged that would define the Performance Confirmation activities that the Surface Facilities would need to support. The Performance Confirmation Facility in the SCP-CDR was deleted in the ADC Report (CRWMS M&O 1996a) and replaced with a small location in the Waste Handling Building labeled as the Performance Confirmation/Filler Cell in recognition of the Performance Confirmation function. The Performance Confirmation Concepts Study is defining the requirements for Performance Confirmation as they impact the various design entities and other impacted organizations in the program.

Table 5-2 compares some of the general differences in concepts regarding Performance Confirmation in the past and Performance Confirmation as currently envisioned. The SCP-CDR and the ACD concepts represent a considerable change. The Performance Confirmation Study column is intended to represent the concepts that have emerged since the ACD as a result of information developed during the course of this study.

Table 5-2. General Differences in Repository Surface Facilities Conceptual Design.

General Differences in Conceptual Design			
Topic	**SCP-CDR**	**ACD**	**Performance Confirmation Study**
Performance Confirmation Facilities	A Performance Confirmation Building was provided in the Radiologically Controlled Area to process retrieved waste packages	The Performance Building was eliminated and replaced with a cell in the Waste Handling Building.	A multi-purpose cell is proposed that will accommodate Performance Confirmation requirements.
Recovery of Waste Packages	It was planned to recover a certain percentage of the waste packages for testing.	With large, robust waste packages, infrequent waste package recovery was assumed.	Only the capability to handle a recovered waste package was provided.
Sample and Data Management	There was no building or facility in the support area identified for Performance Confirmation use.	No building or facility was identified in the support area for Performance Confirmation use.	A small conventional building is proposed for data acquisition, sample management, etc.
On-Site/Off-Site Testing	There would be on-site testing, analyses, etc. Only some of the samples would be sent off-site for measurement.	Nearly all the measurements and associated studies would be conducted off-site primarily at the National Labs.	Nearly all measurements and studies would be done off-site. Packaging and preparation activities would be done on-site.
Waste Package Design	Small, thin-walled waste packages would be used which would probably require more evaluation.	Huge, canistered waste forms in a disposal container formed the waste packages. These are very robust packages.	Huge, robust waste packages would contain uncanistered and canistered waste forms.

The Advanced Conceptual Design deleted the Performance Confirmation Building and instead identified a hot cell in the Waste Handling Building as a location to perform Performance Confirmation. The following identifies some of the reasons that it was thought to be unnecessary to create an entire facility for this purpose:

1. The routine removal of an emplaced waste package for examination in the Surface Facility was assumed to not be necessary. It was assumed that sometime during the operational period, a waste package may (or may not) be recovered. The Performance Confirmation/Filler cell was identified to make it possible to do this operation if it should be necessary.

2. If radioactive samples were to be taken in the subsurface, the Performance Confirmation cell would be capable of handling them, setting up equipment and analyzing them, or for dong any other operation that would be needed for Performance Confirmation. This function could be accomplished in a hot cell as well as in a dedicated separate facility.

3. In 1995 as a part of the ACD, a study was performed (CRWMS M&O 1995d) that examined the layouts options for surface waste handling facilities. This study used the Kepner-Tregoe Decision Making Analysis and concluded that a separate Performance Confirmation Building should be eliminated and Performance Confirmation functions should be performed in a remote cell in the Waste Handling Building. This cell is intended to be a multi-purpose cell in which a host of non-routine activities could be performed, some of which support Performance Confirmation. The cell was identified in the ACD as the "Performance Confirmation/Filler cell" because it was to be used when there was a requirement to add filler material to the Disposal Containers.

A Concept of Operations for the Performance Confirmation cell and/or for operation of any performance confirmation activity was not developed in the ACD. The Performance Confirmation Concepts Study has provided some insight into the performance confirmation function and will identify requirements that can be incorporated into the operations and design to support the Viability Assessment. Another item that was not addressed in the ACD was whether a capability to assemble, store, package, ship, monitor, etc. samples and process scientific data should be provided in the Balance of Plant area. The following sections describe a concept for the Performance Confirmation systems in the surface facilities.

5.2.2.2 Performance Confirmation Multi-Purpose Cell Concept

A standard general purpose hot cell would be provided in the Waste Handling Building for the purpose of performing performance confirmation activities, non-routine activities, and any scientific studies that might develop during the operational period of the repository. In concept, the cell would be large enough to handle a waste package and versatile enough to be able to do a large variety of measurements, etc. it would be possible to change the configuration and use of the cell in fairly rapid order to accommodate equipment that would be used for a variety of purposes. This capability would be based on the use of jumpers, spare lines, removable plugs, etc. which are standard hot cell methods used in multi-purpose cells.

The Performance Confirmation/Filler cell provided in the ACD closely resembles the cell that is the focus of this concept. The conceived cell would differ from that in the ACD in only a few ways which are listed below:

- The cell would have increased versatility and be able to accommodate a greater variety of operations.
- The addition of "filler material" would not necessarily be a major use of the cell.
- An effort would be made to provide a connection (e.g., rabbit, conveyor, etc) to the analytical cells.
- Manipulator and viewing access to more than one cell face would be provided. With the size of equipment and objects that are to be placed in the cell, not much can be done from only one side.
- The cell will have the capabilities to cut open the robust waste packages, perform examinations that may be required, perform non-destructive testing of weld and possibly contents, and other studies that may arise.
- The use of this cell for Performance Confirmation purposes would be a fairly modest part of the cell use.

The Performance Confirmation Concepts Study has generated requirements for a cell which can be used to conduct the many tests, studies, and activities to support performance confirmation requirements. Based upon the information generated in the study, a conceptual cell has been created. Table 5-3 describes such a cell.

The following paragraphs describe the Surface Facilities and the operations that are conceptually planned to be performed in these facilities in normal operations. Performance Conformation activities are expected to be either appurtenant or off-normal tasks that will be performed within the bounds of the operations described below.

Table 5-3. Conceptual Performance Confirmation Multi-Purpose Cell Description.

Cell Dimensions, interior	15 ft W x 15 ft L x 30 ft H
Cell Walls	5 ft ordinary concrete stainless steel lined
Cell Access	Cell roof hatch 10 ft sliding shielding door
Viewing	Shielding windows (3)
Handling	Master slave manipulators (3 sets) Electromechanical manipulator Heavy duty dolly (150 ton Capacity) 5-ton in-cell crane
Power Instrumentation	Overhead and recessed wall lighting Power jumpers with spares Removable electrical plugs Built-in instrumentation jumpers Removable instrumentation plugs
Utilities	Built-in jumpers for air, steam, vacuum, etc. Decontamination wands Cell floor drains in water decon termination system
Other Features	Top to bottom ventilation Dedicated radiation monitoring system Ports for sample, tool, etc. removal Storage racks for samples/specimens

Performance Confirmation Operations

In the reference ACD, the Performance Confirmation Operation for a waste package that is recovered once every ten years will conceptually consist of the following steps:

- Receive disposal container (waste package) retrieved from underground emplacement.
- Transfer the disposal container to the Performance Confirmation/Multi-Purpose Cell.
- Examine surface corrosion and take samples of surface films, if required.
- Open the disposal container and the internal waste canister, if applicable, to remove samples for laboratory analysis.
- Perform whatever evaluation or measurements that are required.
- Replace the disposal container lid, weld the lid and inspect the weld.

- Return the disposal container to the underground transporter for underground re-emplacement.

The following describe in more detail the conceptual operations that will be used to handle a recovered disposal container: A previously emplaced disposal container is unloaded from the underground waste package transporter and transferred to the Performance Confirmation Multi-Purpose Cell as follows:

1. The shielding door to the air lock opens and the waste transporter enters the air lock. The outside air lock door closes and the inside door opens.

2. The transporter's push-pull mechanism pushes the waste package railcar, carrying the disposal container, partially out of the transporter and into the subsurface transfer room. The cart loader pulls the railcar completely into the subsurface transfer room. The door between the air lock and the subsurface transfer room door closes. This door provides the access to the cell from the operational cells.

3. The shielding door to the subsurface transfer gantry room opens. The subsurface transfer gantry lifts the disposal container from the waste package railcar and moves the container into the subsurface transfer gantry room. The shielding door closes.

4. From the subsurface gantry room the disposal container is transferred by opening the shielding door into the Disposal Container Cell.

5. After the disposal container enters the cell and is rotated to a vertical position, the cell crane transfers the disposal container to the cart that takes the disposal container into the Performance Confirmation Multi-Purpose cell.

6. The disposal container is next transferred to the Performance Confirmation Multi-Purpose cell. Some examples of typical operations in the Performance Confirmation Multi-Purpose cell are described below:

   - The surface of the disposal container is visually examined using direct viewing through the shielding window and television.

   - The lid of the disposal container is removed by laser cutting of the container's lid.

   - A spent fuel assembly or other waste form is removed from the disposal container using the cell's overhead crane with grapple.

   - The interior of the disposal container can be visually examined using a portable television camera.

   - Any samples that are taken can be packed and removed from the cell either through the cell transfer port or by means of the pneumatic rabbit conveyor that is connected to the analytical cells which in the ACD layout are located in another part of the Waste Handling

Building. Viability Assessment layout studies might relocate these cells to be nearer to this cell.

5.2.2.3 Performance Confirmation Support Building

A building has been identified to be located outside the Radiologically Controlled Area of the MGDS which would serve a number of purposes relating to Performance Confirmation and associated scientific studies. This building would serve as a location for the administration of performance confirmation programs and any other related programs that would require similar capabilities. Its main purpose is to act as the hub for the acquisition of, the storage of, the distribution of, and the monitoring of, all scientific data and samples that are needed for the various scientific programs including performance confirmation. Table 5-4 describes qualitatively the features of this building:

Table 5-4. Concept Description of a Performance Confirmation Support Building.

Type of Structure	Either metal frame or block
Size	Approx. 10,000 sq.ft.
Contents, Functional Areas	Offices Data collection Storage Sample packaging, preparation, shipping Instrumentation laboratory Site monitoring central control Records management Limited laboratory, (hoods, benches, etc.)

5.3 PERFORMANCE CONFIRMATION EVALUATION AND REPORTING CONCEPT

This section of the report will provide a high-level discussion of the evaluation and reporting concept, including the purpose and scope of the analyses, the types of analyses that are expected to be conducted, and the evaluations to be conducted.

5.3.1 Purpose and Scope

Performance confirmation evaluations are planned to confirm that

1. actual subsurface conditions encountered and changes in those conditions during construction and waste emplacement operations are within the limits assumed in the licensing review [10 CFR 60.140(a)(1)]; and

2. natural and engineered systems and components required for repository operation, or which are designed or assumed to operate as barriers after permanent closure, are functioning as intended and anticipated [10 CFR 60.140(a)(2)].

In order to accomplish the above, the performance evaluations are planned in three phases:

1. pre-license application predictions to evaluate the expected performance of the MGDS using the license application database;

2. performance confirmation data analyses to reduce raw data into the parameters and parameter distributions of interest and to evaluate any changes from the license application database; and

3. post-license application predictions to evaluate any changes in the expected performance of the MGDS as a result of performance confirmation data changes.

Implicit in each of these phases is the preparation of reports that document the predictions, the data collected, and the associated evaluations. Each of these phases is described in more detail in Sections 5.3.2.1 through 5.3.2.3 below.

The first and third phase above include:

1. predictions of system and component behavior after permanent repository closure to demonstrate compliance with the regulatory postclosure performance standards of 10 CFR 60.112 and 60.113; and

2. predictions of system and component behavior during the preclosure period that have relevance to postclosure performance in support of performance confirmation.

These two types of analyses may be performed as separate model runs for the pre- and postclosure period, or they may be performed together, that is, the simulation period for a process model may start with the beginning of construction or waste emplacement and continue into the postclosure period .

The prediction of postclosure performance in support of the license application is not part of performance confirmation per se, but forms the basis for the evaluations of preclosure system and component behavior with respect to postclosure performance implications. All other aspects above, however, are part of performance confirmation.

5.3.2 Evaluation Phases

As identified above, the evaluations and associated reporting can be divided into three major phases. Because performance confirmation data collection starts before the submittal of the license application and continues until repository closure, the second phase, performance confirmation data analyses, overlaps both the pre- and post-license application predictions. The pre- and post-license application predictions, as the terms imply, will be performed sequentially. Following are descriptions of the three evaluation phases.

5.3.2.1 Pre-License Application Predictions

The confirmation of postclosure performance has to rely on preclosure testing to demonstrate compliance with the postclosure standards of 10 CFR 60.112 and 60.113. Performance assessment predictions are therefore required to establish the baseline for the expected behavior of the MGDS from the beginning of construction, through waste emplacement, and from the last waste emplacement until permanent repository closure. To date, performance assessments have concentrated on the preclosure radiological safety of the workers and the general public (CRWMS M&O 1996a) and on the postclosure performance of the natural and engineered barriers (e.g., Barnard et al., 1991; Eslinger et al., 1993; Wilson et al., 1994; Andrews et al., 1994; CRWMS M&O 1995a). In addition, design analyses and operational safety analyses have included waste package, drift stability, and ventilation analyses (CRWMS M&O 1996a).

A complete suite of analyses has not yet been performed, however, that would predict the preclosure response of the natural and engineered system and components that are important for postclosure performance. The simulation period of past postclosure performance assessments usually started with the permanent closure of the repository, that is, assumed the final radioactive waste inventory at the beginning of the simulation period as the initial condition for the predictions. For performance confirmation predictions for the preclosure period, however, the planned progression of construction and waste emplacement needs to be considered.

New predictions are therefore required before the submittal of the license application for all processes to be evaluated and performance confirmation parameters to be measured. These predictions need to predict the performance of the natural and engineered barrier system during the preclosure period, that is, during the performance confirmation period, in order to allow the comparison of the predictions with the performance confirmation measurements. The analyses do not have to predict the full three-dimensional transient state of the natural and engineered barriers, but can be tailored to predict the parameters to be measured only at the locations and times of the planned performance confirmation activities. It needs to be demonstrated, however, that the more limited analyses (and measurements) are sufficiently representative of the total system behavior. The modeling analyses need to include predictions of both in situ and laboratory measurements as defined in the performance confirmation concepts. The specific modeling analyses required and their relationships to the planned performance confirmation concepts are described in Section 5.3.3 below.

5.3.2.2 Performance Confirmation Data Analyses

This phase consists of the conversion of raw data into the parameter values and distributions of interest, interpretations and analyses of the collected data, and comparisons of the collected data with the license application baseline.

Some parameters can be measured directly, for instance, air temperature using a thermometer, but many measurements, especially if through remote means, require the conversion of the measured parameters into the parameters of interest. For some parameters, this may simply include the conversion of electrical currents or voltages into the physical values of interest, like mechanical stress. For others, analyses are necessary to convert measured parameter values into the parameters of interest. An example is the derivation of saturated hydraulic conductivity from water pumping rates and well drawdown measurements as a function of time. This involves the assumption of a mathematical model for the relationship between these parameters. The hydraulic conductivity is then calculated from the other measurements using that mathematical model.

Other analyses involve the calculation of statistical distributions of uncertainty and spatially distributed parameters as required by the performance assessment models. This could include, for instance, 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.

Finally, comparisons need to be made between the license application baseline and the new data collected by the performance confirmation program. Because differences can be expected, statistical analyses are required to evaluate the significance of the differences. Potential statistical methods to be used are described in Section 5.3.5.1 below.

5.3.2.3 Post-License Application Predictions

The same modeling analyses that were performed before the submittal of the license application need to be repeated after its submittal. These predictions will use the original license application database supplemented with the parameter values determined during performance confirmation. The purpose of these analyses is to evaluate the effects of any data changes on the predictions, and consequently, on the expected ability to comply with the regulatory standards of 10 CFR 60.112 and 60.113.

The direct comparisons between parameter values measured before and after the license application indicate the statistical significance of any differences. The regulatory significance of these differences can only be determined, however, by modeling the processes, including total system performance, that demonstrate compliance with the regulatory standards. Because of the interrelationships of parameters, including associated nonlinearities, intuition with respect to the effects of data differences on predicted postclosure performance may be misleading. Consequently, only the modeling analyses can demonstrate the significance of any data differences with respect to any effects on regulatory compliance.

These evaluations need to consider not only the new data collected after the license application, but also the "as-built" conditions, that is, the actual progression of repository construction and waste emplacement, including the actual types and locations of wastes emplaced. Some or all of these could deviate from the original design described in the license application. The repository layout and waste emplacement configuration may have to be changed during construction as a result of underground conditions encountered that are different from the assumptions in the license application. 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 may also be different than planned.

Consequently, the evaluations need to (a) consider the actual repository and waste conditions, together with the new data collected, (b) compare them with the assumptions in the license application, and (c) evaluate their implications with respect to demonstrating compliance with the regulatory standards.

Finally, statistical analyses may be required to compare the pre-license application predictions with the post-license application predictions to determine the significance of any differences. If both types of predictions indicate that compliance with a particular regulatory standard can be achieved with a wide margin of confidence, these statistical analyses may in large part be what is needed for confirming compliance with that standard.

The new data and the advance of general knowledge and understanding of natural and engineered system and component processes may indicate the need for new conceptual and mathematical models and computer codes. This could change the results of the performance predictions even if all other aspects (i.e., parameter values, repository layout, and waste emplacement) remain unchanged. In other words, performance confirmation has to include the effects of mathematical model and computer code changes with respect to demonstrating compliance with the regulatory standards. The actual improvement of mathematical models and computer codes may not be within the scope of performance confirmation.

5.3.3 Modeling of Performance Confirmation Testing

The same analyses are planned for the predictions prior to performance confirmation testing and to compare the results of the testing with the predictions. For the pre-license application predictions, the analyses have to use parameter values, engineered system design, mathematical models, and computer codes that are used for the license application. For the post-license application predictions, the "as-built" conditions and the results of the performance confirmation testing will either replace or argment the corresponding data used in the license application.

The analyses planned for each performance confirmation concept described in Section 5 are listed below by type of analysis. Only those analyses that involve key parameters for design are described in the present report. It is recommended that predictions for surface-based performance confirmation concepts be addressed in follow-on performance confirmation work proposed for next year.

5.3.3.1 Coupled Thermal-Hydrological and Ventilation Modeling

Coupled thermal-hydrological and ventilation modeling is planned to predict:

- The moisture content of the rock adjacent to the excavation locations where samples for laboratory hydrologic analyses will be taken as part of the subsurface geologic mapping, for the times when the samples are expected to be taken.

- The rock temperature, moisture content, in situ fluid potential, and air pressure in the rock at the locations for the underground fault zone hydrology package, for the times when fault zones are expected to be encountered.

- The rock temperature, moisture content, relative humidity, and air pressure at the locations and for the duration selected for the thermal testing package.

- The air temperature and relative humidity in the excavation of the waste package testing locations for the duration of the testing.

- The rock temperature and moisture content of the rock adjacent to selected emplacement drifts and the air temperature and relative humidity within these drifts from the time of excavation until initial waste emplacement in each drift.

- The air temperature and relative humidity in selected excavation drifts from the time of excavation until repository closure.

5.3.3.2 Coupled Thermal-Hydrological Modeling

Coupled thermal-hydrological modeling is planned to predict rock, water, and air temperatures, rock moisture content, air pressure, relative humidity, and in situ fluid potential at the locations of instrumentation that measures these parameters in the observation drifts and associated boreholes from before waste emplacement until repository closure.

5.3.3.3 Coupled Thermal-Mechanical Modeling

Coupled thermal-mechanical modeling is planned to predict:

- The temperatures, mechanical stress, and strain at the surface of actual and dummy waste packages at waste package testing locations for the duration of the testing.

- The rock mechanical stress, strain, and deformation/displacement at the locations and for the duration selected for the thermal testing package.

- The rock mechanical stress, strain, and deformation/displacement in the observation drifts and associated boreholes from before waste emplacement until repository closure.

- The temperature, mechanical stress, strain, and deformation/displacement of the rock adjacent to selected emplacement drifts from the time of excavation until initial waste emplacement in each drift.

- The size and location or related statistics of probable rock falls within the emplacement drifts from the time of excavation until repository closure.

5.3.3.4 Geochemical Modeling

Geochemical modeling is planned to predict:

- The ground-water chemistry at the locations and for the duration selected for the thermal testing package.

- The ground-water chemistry adjacent to the observation drifts and associated borholes from before waste emplacement until repository closure.

- The ground-water chemistry adjacent to the waste package test locations for the duration of the testing.

- The composition of chemical alteration products resulting from waste package corrosion at the waste package test locations for the duration of the testing.

- The composition of chemical alteration products resulting from waste package coupon corrosion for the selected locations and durations.

- The chemical alteration of tracers, fluids and materials introduced into the repository in the preclosure period and remaining after permanent repository closure, including steel, concrete, ground support, railcars, etc., from their introduction into the repository until repository closure.

5.3.3.5 Coupled Waste Package and Near-field Thermal Modeling

Coupled waste package and near-field thermal modeling is planned to predict:

- The temperature at the surface of the waste packages and the excavation walls at the locations of instrumentation measuring these parameters through boreholes from the observation drifts and boreholes emanating from these drifts from before waste emplacement until repository closure.

- The temperature at the surface of real and/or dummy waste packages at the waste package test locations for the duration of the testing.

5.3.3.6 Waste Package Corrosion Modeling

Waste package corrosion modeling is planned to predict:

- The change in waste package barrier thickness of specimens exposed in the laboratory.

- The change in waste package barrier thickness of real and/or dummy waste packages as result of all significant forms of corrosion at the waste package test locations.

- The change in waste package coupon thickness at selected waste package coupon locations from the time of coupon emplacement until planned coupon removal and analysis.

5.3.3.7 Criticality Modeling

Modeling of potential criticality within (internal criticality) and outside (external criticality) the waste package is part of the required safety analyses for the license application. Although criticality is not expected, the analyses are needed before the license application, and again after the license application using "as-built" conditions and performance confirmation data to demonstrate that the original assumptions remain correct.

5.3.3.8 Total System Performance Assessment

Total system performance assessment is required to combine the effects of all individual and two-process coupled modeling and predict the performance of the overall waste isolation system with respect to the total system performance standards. Total system performance assessment includes modeling of 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 needed, and the comparisons will be with the pre-license application predictions, including any changes in the assessment of compliance with the overall system postclosure performance standards.

5.3.4 Correlation with Functional Analysis

The systems engineering approach to performance confirmation should include showing the correlation of the performance confirmation activities with the functions defined in the *MGDS Functional Analysis Document* (CRWMS M&O 1996i). This correlation should demonstrate to what extent the performance confirmation program satisfies the data and performance requirements for these functions. A recommendation of the study is to complete this step in the proposed follow-on work.

5.3.5 Evaluations

As mentioned in Section 5.3.2 above, a variety of techniques are planned for evaluating the results of performance confirmation testing. These techniques include (a) statistical tests, (b) natural and engineered barrier process modeling, and (c) total system performance assessment.

5.3.5.1 Statistical Tests

Statistical tests are planned for comparing the predictions of each performance confirmation parameter with the baseline values and for determining the significance of any differences. The specific statistical tests have not been selected. 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). The choice of tests will depend on the nature of the parameter comparison; for instance, pairs of single valuedistributions of parameters, and the statistical distribution of the parameter values (e.g., normal or log-normal).

5.3.5.2 Process Modeling

Statistical tests evaluating the differences between the baseline values and the values measured following the license application provide only a partial picture of the significance of the differences. Because each comparison looks only at one parameter, independent of other parameters, it neglects the combined, often nonlinear effects of all parameters that determine the performance of a system or component. Consequently, only the modeling of the important natural and engineered barrier processes and of the overall system can show the differences between the predictions in the license application and the predictions resulting from any changes in the parameter values measured after the submittal of the license application.

Thus process modeling is required as listed in Section 4.2 to evaluate the postclosure implications of any parameter value differences and their significance with respect to regulatory standards. The most important part of this is system and subsystem modeling to show any changes in the expected compliance with existing and potential new regulatory standards, including (a) preclosure ground-water travel time, (b) waste package life, (c) radionuclide release from the engineered barrier system, (d) cumulative 10,000-year radionuclide release to the accessible environment, (e) radionuclide concentrations in ground-water, and (f) radiation doses to the public.

5.3.5.3 Total System Performance Assessment

The ultimate test of the results of performance confirmation is to evaluate whether the postclosure performance predicted in support of the license application will change as a result of parameter value changes measured after the submittal of the license application. The critical question then is whether with these parameter value changes, compliance with the regulatory standards can still be demonstrated. In other words, although parameter values may change as a result of the performance confirmation testing, the MGDS may still meet the regulatory standards.

Consequently, total system performance assessments are needed after the submittal of the License Application to demonstrate the degree of compliance or non-compliance with regulatory standards. The timing of these assessments will depend on the results of the testing and the statistical analyses of parameter value differences. A total system performance assessments should be performed whenever the statistical analyses of parameter values show significant differences or if other observations allude to a potential problem with respect to expected repository performance.

Total system performance assessments includes analyzing not only the overall MGDS with respect to system postclosure performance standards, but also analyzing subsystems with respect to the applicable subsystem standards. Current and expected system postclosure performance standards include (a) the 10,000-year cumulative radionuclide release to the accessible environment, (b) radionuclide concentrations in ground water, and (c) radiation doses to a representative member of public. Current subsystem postclosure performance standards include (a) preclosure ground-water travel time, (b) waste package life, and (c) radionuclide release from the engineered barrier system. These standards may change because of a court remand of 40 CFR Part 191 (which is incorporated by reference in 10 CFR Part 60) and the recent recommendations by the National Academy of Sciences for revised standards (NAS 1995).

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6. GENERAL REQUIREMENTS FOR PERFORMANCE CONFIRMATION

Requirements for performance confirmation were developed under Quality Assurance controls as discussed in Section 2.1. They were derived based on applicable regulatory requirements defined in Section 2.2. Assumptions needed for the study were defined in Section 2.3. The definition of key activities was done in Section 3 and then the key parameters for performance confirmation were defined in Section 4. Using these parameters, concepts were developed for performance of the monitoring and testing. Testing facilities and support concepts were developed along with a concept for evaluation of the data. These concepts were discussed in Section 5.

It is assumed that system performance requirements, which would define the proper function of the waste isolation system, will be defined through the systems requirements analysis process, and that performance confirmation is required to confirm the required performance. Several types of general performance confirmation requirements were derived. The following requirements were developed as a result of consideration of the defined activities and functions, the identified parameters, concepts, and some consideration of certain system performance quality attributes (e.g., quantity, quality, coverage, timeliness, and availability). The focus of the analysis was on identification of driving requirements for the repository and engineered barrier system design. Testing and evaluation recommendations, consistent with the design requirements, are made. Requirements on design concepts are also developed. It is reemphasized that the design requirements and testing and evaluation recommendations developed are intended to be used as input to the Viability Assessment design and are not to reflect final design requirements or final recommendations for implementation of the performance confirmation program. The design requirements are based on the parameters developed in Section 4. *Total System Performance Assessment - 1995* (CRWMS M&O 1995a), which is not a qualified source, was used as input to the development of the parameters and thus the requirements listed below should be considered to be verified (TBV) and will need further verification before they could be used for final design and testing.

All requirements have been derived from the information developed in the study and documented in this report. The following style is used in the presentation of the developed requirements. The subject of the requirement(s) is provided as a section heading. The statement of the requirement follows. In square brackets, follow the section of the report on which this information is based. Next, the traceability to the design input(s) are provided, followed by the appropriate 10 CFR Part 60 requirement(s), if applicable. A further distinction between different types of requirements is made - design requirements are in bold type, as these are the focus of this study; and testing and evaluation and programmatic requirement are in normal type.

6.1 PERFORMANCE CONFIRMATION PLANNING AND DESIGN REQUIREMENTS

A. **Repository design and operation shall provide facilities, access, instrumentation, recording, maintenance, and support for measuring/monitoring the performance confirmation parameters identified in Appendix D.**
[DERIVED based on Section 4][MGDS-RD[1] 3.7.2.7.A.2][10CFR60.74(b), 10CFR60.137] and [MGDS-RD 3.7.2.7.A.3][10CFR60.140(a)]

B. The Performance Confirmation Program should document variations in site characterization parameters, values, or conditions defined in Appendix D, based on site characterization data. The variations should be tracked and reported as required to monitor the effects of excavation and waste emplacement during the repository operation and caretaker periods.
[DERIVED based on Section 4][MGDS-RD 3.7.2.7.A.5][10CFR60.140(d)]

C. The Performance Confirmation Program should define expected values, distibutions and uncertainties, and statistical significance levels for each parameter identified in Appendix D and assess all statistically significant deviations from expected values.
[DERIVED based on Section 4][MGDS-RD 3.7.2.7.A.5][10CFR60.140(d)]

D. **The performance confirmation monitoring and measuring system shall have a maintainable service life of 125 years (100 years plus the duration of initial construction, plus the duration of final closure, plus any time period during site characterization for which the system must be operable). Specific equipment and components shall have maintainable service lives dependent upon their identified function. These service lives are (TBD).**
[DERIVED based on Section 2.2.1][MGDS-RD 3.2.1.C][10CFR60.111(b)(1)] and [MGDS-RD 3.7.1.3.B.1][10CFR60.140(b)]

E. The Performance Confirmation Program should be planned as an integral part of the repository design (developmental test and evaluation) and operation (operational test and evaluation).
[DERIVED based on Section 3]

F. The Performance Confirmation Program should develop, define, document, and control a Performance Confirmation Technical Baseline for the parameters identified in Appendix D consisting of reference site characterization data; process, abstraction and assessment models and computer codes; expected values and associated uncertainties; limits of statistically significant deviations.
[DERIVED based on Sections 3, 4 and 5.3][MGDS-RD 3.7.2.7.A.5][10CFR60.140(d)] and [MGDS-RD 3.7.1.3.B.1.bg][10CFR60.141(d)]

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[1] *Mined Geologic Disposal System Requirements Document* (DOE 1996a)

G. **Planning of Repository design and operations for performance confirmation test facilities and support shall consider the performance confirmation concepts identified in Section 5 as a point of departure.**
[DERIVED based on Section 5][MGDS-RD 3.7.2.7.A.3][10CFR60.140(a)] and [MGDS-RD 3.7.2.7.A.4][10CFR60.140(c)]

H. **Performance confirmation test facilities and support shall be planned to permit availability of (TBD) percent.**
[DERIVED based on Section 5][MGDS-RD 3.7.2.7.A.1][10CFR60.74(a)] and [MGDS-RD 3.7.2.7.A.2][10CFR60.74(b), 10CFR60.137]

I. **Test locations/environments, samples, and specimens, on-site and off-site, shall be representative of the repository environments and design elements.**
[DERIVED based on Section 5.3][MGDS-RD 3.7.2.7.E.2][10CFR60.143(c)]

J. Measured accuracy and frequency requirements should be based on analyses considering expected values, associated uncertainties and limits of statistically significant deviations and deviation limits.
[DERIVED based on Section 5.3][MGDS-RD 3.7.2.7.A.3][10CFR60.140(a)]

K. Postclosure performance assessments of quantitative regulatory performance measures should define the uncertainties in the predicted performance measures and sensitivities of the predictions to input uncertainties.
[DERIVED based on Section 5.3][MGDS-RD 3.7.1.3.B.1.bg][10CFR60.141(d)]

6.2 PERFORMANCE CONFIRMATION PROGRAM CRITERIA

A. The Performance Confirmation Program should develop criteria (TBD), for Nuclear Regulatory Commission approval, such that repository closure can occur within 100 years after the start of emplacement operations.
[DERIVED based on Section 2.2.1][MGDS-RD 3.2.1.C][10CFR60.111(b)(1),(3)]

B. The Performance Confirmation Program should develop a plan for scenarios, criteria, and recommended corrective actions for statistically significant deviations from the performance confirmation technical baseline.
[DERIVED based on Sections 1.3.5 and 5.3][MGDS-RD3.7.2.7.A.5][10CFR60.140(d)]

6.3 PERFORMANCE CONFIRMATION OPERATIONS/REPORTING

A. **Performance confirmation staff, measurement and monitoring hardware and software, shall be available to support the variable demand for analysis, assessment, and periodic reporting throughout the Performance Confirmation Program.**
[DERIVED based on Section 5][MGDS-RD 3.7.2.7.A.5][10CFR60.140(d)]

B. Performance confirmation reports and assessments should be submitted as required and to support scheduled milestones.
[DERIVED based on Section 2.2.1 and 5.3][MGDS-RD 3.7.1.3.B.1.bd][10CFR60.141(a)] and [MGDS-RD 3.7.1.3.B.1.bg][10CFR60.141(d)]

C. Statistically significant deviations from the performance confirmation technical baseline should be reported as soon as possible and assessed within (TBD) months.
[DERIVED based on Section 3, 4, and 5.3][MGDS-RD 3.7.2.7.A.5][10CFR60.140(d)]

D. Initial data on natural events (e.g., seismic) and operational accidents involving structures, systems, and components that are important to waste isolation should be reported as soon as possible and their impact assessed within (TBD) days.
[DERIVED based on Section 3, 4, and 5.3][MGDS-RD 3.7.2.7.A.5] [10CFR60.140(d)]

6.4 SITE INVESTIGATION MONITORING AND TEST REQUIREMENTS

The Site Investigation element of the Performance Confirmation Program should perform all surface and subsurface testing related to the natural barrier system.
[DERIVED based on Section 5.1.1][MGDS-RD 3.7.2.7.A.3][10CFR60.140(a)] and [MGDS-RD 3.7.2.7.A.4][10CFR60.140(c)]

6.4.1 Subsurface Geologic Mapping

A. Subsurface geologic mapping should be performed to confirm/document stratigraphy and characteristics of discontinuities and fracture zones.
[DERIVED based on Section 5.1.1.1][MGDS-RD 3.7.1.3.B.1.bd][10CFR60.141(a)] and [MGDS-RD 3.7.2.7.A.3][10CFR60.140(a)]

B. Tests of rock hydrologic properties should include measurements of saturated hydraulic conductivity, effective porosity, moisture content, hydraulic potential-moisture content relationship, and moisture content-hydraulic conductivity relationship) and biological characteristics of fractures and faults.
[DERIVED based on Section 4, 5.1.1.1 and 5.2.1.5][MGDS-RD 3.7.1.3.B.1.bd][10CFR60.141(a)] and [MGDS-RD 3.7.2.7.A.3][10CFR60.140(a)]

C. Subsurface geologic mapping should be independent of the emplacement drift excavation rate, but may immediately follow depending upon the ground support system design.
[DERIVED based on Section 5.1.1.1 and 5.2.1.5][MGDS-RD 3.7.1.3.B.1.bd][10CFR60.141(a)] and [MGDS-RD 3.7.2.7.A.3][10CFR60.140(a)]

6.4.2 Surface-Based Unsaturated Zone Hydrology

A. Surface-based boreholes should be provided to monitor the effect of waste emplacement on unsaturated zone hydrologic characteristics and changes in ambient unsaturated zone hydrologic characteristics, including but not limited to, air rock and water temperature, air pressure, moisture content, and in situ fluid potential.
[DERIVED based on Section 5.1.1.2][MGDS-RD 3.7.2.7.A.3][10CFR60.140(a)]

B. Surface-based boreholes should have provisions for retrievable instrumentation and for removable plug/seal installation when not in use.
[DERIVED based on Section 5.1.1.2][MGDS-RD 3.7.2.7.A.3][10CFR60.140(a)]

C. Drilling of surface-based boreholes should allow detailed characterization or confirmation of previous characterization of the rock mass in the vicinity of the borehole.
[DERIVED based on Section 5.1.1.2][MGDS-RD 3.7.2.7.A.3][10CFR60.140(a)]

D. **The number of surface-based boreholes shall be (TBD) and avoid underground excavations.**
[DERIVED based on Section 5.1.1.2][MGDS-RD 3.7.2.7.A.3][10CFR60.140(a)]

6.4.3 Subsurface Fault Zone Hydrology

A. **Selected (TBD) existing and (TBD) newly encountered faults shall be tested and monitored prior to and following waste emplacement.**
[DERIVED based on Section 5.1.1.3][MGDS-RD 3.7.2.7.A.3][10CFR60.140(a)]

B. Subsurface fault zone hydrology should include monitoring of parameters to include, but not be limited to, air, water, and rock temperature, air pressure, moisture content, and in situ fluid potential.
[DERIVED based on Section 5.1.1.3][MGDS-RD 3.7.2.7.A.3][10CFR60.140(a)]

C. Monitoring of newly encountered faults should permit characterization measurements including coring and in-hole and/or cross-hole air permeability.
[DERIVED based on Section 5.1.1.3][MGDS-RD 3.7.2.7.A.3][10CFR60.140(a)]

6.4.4 Unsaturated Zone Thermal Effects Monitoring

A. **Monitoring of (TBD) percent of the thermal rock mass behavior shall be performed at (TBD) strategic underground locations.**
[DERIVED based on Section 4 and 5.1.1.4][MGDS-RD 3.7.2.7.A.3][10CFR60.140(a)] and [MGDS-RD 3.7.2.7.A.6 [10CFR60.141(b)] and [MGDS-RD 3.7.2.7.C][10CFR60.141(c)] and [MGDS-RD 3.7.2.7.D][10CFR60.141(e)] and [MGDS-RD 3.7.2.7.B][10CFR60.142(a)]

B. The number (TBD) and spacing (TBD) of the instrumentation stations should be consistent with the required coverage and be in representative locations.
[DERIVED based on Section 4 and 5.1.1.4][MGDS-RD 3.7.2.7.A.3][10CFR60.140(a)] and [MGDS-RD 3.7.2.7.A.6][10CFR60.141(b)] and [MGDS-RD 3.7.2.7.C][10CFR60.141(c)] and [MGDS-RD 3.7.2.7.D][10CFR60.141(e)] and [MGDS-RD 3.7.2.7.B][10CFR60.142(a)]

C. The thermal effects of waste emplacement on the natural barrier should be monitored through measurements including temperature, pressure, moisture content, relative humidity, water chemistry, in situ stress, rock mass deformation, rock chemistry and in-hole/cross-hole permeability.
[DERIVED based on Section 4 and 5.1.1.4][MGDS-RD 3.7.2.7.A.3][10CFR60.140(a)] and [MGDS-RD 3.7.2.7.A.6][10CFR60.141(b)] and [MGDS-RD 3.7.2.7.C][10CFR60.141(c)] and [MGDS-RD 3.7.2.7.D][10CFR60.141(e)] and [MGDS-RD 3.7.2.7.B][10CFR60.142(a)]

D. Drilling of underground boreholes should allow detailed characterization of the rock mass in the vicinity of selected waste emplacement drifts.
[DERIVED based on Section 5.1.1.4][MGDS-RD 3.7.2.7.A.3][10CFR60.140(a)]

6.5 SUBSURFACE REPOSITORY MONITORING AND TEST REQUIREMENTS

The Subsurface element of the Performance Confirmation Program (Performance Confirmation/SS) should perform all subsurface testing and monitoring related to emplacement drift geometry and environments, including physical and chemical characteristics of natural and engineered barriers and construction materials. The following measurements should be performed and should be coordinated with site measurements: excavation convergence; rockfall; air temperature; relative humidity; ground-water inflow quantity, rate, temperature, and chemical composition; material chemical composition/alteration; seismic, strong ground motion detection; and radiation.
[DERIVED based on Section 4 and 5.1.2][MGDS-RD 3.7.1.3.B.1.bd][10CFR60.141(a)] and [MGDS-RD 3.7.2.7.A.3][10CFR60.140(a)] and [MGDS-RD 3.7.2.7.A.6] [10CFR60.141(b)] and [MGDS-RD 3.7.2.7.C][10CFR60.141(c)]

6.6 WASTE PACKAGE MONITORING AND TEST REQUIREMENTS

The Waste Package element of the Performance Confirmation Program (Performance Confirmation/WP) should define and implement a program for on-site and off-site laboratory and hot cell (Surface repository) testing of waste packages, simulated waste packages and material coupons or specimens that are retrieved from emplacement drift. The testing should include:

A. Monitoring and testing to be performed by Subsurface Operations should be as follows: remote visual inspection of waste package surfaces to detect (1) corrosion or oxidation of the container material and (2) deformation of the container as a result of rock fall; determination of waste package surface temperatures; retrieving samples from either an emplacement drift or a performance confirmation section; and detection of radioactive contamination in exhaust gas.

[DERIVED based on Section 4 and 5.1.3][MGDS-RD 3.7.2.7.A.3][10CFR60.140(a)] and [MGDS-RD 3.7.2.7.E][10CFR60.143(c)]

B. For routine operations, monitoring and tests to be performed by Surface Operations in a dedicated hot cell should be as follows: measuring levels of radioactivity in or on recovered samples; packaging radioactive samples for shipment to a laboratory; releasing nonradioactive samples; and shipping of radioactive or nonradioactive samples to off-site laboratories.
[DERIVED based on Section 4 and 5.1.3][MGDS-RD 3.7.2.7.A.3][10CFR60.140(a)] and [MGDS-RD 3.7.2.7.E][10CFR60.143(c)]

C. If a waste package breach is detected, monitoring and tests to be performed by Surface Operations in a dedicated hot cell should be as follows: sampling of gases from the interior of a waste package; opening, unloading, and disassembling a waste package; remote or direct visual inspection of waste form and container components; and sectioning and removing samples of waste forms and containers.
[DERIVED based on Section 4 and 5.1.3][MGDS-RD 3.7.2.7.A.3][10CFR60.140(a)] and [MGDS-RD 3.7.2.7.E][10CFR60.143(c)]

D. Laboratory tests and off-site evaluations should be as follows: physical measurement of the geometry and dimensions of waste forms, pellets, and particles; surface area measurements of waste pellets or particles; determination of weight and activity of each radionuclide in a sample; sampling of gas composition inside a fuel element and analysis of gas composition; analysis of crystal structure of waste forms, container materials, and products of corrosion; measurement of depth of corrosion; measurement of pit depths and pit depth distributions; identification of microbial species; chemical analysis of samples; mechanical testing of samples; evaluation of weld integrity; measurement of stress in samples; microscopy of waste forms, container materials, and products of corrosion; testing of waste form degradation and radionuclide release in water and air; thermal testing of waste package mockups; heat treatment of samples, including long-term heat treatment.
[DERIVED based on Section 4 and 5.1.3][MGDS-RD 3.7.2.7.A.3][10CFR60.140(a)] and [MGDS-RD 3.7.2.7.E][10CFR60.143(c)]

E. The laboratory tests and off-site evaluations may be performed on-site.
[DERIVED based on Section 4 and 5.1.3][MGDS-RD 3.7.2.7.A.3][10CFR60.140(a)] and MGDS-RD 3.7.2.7.E][10CFR60.143(c)]

6.7 REPOSITORY SUBSURFACE TEST FACILITIES AND SUPPORT REQUIREMENTS

The Repository Subsurface Facilities shall provide underground openings (drifts, alcoves, boreholes, and ancillary excavations), access, data acquisition, and test support to implement performance confirmation monitoring and test recommendations listed below including interface and coordination with Site Investigation Testing, Repository Testing, Waste Package Testing, and Surface Support. These operations are to include, but are not to be limited to, capabilities for:

6.7.1 Site Investigation Support

A. **Any ground support system (i.e., shotcrete or concrete) that covers the emplacement drift rock wall surface shall not be installed until after any necessary rock mapping is complete.**
[DERIVED based on Section 5.1.1.1 and 5.2.1.5][MGDS-RD 3.7.1.3.B.1.bd] [10CFR60.141(a)] and [MGDS-RD 3.7.2.7.A.3][10CFR60.140(a)]

B. **(TBD) samples of rock core shall be acquired following emplacement drift excavation.**
[DERIVED based on Section 5.1.1.1 and 5.2.1.5][MGDS-RD 3.7.1.3.B.1.bd] [10CFR60.141(a)] and [MGDS-RD 3.7.2.7.A.3][10CFR60.140(a)]

6.7.2 Waste Package Test Support

Placement and recovery of material coupons or specimens in the emplacement drift or other underground locations shall be performed at a (TBD) frequency.
[DERIVED based on Section 4, 5.1.3, and 5.2.1][MGDS-RD 3.7.2.7.A.3][10CFR60.140(a)]

6.7.3 Recovery of Selected Waste Packages

Recovery of selected waste packages shall be performed on a non-routine basis, for malfunctioning waste packages or as required.
[DERIVED based on Section 4, 5.1.3, and 5.2.1][MGDS-RD 3.7.2.7.A.3][10CFR60.140(a)]

6.7.4 Instrumentation

The design, excavation, and ground support of emplacement drifts shall permit installation of and access to test/monitoring instrumentation, and observation drift instrumentation, and provide access for remotely operated vehicles or mobile inspection platforms to obtain measurements.
[DERIVED based on Section 4 and 5.2.1][MGDS-RD 3.7.2.7.A.3][10CFR60.140(a)]

6.7.5 Permanent Observation Drifts

Excavation of (TBD) permanent observation drifts, in or above the repository horizon shall be developed in support of thermal monitoring.
[DERIVED based on Section 4, 5.1.1.4 and 5.2.1][MGDS-RD 3.7.2.7.A.3][10CFR60.140(a)] and [MGDS-RD 3.7.2.7.A.6][10CFR60.141(b)] and [MGDS-RD 3.7.2.7.C][10CFR60.141(c)] and [MGDS-RD 3.7.2.7.D][10CFR60.141(e)] and [MGDS-RD 3.7.2.7.B][10CFR60.142(a)]

6.7.6 Seismic Measurements

At least one alcove shall be prepared for underground monitoring of seismic activities.
[DERIVED based on Section 4 and 5.2.1][MGDS-RD 3.7.2.7.A.3][10CFR60.140(a)]

6.7.7 Ventilation Monitoring

A. **The air temperature, relative humidity, and gaseous radioactive emissions of all emplacement drifts shall be monitored through the drift ventilation.**
[DERIVED based on Section 4 and 5.2.1][MGDS-RD 3.7.2.7.A.1][10CFR60.74(a)] and [MGDS-RD 3.7.2.7.A.3][10CFR60.140(a)]

B. **The ventilation monitoring system shall be capable of identifying the drift which is the source of gaseous radioactive emission, within (TBD) hours of detection of such emission.**
[DERIVED based on Section 4 and 5.2.1] [MGDS-RD 3.7.2.7.A.1][10CFR60.74(a)] and [MGDS-RD 3.7.2.7.A.3][10CFR60.140(a)]

6.7.8 Remote Monitoring

The provision and use of remotely operated vehicles or movable inspection platforms for monitoring emplacement drift environments and effects shall be considered in support of the following requirements:

A. **Personnel access into emplacement drifts shall not be permitted except for emergencies.**
[DERIVED based on Section 4, 5.1.2, 5.1.3, and 5.2][MGDS-RD 3.7.1.3.B.1.bn] [10CFR60.143(b)]

B. **Remote inspections of emplacement drifts at (TBD) frequency shall be performed to monitor rockfall, and visually inspect and thermally image waste packages.**
[DERIVED based on Section 4, 5.1.2, 5.1.3, and 5.2][MGDS-RD 3.7.2.7.A.3] [10CFR60.141(a)]

6.7.9 Ground-Water Inflow Measurement Program

Subsurface facilities operations shall have a program to inspect for ground-water inflow and, if detected, for measuring ground-water inflow quantities via direct measurement for all underground openings except emplacement drifts, direct measurement during construction and prior to waste emplacement for emplacement drifts, and indirect or remote measurement in emplacement drifts after waste emplacement.
[DERIVED based on Section 4 and 5.2][MGDS-RD 3.7.2.7.A.3][10CFR60.141(a)] and [MGDS-RD 3.7.2.7.C][10CFR60.141(c)]

6.7.10 Excavation Convergence

Emplacement drift diameter changes shall be monitored periodically to track excavation convergence. These measurements are required:

A. **In Permanent Observation Drifts, and may be monitored directly or remotely.**
[DERIVED based on Section 4, 5.1 and 5.2][MGDS-RD 3.7.2.7.A.3][10CFR60.141(a)] and [MGDS-RD 3.7.2.7.C][10CFR60.141(c)]

B. **In selected drifts, as indicated by rockfall activities.**
[DERIVED based on Section 4, 5.1 and 5.2][MGDS-RD 3.7.2.7.A.3][10CFR60.141(a)] and [MGDS-RD 3.7.2.7.C][10CFR60.141(c)]

6.7.11 Backfill Experiments and Field Tests

A. **Alcoves or drifts shall be provided to support, if required, backfill performance and constructability experiments and tests.**
[DERIVED based on Section 5.2][MGDS-RD 3.7.2.7.B][10CFR60.142(a)] and [MGDS-RD 3.7.2.7.F][10CFR60.142(c)]

B. Backfill performance testing, if required, is to be performed as early as possible and in representative environments.
[DERIVED based on Section 5.2][MGDS-RD 3.7.2.7.B][10CFR60.142(a)]

C. Backfill constructability demonstration is to be performed prior to the start of backfilling.
[DERIVED based on Section 5.2][MGDS-RD 3.7.2.7.F][10CFR60.142(c)]

6.7.12 Seal Experiment and Field Tests

A. **Alcoves shall be provided to support seal performance and constructability tests.**
[DERIVED based on Section 5.2][MGDS-RD 3.7.2.7.B][10CFR60.142(a)] and [MGDS-RD 3.7.2.7.G][10CFR60.142(d)]

B. Seal performance tests shall be performed for each of the major types of rock stratigraphy above repository horizon where sealing is required.
[DERIVED based on Section 5.2][MGDS-RD 3.7.2.7.B][10CFR60.142(a)]

C. Seal constructability tests shall include surface and subsurface construction and access. [DERIVED based on Section 5.2][MGDS-RD 3.7.2.7.G][10CFR60.142(d)]

6.7.13 Follow-On Drift Heater Test Support

If required, Subsurface Facilities shall provide facilities and test support as required by Site Investigation Thermal Testing to characterize and monitor thermal interaction effects while heating and while cooling, and as required by Waste Package Testing for materials in situ tests.
[DERIVED based on Section 4, 5.1.4, and 5.2][MGDS-RD 3.7.2.7.B][10CFR60.142(a)]

6.8 REPOSITORY SURFACE TEST FACILITIES AND SUPPORT REQUIREMENTS

The Repository Surface Facilities shall have the capability to support Performance Confirmation surface operations equipment and tests including, but not limited to:

A. **The capability to receive, handle, store, examine, test, and return to the underground waste packages, material coupons, and other specimens recovered from underground emplacement. This capability is to be exercised on a non-routine basis, for malfunctioning radioactive waste packages or as required.**
[DERIVED based on Section 5.2.2][MGDS-RD 3.7.2.7.A.3][10CFR60.140(a)] and [MGDS-RD 3.7.2.7.A.2][10CFR60.74(b), 10CFR60.137] and [MGDS-RD 3.7.2.7.E][10CFR60.143(c)]

B. **Handling to include transferring and opening the disposal container and canistered and uncanistered waste forms, removing samples, and repackaging, resealing, and decontaminating the disposal container.**
[DERIVED based on Section 5.2.2][MGDS-RD 3.7.2.7.A.3][10CFR60.140(a)] and [MGDS-RD 3.7.2.7.A.2] [10CFR60.74(b), 10CFR60.137] and [MGDS-RD 3.7.2.7.E] [10CFR60.143(c)]

C. **The capability for routine and non-routine non-destructive testing of sealed or resealed waste packages prior to emplacement or after recovery.**
[DERIVED based on Section 4 and 5.2.2.][MGDS-RD 3.7.2.7.A.3][10CFR60.140(a)] and [MGDS-RD 3.7.2.7.A.2][10CFR60.74(b), 10CFR60.137] and [MGDS-RD 3.7.2.7.E] [10CFR60.143(c)]

D. **The capability to receive, decontaminate, manage, temporarily store, and ship material coupons or specimens, retrieved from the emplacement drift, for off-site testing.**
[DERIVED based on Section 4 and 5.2.2.][MGDS-RD 3.7.2.7.A.3][10CFR60.140(a)] and [MGDS-RD 3.7.2.7.A.2][10CFR60.74(b), 10CFR60.137] and [MGDS-RD 3.7.2.7.E] [10CFR60.143(c)]

E. **The capability to receive, manage, temporarily store, and ship rock samples for off-site testing.**
[DERIVED based on Section 4 and 5.2.2.][MGDS-RD 3.7.2.7.A.3][10CFR60.140(a)] and [MGDS-RD 3.7.2.7.A.2][10CFR60.74(b), 10CFR60.137]

F. **The capability to transfer, automatically acquire, record, process, and communicate instrumentation data from surface and subsurface monitoring equipment and tests.**
[DERIVED based on Section 4 and 5.2.2.][MGDS-RD 3.7.2.7.A.3][10CFR60.140(a)] and [MGDS-RD 3.7.2.7.A.2][10CFR60.74(b), 10CFR60.137]

G. **The capability to support and protect continuous and periodic surface monitoring tests and operations.**
[DERIVED based on Section 4, 5.1.2, and 5.2.2.][MGDS-RD 3.7.2.7.A.3][10CFR60.140(a)] and [MGDS-RD 3.7.2.7.A.2][10CFR60.74(b), 10CFR60.137]

H. **The facilities and equipment to support Performance Confirmation operations such as test monitoring and control, data processing, record management and communication, limited laboratory tests, analysis and evaluations.**
[DERIVED based on Section 4, 5.1.2, and 5.2.2.][MGDS-RD 3.7.2.7.A.3][10CFR60.140(a)] and [MGDS-RD 3.7.2.7.A.2][10CFR60.74(b), 10CFR60.137]

7. SYSTEMS ANALYSIS

A systems analysis will be conducted in order to develop specific performance confirmation requirements on locations, frequency, and accuracy of measurements. The approach for developing alternatives for the specific requirements is proposed, and alternative requirements developed. A reference case is discussed to establish the current state of the design. Alternative concepts meeting the general performance confirmation requirements (as defined in Section 6) and alternative specific requirements are developed. Alternative concept selection criteria, which included cost, scientific confidence, and potential impact on waste isolation, were established to discriminate between the reference case and the alternatives. Finally, an evaluation of the concepts is performed for each criterion and the results are analyzed.

7.1 SPECIFIC PERFORMANCE REQUIREMENTS

As defined in 10 CFR 60.2, performance confirmation conducts tests to evaluate the accuracy of the information in the license application used to show with reasonable assurance that the postclosure performance objectives will be met. The information in the license application is expected to consist of expected parameter values with associated uncertainties. One way to evaluate the accuracy of the information is through statistical inference.

Statistical inference concerns methods by which information obtained from random samples is used to make generalizations about the populations from which the samples were obtained. Random sampling and statistical methods are typically used when conducting tests and evaluations of parameters with uncertainties. Tests of hypotheses are used when a decision is to be made about whether a statement concerning the parameter is true or false. Whenever this type of statistical inference or decision is made there is the possibility of an error. The two types of errors that can occur are: Type I - the hypothesis is reject when it is actually true (false rejection), Type II - the hypothesis is accepted when it is actually false (false acceptance). Thus, tests should be conducted and evaluations performed such that an evaluation of the accuracy, freedom from error, is established. The probability of a Type I error is referred to as the significance level or confidence level for the test and the probability of a Type II error is referred to as the power of the test.

Depending upon the type of test and the alternative hypothesis selected in the test, it may not be possible to compute the probability of a false acceptance. These type of tests are commonly called significance tests. The probability of a false rejection is called the level of significance. Thus, whenever these type of tests are made we should be willing to reserve judgement about the validity of the hypothesis.

The evaluated accuracy of information can specified by setting different levels of significance or confidence of the test and in some tests by setting the confidence level and power of the test. An approach for developing specific performance requirements that would result in a statistically significant confidence level will not be available until additional development of the performance confirmation baseline is complete.

This approach is outlined below and would be followed for each performance confirmation parameter:

1. **Establish current parameter expectations.** Initially, the Reference Information Base (DOE 1995d) should be consulted for its content on the parameter. For each model, including what was used in *Total System Performance Assessment 1995* (CRWMS M&O 1995a), identify the current values used or current expectation and of predicted values covering the applicable time domain (e.g., from now through 1,000,000 years after permanent closure) and the applicable spatial domain of the parameter. In particular, the values from now until closure, assuming this is 100 years after start of initial emplacement, should be established.

2. **Establish expected parameter distribution and uncertainty.** Identify the currently used and predicted distribution of values and the performance required, utilize sensitivity studies to determine the acceptable distribution and/or acceptable limits on the parameter.

   For certain parameters, acceptable limits (e.g., requirements, thermal goals, etc.) May have been established. For these, parameters the established limit will be used to develop the test hypothesis.

3. **Establish the hypothesis to be tested.** Given the current parameter expectation, distribution and uncertainty and the acceptable parameter range if it has been established, develop a hypothesis that can be tested by sampling and observation/measurement of the parameter, for evaluation of the significance of measured deviations from the expectations.

4. **Set criteria for testing.** A target level of confidence should be established on the testing and/or the power of the test.

5. **Develop specific requirements.** Given the current parameter expectation, the acceptable parameter range, and the criteria for testing, develop the specific requirements on frequency, location, precision, and accuracy needed to meet the testing criteria.

As a surrogate for this approach, the study team was solicited to develop reasonable alternatives for specific performance conformance confirmation requirements. The focus was on the design drivers, so specific requirements on frequency, location, precision, and accuracy were not developed for any one parameter. These requirements developed, for a nominal case and a a enhanced case. These requirements represented the range of what was considered reasonable and adequate for the identified design or cost drivers.

These specific requirements, cost or design drivers, were selected for further specification since it was felt that they could have an influence on the Viability Assessment design or cost. These identified requirements, that were listed in Chapter 6, contained TBDs. Table 7-1 below shows the requirement number from Chapter 6, a brief indication of the requirement focusing on the TBD considered, a specification of the Nominal and Enhanced requirement, and an indication of the area of uncertainty. As discussed above, there is still some uncertainty for most of the current parameter expectations and distributions regarding the accuracy need and representativeness of locations for testing or monitoring. Also, for two of the identified requirements, there is an uncertainty in the design or in the resolution of a regulatory issue. Each of these areas will need further refinement, but to support the Viability Assessment design a specific recommendation should be made on these requirements.

Table 7-1. Alternative Specific Requirements

Requirement Number	Requirement Description	Alternative Requirement		Area of Uncertainty
		Nominal	Enhanced	
6.4.2.D	Number of surface-based boreholes for hydrology monitoring	5	15	Accuracy needed and representativeness of locations
6.4.3.A	Number and location of underground fault zone monitoring	1 - Total (existing) Ghost Dance Fault alcove	4 - Total 2- (existing) Ghost Dance Fault alcoves and 2 - (New) Solitario Canyon Fault alcoves	
6.4.4.A	Coverage and location of the thermal rock mass behavior testing	2 percent	10 percent	
6.7.1.B	Number of rock core samples need from emplacement drifts	200	1000	
6.7.2	Frequency of waste package materials coupon/specimen recovery	once per ten years	once per year	
6.7.5	Number of Permanent Observation Drifts	1 - located in the north monitor initially completed emplacement drifts	6 - located throughout the emplacement area	
6.7.8.B	Frequency of remote inspection of emplacement drifts	once per ten years	once per year	
6.4.1.C	Independence of mapping from emplacement drift excavation	independence is allowed by the ground support system	mapping must immediately follow emplacement drift excavation	Uncertainty in the design of the ground support system
6.7.13	Need for follow-on heater testing	not required	required	Uncertainty in the resolution of the regulatory issue regarding 10CFR60.142(a)

7.2 REFERENCE AND ALTERNATIVE CONCEPTS

7.2.1 Reference Case (MGDS ACD Report Description of Performance Confirmation)

The description of the reference case is based on information that was recently documented in the *Mined Geologic Disposal System Advanced Conceptual Design Report* (MGDS ACD) (CRWMS M&O 1996a). In general, there is not much detail in the description, thus the reason for this study. There is a good description of the concept of operations in the *Controlled Design Assumptions Document* (CRWMS M&O 1996c). This information was used in developing the cost estimate that is also documented in the MGDS ACD Report.

The MGDS ACD Report Volume II discusses the Repository design. Section 9.3 of Volume II is devoted to Performance Confirmation. Section 9.3.3 is a general description of the design regarding performance confirmation and is summarized below:

> There has been essentially no design effort expended on performance confirmation, and no description of the performance confirmation program is available. The extent of the program, the types of data to be collected, and the collection interval needed remain largely unknown, 10 CFR 60.141 requires that the information acquired during repository construction and operation be utilized to confirm or provide the basis for change of the data which were used during the design and licensing of the facility. The evaluation of the data will be a central function of the performance confirmation program.
>
> The program may or may not involve the periodic recovery of emplaced waste packages for inspection and/or testing. If all emplacement drifts required continuous monitoring, the operational impacts would be severe. However, if only selected drifts are continuously monitored, or if all drifts are monitored intermittently by mobile remote data acquisition units, the impacts to repository operations would be lessened.

7.2.2 Alternative Performance Confirmation Concepts

The alternative performance confirmation concepts perform the same functions and will monitor or test the same set of parameters, but the amount of data that will be obtained will be different in the two alternatives. The two alternative concepts "nominal" and "enhanced" are based on the alternative requirements stated in Section 7.1. The major differences between the two alternatives are discussed here.

Each of the major concept areas is discussed. In the Site Monitoring and Testing area, the Subsurface Geologic Mapping Package varies for the two cases. The nominal concept has less rock core sampling. The value of 200 would result in a core sample being taken about once per emplacement drift. The enhanced case is a factor of five higher or about every 200 m. The mapping is also different in the two cases. This difference is due to the independence of the mapping effort with the drift construction. If the two are independent as in the nominal case, then the rate of mapping can be higher - a factor of five was used. This is also the case if the mapping is recorded by photogrammetry and later analyzed off-line.

The Surface Based Unsaturated Zone Package has a different number of boreholes in the two cases, 5 for the nominal and 15 for the enhanced. Similarly, for the Underground Fault Zone Package, the number of alcoves that are monitored is what varied. In the nominal case, a single fault zone is monitored, e.g., one of the planned Ghost Dance Fault alcoves is used. For this case, no initial construction and testing is performed since it will be completed as part of site characterization, but monitoring and occasional testing is performed. In the enhanced case, four alcoves are used. The two planned Ghost Dance Fault alcoves are used and it was assumed that the Solitario Canyon Fault is initially tested and monitored at two locations.

The Thermal Package is installed in one of the Observation Drifts in the nominal case. The north end of the repository was selected since it will be developed and emplaced first. The differences between the nominal and enhanced case is the amount of coverage of the rock mass that is required to be monitored and tested. For the nominal case, 2 percent of the rock mass was covered. The enhanced case required a 10 percent coverage of the rock mass be covered via six observation drifts. Three were above the repository horizon and three were in the horizon. The strategic location of the first observation drift in the north end has been specified, but the rock mass covered needs to be representative.

In the Repository Monitoring and Testing Concept, neither case considered the testing needed to support either backfill or seals testing. The Follow-On Heater Test was not included in the nominal case, but was in the enhanced case. Ventilation and seismic monitoring did not vary between the cases. For the remote observation capability, the capability to monitor any drift not just the observation drifts was included in both cases. In the nominal case, the ability to detect radiation leaks remotely was not included, but the capability to perform visual, thermal, geological, and telerobotic inspection was included. In the enhanced case, all the capabilities were included.

Regarding Waste Package Testing, the primary differences were the frequency of the testing activities. In the nominal case, testing was performed once every 10 years and in the enhanced case once a year. The capability to perform tests on a failed waste package was maintained as a contingency. The number of specimens was an order of magnitude higher than the number of "dummy" waste packages.

The Data Acquisitions Concepts vary only slightly between the alternative cases. The Surface Facilities concepts remain the same and the primary cost difference is the observation drift differences described above. A minor difference is also in the number of alcoves constructed— two more for fault testing in the enhanced case.

The Evaluation and Reporting Concept remained basically the same in the two cases except that the enhanced case assumed about twice as much analysis as the nominal case for the larger amount of data and samples going through the system.

7.3 ALTERNATIVE CONCEPT SELECTION

The selection criteria considered in this study are cost, scientific confidence, and the potential waste isolation impacts of the concepts. These criteria are felt to be the most important factors that could influence a recommendation on the design requirements for a performance confirmation program.

Although other criteria could be identified, such as schedule, flexibility, preclosure health and safety, risks to the environment and stakeholder acceptance, the current level of design makes some of these criteria difficult to quantify. Eventually, the preclosure health and safety criterion will be applied. An analysis of the performance confirmation design will be performed to assure that the lowest level of exposure to radiation commensurate with economics and the work to be accomplished will be performed. This will be done in conformance with ALARA (as low as reasonably achievable) and will include evaluations of exposure to the workers. The sections below describe the criteria in additional detail.

After an evaluation of the criteria is performed, an analysis will be performed to develop a recommendation of the desired set of performance confirmation requirements. There are several possible methods that can be used to determine the preferred set of requirements and preferred alternative. First, if there is not a significant difference in the performance of the alternatives, then the recommended set of requirements and alternatives could be determined by a simple cost comparison. The set requirements that result in the alternative with the lowest life cycle cost is recommended.

Another method that is used to develop a recommended alternative is the attribute weighting approach. The following process is used if it is justified to make a recommendation. First, a relative ranking of the alternatives is developed for each criterion. The best alternative will receive the highest relative ranking. A weight for each decision criterion is developed. Once again, the most important criterion receives the highest weight. The product of the criteria weight and the relative ranking is summed for each alternative to obtain a weighted ranking of the alternatives. The alternative with the highest weighted rank will be the desired alternative and requirements that were input to the alternative will be recommended.

Depending upon the results of the evaluation, a recommendation of a preferred set of requirements, will be made using one of the above methods.

7.3.1 Performance Confirmation Program Life Cycle Cost

Performance Confirmation Program Life Cycle Cost estimates were derived. These costs include only those costs attributed to the Performance Confirmation Program the facilities, equipment, and operations needed to support it. These estimates are high-level and should be used to compare between alternatives and are not to be used as input to a Mined Geologic Disposal System life cycle cost estimate that would result from the development of a design. The Repository Life Cycle Cost from the reference ACD (CRWMS M&O 1996a) was used as a basis and the cost attributed to the Performance Confirmation Program was extracted. The information extracted provided by the main integrator and developer of the life cycle cost estimate for the Advanced Conceptual Design. For the alternatives, the cost attributed to the Performance Confirmation Program was estimated for each of the major Performance Confirmation concept elements. Only costs that are directly attributed to these Performance Confirmation concepts are included. The scope of these costs included Site Characterization, also called the Development and Evaluation Phase (for the alternative concepts) Engineering and Construction Phase, Emplacement Operations Phase, Caretaker Operations phase, and the Decommissioning and Closure Phase of the Repository. The cost of Development and Evaluation or Site Characterization phase of the life cycle were estimated in the alternative concepts for completeness and were used to make an initial assessment of those activities that would be initiated during Site Characterization, but the focus of the study is on emplacement and post-emplacement impacts. The Repository Life Cycle Cost estimates for each subsystem were then combined and added to develop relative costs to compare between alternatives. This resulted in a relative cost estimate for each alternative.

7.3.2 Scientific Confidence

A statistical basis for the significance of the testing is desired, but at this time sufficient information and time were not available to develop a quantitative evaluation of the confidence additional testing and monitoring information will produce. It is also unknown what the level of significance will be known at the time of license application. For these reasons, a qualitative measure of significance was used for the testing and monitoring of each parameter. These be measures were grouped to yield a qualitative assessment of the overall confidence for the alternative concepts.

7.3.3 Potential Impacts on Waste Isolation

A qualitative evaluation of the potential waste isolation impacts of the proposed performance confirmation concepts was performed. An overall assessment was performed and if there were specific areas of concern, a comparative evaluation of the concepts would be performed.

7.4 EVALUATIONS

This section contains the results of the evaluations of the reference case and the alternative concepts. The cost evaluations are presented first, followed by the qualitative assessment of scientific confidence, and then an evaluation of the impact on waste isolation. An analysis is then presented which provides an comparative evaluation of the results in order to develop a conclusion and make a recommendation of requirements.

7.4.1 Evaluation of Performance Confirmation Costs for the Reference Case and Alternatives

An overall summary of the performance confirmation costs is provided below in Table 7-2. The cost evaluation of the reference case is shown along with the two alternatives. Following the overall summary, the rest of the section is devoted to addition discussion of each case.

Table 7-2. Summary of Performance Confirmation Life Cycle Costs
(Cost in FY96 $Million)

		Alternative Cases		
	Reference ACD Case*	Nominal Case	Enhanced Case	Totals**
Monitor, Test and Evaluation	208	414	1799	Subtotal**
Site		193	1167	
Repository		91	296	
Waste Package		114	208	
Evaluation		15	29	
Data Acquisition	426	313	359	Subtotal**
Subsurface	4	128	175	
Surface	422	185	185	
Performance Confirmation Concept	634	727	2158	Total**

ACD - *Advanced Conceptual Design Report* (CRWMS M&O 1996a)
* Cost escalated from 1995 dollars to 1996 dollars using 1.038 escalation factor.
** Numbers may not add due to rounding

7.4.1.1 Performance Confirmation Costs of the Reference Case

As described earlier, the reference case is the Advanced Conceptual Design reference design. The costs that are attributable to the performance confirmation activities were identified and grouped in the broad categories of data collection, surface operations, subsurface operations, and waste package procurement. These costs are related to data collection and the cost to recover a waste package once every ten years. The cost drivers in this estimate were the personnel for data collection and the Surface Facility Operations Cost for waste package recovery. The Performance Confirmation Costs included in the *Advanced Conceptual Design Report,* Vol. IV (CRWMS M&O 1996a) are summarized in Table 7-3.

Table 7-3. Summary of Performance Confirmation Costs for the Reference Case
(Cost in FY95 $Million)

Data Collection [1]	Surface Facility Operations[2]	Subsurface Facilities Operations[3]	Waste Package Procurement[4]	Totals
196.04	406.27	3.50	4.54	610.35

1. An annual cost beginning in FY 2010 through FY 2109 for collecting and processing collected data.
2. Cyclic cost in the Caretaker period for surface - waste handling building startup, operation and decommissioning to support the 1 in 10 years waste package recovery operations.
3. Cyclic cost in the Caretaker period for subsurface in support of the 1 in 10 years waste package recovery operations.
4. The cost of 10 bare fuel waste packages procured to support the 1 in 10 years waste package recovery operations.

A discussion of the major assumptions which influence the costs is provided below.

7.4.1.1.1 Surface Facility—ACD Assumptions

Performance confirmation support provided the waste handling operation one per ten years supporting the opening of a retrieved waste package and repackaging of the removed waste in a bare fuel waste package for return to underground. The cyclical nature of this operation required a facility startup phase, which included employee training, a short operation phase, and a decontamination phase in order to return the waste handling building to a standby state. The typical cyclic phase of three years cost $56.1 million (FY95) dollars.

7.4.1.1.2 Subsurface Facility—ACD Assumptions

The cost of the crew and the hardware elements that support the waste package in the emplacement drifts are included in this estimate. The crew cost includes training and required underground waste package shuffling; the basic crew is available from the Caretaker personnel pool. The costs during the emplacement period are absorbed and not charged against performance confirmation activities. The typical cyclic phase cost $0.5 million (FY95) dollars.

7.4.1.1.3 Data Collection and Assessment Personnel Required—ACD Assumptions

Data collection and assessment personnel required for the reference case are listed in Table 7-4.

Table 7-4. Performance Confirmation Personnel for Reference Case

Area of Evaluation	Data Collection Personnel	Technical Personnel
Nuclear/Radiation	2	1
Material	2	1
Engineering	2	1
Thermo-mechanical	2	2
Thermo-hydrological	2	3
Geology	2	2
Support Personnel		
Instrumentation	6	
Computer	3	

7.4.1.1.4 Pay Scale ACD—Assumptions

It is assumed that the data collectors and the technical personnel will be contracted to provide the maximum year per person which yields the annual equivalent of the fully burdened cost shown in Table 7-5. Also note that the ACD performance confirmation period was 100 years, 24 of which occurred during the Emplacement period and 76 during the Caretaker period.

Table 7-5. Performance Confirmation Personnel Pay Scale for Reference Case.

Job Category	Annual Pay, Dollars (FY 95) (Fully burdened)	Duration
Data Collector	$46,800	ACD performance confirmation period was 100 years, 24 during the Emplacement and 76 during the Caretaker periods
Technical	$88,400	
Support	$57,200	

Data collection cost details are shown in Table 7-6.

Table 7-6. Data Collection Cost Details.

	Emplacement Cost (FY 95 $M)	Caretaker Cost (FY95 $M)	
Nuclear/Radiation	4.37	13.83	
Material	4.37	13.83	
Engineering	4.37	13.83	
Thermomechanical	6.49	20.55	
Thermohydrologic	8.61	27.27	
Geology	6.49	20.55	
Support			
Instrumentation	8.24	26.08	
Computer	4.12	13.04	
TOTAL	**47.05**	**148.99**	Total = $196.04M

These costs equate to approximately $2 million per year throughout the program. As discussed, the costs are based on assumptions and there is no sound basis for these costs, but they are shown to provide a basis for comparison of the alternatives.

7.4.1.2 Performance Confirmation Costs of the Alternative Cases

A breakout of the performance confirmation costs of the alternative cases is provided below in Table 7-7. Each of the performance confirmation concept areas summarized in Table 7-2 is broken out to the lower level. An explanation of the costs and an analysis of the cost drivers is provided in the paragraphs that directly follow the table.

Table 7-7. Breakout of Performance Confirmation Concept Costs
(Cost in FY96 $Million)

Performance Confirmation Concept	Alternative Cases		
	Nominal	Enhanced	
Monitoring and Testing and Evaluation	414	1799	Major Subtotal*
Site Monitoring and Testing	193	1167	Minor Subtotal*
Subsurface Geologic Mapping Package	18	89	
Surface Based Unsaturated Zone Package	62	198	
Underground Fault Zone Package	33	170	
Thermal Package	79	709	
Repository Monitoring and Testing	91	296	Minor Subtotal*
Seals Test	0	0	
Backfill Test	0	0	
Follow-On Drift Heater Test	0	196	
Seismic Monitoring	0	0	
Remote Observation	91	100	
Waste Package Monitoring and Testing	114	308	Minor Subtotal*
Off-Site Lab	67	134	
In Situ Monitoring	40	80	
Pull Waste Package	0	0	
Pull Dummy Waste Package	7	72	
Pull Specimen	4	21	
Evaluation and Reporting	15	29	
Test Facilities and Support	313	359	Major Subtotal*
Subsurface	128	175	Minor Subtotal*
Observation Drift	13	40	
Emplacement Drift Ventilation	36	36	
Waste Package Recovery	0	0	
Alcoves	9	16	
Remotely Operated Vehicle	70	83	
Surface	185	185	
Performance Confirmation Concept TOTAL	727	2158	Total*

* Numbers may not total due to rounding

7.4.1.2.1 Site Monitoring and Testing Costs

The first division of test packages discussed is under the Site Monitoring and Testing area. The first package under this area, the Subsurface Geologic Mapping Package, costs vary from the nominal case to the enhanced case because the number of samples is increased and the rate of mapping is decreased. The nominal case assumes the mapping can occur independently of the tunnel boring machine operations. In the enhanced case, the mapping is assumed to be conducted immediately behind the tunnel boring machine. The Mapping Package is not considered to be a large cost driver in comparison to the other concepts, however it does increase by $71 million from the nominal to the enhanced case.

Surface Based Unsaturated Zone Hydrology Package costs are based on the number of boreholes monitored. The more holes monitored, the higher the cost. From the nominal to the enhanced case, costs triple, and $136 million cost increase is seen, this package is also not a large cost driver.

The Underground Fault Zone Package costs are based on the number of faults monitored. The costs increased by a factor of six from the nominal case to the enhanced case. This area is also considered to be a significant cost driver.

The Thermal Package includes a large number of parameters that will be monitored. A large percent of the instrumentation for this test require the need for boreholes for retrievability, recalibration and/or replacement. Coring, sampling, and laboratory work associated with this package has been costed to reflect a low and high number. There is an extremely large cost difference in this package, that is chiefly due to the number of tests conducted, and the number of samples and analysis. This is the major cost driver for the performance confirmation test concepts.

7.4.1.2.2 Repository Monitoring and Testing

The second subdivision under Monitoring and Testing and Evaluation is the Repository Monitoring and Testing packages.

The Seals Test package is an area for which costs are not available at this time. No cost has been assigned to this package.

The Backfill Test package is also an area for which costs are not available at this time. No cost has been assigned to this package.

The Follow-On Drift Heater Test package in the nominal case is representative of no test, but for the enhanced case there is a substantial cost which makes this test a clear and significant cost driver. This test may be needed to comply with 10 CFR 60.142(a). A drift scale heater test is planned for site characterization and may be sufficient. The need for this test is not clear and resolution of the issue should be pursued with the Nuclear Regulatory Commission. The assessment of the team is that this test would provide additional information on the cool-down phase. This test could also be used for simulation of a dummy waste package which is needed for waste package stress measurements, but these measurements may be more efficiently done in a laboratory.

The Seismic Monitoring test package cost is insignificant. This test is not considered to be a cost driver.

The Remote Observation package is connected with the visual, thermal, geological, and radiological inspection, and retrieval of specimens in the emplacement drift(s), by using a remotely operated vehicle. This concept is relatively expensive for the nominal and enhanced case. It has high cost to commit to but is fairly flat for the range of frequencies of observation considered in this report. The cost difference between the and enhanced case varies only slightly. This is not a major cost driver for the enhanced case, but is a significant portion of the nominal case total cost.

7.4.1.2.3 Waste Package Monitoring and Testing

The third area included in the Monitoring and Testing concept is the Waste Package Monitoring and Testing.

This area includes Off-site Lab testing and experiments. The costs vary in this task chiefly due to the number of samples and the number of personnel assigned to support this area. The costs double from the nominal case to the enhanced case. This is the a major cost driver in the Waste Package testing arena.

The In Situ Monitoring package utilized emplacement drift monitoring and temporary in-drift monitoring by using remotely operated equipment, but primarily is based on personnel costs for analysis of the data. This is not a large cost driver area.

The concept of Pulling a Waste Package has been treated as a contingency only, and no costs have been identified for this activity.

The concept of Pulling Dummy Waste Packages for destructive and non-destructive tests is affected by cost based on the number of waste packages needed for evaluation. The cost variation from nominal to enhanced reflects this sample size change. This is not a cost driver by itself but if a heated drift test like the follow-on drift heater test is needed it becomes very important for the amount of money it will cost.

The last area listed under this category is Pulling Specimens. This is chiefly waste package materials in the emplacement drift environment and other areas in the underground. This area covers the corrosion and mechanical effects on barrier thickness and shape. This would require a concept utilizing remotely operated equipment. The cost associated with this concept does not vary greatly from low to high, and is not a cost driver.

7.4.1.2.4 Evaluation and Reporting

The final step of the Performance Confirmation process is the Evaluation and Reporting concept. This area is based on the number of tests, samples, models, and analysis associated with the Performance Confirmation concept. The costs were assumed to double nominal to enhanced case with increased amount of information. This is not considered to be a cost driver area.

7.4.1.2.5 Test Facilities and Support

The last major division under the Performance Confirmation Concepts is Test Facilities and Support. This area is composed of the subsurface and surface. Under the Subsurface category, one identified concept is Observation Drift. This cost is based on one drift above the emplacement drift in the nominal case and three in the enhanced case, but in the enhanced case three drifts in the repository block were used, and consequently the cost remains the same. This is not a major cost driver.

Emplacement Drift Ventilation concept is treated the same in the nominal and enhanced case. This activity is not a major cost driver.

Waste Package Recovery concept is treated as a contingency only concept with no identified costs for either case.

The Alcove concepts are being planned for tests that require boreholes chiefly for instrumentation, rock sample collection, and faulting parameters. The associated costs vary only slightly from the nominal to the enhanced case. This is not a large cost driver.

The last concept under Subsurface Data Acquisition is Remotely Operated Vehicle. This concept only varies slightly from the nominal to enhanced case. The cost is significant with this option, and is a significant cost driver.

The Data Acquisition Surface concept utilized a Performance Confirmation Support Building and a portion of the Waste Handling Building-Multi-Purpose hot cell. The cost for the enhanced and nominal case is the same. The combined cost for new support building and additions to the hot cell indicate this activity is a significant cost driver.

7.4.2 Evaluation of the Reference Case and Alternatives Against Scientific Confidence

A comprehensive evaluation of scientific confidence that includes statistical significance will not be available until additional development of the performance confirmation baseline is complete. Further development of the baseline in follow-on work is required to develop quantifiable measures of the confidence level. After this work is completed, a cost/benefit analysis can be conducted to provide additional input in evaluating alternatives.

7.4.3 Evaluation of the Reference Case and Alternatives Against Potential Waste Isolation Impacts

Waste isolation evaluations are currently being conducted to identify potentially adverse effects of site characterization activities on the performance of a potential high-level radioactive waste repository at the Yucca Mountain site. Due to the similarity of the wording of the requirements, considerations of existing waste isolation evaluations may be used to address the performance confirmation requirement. But, since this is done to support design activities not field activities under site charterization actual determination of importance evaluation is not needed. These evaluations are documented in Determination of Importance Evaluations, which include test interference evaluations and which establish control requirements intended to limit adverse impacts of site characterization activities on waste isolation. Waste isolation evaluations are required by 10 CFR 60.15(c)(1), which states that "investigations to obtain the required information shall be conducted in such a manner as to limit adverse effects on the long-term performance of the geologic repository to the extent practical." Also, per *Mined Geologic Disposal System Requirements Document* requirement 3.7.2.7.A.5.a) which is taken from 10 CFR 60.140(d), the performance confirmation program shall "not adversely affect the ability of the natural and engineered elements of the geologic repository to meet the performance objectives." (DOE 1996c).

Waste isolation evaluations are addressing construction activities, facility operation, and testing activities, including tracers, fluids and materials (TFMs) introduced into the potential repository and surrounding study area. Evaluations center on activities that would cause a permanent disturbance to the natural system and that could increase or enhance the movement of radionuclides from the potential repository to the accessible environment. This includes evaluating the amount of introduced TFMs that may remain emplaced after permanent closure of the potential repository. As a result of these evaluations, controls or limits on the planned activities are established that are expected to minimize adverse impacts on the waste isolation capability of the natural and engineered barrier. Similar evaluations are needed for the planned performance confirmation activities because any controls or limits applied on them may result in requirements on the design of the repository or engineered barrier system components.

Some of the recommended performance confirmation activities are similar to surface-based site characterization activities and to activities currently being conducted within the Exploratory Studies Facility (ESF). Waste isolation evaluations of surface-based activities have addressed the construction of roads, drill pads, and buildings (including for the ESF); the excavation of pits for testing purposes or to obtain construction materials; the drilling of boreholes and testing in boreholes; and activities associated with environmental monitoring. Subsurface ESF waste isolation evaluations have addressed the excavation of the ESF ramps, drifts, and test alcoves; the installation of ground-support systems; the drilling of testing boreholes from the alcoves; and testing activities in the ESF excavations and boreholes. Issues of potential waste isolation concern with respect to both surface-based and underground activities include the creation of potential pathways for water and radionuclides; the use of construction and dust control water; the use of organic materials and other TFMs; and the effects of blasting and other excavation methods on the hydrogeological, thermomechanical, and geochemical characteristics of the natural barriers. The construction, instrumentation, testing, and monitoring for the planned performance confirmation activities need to be evaluated with respect to these issues.

7.4.3.1 Waste Isolation Issues

Waste isolation evaluations for the subsurface ESF are contained in the *Determination of Importance Evaluation for Subsurface Exploratory Studies Facility* (Subsurface ESF DIE) (CRWMS M&O1996h). Many of the issues contained in this document are relevant to the construction and testing required in the performance confirmation program. Not all of the quantitative results of the ESF evaluations, however, will apply to the performance confirmation program due to their unique locations, designs, and tests. Also, quantitative evaluations of the planned performance confirmation activities cannot be made until more detailed designs are developed, including specific locations, dimensions, quantities of specific TFMs to be used and remaining permanently underground, etc.

Nevertheless, the potential major waste isolation issues associated with the planned performance confirmation activities can be evaluated qualitatively on the basis of the current preliminary concepts. The Subsurface ESF DIE identified above can be used to extract preliminary requirements for the repository and engineered barrier system design. Following are brief descriptions of the major waste isolation issues to be addressed by these requirements.

7.4.3.1.1 Water Use

The use of water is necessary for construction, mapping, and instrumentation of the ESF drifts and test alcoves. The same methods used in constructing ESF facilities can be expected to be used for building the proposed drifts and boreholes in the performance confirmation program. Currently, the subsurface use of water is limited so as not to enhance the natural moisture content of the rock above natural levels of variation in the rock. This limit is intended to control the corrosion of waste packages, dissolution of the waste, and transport of radionuclides due to higher moisture levels resulting from the ESF activities. Because water use limits are location-specific, they would have to be developed for the planned performance confirmation activities once their design and operations are defined in more detail. In the meantime, the current limits on water use in the ESF main drift can be used as guidance.

7.4.3.1.2 Organics Use

The addition of organic carbon to the subsurface during construction and testing is of particular concern. Radionuclides may sorb onto organic carbon chemical species and be either retarded or transported more easily. Organic carbon could also increase microbial activity around the waste packages, which could produce acidic conditions. A low pH can greatly affect radionuclide solubilities, which would increase the rate of radionuclide dissolution and transport from waste packages. Other issues may arise as a result of other organic materials that may be used for performance confirmation activities. The current limits on the subsurface use of organics in the ESF are based on the natural variability of organic matter. These limits are so small that they virtually preclude the use of any non-essential organic-based materials in the ESF. Therefore, before using any organic materials for performance confirmation activities, their necessity, intended use, and quantity have to be evaluated.

7.4.3.1.3 Tracers

Various tracers for testing purposes have been evaluated, for example, the use of lithium bromide tracer in mapping water for ESF drifts and alcoves, and the use of organic tracer gas in drilling of the radial boreholes in north ramp test alcoves.

Lithium bromide was proposed to be used at a concentration of generally 20 ppm and not to exceed 30 ppm. Changes to the natural system are expected to be negligible for these concentrations and the planned quantities. Therefore, any effects on repository performance are also expected to be negligible and explicit controls on its use are therefore not required.

Drilling of radial boreholes in ESF north ramp test alcoves will use tracer gas to detect test interference from the introduction of atmospheric components. One of the possible gases is an organic compound tetrafluorethane (CH_2FCF_3). This tracer gas was previously evaluated for use in borehole drilling for the surface-based testing program but not for use underground. The usage of this tracer was expected to have negligible potential for impact to waste isolation capabilities of the site, because it has a limited concentration (30 ppm ± 10 ppm in air), it is removed using suction of the gas from the borehole, and a limited number of boreholes are to be drilled.

7.4.3.1.4 Other TFMs of Concern

The potential use of cement in large quantities, such as used in tunnel, shaft, and alcove linings, may impact the postclosure performance of a potential repository and should therefore be considered in the design and construction of subsurface performance confirmation facilities. Potential problems include the physical and chemical stability of cement under high thermal loads, the dehydration of the cement, the generation of colloids, and potential microbial actions that could produce localized acidic conditions. A resulting concern is the generation of a high-pH contaminant plume within the potential repository that could affect waste package corrosion, waste dissolution, and radionuclide transport. At present, however, insufficient experimental or other information is available on the expected subsurface performance of cementitious materials. Although no quantitative limits have been established on their subsurface use in the ESF, the goal is to minimize their use to the extent practical.

The Subsurface ESF DIE evaluates other TFMs and indicates whether they are approved for use and what controls need to be applied to their use. This DIE can be used to infer any necessary controls and limits for other substances that may be used for the planned performance confirmation activities.

7.4.3.1.5 Excavation Methods

Common methods used in construction of underground facilities are the use of tunneling equipment, including tunnel boring machines, and drill-and-blast methods. These methods disrupt the natural geologic system, first, by adding the excavations themselves, and second, by changing the hydrogeological, thermomechanical, and geochemical characteristics of the adjacent rock. These changes, in turn, may affect the expected performance of engineered barrier system components. No limits have been established on the mechanical aspects of ESF excavation equipment and use, such as tunnel boring machines, but limits have been established on blasting. As mentioned above, limits have been established on the subsurface use of water, including for excavation purposes, and controls have been established to minimize spills and leakage of fluids used by excavation equipment.

7.4.3.1.6 Excavation and Borehole Sealing

The evaluation of the performance confirmation activities must consider any impacts on the effectiveness of future drift and borehole seals and the generation of preferential aqueous and gaseous pathways through the natural barrier system. Sealing concerns include the potential materials used for sealing and the design of the seals. Materials that are commonly suggested are cement grouts, crushed tuff, and smectite clays such as bentonite. Cements are potentially a problem for the reasons stated above; crushed tuff is highly permeable, and smectite clays may shrink or swell under changing moisture conditions. Smectites may also undergo alteration into different minerals under high stress and heat. Therefore, the design of the seals depends greatly on the long-term performance of the selected materials. Eventually, these items need to be fully evaluated before the repository is either built or sealed.

Performance evaluations of potential seals have not yet been conducted, but it is presumed that effective seals can be developed and installed. Thus no constraints have been established on surface-based and subsurface borehole drilling and on subsurface excavation methods with respect to sealing requirements.

7.4.3.2 Summary

At the present, similarities between the current construction and testing activities in the ESF and the recommended subsurface performance confirmation activities can be used to establish preliminary controls on the planned performance confirmation activities in order to minimize impacts on waste isolation. These controls can be derived from the qualitative summaries above together with the requirements established by the Subsurface ESF DIE. Following that, repository and engineered barrier system design requirements can be derived from those controls. Although some of the current controls for subsurface ESF activities are quite conservative because of limitations with respect to site information and modeling, their direct use for the performance confirmation activities may not be conservative. It is important to note that the Subsurface ESF DIE controls consider the distance of the ESF facilities and testing from potential waste emplacement locations. Because some of the planned performance confirmation activities will be closer, judgment needs to be used in translating the ESF requirements into performance confirmation controls and repository and engineered barrier system design requirements.

In the future, a DIE, including waste isolation and test interference evaluations, should be performed using new site data, more detailed repository and engineered barrier system designs, final performance confirmation concepts, and improved performance assessment models. These new evaluations may allow relaxing preliminary controls and design requirements, or perhaps dropping some of them, in order to allow a more flexible performance confirmation program. Pre-license application experience with the ESF construction, operation, and testing with respect to natural barrier system alterations potentially affecting waste isolation will provide additional guidance prior to the post-license application performance confirmation program for revising the initial design requirements.

Detailed evaluations of the planned performance confirmation activities will require more detailed information on the location and design of the facilities, such as observation drifts, test alcoves, and boreholes, and the types and quantities of TFMs to be used. The evaluations would have to consider alternative performance confirmation concepts in terms of the number of similar facilities, like observation drifts. Qualitatively, any adverse effects on waste isolation of a single facility or activity can be expected to be multiplied by the number of such facilities or activities, provided there is no interference between facilities or activities. The latter needs to be avoided because of potential test interference between adjacent performance confirmation activities.

The more detailed waste isolation evaluations are expected to produce adequate controls that would prevent significant long-term impacts to waste isolation due to water use, construction methods, and TFM use. Differences from current controls may result because of unique locations and designs required for performance confirmation. For example, based on the current plans, the specific effects on the local ground-water conditions would need to be evaluated solely because of the planned observation drift placement above the repository drifts. This could alter ground-water pathways during both the observation and postclosure period. In addition to the drift location, observation boreholes are of concern because of the ultimate necessity to seal them in order to prevent them from becoming fast ground-water pathways. This problem then brings into play the use of materials for sealing, including their geochemical effects. Another concern would be the extent of the thermal dry-out perturbation from the emplaced canisters and if the observation drift would be located in the condensation zone. Based on this assessment of the concepts, an individual comparison of the different alternatives is not necessary.

7.5 SYSTEMS ANALYSIS

A systems analysis is conducted when a recommendation is to be made that considers several criteria that are important and can be used to distinguish between alternatives. In this study, the criteria of cost, confidence, and adverse impacts on waste isolation were considered. The cost criterion was quite successful in discriminating between the reference case and each of the alternatives. The criteria was quantifiable and high-level estimates were developed based on the requirements concepts developed. Cost drivers were identified and additional attention will be placed on refining the specific requirements for these drivers. The criterion for confidence could not be quantified and a qualitative measure was attributed to each case. For the nominal alternative, all of the low frequency, coverage, and quantity requirements were grouped together. For the enhanced case, all the high frequency, coverage, and quantity requirements were assembled. Thus, the nominal case has less data collected, but it is not known whether the amount of data is sufficient in either case. But cost vs. qualitative confidence drivers were identified. The final criterion, impact on waste isolation, did not turn out to be a discriminator between the concepts.

In conclusion, it is recommended that specific requirements for the "nominal" case be established. These requirements will provide sufficient direction to complete a Viability Assessment design. Further development of the baseline in follow-on work is needed to develop a quantifiable measure of the confidence level. When this is completed, more meaningful cost/benefit analysis can be conducted along with refinement of the performance confirmation plan and development of associated specific performance confirmation requirements will be possible.

Regarding the requirement 6.4.2.D, on the number of surface-based boreholes, this requirement was a significant cost driver, so the nominal value of five was selected. The nominal value was considered a reasonable value by the team. The requirement will include at least five surface-based boreholes be provided. This specific value should be used for the Viability Assessment design, until different values are justified. Requirement 6.4.3.A is on the number and location of the underground fault zone monitoring. This requirement was a significant cost driver, so the nominal case was selected for the same reason as listed above. The requirement will include at least one alcove for monitoring the Ghost Dance Fault. Again, the specific value and location should be used for the Viability Assessment design, until different levels are justified. The requirement on the coverage and location of the thermal rock mass behavior is 6.4.4.A. This is the major cost driver and the logic for choosing the nominal case is the same as above. Requirement 6.7.5, on the number of permanent observation drifts, is directly related to 6.4.4.A, so it should also have the nominal case value. Requirement 6.7.1.B, on the number of rock core samples needed, did not to turn out to be cost driver and the capability to acquire the samples does not appear to be a significant design driver for the reference ground support system. Therefore, a specification of the number is not necessary for the Viability Assessment design. The number will remain TBD. There is concern and uncertainty regarding the ground support system and impacts on sample collection, so if the reference changes this assessment may need to be revised. Requirements 6.7.2 and 6.7.8.B are both related to remotely operated vehicle capabilities. The cost of this capability is a significant cost driver so the nominal frequency is used. Requirement 6.4.1.C, on mapping, did not turn out to be a cost driver, but depending upon the ground support system it could be a design driver. This requirement will not be further specified at this time, but Requirement 6.7.1.A insures mapping will occur even if the ground support system changes. Finally, Requirement 6.7.13, on the need for the follow-on heater test, is a major cost driver. Resolution of the issue is needed, but it is assumed that a favorable resolution is made and the test will not be required.

Given this assessment, the nominal set of requirements will provide the specific guidance needed for the Viability Assessment design regarding performance confirmation. As discussed above, some of the nominal set requirements did not need to be specified at this time. The final recommended requirements will reflect this assessment.

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8. STUDY CONCLUSIONS AND RECOMMENDATIONS

The primary objective of this study was to develop a technical basis for the recommendation of performance confirmation related updates to the requirements documents of the Yucca Mountain Site Characterization Project. The study emphasis was on identifying the key performance confirmation drivers for the Mined Geologic Disposal System (MGDS) design. The recommendations were to include concepts for measuring, monitoring, observing, and testing the key performance confirmation parameters whose data acquisition needs to be considered in the MGDS design and to identify locations, frequencies, and accuracies for the data acquisition.

8.1 CONCLUSIONS

The study used a systematic approach to develop its recommendations. This approach identified the applicable regulatory requirements and used them to formulate the recommended key performance confirmation activities. A structured and thorough process was performed to select the key parameters for performance confirmation. The list of key performance confirmation parameters provides the basis for the types of measurements and testing needed for performance confirmation. Requirements and concepts were developed to perform the measurements and testing. Specific requirements were developed for the design drivers. Alternative concepts were developed and evaluated in order to recommend the set of specific requirements.

These requirements, concept descriptions, and a draft performance confirmation plan (Appendix A) provide guidance for developing a performance confirmation program. This guidance is sufficient for incorporating performance confirmation requirements into the MGDS design for the Viability Assessment.

As part of this study, Scientific Programs and Waste Package Materials have provided input to Repository Design with respect to recommended performance confirmation activities. Repository Design can now proceed with designing MGDS facilities and features that incorporate these recommendations.

The U.S. Nuclear Regulatory Commission (NRC) has stated that it is not satisfied with the level of detail supplied in the *Site Characterization Plan* (SCP) (DOE 1988) regarding plans for the performance confirmation program. This study is the next step in the process to add additional detail and begin the development of a Performance Confirmation Plan. The timing of the study is consistent with the DOE's response that performance confirmation details would be developed in parallel with the Advanced Conceptual Design (ACD). After DOE approval of this report, the "NRC-DOE interaction" mentioned in the NRC SCP comments and DOE response would provide useful feedback from the NRC with respect to the NRC's expectations on details of the recommended performance confirmation program and, consequently, its compliance with 10 CFR 60, Subpart F.

Several foreign countries considering geologic disposal of radioactive waste will be developing performance confirmation or related pre- and postclosure monitoring programs in the future. Information exchange with respect to monitoring technology and experience is expected to be beneficial to both the Yucca Mountain Site Characterization Project and the foreign repository programs. International outreach by the Project is recommended in the 1994 findings and recommendations of the report to Congress by the National Waste Technical Review Board to the U.S. Congress and the Secretary of Energy (NWTRB 1995)

8.2 RECOMMENDED DESIGN REQUIREMENTS

It is recommended that the nominal alternative case should be used for the specific set of recommended requirements along with the general set of requirements as defined in Section 6. It is recommended that the design requirements be incorporated into the *Controlled Design Assumptions* (CDA) document (CRWMS M&O 1996c) as an initial set of performance confirmation-related requirements. It is also recommended that the work that evaluated the enhanced alternative case should be archived for potential future revisions to the design requirements and Performance Confirmation Plan.

Following are recommendations for specific MGDS design requirements. Requirements for performance confirmation concepts and parameters that do not affect MGDS design will be developed in the future.

A. Repository design and operation shall provide facilities, access, instrumentation, recording, maintenance, and support for measuring/monitoring the performance confirmation parameters identified in Appendix D.

B. The performance confirmation monitoring and measuring system shall have a maintainable service life of 125 years (100 years plus the duration of initial construction plus the duration of final closure plus any time period during site characterization for which the system must be operable). Specific equipment and components shall have maintainable service lives dependent upon their identified function. These service lives are (TBD).

C. Planning of Repository design and operations for performance confirmation test facilities and support shall consider the performance confirmation concepts identified in Section 5 as a point of departure.

D. The performance confirmation system shall be planned to permit availability of (TBD) percent.

E. Test locations/environments, samples, and specimens, on-site and off-site, shall be representative of the Repository environments and design elements.

F. Performance confirmation staff, measurement and monitoring hardware and software, shall be available to support the variable demand for analysis, assessment, and periodic reporting throughout the Performance Confirmation Program.

G. At least five surface-based boreholes shall be provided for monitoring unsaturated zone hydrology and shall avoid underground excavations.

H. At least one alcove shall be provided for testing and monitoring the Ghost Dance Fault prior to and following waste emplacement.

I. Monitoring of at least two percent of the thermal rock mass behavior shall be performed with a portion of the rock mass monitored near the first emplacement drifts to contain waste.

J. The Repository Subsurface Facilities shall provide underground openings (drifts, alcoves, boreholes, and ancillary excavations), access, data acquisition, and test support to implement performance confirmation monitoring and test recommendations including interface and coordination with Site Investigation Testing, Repository Testing, Waste Package Testing, and Surface Support. These operations are to include, but are not to be limited to, capabilities for:

1. Any ground support system (i.e., shotcrete or concrete) that covers the emplacement drift rock wall surface shall not be installed until after any necessary rock mapping is complete.

2. (TBD) samples of rock core shall be acquired following emplacement drift excavation.

3. Placement and recovery of material coupons or specimens in the emplacement drift or other underground locations shall be performed at least once every ten years.

4. Recovery of selected waste packages shall be performed on a non-routine basis, for malfunctioning waste packages or as required.

5. The design, excavation, and ground support of emplacement drifts shall permit installation of and access to test/monitoring instrumentation, and observation drift instrumentation, and provide access for remotely operated vehicles or mobile inspection platforms to obtain measurements.

6. Excavation of at least one permanent observation drift above the repository horizon shall be developed in support of thermal monitoring.

7. At least one alcove shall be prepared for underground monitoring of seismic activities.

8. The air temperature, relative humidity, and gaseous radioactive emissions of all emplacement drifts shall be monitored through the drift ventilation.

9. The ventilation monitoring system shall be capable of identifying the specific drifts that are sources of gaseous radioactive emissions, if any, within (TBD) hours of detection of such emission.

10. The provision and use of remotely operated vehicles or movable inspection platform for monitoring emplacement drift environments and effects shall be considered in support of the following requirements:

a. Personnel access into emplacement drifts shall not be permitted except for emergencies.

b. Remote inspections of emplacement drifts at least once every ten years shall be performed to monitor rockfall, and visually inspect and thermally image waste packages.

11. Subsurface facilities operations shall have a program to inspect for ground-water inflow and, if detected, for measuring ground-water inflow quantities, temperature, and chemical composition via direct measurement for all underground openings except emplacement drifts direct measurement during construction and prior to waste emplacement for emplacement drifts and indirect or remote measurement in emplacement drifts after waste emplacement.

12. Emplacement drift diameter changes shall be monitored periodically to track excavation convergence. These measurements are required:

a. In Permanent Observation Drifts, and may be monitored directly or remotely.

b. In selected drifts, as indicated by rockfall activities.

13. Alcoves or drifts shall be provided to support backfill performance and constructability experiments and tests, if backfill is required.

14. Alcoves shall be provided to support seal performance and constructability tests.

15. Subsurface Facilities shall provide facilities and test support as required by Site Investigation Thermal Testing to characterize and monitor thermal interaction effects while heating and while cooling and as required by Waste Package Testing for materials in situ tests.

K. The Repository Surface Facilities shall have the capability to support Performance Confirmation surface operations, equipment, and tests including, but not limited to:

1. The capability to receive, handle, store, examine, test, and return to the underground waste packages, material coupons, and other specimens recovered from underground emplacement. This capability is to be exercised on a non-routine basis, for malfunctioning radioactive waste packages, if any.

2. Handling to include transferring and opening the disposal container and canistered and uncanistered waste forms, removing of samples, and repackaging, resealing, and decontaminating the disposal container.

3. The capability for routine and non-routine non-destructive testing of sealed or resealed waste packages prior to emplacement or after recovery.

4. The capability to receive, decontaminate, manage, temporarily store, and ship material coupons or specimens, retrieved from the emplacement drift, for off-site testing.

5. The capability to receive, manage, temporarily store, and ship rock samples for off-site testing.

6. The capability to transfer, automatically acquire, record, process, and communicate instrumentation data from surface and subsurface monitoring equipment and tests.

7. The capability to support and protect continuous and periodic surface monitoring and tests, operations.

8. The facilities and equipment to support Performance Confirmation operations such as test monitoring and control, data processing, record management and communication, limited laboratory tests, analysis and evaluations.

8.3 OTHER RECOMMENDATIONS

Following is a summary of recommendations stated in the body of the report that do not entail MGDS design requirements.

Adequacy of License Application Data. The selection of performance confirmation parameters assumed that sufficient data will be collected for many parameters during site characterization so that additional data collection, including performance confirmation, will not be necessary for them after the submittal of the License Application. This assumption may not be correct for some parameters because of uncertainties with respect to details of the site characterization program between now and the License Application. Consequently, this assumption may need to be checked annually for the affected parameters. If this assumption is not correct anymore for some of the parameters, they may need to be added to the Performance Confirmation Program.

Baseline Development. The identified performance confirmation parameters are recommended for confirmation and for baseline development. Baseline development will require a number of related activities, including the definition of technical performance measures, a determination of importance evaluation to identify performance requirements and controls for structures, systems and components important to waste isolation, total system performance assessment sensitivity studies to calculate expected values and uncertainties for the parameters, and establishing a confidence goal or policy guidance for performance confirmation measurements and testing (e.g., repository closure criteria).

Concept and Requirement Development. The performance confirmation concepts and requirements developed in this study concentrate on MGDS design requirements arising from the key performance confirmation parameters. Performance confirmation concepts and requirements need to be developed yet for the other performance confirmation parameters. Additional requirements may be needed for the key performance confirmation parameters for other project activities that do not drive MGDS design, including for surface-based measurements and testing.

Functional Analysis Correlation. The *MGDS Functional Analysis Document* (FAD) (CRWMS M&O 1996i) identifies the functions that have to be addressed to demonstrate compliance with the postclosure performance requirements of 10 CFR Part 60. Correlating the performance confirmation activities with the FAD functions would demonstrate to what extent the performance confirmation program satisfies the data and performance requirements for these functions.

Performance Confirmation Plan. Completion of a Performance Confirmation Plan is recommended, with special focus on near-term activities. This Plan should include more detail with respect to the costs of confirming each parameter and the benefits to be gained. It should be more specific with respect to locations, frequency, and accuracy expected for the data acquisition of each parameter than was addressed by the current study. Following approval of the Plan, Project participants could start preparing for its implementation.

9. REFERENCES, CODES, AND STANDARDS

Section 9.1 contains the references cited in the report. Codes and Standards are listed in Section 9.2. Procedures are listed in Section 9.3.

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APPENDIX A

DRAFT PERFORMANCE CONFIRMATION PLAN

PREFACE

This appendix contains the first draft of the Performance Confirmation Program Plan. The purpose of this plan is to provide an overview of the performance confirmation approach, performance confirmation objectives, and organizational responsibilities. The plan will also contain schedules for performance confirmation activities and a performance confirmation concept of operations. The draft version of the plan contained in this appendix contains text proposed for the plan as well as annotations for necessary text in sections where the text is not yet available.

DRAFT

WBS:
SCPB:
QA:
Title Page:

Civilian Radioactive Waste Management System
Management and Operating Contractor

Performance Confirmation Plan
Draft

Document Identifier Number
XXXXXXXXX-XXXXX-XXXX-XXXXX

August 30, 1996

Prepared for:

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Under Contract Number
DE-AC01-91RW00134

DRAFT

DRAFT PERFORMANCE CONFIRMATION PLAN

EXECUTIVE SUMMARY

This Performance Confirmation Plan defines the test and evaluation program for confirming the confinement and waste isolation performance of the Mined Geologic Disposal System.

The Performance Confirmation Plan establishes monitoring, test and analysis requirements in the form of scope sheets which provide, for each test or analysis, a brief description of objectives, responsibilities, and requirements for facilities, equipment, data acquisition, evaluation, and reporting.

This document is to be used as a basis for detailed planning of the Performance Confirmation system and is to be integrated with the Development Test and Evaluation and Operational Test and Evaluation of the Mined Geologic Disposal System, in accordance with the *Office of Civilian Radioactive Waste Management Test and Evaluation Master Plan* (DOE 1995a).

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CONTENTS

CONTENTS (Continued)

CONTENTS (Continued)

LIST OF FIGURES

1. PERFORMANCE CONFIRMATION PROGRAM

This section introduces the Performance Confirmation (PC) Program and defines the PC System objectives, responsibilities, concept of operation, and schedule.

1.1 INTRODUCTION

1.1.1 Purpose

The Performance Confirmation Plan (PCP) specifies monitoring, test and analysis requirements necessary to confirm that Mined Geologic Disposal System (MGDS) expected, long-term waste confinement and isolation performance objectives will be met prior to permanent closure. The scope of tests and analyses are defined (a) to ensure integration with MGDS design and with Development Test and Evaluation (DT&E) and Operational Test and Evaluation (OT&E) planning, and (b) to provide a basis for detailed Test and Evaluation (T&E) planning.

1.1.2 Scope

The PCP establishes test and analysis requirements in the form of scope sheets which provide a brief description of objectives, responsibilities and requirements for facilities, equipment data acquisition, evaluation and reporting for each test or analysis. The T&E covered include process modeling, performance predictions, site monitoring and test, waste package monitoring and test, repository monitoring and test, test data analysis, evaluation, and performance assessment.

1.1.3 Application

This document is to be used as input to detailed planning of PC testing. The Contractor/M&O organizations identified as Responsible Organization, Performing Organization, and Supporting Organization are responsible for compliance with the scope sheets described in Section 1.1.10 and compiled in Section 4 of this PCP.

1.1.4 Revisions

This plan will be updated as required until final approval and submission as part of the License Application (LA) to the Nuclear Regulatory Commission (NRC). The plan however, will not be revised as a result of detailed planning of the tests or analyses/evaluations.

1.1.5 CRWMS Overview

[Provide a very brief description of the CRWMS]

1.1.6 MGDS Overview

[Provide a brief description of MGDS. Include Figure showing phases and operations

1.1.7 MGDS Test and Evaluation Program

The MGDS T&E Program tests and evaluates the design, development and operational performance of the repository for the purposes of verifying design requirements and specifications, evaluating compliance with government regulations, and assessing environmental impact.

The T&E Program includes developmental, operational, and performance confirmation T&E. The program interfaces with all MGDS functions, beginning with Site Characterization and ending with Closure. It is also part of the overall Program T&E as specified in the Office of Civilian Radioactive Waste Management (OCRWM) T&E Master Plan.

1.1.7.1 Development Test and Evaluation

The MGDS DT&E Program tests and evaluates the design and development performance of the repository for the purpose of verifying design requirements and specifications and evaluating compliance with government regulations. DT&E tests and analyses include design development and qualification tests, demonstrations, analyses, assessments, and predictions–all preceding full repository operations.

1.1.7.2 Operations Test and Evaluation

The MGDS OT&E Program tests and evaluates the operational performance of the repository, its compliance with government regulations and its impact on the environment while operational. It includes system and subsystem tests and analyses beginning with the authorization to construct the repository and ending when all operational requirements have successfully been met.

1.1.7.3 Performance Confirmation

The MGDS PC Program tests and evaluates the repository natural and engineered barrier systems' post closure waste confinement and isolation performance. It relies on in situ monitoring, field and laboratory tests, and experiments to collect data during repository construction and operation, which are used to confirm predictions, evaluate pre-closure performance, and recommend corrective actions or repository closure. Analytical models and processes are utilized in the prediction and evolution processes.

1.1.8 PC Program Objectives

The PC Program objectives are:

A. Confirmation that subsurface conditions encountered and changes in those conditions during construction and waste emplacement operations are within the limits assumed in the licensing process;

B. Confirmation that natural and engineered systems and components that are required for repository operations, or that are assumed to operate as barriers after permanent closure, are functioning as intended and anticipated (10 CFR 60.140). These components specifically include the waste package, drift backfill and borehole seals;

C. Evaluation of compliance with regulatory and license requirements, related to post closure performance requirements.

D. Evaluation of the repository readiness for permanent closure.

1.1.9 MGDS Post-Closure Critical Performance Measures

[List top-level (critical) objectives/requirements for waste confinement and isolation (e.g., exposure limits, thermal loading, periods of performance, etc.) that must be met and confirmed by PC T&E]

1.1.10 Test/Analysis Scope Sheet Description

Test/Analysis Scope Sheets [used to define the scope of each test or analysis] are compiled in Sections 4 and 5 of this plan. *[Figure 1 will provide an example of a test scope sheet with annotated entries.]*

1.1.11 PCP Organization

[Describe the structure of the document and list the contents of the various sections]

1.1.12 Quality Assurance

[Discuss applicable QA requirements]

TEST/ANALYSIS SCOPE SHEET
(Annotated Outline)

ID #:

TITLE: *Descriptive Title for Test or Analysis*

RESPONSIBLE ORG.:

PERFORMING ORG.:

SUPPORTING ORGs:

TEST/ANALYSIS LOCATION:

A. TEST/ANALYSIS DESCRIPTION:

B. TEST/ANALYSIS OBJECTIVES:

C. TEST/ANALYSIS CONSTRAINTS:

D. PRETEST& SCHEDULE REQUIREMENTS:

E. TEST HW/SW/FACILITIES REQUIREMENTS:

F. DATA ACQUISITION REQUIREMENTS:

G. TEST/ANALYSIS/ASSESSMENTS REPORTS

Figure 1. Test/Analysis Scope Sheet Description

1.2 PERFORMANCE CONFIRMATION PROGRAM SUMMARY

1.2.1 PC Approach

The MGDS PC Approach may be described as follows:

A. Define a PC baseline which identifies and documents (1) critical performance measures for waste confinement and isolation, (2) key performance confirmation parameters to be monitored, and (3) key analytical processes models and performance assessment models that are used to predict and evaluate performance. The PC baseline is to be documented as part of the license application.

B. Predict pre-closure values and variations of critical performance measures and key PC parameters. The predictions are to be provided as part of the license application.

C. Establish, for the licensing process:

   1. Tolerances or acceptable limits of deviations from predicted performance. These include acceptable ranges of key parameter values, regulatory limits and model validity or credibility limits.

   2. Criteria and guidelines for recommended corrective actions, to be taken if tolerances are exceeded.

(It is noted that steps A, B, and C above, require model development, computations, sensitivity analyses, and periodic total performance assessments.)

D. Monitor performance, perform tests and collect data.

E. Analyze and evaluate data including process model validation, analysis, statistical tests and total performance assessment. The analysis and evaluation is to address (1) changes with respect to site characterization data, and license application data as a result of construction, waste emplacement and operation, (2) deviation from predicted performance, and (3) regulatory compliance.

F. Recommend and implement corrective actions, continued operation or permanent closure.

Figure 2 summarizes the PC approach.

1.2.2 Key Performance Parameters

[Brief description of performance confirmation parameters]

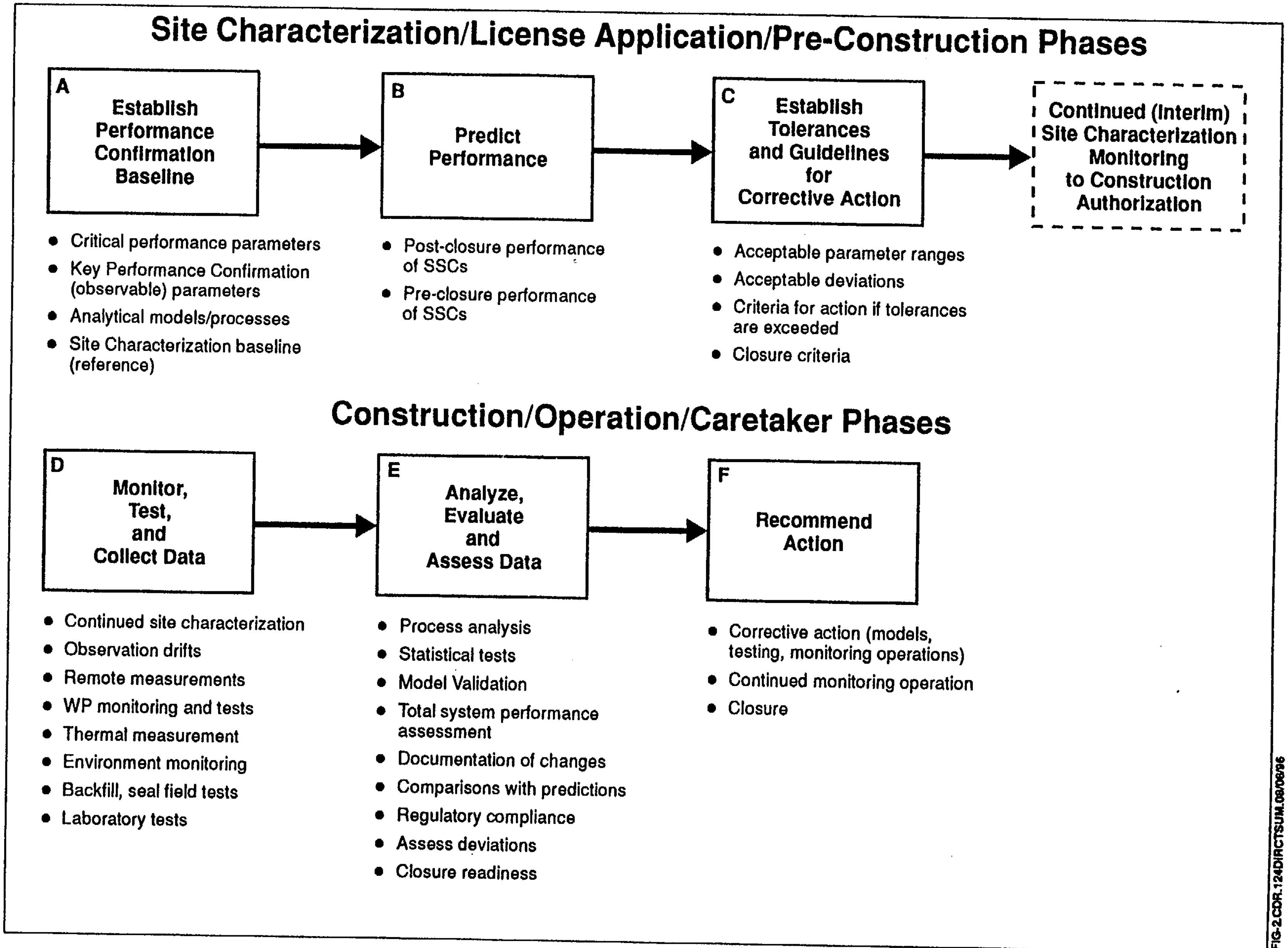

Figure 2. MGDS Performance Confirmation Approach

1.2.3 Process Abstractions and TSPA Models

[Describe the relationship, between data, process models, and process model abstractions. Identify the data flow, and provide a model listing and description of each model]

1.2.4 Requirements Development

PC requirements have and will continue to be established based on applicable regulations and as a result, the requirements will focus on (a) non-exceedance of critical performance measures, (b) continued site measurements remaining with ranges that were documented based on site characterization, and (c) optimization of the number of measurements to achieve a required degree of confidence, while minimizing cost. The PC requirements are compiled in Section 2.2.

1.2.5 Monitoring, Test and Data Acquisition/Concepts

Figure 3 shows preliminary lists of Test and Data Acquisition Concepts. *[Provide reference to concept descriptions]*

1.2.6 Test and Evaluation Facilities

The facilities that support PC T&E operations include:

A. Subsurface Data Acquisition Facilities. These include emplacement drifts, observation drifts, test and instrumentation alcoves, boreholes, etc.

B. Surface Support Facilities. These include surface facilities for data acquisition and computers, offices, laboratory, sample storage, a multi-purpose hot cell for destructive testing of recovered waste packages and surface test and monitoring station.

C. Off-site Laboratories

1.2.7 Test Equipment and Instrumentation

Test support equipment that will be used in PC data acquisition include:

A. The Performance Assessment computing hardware and software.

B. Site Investigation and Repository equipment and instrumentation. These include equipment for geologic mapping, fault monitoring, and underground and surface environmental measurements.

C. The data acquisition system including sensor, data communicator, control and processing.

SITE MONITORING

- Subsurface Mapping
- Rock Sampling
- Laboratory Testing
- Subsurface UZ Borehole Hydrology
- Subsurface Fault Zone Hydrology
- Emplacement Drift-Thermal
- Multi Drift Heater Test
- Visual Inspection

REPOSITORY SUBSURFACE MEASUREMENTS

- Backfill Constructability
- Heated Backfill Small Scale Test
- Borehole Seal Test
- Underground Seismic Monitoring
- Rockfall Monitoring
- Convergence Measurement
- Emplacement Drift Ventilation
- Radiation

REPOSITORY SUBSURFACE DATA ACQUISITION

- Permanent Observation Drifts
- Emplacement Drift Ventilation
- Recovery of WPs
- Recovery of Dummy WPs
- Recovery of Material Specimen
- Remotely Operated Vehicle (ROV) Inspection Systems
  - Gantry Rail-Based
  - Mini-Rover Based
  - Overhead Monorail Based
- Sample Handling and Management
- Date Handling
- Seismic Alcove
- Fault Monitoring Alcove
- Heater Test Alcove
- Backfill Thermal and Constructability Alcove
- Seal Testing Alcove

WASTE PACKAGE (WP) TESTING

- Off-Site Material Laboratory
- In-Situ WP Monitoring
- Non Destructive WP
- Recovered WP Destructive Testing
- WP with Simulated Heat Source
- WP Material Specimen

REPOSITORY SURFACE SUPPORT

- Multi-Purpose Hot Cell for Recovered Radioactive WP and Simulated WP Testing
- PC Support Building
  - Sample Storage
  - Sample Handling and Management
  - Instrumentation Lab
- Data Acquisition and Management
- Surface-Based Boreholes
- Surface-Based Seismic and Environment

FIG-3.CDR.124DIRCYSUM.08/08/96

Figure 3. Performance Confirmation Preliminary Test and Data Acquisition Concepts

D. Surface support equipment including waste package handling equipment, for destructive as well as undestructive testing. In general, the instrumentation is required to support 100 years of testing and will be designed to be retrievable for protection and monitoring.

1.2.8 PC Program Flow

Figure 4 is a flow diagram of PC Operations. The operations are discussed in detail in Section 3.

1.2.9 PC Activities and MGDS Phases of Operations

Figure 5 lists PC activities that are performed during the phases of MGDS operation.

1.3 PC PLANNING AND DESIGN

The integration of PC planning and design with MGDS design, DT&E and OT&E is of major importance. It is expected to impact the completion of this plan as well as detailed PC test/analysis planning. The implication of these requirements is that the design and operation of the PC system must be planned and designed for as an integral part of MGDS design and operation.

Since PC must also be planned in accordance with DT&E and OT&E, it is also to be expected that PC design cannot be finalized without input from the *Test and Evaluation Master Plan* and coordination with DT&E and OT&E planning.

1.4 PC PROGRAM MANAGEMENT AND ORGANIZATIONAL RESPONSIBILITIES

[Describe roles and responsibilities of the various organizations participating in the program]

1.4.1 DOE/OCRWM

1.4.2 YMSCO

1.4.3 M&O Organizations

1.4.4 The NRC

1.4.5 The NWTRB

1.4.6 IAEA

1.4.7 Other Organizations

1.5 PROGRAM SCHEDULE

Two schedules are provided to show the timing for phasing site characterization

Performance Confirmation (PC) Program Flow

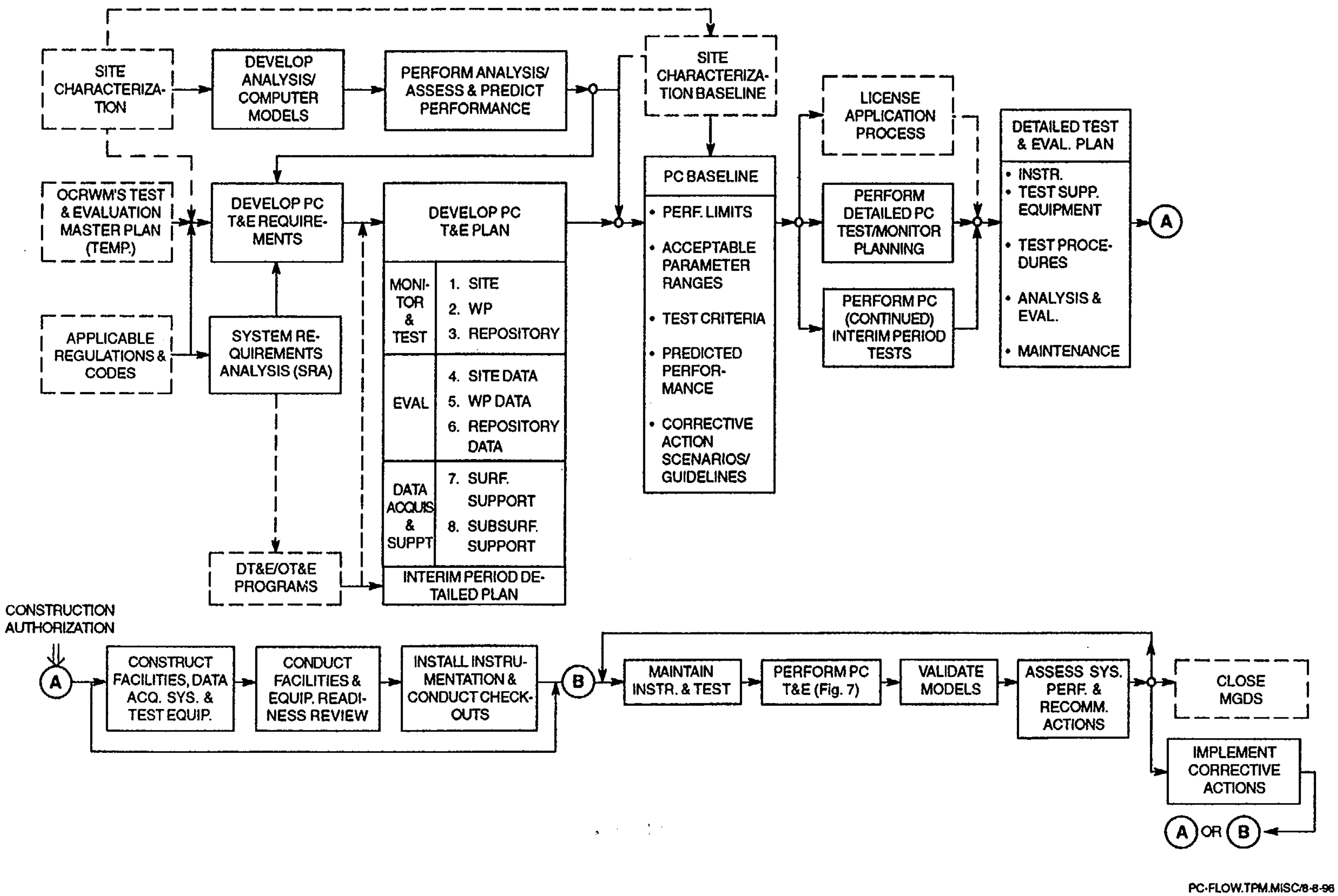

Figure 4. Performance Confirmation Program Flow

Site Characterization (SC)	Interim Period	Initial Construction	Waste Emplacement	Caretaker	Closure
Collect Relevant SC Data Develop Models and Processes Perform Analyses and Total System Performance Assessment Identify Critical Performance Measures Identify Key Parameters Develop Requirements Define and Develop PCC Baseline for LA Develop and Implement Performance Confirmation Plan (PCP) (including Org. Structure) Design PC Systems	Continue Selected Monitoring Perform Detailed Planning for Initial Construction Period Update Planning as Required by LA Process	Update/Revise Planning Perform Geological Mappng and Fan H Monitoring Acquire Site Identify/Report Constructino Impact Perform Operational Demonstrations Update Models and Predictions Construct and Equip at Leaste One Observation Drift and one Instrumented Emplacement Drift	Update/Revise PCP Continue Construction Tests and Data Acquisition Expand Monitoring and Tests Per Plan Acquire and Communicate Test Data Perofrm Field Tests and Experiments Perform Laboratory Tests Perform Test Data Analyses and Cmopare With Predictions Validate Models Assess Performance and report Recommend and Implement Corrective Actions Update Models and Predictions	Maintain the PC System Contnue Emplacement Period, Selected Tests, Monitoring and Related evaluation Assessment and Reporting Tasks Check Closure Criteria Plan Test and Monitoring During Closure and Post-Closure Period, if Required	Deactivate PC System Implement Closure and Post-Closure Monitoring, if Required

Figure 5. Phases of Performance Confirmation Flow

activities into performance confirmation activities. The first schedule, Figure 6, separates the complete set of testing activities into three categories. The first category consists of those tests conducted as part of the site characterization program in order to support the development of a waste isolation reasonable assurance argument and the development of the performance confirmation baseline. This category is shown to be ongoing and will phase out as the development of the performance confirmation becomes complete. The second category consists of other testing, including site characterization testing in support of a site recommendation, testing to show conformance of the design to the requirements, preclosure safety testing, etc. This category of tests is also ongoing, and certain aspects of this testing activity are expected to continue through the waste emplacement time period. The third category consists of testing conducted in support of the performance confirmation program. This activity is shown to begin at the time of Viability Assessment, prior to the end of site characterization, and phases into a full program at about the time of License Application. The second schedule, Figure 7, provides a top level view of the data flow between the waste isolation reasonable assurance testing, the performance confirmation testing activities, total system performance assessment, and the activities required to plan and develop the performance confirmation program.

Schedules will be further developed as more information becomes available.

Transition to Performance Confirmation Program Testing

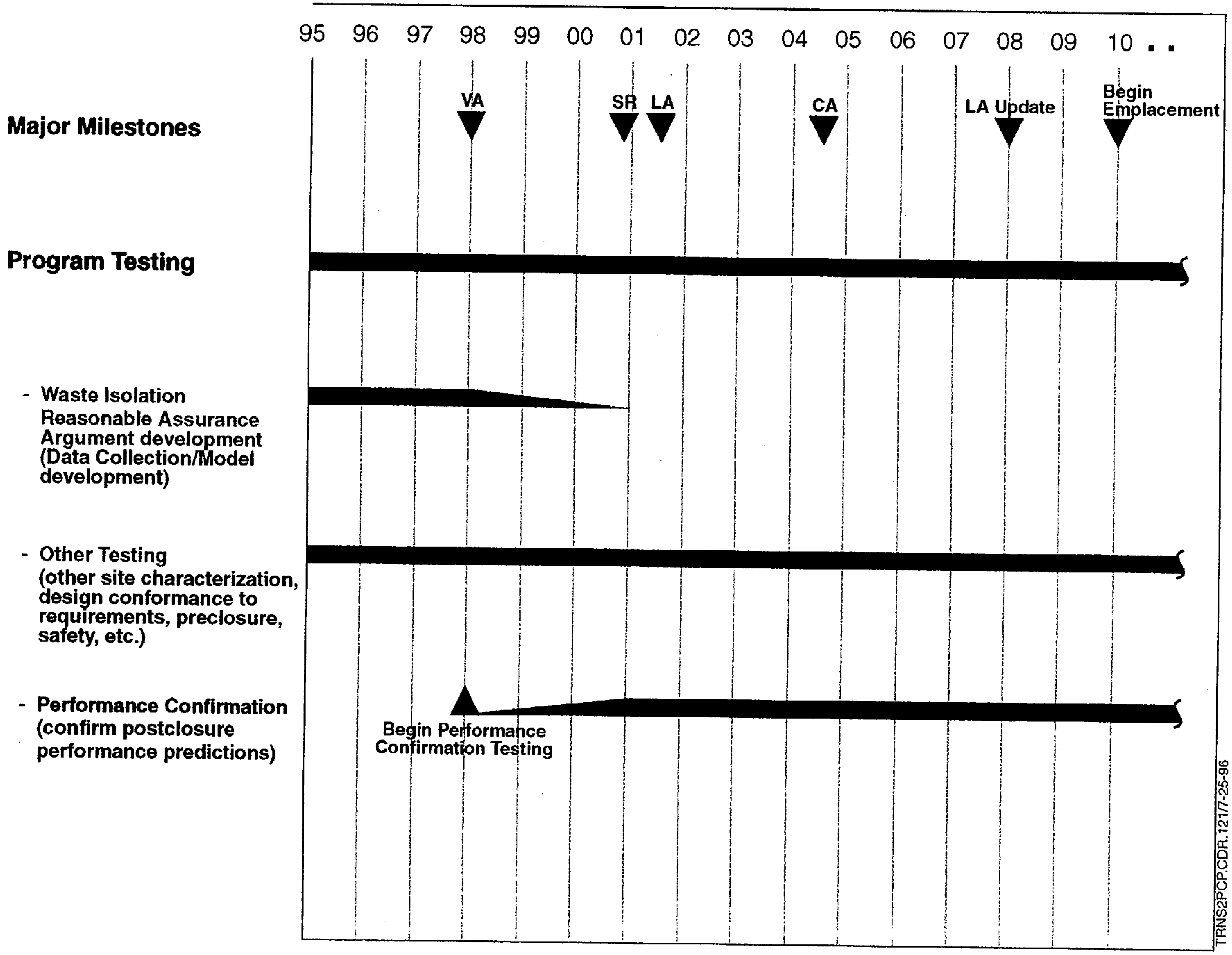

Figure 6. Transition to Performance Confirmation Program Testing

Development and Conduct Approach Performance Confirmation Program

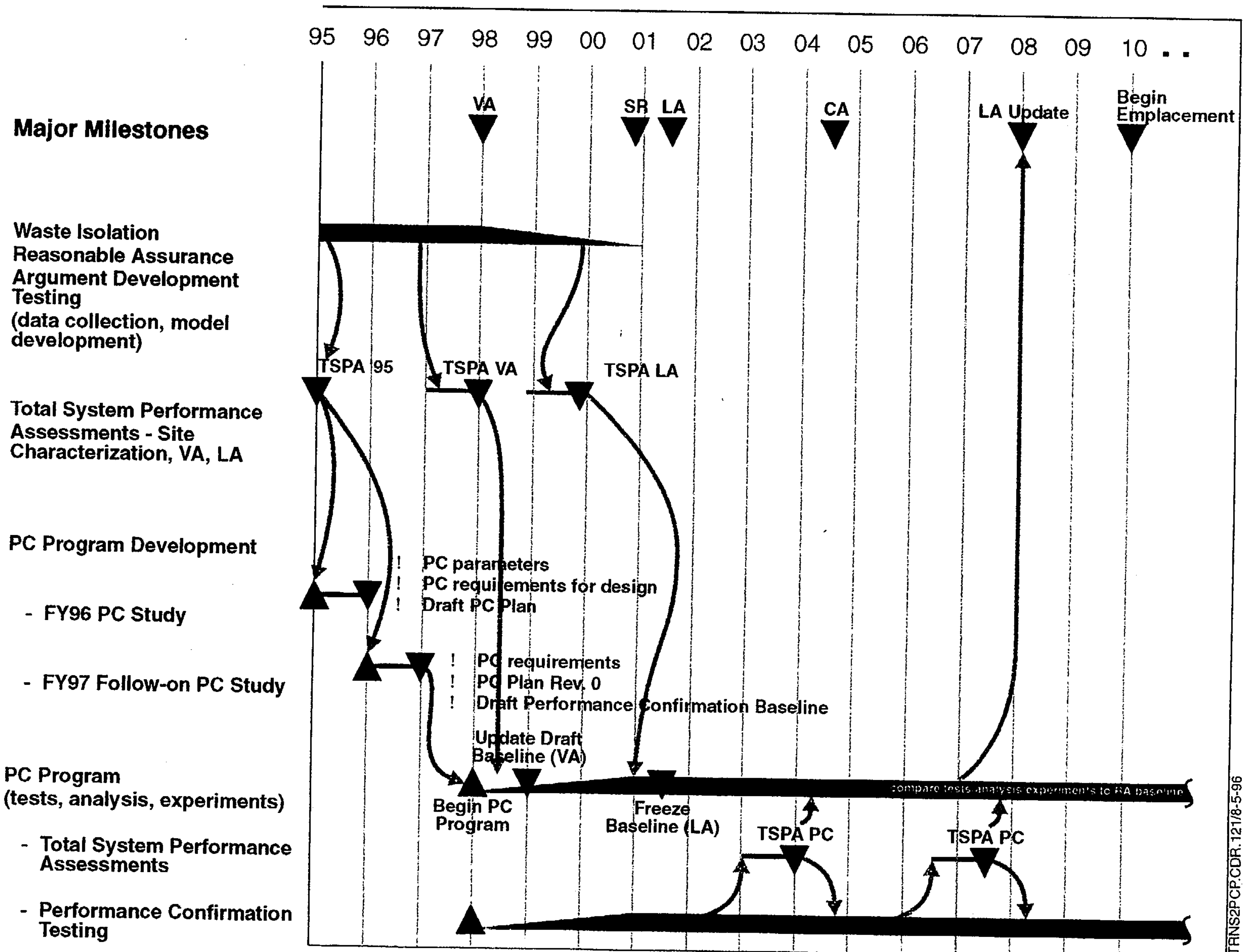

Figure 7. Development and Conduct Approach Performance Confirmation Program

2. FUNCTIONS, REQUIREMENTS AND T&E CONCEPTS

2.1 FUNCTIONS

[Include corresponding sections from the PC Study Report.
Include functional flows from recent MGDS Functional Analysis]

Figure 7.

2.2 REQUIREMENTS

[Include corresponding sections from the PC Study Report.
List all requirements - relate to the SRA Process.
Note that all tests and analyses will be traced to the requirements.
Provide Test/Analysis and Requirements Traceability.]

2.3 PROCESS, ABSTRACTIONS AND TOTAL PERFORMANCE ASSESSMENT MODELS

[Include corresponding sections from PC Study Report.
Include table identifying models, their characteristics and relationships.
Provide PC Model Description.]

2.4 PARAMETERS AND TECHNICAL DATA SUMMARY

[Include corresponding sections from the PC Study Report.
Include tables relating parameters to functions and models.
Add table showing acceptable parameter values when available.
Provide PC key parameter definitions.]

2.5 TEST AND EVALUATION CONCEPTS

[Include corresponding sections from PC Study Report.

PERFORMANCE CONFIRMATION TEST & EVALUATION FUNCTIONS

Performance Confirmation

Test Functions

Measure Natural Environments
- CLIMATIC EFFECTS
  - -Precipitation
  - -Wind
  - -Temperature
- NATURAL PROCESSES
  - -Erosion
  - -Tectonics
  - -Volcanism
- HUMAN POPULATION
  - -Access
  - -Economics
- SITE GEOLOGY
- SITE HYDROLOGY
- SITE GEOCHEMISTRY

Measure Induced Environments
- THERMAL
  - -Rock Temp
  - -Air Temp
  - -WP Temp
  - -Humidity
- THERMO-HYDRO
  - -Water Inflow
  - -Water Outflow
  - -Moisture Content
- STRUCTURAL/MECH.
  - -Rockfall
  - -Convergence
  - -Strain/Stress
  - -Seismic
- THERMO-CHEMICAL
- RADIATION

Measure Effects on Design Elements
- WASTE PACKAGE
  - -Disposal Container
  - -Emplacement Car
  - -Empl. Drift Backfill
  - -Invert
- EMPL DRIFT CONSTRUCTION
  - -Metal
  - -Concrete
  - -Rockbolt
- ACCESS DRIFT BACKFILL
- SEALS

Evaluation Functions

Evaluate WP Performance
- WASTE STABILITY
  - - Internal Criticality
  - - Internal Mobilization
- WASTE CONTAINMENT
  - -Structure Integrity
  - -Material Integrity

Evaluate EB Effectiveness
- RN TRANSPORT
  - -Water Out Flow/EB
  - -Colloid Effects
  - -Sorbing/EB
  - -RN Concentration
- EXTERNAL CRITICALITY
- EXTERNAL MOBILIZ
  - -Waste Dissolution
  - -Waste Oxidation

Evaluate NB Effectiveness
- UNSATURATED ZONE
  - -Sorbing/UZ
  - -Dilution/UZ
  - - Time for Decay/UZ
- SATURATED ZONE
  - -Sorbing/SZ
  - -Dilution/SZ
  - -Time for Decay/SZ
- GASEOUS RELEASE
- DOSE POTENTIAL

Evaluate Human Intrusion
- ACCESS CONTROL
- ECON. DESIRABILITY

Evaluate Natural & Induced Envir. Effects
- ROCKFALL & CONVERGENCE
- FAST PATHWAYS TO EB
- EXPOS. OF WASTE
- WATER FLOW INTO EB
- VENTILATION EFFECTS
- THERMAL IMPACT TO ENVIR
- INDUCED MATERIAL EFFECTS

Figure 8. Performance Confirmation Test and Evaluation Functions

3. CONCEPTS OF OPERATION

[Reintroduce the program and the flow diagram from Section 1. Explain that this section will provide details on the operations included in that flow.]

3.1 PC BASELINE DEFINITION

[Describe what constitutes the PC Baseline. Address all PC Baseline Elements in detail.]

3.1.1 Critical Performance Measures and Limits

3.1.2 Acceptable Parameters Ranges

3.1.3 Test Criteria

3.1.4 Predicted Performance

3.1.5 Corrective Action Scenarios and Guidelines

3.1.6 Closure Criteria

3.2 PERFORMANCE MODELING AND ASSESSMENT

[Describe Process, Abstract and TSPA model development updates and relationships to Site Characterization Data and to future monitoring data.
Describe HW and SW sequence of operations.
State how the evaluation will be used to support (a) requirement development, and (b) PC baseline definition (See Section 3.1).]

3.3 TEST AND EVALUATION ELEMENTS

[Explain that testing is basically performed to satisfy evaluation requirements.
Explain that the actual test and evaluation scope and requirements are described in the scope sheets of Section 4 and 5. Include a summary, preferably a table listing the Tests/Analysis and their objective, location and brief description in each of the following subsection.]

3.3.1 Site Monitoring and Tests

[Subsurface and Surface]

3.3.2 Waste Package Monitoring and Tests

3.3.3 Repository Monitoring and Tests

3.3.4 Site Data Evaluation

3.3.5 WP Data Evaluation

3.3.6 Repository Data Evaluation

3.3.7 Total Performance Assessment

3.3.8 Subsurface Data Acquisition/Support

3.3.9 Surface Data Acquisition/Support

3.3.10 Operation and Management Plan

3.4 INTERIM PERIOD T&E

3.5 RELATIONSHIP/COORDINATION/INTEGRATION WITH DT&E/OT&E

3.6 DETAILED TEST AND EVALUATION PLANNING

[Explain the functions of detailed test planning to analyze the requirements specified in the PCP and translate into concrete actions including requirement specification and test procedures.]

3.6.1 Test Management

3.6.2 Test/Analysis Configuration and/or Model Assumptions

3.6.3 Test Operation/Conduct Plan and Schedule

3.6.4 Instrumentation and Data Acquisition Specifications/Design

3.6.5 Facilities and Test Support Equipment Specifications/Design

3.6.6 Evaluation Procedures

3.6.7 Data Communication and Reporting

3.6.8 Maintenance Plan

3.7 TOTAL SYSTEM ASSESSMENT

3.7.1 Compliance Evaluation

3.7.2 Prediction Confirmation

3.7.3 Model Validation

3.7.4 Trend Detection

3.7.5 Recommended Corrective Actions

3.7.6 Corrective Action Implementation

3.7.7 PC Baseline Change/Control

3.8 REPORTING

3.9 TRAINING

3.10 QUALITY CONTROL

4. T&E SCOPE AND REQUIREMENTS

[Scope sheet compilation. A table of contents preceding each section. A flow chart showing test sequence and relationship.]

4.1 SITE MONITORING AND TESTS SCOPE SHEETS

[Subsurface and Surface]

4.2 WASTE PACKAGE MONITORING AND TESTS SCOPE SHEETS

4.3 REPOSITORY MONITORING AND TESTS SCOPE SHEETS

4.4 SITE DATA EVALUATION SCOPE SHEETS

4.5 WP DATA EVALUATION SCOPE SHEETS

4.6 REPOSITORY DATA EVALUATION SCOPE SHEETS

4.7 TOTAL PERFORMANCE ASSESSMENT SCOPE SHEETS

4.8 SUBSURFACE DATA ACQUISITION/SUPPORT SCOPE SHEETS

4.9 SURFACE DATA ACQUISITION/SUPPORT SCOPE SHEETS

4.10 OPERATION AND MANAGEMENT PLAN SCOPE SHEETS

5. INTERIM PERIOD T&E SCOPE AND REQUIREMENTS

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APPENDIX B

CANDIDATE PERFORMANCE CONFIRMATION PARAMETER MATRICES

CANDIDATE PERFORMANCE CONFIRMATION PARAMETER MATRICES

This appendix contains five matrices that list all parameters that have relevance for postclosure performance assessments. They represent characteristics of the natural and engineered barrier systems and regulatory requirements. Parameter values are obtained from site characterization, MGDS design, and postclosure performance assessments. The parameters were identified on the basis of the experience of the performance confirmation team members and the use of various reference documents, including the YMP Reference Information Base (DOE 1993), the Total System Performance Assessment - 1995 (TSPA - 1995) report (CRWMS M&O 1995), and the MGDS advanced conceptual design report (CRWMS M&O 1996). The matrices list 435 parameters. The actual number of parameters is greater because some parameters require several separate measurements; for instance, geochemical compositions require the analysis of several cations and anions and a few additional characteristics.

Because of the large number of parameters, they are listed in five separate matrices in accordance with the major subsystems of the natural and engineered barrier system:

1. general site parameters,
2. saturated zone parameters,
3. unsaturated zone parameters,
4. repository excavation and borehole parameters, and
5. waste package parameters.

The parameters are listed in the first column of each matrix. The other columns show which major category of performance assessment process modeling requires them as input or produces them as output. Each of these columns may represent several detailed, including coupled, processes. For instance, unsaturated hydrology includes ground-water flow modeling and coupled heat and multiphase fluid flow modeling, including liquid water, water vapor/steam, air, and gases (see the descriptions of the processes in Section 4.2 of the report).

The name of a parameter and other column entries are shown in bold type if a parameter is considered important for performance assessment modeling of a particular process, based on past modeling experience. This qualitative designation is used as one of the criteria for selecting performance confirmation parameters (see Appendix C).

Within each matrix, the parameters are organized by category. For instance, the saturated zone parameter matrix includes the categories alluvium/colluvium and rock matrix, rock fracture zones (including faults), ground water, etc.

Within each category, the parameters are grouped by subcategory. For instance, in the saturated zone parameter matrix, the alluvium/colluvium and rock matrix category includes the subcategories stratigraphy and biological, chemical/mineralogical, hydraulic, and a few other characteristics.

Additional explanations are given in the headers and footers of each matrix.

Table B-1. General Site Parameters

BC = boundary condition, IC = initial condition, I = input variable, O = output variable, P = parameter
(see end of table for definitions & additional abbreviations)

This matrix lists site characteristics that are not listed in the Unsaturated Zone and Saturated Zone Parameters matrices. The characteristics of excavations, including the subsurface repository and subsurface- and surface-based boreholes, are listed in the Repository Excavation and Borehole Parameters matrix. Radionuclide, waste form, and waste container characteristics are listed in the Waste Package Parameters matrix.

Parameters (important performance assessment parameters are bolded)	Processes/Computer Codes/Data Use															
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
	Climate	Tectonism	Erosion	Infiltration	FF UZ hydrology	SZ hydrology	Geomechanics	NF UZ hydrology	WP degradation	NF UZ transport	FF UZ transport	SZ transport	Geochemistry	Volcanism	Human interference	Biosphere transp.
	TBD	TBD	None	TBD	FEHMN NUFT TOUGH2 V-TOUGH	MODFLOW FEHMN NUFT TOUGH2 V-TOUGH	3DEC ABAQUS ANSYS FLAC UDEC UNWEDGE	FEHMN NUFT TOUGH2 V-TOUGH	AREST PIGS WAPDEG YMIM	FEHMN NUFT TGIF TRACRN	FEHMN NUFT TRACRN	FEHMN NUFT TRACRN	EQ3/6	TBD	TBD	GENII MACCS
PHYSIOGRAPHY																
Topography																
Ground surface elevation	P	P	IC/O	P	P	P	P	P		P	P	P		P	P	P
Vegetation																
Plant type			P	P												P
Areal distribution			P	P												P
Climate and Meteorology																
Precipitation	O		P	BC												
Dry bulb temperature	O			BC												
Wet bulb temperature				P												
Dew point temperature				P												
Atmospheric pressure					BC											
Snow depth				P												
Snow moisture content				P												
Depth of ground freeze				P												

Table B-1. General Site Parameters

Parameters (important performance assessment parameters are bolded)	Processes/Computer Codes/Data Use															
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
	Climate	Tecto-nism	Erosion	Infiltra-tion	FF UZ hydro-logy	SZ hydro-logy	Geo-mech-anics	NF UZ hydro-logy	WP degra-dation	NF UZ trans-port	FF UZ trans-port	SZ trans-port	Geo-chemi-stry	Volca-nism	Human inter-ference	Bio-sphere transp.
Relative humidity				P												
Actual evapo-transpiration				P												
Potential evapo-transpiration				P												
Percent cloud cover				P												
Solar radiation (incoming)				P												
Terrestrial radiation (outgoing)				P												
Wind velocity & direction	O		P	P												P
Atmospheric dispersion coefficient	O															P
Surface Hydrology																
Recharge locations for saturated zone				P		P										
Recharge rates to saturated zone				O		BC										
Discharge locations				P		P										P
Discharge rates				O		BC										P
Discharge chemistry						P										
Discharge temperature						BC										
Overland flow areas			P	P	P											
Overland flow rates			P	BC	BC											
Channel locations			P	P		P										

Table B-1. General Site Parameters

Parameters (important performance assessment parameters are bolded)	Processes/Computer Codes/Data Use															
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
	Climate	Tecto-nism	Erosion	Infiltra-tion	FF UZ hydro-logy	SZ hydro-logy	Geo-mech-anics	NF UZ hydro-logy	WP degra-dation	NF UZ trans-port	FF UZ trans-port	SZ trans-port	Geo-chemi-stry	Volca-nism	Human inter-ference	Bio-sphere transp.
Channel profiles			P													
Channel cross-sections			P													
Channel flow rate			P	BC		BC										
Flood magnitudes & frequencies			P													
Maximum probable flood			P													
Depth-flow rate relationship			P													
GEOLOGIC EVENTS AND PROCESSES (see the Unsaturated and Saturated Zone matrices for faults and faulting)																
Erosion and Deposition																
Overland water erosion rate			O													
Overland water sediment deposit rate			O													
Overland suspended solids loads			O													
Channel erosion rate			O													
Channel sediment deposition rate			O													
Channel suspended solids loads			O													
Wind erosion rate			O													
Wind sediment deposition rate			O													
Wind suspended solid loads			O													

Table B-1. General Site Parameters

Parameters (important performance assessment parameters are bolded)	Processes/Computer Codes/Data Use															
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
	Climate	Tecto-nism	Erosion	Infiltra-tion	FF UZ hydro-logy	SZ hydro-logy	Geo-mech-anics	NF UZ hydro-logy	WP degra-dation	NF UZ trans-port	FF UZ trans-port	SZ trans-port	Geo-chemi-stry	Volca-nism	Human inter-ference	Bio-sphere transp.
Uplift and Subsidence																
Location		O														
Areal extent		O														
Depth		O														
Rate of uplift/subsidence		O														
Frequency/probability		P														
Volcanic Eruptions and Magmatic Intrusions																
Location														O		P
Areal extent														O		P
Geometry														O		P
Magnitude														O		P
Duration														O		P
Magma flow path														O		P
Frequency/probability														P		P
Seismicity																
Location		O			P	P	P	P								
Magnitude		O			P	P	P	P								
Acceleration/ground motion		O			P	P	P	P								
Frequency/probability		P														

Table B-1. General Site Parameters

Parameters (important performance assessment parameters are bolded)	Processes/Computer Codes/Data Use															
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
	Climate	Tecto-nism	Erosion	Infiltra-tion	FF UZ hydro-logy	SZ hydro-logy	Geo-mech-anics	NF UZ hydro-logy	WP degra-dation	NF UZ trans-port	FF UZ trans-port	SZ trans-port	Geo-chemi-stry	Volca-nism	Human inter-ference	Bio-sphere transp.
HUMAN INTERFERENCE																
Borehole Drilling (Directly into Engineered Barrier System)																
Locations															P	P
Sizes															P	P
Depths															P	P
Frequency/probability															P	P
Hydrocarbon (Coal, Oil and Gas) and Mineral Resource Exploration and Extraction																
Location															P	P
Quantity															P	P
Economics															P	
Ground-Water Use (e.g., Domestic, Municipal, Industrial, and Irrigation) and Liquid Waste Disposal																
Location					P	P					P	P	P		P	
Quantity					BC	BC					P	P	P		P	
Waste composition											P	P	BC		P	
Solid Waste Disposal																
Location											P	P	P		P	
Quantity											P	P	P		P	
Waste composition											P	P	BC		P	
DEMOGRAPHY, LIFESTYLES AND PUBLIC EXPOSURE MECHANISMS																
Population																
Size																P
Distribution																P

Table B-1. General Site Parameters

Parameters (important performance assessment parameters are bolded)	Processes/Computer Codes/Data Use															
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
	Climate	Tecto-nism	Erosion	Infiltra-tion	FF UZ hydro-logy	SZ hydro-logy	Geo-mech-anics	NF UZ hydro-logy	WP degra-dation	NF UZ trans-port	FF UZ trans-port	SZ trans-port	Geo-chemi-stry	Volca-nism	Human inter-ference	Bio-sphere transp.
Crops, Livestock and Food																
Farming & gardening locations																P
Types of crops & livestock																P
Growing period per crop type																P
Annual yield per crop type																P
Annual irrigation per crop type																P
Sources of irrigation water																P
Types of food consumed																P
Food consumption rate																P
Sources of drinking water																P
Drinking water consumption																P
Depths of drinking water wells																P

Table B-1. General Site Parameters

Parameters (important performance assessment parameters are bolded)	Processes/Computer Codes/Data Use															
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
	Climate	Tecto-nism	Erosion	Infiltra-tion	FF UZ hydro-logy	SZ hydro-logy	Geo-mech-anics	NF UZ hydro-logy	WP degra-dation	NF UZ trans-port	FF UZ trans-port	SZ trans-port	Geo-chemi-stry	Volca-nism	Human inter-ference	Bio-sphere transp.
Other Radiological Exposure Mechanisms																
Annual duration of swimming																P
Annual duration of boating																P
Annual duration of shoreline exposure																P
Annual duration of ground exposure																P
Public Radiological Health Risk																
Background radiation level																P
Peak radiation dose to maximally exposed individual																O
Peak radiation dose to representative group																O

Definitions:

Boundary condition: The values of a variable at the boundary of a domain, whose values affect the variable(s) to be computed for the interior of the domain; may be a function of time for transient problems.

Initial condition: The values of a variable at the beginning of the computation in the interior of the domain, whose values are expected to change as a result of the boundary conditions.

Input variable: The values of variables needed for a computation, other than the properties of a physical substance; examples: temperature, fluid potential, concentration.

Output variable: The values of variables resulting from the computation, other than the properties of a physical substance; examples: temperature, fluid potential, concentration.

Parameter: The chemical and physical properties of gaseous, liquid, and solid substances; may change as functions of other parameters and variables; examples: rock thermal conductivity, rock porosity, water density, radionuclide half-life.

Abbreviations:
FF = far field, **NF** = near field, **SW** = surface water, **SZ** = saturated zone, **TBD** = to be determined or developed, **TSPA** = total system performance assessment, **UZ** = unsaturated zone, **WP** = waste package.

TSPA-1995 Radionuclide List (for spent-fuel inventory):
Ac-227, Am-241, Am-242M, Am-243, C-14 (gaseous), Cl-36 (gaseous), Cm-244, Cm-245, Cm-246, Cs-135, I-129 (gaseous), Nb-93M, Nb-94, Ni-59, Ni-63, Np-237, Pa-231, Pb-210, Pd-107, Pu-238, Pu-239, Pu-240, Pu-241, Pu-242, Ra-226, Ra-228, Se-79, Sm-151, Sn-126, Tc-99, Th-229, Th-230, Th-232, U-233, U-234, U-235, U-236, U-238, Zr-93.

Table B-2. Unsaturated Zone Parameters

BC = boundary condition, IC = initial condition, I = input variable, O = output variable, P = parameter
(see end of table for definitions & additional abbreviations)

This matrix lists unsaturated zone characteristics, including for the rock bounding the excavations. Other natural barrier characteristics are listed in the General Site and Saturated Zone Parameters matrices. The characteristics of excavations, including the subsurface repository and subsurface- and surface-based boreholes, are listed in the Repository Excavation and Borehole Parameters matrix. Radionuclide, waste form, and waste container characteristics are listed in the Waste Package Parameters matrix.

Parameters (important performance assessment parameters are bolded)	Processes/Computer Codes/Data Use															
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
	Climate	Tecto-nism	Erosion	Infiltra-tion	FF UZ hydro-logy	SZ hydro-logy	Geo-mech-anics	NF UZ hydro-logy	WP degrada-tion	NF UZ trans-port	FF UZ trans-port	SZ trans-port	Geo-chemi-stry	Volca-nism	Human inter-ference	Bio-sphere transp.
	TBD	TBD	None	TBD	FEHMN NUFT TOUGH2 V-TOUGH	MODFLOW FEHMN NUFT TOUGH2 V-TOUGH	3DEC ABAQUS ANSYS FLAC UDEC UNWEDGE	FEHMN NUFT TOUGH2 V-TOUGH	AREST PIGS WAPDEG YMIM	FEHMN NUFT TGIF TRACRN	FEHMN NUFT TRACRN	FEHMN NUFT TRACRN	EQ3/6	TBD	TBD	GENII MACCS
ALLUVIUM/COLLUVIUM AND ROCK MATRIX																
Stratigraphy																
Lateral extent		IC/O	P	P	P	P	P	P		P	P	P		P		
Depth		IC/O	P	P	P	P	P	P		P	P	P		P		
Thickness		IC/O	P	P	P	P	P	P		P	P	P		P		
Rock types		P	P	P	P	P	P	P		P	P	P	P	P	P	
Mineralogy				P				P		P	P	P	BC		P	
Biological Characteristics of Alluvium/Colluvium and Rock Matrix																
List of microbes									P	P	P		P			
Microbial activity									P	P	P		P			
Chemical/Mineralogical Characteristics of Alluvium/Colluvium and Rock Matrix																
Mineralogy										P	P		P			
Chemical composition of minerals										P	P		BC			

Table B-2. Unsaturated Zone Parameters

Parameters (important performance assessment parameters are bolded)	Processes/Computer Codes/Data Use															
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
	Climate	Tecto-nism	Erosion	Infiltra-tion	FF UZ hydro-logy	SZ hydro-logy	Geo-mech-anics	NF UZ hydro-logy	WP degrada-tion	NF UZ trans-port	FF UZ trans-port	SZ trans-port	Geo-chemi-stry	Volca-nism	Human inter-ference	Bio-sphere transp.
Apparent age of minerals					P								P			
Mineral solubility													P			
Mineral dissolution rate													P			
Mineral precipitation rate													P			
Hydraulic Characteristics of Alluvium/Colluvium & Rock Matrix of Altered Zone																
Saturated hydraulic conductivity/ permeability								P								
Effective porosity								P		P						
Dispersivity/ dispersion coefficient										P						
Hydraulic potential - moisture content relationship								P								
Moisture content - hydraulic conductivity relationship								P								
Molecular diffusion coefficient										P						
Storativity/storage coefficient				P	P			P								
Dispersivity - moisture content relationship										P						

Table B-2. Unsaturated Zone Parameters

Parameters (important performance assessment parameters are bolded)	Processes/Computer Codes/Data Use															
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
	Climate	Tecto-nism	Erosion	Infiltra-tion	FF UZ hydro-logy	SZ hydro-logy	Geo-mech-anics	NF UZ hydro-logy	WP degrada-tion	NF UZ trans-port	FF UZ trans-port	SZ trans-port	Geo-chemi-stry	Volca-nism	Human inter-ference	Bio-sphere transp.
Hydraulic Characteristics of Alluvium/Colluvium & Rock Matrix of Unaltered Zone																
Saturated hydraulic conductivity/ permeability								P								
Effective porosity				P	P						P					
Dispersivity/ dispersion coefficient											P					
Hydraulic potential - moisture content relationship				P	P											
Moisture content - hydraulic conductivity relationship				P	P											
Molecular diffusion coefficient											P					
Storativity/storage coefficient				P	P			P								
Dispersivity - moisture content relationship											P					
Pneumatic Characteristics of Alluvium/Colluvium & Rock Matrix																
Altered zone air permeability								P		P						
Far-field air permeability					P					P						
Gaseous dispersion coefficient										P	P					

Table B-2. Unsaturated Zone Parameters

Parameters (important performance assessment parameters are bolded)	Processes/Computer Codes/Data Use															
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
	Climate	Tectonism	Erosion	Infiltration	FF UZ hydrology	SZ hydrology	Geomechanics	NF UZ hydrology	WP degradation	NF UZ transport	FF UZ transport	SZ transport	Geochemistry	Volcanism	Human interference	Biosphere transp.
Mechanical Characteristics of Alluvium/Colluvium & Rock Matrix																
Altered zone in-situ stress							IC/O									
Altered zone strain							O									
Altered zone rock deformation/ displacement					P		O	P	P							
Far-field in-situ stress							IC/O									
Far-field rock deformation/displacement							O									
Bulk density				P	P		P	P			P					
Compressive strength							P									
Tensile strength							P									
Cohesion							P									
Friction angle							P									
Elasticity							P									
Compressibility							P									
Young's modulus							P									
Poisson ratio							P									
Thermal Characteristics of Alluvium/Colluvium and Rock Matrix																
Altered zone soil & rock temperature					BC		IC/O	IC/O	I	P			P			
Far-field soil & rock temperature				P	IC/O	BC	IC/O				P		P			
Thermal conductivity					P		P	P								

Table B-2. Unsaturated Zone Parameters

Parameters (important performance assessment parameters are bolded)	Processes/Computer Codes/Data Use															
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
	Climate	Tectonism	Erosion	Infiltration	FF UZ hydrology	SZ hydrology	Geomechanics	NF UZ hydrology	WP degradation	NF UZ transport	FF UZ transport	SZ transport	Geochemistry	Volcanism	Human interference	Biosphere transp.
Thermal expansion coefficient							P									
Heat capacity					P		P	P								
ROCK FRACTURE ZONES (INCLUDING FAULTS)																
Geometry, Including Future Displacements of Rock Fracture Zones (Including Faults)																
Location				**P**	**P**		**P**	**P**		**P**	**P**					
Width				**P**	**P**		**P**	**P**		**P**	**P**					
Length				**P**	**P**		**P**	**P**		**P**	**P**					
Orientation				**P**	**P**		**P**	**P**		**P**	**P**					
Displacement				**P**	**P**		**P**	**P**		**P**	**P**					
Fracture aperture				**P**	**P**		**P**	**P**		**P**	**P**					
Fracture density				**P**	**P**		**P**	**P**		**P**	**P**					
Frequency/probability of future faulting		**P**														
Biological Characteristics of Rock Fracture Zones (Including Faults)																
List of microbes									**P**	P	P		**P**			
Microbial activity									**P**	P	P		**P**			
Chemical/Mineralogical Characteristics of Infillings of Rock Fracture Zones (Including Faults)																
Mineralogy										**P**	**P**		**P**			
Chemical composition of minerals										**P**	**P**		**BC**			
Mineral solubility													**P**			
Mineral dissolution rate													**P**			

Table B-2. Unsaturated Zone Parameters

Parameters (important performance assessment parameters are bolded)	Processes/Computer Codes/Data Use															
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
	Climate	Tecto-nism	Erosion	Infiltra-tion	FF UZ hydro-logy	SZ hydro-logy	Geo-mech-anics	NF UZ hydro-logy	WP degrada-tion	NF UZ trans-port	FF UZ trans-port	SZ trans-port	Geo-chemi-stry	Volca-nism	Human inter-ference	Bio-sphere transp.
Mineral precipitation rate													P			
Apparent age of minerals					P								P			
Hydraulic Characteristics of Rock Fracture Zones (Including Faults)																
Saturated hydraulic conductivity/ permeability				P	P			P		P	P					
Effective porosity				P	P			P		P	P					
Dispersivity/ dispersion coefficient										P	P					
Hydraulic potential - moisture content relationship				P	P			P								
Moisture content - hydraulic conductivity relationship				P	P			P								
Altered zone matrix/ fracture flow interaction								P		P						
Far-field matrix/ fracture flow interaction				P	P						P					
Dispersivity - moisture content relationship										P	P					
Storativity/storage coefficient				P	P			P								
Roughness coefficient					P			P								
Pneumatic Characteristics of Rock Fracture Zones (Including Faults)																
Altered zone air permeability								P		P						

Table B-2. Unsaturated Zone Parameters

Parameters (important performance assessment parameters are bolded)	Processes/Computer Codes/Data Use															
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
	Climate	Tecto-nism	Erosion	Infiltra-tion	FF UZ hydro-logy	SZ hydro-logy	Geo-mech-anics	NF UZ hydro-logy	WP degrada-tion	NF UZ trans-port	FF UZ trans-port	SZ trans-port	Geo-chemi-stry	Volca-nism	Human inter-ference	Bio-sphere transp.
Altered zone gaseous dispersion coefficient										P						
Altered zone matrix/ fracture flow interaction								P		P						
Far-field air permeability					P						P					
Far-field gaseous dispersion coefficient											P					
Far-field matrix/fracture flow interaction				P	P						P					
Thermal Characteristics of Rock Fracture Zones (Including Faults)																
Altered zone rock temperature					BC		IC/O	IC/O	I	P			P			
Far-field rock temperature				P	IC/O	BC	IC/O				P		P			
Thermal conductivity					P		P	P								
Thermal expansion coefficient							P									
Heat capacity					P		P	P								
GROUND WATER (IN ROCK MATRIX, FRACTURES, FAULT ZONES, AND OTHER DISCONTINUITIES)																
Chemical Characteristics of Ground Water (in Rock Matrix, Fractures, Fault Zones, and Other Discontinuities)																
Altered zone chemical composition, Eh & pH									P	P	BC		IC/O			
Far-field chemical composition, Eh & pH										BC	P	BC	IC/O			
Age (H-3, C-14, Cl-36)				P	P								P			

Table B-2. Unsaturated Zone Parameters

Parameters (important performance assessment parameters are bolded)	Processes/Computer Codes/Data Use															
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
	Climate	Tecto-nism	Erosion	Infiltra-tion	FF UZ hydro-logy	SZ hydro-logy	Geo-mech-anics	NF UZ hydro-logy	WP degrada-tion	NF UZ trans-port	FF UZ trans-port	SZ trans-port	Geo-chemi-stry	Volca-nism	Human inter-ference	Bio-sphere transp.
Hydraulic Characteristics of Ground Water (in Rock Matrix, Fractures, Fault Zones, and Other Discontinuities)																
Surface water infiltration				O	BC	BC		BC								
In-situ fluid potential				IC/O	IC/O	BC		IC/O								
Altered zone moisture content					BC			IC/O	I				I			
Far-field moisture content				IC/O	IC/O			BC					I			
Altered zone liquid water flux					BC			O	I	I			I			
Far-field liquid water flux				BC	O	BC		BC		I	I		I			
Altered zone water vapor content/humidity					BC			IC/O	I							
Far-field water vapor content/humidity					IC/O			BC								
Altered zone water vapor flux					BC			O	I	I			I			
Far-field water vapor flux				BC	O	BC		BC		I	I		I			
Pre-waste emplacement GWTT from disturbed zone to water table					O			O								
Post-waste emplacement GWTT from disturbed zone to water table					O			O								
Mechanical Characteristics of Ground Water (in Rock Matrix, Fractures, Fault Zones, and Other Discontinuities)																
Density				P	P			P								

Table B-2. Unsaturated Zone Parameters

Parameters (important performance assessment parameters are bolded)	Processes/Computer Codes/Data Use															
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
	Climate	Tecto-nism	Erosion	Infiltra-tion	FF UZ hydro-logy	SZ hydro-logy	Geo-mech-anics	NF UZ hydro-logy	WP degrada-tion	NF UZ trans-port	FF UZ trans-port	SZ trans-port	Geo-chemi-stry	Volca-nism	Human Inter-ference	Bio-sphere transp.
Viscosity				P	P			P								
Compressibility					P			P								
Thermal Characteristics of Ground Water (in Rock Matrix, Fractures, Fault Zones, and Other Discontinuities)																
Altered zone fluid temperature					O			O	P	P	P		I			
Far-field fluid temperature				BC	IC/O	BC		IC/O			P	BC	I			
Heat capacity					P			P								
Thermal conductivity					P			P								
Thermal expansion coefficient					P			P								
Aqueous Radionuclide Transport for Each Important Aqueous Radionuclide (see TSPA-1995 list at end of table)																
Molecular diffusion coefficient										P	P					
Sorption/retardation coefficient/Kd										P	P					
Radionuclide concentration										O	O	BC				
Radionuclide release rate to water table										O	O	BC				
SUBSURFACE AIR AND GASES (IN ROCK MATRIX, FRACTURE, FAULT ZONES, AND OTHER DISCONTINUITIES)																
Chemical Characteristics of Subsurface Air and Gases (In Rock Matrix, Fracture, Fault Zones, and Other Discontinuities)																
Chemical composition									P	P	P		BC			
Age					P			P								
Pneumatic Characteristics of Subsurface Air and Gases (In Rock Matrix, Fracture, Fault Zones, and Other Discontinuities)																
Air pressure					IC/O			IC/O								

Table B-2. Unsaturated Zone Parameters

Parameters (important performance assessment parameters are bolded)	Processes/Computer Codes/Data Use															
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
	Climate	Tecto-nism	Erosion	Infiltra-tion	FF UZ hydro-logy	SZ hydro-logy	Geo-mech-anics	NF UZ hydro-logy	WP degrada-tion	NF UZ trans-port	FF UZ trans-port	SZ trans-port	Geo-chemi-stry	Volca-nism	Human inter-ference	Bio-sphere transp.
Air flow					O			O	P	P	P					
Thermal/Mechanical Characteristics of Subsurface Air and Gases (In Rock Matrix, Fracture, Fault Zones, and Other Discontinuities)																
Compressibility					P			P								
Thermal expansion coefficient					P			P								
Thermal conductivity					P			P								
Naturally Occurring Radon (In Rock Matrix, Fracture, Fault Zones, and Other Discontinuities)																
Concentration										BC	BC					I
Flux										BC	BC					I
Gaseous Radionuclide Transport for Each Important Gaseous Radionuclide (see TSPA-1995 list at end of table)																
Molecular diffusion coefficient										P	P					
Sorption/retardation coefficient/Kd										P	P					
Radionuclide concentration										O	O					
Radionuclide release rate to ground surface											O					I

Definitions:

Boundary condition: The values of a variable at the boundary of a domain, whose values affect the variable(s) to be computed for the interior of the domain; may be a function of time for transient problems.
Initial condition: The values of a variable at the beginning of the computation in the interior of the domain, whose values are expected to change as a result of the boundary conditions.
Input variable: The values of variables needed for a computation, other than the properties of a physical substance; examples: temperature, fluid potential, concentration.
Output variable: The values of variables resulting from the computation, other than the properties of a physical substance; examples: temperature, fluid potential, concentration.
Parameter: The chemical and physical properties of gaseous, liquid, and solid substances; may change as functions of other parameters and variables; examples: rock thermal conductivity, rock porosity, water density, radionuclide half-life.

Abbreviations:

FF = far-field, GWTT = ground-water travel time, NF = near-field, SZ = saturated zone, TBD = to be determined or developed, TSPA = total system performance assessment, UZ = unsaturated zone, WP = waste package.

TSPA-1995 Radionuclide List (for spent-fuel inventory):
Ac-227, Am-241, Am-242M, Am-243, C-14 (gaseous), Cl-36 (gaseous), Cm-244, Cm-245, Cm-246, Cs-135, I-129 (gaseous), Nb-93M, Nb-94, Ni-59, Ni-63, Np-237, Pa-231, Pb-210, Pd-107, Pu-238, Pu-

Table B-3. Saturated Zone Parameters

239, Pu-240, Pu-241, Pu-242, Ra-226, Ra-228, Se-79, Sm-151, Sn-126, Tc-99, Th-229, Th-230, Th-232, U-233, U-234, U-235, U-236, U-238, Zr-93.

BC = boundary condition, IC = initial condition, I = input variable, O = output variable, P = parameter
(see end of table for definitions & additional abbreviations)

This matrix lists saturated zone characteristics. Other natural barrier characteristics are listed in the General Site and Saturated Zone Parameters matrices, including for the rock bounding the excavations. The characteristics of excavations, including the subsurface repository and subsurface- and surface-based boreholes, are listed in the Repository Excavation and Borehole Parameters matrix. Radionuclide, waste form, and waste container characteristics are listed in the Waste Package Parameters matrix.

Parameters (important performance assessment parameters are bolded)	Processes/Computer Codes/Data Use															
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
	Climate	Tecto-nism	Erosion	Infiltra-tion	FF UZ hydro-logy	SZ hydro-logy	Geo-mech-anics	NF UZ hydro-logy	WP degrada-tion	NF UZ trans-port	FF UZ trans-port	SZ trans-port	Geo-chemi-stry	Volca-nism	Human inter-ference	Bio-sphere transp.
	TBD	TBD	None	TBD	FEHMN NUFT TOUGH2 V-TOUGH	MODFLOW FEHMN NUFT TOUGH2 V-TOUGH	3DEC ABAQUS ANSYS FLAC UDEC UNWEDGE	FEHMN NUFT TOUGH2 V-TOUGH	AREST PIGS WAPDEG YMIM	FEHMN NUFT TGIF TRACRN	FEHMN NUFT TRACRN	FEHMN NUFT TRACRN	EQ3/6	TBD	TBD	GENII MACCS
ALLUVIUM/COLLUVIUM AND ROCK MATRIX																
Stratigraphy																
Lateral extent		IC/O	P	P	P	P	P	P		P	P	P		P		
Depth		IC/O	P	P	P	P	P	P		P	P	P		P		
Thickness		IC/O	P	P	P	P	P	P		P	P	P		P		
Rock types		P	P	P	P	P	P	P		P	P	P	P	P	P	
Mineralogy				P				P		P	P	P	BC		P	
Biological Characteristics of Alluvium/Colluvium and Rock Matrix																
List of microbes												P	P			
Microbial activity												P	P			
Chemical/Mineralogical Characteristics of Alluvium/Colluvium and Rock Matrix																
Mineralogy												P	P			
Chemical composition of minerals												P	BC			
Mineral solubility													P			

Table B-3. Saturated Zone Parameters

Parameters (important performance assessment parameters are bolded)	Processes/Computer Codes/Data Use															
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
	Climate	Tecto-nism	Erosion	Infiltra-tion	FF UZ hydro-logy	SZ hydro-logy	Geo-mech-anics	NF UZ hydro-logy	WP degrada-tion	NF UZ trans-port	FF UZ trans-port	SZ trans-port	Geo-chemi-stry	Volca-nism	Human inter-ference	Bio-sphere transp.
Mineral dissolution rate													P			
Mineral precipitation rate													P			
Apparent age of minerals													P			
Hydraulic Characteristics of Alluvium/Colluvium and Rock Matrix																
Saturated hydraulic conductivity/ permeability						P										
Effective porosity						P						P				
Dispersivity/dispersion coefficient												P				
Vertical mixing factor												P				
Vertical mixing depth												P				
Storativity/storage coefficient						P										
Transmissivity						P										
Mechanical Characteristics of Alluvium/Colluvium and Rock Matrix																
Bulk density						P						P				
Compressibility						P										
Thermal Characteristics of Alluvium/Colluvium and Rock Matrix																
Rock temperature						IC/O						I				
Thermal conductivity						P										
Thermal expansion coefficient																
Heat capacity						P										

Table B-3. Saturated Zone Parameters

Parameters (important performance assessment parameters are bolded)	Processes/Computer Codes/Data Use															
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
	Climate	Tecto-nism	Erosion	Infiltra-tion	FF UZ hydro-logy	SZ hydro-logy	Geo-mech-anics	NF UZ hydro-logy	WP degrada-tion	NF UZ trans-port	FF UZ trans-port	SZ trans-port	Geo-chemi-stry	Volca-nism	Human inter-ference	Bio-sphere transp.
ROCK FRACTURE ZONES (INCLUDING FAULTS)																
Geometry of Rock Fracture Zones (Including Faults)																
Location						P						P				
Width						P						P				
Length						P						P				
Orientation						P						P				
Displacement						P						P				
Fracture aperture						P						P				
Fracture density						P						P				
Frequency/probability of future faulting						P						P				
Biological Characteristics of Rock Fracture Zones (Including Faults)																
List of microbes												P	P			
Microbial activity												P	P			
Chemical/Mineralogical Characteristics of Infillings of Rock Fracture Zones																
Mineralogy												P	P			
Chemical composition of minerals												P	BC			
Mineral solubility													P			
Mineral dissolution rate													P			
Mineral precipitation rate													P			
Apparent age of minerals													P			

Table B-3. Saturated Zone Parameters

Parameters (important performance assessment parameters are bolded)	Processes/Computer Codes/Data Use															
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
	Climate	Tecto-nism	Erosion	Infiltra-tion	FF UZ hydro-logy	SZ hydro-logy	Geo-mech-anics	NF UZ hydro-logy	WP degrada-tion	NF UZ trans-port	FF UZ trans-port	SZ trans-port	Geo-chemi-stry	Volca-nism	Human inter-ference	Bio-sphere transp.
Hydraulic Characteristics of Rock Fracture Zones (Including Faults)																
Saturated hydraulic conductivity/ permeability						P										
Effective porosity						P						P				
Dispersivity/dispersion coefficient												P				
Storativity/storage coefficient						P										
Roughness coefficient						P										
GROUND WATER (IN ROCK MATRIX, FRACTURE, FAULT ZONES, AND OTHER DISCONTINUITIES)																
Chemical Characteristics of Ground Water (In Rock Matrix, Fracture, Fault Zones, and Other Discontinuities)																
Chemical composition, incl. Eh and pH												P	IC/O			
Age (H-3, Cl-36, C-14)						P							P			
Hydraulic Characteristics of Ground Water (In Rock Matrix, Fracture, Fault Zones, and Other Discontinuities)																
Water table elevation						IC/O										
Fluid potential in confined aquifers						IC/O										
Ground-water flux						O							I			
Pre-waste emplacement GWTT from beneath repository to accessible environment						O										

Table B-3. Saturated Zone Parameters

Parameters (important performance assessment parameters are bolded)	Processes/Computer Codes/Data Use															
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
	Climate	Tecto-nism	Erosion	Infiltra-tion	FF UZ hydro-logy	SZ hydro-logy	Geo-mech-anics	NF UZ hydro-logy	WP degrada-tion	NF UZ trans-port	FF UZ trans-port	SZ trans-port	Geo-chemi-stry	Volca-nism	Human inter-ference	Bio-sphere transp.
Post-waste emplacement GWTT from beneath repository to access-ible environment						O										
Mechanical Characteristics of Ground Water (In Rock Matrix, Fracture, Fault Zones, and Other Discontinuities)																
Density						P										
Viscosity						P										
Thermal Characteristics of Ground Water (In Rock Matrix, Fracture, Fault Zones, and Other Discontinuities)																
Ground-water temperature						IC/O							I	I		
Heat capacity						P										
Thermal conductivity						P										
Aqueous Radionuclide Transport of Each Important Radionuclide (see TSPA-1995 list at end of table)																
Sorption/retardation coefficient/Kd												P				

Table B-3. Saturated Zone Parameters

Parameters (important performance assessment parameters are bolded)	Processes/Computer Codes/Data Use															
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
	Climate	Tecto-nism	Erosion	Infiltra-tion	FF UZ hydro-logy	SZ hydro-logy	Geo-mech-anics	NF UZ hydro-logy	WP degrada-tion	NF UZ trans-port	FF UZ trans-port	SZ trans-port	Geo-chemi-stry	Volca-nism	Human inter-ference	Bio-sphere transp.
Radionuclide concentration												O				I
Radionuclide release rate to accessible environment												O				I

Definitions:

Boundary condition: The values of a variable at the boundary of a domain, whose values affect the variable(s) to be computed for the interior of the domain; may be a function of time for transient problems.

Initial condition: The values of a variable at the beginning of the computation in the interior of the domain, whose values are expected to change as a result of the boundary conditions.

Input variable: The values of variables needed for a computation, other than the properties of a physical substance; examples: temperature, fluid potential, concentration.

Output variable: The values of variables resulting from the computation, other than the properties of a physical substance; examples: temperature, fluid potential, concentration.

Parameter: The chemical and physical properties of gaseous, liquid, and solid substances; may change as functions of other parameters and variables; examples: rock thermal conductivity, rock porosity, water density, radionuclide half-life.

Abbreviations:
FF = far field, **GWTT** = ground-water travel time, **NF** = near-field, **SZ** = saturated zone, **TBD** = to be determined or developed, **TSPA** = total system performance assessment, **UZ** = unsaturated zone, **WP** = waste package.

TSPA-1995 Radionuclide List (for spent-fuel inventory):
Ac-227, Am-241, Am-242M, Am-243, C-14 (gaseous), Cl-36 (gaseous), Cm-244, Cm-245, Cm-246, Cs-135, I-129 (gaseous), Nb-93M, Nb-94, Ni-59, Ni-63, Np-237, Pa-231, Pb-210, Pd-107, Pu-238, Pu-239, Pu-240, Pu-241, Pu-242, Ra-226, Ra-228, Se-79, Sm-151, Sn-126, Tc-99, Th-229, Th-230, Th-232, U-233, U-234, U-235, U-236, U-238, Zr-93.

Table B-4. Repository Excavation and Borehole Parameters

BC = boundary condition, IC = initial condition, I = input variable, O = output variable, P = parameter
(see end of table for definitions & additional abbreviations)

This matrix lists the characteristics of excavations, including the subsurface repository and subsurface- and surface-based boreholes. Radionuclide, waste form, and waste container characteristics are listed in the Waste Package Parameters matrix. Natural barrier characteristics, including for the rock bounding the excavations, are listed in the General Site, Unsaturated Zone, and Saturated Zone Parameters matrices.

Parameters (important performance assessment parameters are bolded)	Processes/Computer Codes/Data Use															
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
	Climate	Tecto-nism	Erosion	Infiltra-tion	FF UZ hydro-logy	SZ hydro-logy	Geo-mech-anics	NF UZ hydro-logy	WP degrada-tion	NF UZ trans-port	FF UZ trans-port	SZ trans-port	Geo-chemi-stry	Volca-nism	Human inter-ference	Bio-sphere transp.
	TBD	TBD	None	TBD	FEHMN NUFT TOUGH2 V-TOUGH	MODFLOW FEHMN NUFT TOUGH2 V-TOUGH	3DEC ABAQUS ANSYS FLAC UDEC UNWEDGE	FEHMN NUFT TOUGH2 V-TOUGH	AREST PIGS WAPDEG YMIM	FEHMN NUFT TGIF TRACRN	FEHMN NUFT TRACRN	FEHMN NUFT TRACRN	EQ3/6	TBD	TBD	GENII MACCS
EXCAVATION GEOMETRY																
Geometry of Ramps, Shafts, Alcoves, and Transportation Drifts																
Layout					P		P	P		P	P					
Initial dimensions					P		P	P		P	P					
Deformation/ convergence							O	P		P						
Rock fall/collapse size							O	P		P						
Geometry of Waste Emplacement Drifts																
Layout					P	P	P	P	P	P	P				P	
Initial dimensions					P	P	P	P	P	P	P				P	
Deformation/ convergence							O	P	P	P						
Rock falls/collapse							O	P	P	P						P
Geometry of Subsurface and Surface-Based Boreholes																
Locations				P	P	P		P		P	P	P				
Drilled Depth				P	P	P		P		P	P	P				

Table B-4. Repository Excavation and Borehole Parameters

Parameters (important performance assessment parameters are bolded)	Processes/Computer Codes/Data Use															
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
	Climate	Tecto-nism	Erosion	Infiltra-tion	FF UZ hydro-logy	SZ hydro-logy	Geo-mech-anics	NF UZ hydro-logy	WP degrada-tion	NF UZ trans-port	FF UZ trans-port	SZ trans-port	Geo-chemi-stry	Volca-nism	Human inter-ference	Bio-sphere transp.
Drilled Diameter				P	P	P		P		P	P	P				
Deformation				P	P	P		P		P	P	P				
SUBSURFACE REPOSITORY EXCAVATION ENVIRONMENT (RAMPS, SHAFTS, ALCOVES, AND EMPLACEMENT DRIFTS)																
Physical Characteristics of Excavation Environment																
Air pressure					IC/O			IC/O		I	I					
Air velocity/flux					IC/O			IC/O		I	I					
Dry bulb air temperature					IC/O			IC/O	I	I	I					
Wet bulb air temperature					P											
Relative humidity					IC/O			IC/O	I	I						
Ground-water inflow rate into excavation					O			O	I	I	I					
Ground-water inflow temperature					BC/O			BC/O	I	I	I					
Ground-water outflow rate from excavation					O			O	I	O						
Ground-water outflow temperature					BC/O			BC/O	I	I	I					
Rate/volume of ground-water pumped to surface								IC								
Chemical Characteristics of Excavation Environment																
Airborne particulate concentration													P			
Carbon monoxide concentration													P			

Table B-4. Repository Excavation and Borehole Parameters

Parameters (important performance assessment parameters are bolded)	Processes/Computer Codes/Data Use															
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
	Climate	Tecto-nism	Erosion	Infiltra-tion	FF UZ hydro-logy	SZ hydro-logy	Geo-mech-anics	NF UZ hydro-logy	WP degrada-tion	NF UZ trans-port	FF UZ trans-port	SZ trans-port	Geo-chemi-stry	Volca-nism	Human inter-ference	Bio-sphere transp.
Oxygen concentration													P			
NOx concentrations													P			
SOx concentrations													P			
Natural radon gas concentrations													P			
Chemical composition, Eh & pH of ground-water inflow								P	P	P	P		BC			
Radiological Characteristics of Excavation Environment																
Alpha radiation									O							I
Beta radiation									O							I
Gamma radiation									O							I
Neutron radiation									O							I
WASTE EMPLACEMENT FOR EACH WASTE TYPE AND PACKAGE DESIGN (see waste package parameters table for radionuclide, waste form, and waste container parameters)																
Location within repository					P	P	P	P	P	P	P				P	
Location within individual drift					P	P	P	P	P	P	P				P	
Thermal loading					IC	IC	IC	IC	IC							
Areal mass loading					IC	IC	IC	IC	IC							
Number of waste packages							P	P	P	P	P				P	

Table B-4. Repository Excavation and Borehole Parameters

Parameters (important performance assessment parameters are bolded)	Processes/Computer Codes/Data Use															
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
	Climate	Tecto-nism	Erosion	Infiltra-tion	FF UZ hydro-logy	SZ hydro-logy	Geo-mech-anics	NF UZ hydro-logy	WP degrada-tion	NF UZ trans-port	FF UZ trans-port	SZ trans-port	Geo-chemi-stry	Volca-nism	Human inter-ference	Bio-sphere transp.
BACKFILL, INCLUDING CAPILLARY BARRIER (if used -- only confirmatory backfilling is assumed prior to backfilling for repository closure, if used)																
Geometry of Backfill																
Location								P	P	P						
Component types								P	P	P						
Initial dimensions								P	P	P						
Deformation/settling/ compaction								**P**	**P**	**P**						
Biological Characteristics of each Backfill Component																
List of microbes									P							
Microbial activity									P							
Chemical/Mineralogical Characteristics of each Backfill Component																
Mineralogy								P	P	P			BC			
Chemical composi-tion/alteration								**P**	**P**	**P**			**BC**			
Radionuclide sorption/retardation coefficient/Kd										**P**						
Hydraulic Characteristics of each Backfill Component																
Water flow through backfill								**O**	**I**							
Moisture content								**O**	**I**	**I**						
Capillary barrier effectiveness								**O**	**P**	**P**						
Saturated hydraulic conductivity								**P**								
Effective porosity										**P**						

Table B-4. Repository Excavation and Borehole Parameters

Parameters (important performance assessment parameters are bolded)	Processes/Computer Codes/Data Use															
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
	Climate	Tecto-nism	Erosion	Infiltra-tion	FF UZ hydro-logy	SZ hydro-logy	Geo-mech-anics	NF UZ hydro-logy	WP degrada-tion	NF UZ trans-port	FF UZ trans-port	SZ trans-port	Geo-chemi-stry	Volca-nism	Human inter-ference	Bio-sphere transp.
Diffusion/dispersivity/ dispersion coefficient										P						
Storativity/storage coefficient								P								
Hydraulic potential - moisture content relationship								P								
Moisture content - hydraulic conductivity relationship								P								
Pneumatic Characteristics of each Backfill Component																
Air flow through backfill								O	I	I						
Air permeability								P								
Mechanical Characteristics of each Backfill Component																
In situ stress							IC/O									
Grain size distribution										P						
Bulk density										P						
Compressive strength							P									
Tensile strength							P									
Cohesion							P									
Natural angle of repose							P									
Friction angle/ coefficient of friction							P									
Elasticity							P									
Compressibility							P									

Table B-4. Repository Excavation and Borehole Parameters

Parameters (important performance assessment parameters are bolded)	Processes/Computer Codes/Data Use															
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
	Climate	Tecto-nism	Erosion	Infiltra-tion	FF UZ hydro-logy	SZ hydro-logy	Geo-mech-anics	NF UZ hydro-logy	WP degrada-tion	NF UZ trans-port	FF UZ trans-port	SZ trans-port	Geo-chemi-stry	Volca-nism	Human inter-ference	Bio-sphere transp.
Young's modulus							P									
Poisson ratio							P									
Thermal Characteristics of each Backfill Component																
Temperature								IC/O	I	P			P			
Thermal conductivity								P								
Thermal expansion coefficient								P								
Heat capacity								P								
Radionuclide Transport Characteristics of each Important Radionuclide for Backfill																
Gaseous radionuclide concentration in backfill										O	BC					
Gaseous radionuclide transport through backfill										O	BC					
Aqueous radionuclide concentration in backfill										O	BC					
Aqueous radionuclide transport through backfill										O	BC					
SEALS FOR EACH DRIFT, RAMP, SHAFT, AND BOREHOLE (only confirmatory sealing of subsurface excavations is assumed prior to sealing for repository closure)																
Geometry of Seals																
Locations					P	P		P			P	P				
Component types					P	P		P			P	P				
Initial dimensions					P	P		P			P	P				
Deformation					P	P		P			P	P				

Table B-4. Repository Excavation and Borehole Parameters

Parameters (important performance assessment parameters are bolded)	Processes/Computer Codes/Data Use															
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
	Climate	Tecto-nism	Erosion	Infiltra-tion	FF UZ hydro-logy	SZ hydro-logy	Geo-mech-anics	NF UZ hydro-logy	WP degrada-tion	NF UZ trans-port	FF UZ trans-port	SZ trans-port	Geo-chemi-stry	Volca-nism	Human inter-ference	Bio-sphere transp.
Biological Characteristics of Seals																
List of microbes											P	P				
Microbial activity											P	P				
Chemical/Mineralogical Characteristics of each Seal Component																
Mineralogy											P	P	BC			
Chemical composition/alteration											**P**	**P**	BC			
Radionuclide sorption/retardation coefficient/Kd											**P**	**P**				
Hydraulic Characteristics of each Seal Component																
Water flow through seals					**O**	**O**					I	I				
Moisture content near seals					**O**	**O**										
Saturated hydraulic conductivity					**P**	**P**										
Effective porosity											**P**	**P**				
Dispersivity/dispersion coefficient											**P**	**P**				
Storativity/storage coefficient					**P**	**P**										
Hydraulic potential - moisture content relationship					**P**											
Moisture content - hydraulic conductivity relationship					**P**											

Table B-4. Repository Excavation and Borehole Parameters

Parameters (important performance assessment parameters are bolded)	Processes/Computer Codes/Data Use															
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
	Climate	Tecto-nism	Erosion	Infiltra-tion	FF UZ hydro-logy	SZ hydro-logy	Geo-mech-anics	NF UZ hydro-logy	WP degrada-tion	NF UZ trans-port	FF UZ trans-port	SZ trans-port	Geo-chemi-stry	Volca-nism	Human inter-ference	Bio-sphere transp.
Pneumatic Characteristics of each Seal Component																
Air flow through seals					O	O				I	I					
Air permeability					P	P										
Mechanical Characteristics of each Seal Component																
In situ stress							P									
Grain size distribution							P			P						
Bulk density					P	P	P			P	P					
Compressive strength							P									
Tensile strength							P									
Cohesion							P									
Friction angle/ coefficient of friction							P									
Elasticity							P									
Compressibility							P									
Young's modulus							P									
Poisson ratio							P									
Thermal Characteristics of each Seal Component																
Temperature					IC/O	IC/O	I	I		I	I	I				
Thermal conductivity					P	P	P	P								
Thermal expansion coefficient					P	P	P									
Heat capacity					P	P	P									

Table B-4. Repository Excavation and Borehole Parameters

Parameters (important performance assessment parameters are bolded)	Processes/Computer Codes/Data Use															
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
	Climate	Tecto-nism	Erosion	Infiltra-tion	FF UZ hydro-logy	SZ hydro-logy	Geo-mech-anics	NF UZ hydro-logy	WP degrada-tion	NF UZ trans-port	FF UZ trans-port	SZ trans-port	Geo-chemi-stry	Volca-nism	Human inter-ference	Bio-sphere transp.
Radionuclide Transport Characteristics of each Important Radionuclide for Seals																
Gaseous radionuclide concentrations near seals										I/O	I/O					
Gaseous radionuclide transport rate through seals										I/O	I/O					
Aqueous radionuclide concentrations near seals										I/O	I/O	I/O				
Aqueous radionuclide transport rate through seals										I/O	I/O	I/O				
ESF & REPOSITORY CONSTRUCTION FLUIDS AND MATERIALS REMAINING AFTER REPOSITORY CLOSURE (other than backfill and seals)																
Construction and Fire Water, including Accidental Spills																
Quantity used					P			P								
Quantity remaining in rock					IC			IC		IC						
Chemical composition, incl. Eh & pH										P	P		IC			
Hydrocarbons, Including Accidental Spills (each type that may affect postclosure performance)																
Quantity used													P			
Quantity remaining in rock									P	P			IC			
Chemical composition/alteration									P	P			IC			
Concrete																
Quantity								P	P	P			IC			

Table B-4. Repository Excavation and Borehole Parameters

Parameters (important performance assessment parameters are bolded)	Processes/Computer Codes/Data Use															
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
	Climate	Tecto-nism	Erosion	Infiltra-tion	FF UZ hydro-logy	SZ hydro-logy	Geo-mech-anics	NF UZ hydro-logy	WP degrada-tion	NF UZ trans-port	FF UZ trans-port	SZ trans-port	Geo-chemi-stry	Volca-nism	Human inter-ference	Bio-sphere transp.
Chemical composition/alteration								P	P	P			IC			
Steel																
Quantity									P	P			IC			
Chemical composition/alteration									P	P			IC			
Ground Support																
Design/emplacement specifications									P	P			IC			
Chemical composition/alteration									P	P			IC			
Railcars																
Number									P	P			IC			
Design specifications									P	P			IC			
Chemical composition/alteration									P	P			IC			
Other Construction/Operation/Testing Fluids and Materials Remaining in Repository after Closure (each type that may affect postclosure performance)																
Quantity								P	P	P			IC			
Chemical composition/alteration								P	P	P			IC			
ENGINEERED BARRIER SYSTEM RADIONUCLIDE RELEASE OF EACH IMPORTANT RADIONUCLIDE (see TSPA-1995 list at end of table)																
Gaseous radionuclide concentration in emplacement drift walls										O	I					
Gaseous radionuclide release rate into host rock										O	I					

Table B-4. Repository Excavation and Borehole Parameters

Parameters (important performance assessment parameters are bolded)	Processes/Computer Codes/Data Use															
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
	Climate	Tecto-nism	Erosion	Infiltra-tion	FF UZ hydro-logy	SZ hydro-logy	Geo-mech-anics	NF UZ hydro-logy	WP degrada-tion	NF UZ trans-port	FF UZ trans-port	SZ trans-port	Geo-chemi-stry	Volca-nism	Human Inter-ference	Bio-sphere transp.
Aqueous radionuclide concentration in em-placement drift walls										O	I					
Aqueous radionuclide release rate into host rock										O	I					
Fractional radionuc-lide release relative to 1000-year inventory										O	I					

Definitions:

Boundary condition: The values of a variable at the boundary of a domain, whose values affect the variable(s) to be computed for the interior of the domain; may be a function of time for transient problems.

Initial condition: The values of a variable at the beginning of the computation in the interior of the domain, whose values are expected to change as a result of the boundary conditions.

Input variable: The values of variables needed for a computation, other than the properties of a physical substance; examples: temperature, fluid potential, concentration.

Output variable: The values of variables resulting from the computation, other than the properties of a physical substance; examples: temperature, fluid potential, concentration.

Parameter: The chemical and physical properties of gaseous, liquid, and solid substances; may change as functions of other parameters and variables; examples: rock thermal conductivity, rock porosity, water density, radionuclide half-life.

Abbreviations:

ESF = Exploratory Studies Facility, FF = far field, NF = near field, SZ = saturated zone, TBD = to be determined or developed, TSPA = total system performance assessment, UZ = unsaturated zone, WP = waste package.

TSPA-1995 Radionuclide List (for spent-fuel inventory):

Ac-227, Am-241, Am-242M, Am-243, C-14 (gaseous), Cl-36 (gaseous), Cm-244, Cm-245, Cm-246, Cs-135, I-129 (gaseous), Nb-93M, Nb-94, Ni-59, Ni-63, Np-237, Pa-231, Pb-210, Pd-107, Pu-238, Pu-239, Pu-240, Pu-241, Pu-242, Ra-226, Ra-228, Se-79, Sm-151, Sn-126, Tc-99, Th-229, Th-230, Th-232, U-233, U-234, U-235, U-236, U-238, Zr-93.

Table B-5. Waste Package Parameters

BC = boundary condition, IC = initial condition, I = input variable, O = output variable, P = parameter
(see end of table for definitions & additional abbreviations)

This matrix lists radionuclide, waste form, and waste container characteristics. The characteristics of excavations, including the subsurface repository and subsurface- and surface-based boreholes, are listed in the Repository Excavation and Borehole Parameters matrix. Natural barrier characteristics, including for the rock bounding the excavations, are listed in the General Site, Unsaturated Zone, and Saturated Zone Parameters matrices.

Parameters for each waste type & waste package design (important performance assessment parameters are bolded)	**Processes/Computer Codes/Data Use**															
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**
	Climate	**Tecto-nism**	**Erosion**	**Infiltra-tion**	**FF UZ hydro-logy**	**SZ hydro-logy**	**Geo-mech-anics**	**NF UZ hydro-logy**	**WP degrada-tion**	**NF UZ trans-port**	**FF UZ trans-port**	**SZ trans-port**	**Geo-chemi-stry**	**Volca-nism**	**Human inter-ference**	**Bio-sphere transp.**
	TBD	TBD	None	TBD	FEHMN NUFT TOUGH2 V-TOUGH	MODFLOW FEHMN NUFT TOUGH2 V-TOUGH	3DEC ABAQUS ANSYS FLAC UDEC UNWEDGE	FEHMN NUFT TOUGH2 V-TOUGH	AREST PIGS WAPDEG YMIM	FEHMN NUFT TGIF TRACRN	FEHMN NUFT TRACRN	FEHMN NUFT TRACRN	EQ3/6	TBD	TBD	GENII MACCS
WASTE FORM CHARACTERISTICS (e.g., of Spent Fuel and Glass Defense High-level Waste)																
Type of waste									**P**							
Weight of waste per waste package									**P**							
Age at emplacement time									P							
Geometry/dimensions of waste form									**P**							
Geometry/dimensions of waste pellets or particles									**P**							
Surface area of waste pellets or particles									**P**							
Spent-fuel burnup rate									P							
List of all radionuclides									P							P
List of important radionuclides									**P**							**P**
Radionuclide chain definition									P							P

Table B-5. Waste Package Parameters

Parameters for each waste type & waste package design (important performance assessment parameters are bolded)	Processes/Computer Codes/Data Use															
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
	Climate	Tecto-nism	Erosion	Infiltra-tion	FF UZ hydro-logy	SZ hydro-logy	Geo-mech-anics	NF UZ hydro-logy	WP degrada-tion	NF UZ trans-port	FF UZ trans-port	SZ trans-port	Geo-chemi-stry	Volca-nism	Human inter-ference	Bio-sphere transp.
Weight of each radionuclide									BC							
Activity of each radionuclide									BC							
Thermal output/decay heat					BC	BC	BC	BC	BC				BC			
Alpha radiation at waste surface									BC							
Beta radiation at waste surface									BC							
Gamma radiation at waste surface									BC							
Neutron radiation at waste surface									BC							
Dry oxidation rate									P							
Dry oxidation products									P				BC			
Dissolution rate of original waste form									P							
Dissolution rate of oxidation products									P							
Devitrification of glass waste									P							
Dissolution rate of de-vitrified glass waste									P							
Oxidation enhancement by radiation									P							
Dissolution enhance-ment by radiation									P							

Table B-5. Waste Package Parameters

Parameters for each waste type & waste package design (important performance assessment parameters are bolded)	Processes/Computer Codes/Data Use															
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
	Climate	Tecto-nism	Erosion	Infiltra-tion	FF UZ hydro-logy	SZ hydro-logy	Geo-mech-anics	NF UZ hydro-logy	WP degrada-tion	NF UZ trans-port	FF UZ trans-port	SZ trans-port	Geo-chemi-stry	Volca-nism	Human inter-ference	Bio-sphere transp.
RADIONUCLIDE CHARACTERISTICS OF EACH IMPORTANT RADIONUCLIDE (see TSPA-1995 list at end of table)																
Half-life									P	P	P	P	P			P
Solubility									P	P	P	P	P			
Dissolution rate									P	P	P	P	P			
Dissolution enhance-ment by radiation									P							
Speciation									P	P	P	P	P			
Colloid transport properties										P	P	P				
Molecular diffusion coefficient									P	P	P	P				
GEOMETRY OF WASTE PACKAGE (Excluding Backfill)																
Initial outside dimen-sions of waste package								P	P	P						
Number of barriers									P							
Material of each barrier									P				BC			
Initial thickness of each barrier									P	P						
Corrosion effects on barrier thickness & shape									O							
Mechanical effects on barrier thickness & shape									O							

Table B-5. Waste Package Parameters

Parameters for each waste type & waste package design (important performance assessment parameters are bolded)	Processes/Computer Codes/Data Use															
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
	Climate	Tecto-nism	Erosion	Infiltra-tion	FF UZ hydro-logy	SZ hydro-logy	Geo-mech-anics	NF UZ hydro-logy	WP degrada-tion	NF UZ trans-port	FF UZ trans-port	SZ trans-port	Geo-chemi-stry	Volca-nism	Human inter-ference	Bio-sphere transp.
CORROSION AND OTHER DEGRADATION CHARACTERISTICS OF EACH WASTE PACKAGE BARRIER (Excluding Backfill)																
Polarity of current for galvanic protection									P/O							
Common potential for galvanic protection									P/O							
Dry oxidation corrosion rate									P/O							
Threshold humidity for humid-air corrosion									P							
Humid-air general corrosion rate									P/O							
Aqueous general corrosion rate									P/O							
Humid-air pit corrosion rate									P/O							
Aqueous pit corrosion rate									P/O							
Microbial corrosion rate									P/O							
Threshold stress for stress-corrosion cracking									P							
Stress-corrosion crack growth rate									P/O							
Corrosion rate induced by mechanical damage/deformation									P/O							

Table B-5. Waste Package Parameters

Parameters for each waste type & waste package design (important performance assessment parameters are bolded)	Processes/Computer Codes/Data Use															
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
	Climate	Tecto-nism	Erosion	Infiltra-tion	FF UZ hydro-logy	SZ hydro-logy	Geo-mech-anics	NF UZ hydro-logy	WP degrada-tion	NF UZ trans-port	FF UZ trans-port	SZ trans-port	Geo-chemi-stry	Volca-nism	Human inter-ference	Bio-sphere transp.
Cladding failure rate [1]									P/O							
Internal corrosion									P/O							
Oxidation enhancement by radiation									P							
Corrosion enhancement by radiation									P							
CHEMISTRY OF EACH WASTE PACKAGE BARRIER (Including Degradation Products but Excluding Backfill)																
Initial chemical composition									IC/O				I			
Gas composition inside container									IC/O				I			
Phase stability of materials									P				P			
Chemical composition of criticality control materials									IC/O				I			
Oxidation product composition								I	O	I			I			
Aqueous corrosion product composition								I	O	I			I			
Physical/chemical degree of embrittlement									P							
Physical/chemical weld integrity									P							

[1] Needed only if (a) credit will be taken for cladding performance or (b) its performance will adversely affect the performance of other engineered barrier system components.

Table B-5. Waste Package Parameters

Parameters for each waste type & waste package design (important performance assessment parameters are bolded)	Processes/Computer Codes/Data Use															
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
	Climate	Tecto-nism	Erosion	Infiltra-tion	FF UZ hydro-logy	SZ hydro-logy	Geo-mech-anics	NF UZ hydro-logy	WP degrada-tion	NF UZ trans-port	FF UZ trans-port	SZ trans-port	Geo-chemi-stry	Volca-nism	Human inter-ference	Bio-sphere transp.
Radionuclide sorption/ retardation coefficient/ Kd for waste package degradation products									P	P						
HYDRAULIC CHARACTERISTICS OF POROUS WASTE PACKAGE MATERIALS, IF ANY [2] (Excluding Backfill)																
Moisture content									IC/O							
Humidity									IC/O							
Saturated hydraulic conductivity									P							
Effective porosity									P							
Dispersivity/dispersion coefficient									P							
Storativity/storage coefficient									P							
Hydraulic potential - moisture content relationship									P							
Moisture content - hydraulic conductivity relationship									P							
Diffusivity - moisture content relationship									P							
MECHANICAL CHARACTERISTICS OF EACH WASTE PACKAGE BARRIER (Excluding Backfill)																
In-situ stress									IC/O							
Strain									O							

2 Needed only if porous materials other than the waste itself will be used inside the waste package, and (a) credit will be taken for the performance of these materials and/or their degradation products, or (b) these porous materials and/or their degradation products will adversely affect the performance of other engineered barrier system components.

Table B-5. Waste Package Parameters

Parameters for each waste type & waste package design (important performance assessment parameters are bolded)	Processes/Computer Codes/Data Use															
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
	Climate	Tecto-nism	Erosion	Infiltra-tion	FF UZ hydro-logy	SZ hydro-logy	Geo-mech-anics	NF UZ hydro-logy	WP degrada-tion	NF UZ trans-port	FF UZ trans-port	SZ trans-port	Geo-chemi-stry	Volca-nism	Human inter-ference	Bio-sphere transp.
Bulk density									P							
Compressive strength									P							
Tensile strength									P							
Yield strength									P							
Fracture toughness									P							
Elasticity									P							
Compressibility									P							
Young's modulus									P							
Poisson ratio									P							
THERMAL CHARACTERISTICS OF EACH WASTE PACKAGE BARRIER (Excluding Backfill)																
Waste package center temperature									O							
Barrier wall temperature							BC	BC	O							
Thermal conductivity									P							
Thermal expansion coefficient									P							
Heat capacity									P							

Parameters for each waste type & waste package design (important performance assessment parameters are bolded)	Processes/Computer Codes/Data Use															
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
	Climate	Tecto-nism	Erosion	Infiltra-tion	FF UZ hydro-logy	SZ hydro-logy	Geo-mech-anics	NF UZ hydro-logy	WP degrada-tion	NF UZ trans-port	FF UZ trans-port	SZ trans-port	Geo-chemi-stry	Volca-nism	Human inter-ference	Bio-sphere transp.
WASTE PACKAGE RADIONUCLIDE RELEASE FOR EACH WASTE FORM, PACKAGE DESIGN, AND IMPORTANT RADIONUCLIDE (see TSPA-1995 list at end of table)																
Waste package life or time of initial radio-nuclide release									O		I					I
Radionuclide release rate from waste form									O							
Radionuclide release rate from waste package									O	I						I

Definitions:

Boundary condition: The values of a variable at the boundary of a domain, whose values affect the variable(s) to be computed for the interior of the domain; may be a function of time for transient problems.

Initial condition: The values of a variable at the beginning of the computation in the interior of the domain, whose values are expected to change as a result of the boundary conditions.

Input variable: The values of variables needed for a computation, other than the properties of a physical substance; examples: temperature, fluid potential, concentration.

Output variable: The values of variables resulting from the computation, other than the properties of a physical substance; examples: temperature, fluid potential, concentration.

Parameter: The chemical and physical properties of gaseous, liquid, and solid substances; may change as functions of other parameters and variables; examples: rock thermal conductivity, rock porosity, water density, radionuclide half-life.

Abbreviations:

FF = far field, **NF** = near-field, **SZ** = saturated zone, **TBD** = to be determined or developed, **TSPA** = total system performance assessment, **UZ** = unsaturated zone, **WP** = waste package.

TSPA-1995 Radionuclide List (for spent-fuel inventory):

Ac-227, Am-241, Am-242M, Am-243, C-14 (gaseous), Cl-36 (gaseous), Cm-244, Cm-245, Cm-246, Cs-135, I-129 (gaseous), Nb-93M, Nb-94, Ni-59, Ni-63, Np-237, Pa-231, Pb-210, Pd-107, Pu-238, Pu-239, Pu-240, Pu-241, Pu-242, Ra-226, Ra-228, Se-79, Sm-151, Sn-126, Tc-99, Th-229, Th-230, Th-232, U-233, U-234, U-235, U-236, U-238, Zr-93.

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APPENDIX C

PERFORMANCE CONFIRMATION PARAMETER SELECTION MATRICES

PERFORMANCE CONFIRMATION PARAMETER SELECTION MATRIXES

This appendix contains five matrices that identify the selected performance confirmation parameters, including the key performance confirmation parameters for design, preliminary performance confirmation concepts, and brief reasons for not selecting many parameters as performance confirmation parameters.

The matrices list the same parameters as Appendix B in the first column. As in Appendix B, the names of parameters that are important for postclosure performance assessments are shown in bold type.

The following eleven columns identify the applicability of the performance confirmation parameter selection criteria for each parameter. The selection criteria are abbreviated in the column headers. A brief explanation of the screening process is given in the header of each matrix. See Section 4.4 for a detailed description of the criteria and explanation of the screening process.

The next two columns identify all of the selected performance confirmation parameters and the key performance confirmation parameters for design, respectively. From a total of 435 parameters listed in the five matrices, 126 were selected as performance confirmation parameters and 94 of these were selected as key performance confirmation parameters for design (the actual number is greater because some parameters consist of several different measurements, for instance, geochemical compositions).

The last column identifies preliminary performance confirmation concepts for the selected performance confirmation parameters. See Section 5 for detailed descriptions of the concepts.

The last column also lists briefly the main reasons why many parameters were not selected as performance confirmation parameters. A fairly frequent reason is "because sufficiently known for License Application." This reason is based on a qualitative judgment by the performance confirmation study team that site characterization and/or MGDS design and related research and development will provide sufficient information with acceptable uncertainties in support of the License Application that performance confirmation will not be needed thereafter. Because of uncertainties in the future of the site characterization program, however, this judgment should be revisited periodically to assess whether that conclusion remains valid, and if not, whether some of these parameters should be added to the list of performance confirmation parameters.

Some parameters that were not selected appear to be strong contenders to be performance confirmation parameters. Examples are rock and ground-water temperatures in the saturated zone that may be affected by the emplaced waste. These parameters were not selected because thermal effects are not expected in the saturated zone in the 100-year time frame before repository closure, based on modeling analyses. This is identified in the matrix. Other examples are radionuclide concentrations in the unsaturated and saturated zone. These parameters were not selected for similar reasons, that is, radionuclide releases are not expected before repository closure because of the expected reliability of the waste package design. If a waste package should be breached unexpectedly during the preclosure phase, however, remedial actions would be taken to prevent radionuclide releases into the rocks. These actions could entail radiation measurements of the rocks surrounding the breached waste package.

Selection process: A parameter has to pass each screen in order to be considered for the next screen. Only one criterion needs to apply in order for a parameter to move from Screen 1 to Screen 2 and from Screen 2 to Screen 3. At least one criterion has to apply from both Screen 1 and Screen 2, all three criteria of Screen 3, and the criterion of Screen 4 have to apply in order for a parameter to be selected as a performance confirmation parameter. See the text and flowchart for a more detailed explanation of the selection criteria and process.

Matrix scope: This matrix lists site characteristics that are not listed in the Unsaturated Zone and Saturated Zone Performance Confirmation Parameter Selection matrices. The characteristics of excavations, including the subsurface repository and subsurface- and surface-based boreholes, are listed in the Repository Performance Confirmation Parameter Selection matrix. Radionuclide, waste form, and waste container characteristics are listed in the Waste Package Performance Confirmation Parameter Selection matrix.

Table C-1. General Site Parameter Selection

Selection process: A parameter has to pass each screen in order to be considered for the next screen. Only one criterion needs to apply in order for a parameter to move from Screen 1 to Screen 2 and from Screen 2 to Screen 3. At least one criterion has to apply from both Screen 1 and Screen 2, all three criteria of Screen 3, and the criterion of Screen 4 have to apply in order for a parameter to be selected as a performance confirmation parameter. See the text and flowchart for a more detailed explanation of the selection criteria and process.

Matrix scope: This matrix lists site characteristics that are not listed in the Unsaturated Zone and Saturated Zone Performance Confirmation Parameter Selection matrices. The characteristics of excavations, including the subsurface repository and subsurface- and surface-based boreholes, are listed in the Repository Performance Confirmation Parameter Selection matrix. Radionuclide, waste form, and waste container characteristics are listed in the Waste Package Performance Confirmation Parameter Selection matrix.

Parameters (important performance assessment parameters are bolded)	Selection Criteria											Performance Confirmation Parameters		Preliminary Performance Confirmation Concepts (bolded if influencing design)
	Screen 1 (one must apply)				Screen 2 (one must apply)			Screen 3 (all must apply)			Screen 4			
	10 CFR 60 Subpart F	Confine & Isolate Waste Funct.	Contain. & Isol. Strategy	TSPA & PA process models	Subsurface conditions	Affected by const./emplacement	Time dependent variable	Can be measured or derived	Can be predicted or estimated	Important to performance	Reduce uncertainty	All perf. conf. parameters	Key parameters for design	
PHYSIOGRAPHY														
Topography														
Ground surface elevation		X	X	X			X	X	X	X	X	X		Geodetic surveys during & after geologic events
Vegetation														
Plant type		X		X			X	X	X	X	X	X		Annual seasonal surveys within controlled area
Areal distribution		X		X			X	X	X	X	X	X		
Climate and Meteorology														
Precipitation		X	X	X			X	X	X	X	X	X		Continuous at YMP weather stations
Dry bulb temperature		X	X	X			X	X	X	X	X	X		
Wet bulb temperature		X	X	X			X	X	X	X				Derived from dry bulb temperature & relative humidity
Dew point temperature							X	X	X					None because not important for postclosure performance
Atmospheric pressure		X	X	X			X	X	X	X	X	X		Continuous at YMP weather stations

Table C-1. General Site Parameter Selection

Parameters (important performance assessment parameters are bolded)	Selection Criteria: Screen 1 (one must apply): 10 CFR 60 Subpart F	Screen 1: Confine & Isolate Waste Funct.	Screen 1: Contain. & Isol. Strategy	Screen 1: TSPA & PA process models	Screen 2 (one must apply): Subsurface conditions	Screen 2: Affected by const./empl acement	Screen 2: Time dependent variable	Screen 3 (all must apply): Can be measured or derived	Screen 3: Can be predicted or estimated	Screen 3: Important to performance	Screen 4: Reduce uncertainty	Performance Confirmation Parameters: All perf. conf. parameters	Performance Confirmation Parameters: Key parameters for design	Preliminary Performance Confirmation Concepts (bolded if influencing design)
Snow depth				X			X	X	X					Needed only for infiltration research before license application
Snow moisture content				X			X	X	X					
Depth of ground freeze				X			X	X	X					
Relative humidity		X	X	X			X	X	X	X	X	X		Continuous monitoring at YMP weather stations
Actual evapotranspiration		X	X	X			X	X	X	X				Needed only for infiltration research before license application
Potential evapotranspiration				X			X	X	X					None because sufficiently known for license application
Percent cloud cover				X			X	X	X					Needed only for infiltration research before license application
Solar radiation (incoming)				X			X	X	X					
Terrestrial radiation (outgoing)				X			X	X	X					
Wind velocity & direction				X			X	X	X	X	X			Continuous monitoring at YMP weather stations
Atmospheric dispersion coefficient				X			X	X	X	X	X			Derived from other meteorological measurements
Surface Hydrology														
Recharge locations for saturated zone		X	X	X			X	X	X	X				None because sufficiently known for license application

Table C-1. General Site Parameter Selection

Parameters (important performance assessment parameters are bolded)	Selection Criteria											Performance Confirmation Parameters		Preliminary Performance Confirmation Concepts (bolded if influencing design)
	Screen 1 (one must apply)				Screen 2 (one must apply)			Screen 3 (all must apply)			Screen 4			
	10 CFR 60 Subpart F	Confine & Isolate Waste Funct.	Contain. & Isol. Strategy	TSPA & PA process models	Subsurface conditions	Affected by const./emplacement	Time dependent variable	Can be measured or derived	Can be predicted or estimated	Important to performance	Reduce uncertainty	All perf. conf. parameters	Key parameters for design	
Recharge rates to saturated zone		X	X	X			X	X	X	X				None because sufficiently known for license application
Discharge locations		X	X	X			X	X	X	X				
Discharge rates		X	X	X			X	X	X	X				
Discharge chemistry							X	X	X					
Discharge temperature							X	X	X					
Overland flow areas								X	X					
Overland flow rates							X	X	X					
Channel locations								X	X					
Channel profiles							X	X	X					
Channel cross-sections							X	X	X					
Channel flow rate							X	X	X					
Flood magnitudes & frequencies							X	X	X					None because calculated from weather & flow data
Maximum probable flood							X	X	X					
Depth-flow rate relationship								X	X					None because sufficiently known for license application
GEOLOGIC EVENTS AND PROCESSES (see the Unsaturated and Saturated Zone matrices for faults and faulting)														
Erosion and Deposition														
Overland water erosion rate								X	X					None because sufficiently known for license application

Table C-1. General Site Parameter Selection

Parameters (important performance assessment parameters are bolded)	Selection Criteria											Performance Confirmation Parameters		Preliminary Performance Confirmation Concepts (bolded if influencing design)
	Screen 1 (one must apply)				Screen 2 (one must apply)			Screen 3 (all must apply)			Screen 4			
	10 CFR 60 Sub-part F	Con-fine & Isolate Waste Funct.	Con-tain. & Isol. Stra-tegy	TSPA & PA process models	Subsur-face condi-tions	Affec-ted by const./empl ace-ment	Time depen-dent vari-able	Can be mea-sured or derived	Can be pre-dicted or esti-mated	Impor-tant to per-form-ance	Reduce uncer-tainty	All perf. conf. para-meters	Key para-meters for design	
Overland water sediment deposit rate								X	X					None because sufficiently known for license application
Overland suspended solids loads							X	X	X					
Channel erosion rate								X	X					
Channel sediment deposition rate								X	X					
Channel suspended solids loads							X	X	X					
Wind erosion rate								X	X					
Wind sediment deposition rate								X	X					
Wind suspended solid loads							X	X	X					
Uplift and Subsidence														
Location							X	X	X					See geodetic surveys under Topography
Areal extent							X	X	X					
Depth							X	X	X					
Rate of uplift/subsidence								X	X					None because calculated from geodetic surveys
Frequency/probability								X	X					
Volcanic Eruptions and Magmatic Intrusions														
Location				X			X	X	X	X				See geodetic surveys under Topography

Table C-1. General Site Parameter Selection

Parameters (important performance assessment parameters are bolded)	Selection Criteria: Screen 1 (one must apply): 10 CFR 60 Subpart F	Screen 1: Confine & Isolate Waste Funct.	Screen 1: Contain. & Isol. Strategy	Screen 1: TSPA & PA process models	Screen 2 (one must apply): Subsurface conditions	Screen 2: Affected by const./emplacement	Screen 2: Time dependent variable	Screen 3 (all must apply): Can be measured or derived	Screen 3: Can be predicted or estimated	Screen 3: Important to performance	Screen 4: Reduce uncertainty	Performance Confirmation Parameters: All perf. conf. parameters	Performance Confirmation Parameters: Key parameters for design	Preliminary Performance Confirmation Concepts (bolded if influencing design)
Areal extent				X			X	X	X	X				See geodetic surveys under Topography
Geometry				X			X	X	X	X				
Magnitude				X			X	X	X	X				
Duration				X			X	X	X	X				
Magma flow path				X			X	X	X	X				
Frequency/probability				X				X	X	X				None because computed from other observations
Seismicity														
Location				X			X	X	X	X	X	X	X	**Continuous at existing surface-based & new underground seismic stations**
Magnitude				X			X	X	X	X	X	X	X	
Acceleration/ground motion				X			X	X	X	X	X	X	X	
Frequency/probability				X				X	X	X				None because computed from other observations
HUMAN INTERFERENCE (importance and data needs depend on future regulations)														
Borehole Drilling (Directly into Engineered Barrier System)														
Locations				X			X							None because not predictable
Sizes				X			X							
Depths				X			X							
Frequency/probability				X										

Table C-1. General Site Parameter Selection

Parameters (important performance assessment parameters are bolded)	Selection Criteria: Screen 1 (one must apply): 10 CFR 60 Subpart F	Screen 1: Confine & Isolate Waste Funct.	Screen 1: Contain. & Isol. Strategy	Screen 1: TSPA & PA process models	Screen 2 (one must apply): Subsurface conditions	Screen 2: Affected by const./emplacement	Screen 2: Time dependent variable	Screen 3 (all must apply): Can be measured or derived	Screen 3: Can be predicted or estimated	Screen 3: Important to performance	Screen 4: Reduce uncertainty	Performance Confirmation Parameters: All perf. conf. parameters	Performance Confirmation Parameters: Key parameters for design	Preliminary Performance Confirmation Concepts (bolded if influencing design)
Hydrocarbon (Coal, Oil and Gas) and Mineral Resource Exploration and Extraction														
Location	X				X			X	X	X	X	X	X	**Geologic mapping during underground excavation & off-site lab analysis**
Quantity	X				X			X	X	X	X	X	X	
Economics							X							None, derived from location, quantity, and other factors
Ground-Water Use (e.g., Domestic, Municipal, Industrial, and Irrigation) and Liquid Waste Disposal														
Location				X			X							None because not predictable
Quantity				X			X							
Waste composition							X							
Solid Waste Disposal														
Location							X							None because not predictable
Quantity							X							
Waste composition							X							
DEMOGRAPHY, LIFESTYLES AND PUBLIC EXPOSURE MECHANISMS (importance and data needs depend on future regulations)														
Population														
Size				?			X			?				None because not predictable
Distribution				?			X			?				
Crops, Livestock and Food														
Farming & gardening locations				?			X			?				None because not predictable

Table C-1. General Site Parameter Selection

Parameters (important performance assessment parameters are bolded)	Selection Criteria											Performance Confirmation Parameters		Preliminary Performance Confirmation Concepts (bolded if influencing design)
	Screen 1 (one must apply)				Screen 2 (one must apply)			Screen 3 (all must apply)			Screen 4			
	10 CFR 60 Subpart F	Confine & Isolate Waste Funct.	Contain. & Isol. Strategy	TSPA & PA process models	Subsurface conditions	Affected by const./emplacement	Time dependent variable	Can be measured or derived	Can be predicted or estimated	Important to performance	Reduce uncertainty	All perf. conf. parameters	Key parameters for design	
Types of crops & livestock				?			X			?				
Growing period per crop type				?			X			?				
Annual yield per crop type				?			X			?				
Annual irrigation per crop type				?			X			?				
Sources of irrigation water				?			X			?				None because not predictable
Types of food consumed				?			X			?				
Food consumption rate				?			X			?				
Sources of drinking water				X			X			X				
Drinking water consumption				X			X			X				
Depths of drinking water wells				X			X			X				
Other Radiological Exposure Mechanisms														
Annual duration of swimming				?			X			?				
Annual duration of boating				?			X			?				None because not predictable
Annual duration of shoreline exposure				?			X			?				

Table C-1. General Site Parameter Selection

Parameters (important performance assessment parameters are bolded)	Selection Criteria: Screen 1 (one must apply)				Screen 2 (one must apply)			Screen 3 (all must apply)			Screen 4	Performance Confirmation Parameters		Preliminary Performance Confirmation Concepts (bolded if influencing design)
	10 CFR 60 Subpart F	Confine & Isolate Waste Funct.	Contain. & Isol. Strategy	TSPA & PA process models	Subsurface conditions	Affected by const./emplacement	Time dependent variable	Can be measured or derived	Can be predicted or estimated	Important to performance	Reduce uncertainty	All perf. conf. parameters	Key parameters for design	
Annual duration of ground exposure				?			X			?				None because not predictable
Public Radiological Health Risk														
Background radiation level							X	X	X		X	X		Continue surface-based monitoring for preclosure health & safety
Peak radiation dose to maximally exposed individual			X	X		X	X			X	X			None because computed from TSPA
Peak radiation dose to representative group				?		X	X			?	X			

<u>Abbreviations</u>:
CFR = Code of Federal Regulations, GWTT = ground-water travel time, PA = performance assessment, TSPA = total system performance assessment, WP = waste package, YMP = Yucca Mountain Site Characterization Project.

<u>TSPA-1995 Radionuclide List</u> (for spent-fuel inventory):
Ac-227, Am-241, Am-242M, Am-243, C-14 (gaseous), Cl-36 (gaseous), Cm-244, Cm-245, Cm-246, Cs-135, I-129 (gaseous), Nb-93M, Nb-94, Ni-59, Ni-63, Np-237, Pa-231, Pb-210, Pd-107, Pu-238, Pu-239, Pu-240, Pu-241, Pu-242, Ra-226, Ra-228, Se-79, Sm-151, Sn-126, Tc-99, Th-229, Th-230, Th-232, U-233, U-234, U-235, U-236, U-238, Zr-93.

Table C-2. Unsaturated Zone Parameter Selection

Selection process: A parameter has to pass each screen in order to be considered for the next screen. Only one criterion needs to apply in order for a parameter to move from Screen 1 to Screen 2 and from Screen 2 to Screen 3. Atleast one criterion has to apply from both Screen 1 and Screen 2, all three criteria of Screen 3 and the criterion of Screen 4 have to apply in order for a parameter to be selected as a performance confirmation parameter. See the text and flowchart for a more detailed explanation of the selection criteria and process.

Matrix scope: This matrix lists unsaturated zone characteristics, including for the rock bounding the excavations. Other natural barrier characteristics are listed in the General Site and Saturated Zone parameter matrices. The characteristics of excavations, including the subsurface repository and subsurface- and surface-based boreholes, are listed in the Repository Parameter matrix. Radionuclide, waste form, and waste container characteristics are listed in the Waste Package Parameter matrix.

Parameters (important performance assessment parameters are bolded)	Selection Criteria											Performance Confirmation Parameters		Preliminary Performance Confirmation Concepts (bolded if influencing design)
	Screen 1 (one must apply)				Screen 2 (one must apply)			Screen 3 (all must apply)			Screen 4			
	10 CFR 60 Subpart F	Confine & Isolate Waste Funct.	Contain. & Isol. Strategy	TSPA & PA process models	Subsurface conditions	Affected by const./emplacement	Time dependent variable	Can be measured or derived	Can be predicted or estimated	Important to performance	Reduce uncertainty	All perf. conf. parameters	Key parameters for design	
ALLUVIUM/COLLUVIUM AND ROCK MATRIX														
Stratigraphy														
Lateral extent	X	X	X	X	X		X	X	X	X	X	X	X	**Geologic mapping during underground excavation**
Depth	X	X	X	X	X		X	X	X	X	X	X	X	
Thickness	X	X	X	X	X		X	X	X	X	X	X	X	
Rock types	X	X	X	X	X			X	X	X	X	X	X	
Mineralogy	X	X	X	X	X		X	X	X	X	X	X	X	
Biological Characteristics of Alluvium/Colluvium and Rock Matrix														
List of microbes	X	X	X	X	X	X	X	X	X					None because sufficiently known for license application
Microbial activity	X	X	X	X	X	X	X	X	X					
Chemical/Mineralogical Characteristics of Alluvium/Colluvium & Rock Matrix														
Mineralogy	X	X		X	X	X	X	X	X	X				None because sufficiently known for license application
Chemical composition of minerals	X	X		X	X	X	X	X	X	X				

Table C-2. Unsaturated Zone Parameter Selection

Parameters (important performance assessment parameters are bolded)	Selection Criteria: Screen 1 (one must apply)				Screen 2 (one must apply)			Screen 3 (all must apply)			Screen 4	Performance Confirmation Parameters		Preliminary Performance Confirmation Concepts (bolded if influencing design)
	10 CFR 60 Subpart F	Confine & Isolate Waste Funct.	Contain. & Isol. Strategy	TSPA & PA process models	Subsurface conditions	Affected by const./emplacement	Time dependent variable	Can be measured or derived	Can be predicted or estimated	Important to performance	Reduce uncertainty	All perf. conf. parameters	Key parameters for design	
Apparent age of minerals							X	X	X					None because sufficiently known for license application
Mineral solubility	X	X		X		X		X	X	X				
Mineral dissolution rate	X	X		X		X		X	X	X				
Mineral precipitation rate	X	X		X		X		X	X	X				
Hydraulic Characteristics of Alluvium/Colluvium & Rock Matrix of Altered Zone														
Saturated hydraulic conductivity/ permeability	X	X	X	X	X	X		X	X	X	X	X	X	**Underground testing/ sampling & off-site lab analysis**
Effective porosity	X	X	X	X	X	X		X	X	X	X	X	X	
Dispersivity/dispersion coefficient	X	X	X	X	X	X		X	X	X	X	X	X	
Hydraulic potential - moisture content relationship	X	X	X	X	X	X		X	X	X	X	X	X	
Moisture content - hydraulic conductivity relationship	X	X	X	X	X	X		X	X	X	X	X	X	
Storativity/storage coefficient				X	X			X	X					None because sufficiently known for license application
Molecular diffusion coefficient								X	X					
Dispersivity - moisture content relationship	X				X	X		X	X					Not well understood, thus not considered

Table C-2. Unsaturated Zone Parameter Selection

Parameters (important performance assessment parameters are bolded)	Selection Criteria											Performance Confirmation Parameters		Preliminary Performance Confirmation Concepts (bolded if influencing design)
	Screen 1 (one must apply)				Screen 2 (one must apply)			Screen 3 (all must apply)			Screen 4			
	10 CFR 60 Subpart F	Confine & Isolate Waste Funct.	Contain. & Isol. Strategy	TSPA & PA process models	Subsurface conditions	Affected by const./emplacement	Time dependent variable	Can be measured or derived	Can be predicted or estimated	Important to performance	Reduce uncertainty	All perf. conf. parameters	Key parameters for design	
Hydraulic Characteristics of Alluvium/Colluvium & Rock Matrix of Unaltered Zone														
Saturated hydraulic conductivity/ permeability		X	X	X				X	X	X				None because sufficiently known for license application
Effective porosity		X	X	X				X	X	X				
Dispersivity/dispersion coefficient		X	X	X				X	X	X				
Hydraulic potential - moisture content relationship		X	X	X				X	X	X				
Moisture content - hydraulic conductivity relationship		X	X	X				X	X	X				
Molecular diffusion coefficient								X	X					
Storativity/storage coefficient				X				X	X					
Dispersivity - moisture content relationship								X	X					Not well understood, thus not considered
Pneumatic Characteristics of Alluvium/Colluvium & Rock Matrix														
Altered zone air permeability	X	X		X	X	X		X	X	X	X	X	X	**Underground testing/ sampling & off-site lab analysis**
Far-field air permeability		X		X				X	X	X				None because sufficiently known for license application
Gaseous dispersion coefficient		X		X	X			X	X	X				

Table C-2. Unsaturated Zone Parameter Selection

Parameters (important performance assessment parameters are bolded)	Selection Criteria: Screen 1 (one must apply): 10 CFR 60 Subpart F	Screen 1: Confine & Isolate Waste Funct.	Screen 1: Contain. & Isol. Strategy	Screen 1: TSPA & PA process models	Screen 2 (one must apply): Subsurface conditions	Screen 2: Affected by const./emplacement	Screen 2: Time dependent variable	Screen 3 (all must apply): Can be measured or derived	Screen 3: Can be predicted or estimated	Screen 3: Important to performance	Screen 4: Reduce uncertainty	Performance Confirmation Parameters: All perf. conf. parameters	Performance Confirmation Parameters: Key parameters for design	Preliminary Performance Confirmation Concepts (bolded if influencing design)
Mechanical Characteristics of Alluvium/Colluvium & Rock Matrix														
Altered zone in-situ stress	X	X		X	X	X	X	X	X	X	X	X	X	**Continuous underground monitoring**
Altered zone strain	X			X	X	X	X	X	X	X	X	X	X	
Altered zone rock deformation & displacement	X	X		X		X	X	X	X	X	X	X	X	
Far-field in-situ stress				X			X	X	X					None because not important (see separate entry for faults)
Far-field rock deformation & displacement				X			X	X	X					
Bulk density	X	X	X	X	X	X		X	X	X				None because sufficiently known for license application
Compressive strength	X			X	X	X		X	X	X				
Tensile strength	X			X	X	X		X	X	X				
Cohesion	X			X	X	X		X	X					
Friction angle	X			X	X	X		X	X					
Elasticity	X			X	X	X		X	X					
Compressibility	X			X	X	X		X	X					
Young's modulus	X			X	X	X		X	X					
Poisson ratio	X			X	X	X		X	X					
Thermal Characteristics of Alluvium/Colluvium & Rock Matrix														
Altered zone soil & rock temperature	X	X	X	X	X	X	X	X	X	X	X	X	X	**Continuous surface-based & underground monitoring**

Table C-2. Unsaturated Zone Parameter Selection

Parameters (important performance assessment parameters are bolded)	Selection Criteria											Performance Confirmation Parameters		Preliminary Performance Confirmation Concepts (bolded if influencing design)
	Screen 1 (one must apply)				Screen 2 (one must apply)			Screen 3 (all must apply)			Screen 4			
	10 CFR 60 Subpart F	Confine & Isolate Waste Funct.	Contain. & Isol. Strategy	TSPA & PA process models	Subsurface conditions	Affected by const./emplacement	Time dependent variable	Can be measured or derived	Can be predicted or estimated	Important to performance	Reduce uncertainty	All perf. conf. parameters	Key parameters for design	
Far-field soil & rock temperature		X	X	X			X	X	X	X	X	X	X	Continuous surface-based monitoring (in new boreholes)
Thermal conductivity	X	X		X	X	X		X	X	X				
Thermal expansion coefficient	X			X	X	X		X	X					None because sufficiently known for license application
Heat capacity	X			X	X	X		X	X					
ROCK FRACTURE ZONES (INCLUDING FAULTS)														
Geometry, Including Future Displacements of Rock Fracture Zones (Including Faults)														
Location	X	X	X	X	X		X	X	X	X	X	X	X	
Width	X	X	X	X	X		X	X	X	X	X	X	X	
Length	X	X	X	X	X		X	X	X	X	X	X	X	
Orientation	X	X	X	X	X		X	X	X	X	X	X	X	**Geologic mapping during underground excavation**
Displacement				X			X	X	X	X	X	X	X	
Fracture aperture	X	X	X	X	X		X	X	X	X	X	X	X	
Fracture density	X			X	X		X	X	X	X	X	X	X	
Frequency/probability of future faulting				X				X	X	X	X			None because computed from other observations
Biological Characteristics of Rock Fracture Zones (Including Faults)														
List of microbes	X	X	X	X	X	X	X	X	X	X	X	X	X	**Underground sampling & off-site lab analysis**
Microbial activity	X	X	X	X	X	X	X	X	X	X	X	X	X	

Table C-2. Unsaturated Zone Parameter Selection

Parameters (important performance assessment parameters are bolded)	Selection Criteria: Screen 1 (one must apply): 10 CFR 60 Subpart F	Screen 1: Confine & Isolate Waste Funct.	Screen 1: Contain. & Isol. Strategy	Screen 1: TSPA & PA process models	Screen 2 (one must apply): Subsurface conditions	Screen 2: Affected by const./emplacement	Screen 2: Time dependent variable	Screen 3 (all must apply): Can be measured or derived	Screen 3: Can be predicted or estimated	Screen 3: Important to performance	Screen 4: Reduce uncertainty	Performance Confirmation Parameters: All perf. conf. parameters	Performance Confirmation Parameters: Key parameters for design	Preliminary Performance Confirmation Concepts (bolded if influencing design)
Chemical/Mineralogical Characteristics of Infillings of Rock Fracture Zones (Including Faults)														
Mineralogy	X	X		X	X	X		X	X	X				
Chemical composition of minerals	X	X		X	X	X	X	X	X	X				
Mineral solubility	X	X		X		X		X	X	X				None because sufficiently known for license application
Mineral dissolution rate	X	X		X		X		X	X	X				
Mineral precipitation rate	X	X		X		X		X	X	X				
Apparent age of minerals	X	X		X	X	X	X	X	X	X	X	X	X	**Underground sampling & off-site lab analysis**
Hydraulic Characteristics of Rock Fracture Zones (Including Faults)														
Saturated hydraulic conductivity/ permeability		X	X	X	X	X		X	X	X	X	X	X	
Effective porosity		X	X	X	X	X		X	X	X	X	X	X	
Dispersivity/dispersion coefficient		X	X	X	X	X		X	X	X	X	X	X	**Underground testing/ sampling & off-site lab analysis if untested fracture zones encountered during excavations**
Hydraulic potential - moisture content relationship		X	X	X	X	X		X	X	X	X	X	X	
Moisture content - hydraulic conductivity relationship		X	X	X	X	X		X	X	X	X	X	X	
Altered zone matrix/fracture flow interaction	X	X	X	X	X	X		X	X	X				None because sufficiently known for license application

Table C-2. Unsaturated Zone Parameter Selection

Parameters (important performance assessment parameters are bolded)	Selection Criteria: Screen 1 (one must apply): 10 CFR 60 Subpart F	Screen 1: Confine & Isolate Waste Funct.	Screen 1: Contain. & Isol. Strategy	Screen 1: TSPA & PA process models	Screen 2 (one must apply): Subsurface conditions	Screen 2: Affected by const./emplacement	Screen 2: Time dependent variable	Screen 3 (all must apply): Can be measured or derived	Screen 3: Can be predicted or estimated	Screen 3: Important to performance	Screen 4: Reduce uncertainty	Performance Confirmation Parameters: All perf. conf. parameters	Performance Confirmation Parameters: Key parameters for design	Preliminary Performance Confirmation Concepts (bolded if influencing design)
Far-field matrix/fracture flow interaction	X	X	X	X				X	X	X				
Dispersivity - moisture content relationship								X	X					Not well understood, thus not considered
Storativity/storage coefficient				X	X			X	X					None because not considered important
Roughness coefficient				X	X	X		X	X					
Pneumatic Characteristics of Rock Fracture Zones (Including Faults)														
Altered zone air permeability	X	X		X	X	X		X	X	X	X	X	X	**Underground testing/ sampling & off-site lab analysis**
Altered zone gaseous dispersion coefficient	X	X		X	X			X	X	X	X	X	X	
Altered zone matrix/fracture flow interaction	X	X		X	X	X		X	X	X				None because not considered important
Far-field air permeability		X		X				X	X					
Far-field gaseous dispersion coefficient		X		X				X	X					
Far-field matrix/fracture flow interaction		X		X				X	X					

Table C-2. Unsaturated Zone Parameter Selection

Parameters (important performance assessment parameters are bolded)	Selection Criteria: Screen 1 (one must apply): 10 CFR 60 Subpart F	Screen 1: Confine & Isolate Waste Funct.	Screen 1: Contain. & Isol. Strategy	Screen 1: TSPA & PA process models	Screen 2 (one must apply): Subsurface conditions	Screen 2: Affected by const./emplacement	Screen 2: Time dependent variable	Screen 3 (all must apply): Can be measured or derived	Screen 3: Can be predicted or estimated	Screen 3: Important to performance	Screen 4: Reduce uncertainty	Performance Confirmation Parameters: All perf. conf. parameters	Performance Confirmation Parameters: Key parameters for design	Preliminary Performance Confirmation Concepts (bolded if influencing design)
Thermal Characteristics of Rock Fracture Zones (including Faults)														
Altered zone rock temperature	X	X	X	X	X	X	X	X	X	X	X	X	X	**Continuous surface-based & underground monitoring**
Far-field rock temperature		X	X	X			X	X	X	X	X	X	X	Continuous surface-based monitoring (in new boreholes)
Thermal conductivity	X	X		X	X	X		X	X	X				None because sufficiently known for license application
Thermal expansion coefficient	X			X	X	X		X	X					
Heat capacity	X			X	X	X		X	X					
GROUND WATER (IN ROCK MATRIX, FRACTURES, FAULT ZONES, AND OTHER DISCONTINUITIES)														
Chemical Characteristics of Ground Water (in Rock Matrix, Fractures, Fault Zones, and Other Discontinuities)														
Altered zone chemical composition, Eh & pH	X	X	X	X	X	X	X	X	X	X	X	X	X	**Surface-based & underground sampling & off-site lab analysis**
Far-field chemical composition, Eh & pH		X	X	X			X	X	X	X	X	X		Surface-based sampling & off-site lab analysis
Age (H-3, C-14, Cl-36)				X			X	X	X	X	X	X	X	**Surface-based & underground sampling & off-site lab analysis**
Hydraulic Characteristics of Ground Water (in Rock Matrix, Fractures, Fault Zones, and other Discontinuities)														
Surface water infiltration		X	X	X			X	X	X	X	X	X		Derived from soil/rock moisture measurements
In-situ fluid potential	X	X	X	X		X	X	X	X	X	X	X	X	**Continuous surface-based & underground monitoring**
Altered zone moisture content	X	X	X	X	X	X	X	X	X	X	X	X	X	**Continuous underground monitoring**

Table C-2. Unsaturated Zone Parameter Selection

Parameters (important performance assessment parameters are bolded)	Selection Criteria											Performance Confirmation Parameters		Preliminary Performance Confirmation Concepts (bolded if influencing design)
	Screen 1 (one must apply)				Screen 2 (one must apply)			Screen 3 (all must apply)			Screen 4			
	10 CFR 60 Subpart F	Confine & Isolate Waste Funct.	Contain. & Isol. Strategy	TSPA & PA process models	Subsurface conditions	Affected by const./emplacement	Time dependent variable	Can be measured or derived	Can be predicted or estimated	Important to performance	Reduce uncertainty	All perf. conf. parameters	Key parameters for design	
Far-field moisture content		X	X	X			X	X	X	X	X	X	X	Continuous surface-based monitoring (new boreholes)
Altered zone liquid water flux	X	X	X	X	X	X	X	X	X	X	X	X		Calculated from soil/rock moisture measurements
Far-field liquid water flux		X	X	X			X	X	X	X	X	X		
Altered zone water vapor content/humidity	X	X	X	X	X	X	X	X	X	X	X	X	X	**Continuous surface-based & underground monitoring**
Far-field water vapor content/humidity		X	X	X			X	X	X	X	X	X	X	Continuous surface-based monitoring (new boreholes)
Altered zone water vapor flux	X	X	X	X	X	X	X	X	X	X	X	X		Calculated from soil/rock moisture measurements
Far-field water vapor flux		X	X	X			X	X	X	X	X	X		
Pre-waste emplacement GWTT from disturbed zone to water table		X		X			X	X	X	X	X	X		Calculated from other hydrogeologic measurements
Post-waste emplacement GWTT from disturbed zone to water table				X		X	X	X	X	X	X	X		
Mechanical Characteristics of Ground Water (In Rock Matrix, Fractures, Fault Zones, and Other Discontinuities)														
Density				X		X		X	X					None because well established
Viscosity				X		X		X	X					
Compressibility				X				X	X					None because well established
Thermal Characteristics of Ground Water (In Rock Matrix, Fractures, Fault Zones, and Other Discontinuities)														

Table C-2. Unsaturated Zone Parameter Selection

Parameters (important performance assessment parameters are bolded)	Selection Criteria										Performance Confirmation Parameters		Preliminary Performance Confirmation Concepts (bolded if influencing design)
	Screen 1 (one must apply)				Screen 2 (one must apply)			Screen 3 (all must apply)			Screen 4			
	10 CFR 60 Subpart F	Confine & Isolate Waste Funct.	Contain. & Isol. Strategy	TSPA & PA process models	Subsurface conditions	Affected by const./emplacement	Time dependent variable	Can be measured or derived	Can be predicted or estimated	Important to performance	Reduce uncertainty	All perf. conf. parameters	Key parameters for design	
Altered zone fluid temperature	X	X	X	X	X	X	X	X	X	X	X	X	X	**Continuous surface-based & underground monitoring**
Far-field fluid temperature		X	X	X			X	X	X	X	X	X	X	Continuous surface-based monitoring (new boreholes)
Heat capacity				X				X	X					
Thermal conductivity				X				X	X					None because well established
Thermal expansion coefficient				X				X	X					
Aqueous Radionuclide Transport for each Important Aqueous Radionuclide (see TSPA-1995 list at end of table)														
Molecular diffusion coefficient				X	X			X	X					None because sufficiently known for license application
Sorption/retardation coefficient/Kd	X	X	X	X		X		X	X	X				Underground sampling & off-site lab analysis if unexpected mineral changes
Radionuclide concentration		X		X		X	X	X	X	X				None, no release expected before repository closure
Radionuclide release rate to water table		X		X		X	X	X	X	X				Calculated from unsaturated zone water flux & radionuclide concentrations

Table C-2. Unsaturated Zone Parameter Selection

Parameters (important performance assessment parameters are bolded)	Selection Criteria											Performance Confirmation Parameters		Preliminary Performance Confirmation Concepts (bolded if influencing design)
	Screen 1 (one must apply)				Screen 2 (one must apply)			Screen 3 (all must apply)			Screen 4			
	10 CFR 60 Subpart F	Confine & Isolate Waste Funct.	Contain. & Isol. Strategy	TSPA & PA process models	Subsurface conditions	Affected by const./emplacement	Time dependent variable	Can be measured or derived	Can be predicted or estimated	Important to performance	Reduce uncertainty	All perf. conf. parameters	Key parameters for design	
SUBSURFACE AIR AND GASES (IN ROCK MATRIX, FRACTURE, FAULT ZONES, AND OTHER DISCONTINUITIES)														
Chemical Characteristics of Subsurface Air and Gases (in Rock Matrix, Fractures, Fault Zones, and Other Discontinuities)														
Chemical composition				X			X	X	X					None because sufficiently known for license application
Age				X			X	X						None because sufficiently known for license application
Pneumatic Characteristics of Subsurface Air and Gases (in Rock Matrix, Fractures, Fault Zones, and other Discontinuities)														
Air pressure	X			X	X	X	X	X	X	X	X	X	X	**Continuous surface-based & underground monitoring**
Air flow	X			X	X	X	X	X	X	X	X	X		Calculated from air pressure & permeability
Thermal/Mechanical Characteristics of Subsurface Air and Gases (in Rock Matrix, Fractures, Fault Zones, and Other Discontinuities)														
Compressibility				X				X	X					None because well established
Thermal expansion coefficient				X				X	X					
Thermal conductivity				X				X	X					
Naturally Occurring Radon (in Rock Matrix, Fractures, Fault Zones, and Other Discontinuities)														
Concentration								X	X					None because not a postclosure concern
Flux								X	X					Calculated from concentrations & air pressure
Gaseous Radionuclide Transport for each Important Gaseous Radionuclide (see TSPA-1995 list at end of table)														
Molecular diffusion coefficient				X	X			X	X					None because sufficiently known for license application

Parameters (important performance assessment parameters are bolded)	Selection Criteria											Performance Confirmation Parameters		Preliminary Performance Confirmation Concepts (bolded if influencing design)
	Screen 1 (one must apply)				Screen 2 (one must apply)			Screen 3 (all must apply)			Screen 4			
	10 CFR 60 Subpart F	Confine & Isolate Waste Funct.	Contain. & Isol. Strategy	TSPA & PA process models	Subsurface conditions	Affected by const./emplacement	Time dependent variable	Can be measured or derived	Can be predicted or estimated	Important to performance	Reduce uncertainty	All perf. conf. parameters	Key parameters for design	
Sorption/retardation coefficient/Kd	X	X	X	X		X		X	X					Underground sampling & off-site lab analysis if unexpected mineral changes
Radionuclide concentration		X		X		X	X	X	X					None, no release expected before repository closure
Radionuclide release rate to ground surface		X		X		X	X	X	X					Calculated from air flow & radionuclide concentrations

Abbreviations:
CFR = Code of Federal Regulations, GWTT = ground-water travel time, PA = performance assessment, TSPA = total system performance assessment, WP = waste package.

TSPA-1995 Radionuclide List (for spent-fuel inventory):
Ac-227, Am-241, Am-242M, Am-243, C-14 (gaseous), Cl-36 (gaseous), Cm-244, Cm-245, Cm-246, Cs-135, I-129 (gaseous), Nb-93M, Nb-94, Ni-59, Ni-63, Np-237, Pa-231, Pb-210, Pd-107, Pu-238, Pu-239, Pu-240, Pu-241, Pu-242, Ra-226, Ra-228, Se-79, Sm-151, Sn-126, Tc-99, Th-229, Th-230, Th-232, U-233, U-234, U-235, U-236, U-238, Zr-93.

Table C-3. Saturated Zone Parameter Selection

Selection process: A parameter has to pass each screen in order to be considered for the next screen. Only one criterion needs to apply in order for a parameter to move from Screen 1 to Screen 2 and from Screen 2 to Screen 3. At least one criterion has to apply from both Screen 1 and Screen 2, all three criteria of Screen 3 and the criterion of Screen 4 have to apply in order for a parameter to be selected as a performance confirmation parameter. See the text and flowchart for a more detailed explanation of the selection criteria and process.

Matrix scope: This matrix lists saturated zone characteristics. Other natural barrier characteristics are listed in the General Site and Saturated Zone Parameters matrices, including for the rock bounding the excavations. The characteristics of excavations, including the subsurface repository and subsurface- and surface-based boreholes, are listed in the Repository Excavation and Borehole Parameters matrix. Radionuclide, waste form, and waste container characteristics are listed in the Waste Package Parameters matrix.

Parameters (important performance assessment parameters are bolded)	Selection Criteria											Performance Confirmation Parameters		Preliminary Performance Confirmation Concepts (bold if influencing design)
	Screen 1 (one must apply)				Screen 2 (one must apply)			Screen 3 (all must apply)			Screen 4			
	10 CFR 60 Subpart F	Confine & Isolate Waste Funct.	Contain. & Isol. Strategy	TSPA & PA process models	Subsurface conditions	Affected by const./emplacement	Time dependent variable	Can be measured or derived	Can be predicted or estimated	Important to performance	Reduce uncertainty	All perf. conf. parameters	Key parameters for design	
ALLUVIUM/COLLUVIUM AND ROCK MATRIX														
Stratigraphy														
Lateral extent	X	X	X	X			X	X	X	X				
Depth	X	X	X	X			X	X	X	X				
Thickness	X	X	X	X			X	X	X	X				None because sufficiently known for license application
Rock types	X	X	X	X				X	X	X				
Mineralogy	X	X	X	X			X	X	X	X				
Biological Characteristics of Alluvium/Colluvium and Rock Matrix														
List of microbes				X			X	X						None because sufficiently known for license application
Microbial activity				X		X	X	X						
Chemical/Mineralogical Characteristics of Alluvium/Colluvium and Rock Matrix														
Mineralogy				X				X						None because sufficiently known for license application

Table C-3. Saturated Zone Parameter Selection

Parameters (important performance assessment parameters are bolded)	Selection Criteria											Performance Confirmation Parameters		Preliminary Performance Confirmation Concepts (bold if influencing design)
	Screen 1 (one must apply)				Screen 2 (one must apply)			Screen 3 (all must apply)			Screen 4			
	10 CFR 60 Subpart F	Confine & Isolate Waste Funct.	Contain. & Isol. Strategy	TSPA & PA process models	Subsurface conditions	Affected by const./emplacement	Time dependent variable	Can be measured or derived	Can be predicted or estimated	Important to performance	Reduce uncertainty	All perf. conf. parameters	Key parameters for design	
Chemical composition of minerals				X			X	X	X					None because sufficiently known for license application
Mineral solubility				X				X	X					
Mineral dissolution rate				X				X	X					
Mineral precipitation rate				X				X	X					
Apparent age of minerals				X				X	X					
Hydraulic Characteristics of Alluvium/Colluvium and Rock Matrix														
Saturated hydraulic conductivity/ permeability		X	X	X				X	X	X				None because sufficiently known for license application
Effective porosity		X	X	X				X	X	X				
Dispersivity/dispersion coefficient		X	X	X				X	X	X				
Vertical mixing factor		X	X	X				X	X	X				
Vertical mixing depth		X	X	X				X	X	X				
Storativity/storage coefficient		X	X	X				X	X	X				
Transmissivity		X	X	X				X	X	X				
Mechanical Characteristics of Alluvium/Colluvium and Rock Matrix														
Bulk density				X				X	X	X				None because sufficiently known for license application
Compressibility				X				X	X					

Table C-3. Saturated Zone Parameter Selection

Parameters (important performance assessment parameters are bolded)	Selection Criteria: Screen 1 (one must apply): 10 CFR 60 Subpart F	Screen 1: Confine & Isolate Waste Funct.	Screen 1: Contain. & Isol. Strategy	Screen 1: TSPA & PA process models	Screen 2 (one must apply): Subsurface conditions	Screen 2: Affected by const./emplacement	Screen 2: Time dependent variable	Screen 3 (all must apply): Can be measured or derived	Screen 3: Can be predicted or estimated	Screen 3: Important to performance	Screen 4: Reduce uncertainty	Performance Confirmation Parameters: All perf. conf. parameters	Performance Confirmation Parameters: Key parameters for design	Preliminary Performance Confirmation Concepts (bold if influencing design)
Thermal Characteristics of Alluvium/Colluvium and Rock Matrix														
Rock temperature		X		X		X	X	X	X	X				None, no effect expected prior to repository closure
Thermal conductivity		X		X				X	X	X				None because sufficiently known for license application
Thermal expansion coefficient				X				X	X					
Heat capacity				X				X	X					
ROCK FRACTURE ZONES (INCLUDING FAULTS)														
Geometry, Including Future Displacements of Rock Fracture Zones (including Faults)														
Location				X			X	X	X					None because sufficiently known for license application
Width				X			X	X	X					
Length				X			X	X	X					
Orientation				X			X	X	X					
Displacement				X			X	X	X	X				
Fracture aperture				X			X	X	X					
Fracture density				X			X	X	X					
Frequency/probability of future faulting				X				X	X	X				None because computed from other observations
Biological Characteristics of Rock Fracture Zones (including Faults)														
List of microbes				X		X	X	X						None because sufficiently known for license application
Microbial activity				X		X	X	X						

Table C-3. Saturated Zone Parameter Selection

Parameters (important performance assessment parameters are bolded)	Selection Criteria: Screen 1 (one must apply): 10 CFR 60 Subpart F	Screen 1: Confine & Isolate Waste Funct.	Screen 1: Contain. & Isol. Strategy	Screen 1: TSPA & PA process models	Screen 2 (one must apply): Subsurface conditions	Screen 2: Affected by const./emplacement	Screen 2: Time dependent variable	Screen 3 (all must apply): Can be measured or derived	Screen 3: Can be predicted or estimated	Screen 3: Important to performance	Screen 4: Reduce uncertainty	Performance Confirmation Parameters: All perf. conf. parameters	Performance Confirmation Parameters: Key parameters for design	Preliminary Performance Confirmation Concepts (bold if influencing design)
Chemical/Mineralogical Characteristics of Infillings of Rock Fractures														
Mineralogy				X				X	X					None because sufficiently known for license application
Chemical composition of minerals				X			X	X	X					
Mineral solubility				X				X	X					
Mineral dissolution rate				X				X	X					
Mineral precipitation rate				X				X	X					
Apparent age of minerals				X			X	X						
Hydraulic Characteristics of Rock Fracture Zones (including Faults)														
Saturated hydraulic conductivity/permeability				X				X	X					None because sufficiently known for license application
Effective porosity				X				X	X					
Dispersivity/dispersion coefficient				X				X	X					
Storativity/storage coefficient				X				X	X					
Roughness coefficient				X				X	X					
GROUND WATER (IN ROCK MATRIX, FRACTURE, FAULT ZONES, AND OTHER DISCONTINUITIES)														
Chemical Characteristics of Ground Water (In Rock Matrix, Fracture, Fault Zones, and Other Discontinuities)														
Chemical composition, incl. Eh and pH		X		X		X	X	X	X	X				None because sufficiently known for license application
Age (H-3, Cl-36, C-14)				X			X	X						None because sufficiently known for license application

Table C-3. Saturated Zone Parameter Selection

Parameters (important performance assessment parameters are bolded)	Selection Criteria: Screen 1 (one must apply)				Screen 2 (one must apply)			Screen 3 (all must apply)			Screen 4	Performance Confirmation Parameters		Preliminary Performance Confirmation Concepts (bold if influencing design)
	10 CFR 60 Subpart F	Confine & Isolate Waste Funct.	Contain. & Isol. Strategy	TSPA & PA process models	Subsurface conditions	Affected by const./emplacement	Time dependent variable	Can be measured or derived	Can be predicted or estimated	Important to performance	Reduce uncertainty	All perf. conf. parameters	Key parameters for design	
Hydraulic Characteristics of Ground Water (In Rock Matrix, Fracture, Fault Zones, and Other Discontinuities)														
Water table elevation		X	X	X		X	X	X	X	X	X	X		Continuously or periodically in surface-based boreholes
Fluid potential in confined aquifers				X			X	X	X					None because sufficiently known for license application
Ground-water flux		X	X	X		X	X	X	X	X	X	X		Calculated from soil/rock moisture measurements
Pre-waste emplacement GWTT from beneath repository to accessible environment		X		X			X	X	X	X	X	X		Calculated from other hydrogeologic measurements
Post-waste emplacement GWTT from beneath repository to accessible environment				X			X	X	X	X	X	X		
Mechanical Characteristics of Ground Water (In Rock Matrix, Fracture, Fault Zones, and Other Discontinuities)														
Density				X		X	X	X	X					None because sufficiently known for license application
Viscosity				X		X	X	X	X					
Thermal Characteristics of Ground Water														
Ground-water temperature		X		X		X	X	X	X	X				None, no effects expected before repository closure
Heat capacity				X				X	X					None because sufficiently known for license application
Thermal conductivity				X				X	X					None because sufficiently known for license application

Table C-3. Saturated Zone Parameter Selection

Parameters (important performance assessment parameters are bolded)	Selection Criteria: Screen 1 (one must apply): 10 CFR 60 Subpart F	Screen 1: Confine & Isolate Waste Funct.	Screen 1: Contain. & Isol. Strategy	Screen 1: TSPA & PA process models	Screen 2 (one must apply): Subsurface conditions	Screen 2: Affected by const./emplacement	Screen 2: Time dependent variable	Screen 3 (all must apply): Can be measured or derived	Screen 3: Can be predicted or estimated	Screen 3: Important to performance	Screen 4: Reduce uncertainty	Performance Confirmation Parameters: All perf. conf. parameters	Performance Confirmation Parameters: Key parameters for design	Preliminary Performance Confirmation Concepts (bold if influencing design)
Aqueous Radionuclide Transport of each Important Radionuclide (see TSPA-1995 list at end of table)														
Sorption/retardation coefficient/Kd		X		X		X	X	X	X	X				None because sufficiently known for license application
Radionuclide concentration		X	X	X		X	X	X	X	X	X	X		Annually in surface-based boreholes, continuously or more frequently if detected
Radionuclide release rate to accessible environment		X	X	X		X	X	X	X	X	X	X		Calculated from saturated-zone water flux & radionuclide concentrations

<u>**Abbreviations**</u>:
CFR = Code of Federal Regulations, GWTT = ground-water travel time, PA = performance assessment, TSPA = total system performance assessment, WP = waste package.

<u>TSPA-1995 Radionuclide List</u> (for spent-fuel inventory):
Ac-227, Am-241, Am-242M, Am-243, C-14 (gaseous), Cl-36 (gaseous), Cm-244, Cm-245, Cm-246, Cs-135, I-129 (gaseous), Nb-93M, Nb-94, Ni-59, Ni-63, Np-237, Pa-231, Pb-210, Pd-107, Pu-238, Pu-239, Pu-240, Pu-241, Pu-242, Ra-226, Ra-228, Se-79, Sm-151, Sn-126, Tc-99, Th-229, Th-230, Th-232, U-233, U-234, U-235, U-236, U-238, Zr-93.

Table C-4. Repository Excavation and Borehole Parameter Selection

Selection process: A parameter has to pass each screen in order to be considered for the next screen. Only one criterion needs to apply in order for a parameter to move from Screen 1 to Screen 2 and from Screen 2 to Screen 3. At least one criterion has to apply from both Screen 1 and Screen 2, all three criteria of Screen 3 and the criterion of Screen 4 have to apply in order for a parameter to be selected as a performance confirmation parameter. See the text and flowchart for a more detailed explanation of the selection criteria and process.

Matrix scope: This matrix lists the characteristics of excavations, including the subsurface repository and subsurface- and surface-based boreholes. Radionuclide, waste form, and waste container characteristics are listed in the Waste Package Parameters matrix. Natural barrier characteristics, including for the rock bounding the excavations, are listed in the General Site, Unsaturated Zone, and Saturated Zone Parameters matrices.

Parameters (important performance assessment parameters are bolded)	Selection Criteria											Performance Confirmation Parameters		Preliminary Performance Confirmation Concepts (bold if influencing design)
	Screen 1 (one must apply)				Screen 2 (one must apply)			Screen 3 (all must apply)			Screen 4			
	10 CFR 60 Subpart F	Confine & Isolate Waste Funct.	Contain. & Isol. Strategy	TSPA & PA process models	Subsurface conditions	Affected by const./emplacement	Time dependent variable	Can be measured or derived	Can be predicted or estimated	Important to performance	Reduce uncertainty	All perf. conf. parameters	Key parameters for design	
EXCAVATION GEOMETRY														
Geometry of Ramps, Shafts, Alcoves, and Transportation Drifts														
Layout				X				X						None because initial condition
Initial dimensions				X				X						
Deformation/ convergence	X			X	X	X		X	X					As required for preclosure health & safety
Rock fall/collapse size	X			X	X	X		X	X					
Geometry of Waste Emplacement Drifts														
Layout				X				X						None because initial condition
Initial dimensions				X				X						
Deformation/ convergence	X	X		X	X	X	X	X	X	X	X	X	X	**Continuous at selected underground locations**
Rock fall/collapse size	X	X		X	X	X	X	X	X	X	X	X	X	**Periodic underground inspection**

Table C-4. Repository Excavation and Borehole Parameter Selection

Parameters (important performance assessment parameters are bolded)	Selection Criteria											Performance Confirmation Parameters		Preliminary Performance Confirmation Concepts (bold if influencing design)
	Screen 1 (one must apply)				Screen 2 (one must apply)			Screen 3 (all must apply)			Screen 4			
	10 CFR 60 Subpart F	Confine & Isolate Waste Funct.	Contain. & Isol. Strategy	TSPA & PA process models	Subsurface conditions	Affected by const./emplacement	Time dependent variable	Can be measured or derived	Can be predicted or estimated	Important to performance	Reduce uncertainty	All perf. conf. parameters	Key parameters for design	
Geometry of Subsurface- and Surface-Based Boreholes														
Location				X				X						None because initial condition
Drilled Depth				X				X						
Drilled Diameter				X				X						
Defomation				X			X	X	X					Inspection prior to sealing as part of sealing program
SUBSURFACE REPOSITORY EXCAVATION ENVIRONMENT (RAMPS, SHAFTS, ALCOVES, AND EMPLACEMENT DRIFTS)														
Physical Characteristics of Excavation Environment (Ramps, Shafts, Alcoves, and Emplacement Drifts)														
Air pressure				X		X	X	X	X					As required for preclosure health & safety
Air velocity/flux (ventilation air flow)				X		X	X	X	X					
Dry bulb air temperature		X		X		X	X	X	X	X	X	X	X	**Continuous at portals & selected underground locations**
Wet bulb air temperature				X		X	X	X	X					Derived from dry bulb temp. & relative humidity
Relative humidity		X	X	X		X	X	X	X	X	X	X	X	**Continuous at portals & selected underground locations**
Ground-water inflow rate into excavation	X	X	X	X	X	X	X	X	X	X	X	X	X	**According to perched water procedure**
Ground-water inflow temperature	X	X		X	X	X	X	X	X	X	X	X	X	

Table C-4. Repository Excavation and Borehole Parameter Selection

Parameters (important performance assessment parameters are bolded)	Selection Criteria: Screen 1 (one must apply)				Screen 2 (one must apply)			Screen 3 (all must apply)			Screen 4	Performance Confirmation Parameters		Preliminary Performance Confirmation Concepts (bold if influencing design)
	10 CFR 60 Sub-part F	Con-fine & Isolate Waste Funct.	Con-tain. & Isol. Stra-tegy	TSPA & PA process models	Sub-surface condi-tions	Affec-ted by const./ empla-cement	Time depen-dent vari-able	Can be mea-sured or derived	Can be pre-dicted or esti-mated	Impor-tant to per-form-ance	Reduce uncer-tainty	All perf. conf. para-meters	Key para-meters for design	
Ground-water outflow rate from excavation		X	X	X		X	X	X	X	X				Not practical to monitor, estimated from ground -water flow modeling
Ground-water outflow temperature				X		X	X	X	X	X				
Rate/volume of ground-water pumped to surface				X		X	X	X		X				As required for preclosure operations
Chemical Characteristics of Excavation Environment (Ramps, Shafts, Alcoves, and Emplacement Drifts)														
Airborne particulate concentration				X			X	X	X					As required for preclosure health & safety
Carbon monoxide concentration				X			X	X	X					
Oxygen concentration				X			X	X	X					
NOx concentration				X			X	X	X					
SOx concentration				X			X	X	X					
Natural radon gas concentration				X			X	X	X					
Chemical composition, Eh & pH of ground-water inflow	X	X		X	X	X	X	X	X	X	X	X	X	**According to perched water procedure**
Chemical composition, Eh & pH of ground-water outflow		X		X		X	X	X	X	X	X	X		Not practical to monitor, estimated from geochemical modeling

Table C-4. Repository Excavation and Borehole Parameter Selection

Parameters (important performance assessment parameters are bolded)	Selection Criteria											Performance Confirmation Parameters		Preliminary Performance Confirmation Concepts (bold if influencing design)
	Screen 1 (one must apply)				Screen 2 (one must apply)			Screen 3 (all must apply)			Screen 4			
	10 CFR 60 Subpart F	Confine & Isolate Waste Funct.	Contain. & Isol. Strategy	TSPA & PA process models	Subsurface conditions	Affected by const./emplacement	Time dependent variable	Can be measured or derived	Can be predicted or estimated	Important to performance	Reduce uncertainty	All perf. conf. parameters	Key parameters for design	
Radiological Characteristics of Excavation Environment (Ramps, Shafts, Alcoves, and Emplacement Drifts)														
Alpha radiation	X			X		X	X	X	X					Will be detected, if any, by ventilation air monitoring required for preclosure health & safety
Beta radiation	X			X		X	X	X	X					
Gamma radiation	X			X		X	X	X	X					Remedial action if alpha or beta radiation detected in ventilation air monitoring
Neutron radiation	X			X		X	X	X	X					
WASTE EMPLACEMENT FOR EACH WASTE TYPE AND WASTE PACKAGE DESIGN (see waste package table for radionuclide, waste form, and waste container characteristics)														
Location within repository				X				X	X	X				None because initial condition
Location within individual drift				X				X	X	X				
Thermal loading				X			X	X	X	X				
Areal mass loading				X			X	X	X	X				
Number of waste packages				X			X	X	X	X				
ESF & REPOSITORY CONSTRUCTION FLUIDS AND MATERIALS REMAINING AFTER REPOSITORY CLOSURE (other than backfill and seals)														
Construction and Fire Water, Including Accidental Spills														
Quantity used		X		X			X	X	X	X				None because construction & operation records
Quantity remaining in rock		X		X		X	X	X	X	X	X	X	X	**Periodic rock sampling at selected underground locations & off-site lab analyses**
Chemical composition, incl. Eh & pH		X		X		X	X	X	X	X	X	X	X	

Table C-4. Repository Excavation and Borehole Parameter Selection

Parameters (important performance assessment parameters are bolded)	Selection Criteria											Performance Confirmation Parameters		Preliminary Performance Confirmation Concepts (bold if influencing design)
	Screen 1 (one must apply)				Screen 2 (one must apply)			Screen 3 (all must apply)			Screen 4			
	10 CFR 60 Subpart F	Confine & Isolate Waste Funct.	Contain. & Isol. Strategy	TSPA & PA process models	Subsurface conditions	Affected by const./emplacement	Time dependent variable	Can be measured or derived	Can be predicted or estimated	Important to performance	Reduce uncertainty	All perf. conf. parameters	Key parameters for design	
Hydrocarbons, Including Accidental Spills (each type that may affect postclosure performance)														
Quantity used		X					X	X	X	X				None because construction & operation records
Quantity remaining in rock		X		X		X	X	X	X	X	X	X	X	**Periodic rock sampling at selected underground locations & off-site lab analyses**
Chemical composition, incl. Eh & pH		X		X		X	X	X	X	X	X	X	X	
Concrete														
Quantity		X		X		X	X	X	X	X				None because construction & operation records
Chemical composition/alteration		X		X		X	X	X	X	X	X	X	X	**Periodic inspection & off-site lab analysis of samples**
Steel														
Quantity		X		X		X	X	X	X	X				None because construction & operation records
Chemical composition/alteration		X		X		X	X	X	X	X	X	X	X	**Periodic inspection & off-site lab analysis of samples**
Ground Support														
Design/emplacement specifications		X		X		X	X	X	X	X				None because construction & operation records
Chemical composition/alteration		X		X		X	X	X	X	X	X	X	X	**Periodic inspection & off-site lab analysis of specimens**

Table C-4. Repository Excavation and Borehole Parameter Selection

Parameters (important performance assessment parameters are bolded)	Selection Criteria: Screen 1 (one must apply): 10 CFR 60 Subpart F	Screen 1: Confine & Isolate Waste Funct.	Screen 1: Contain. & Isol. Strategy	Screen 1: TSPA & PA process models	Screen 2 (one must apply): Subsurface conditions	Screen 2: Affected by const./emplacement	Screen 2: Time dependent variable	Screen 3 (all must apply): Can be measured or derived	Screen 3: Can be predicted or estimated	Screen 3: Important to performance	Screen 4: Reduce uncertainty	Performance Confirmation Parameters: All perf. conf. parameters	Performance Confirmation Parameters: Key parameters for design	Preliminary Performance Confirmation Concepts (bold if influencing design)
Railcars														
Number		X		X		X	X	X	X	X				None because construction & operation records
Design specifications		X		X		X	X	X	X	X				
Chemical composition/alteration		X		X		X	X	X	X	X	X	X	X	**Periodic inspection & off-site lab analysis of specimens**
Other Fluids and Materials Remaining in Repository after Closure (each type that may affect postclosure performance)														
Quantity		X		X		X	X	X	X	X				None because construction & operation records
Chemical composition/alteration		X		X		X	X	X	X	X	X	X	X	**Periodic inspection & off-site lab analysis of specimens or rock samples, as applicable**
ENGINEERED BARRIER SYSTEM RELEASE OF EACH IMPORTANT RADIONUCLIDE (see TSPA-1995 list at end of table)														
Gaseous radionuclide concentration in emplacement drift walls		X		X		X	X	X	X	X				Underground air monitoring, remedial action if detected
Gaseous radionuclide release rate into host rock		X		X		X	X	X	X	X				None because calculated from radionuclide concentrations
Aqueous radionuclide concentration in emplacement drift walls		X	X	X		X	X	X	X	X				Underground air monitoring, remedial action if gaseous release detected
Aqueous radionuclide release rate into host rock		X	X	X		X	X	X	X	X				None because calculated from radionuclide concentrations

Table C-4. Repository Excavation and Borehole Parameter Selection

Parameters (important performance assessment parameters are bolded)	Selection Criteria											Performance Confirmation Parameters		Preliminary Performance Confirmation Concepts (bold if influencing design)
	Screen 1 (one must apply)				Screen 2 (one must apply)			Screen 3 (all must apply)			Screen 4			
	10 CFR 60 Subpart F	Confine & Isolate Waste Funct.	Contain. & Isol. Strategy	TSPA & PA process models	Subsurface conditions	Affected by const./emplacement	Time dependent variable	Can be measured or derived	Can be predicted or estimated	Important to performance	Reduce uncertainty	All perf. conf. parameters	Key parameters for design	
Fractional radionuclide release relative to 1000-yr inventory		X		X		X	X	X	X	X	X	X		None because calculated from release into host rock

Abbreviations:
CFR = Code of Federal Regulations, ESF = Exploratory Studies Facility, PA = performance assessment, TSPA = total system performance assessment, WP = waste package.

TSPA-1995 Radionuclide List (for spent-fuel inventory):
Ac-227, Am-241, Am-242M, Am-243, C-14 (gaseous), Cl-36 (gaseous), Cm-244, Cm-245, Cm-246, Cs-135, I-129 (gaseous), Nb-93M, Nb-94, Ni-59, Ni-63, Np-237, Pa-231, Pb-210, Pd-107, Pu-238, Pu-239, Pu-240, Pu-241, Pu-242, Ra-226, Ra-228, Se-79, Sm-151, Sn-126, Tc-99, Th-229, Th-230, Th-232, U-233, U-234, U-235, U-236, U-238, Zr-93.

Table C-5. Waste Package Parameter Selection

Selection process: A parameter has to pass each screen in order to be considered for the next screen. Only one criterion needs to apply in order for a parameter to move from Screen 1 to Screen 2 and from Screen 2 to Screen 3. At least one criterion has to apply from both Screen 1 and Screen 2, all three criteria of Screen 3 and the criterion of Screen 4 have to apply in order for a parameter to be selected as a performance confirmation parameter. See the text and flowchart for a more detailed explanation of the selection criteria and process.

Matrix scope: This matrix lists radionuclide, waste form, and waste container characteristics. The characteristics of excavations, including the subsurface repository and subsurface- and surface-based boreholes, are listed in the Repository Key Performance Confirmation Parameter Selection matrix. Natural barrier characteristics, including for the rock bounding the excavations, are listed in the General Site, Unsaturated Zone, and Saturated Zone Key Performance Confirmation Parameter Selection matrices.

Parameters for each waste type & waste package design (important performance assessment parameters are bolded)	**Selection Criteria**											**Performance Confirmation Parameters**		**Preliminary Performance Confirmation Concepts** (bolded if influencing design)
	Screen 1 (one must apply)				**Screen 2** (one must apply)			**Screen 3** (all must apply)			**Screen 4**			
	10 CFR 60 Subpart F	**Confine & Isolate Waste Funct.**	**Contain. & Isol. Strategy**	**TSPA & PA process models**	**Subsurface conditions**	**Affected by const./emplacement**	**Time dependent variable**	**Can be measured or derived**	**Can be predicted or estimated**	**Important to performance**	**Reduce uncertainty**	**All perf. conf. parameters**	**Key parameters for design**	
WASTE FORM CHARACTERISTICS (e.g., of Spent Fuel and Glass Defense High-level Waste)														
Type of waste		X	X	X				X	X	X				None because design & emplacement records
Weight of waste per waste package		X	X	X			X	X	X	X				None, change before repository closure predictable
Age at emplacement time		X	X	X				X	X					None because design & emplacement records
Geometry/dimensions of waste form	X	X	X	X			X	X	X	X	X	X	X	**On-site lab analyses of failed waste packages, if any, and of waste not emplaced**
Geometry/dimensions of waste pellets/ particles	X	X	X	X			X	X	X	X	X	X	X	
Surface area of waste pellets or particles	X	X	X	X			X	X	X	X	X	X	X	
Spent-fuel burnup rate		X	X	X				X	X	X				None because design & emplacement records
List of all radionuclides				X				X	X					
of important radionuclides		X	X	X				X	X	X				None because identified by performance analyses

Table C-5. Waste Package Parameter Selection

Parameters for each waste type & waste package design (important performance assessment parameters are bolded)	Selection Criteria											Performance Confirmation Parameters		Preliminary Performance Confirmation Concepts (bolded if influencing design)
	Screen 1 (one must apply)				Screen 2 (one must apply)			Screen 3 (all must apply)			Screen 4			
	10 CFR 60 Sub-part F	Con-fine & Isolate Waste Funct.	Con-tain. & Isol. Stra-tegy	TSPA & PA process models	Sub-surface condi-tions	Affec-ted by const./ empla-cement	Time depen-dent vari-able	Can be mea-sured or derived	Can be pre-dicted or esti-mated	Impor-tant to per-form-ance	Reduce uncer-tainty	All perf. conf. para-meters	Key para-meters for design	
Radionuclide chain definition		X	X	X				X	X					None because well established
Weight & activity of each radionuclide		X	X	X			X	X	X	X	X	X	X	**On-site lab analyses of failed waste packages, if any, and of waste not emplaced**
Gas composition inside fuel element		X	X	X			X	X	X	X	X	X	X	
Thermal output/decay heat		X	X	X			X	X	X	X				See waste package & drift air temperature monitoring
Alpha radiation at waste surface	X			X			X	X	X					None because not considered important
Beta radiation at waste surface	X			X			X	X	X					
Gamma radiation at waste surface	X	X		X			X	X	X					
Neutron radiation at waste surface	X	X		X			X	X	X					
Dry oxidation rate		X	X	X			X	X	X	X	X	X		**Off-site laboratory research because cannot complete for all waste forms before license application**
Dry oxidation products		X	X	X				X	X	X	X	X		
Dissolution rate of original waste form		X	X	X				X	X	X	X	X		
Dissolution rate of oxidation products		X	X	X				X	X	X	X	X		
Devitrification rate of glass waste		X	X	X				X	X					None because not considered important for long enough times at expected temperatures

Table C-5. Waste Package Parameter Selection

Parameters for each waste type & waste package design (important performance assessment parameters are bolded)	Selection Criteria											Performance Confirmation Parameters		Preliminary Performance Confirmation Concepts (bolded if influencing design)
	Screen 1 (one must apply)				Screen 2 (one must apply)			Screen 3 (all must apply)			Screen 4			
	10 CFR 60 Subpart F	Confine & Isolate Waste Funct.	Contain. & Isol. Strategy	TSPA & PA process models	Subsurface conditions	Affected by const./emplacement	Time dependent variable	Can be measured or derived	Can be predicted or estimated	Important to performance	Reduce uncertainty	All perf. conf. parameters	Key parameters for design	
Dissolution rate of devitrified glass waste			X	X				X	X					None because not considered important for long enough times at expected temperatures
Oxidation enhancement by radiation			X	X				X	X					None because not considered important
Dissolution rate enhancement by radiation				X				X	X					
RADIONUCLIDE CHARACTERISTICS OF EACH IMPORTANT RADIONUCLIDE (see TSPA-1995 list at end of table)														
Half-life		X	X	X				X	X	X				None because well established
Solubility		X	X	X				X	X	X				None because sufficiently known for license application
Dissolution rate		X	X	X				X	X	X				
Dissolution rate enhancement by radiation				X				X	X					None because not considered important
Speciation		X	X	X			X	X	X	X				None because sufficiently known for license application
Colloid transport properties		X	X	X				X	X	X				
Molecular diffusion coefficient		X		X				X	X	X				None because well established
GEOMETRY OF WASTE PACKAGE (Excluding Backfill)														
Initial outside dimensions of waste package				X				X	X	X				None because design & emplacement records
Number of barriers			X	X				X	X	X				
Material of each barrier		X	X	X				X	X	X				
Initial thickness of each barrier		X		X				X	X	X				None because design parameter

Table C-5. Waste Package Parameter Selection

Parameters for each waste type & waste package design (important performance assessment parameters are bolded)	Selection Criteria: Screen 1 (one must apply): 10 CFR 60 Subpart F	Screen 1: Con-fine & Isolate Waste Funct.	Screen 1: Con-tain. & Isol. Stra-tegy	Screen 1: TSPA & PA process models	Screen 2 (one must apply): Sub-surface condi-tions	Screen 2: Affec-ted by const./ empla-cement	Screen 2: Time depen-dent vari-able	Screen 3 (all must apply): Can be mea-sured or derived	Screen 3: Can be pre-dicted or esti-mated	Screen 3: Impor-tant to per-form-ance	Screen 4: Reduce uncer-tainty	Performance Confirmation Parameters: All perf. conf. para-meters	Performance Confirmation Parameters: Key para-meters for design	Preliminary Performance Confirmation Concepts (bolded if influencing design)
Corrosion effects on barrier thickness & shape		X	X	X		X	X	X	X	X	X	X	X	**Periodic visual inspection, on-site lab analyses of pulled specimens & non-waste packages**
Mechanical effects on barrier thickness & shape		X		X		X	X	X	X	X	X	X	X	**Periodic visual inspection**
Location & geometry of criticality control materials		X		X			X	X	X	X	X	X	X	**Non-waste package off-site & pulled dummy waste package on-site lab analysis**
CORROSION AND OTHER DEGRADATION CHARACTERISTICS OF EACH WASTE PACKAGE BARRIER (Excluding Backfill)														
Polarity of current for galvanic protection		X	X	X			X	X	X	X	X	X		Off-site lab research
Common potential for galvanic protection		X	X	X			X	X	X	X	X	X		
Dry oxidation corrosion rate		X	X	X		X		X	X	X	X	X	X	**On-site lab analysis of pulled specimens & dummy waste packages**
Threshold humidity for humid-air corrosion			X	X			X	X	X	X	X	X	X	
Humid-air general corrosion rate		X	X	X		X		X	X	X	X	X	X	
Aqueous general corrosion rate		X	X	X		X		X	X	X	X	X	X	

Table C-5. Waste Package Parameter Selection

Parameters for each waste type & waste package design (important performance assessment parameters are bolded)	Selection Criteria											Performance Confirmation Parameters		Preliminary Performance Confirmation Concepts (bolded if influencing design)
	Screen 1 (one must apply)				Screen 2 (one must apply)			Screen 3 (all must apply)			Screen 4			
	10 CFR 60 Sub-part F	Con-fine & Isolate Waste Funct.	Con-tain. & Isol. Stra-tegy	TSPA & PA process models	Sub-surface condi-tions	Affec-ted by const./ empla-cement	Time depen-dent vari-able	Can be mea-sured or derived	Can be pre-dicted or esti-mated	Impor-tant to per-form-ance	Reduce uncer-tainty	All perf. conf. para-meters	Key para-meters for design	
Humid-air pit corrosion rate		X	X	X		X		X	X	X	X	X	X	**On-site lab analysis of pulled specimens & dummy waste packages**
Aqueous pit corrosion rate		X	X	X		X		X	X	X	X	X	X	
Microbial corrosion rate				X		X		X	X	X	X	X	X	
Threshold stress for stress-corrosion cracking				X			X	X	X					None because not expected before repository closure
Stress-corrosion crack growth rate				X		X		X	X					
Corrosion rate induced by mechanical damage/deformation				X		X	X	X	X					
Cladding failure rate [1]		X		X		X		X	X	X	X	X	X	**On-site lab analysis of pulled waste packages**
Internal corrosion rate				X		X		X	X					None because not important if waste package loaded in dry environment
Oxidation rate enhance-ment by radiation				X				X	X					None because not considered important due to low radiation dose rates at waste package surface
Corrosion rate enhance-ment by radiation				X				X	X					

[1] Needed only if (a) credit will be taken for cladding performance or (b) its performance will adversely affect the performance of other engineered barrier system components.

Table C-5. Waste Package Parameter Selection

Parameters for each waste type & waste package design (important performance assessment parameters are bolded)	Selection Criteria: Screen 1 (one must apply)				Screen 2 (one must apply)			Screen 3 (all must apply)			Screen 4	Performance Confirmation Parameters		Preliminary Performance Confirmation Concepts (bolded if influencing design)
	10 CFR 60 Sub-part F	Con-fine & Isolate Waste Funct.	Con-tain. & Isol. Stra-tegy	TSPA & PA process models	Sub-surface condi-tions	Affec-ted by const./ empla-cement	Time depen-dent vari-able	Can be mea-sured or derived	Can be pre-dicted or esti-mated	Impor-tant to per-form-ance	Reduce uncer-tainty	All perf. conf. para-meters	Key para-meters for design	
CHEMISTRY OF EACH WASTE PACKAGE BARRIER (Including Degradation Products but Excluding Backfill)														
Initial chemical composition				X				X	X	X				None because design parameter
Gas composition inside waste container		X	X	X			X	X	X	X	X	X	X	**On-site lab analyses of failed waste packages, if any, and of waste not emplaced**
Phase stability of materials				X				X	X					None because well established
Chemical composition of criticality control materials		X		X			X	X	X	X	X	X	X	**Non-waste package off-site & pulled dummy waste package on-site lab analysis**
Oxidation product composition			X	X			X	X	X	X	X	X	X	
Aqueous corrosion product composition			X	X			X	X	X	X	X	X	X	
Physical/chemical degree of embrittlement				X		X	X	X	X	X	X	X	X	
Physical/chemical weld integrity	X			X		X	X	X	X	X	X	X	X	
Radionuclide sorption/ retardation coefficient/ Kd for waste package degradation products				X				X	X					None because do not plan to take credit

Table C-5. Waste Package Parameter Selection

Parameters for each waste type & waste package design (important performance assessment parameters are bolded)	Selection Criteria: Screen 1 (one must apply)				Screen 2 (one must apply)			Screen 3 (all must apply)			Screen 4	Performance Confirmation Parameters		Preliminary Performance Confirmation Concepts (bolded if influencing design)
	10 CFR 60 Subpart F	Confine & Isolate Waste Funct.	Contain. & Isol. Strategy	TSPA & PA process models	Subsurface conditions	Affected by const./emplacement	Time dependent variable	Can be measured or derived	Can be predicted or estimated	Important to performance	Reduce uncertainty	All perf. conf. parameters	Key parameters for design	
HYDRAULIC CHARACTERISTICS OF POROUS WASTE PACKAGE MATERIALS, IF ANY [2] (Including Degradation Products but Excluding Backfill)														
Moisture content				X			X	X	X					None because not considered important
Humidity				X			X	X	X					
Saturated hydraulic conductivity				X				X	X					
Effective porosity				X				X	X					
Dispersivity/dispersion coefficient				X				X	X					None because sufficiently known for license application
Storativity/storage coefficient				X				X	X					None because not considered important
Hydraulic potential - moisture content relationship				X				X	X					
Moisture content - hydraulic conductivity relationship				X				X	X					
Dispersivity - moisture content relationship				X				X	X					Not well understood, thus not considered
MECHANICAL CHARACTERISTICS OF EACH WASTE PACKAGE BARRIER (Excluding Backfill)														
In-situ stress		X		X		X	X	X	X	X	X	X	X	**Non-waste package off-site & pulled dummy waste package on-site lab analysis**
Strain				X		X	X	X	X	X	X	X	X	

2 Needed only if porous materials other than the waste itself will be used inside the waste package, and (a) credit will be taken for the performance of these materials and/or their degradation products, or (b) these porous materials and/or their degradation products will adversely affect the performance of other engineered barrier system components.

Table C-5. Waste Package Parameter Selection

Parameters for each waste type & waste package design (important performance assessment parameters are bolded)	Selection Criteria: Screen 1 (one must apply): 10 CFR 60 Subpart F	Con-fine & Isolate Waste Funct.	Con-tain. & Isol. Stra-tegy	TSPA & PA process models	Screen 2 (one must apply): Sub-surface condi-tions	Affec-ted by const./ empla-cement	Time depen-dent vari-able	Screen 3 (all must apply): Can be mea-sured or derived	Can be pre-dicted or esti-mated	Impor-tant to per-form-ance	Screen 4: Reduce uncer-tainty	Performance Confirmation Parameters: All perf. conf. para-meters	Key para-meters for design	Preliminary Performance Confirmation Concepts (bolded if influencing design)
Bulk density				X				X	X	X				None because design values sufficient
Compressive strength		X		X				X	X	X				
Tensile strength		X		X				X	X	X				
Yield strength		X		X				X	X	X				
Fracture toughness				X				X	X	X				None because sufficiently known for license application
Elasticity				X				X	X					None because design values sufficient
Compressibility				X				X	X					
Young's modulus				X				X	X					
Poisson ratio				X				X	X					
THERMAL CHARACTERISTICS OF EACH WASTE PACKAGE BARRIER (Excluding Backfill)														
Waste package center temperature		X	X	X		X	X	X	X	X	X	X		None because cannot be measured (can be derived)
Barrier wall temperature		X	X	X		X	X	X	X	X	X	X	X	**In-situ monitoring, selected waste packages & PC section**
Thermal conductivity				X				X	X	X				None because design values sufficient
Thermal expansion coefficient				X				X	X					
Heat capacity				X				X	X					
WASTE PACKAGE RADIONUCLIDE RELEASE FOR EACH WASTE FORM, PACKAGE DESIGN, AND IMPORTANT RADIONUCLIDE (see TSPA-1995 list at end of table)														
Waste package life or time of initial radio-nuclide release	X	X	X	X		X	X	X	X	X	X	X	X	**Continuous radiation monitoring of excavation air**

Table C-5. Waste Package Parameter Selection

Parameters for each waste type & waste package design (important performance assessment parameters are bolded)	Selection Criteria											Performance Confirmation Parameters		Preliminary Performance Confirmation Concepts (bolded if influencing design)
	Screen 1 (one must apply)				Screen 2 (one must apply)			Screen 3 (all must apply)			Screen 4			
	10 CFR 60 Subpart F	Confine & Isolate Waste Funct.	Contain. & Isol. Strategy	TSPA & PA process models	Subsurface conditions	Affected by const./emplacement	Time dependent variable	Can be measured or derived	Can be predicted or estimated	Important to performance	Reduce uncertainty	All perf. conf. parameters	Key parameters for design	
Radionuclide release rate from waste form	X	X	X	X		X	X	X	X	X	X	X	X	**Remedial action if needed**
Radionuclide release rate from waste package	X	X	X	X		X	X	X	X	X	X	X	X	

__Abbreviations__:
CFR = Code of Federal Regulations, PA = performance assessment, TSPA = total system performance assessment, WP = waste package.

__TSPA-1995 Radionuclide List__ (for spent-fuel inventory):
Ac-227, Am-241, Am-242M, Am-243, C-14 (gaseous), Cl-36 (gaseous), Cm-244, Cm-245, Cm-246, Cs-135, I-129 (gaseous), Nb-93M, Nb-94, Ni-59, Ni-63, Np-237, Pa-231, Pb-210, Pd-107, Pu-238, Pu-239, Pu-240, Pu-241, Pu-242, Ra-226, Ra-228, Se-79, Sm-151, Sn-126, Tc-99, Th-229, Th-230, Th-232, U-233, U-234, U-235, U-236, U-238, Zr-93.