Physical System Requirements
Exploratory Studies Facility

Appendix G, ESF Mission Analysis
and
Appendix H, Traceability of ESF Mission to "Dispose of Waste" Requirements

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by

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APPENDIX G

ESF MISSION ANALYSIS

APPENDIX G
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1.0 INTRODUCTION

1.1 BACKGROUND

The Nuclear Waste Policy Act (NWPA) of 1982 assigned to the U.S. Department of Energy (DOE) the responsibility for managing the disposal of spent nuclear fuel and high-level radioactive waste and established the Office of Civilian Radioactive Waste Management (OCRWM) for that purpose. The Secretary of Energy, in his November 1989 report to Congress (DOE/RW-0247), announced three new initiatives for conduct of the Civilian Radioactive Waste Management (CRWM) program. One of these initiatives was to establish improved management structure and procedures. In response, OCRWM performed a management study and the Director subsequently issued the Management System Improvement Strategy (MSIS) on August 10, 1990, calling for a rigorous implementation of systems engineering principles with special emphasis on functional analysis.

A primary objective of OCRWM's MSIS is to establish a consistent set of program requirements, including:

- Requirements for the physical systems that will ultimately comprise the Waste Management System,
- Requirements for the management program that must bring this system into being, and
- Requirements for the test facilities that will be used to demonstrate that the selected site and engineered systems will comply with their ultimate requirements.

Just as the requirements for the waste management physical and programmatic systems are being developed via functional analysis, so too are the requirements for the Exploratory Studies Facility (ESF). However, before a functional analysis of the ESF can begin, the mission of the ESF must be explicitly described. This appendix presents details of the results of a comprehensive mission analysis for the ESF from which an ESF functional analysis can proceed.

1.2 OBJECTIVE

The mission of the ESF, as interpreted from the NWPA, can be stated succinctly as,

...to conduct subsurface exploration and testing, in support of site suitability determination and license application, in a manner that protects the environment and nuclear waste isolation capabilities of the site.

The objective of the ESF mission analysis effort is to expand this general mission statement into the explicit program needs that must be fulfilled by an ESF during the site characterization program.

According to the Code of Federal Regulations in Title 10, Part 60 (10 CFR 60.2), site characterization means,

The program of exploration and research, both in the laboratory and in the field, undertaken to establish the geologic conditions and the ranges of those parameters of a particular site relevant to the procedures under this part. Site characterization includes borings, surface excavations, excavation of exploratory shafts, limited subsurface lateral excavations and borings, and in situ testing at depth needed to determine the suitability of the site for a geologic repository, but does not include preliminary borings and geophysical testing needed to decide whether site characterization should be undertaken.

Furthermore, 10 CFR 60.15(b) states that,

Unless the Commission determines with respect to the site described in the application that it is not necessary, site characterization shall include a program of in situ exploration and testing at the depths that waste would be emplaced.

The objective of this appendix is to present the results of the ESF mission analysis effort in support of site characterization. Appendix H demonstrates the traceability of these results to the "Dispose of Waste" functional analysis.

1.3 SCOPE

The scope of this ESF mission analysis effort is limited to the specification of test requirements that must be satisfied by an ESF in support of site characterization and, if the site is determined to be suitable, license application for construction of a geologic repository. The time period covers from initiation of ESF testing through either Presidential recommendation as a geologic repository or Secretarial determination of unsuitability as a geologic repository, whichever comes first. The analysis stems from the requirements contained in the Physical System Requirements - Dispose of Waste document and draws upon the extensive technical knowledge behind the preparation of the Site Characterization Program Baseline.

2.0 TECHNICAL APPROACH

Figure 2-1 illustrates the overall approach used to define the Exploratory Studies Facility (ESF) mission, such that it is consistent with the results of the "Dispose of Waste" functional analysis and provides the basis for conducting an ESF functional analysis.

2.1 OVERVIEW

A primary objective of the ESF is to collect data that are necessary to evaluate the ability of the site to comply with the requirements imposed upon a geologic repository. Thus, the first step of the mission analysis effort was to collect the entire set of requirements, as specified in the Physical System Requirements - Dispose of Waste document, and to define explicit performance measures for each requirement. Estimated values for the performance measures are the ultimate indicators for whether each geologic repository requirement is likely to be satisfied, or not. These estimates will be based on evaluations by the appropriate experts.

Because many of the geologic repository requirements/performance measures can be completely addressed with non-ESF data, it was necessary to segment the performance measures into two distinct groups: those related to subsurface-based testing in an ESF and those not requiring ESF data. The former subgroup of geologic repository requirements/performance measures became the basis for developing a set of conceptual models portraying the logic that would eventually be used to estimate values for performance measures and, hence, evaluate the degree of compliance with the corresponding geologic repository requirements.

To make maximum use of the enormous technical effort put into the Site Characterization Program Baseline (SCPB), the geologic repository requirements/performance measures were related to a subset of the issues upon which the SCPB was based. Program experts then developed comprehensive logic diagrams that explicitly display the interrelationships between requirements, their corresponding performance measures, models of physical processes, and site parameters such that each relevant issue could eventually be adequately addressed. The starting point for developing these logic diagrams was to replicate the logic that was implied in the SCPB. However, to the extent that there have been changes in understanding since the preparation of the SCPB, these were incorporated into the logic diagrams.

Each logic diagram proceeds from the corresponding requirement(s) necessary to address the issue, through the primary- and intermediate-level performance measures, the required models and analyses, down to the specific data needs (site parameters) that will be necessary to support the analysis from the bottom up. Many of the data will have to come from the ESF, but some will be obtained from non-ESF sources (e.g., surface-based testing); this distinction is noted on the logic diagrams.

The resulting consolidated list of ESF data needs becomes the basis for identifying (and justifying) the specific tests (activities) to be conducted in the ESF. These activities were further defined to establish firm test requirements.

Given the individual test requirements, specific ESF capabilities necessary to support the testing program were identified. These facility functional capabilities together with the test require-

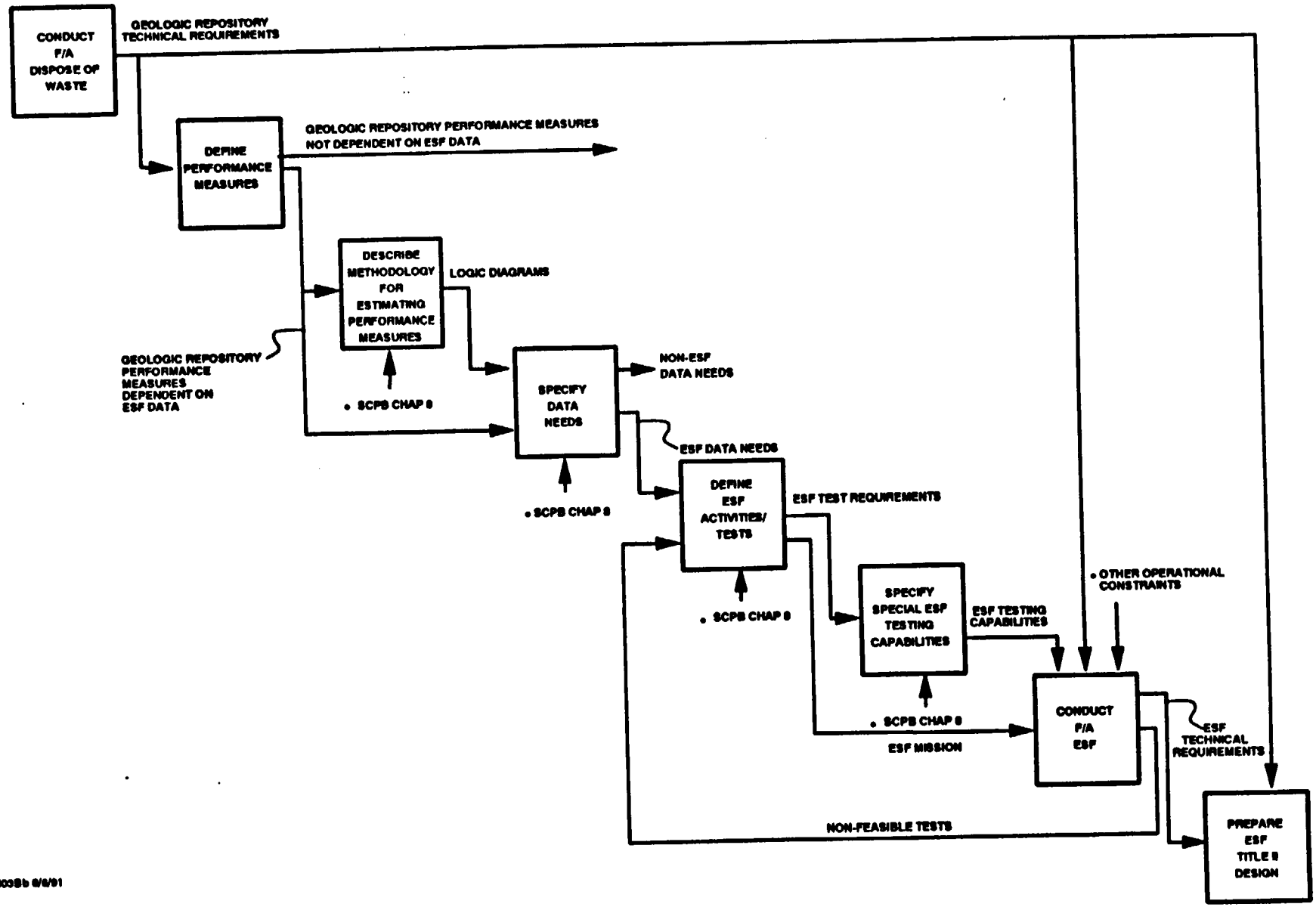


Figure 2-1. Exploratory Studies Facility (ESF) Mission Analysis Approach

ments (i.e., mission), certain other constraints imposed upon the ESF by the eventual desire to convert it into a part of a geologic repository, and some additional operational constraints provide the necessary inputs to proceed with a functional analysis of the ESF.

2.2 TRACEABILITY TO "DISPOSE OF WASTE" REQUIREMENTS

Test requirements for the ESF must be derived from the requirements imposed on the geologic repository for two reasons:

- The ESF must collect the geoscientific data necessary to support the analyses for evaluating the ability of the site to comply with a certain subset of the geologic repository requirements.

- Because the possibility of the ESF eventually becoming a part of the geologic repository must not be precluded, the ESF must not compromise the nuclear waste isolation capabilities of the site.

Appendix H contains an explicit identification of each geologic repository requirement (from the Physical System Requirements: Dispose of Waste document) and its corresponding performance measure(s) plus an indication of whether estimates for the performance measure will require ESF data or not. The results contained in Appendix H establish the necessary traceability back to the Dispose of Waste document.

2.3 RELEVANCE OF SCPB ISSUES

The Site Characterization Program Baseline (SCPB) is organized about an issues hierarchy that provides a framework that relates to regulatory requirements for siting and licensing a geologic repository and which describes the work that needs to be completed during site characterization to resolve those issues. The issues are defined as the questions relating to the performance or design of the geologic repository that must be resolved to demonstrate compliance with the applicable Federal regulations (including, 10 CFR Part 20, 10 CFR Part 60, 10 CFR Part 960, and 40 CFR Part 191).

Table 2-1 indicates that the SCPB issues can be assigned to one of three categories:

1. Issues that are dependent on primary ESF data for resolution,
2. Issues that can make use of ESF data gathered primarily for resolving other issues (viz., category 1 issues), and
3. Issues that require no ESF data for resolution.

Logic diagrams were prepared for each issue in category 1. These logic diagrams explicitly portray the relationships among the associated requirements, the corresponding performance measures, supporting models and analyses, and the site data and activities necessary to conduct the implied analyses. The geologic repository requirements and performance measures from the Dispose of Waste document were cross-checked with the information on these logic diagrams to ensure that all relevant geologic repository requirements/ performance measures were addressed.

A check was made to ensure that all the tests/activities were related to the requirements and performance measures. Appendix H contains the results of these cross-checks.

Figure 2-2 illustrates the integrative approach that was needed to ensure a comprehensive analysis of the ESF.

CATEGORY 1. ISSUES REQUIRING PRIMARY ESF DATA FOR RESOLUTION	CATEGORY 2. ISSUES MAKING USE OF ESF DATA GATHERED PRIMARILY FOR RESOLVING OTHER ISSUES (VIZ, CATEGORY 1 ISSUES) [1]												CATEGORY 3 *	
	1.2 INDIVIDUAL PROTECTION	1.3 GROUND WATER PROTECTION	1.7 PERFORMANCE CONFIRMATION	1.8 NRC SITING CRITERIA	1.9 DOE GUIDELINE FINDINGS	2.1 PUBLIC SAFETY DURING NORMAL OPERATIONS	2.3 PUBLIC SAFETY DURING ACCIDENTS	2.4 RETRIEVABILITY	2.5 DOE GUIDELINE FINDINGS	4.1 GUIDELINE FINDINGS	4.2 NON-RADIOLOGICAL WORKER SAFETY	4.5 COSTS	2.6 WASTE PACKAGE DESIGN	4.3 WASTE PACKAGE PRODUCTION
1.1 TOTAL SYSTEM PERFORMANCE	X	X	X	X	X									
1.4 WASTE PACKAGE CONTAINMENT			X		X									
1.5 EBS RELEASE RATE			X		X									
1.6 GROUNDWATER TRAVEL TIME			X		X									
1.10 WASTE PACKAGE CHARACTERISTICS														
1.11 UNDERGROUND FACILITIES														
1.12 SEAL CHARACTERISTICS														
2.2 WORKER RADIOLOGICAL SAFETY-NORMAL CONDITIONS														
2.7 REPOSITORY DESIGN CRITERIA FOR RADIOLOGICAL SAFETY														
4.4 PRECLOSURE DESIGN AND TECHNICAL FEASIBILITY						X	X	X	X	X	X	X		

* Issues that Require no ESF Data for Resolution

1. As determined in the SCPB

This PSK-ESF document "ESF issues" the HLWDS-only cover Rev. and G-7 & 3 issues (RD), MI-A would cover these categories as well + other

Table 2-1. SCPB Issue Data Needs

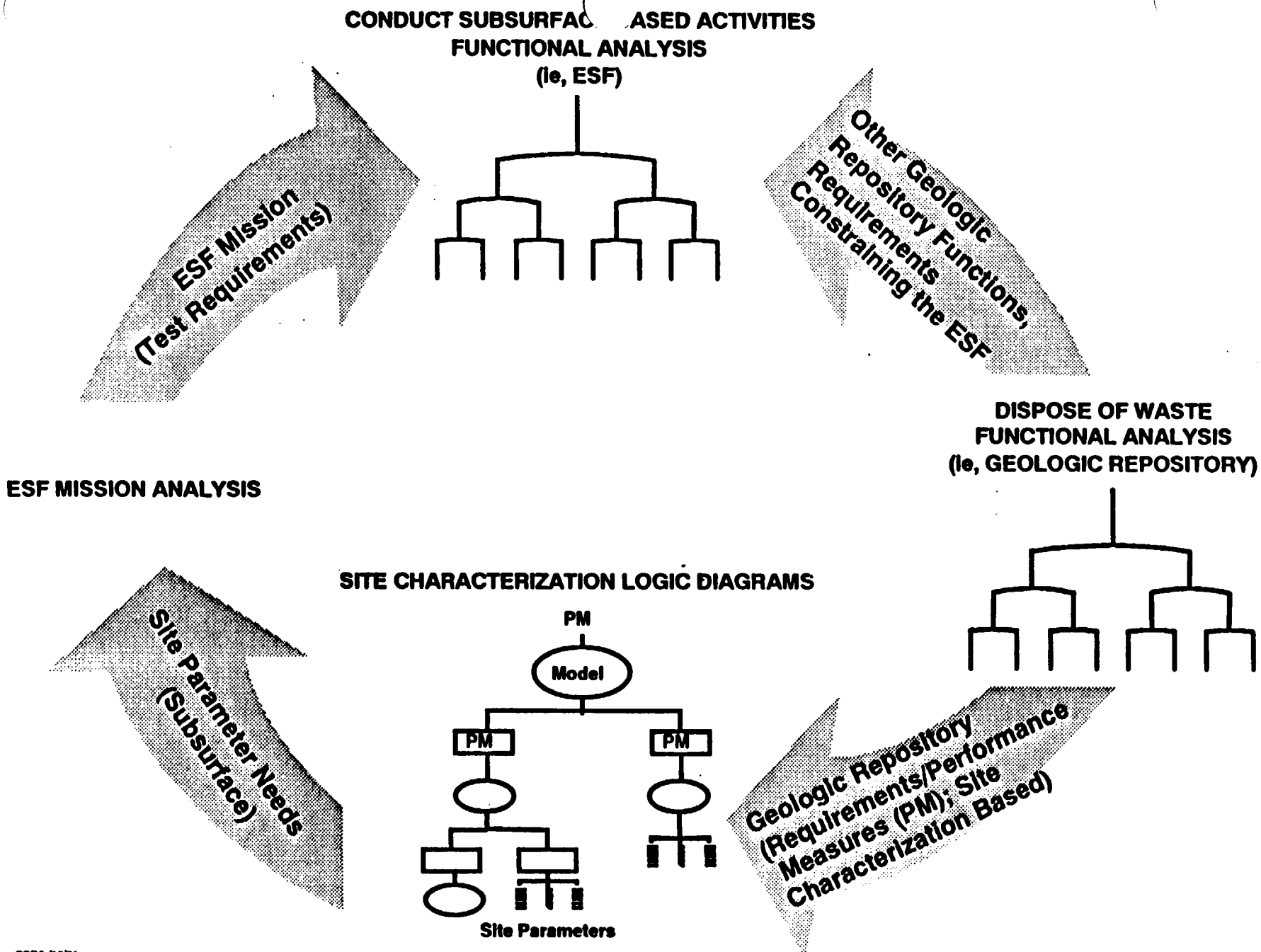


Figure 2-2. Integrative Approach for Comprehensive ESF Analysis

3.0 LOGIC DESCRIPTIONS

The issues hierarchy is based on resolving four key issues that correspond to the four system guidelines in DOE's Siting Guidelines (10 CFR 960). The first key issue addresses postclosure performance of the repository; the second, preclosure safety; the third, environmental and socioeconomic concerns (which are not included in the SCP); and the fourth, ease and cost of repository construction, operation, closure, and decommissioning.

Each key issue is comprised of a group of issues specifically related to performance and design. These performances and design issues lead to information needs which completely define the data needed to resolve each issue.

Ten performance and design issues have been identified as requiring primary data from the ESF for their resolution. This section contains detailed description of the logic that will be used to address these issues and, identifies both the ESF data and tests that will be necessary to support the analyses.

Verification and validation were recognized as important overlays to every component of the logic diagram. Although initially these concepts were discussed in terms of the models and codes used in issue resolution, it became apparent that verification and validation are important components of every process described in the diagram. Therefore, no attempt was made to show these functions as part of the logic diagram. However, it is important to acknowledge their role in the issue resolution process and to recognize their potential independent data needs. Also, the logic diagram does not deal with the necessary communication and iterative interactions between the modeling and characterization activities. These interactions are important components of the testing/-analysis/modeling/validation/resolution process.

3.1 ISSUE 1.1, TOTAL SYSTEM PERFORMANCE

Issue 1.1: Will the mined geologic disposal system meet the system performance objective for limiting radionuclide releases to the accessible environment as required by 10 CFR 60.112 and 40 CFR 191.13?

3.1.1 Introduction

The total system performance issue asks whether the repository system will meet the system performance objective defined by the U.S. Nuclear Regulatory Commission (NRC) in 10 CFR Part 60. That performance objective is a requirement that the system meet the standard promulgated by the U.S. Environmental Protection Agency (EPA) for long-term containment of waste (which the U.S. Department of Energy (DOE) program usually calls the "isolation" of waste). The standard requires that the DOE make estimates of release of radionuclides; that these estimates consider all significant events and processes for 10,000 years; and that the releases have a likelihood of less than one chance in 10 of exceeding a set of stated limits and less than one chance in 1,000 of exceeding 10 times those limits.

The EPA suggests, in the standard, an acceptable performance measure for demonstrating resolution of this issue. The DOE has adopted this measure: a complementary cumulative distribution function (CCDF), which shows the probability that releases will not exceed any given value.

To construct the CCDF, the DOE will use data and models produced for many aspects of the program. In order for the CCDF to be statistically valid, multiple estimates of releases covering multiple possibilities for release mechanisms and uncertainties in the models and data will be required.

To make the many thousands of calculations that will be necessary, construction of the CCDF will require the development of simplified models for the complex processes that may occur at Yucca Mountain. These simplified models will be based on much more elaborate models that will be used to study the processes in detail. The logic diagram for Issue 1.1 (Figure 3-1) shows the simplified models near the top. The models appearing lower are progressively more elaborate; they, in turn, are ultimately built from the results of studies carried out in the Exploratory Studies Facility (ESF), in field tests, and in laboratory tests.

Preparing a CCDF will require probability distributions for many parameters used in the analyses. For brevity, the chart does not always call for statistical distributions; the reader should keep in mind, however, that site characterization planning calls for means, variances, correlations, and other statistical measures for most parameters.

3.1.2 Logic Description

The logic diagram for Issue 1.1, Figure 3-1, shows the logic for evaluating total system performance. The top of the chart shows the requirement taken from the "Dispose of Waste" functional analysis. Parameters that must be calculated, measured, or otherwise evaluated are shown in rectangular boxes. Key models are shown in rounded rectangles. Models include all mechanisms that allow one to quantify the output parameters given the input parameters, shown below the model.

References to testing activities are shown in brackets. Round brackets indicate ESF tests, while square brackets indicate non-ESF tests. The general logic is further described below.

Requirement

The regulation that governs this issue is given in 10 CFR 60.112. This regulation implements the containment requirements of 40 CFR 191.13(a):

> *Disposal systems for spent nuclear fuel or high-level or transuranic 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); and*

(2) *Have a likelihood of less than one chance of 1,000 of exceeding ten times the quantities calculated according to Table 1 (Appendix A).* (Note: Appendix A is not reproduced in this report.)

Appendix A of 40 CFR Part 191 gives, in table form, the radionuclide release limits that will be used to make the calculations referred to above. These limits, expressed as curies (Ci) per 1,000 metric tons of heavy metal (MTHM), are the release limits for each radionuclide to be used in calculating the normalized release to the accessible environment.

Models and processes for water-pathway releases

A representation of the present hydrologic setting at Yucca Mountain is shown in Figure 3-2, which also shows the abbreviations used for the hydrogeologic units. The proposed location of the repository is in the Topopah Spring welded unit (TSw). The TSw unit includes the TSw1 and TSw2 units shown on the diagram. It is believed that, within each unsaturated-zone rock unit, water flows downward and mainly in the matrix of the rock units, with spatially averaged percolation flux not exceeding 0.5 mm/yr. Some lateral diversion of averaged percolation flux may occur at the interfaces between distinct hydrologic rock units (e.g., the interface between units TSw2 and CHnv and CHnz below the repository, and the interface between units PTn and TSw1 above the repository). This diverted water may be directed downdip along the interface (as matrix flow, given the present recharge rates) to the water table or to downward drainage points in the highly faulted zone southeast from the edge of the emplacement zone. Water reaching the water table may then flow in a lateral direction to the accessible environment boundary to the southeast of the controlled area.

Those radionuclide-bearing compounds that might be released in the liquid phase as water percolates through the host rock (TSw2) could be transported along these water pathways, and may eventually reach the boundary of the accessible environment. The subsurface portion of this boundary may be imagined as a vertical, curved sheet that is everywhere located up to 5 km from the edge of the waste emplacement.

Radionuclide transport model

The radionuclide transport model must include both advective and dispersive-diffusive fluxes of the radionuclides based on the groundwater flow in the unsaturated and saturated zones. Retardation factors for both matrix and fracture flow based on sorption of radionuclides should also be included in the model. The radionuclide transport model must also include equations describing the air flow in the unsaturated zone; the movement of the radionuclides in this airflow; transfer of the radionuclides among solid, liquid, and gaseous phases; and the chemical environment. Because air flow is driven by thermal gradients and gradients in the partial pressure of water vapor, equations must describe the effects of variations in these processes on the air flow and on subsequent transport of radionuclides. Models also need to include radionuclide decay to daughter products. To be able to simulate disruptive scenarios, geologic and transport properties within the unsaturated zone must be able to be varied temporally and spatially. Spatial and temporal variation of the boundary conditions must also be allowed for in the models. Note that the models of the radionuclide transport processes are highly dependent on the assumed groundwater flow model.

Models and processes for air-pathway releases

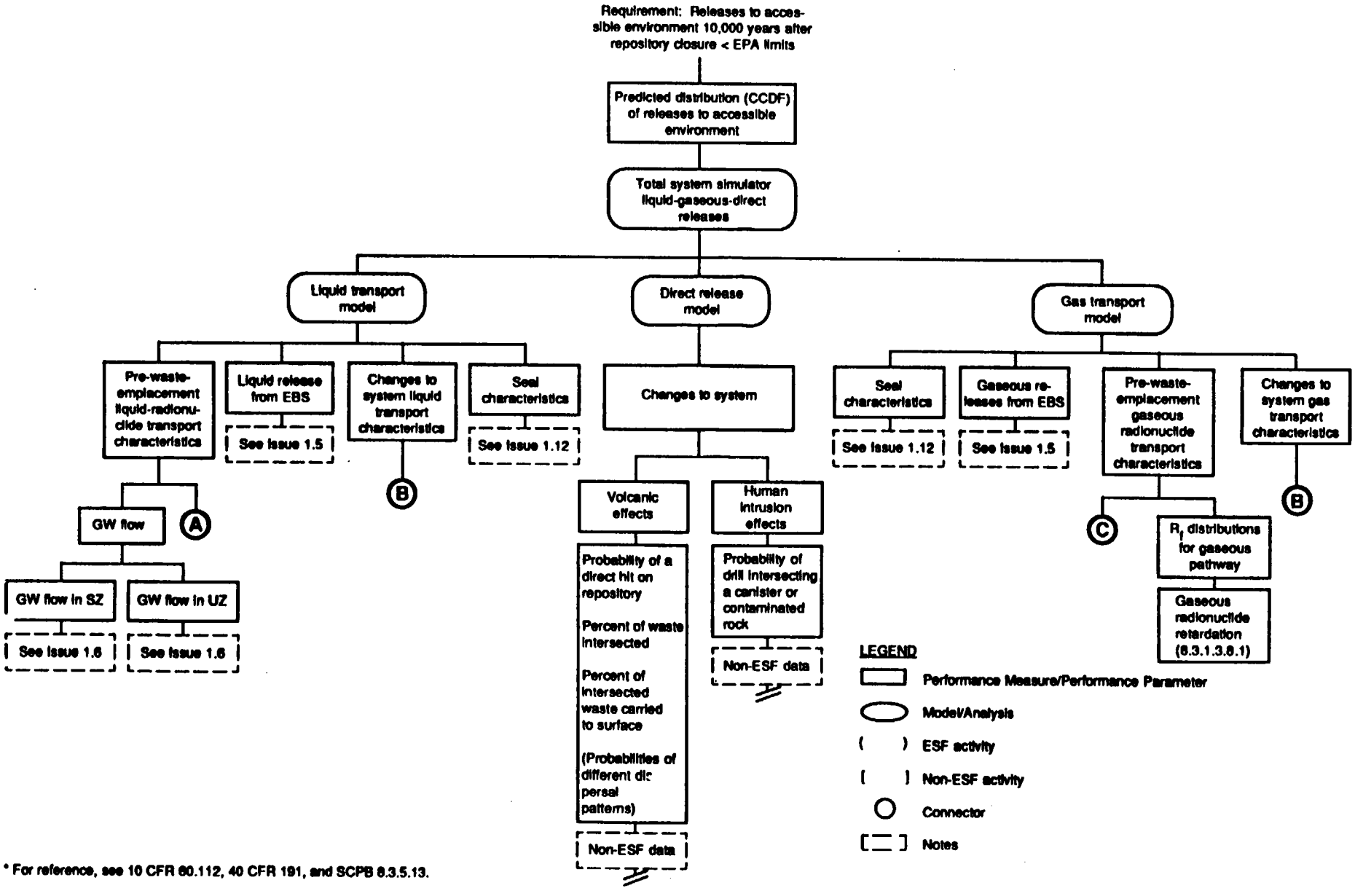
Radionuclides, primarily C-14, H-3, Kr-85, and I-129, can be released from waste packages as gases or compounds that form gases. These gaseous radionuclides move upward through air-filled pores and fractures in the unsaturated zone by molecular diffusion and by advection in thermally driven air-convection cells. Isotopic equilibrium is assumed to exist between the radionuclides in the air and in aqueous phases. Radionuclides may be removed from the air by precipitation of solid phases. A significant gas-phase process, based on preliminary analyses, is limited rapid release of C-14 as carbon dioxide.

Scenario classes/changes to the system

A scenario class will be developed for undisturbed performance of the geologic repository; it will take into account the legitimate, distinguishable alternative conceptual models that are supported by the available information. This class is called the nominal class; it is associated with anticipated or expected conditions. By undisturbed performance, the DOE means the predicted behavior of a geologic repository, taking into account the uncertainties in predicted behavior, and considering only likely natural events. In this instance, "natural events" refer to those natural processes and events that are reasonable likely to occur in the 10,000-yr period following permanent closure. The judgments of which natural processes and events are likely to occur during this period will be based on the assumption that those processes operating in the geologic setting during the Quaternary will continue to operate, but that some perturbation will be caused by the construction of the repository and the presence of emplaced waste.

Disruptive scenario classes will also be developed for the analysis. Such scenario classes will consider processes and events that are sufficiently credible to warrant consideration, but which are outside the range of those considered for the nominal case. For example, these scenarios may involve disruptive natural processes such as significant fault displacement, climate change, or volcanic activity that have a low probability of occurrence in the next 10,000 years. These scenario classes would also include those developed for human interference activities discussed earlier.

FIGURE 3-1 ISSUE 1.1*: TOTAL SYSTEM PERFORMANCE



* For reference, see 10 CFR 60.112, 40 CFR 191, and SCPB 8.3.5.13.

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FIGURE 3-1 (cont.) ISSUE 1.1: TOTAL SYSTEM PERFORMANCE

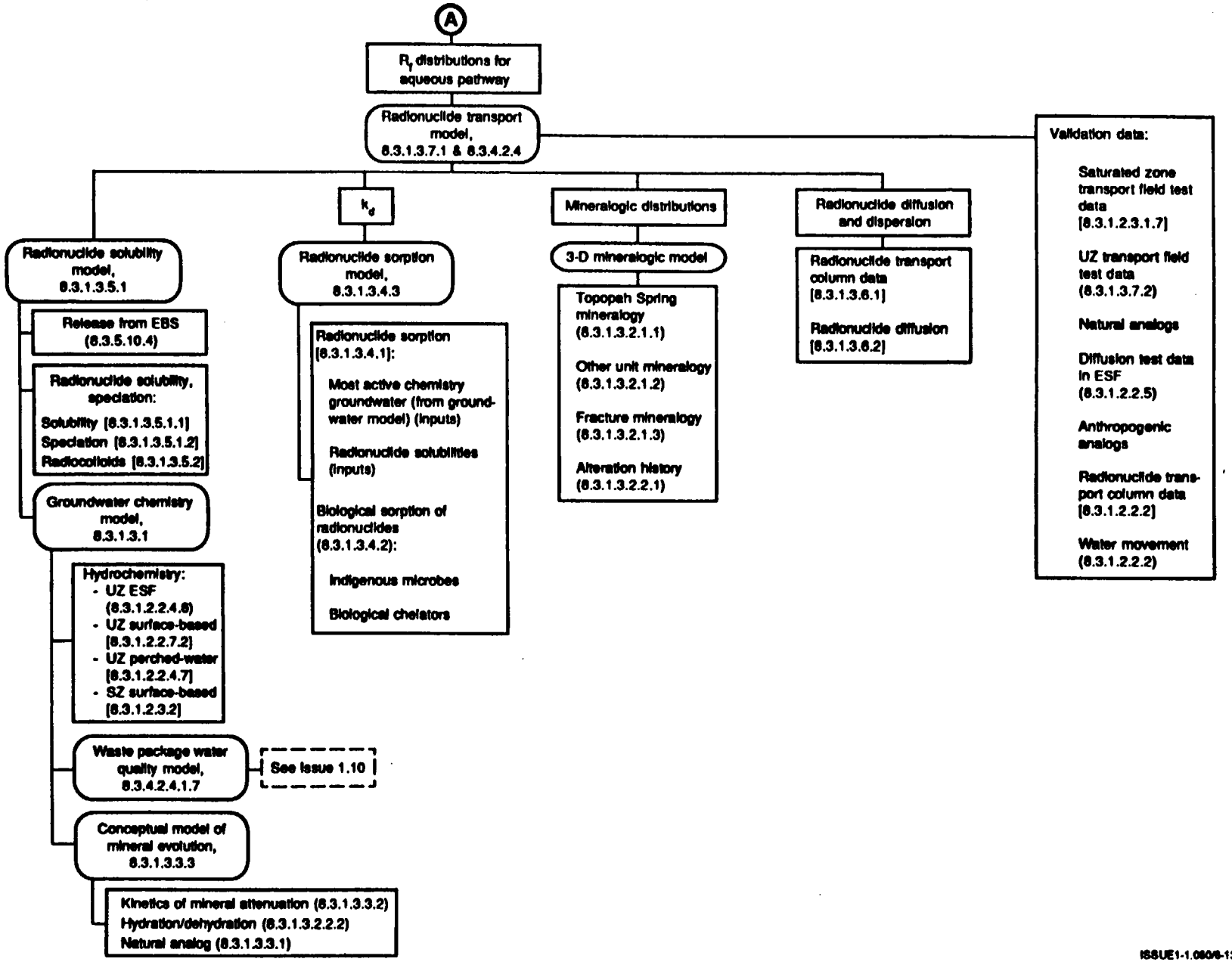

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FIGURE 3-1 (cont.) ISSUE 1.1: TOTAL SYSTEM PERFORMANCE

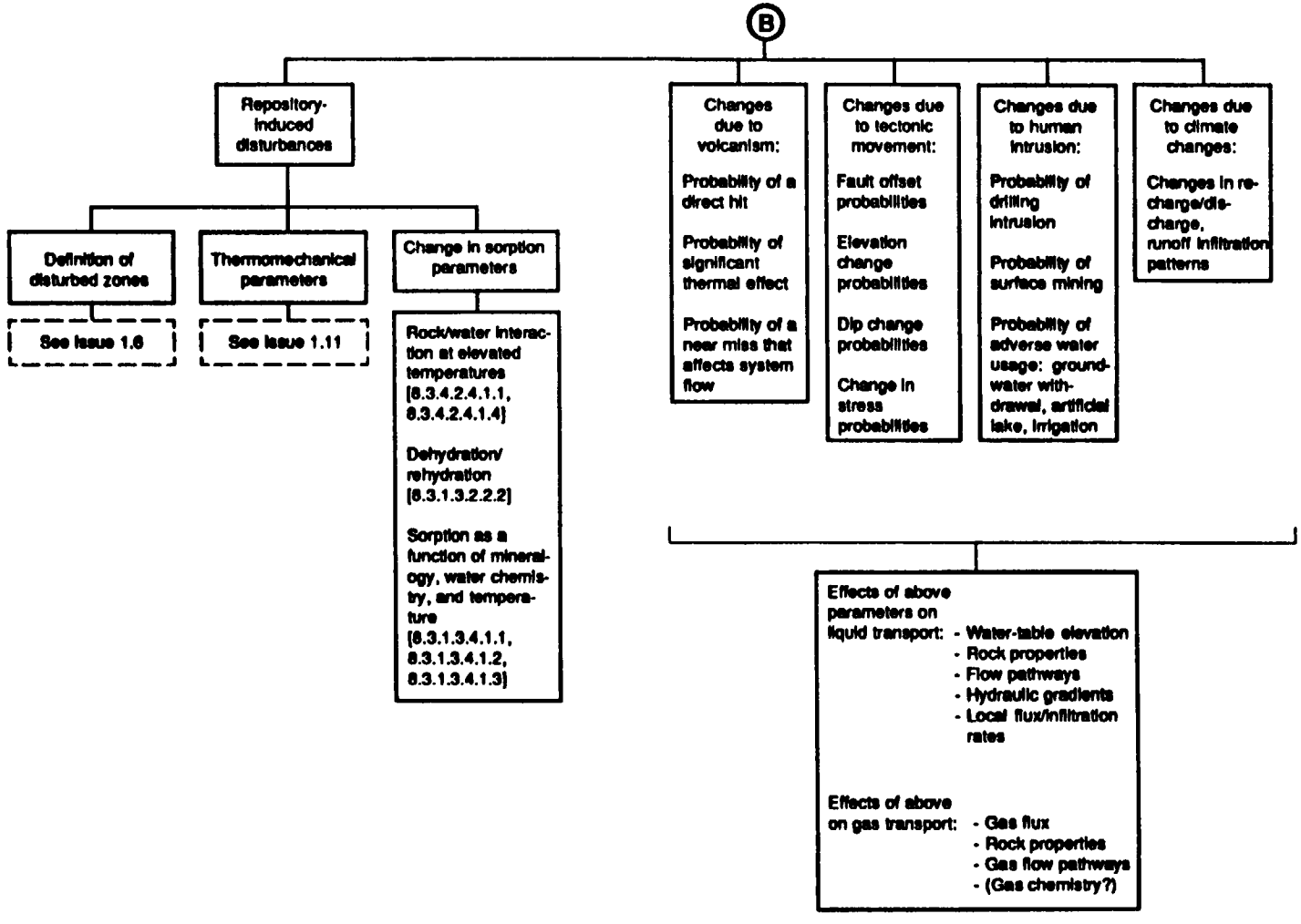

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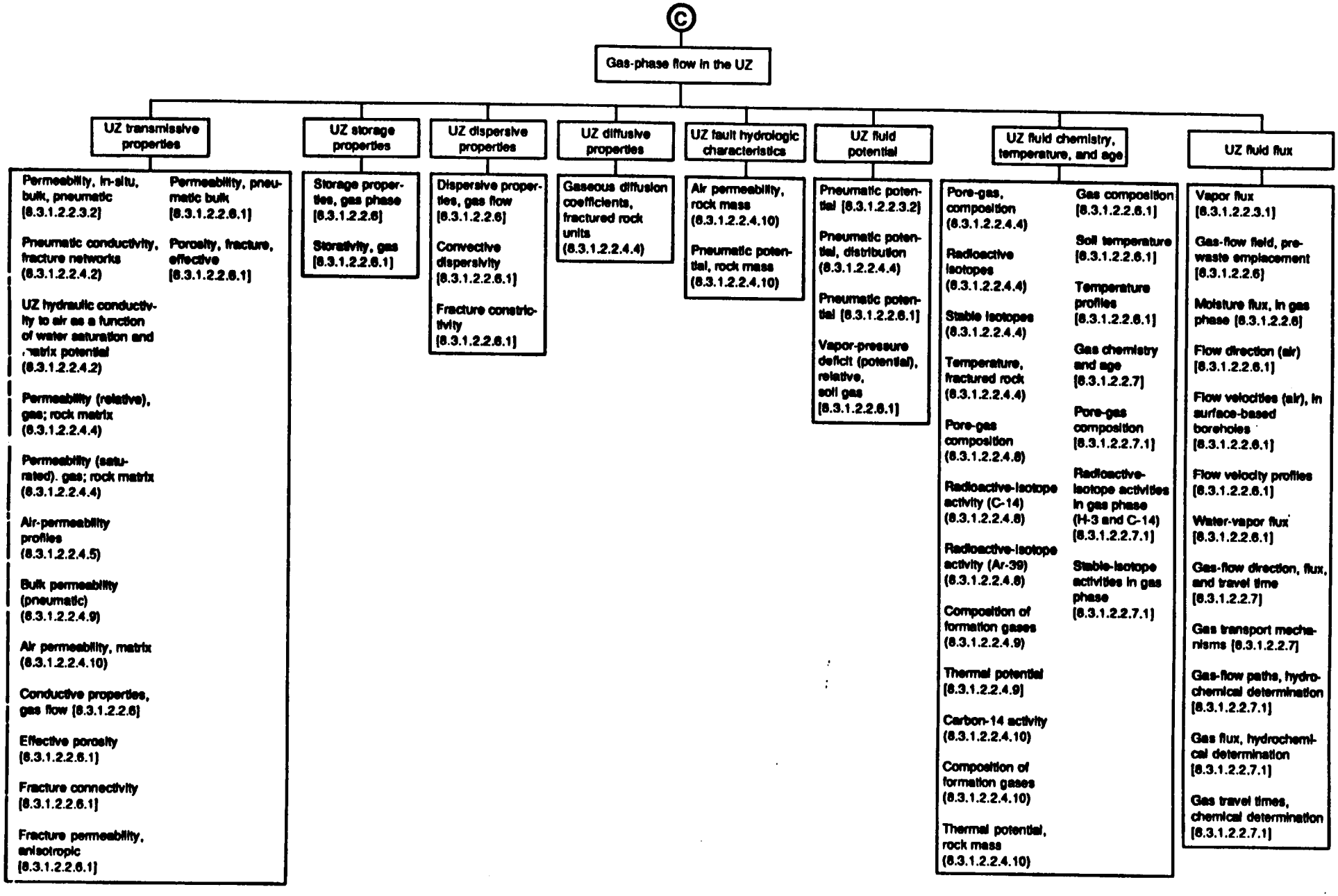
FIGURE 3-1 (cont.) ISSUE 1.1: TOTAL SYSTEM PERFORMANCE



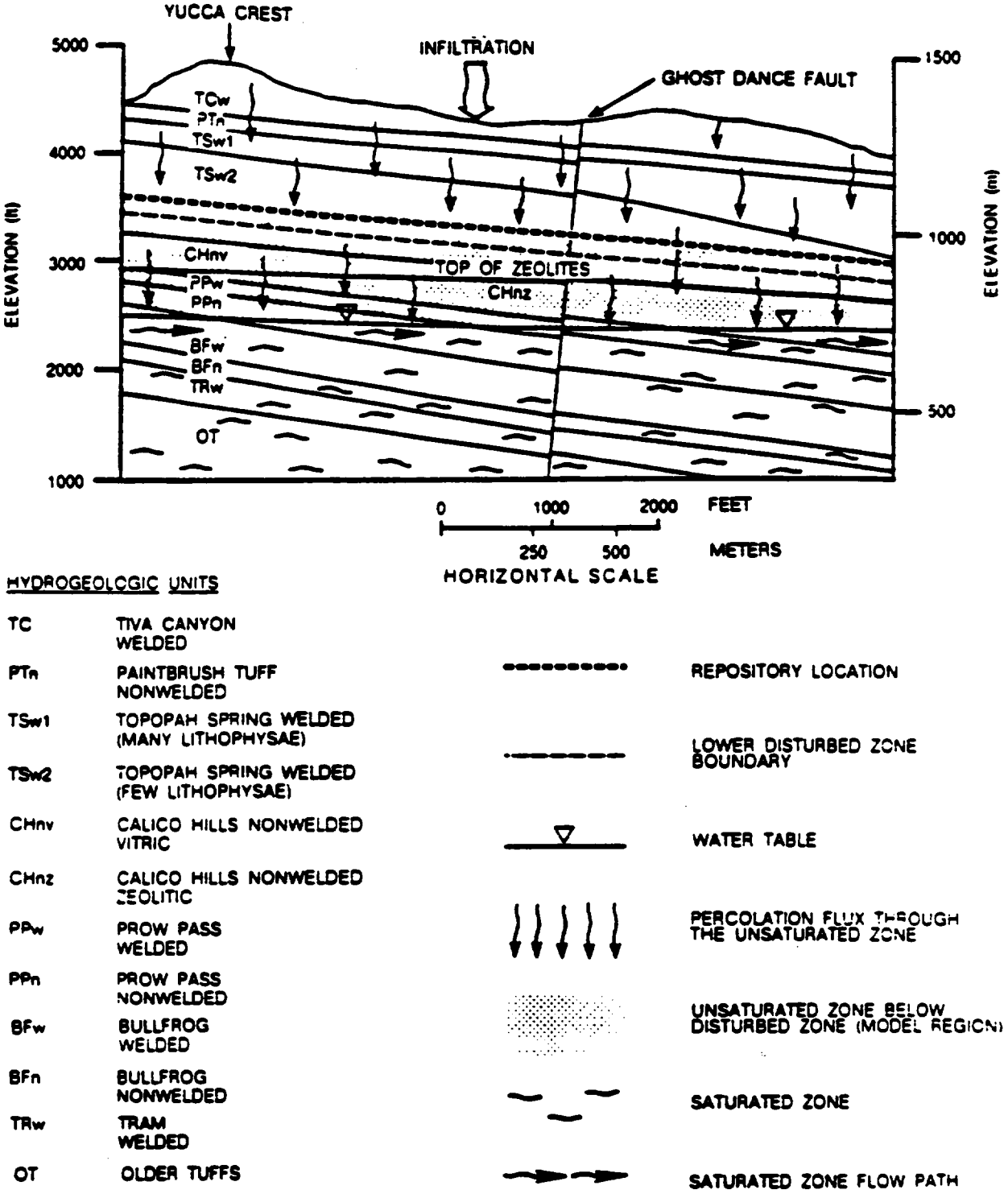


Figure 3-2. General Hydrogeologic Cross Section at Yucca Mountain. The wavy arrows show the flow paths, as assumed in this report, from a potential repository through the unsaturated zone to the water table and along the upper portion of the saturated zone toward the accessible environment (5 km away). Modified from Sinnock et al. (1986); taken from SCPB Section 8.3.5.13.

3.2 ISSUE 1.4, WASTE PACKAGE CONTAINMENT ISSUE 1.5, EBS RELEASE RATE

Issue 1.4: Will the waste package meet the performance objective for containment as required by 10 CFR 60.113?
Issue:1.5: Will the waste package and the repository engineered barriers meet the performance objective for limiting radionuclide release rates as required by 10 CFR 60.113?

3.2.1 Introduction

Issues 1.4 and 1.5 both relate to the predicted rate of radionuclide release from the engineered barrier system (EBS). Issue 1.4 covers the containment period (the first 300 to 1,000 years after closure of the repository), and Issue 1.5 addresses the time from the end of the containment period to 10,000 years. The requirements as stated in 10 CFR 60.113 (a) (1) (ii) are as follows:

> *. . .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 factors specified in 60.113 (b) provided that such period shall not be less than 300 years nor more than 1,000 years after permanent closure of the geologic repository; and (B) 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 percent 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.*

The primary performance measure that addresses these Issues is the predicted release of radionuclides from the EBS as a function of time. Secondary performance measures that contribute to this prediction include the fractional container failure rate in any given year and the fractional release of radionuclides from breached packages by either aqueous or gas phase transport. Performance measures contributing to these factors include:

- The quantity of water that contacts the container as a function of time,
- The quality of liquid water contacting the container at a given time,
- Rock-induced loads on the waste package,
- Container material performance characteristics,
- Waste form performance characteristics, and
- Radionuclide transport characteristics from the waste form to the EBS boundary.

3.2.2 Logic Description

As shown on the logic diagram for Issue 1.4 (Figure 3-3), the final result of Issues 1.4 and 1.5 is the release rates of radionuclides from the EBS. This is estimated by the EBS/Waste Package Performance Assessment Model in conjunction with its subcomponents (A) the EBS release rate model and (B) the container breach model.

The EBS release rate model predicts radionuclide release rates from the EBS based on a variety of inputs that are the product of EBS component models:

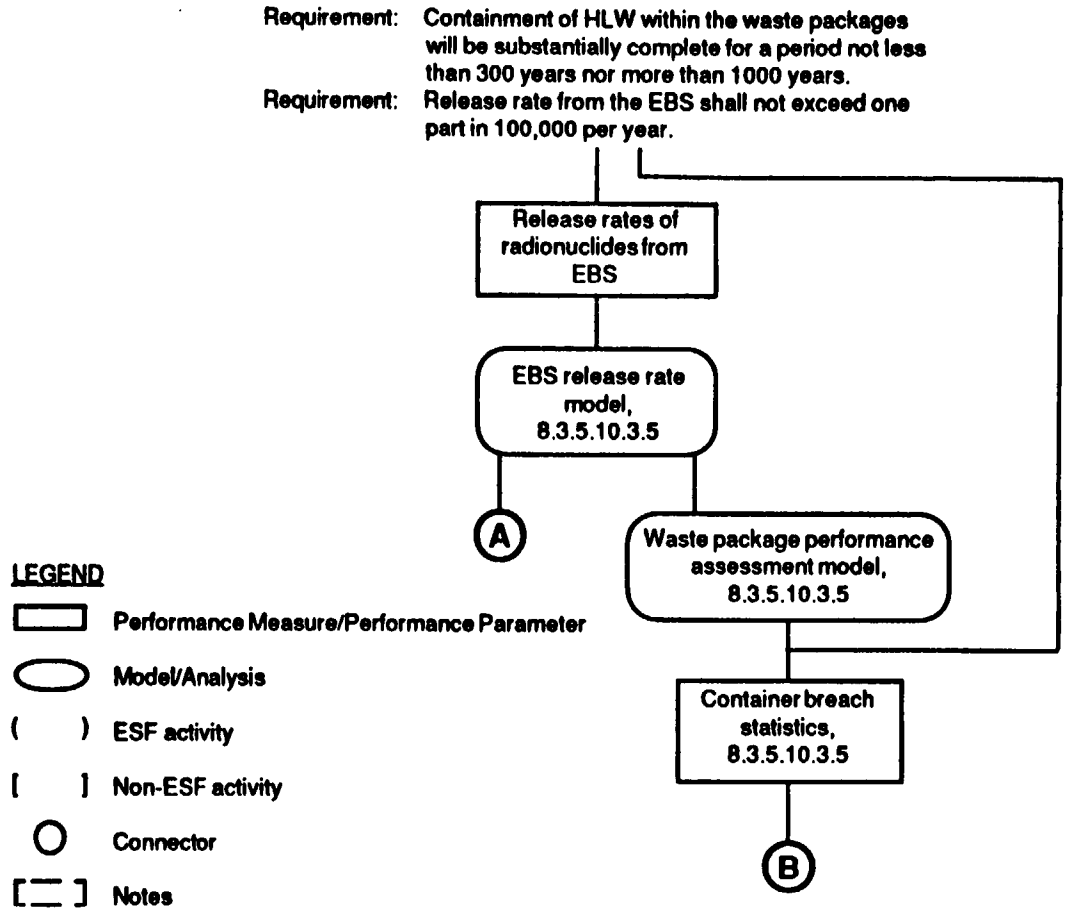
- Statistics of container breach times, location, and sizes from the container breach model (B);
- Waste package geometry and physical properties that come from models of geometry, mechanical stress, thermal properties, and radiation attenuation;
- The near-field water quantity, quality, and saturation from models under Issue 1.10; and
- Waste form behavior information from models of aqueous interaction, gaseous release, spent fuel, glass and hardware release.

Similarly, the container breach model provides container breach statistics based on several inputs:

- Waste package geometry and physical properties that come from models of geometry, mechanical stress, thermal properties, and radiation attenuation;
- The near-field water quantity, quality, and saturation from models under Issue 1.10; and
- Container material behavior under a range of mechanical conditions and chemical environments from a container degradation model.

The lower level models in turn rely on probabilistic and mechanistic descriptions of conditions and processes that must be understood to predict EBS performance.

FIGURE 3-3 ISSUE 1.4*: WASTE PACKAGE CONTAINMENT AND ISSUE 1.5*: EBS RELEASE RATE



*For reference, see 10 CFR 60.113(a)(I)(ii) and SCPB 8.3.5.9 and 8.3.5.10.

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FIGURE 3-3 (cont.) ISSUE 1.4: WASTE PACKAGE CONTAINMENT
AND
ISSUE 1.5: EBS RELEASE RATE

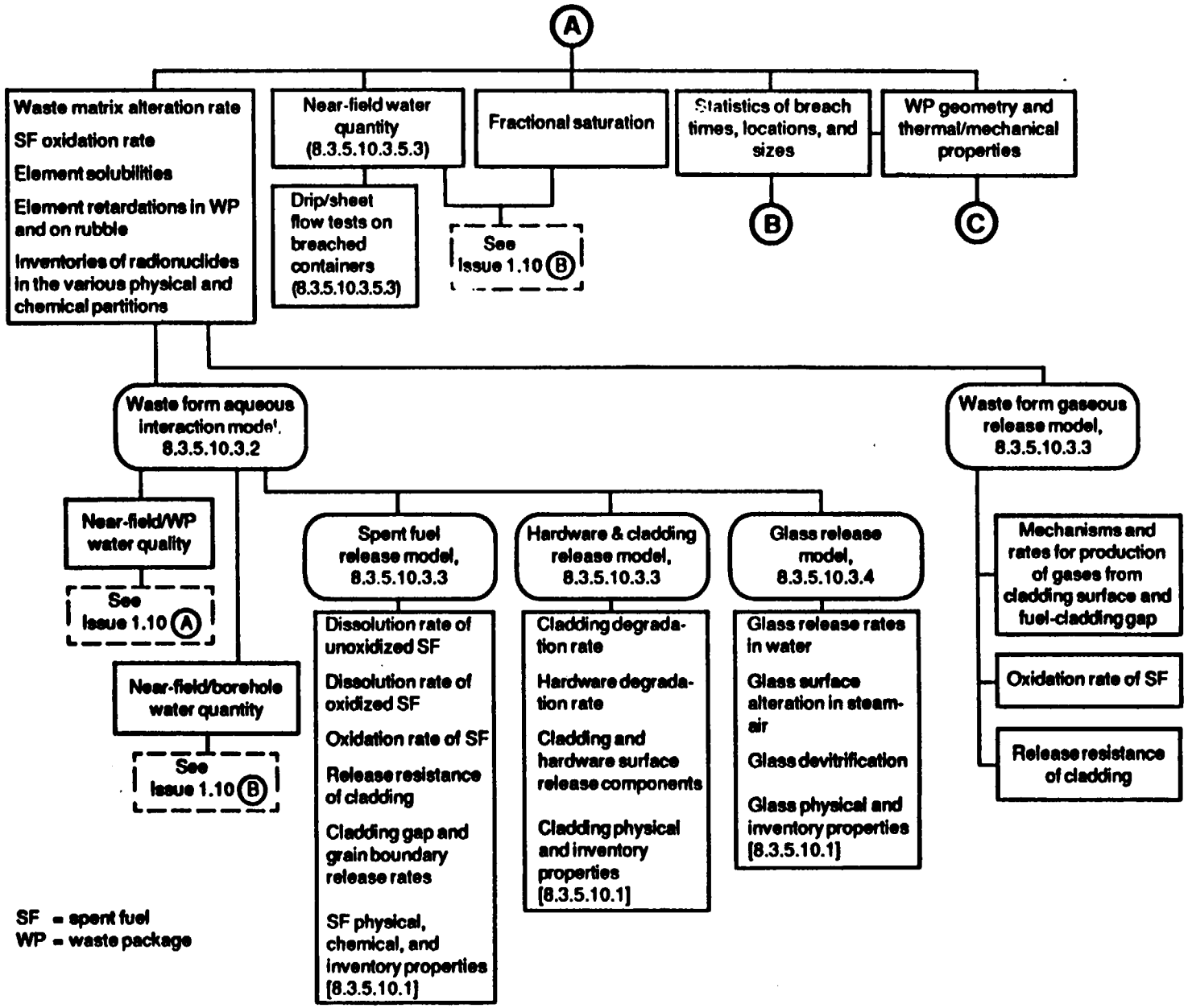

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FIGURE 3-3 (cont.) ISSUE 1.4: WASTE PACKAGE CONTAINMENT AND ISSUE 1.5: EBS RELEASE RATE

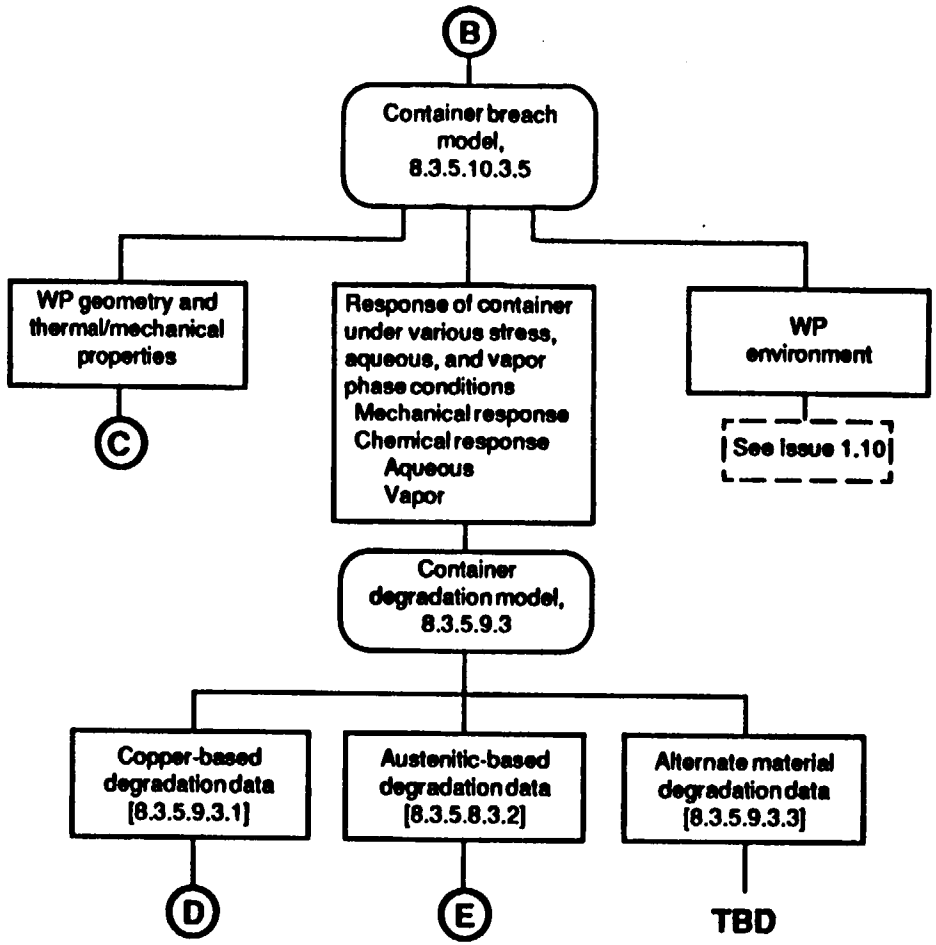

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FIGURE 3-3 (cont.) ISSUE 1.4: WASTE PACKAGE CONTAINMENT
AND
ISSUE 1.5: EBS RELEASE RATE

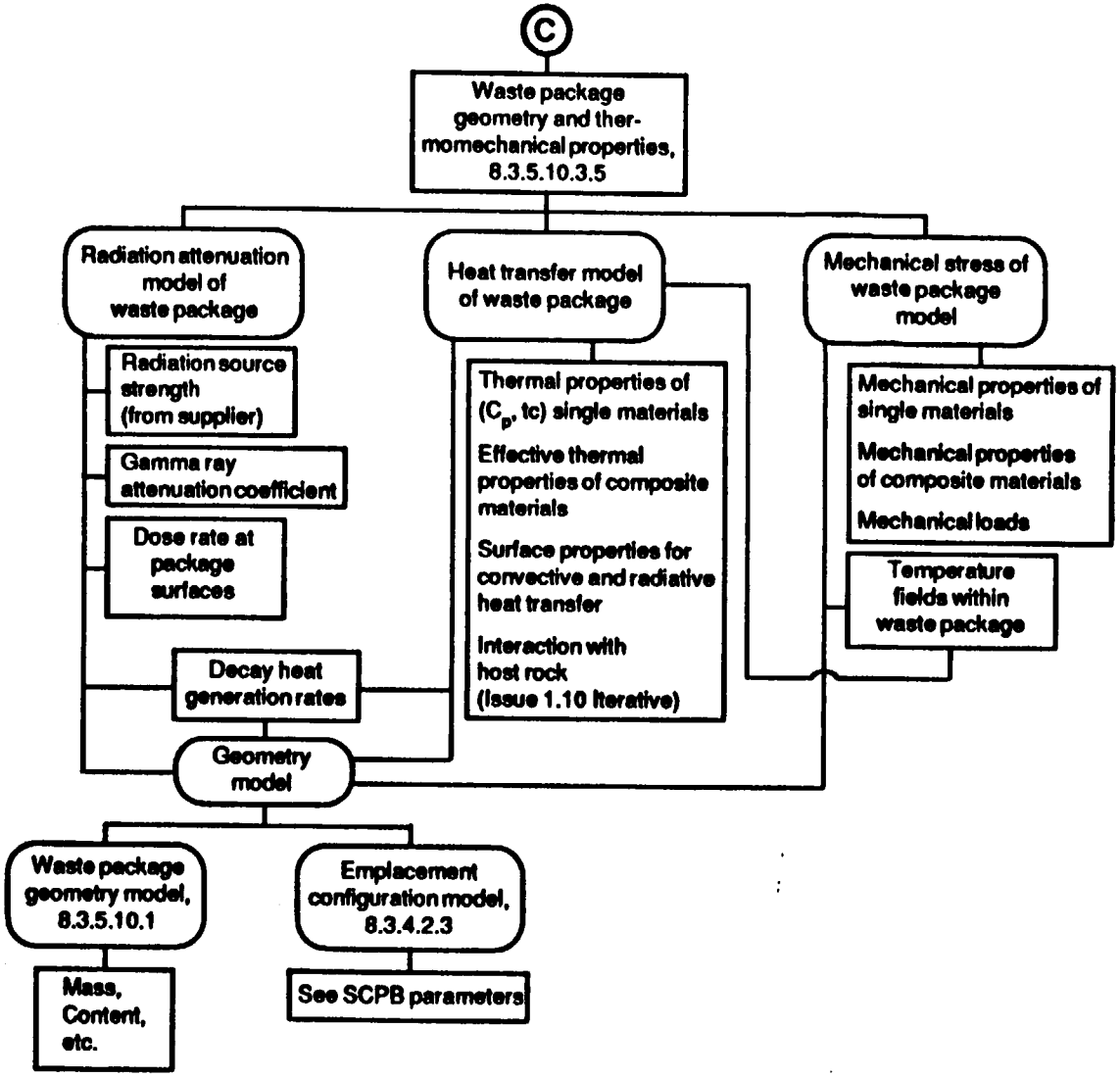

FIGURE 3-3 (cont.) ISSUE 1.4: WASTE PACKAGE CONTAINMENT
AND
ISSUE 1.5: EBS RELEASE RATE

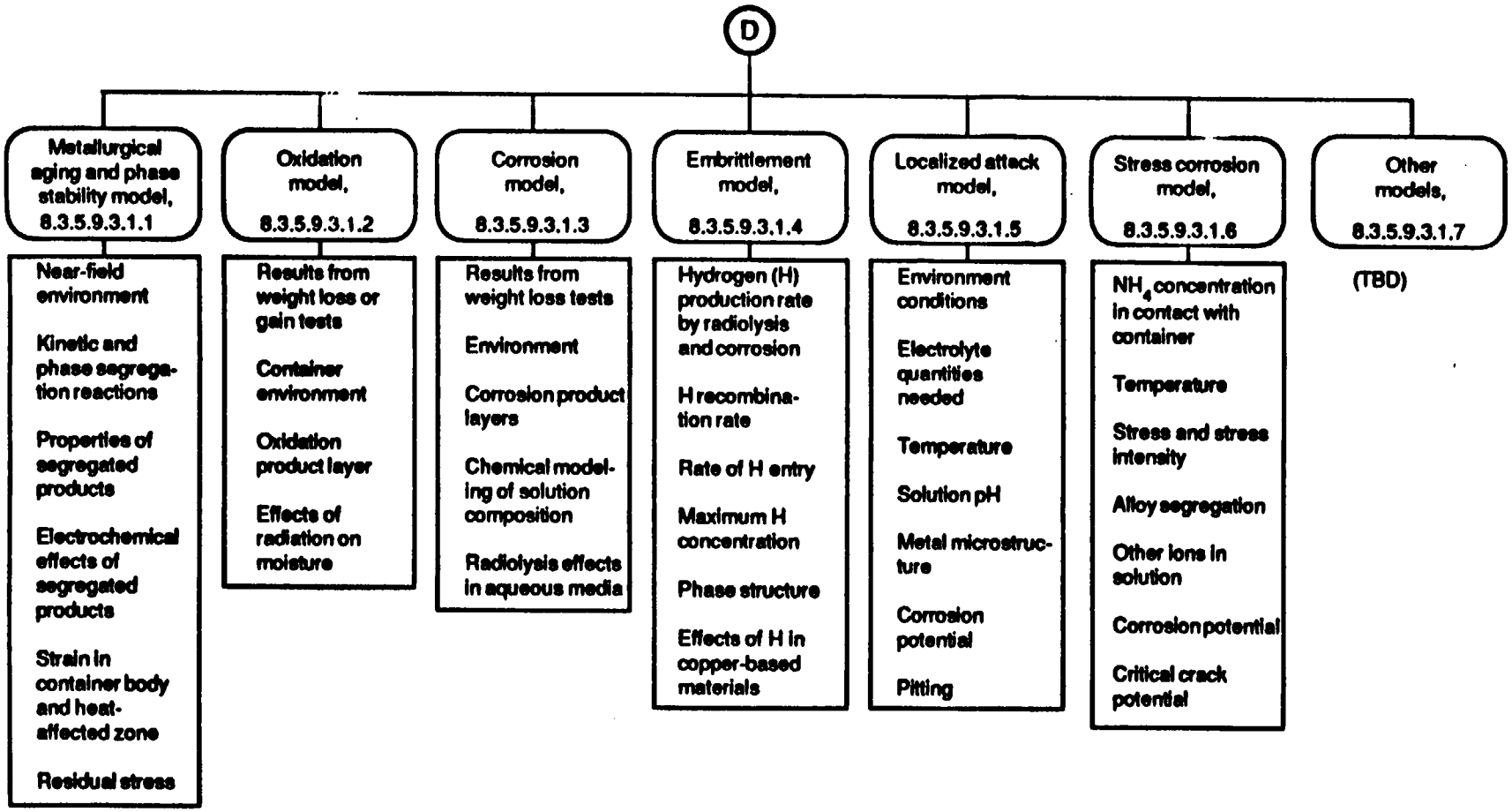

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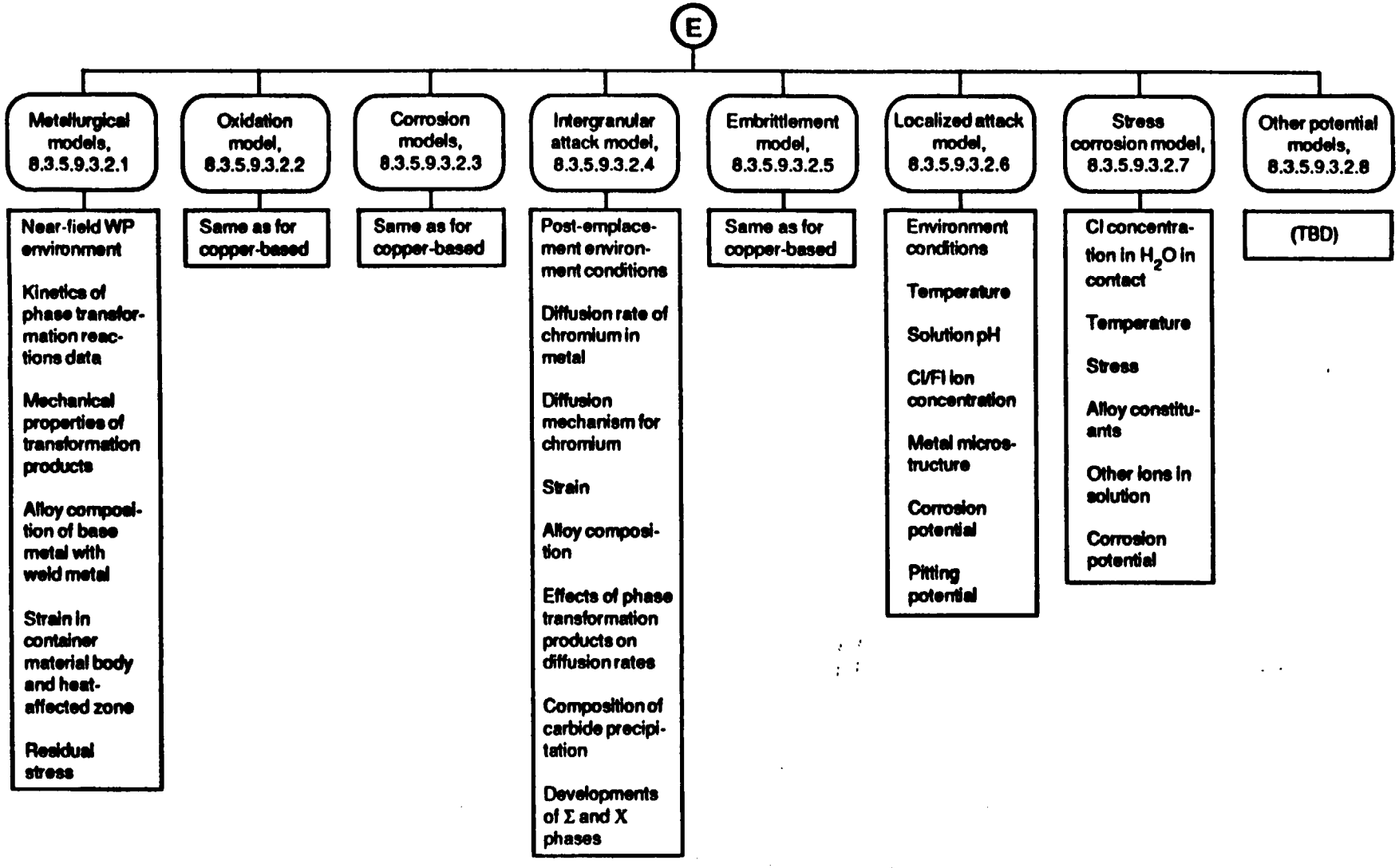
FIGURE 3-3 (cont.) . ..JE 1.4: WASTE PACKAGE CONTAINMENT AND ISSUE 1.5: EBS RELEASE RATE



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3.3 ISSUE 1.6, GROUNDWATER TRAVEL TIME

Issue 1.6: Will the site meet the performance objective for pre-waste ground-water travel time as required by 10 CFR 60.113?

3.3.1 Introduction

The groundwater travel time issue asks whether the pre-waste- emplacement groundwater 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. Current concepts generally distinguish two general modes of groundwater movement through the unsaturated zone:

1. *Flow predominately through pores in the rock matrix.* In this mode, the time of water movement through a given volume of rock is dominated by flow through the small but abundant matrix pores of the tuffaceous rocks. Current data on site characteristics and likely flux values beneath the repository depths suggest that this is presently the predominant mode of groundwater movement from the disturbed zone to the water table. Although local regions of fracture flow may exist along significant fractions of any flow path, continuous fracture flow probably does not occur along the entire distance of any given flow path from the disturbed zone to the water table.

2. *Continuous flow through fractures or faults.* In this mode, the flow rate is relatively rapid because flow along one or more entire paths is constrained to the relatively large but sparse openings constituting a fracture network. Continuous fracture flow from the disturbed zone to the accessible environment may be caused by various sequences of events and may occur in only one general location or be distributed throughout the site. This flow may be caused by episodic or continual lateral diversion of water toward a fault; by an average, sustained percolation rate higher than the values of matrix saturated conductivity; by periodic, high-intensity infiltration events at the surface; or by other means. Continuous fracture flow beneath the potential repository is not considered likely at Yucca Mountain (Montazer and Wilson, 1984; Peters et al., 1986; Sinnock et al., 1984a, 1986; Wang and Narasimhan, 1986).* However, because implications of such flow include short travel times, this mode of flow will be considered in resolution of this issue.

The strategy for determining groundwater travel times is to account for the current uncertainty about flow mechanisms that may occur at the site, about the spatial distribution of rock characteristics along flow paths, and about initial and boundary conditions. Therefore, site data are needed to reduce the current uncertainty about whether the likely groundwater flow paths include continuous fracture flow. Flow in both the matrix and fractures in the unsaturated zone (UZ) will be considered on a probabilistic basis, unless site data unambiguously support a position that continuous fracture flow is not likely enough for serious consideration.

Also in the saturated zone, the general pathway for water movement probably includes travel through alternating matrix blocks and fractures. For purposes of conservatively evaluating groundwater travel time, the saturated zone will probably be treated solely as an equivalent porous medium where fracture properties characterize the medium.

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* Bibliographic data for references cited within this document are contained in the SCPB.

3.3.2 Logic Description

The logic diagram for Issue 1.6 (Figure 3-4) shows the logic for evaluating groundwater travel time. The top of the chart shows the requirement taken from the "Dispose of Waste" functional analysis. Parameters that must be calculated, measured, or otherwise evaluated are shown in rectangular boxes. Key models are shown in rounded rectangles. Models include all mechanisms that allow one to quantify the output parameters given the input parameters shown below the model. References to testing activities are shown in brackets. Round brackets indicate ESF activities, while square brackets indicate non-ESF activities. The general logic is further described below.

Requirement

One of the NRC performance objectives for high-level waste repositories is stated in 10 CFR 60.113(a)(2) as

> *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 time as may be approved or specified by the Commission.*

The disturbed zone has been defined qualitatively in 10 CFR 60.2 as

> *That portion of the controlled area the physical or chemical properties of which have changed as a result of underground facility construction or as result of heat generated by the emplaced radioactive wastes such that the resultant change of properties may have a significant effect on the performance of the geologic repository.*

The accessible environment has been defined in 10 CFR 60.2 to mean the atmosphere, the land surface, surface water, oceans, and the portion of the lithosphere that is outside the controlled area. The controlled area, defined in 40 CFR 191.12(g), means

> *(1) A surface location, to be identified by passive institutional controls, that encompasses no more than 100 square kilometers and extends horizontally no more than five kilometers in any direction from the outer boundary of the original location of the radioactive wastes in a disposal system, and (2) the subsurface underlying such a surface location.*

The fastest path of likely radionuclide travel is not defined in the regulation. For the purpose of resolving this issue, the DOE assumes that it is possible to identify geographically or geometrically distinct pathways for likely radionuclide travel at the Yucca Mountain site. One of these pathways is the generally downward flow of liquid water through unsaturated zone hydrostratigraphic units underlying the repository level to the water table and then to the accessible environment. The flow in this pathway could be through pores in the rock matrix and through fractures in these units. Pathways may also be identified with potential fracture zones associated with the Ghost Dance fault or other faults that may significantly affect flow times through the site. In addition, there may be local zones within the heterogeneous system in which the necessary values of hydrologic parameters are sufficiently correlated that a discrete, rapid velocity pathway can be identified.

Although water may move through the unsaturated zone in both liquid and vapor phases, this issue is concerned only with the travel time of liquid water. The direct effects on performance of vapor flux through the unsaturated zone are addressed by Issue 1.1. Vapor flux through the unsaturated zone at Yucca Mountain may significantly influence both the magnitude and direction of liquid water flux and will therefore be considered in determining groundwater (liquid) travel time.

Models and processes

The proposed repository will be located in the unsaturated zone. This means that the flow paths of concern will have two parts:

- An approximately vertically downward portion through the unsaturated zone
- A generally horizontal portion through the saturated zone, as shown in Figure 3-5.

Several processes may be used to describe flow along each pathway. Darcian flow with dispersion in a fractured porous medium is the process that will be used as a baseline case to describe water movement through the unsaturated and saturated hydrogeologic units. Dispersion is a mixing and spreading process that should be considered to account for the times of first arrivals in a travel-time distribution. Dispersion is believed to be caused by small- to large-scale heterogeneities along a flow path. The dispersive effects of medium- to large-scale heterogeneities will be addressed by accounting for macroscopic property variations along flow paths. Small-scale effects also may be addressed, if they are shown to accelerate significantly first arrivals, by assigning a dispersivity factor to each unit.

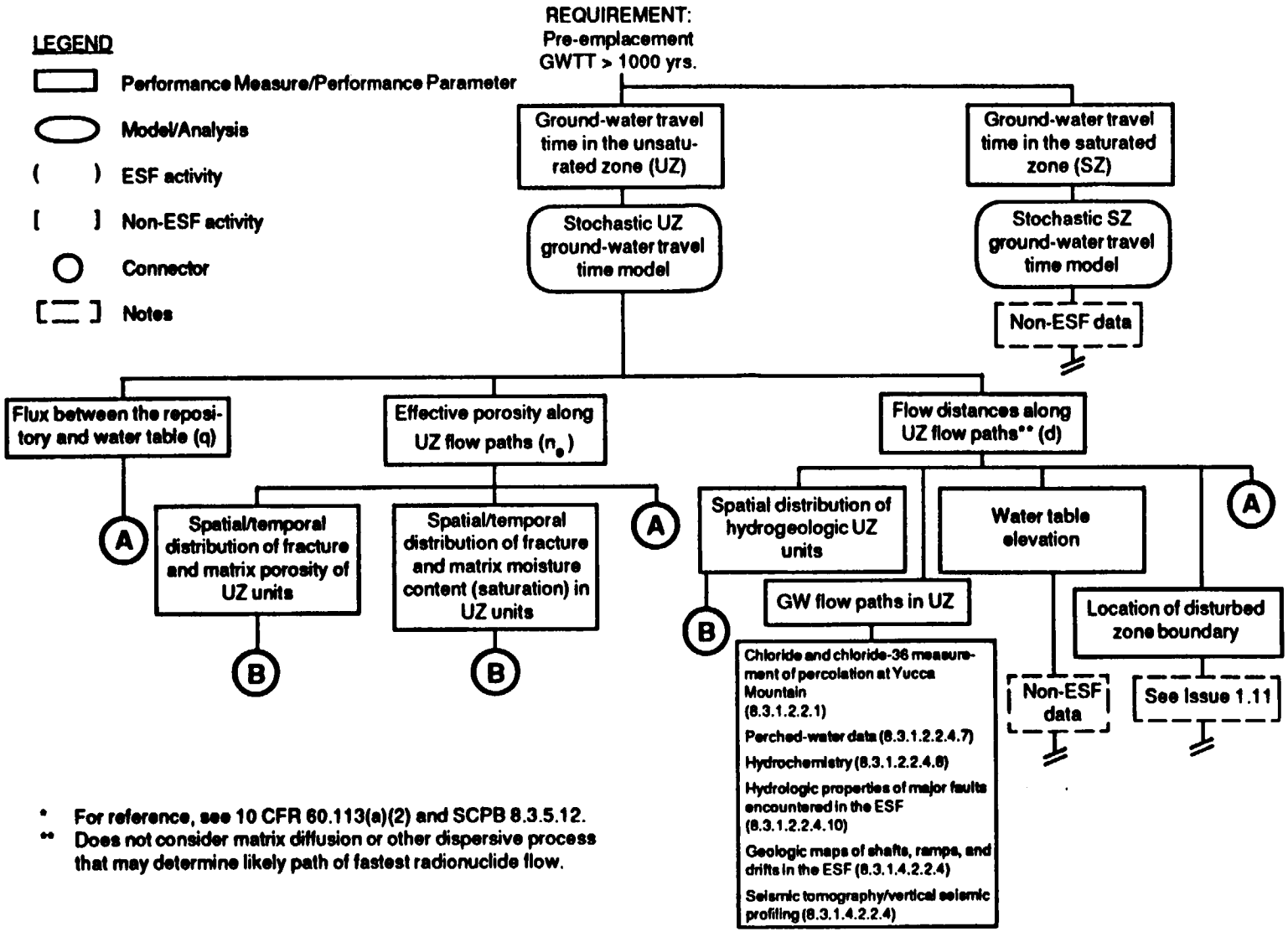
Parameters

The parameters required to satisfy this issue are those that can establish a basis for reasonable assurance that the requirement is met. This assurance can be achieved, in large part, if it can be demonstrated that water flows predominantly through the matrix rather than through the fractures. This would occur if the water flows through a sufficient volume of matrix pores for at least some minimal portion of each unit. For each unit, the sufficient volume of pore space may be expressed as effective porosity, n_e. The minimum portion of each unit may be expressed for a given flux, q, as distance, d, along a path (generally equivalent to thickness of units in the unsaturated zone, assuming vertical flow).

An auxiliary facet of the strategy for assessing groundwater travel times involves the estimation of groundwater ages at different points along the flow paths. Geochronology using carbon, chlorine, and hydrogen isotopes in the groundwater can provide a basis for estimating groundwater residence times.

The characterization parameters at the bottom of the chart are generally the point data acquired in the process of characterization activities; i.e., a specific sample at a well-defined location (x, y, z). Parameters at the top of the chart, on the other hand, represent the same parameters at a larger scale. These data may be expressed as statistical distributions, using information such as means, medians, standard deviations, maxima, minima, correlations, etc.

FIGURE 3-4 ISSUE 1.6*: GROUND-WATER TRAVEL TIME



* For reference, see 10 CFR 60.113(a)(2) and SCPB 8.3.5.12.

** Does not consider matrix diffusion or other dispersive process that may determine likely path of fastest radionuclide flow.

FIGURE 3-4 (cont.) ISSUE 1.6: GROUND-WATER TRAVEL TIME

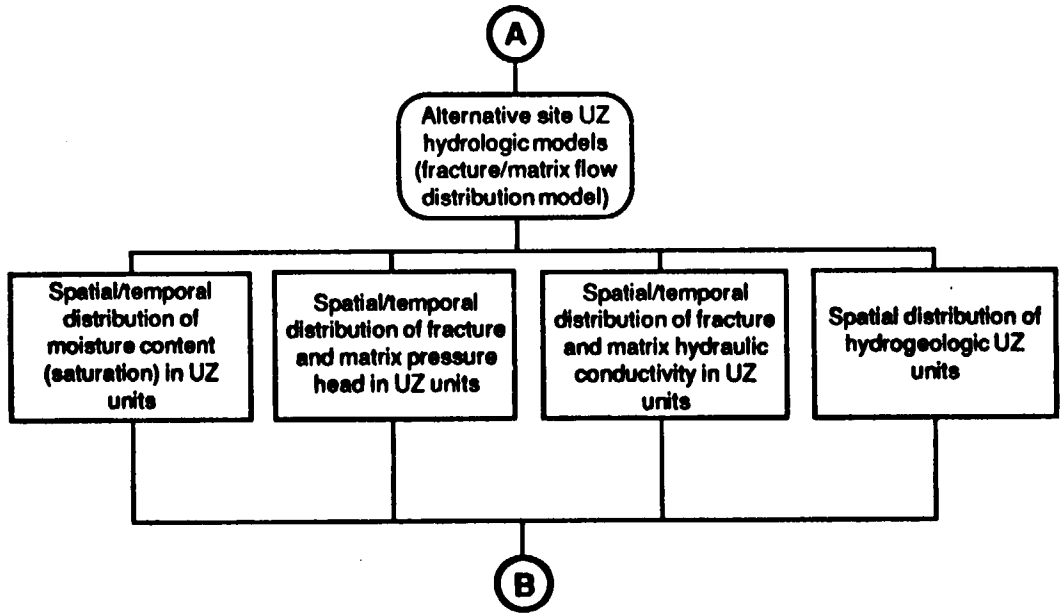


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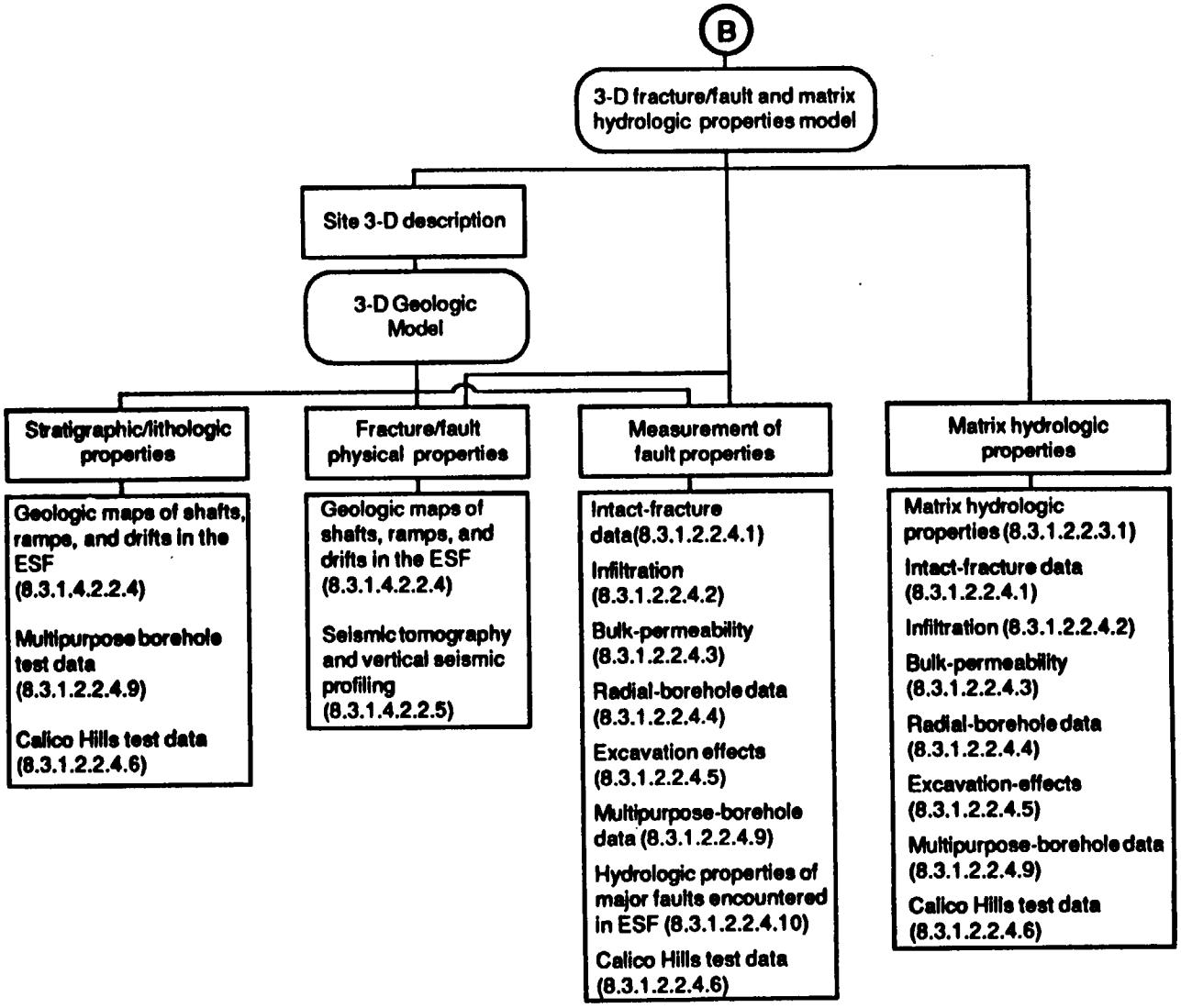
FIGURE 3-4 (cont.) ISSUE 1.6: GROUND-WATER TRAVEL TIME



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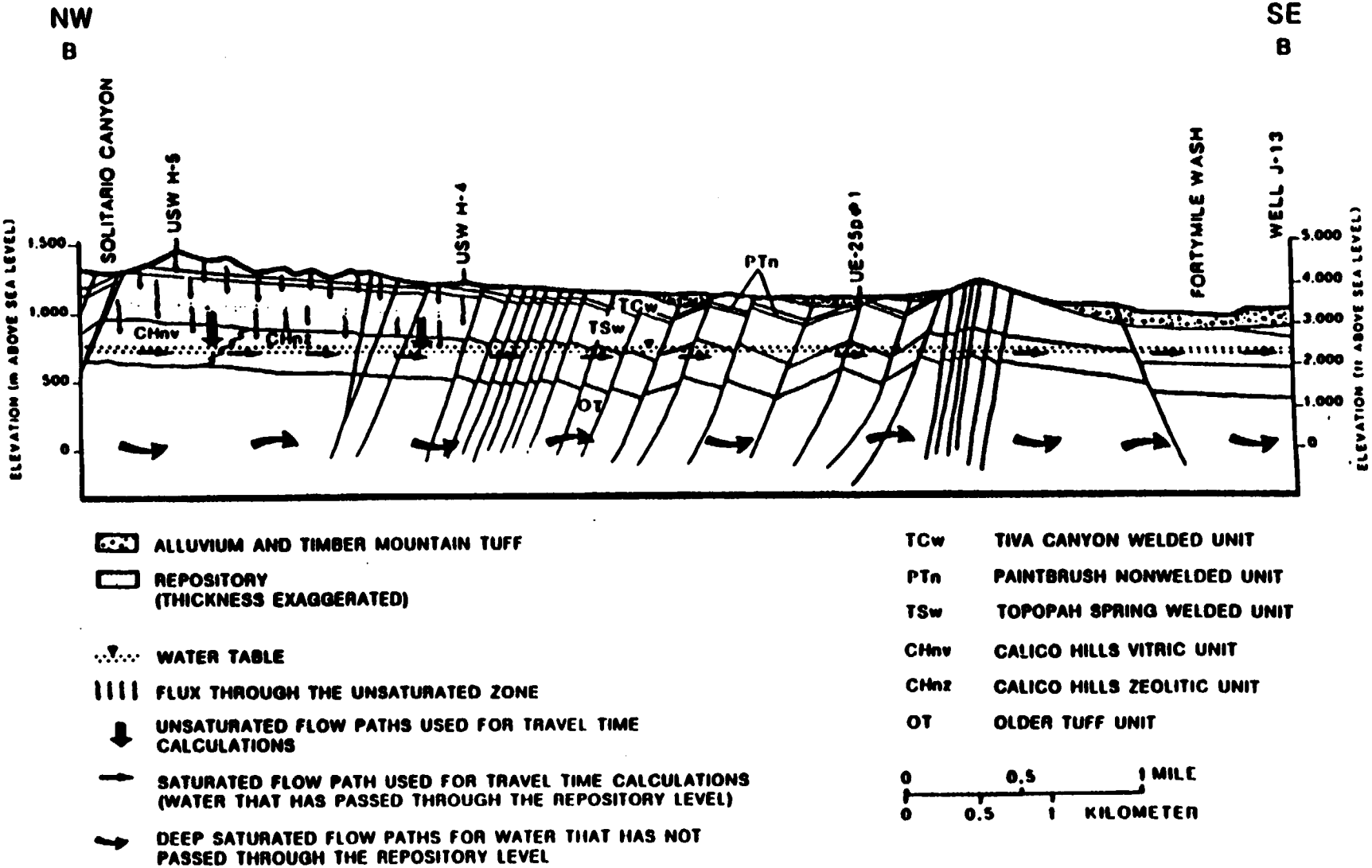


Figure 3-5. Conceptual Hydrogeologic Section from Solitario Canyon Well J-13. Section location shown in SCPB Figure 8.3.5.12-2 (modified from Scott and Bonk, 1984). Source SCPB Section 8.3.5.12.

3.4 ISSUE 1.10, WASTE PACKAGE CHARACTERISTICS

Issue 1.10: Have the characteristics and configurations of the waste packages been adequately established to (a) show compliance with the postclosure design criteria of 10 CFR 60.135 and (b) provide information to support resolution of the performance issues?

3.4.1 Introduction

Issue 1.10 deals with two aspects of the waste package postclosure behavior. The first aspect relates to the specific requirements contained in Section 135(a) of the NRC rule that states, in part:

1. *Packages for HLW shall be designed so that the in situ chemical, physical, and nuclear properties of the waste package and its interactions with the emplacement environment do not compromise the function of the waste packages or the performance of the underground facility or the geologic setting.*

2. *The design shall include but not be limited to consideration of the following factors: solubility, oxidation/reduction reactions, corrosion, hydrating, gas generation, thermal effects, mechanical strength, mechanical stress, radiolysis, radiation damage, radionuclide retardation, leaching, fire and explosion hazards, thermal loads, and synergistic interactions.*

These requirements will be addressed by gathering the information detailed in SCPB Sections 8.3.4.2.1 and 8.3.4.2.4.

The second part of this issue is more global in its application. Many of the performance issues require information on the behavior of the waste package. To provide this information, appropriate testing and analyses of the waste package components and system must be done. To identify appropriate tests and analyses, the service environment for the waste package must be determined.

The waste package environment, upon initial emplacement of the package, will depend on the ambient conditions at the repository level and how those conditions are altered by repository construction and operation. The environment following emplacement will depend on the initial emplacement conditions and how those conditions are altered by the waste package characteristics. Therefore, there is an interactive process between design and environment characterization. The design is initially based on the ambient conditions and a prediction of how those conditions would alter under the stresses applied by repository construction and waste emplacement. Once a design is available, analysis of that design provides a set of environmental stress factors. Testing is then done to determine the effects of those stresses, such as thermal and radiation fields and mechanical stresses, on the package environment. Based on those tests and subsequent analyses, designs may be modified and the test and analysis cycle repeated.

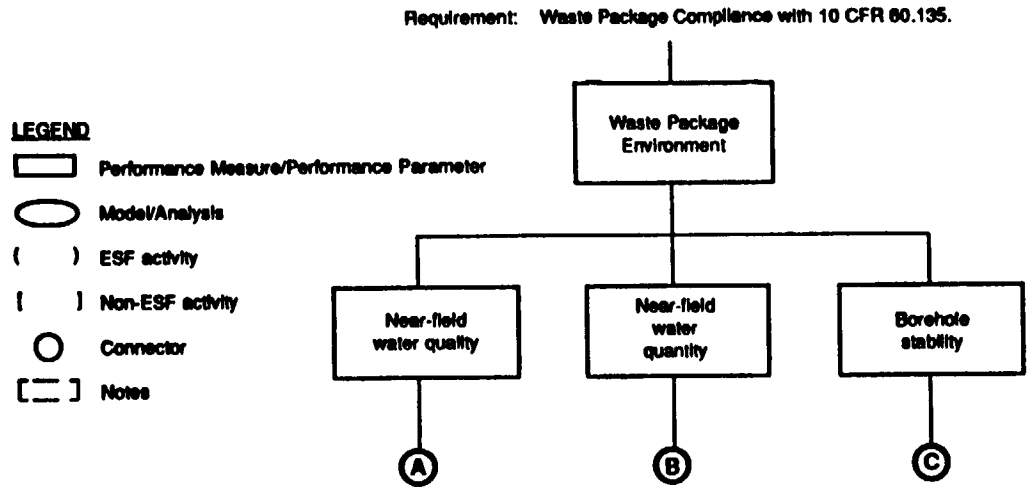
3.4.2 Logic Description

Issue 1.10 establishes the basis of the near-field postclosure waste package environment. The logic, shown on Figure 3-6, evolves from lower-level laboratory- and field-generated data through lower-level models to the Waste Package Water Quality Model, the Near-Field

Thermohydrologic Model, and the Borehole Stability Model. The model outputs are used to perform waste package performance assessment.

Field data must be obtained from samples for vadose chemistry, rock mineralogy, in situ rock stress, and rock mass thermal and mechanical properties. Other field in situ heated rock tests are required to validate the water quality and thermohydrologic models.

FIGURE 3-6 ISSUE 1.10*: WASTE PACKAGE CHARACTERISTICS



*For reference, see SCPB 8.3.4.2 and 10 CFR 60.135(a)(1), (2).

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FIGURE 3-6 (cont.) ISSUE 1.10: WASTE PACKAGE CHARACTERISTICS

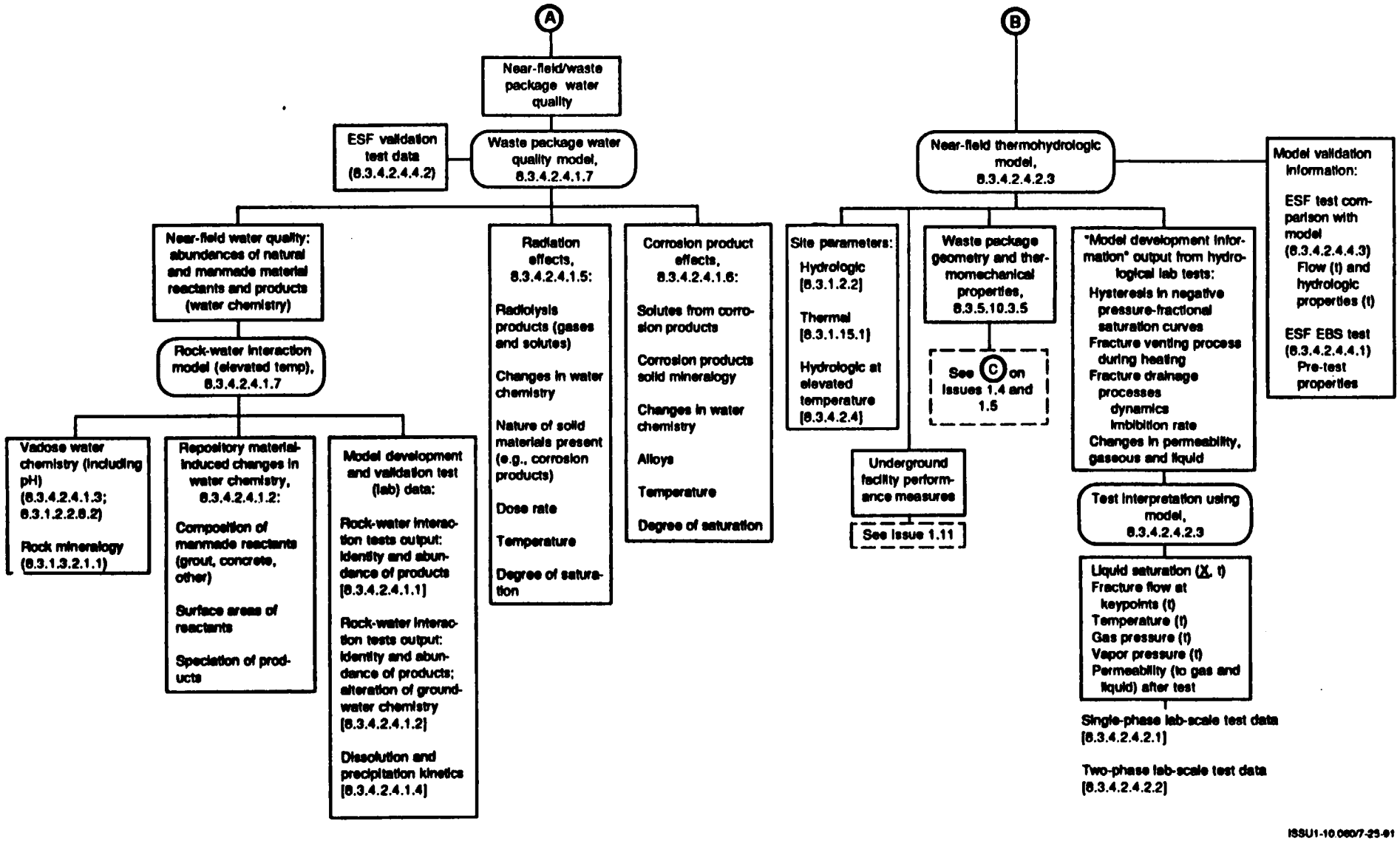
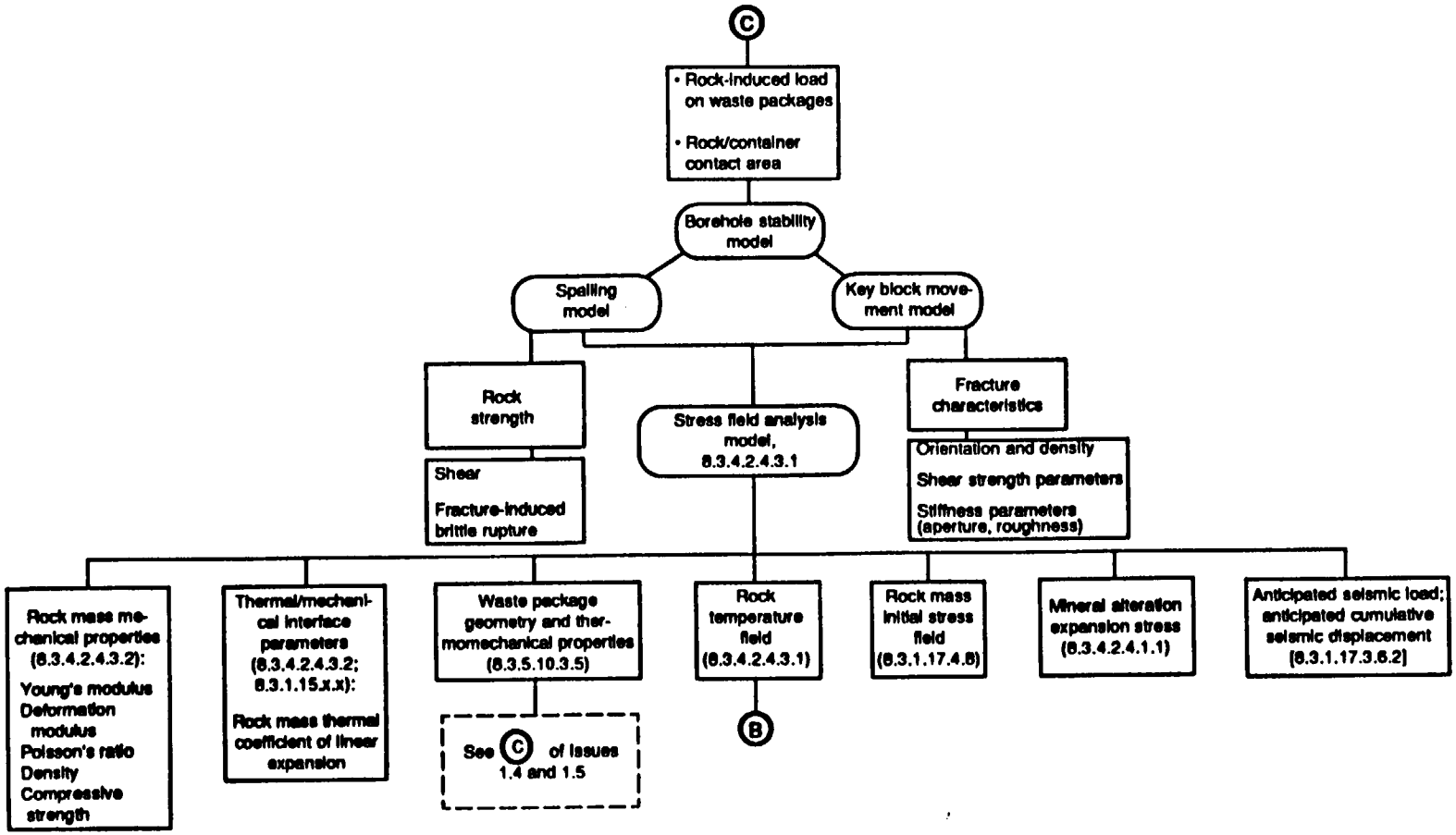


FIGURE 3-6 (cont.) ISSUE 1.10: WASTE PACKAGE CHARACTERISTICS



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3.5 ISSUE 1.11, CONFIGURATION OF UNDERGROUND FACILITIES (POSTCLOSURE)

Issue 1.11: Have the characteristics and configurations of the repository and the repository engineered barriers been adequately established to (a) show compliance with the postclosure design criteria of 10 CFR 60.133 and (b) provide information for the resolution of the performance issues?

3.5.1 Introduction

Section 8.3.2.2 of the SCPB identifies repository characteristics and configurations important to demonstrating compliance with the postclosure design criteria of 10 CFR 60.133 and provides information needed to incorporate postclosure performance objectives into the design. The former criteria require that the underground facility and engineered barrier system are designed to:

- Contribute to containment and isolation.
- Assist the geologic setting in meeting performance objectives.
- Take into account the thermal and thermomechanical response and the need for sufficient flexibility to accommodate site-specific changes.

This section of the SCPB is specifically associated with the following portions of 10 CFR 60.133, which have been grouped together as Issue 1.11:

(a)(1)	General Criteria	(f)	Rock Excavation
(b)	Design Flexibility	(h)	Engineered Barriers
(e)(2)	Underground Openings	(i)	Thermal Loading

The remaining concerns of 10 CFR 60.133 are discussed in SCPB Sections 8.3.5.5 (Issue 2.3), 8.3.2.3 (Issue 2.7), 8.3.2.4 (Issue 4.2), and 8.3.2.5 (Issue 4.4).

The approach used to show the relationship between the strategy developed to meet these objectives and the testing needs is summarized in Section 3.5.2 of this document and illustrated in the accompanying logic diagram for Issue 1.11 (Figure 3-7).

3.5.2 Logic Description

Four basic functions are described in SCPB Section 8.3.2.2 to address the postclosure design concerns of 10 CFR 60.133. The first function relates to establishing a flexible underground facility configuration to accommodate site-specific conditions and contribute to containment and isolation, as expressed in 10 CFR 60.133(a)(1) and (b). The second function is concerned with avoiding potential adverse impact in the chemical environment and degree of saturation of the host rock by establishing limits on water usage and potential chemical changes, per 10 CFR 60.133(a)(1) and (h). The third function, addressing 10 CFR 60.133(e)(2) and (f), is to limit the potential for excavation-induced changes in rock mass permeability. The fourth function, associated with 10 CFR 60.133(i), is to design the thermal loading of the repository to account for postclosure performance objectives and the thermal response of the host rock.

A considerable amount of information and the results generated by each function are transferred between these functions and among other SCPB activities. The intent of this discussion and the accompanying diagrams, however, is not to describe the overall logic and information needed to demonstrate compliance with regulatory requirements. Rather, the intent is to show relationships between the functions and site data collection activities. The logic paths for each of the four functions are discussed separately in the following subsections and illustrated in Figure 3-7.

Underground facility configuration

The first function addresses the selection of the underground facility configuration to satisfy containment and isolation considerations in light of site-specific conditions. These considerations include the repository configuration, the environment of the waste containers, and the need for design flexibility. Eight measures of how well this function will be performed have been defined and are shown as the top level of the logic diagram (Figure 3-7).

Associated with the first of these, determining if the usable area is adequate for 70,000 MTU of waste, are six parameters for which data are needed. For the first performance measure, it is necessary to determine the area needed for disposal of the waste and the usable area. Specification of the usable area must consider the necessity of incorporating sufficient flexibility in the design to allow adjustments to accommodate specific site conditions that may be identified through in situ monitoring, testing, or excavation. The needed area is the total thermal output of the waste divided by the allowable thermal load. In turn, the total thermal output is determined from the waste inventory, including the thermal output of the waste as a function of waste type, age, burnup, and enrichment.

To determine adequate area requires the following: The depth, dip, orientation, and lateral extent of the underground facility will be varied to provide host rock with favorable containment and isolation characteristics. The layout or design of the underground facility will need to take into account several site characteristics, including topography, unit contact elevations, water table elevation, the description of faults, and exploratory borehole locations. These site characterization data, presented in the form of maps, will be determined through a combination of surface and subsurface testing activities as shown at the base of the diagram. Subsurface activities are described in SCPB Section 8.3.1.4.2.2.4.

Design concepts that contribute to performance and flexibility may be impacted by the decision between vertical and horizontal boreholes for waste emplacement; thus, this decision must be made. This decision is indicated by the second performance measure of the diagram and will be based on performance considerations and equipment capabilities with respect to waste package thermal output and borehole orientation and spacing. The performance of the system with respect to regulatory requirements more directly related to waste containment and isolation considerations of the waste package environment will be used to show compliance with postclosure design considerations of SCPB Section 8.3.2.2. For this reason, no additional site data are directly associated with this performance measure or identified on the logic diagram.

The next four performance measures for the first function are concerned with site properties that influence the waste package environment and include determining regions of condensation or dehydration and drainage pattern to limit moisture content, establishing the local ground quality and distance from areas having unfavorable properties, and determining changes in saturation or water chemistry that could influence containment or isolation. This work will provide postclosure

design requirements that will limit the amount of water in contact with the container so as to provide a favorable containment and isolation environment. This work will also develop criteria that will be used to establish whether actual site conditions are consistent with the design bases. The latter will be discussed in a contingency plan, which will describe actions needed to deal with the possibilities of unexpected conditions in order to provide confidence that the repository will provide waste containment and isolation for the required repository capacity.

An evaluation of water drainage control requirements is necessary because such requirements may impact the design concepts that contribute to performance and flexibility. Measurement of the performance in this area requires information provided by total system performance assessment activities, which will be based on data on the waste package thermal output and other data obtained from surface testing and unsaturated zone percolation testing that will be used to model fluid flow and hydrothermal effects. Simple thermal calculations (heat transfer by conduction) will be used to identify regions of vaporization and condensation so that the emplacement drifts and boreholes can be designed to control water migration away from waste containers, as discussed in SCPB Section 8.3.3.2. Site data needed to conduct the near-field thermal calculations are expected to be identical to the data needed for the fourth function, thermal loading, described below. Effects on saturation and water chemistry will be determined from information from percolation and surface testing. Establishing the distance from ground with unfavorable properties makes use of geochemical information derived from hydrochemical and surface-based testing information.

The last two performance measures of this function address design flexibility because they are related to: (1) the need to account for thermal loads appropriately so as not to adversely affect thermal impacts on isolation and containment and, (2) thermomechanical effects on the local environment. Information supplied by the results of the fourth function will be used for these determinations.

Water and material limits

The second function is to limit and control the use of water and materials during construction, operation, and decommissioning to ensure that the performance of the Engineered Barrier System (EBS) is not compromised. Two sets of criteria will be developed for use in control of the repository design, construction, operation, and closure. The first set of criteria concerns the modification of the postclosure geochemical environment of the waste package as a result of all preclosure activities. The second set of criteria concerns changes in the degree of saturation of the host rock as a result of all preclosure activities. Other criteria are established under the first and third functions. The performance of this function is measured by determining the type, quantity, and locations of materials introduced into the environment as a result of these activities and the net water that remains in the host rock at emplacement. This information on material inventories, geochemical effects, planned water usage in the repository and ESF, and allowable saturations will be provided by preclosure design and long-term performance activities. Water usage for the ESF will use information established through design specifications and ESF percolation and diffusion tests.

Excavation impacts

The third function is to limit the potential for changing the rock-mass permeability through excavation method effects that might adversely impact postclosure performance by ensuring that appropriate criteria are provided as guidelines for repository design. Excavation damage to the host rock can result in modification of the hydrologic environment in the vicinity of the waste package or in the general underground facility area. Realistic criteria for establishing the suitability of proposed construction methods must be developed based on performance assessment requirements. The measures of how well this is achieved include determining that permeability changes do not change the boundary of the disturbed zone or complicate emplacement and seal evaluation, and that engineering specifications for extraction ratio, drift span, and fill quantities do not significantly change the rock mass permeability. Results of excavation effects and radial borehole tests are used to determine blast-induced permeability changes. Other preclosure design information and plans for permanent closure plans are also needed.

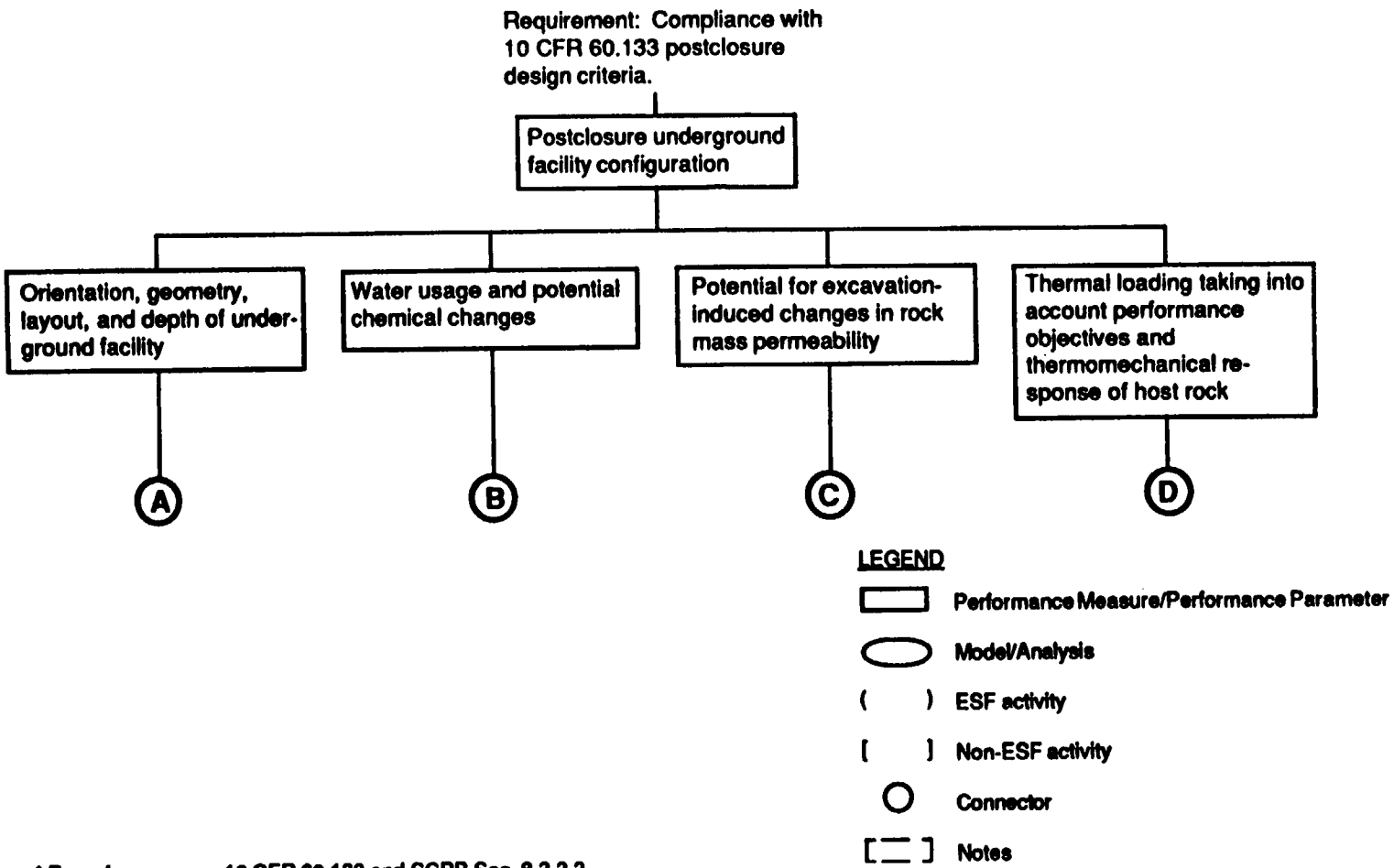
Thermal loading

The fourth function, the design of thermal loading to take into account performance objectives and the thermomechanical response of the host rock, is concerned with the requirement of 10 CFR 60.133(i) to select thermal loading so that postclosure performance objectives will be met and to limit surface environmental impacts. Activities performed under this function include determining the thermal fields in the immediate vicinity of the waste and below the underground facility, limiting deleterious rock movements due to thermomechanical effects, and limiting surface changes resulting from waste emplacement. This will be done through a variety of thermal and thermomechanical analyses performed at container, drift, and far-field scale, which will be used to establish the areal power density and borehole spacing, and to develop a strategy for enhancing containment performance through waste loading.

Performance measures for this function include thermal loading, temperature of several thermomechanical units, changes in surface temperatures and elevation, thermomechanical effects such as stress, deformation, factor of safety, and rockfall potential or other displacement movements, and the time containers will be subjected to temperatures above the boiling point of water. These parameters are needed to evaluate hydrologic effects, thermomechanical behavior, and container corrosiveness, all of which are related to postclosure containment and isolation.

A variety of fundamental geologic, thermal, mechanical, and tectonic site data are needed to evaluate the performance of this function, and will be supplied through activities identified under Issue 4.4, which concerns preclosure design. In addition, other design information such as emplacement geometry, waste inventory, and thermal output will be used in the analyses.

FIGURE 3-7 ISSUE 1.11*: CONFIGURATION OF UNDERGROUND FACILITIES (POSTCLOSURE)



* For reference, see 10 CFR 60.133 and SCPB Sec. 8.3.2.2.

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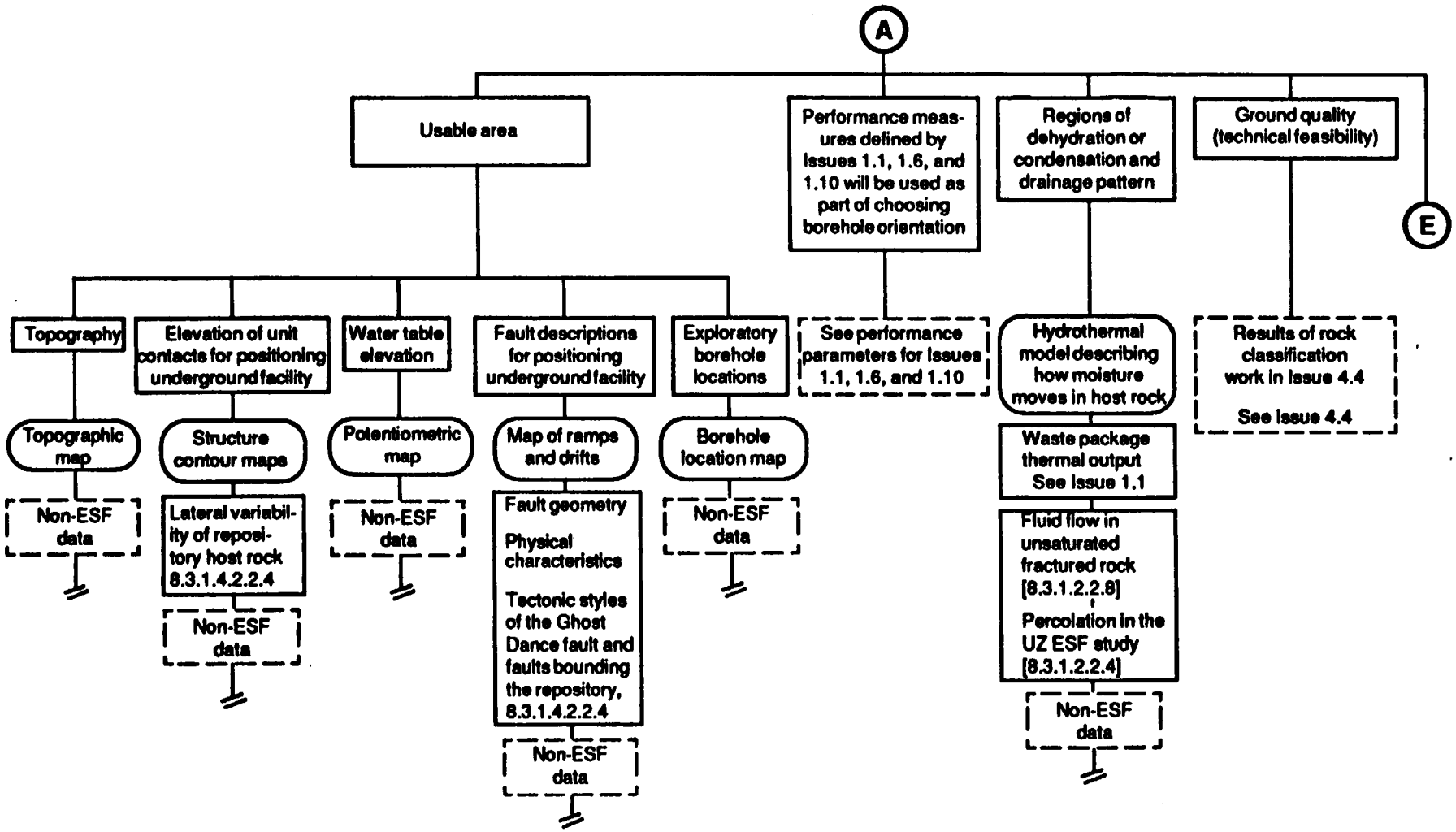
FIGURE 3-7 (cont.) ISSUE 1.11: CONFIGURATION OF UNDERGROUND FACILITIES (POSTCLOSURE)



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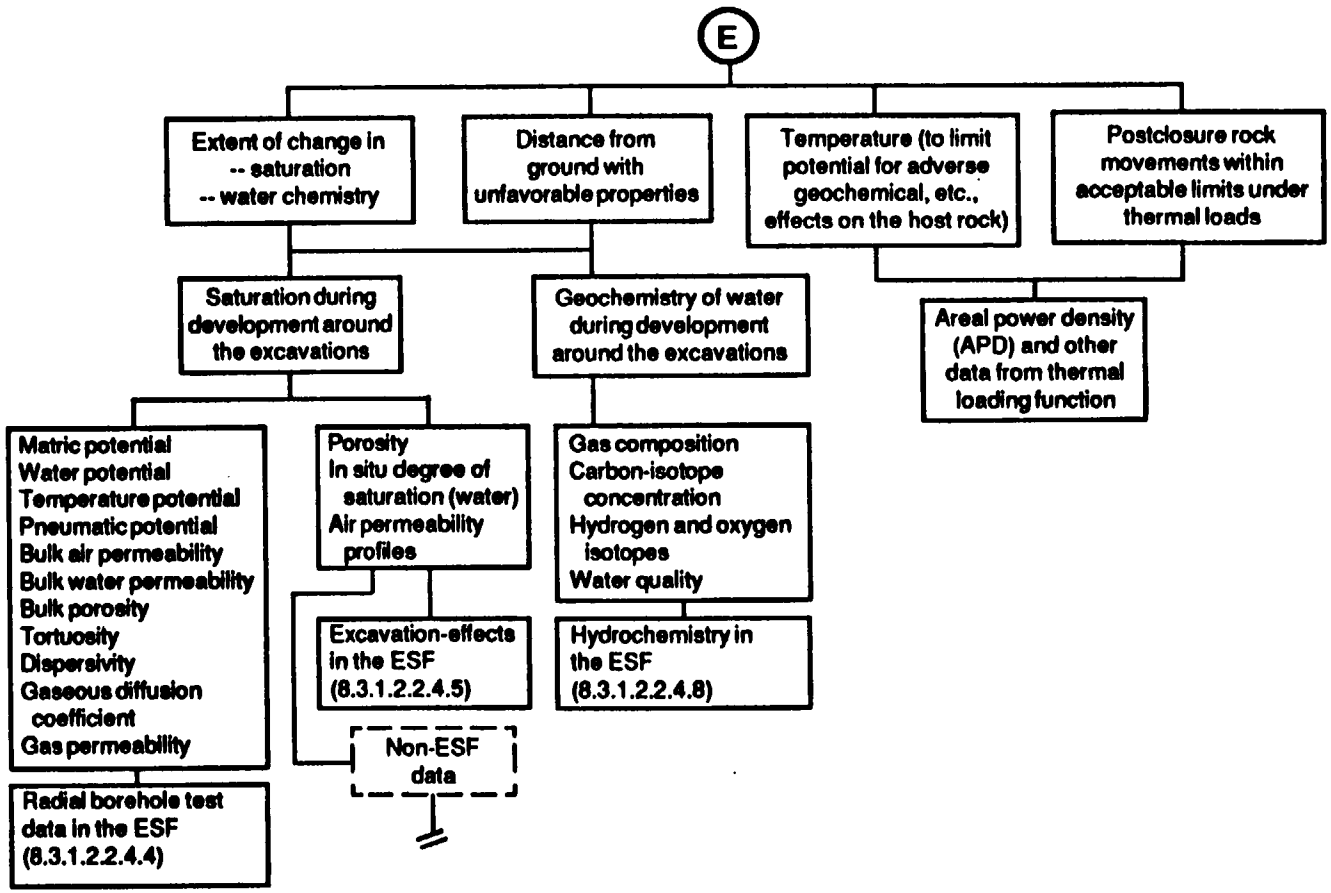

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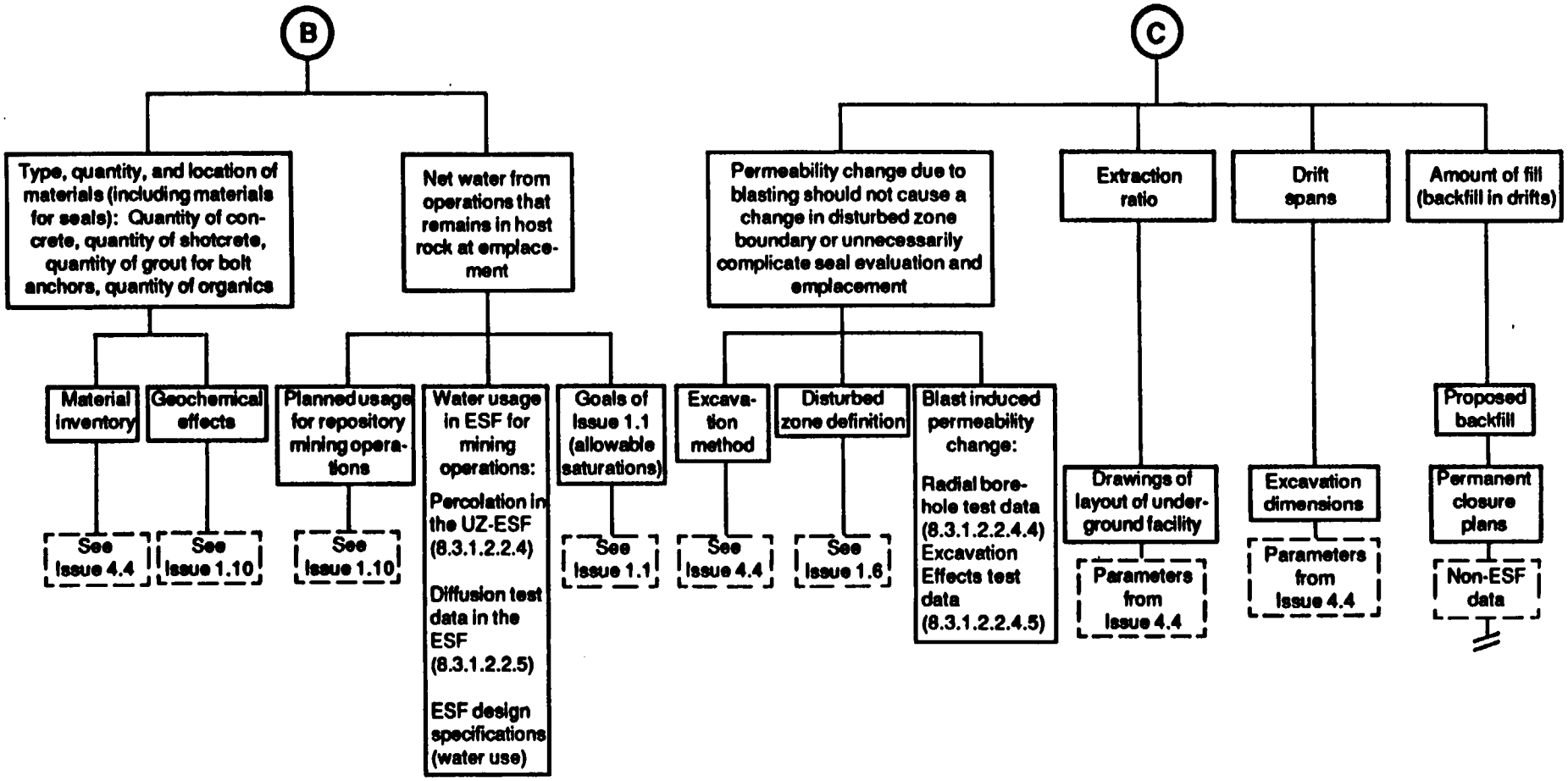

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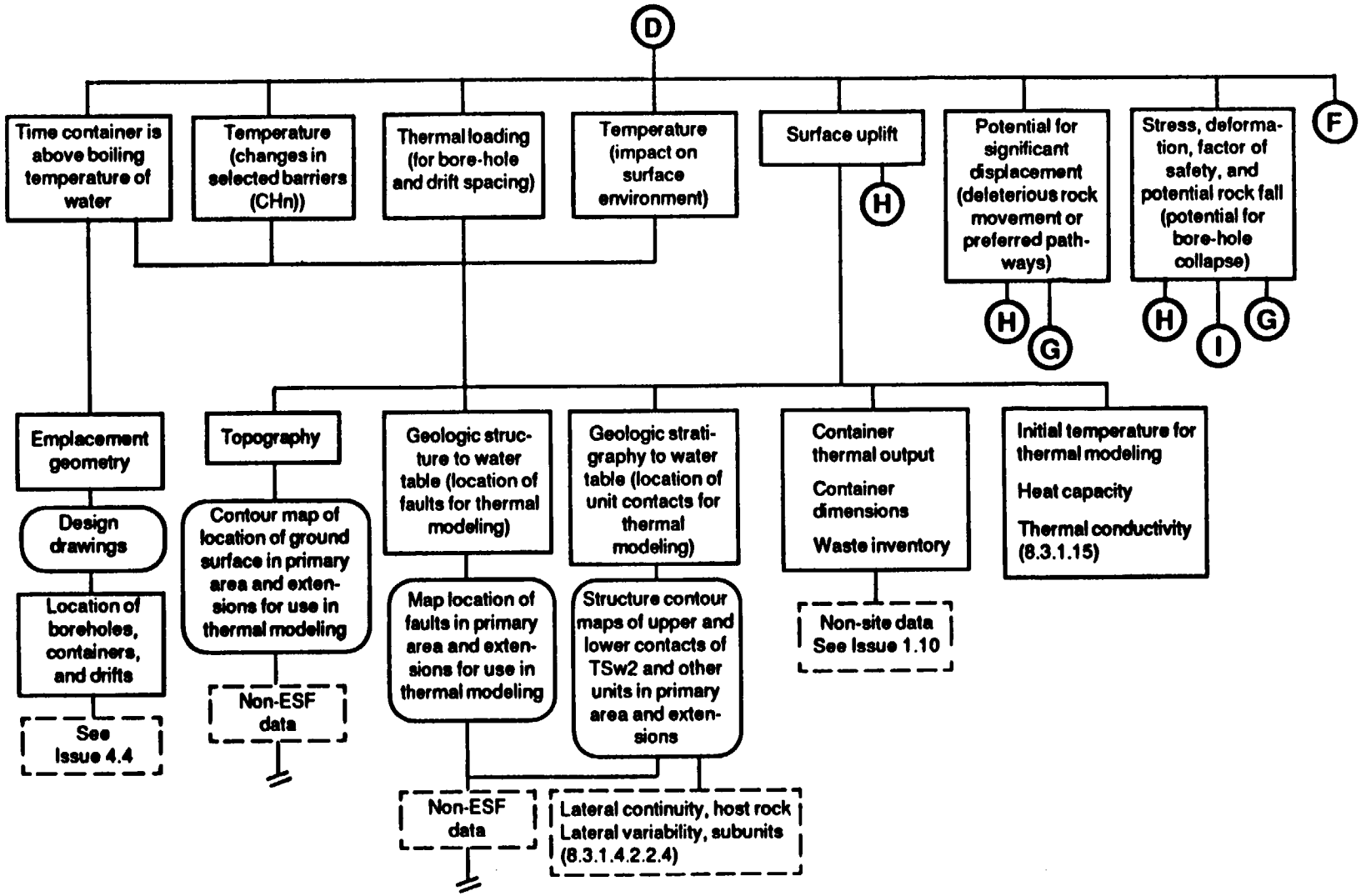

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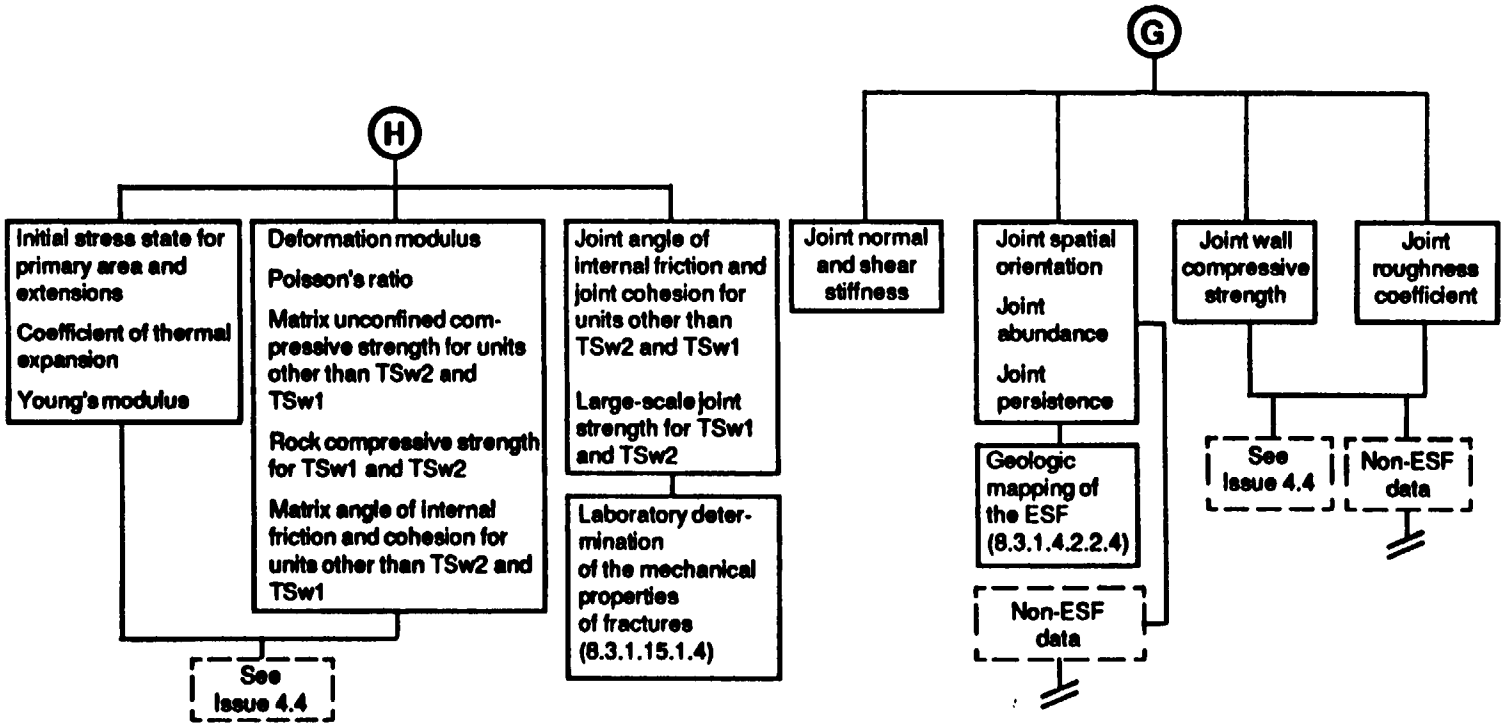

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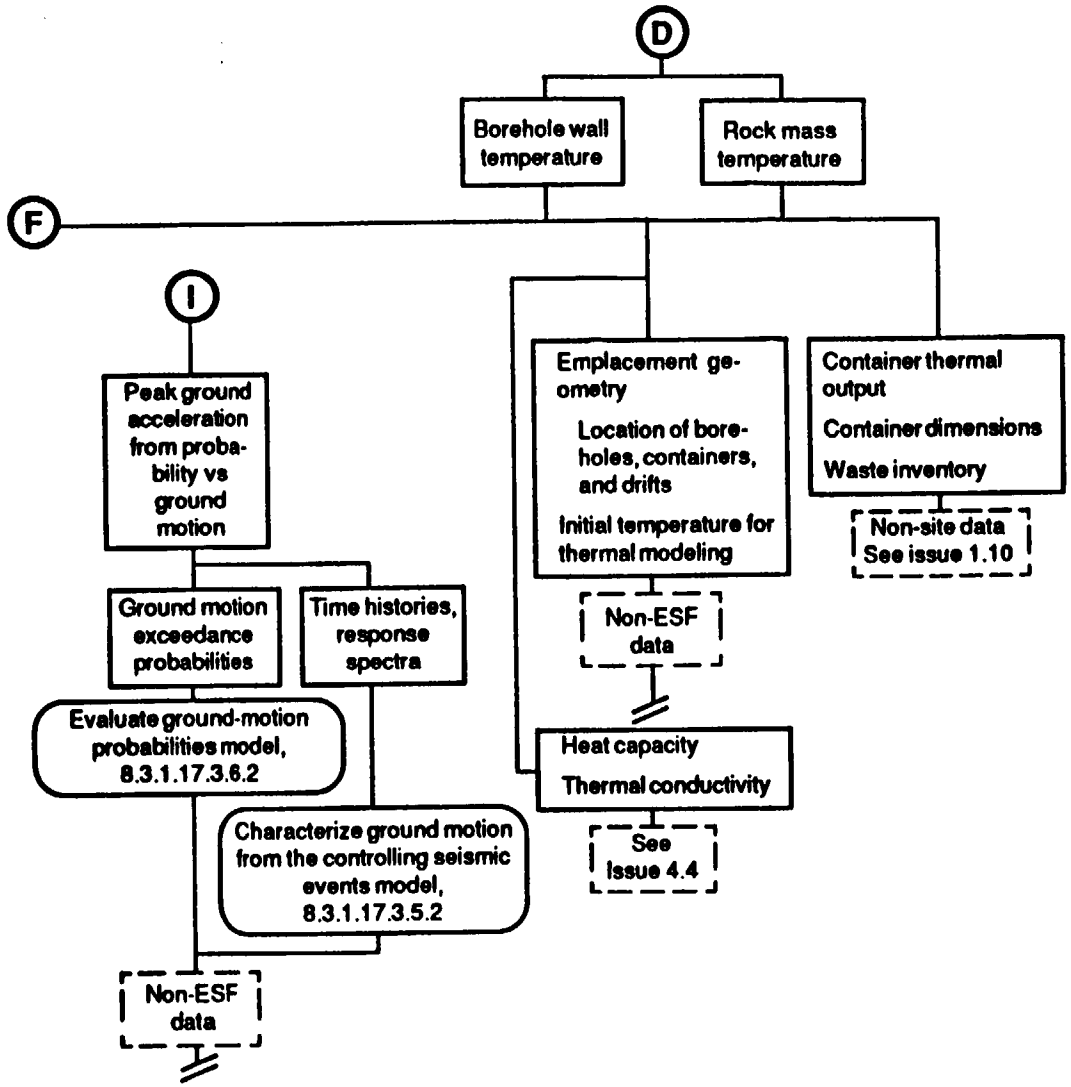
FIGURE 3-7 (cont.) ISSUE 1.11: CONFIGURATION OF UNDERGROUND FACILITIES (POSTCLOSURE)



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3.6 ISSUE 1.12, SEAL CHARACTERISTICS

Issue 1.12: Have the characteristics and configurations of the shaft and borehole seals been adequately established to (a) show compliance with the postclosure design criteria of 10 CFR 60.134 and (b) provide information for the resolution of the performance issues?

3.6.1 Introduction

Section 8.3.3.2 of the SCPB is concerned with the seals for ramps, shafts, boreholes, and all other sealing components within the underground facility. Demonstration of compliance with the postclosure design criteria of 10 CFR 60.134 and providing information needed for the resolution of performance issues related to sealing are addressed through Issue 1.12, the resolution strategy discussed in this section of the SCPB. Regulatory requirements related to sealing include the following portions of 10 CFR Part 60:

- 112 — Overall postclosure system performance objectives,
- 113 (a) — Postclosure performance of barriers,
- 134 (a) — General design criteria for shaft and borehole seals,
- 134 (b) — Selection of materials and placement methods, and
- 142 (a)-(b) — Performance confirmation.

The role of sealing in contributing to preclosure performance is addressed by other sections of the SCPB, in particular Sections 8.3.5.3 (Issue 2.1), 8.3.5.4 (Issue 2.2), 8.3.5.5 (Issue 2.3), and 8.3.2.3 (Issue 2.7). The approach used to show the relationship between the strategy developed to meet these objectives and the testing needs is summarized in Section 3.6.2 of this document and illustrated in the logic diagrams for Issue 1.12 (Figure 3-8).

3.6.2 Logic Description

The logic diagrams for Issue 1.12 (Figure 3-8) show a successively detailed breakout of sealing functions, performance measures selected to determine how well these functions are performed, and parameters needed to measure function performance. A considerable amount of information and the results generated by each function are transferred between these functions and among other SCPB activities. The intent of this discussion and the accompanying diagrams, however, is not to describe the overall logic and information needed to demonstrate compliance with regulatory requirements. Rather, the intent is to show relationships between the functions performed by seal components and site data collection activities.

The three types of sealing locations – shaft and ramp seals, exploratory borehole seals, and underground facility seals – are used to begin the logical decomposition and are identified at the top of the logic diagram. The logic paths for each of these are discussed separately in the following subsections and illustrated in the diagrams.

Shaft and ramp seals

Four functions have been defined for shaft and ramp seals. The first, which is to reduce the amount of water that could potentially reach the waste disposal rooms, is performed by three sealing components (not shown) – the anchor-to-bedrock plug/seal, general fill, and the station plugs. The second function is to reduce the potential for human intrusion into the repository and is performed by the anchor-to-bedrock plug/seal and general fill components. The third function is to reduce the air flow up through shafts. This function is performed by the general fill-sealing component. The fourth function is to encourage drainage from the base of shafts, which is performed by the unsaturated rock of the Topopah Spring member (TSw2), at the base of the shafts. This rock is considered one of the four sealing components for ramp and shaft seals.

The performance measures selected for the four functions, respectively, are:

- The quantity of water,
- Physical presence,
- Percentage of gaseous radionuclides preferentially exiting shafts, and
- Drainage capacity.

To determine the quantity of water entering the facility, a variety of site specific data is needed, as shown in the logic diagram (Figure 3-8). No site-specific data are needed to determine the physical presence of humans entering the facility. To determine how well the function of reducing air flow performs requires information on the properties of shaft and ramp fill materials, such as those shown on the logic diagram (Figure 3-8). Finally, to determine drainage performance, the drainage capacity, saturated bulk rock hydraulic conductivity, and quantity of water entering shafts must be known.

Exploratory borehole seals

Three functions have been defined for the sealing of exploratory boreholes, which are similar to those discussed above:

- To reduce the amount of water that could potentially reach waste disposal rooms,
- To reduce the air flow up through the boreholes, and
- To reduce the potential for water-transported radionuclides to be preferentially transported through boreholes.

The first two functions are performed by the upper borehole-sealing component, and the third function is performed by the lower borehole sealing component.

The first function, which is to reduce the amount of water that could potentially reach the waste disposal rooms, uses the quantity of water as the measure of how well the function is performed. Site data used to measure performance include hydraulic conductivities, saturation profiles, predictive flood information, and geologic characteristics. The second function is to reduce the air flow up through the boreholes. The performance measure for this function is the percentage of gaseous radionuclides preferentially exiting boreholes. Parametric input to this function includes saturated hydraulic conductivities, unsaturated hydraulic properties, geochemical data, exploratory borehole casing locations and condition, alluvial thickness, and locations of exploratory borehole unit contacts. The third function is to reduce the potential for preferential

transport of radionuclides through boreholes by liquid transport, the performance of which is measured by the percentage of flow. Parametric input to this function includes the saturated bulk rock hydraulic conductivity, geochemical data, exploratory borehole casing locations and condition, and locations of exploratory borehole unit contacts.

Underground facility seals

The following seven functions have been defined for underground facility seals:

- To retain and drain water entering emplacement drifts where water entry occurs,
- To retain and drain water entering nonemplacement areas,
- To retain and drain water entering drifts,
- To divert water away from waste emplacement areas,
- To reduce the amount of water entering horizontal emplacement boreholes,
- To reduce the potential for subsidence, and
- To reduce the potential for human intrusion into the repository.

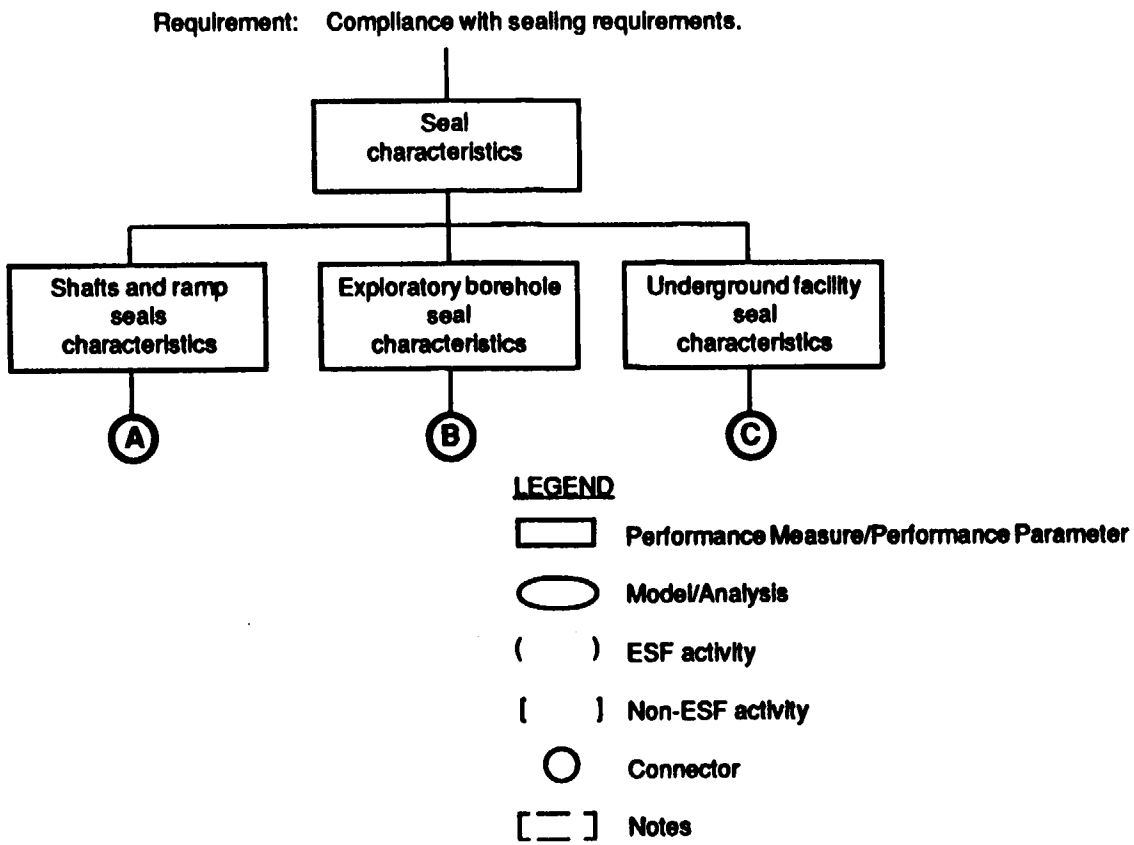
A single performance measure, the quantity of water, has been identified for the first four functions, which will utilize parameters that include drainage capacity, seismic response, geochemistry, maximum temperatures at sealing locations, thermal properties of the sealing environment, fracture characteristics, water chemistry, and design information.

The fifth function performed by underground facility seals is to reduce the amount of water entering horizontal emplacement boreholes. The performance of this function is also measured by the quantity of water. Thermal properties of the seal emplacement environment are identified as parametric needs of this function.

The sixth function is to reduce the potential for subsidence, the performance measure for which is identified as the amount of fill. Compressive strength, in situ stresses, temperatures at sealing locations, fracture characteristics, and water chemistry in faults are shown as input parameters to this function.

The seventh function is to reduce the potential for human intrusion into the repository. The performance measure for this function is physical presence of humans. No site data are required for this performance measure.

FIGURE 3-8 ISSUE 1.12*: SEAL CHARACTERISTICS



*For reference, see 10 CFR 60.134(a) and (b), 10 CFR 60.112, 10 CFR 60.113(a), 10 CFR 60.142(a) through (d), and SCPB Section 8.3.3.2.

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FIGURE 3-8 (cont.) ISSUE 1.12: SEAL CHARACTERISTICS

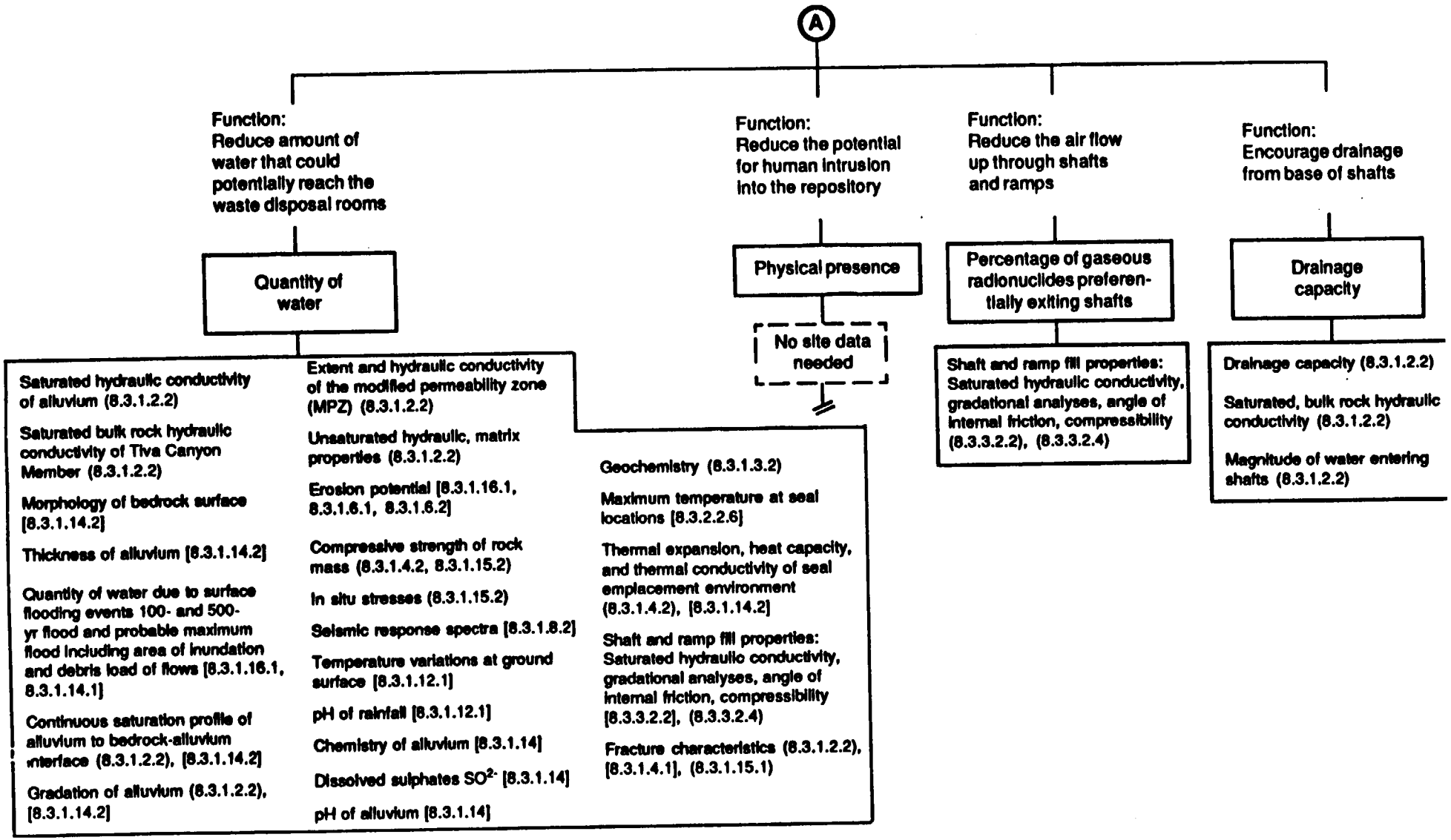

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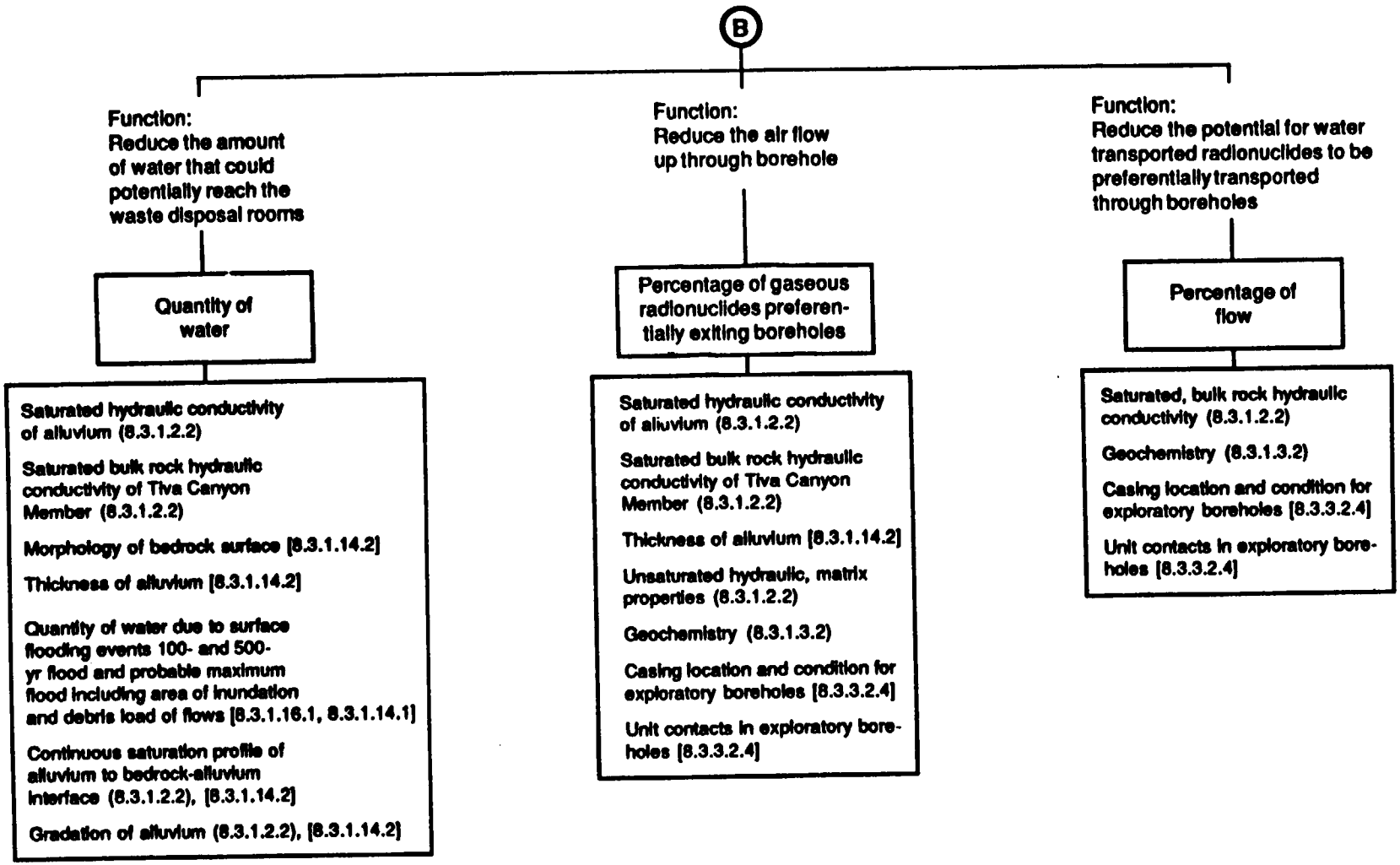
FIGURE 3-8 (cont.) ISSUE 1.12: SEAL CHARACTERISTICS



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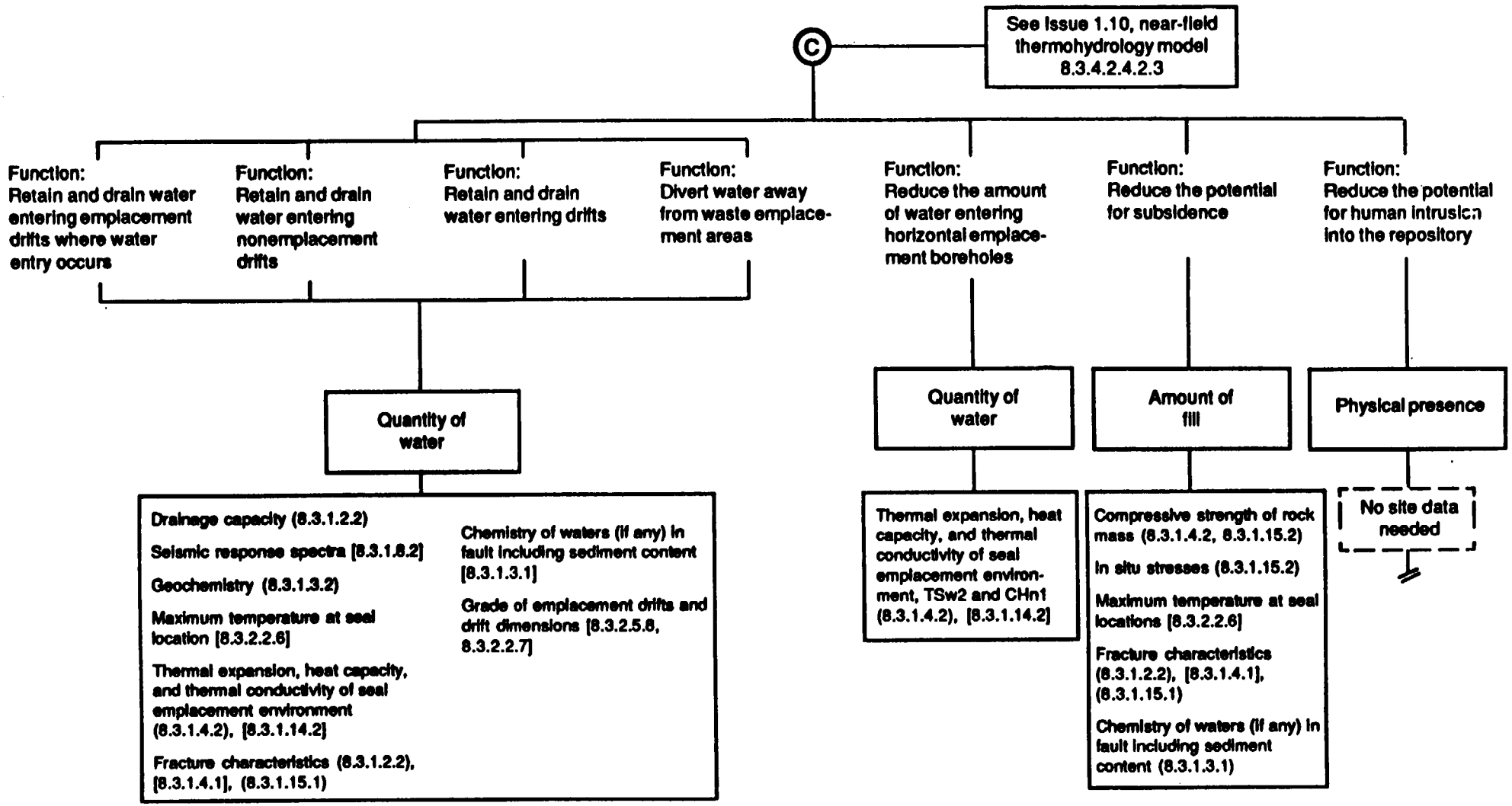
C
See Issue 1.10, near-field thermohydrology model 8.3.4.2.4.2.3
Function: Retain and drain water entering emplacement drifts where water entry occurs
Function: Retain and drain water entering nonemplacement drifts
Function: Retain and drain water entering drifts
Function: Divert water away from waste emplacement areas
Function: Reduce the amount of water entering horizontal emplacement boreholes
Function: Reduce the potential for subsidence
Function: Reduce the potential for human intrusion into the repository
Quantity of water
Quantity of water
Amount of fill
Physical presence
Drainage capacity (8.3.1.2.2)
Seismic response spectra [8.3.1.8.2]
Geochemistry (8.3.1.3.2)
Maximum temperature at seal location [8.3.2.2.6]
Thermal expansion, heat capacity, and thermal conductivity of seal emplacement environment (8.3.1.4.2), [8.3.1.14.2]
Fracture characteristics (8.3.1.2.2), [8.3.1.4.1], (8.3.1.15.1)
Chemistry of waters (if any) in fault including sediment content [8.3.1.3.1]
Grade of emplacement drifts and drift dimensions [8.3.2.5.8, 8.3.2.2.7]
Thermal expansion, heat capacity, and thermal conductivity of seal emplacement environment, TSw2 and CHn1 (8.3.1.4.2), [8.3.1.14.2]
Compressive strength of rock mass (8.3.1.4.2, 8.3.1.15.2)
In situ stresses (8.3.1.15.2)
Maximum temperature at seal locations [8.3.2.2.6]
Fracture characteristics (8.3.1.2.2), [8.3.1.4.1], (8.3.1.15.1)
Chemistry of waters (if any) in fault including sediment content (8.3.1.3.1)
No site data needed
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3.7 ISSUE 2.2, WORKER RADIOLOGICAL SAFETY – NORMAL CONDITIONS

Issue 2.2: Can the repository be designed, constructed, operated, closed, and decommissioned in a manner that ensures the radiological safety of workers under normal operations as required by 10 CFR 60.111, and 10 CFR Part 20?

3.7.1 Introduction

The mined geologic disposal system with geologic repository at Yucca Mountain will be designed to limit the radiation doses to workers during construction, operation, closure, and decommissioning of the repository to less than the limits specified in 10 CFR Part 20 during normal operations. Design criteria and assumptions will be needed for both repository system operation and worker radiation safety. Many of the same parameters apply to both areas and require appropriate input from design development. In these iterative design activities, appropriate guidelines will be used in designing for repository worker radiation safety. Administrative procedures will be required to limit personnel exposure (e.g., personnel monitoring, limited access, and operational changes) for any operational activities for which design features are not able to preclude the possibility of dose rates to personnel in excess of the guidelines.

Although Issue 2.2 refers to both 10 CFR 60.111(a) and 10 CFR Part 20, 10 CFR 60.111(a) simply refers to 10 CFR Part 20 and 40 CFR Part 191, Subpart A. Because 40 CFR Part 191, Subpart A, is applicable only to members of the public, 10 CFR Part 20 (standards for protection against radiation) is the only regulation directly relevant to Issue 2.2. In addition, there are other sections of 10 CFR Part 60 that either require conformance with 10 CFR Part 20 or for which compliance with 10 CFR Part 20 is relevant. These include the following:

- 10 CFR 60.21(c)(7), which requires description of the program to maintain effluents and occupational exposures in accordance with 10 CFR Part 20.
- 10 CFR 60.131, which requires the design to meet the radiation protection requirements of 10 CFR Part 20.
- 10 CFR 60.132, which requires the design to provide effluent control and monitoring in accordance with 10 CFR 60.111(a), which in turn invokes 10 CFR Part 20.
- 10 CFR 60.133, which requires the underground ventilation system to maintain radionuclide concentrations and releases in accordance with 10 CFR 60.111(a) (which invokes 10 CFR Part 20).

10 CFR Part 20 specifies the regulatory requirements for control of occupational radiation exposure. In addition, to ensure adequate protection of repository workers, the contribution of radon and its daughter products to occupational exposure will be considered in assessing compliance with the applicable standards of 10 CFR Part 20.

The ALARA concept (as low as reasonably achievable), and its application, also applies to worker radiation exposure. In addition to the requirements that worker doses be maintained at less than regulatory limits and conform to an ALARA philosophy, design guidelines are generally established at a fraction of the limits to ensure that necessary operations can be performed and

occupational doses can be maintained below allowable limits. The establishment of design criteria for radiological safety are established under Issue 2.7, which uses the performance criteria established in this issue (Issue 2.2) to develop the design criteria.

3.7.2 Logic Description

To ensure that the occupational exposure limits are met, design guidelines in the form of performance parameters will be specified and transmitted to Issue 2.7, where radiological safety design criteria will be developed based on these design guidelines. The design criteria will specify dose rates in normally occupied areas and annual individual dose limits from penetrating radiation. The design criteria will also specify airborne radioactivity concentration limits in normally occupied areas. For some operational activities, design features may not be able to preclude the possibility of dose rates to personnel above the guidelines.

The logic to be used in this resolution of the issue is illustrated in the logic diagram for Issue 2.2 (Figure 3-9).

System element functions

To allocate performance in this issue to specific system elements of the geologic repository at Yucca Mountain, the functions of these system elements with respect to the radiological safety of the repository workers must be identified. The preclosure portion of the geologic repository is divided into two major system elements: the surface, and the subsurface.

The following describe each of these system elements and their functions. Functions are shown in the top-level rectangles of the logic diagram for Issue 2.2 (Figure 3-9). Each system element has one function for this issue.

Surface. The surface system element includes both natural and man-made radiation exposure mechanisms that affect the occupational exposure of surface repository workers. Atmospheric transport mechanisms are important in that underground and surface facility releases on a routine basis are expected. The main processes involved are the physical transport, dispersion, and deposition of potential releases of radionuclides within the site boundary.

In the restricted areas on the surface, the principal source of exposure to radiation is expected to be from high-level waste (HLW) handling operations. For these operations, the dominant source of occupational exposure is expected to be penetrating radiation (gamma rays and neutrons) emitted by the radioactive constituents of HLW. Exposure to radiation fields can be reduced by shielding or by limiting occupancy in the affected areas. These factors, among others, such as remote operation, will be considered in analysis of the repository design when recommendations are made for alternative means of meeting the performance goals for this issue and reducing the occupational exposures to ALARA levels.

Secondary radioactive wastes that will be generated on the site and processed by the waste treatment systems are another source of occupational exposure in the repository system element. The dominant mode of exposure to these sources is expected to be external exposure to the resulting radiation fields. As with the waste handling operations, the waste treatment system design

will be periodically analyzed and, if necessary, modified to ensure that occupational exposure will be adequately controlled.

In addition to external exposure from the contained sources discussed above, there is a potential for internal exposure from radionuclides that may be released from containment and entrained in the ventilation air flow or brought to the surface by the mine dewatering system (if any). These exposures will be precluded during normal operations by measures such as radiation monitoring and sampling and ventilation control. In addition, protective clothing, and respiratory protection equipment will be available for use, if necessary.

The construction and operation of the repository may also require the use of radioactive sources not generated from HLW handling operations. These would include sealed sources used for the calibration of health physics and radiation monitoring equipment, the radiography sources used for nondestructive examination of welds, and radioactive sources used in scientific investigations.

The last potential source of occupational radiation exposure is from process contamination and from the decommissioning of the facilities. The exposure during this phase of operation would be from contaminated and activated equipment, buildings, and natural materials. The worker dose will be controlled by designing the facilities for easy disassembly, control, and consolidation of contaminated materials and by limiting the generation of neutron activation products. Note that the retrieval of waste containers is considered an operation activity.

Subsurface. The subsurface system element includes both the natural systems of the site and emplaced HLW that have a potential to impact the radiological safety of the repository workers while in the underground facilities. The natural radioactivity in the host rock (i.e., uranium, thorium, and radon, and their daughter products) is a source that has the potential to increase the radiation level in the restricted and unrestricted areas. The release of radionuclides results from mining, transporting, and storing the mined tuff and from the mine dewatering processes (if any). Note that exposure to naturally occurring radionuclides is not specifically regulated under 10 CFR Part 20. However, prudence dictates that total worker exposure be monitored and controlled through the implementation of applicable Mine Safety and Health Administration regulations (30 CFR Part 57) and DOE Orders. In the restricted areas, emplaced wastes are the most important radiological safety concern.

1. Performance measures. Each system function identified above flows to a performance measure (PM). PMs are those physical quantities that describe the ability or performance of a system, system element, structure, component, or process in meeting the licensing strategy for an issue. The surface function has three PMs and the subsurface function has three PMs. PMs are shown in rectangles in the logic diagram for Issue 2.2 (Figure 3-9).

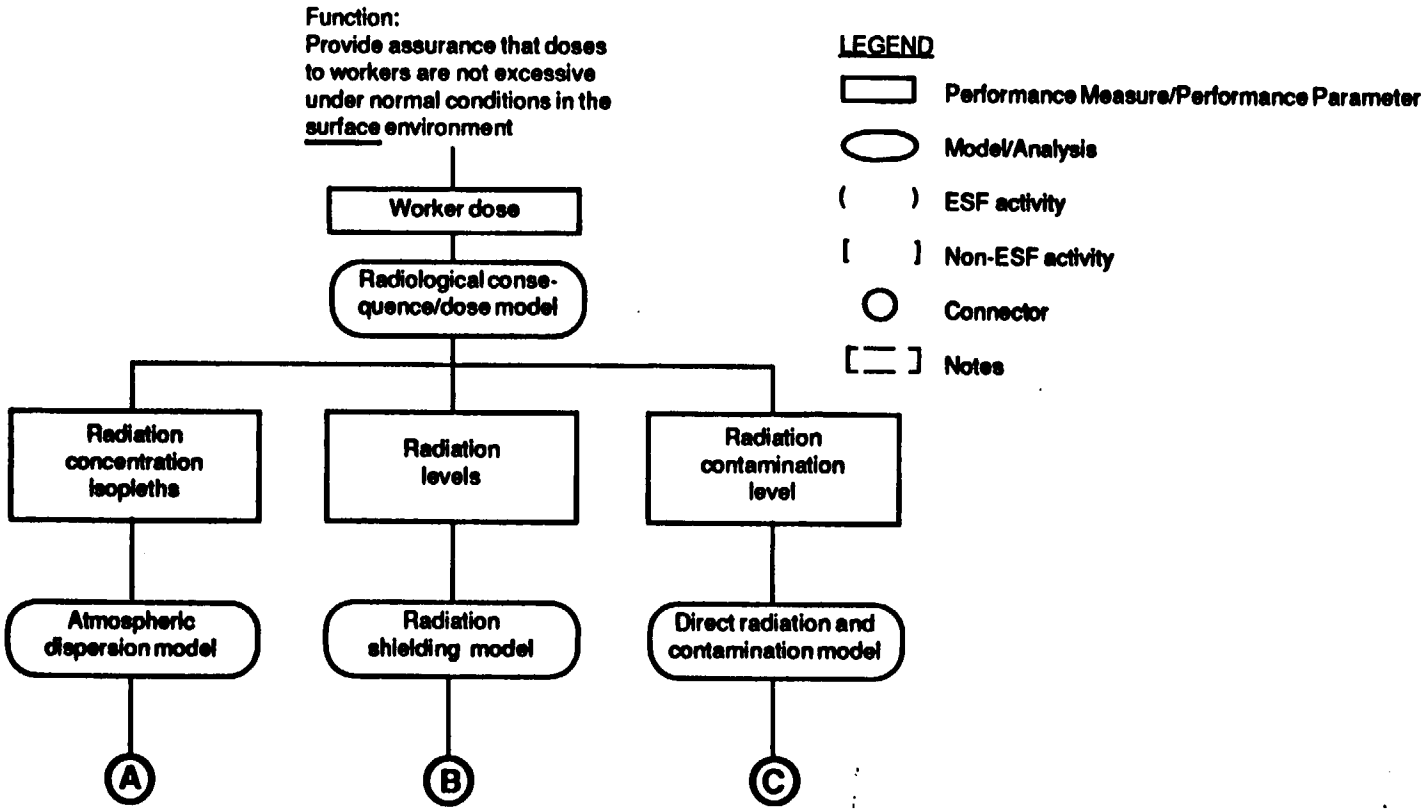
2. Models. Each system function identified above flows to a model. Models can also be others identified in other issues. Models are identified in the oval symbols in the logic diagram for Issue 2.2 (Figure 3-9) and can flow to submodels. The models shown in the logic diagram consist of both empirical and theoretical relationships and are to provide a descriptive conceptual system of the processes and events that will be used in assessing the performance of the issue. Models will rely on various parameter inputs.

3. Performance or design parameters. Beneath each model identified above are listed the performance or design parameters necessary to address the model concept. Parameters are those

physical quantities used as inputs to evaluate a model. Parameters are either derived or measured and may or may not be associated with a desired performance goal or value. Parameters are noted in rectangles below the models on the logic diagram for Issue 2.2 (Figure 3-9). The SCPB activity reference is noted in parentheses.

FIGURE 3-9 ISSUE 2.2*: WORKER RADIOLOGICAL SAFETY - NORMAL CONDITIONS

Requirement: Compliance with worker radiological safety requirements under normal conditions per 10 CFR 20.



NOTE: Collection of these data is part of the environmental program planned activities and is addressed in the Radiological Monitoring Plan discussed in Section 8.3.1.13.

*For reference, see 10 CFR 60.21(c)(7), .131, .132, .133; 10 CFR Part 20, and SCPB 8.3.5.4.

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FIGURE 3-9 (cont.) ISSUE 2.2: WORKER RADIOLOGICAL SAFETY - NORMAL CONDITIONS

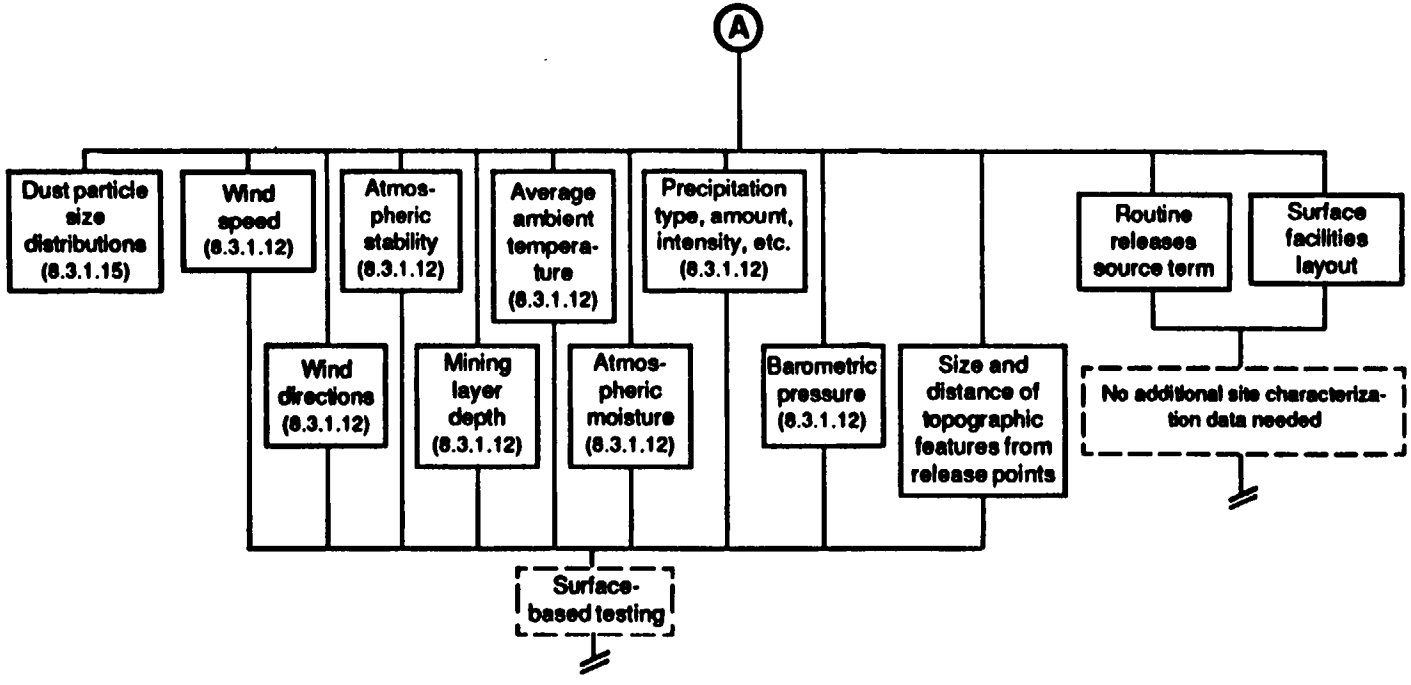

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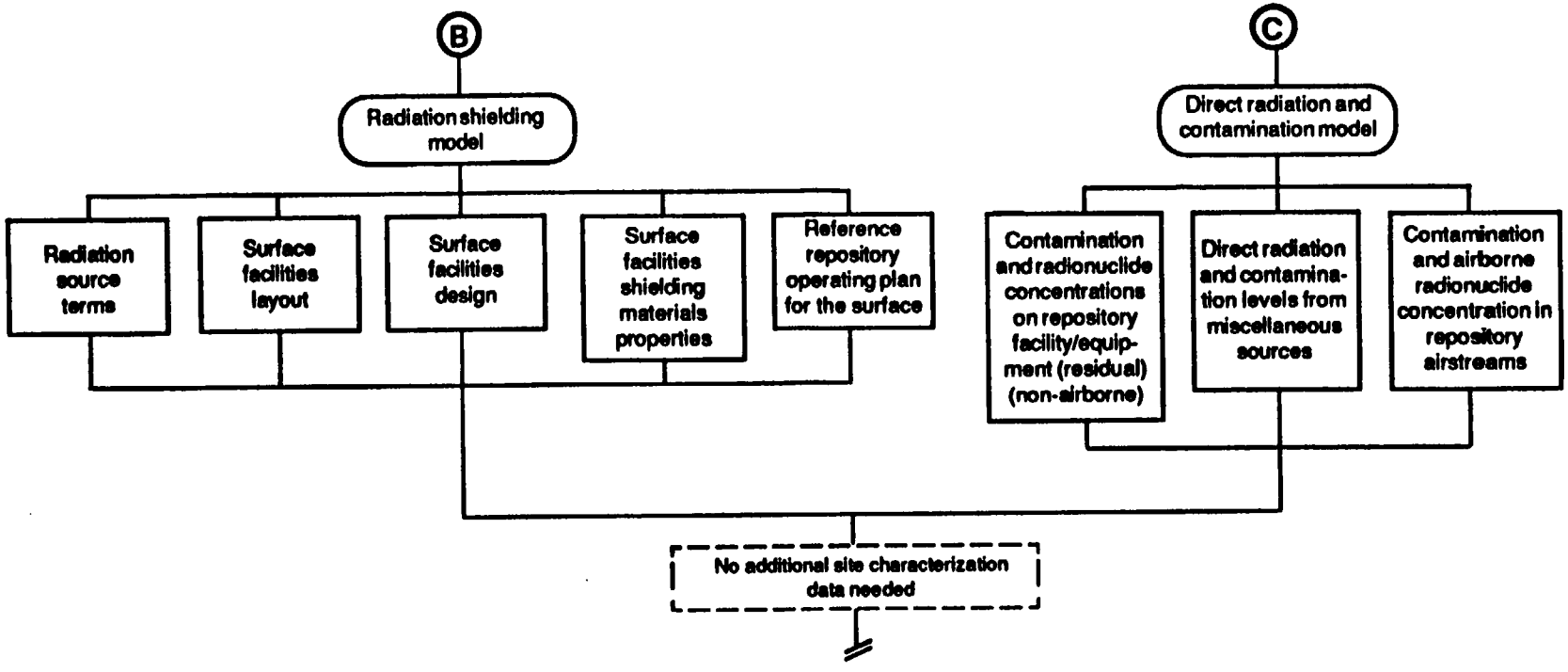
FIGURE 3-9 (cont.) ISSUE 2.2: WORKER RADIOLOGICAL SAFETY - NORMAL CONDITIONS



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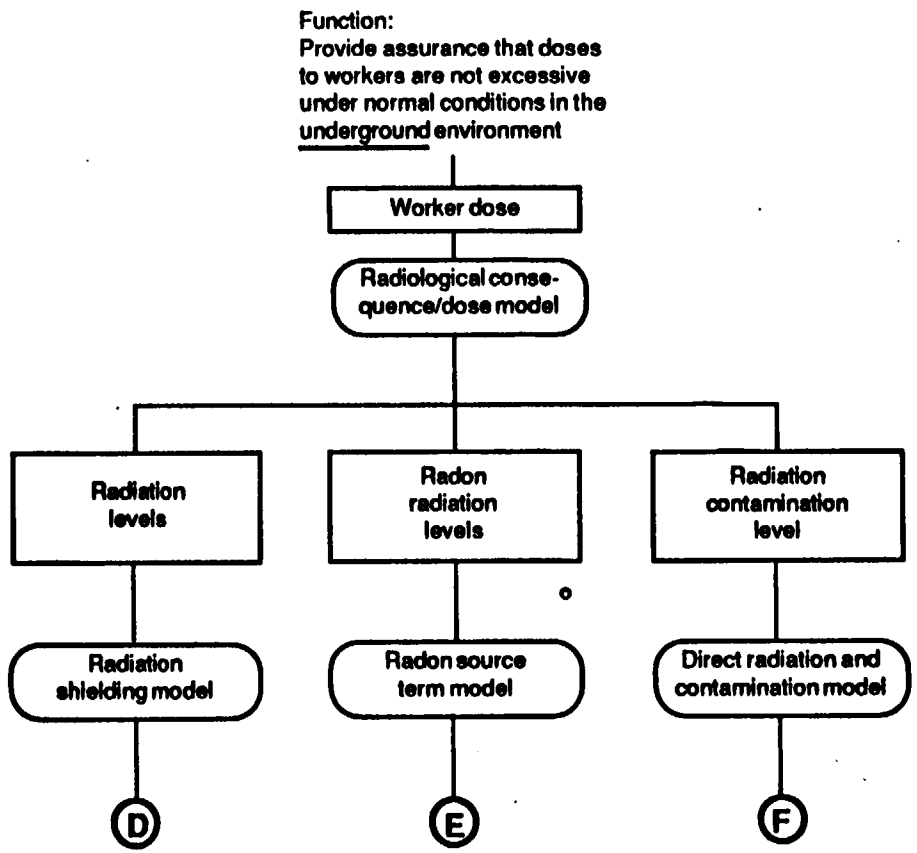
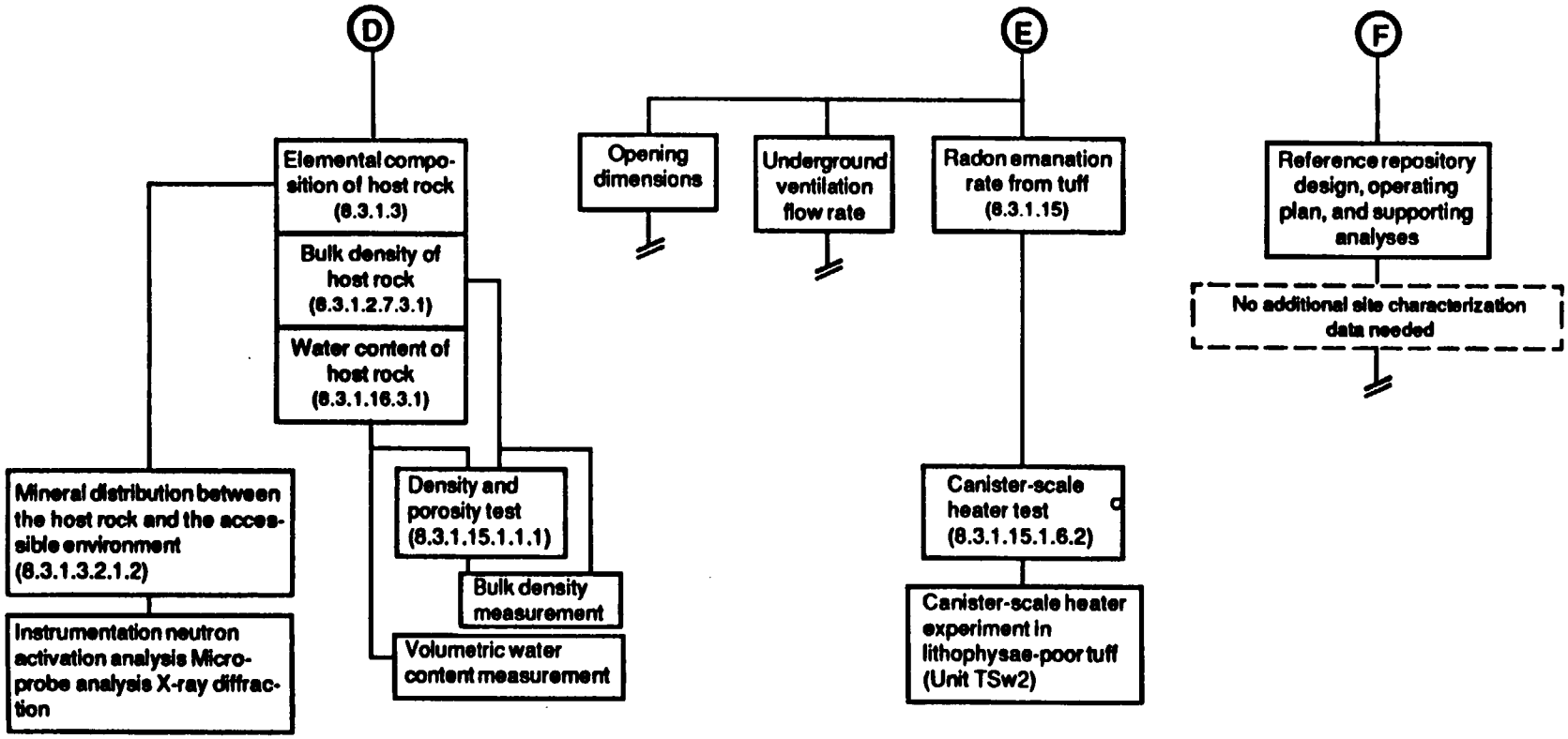

Function:
Provide assurance that doses to workers are not excessive under normal conditions in the underground environment
Worker dose
Radiological consequence/dose model
Radiation levels
Radon radiation levels
Radiation contamination level
Radiation shielding model
Radon source term model
Direct radiation and contamination model
D
E
F

FIGURE 3-9 (cont.) ISSUE 2.2: WORKER RADIOLOGICAL SAFETY - NORMAL CONDITIONS



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3.8 ISSUE 2.7, REPOSITORY DESIGN CRITERIA FOR RADIOLOGICAL SAFETY

Issue 2.7: Have the characteristics and configurations of the repository been adequately established to (a) show compliance with the preclosure design criteria of 10 CFR 60.130 through 60.133 and (b) provide information for the resolution of the performance issues?

3.8.1 Introduction

Section 8.3.2.3 of the SCPB is concerned with the features of the repository that relate to radiological safety, identifies repository characteristics and configurations important to demonstrating compliance with the related preclosure design criteria of 10 CFR 60.130 through 133, and provides information needed for the resolution of performance issues. Portions of 10 CFR 60.130 through 133 that are concerned with preclosure radiological safety are treated by Issue 2.7, the resolution strategy for which is discussed in SCPB Section 8.3.2.3. Five functions have been defined under this issue:

- Radiological protection,
- Design and protection of structure, systems, and components important to safety,
- Criticality control,
- Compliance with mining regulations, and
- Waste treatment.

Section 3.8.2 of this document describes the logic diagrams provided for each of these functions, the relationship of these functions to performance measures, and the data needed to measure the performance. The relationship of each function to the regulatory requirements is also given in Section 3.8.2. The approach used to identify ESF testing requirements is shown in the logic diagram, Figure 3-10.

3.8.2 Logic Description

The five basic functions – Radiological protection; Design and protection of structure, systems, and components important to safety; Criticality control; Compliance with mining regulations; and Waste treatment – are described in SCPB Section 8.3.2.3 to address the preclosure design criteria relevant to radiological safety. A considerable amount of information and the results generated by each function are transferred between these functions and among other SCPB activities. The intent of this discussion and the accompanying logic diagrams, however, is not to describe the overall logic and information needed to demonstrate compliance with regulatory requirements. Rather, the intent is to show relationships between the functions and site data collection activities. The logic paths for each of the five functions are discussed separately below and illustrated in the diagrams. The accompanying diagram shows a breakout at successively detailed levels by function, subfunction (if any), performance measures, and parameter.

Radiological protection

The first function, radiological protection, is to maintain radiation doses, levels, and concentrations of radioactive material in restricted areas within the limits specified in 10 CFR Part 20. This function has been subdivided into 10 subfunctions, because it involves a number of activities. Subfunctions of the radiological protection function, and the associated regulatory requirements are shown in Table 3-1.

Table 3-1. Subfunctions of the Radiological Protection Function and Associated Regulatory Requirements

10 CFR Part 60 Citation No.	Description
1. 131(a)(1)	Limit concentrations of radioactive materials in air
2. 131(a)(2)	Limit time required to perform work in the vicinity of radioactive materials
3. 131(a)(3)	Provide suitable shielding materials where necessary
4. 131(a)(4)	Monitor and control the dispersal of radioactive contamination
5. 131(a)(5)	Control access to high radiation areas
6. 131(a)(6)	Provide radiation alarm systems for worker protection
7. 132(c)	Monitor and control radioactive materials in repository effluents
8. 131(a)(6)	Provide radiation alarm systems for repository effluents
9. 132(a)	Provide safe handling of waste whether awaiting emplacement or being retrieved
10. 132(b) and 133(g)	Provide repository facility ventilation systems that will protect against radiation exposure, and assure the continued function and separation of ventilation systems during normal operations and under accident conditions

Site data are needed to address subfunctions 1, 3, 4, 7, 9, and 10 of this function. To determine concentrations of airborne radioactive materials (performance measure 1), radon emanation rates from tuff and dust and particle-size distributions are needed. Size distributions are also needed to determine contamination levels (performance measure 4) and to design ventilation systems (performance measure 10). Shielding and handling safety considerations (performance measures 3 and 9) require data on host rock composition, density, and water content. The performance of many of the subfunctions of the radiological protection function requires data on the frequency and magnitude of natural phenomena and accidents, and on environmental conditions. This information will be needed to assess accident probabilities and to compute radiation doses.

Design and protection of structure, systems, and components important to safety

The second function – design and protection of structure, systems, and components important to safety – is intended to assure that radiation design features will operate effectively when they are needed. This function also involves multiple activities and has been subdivided into eight subfunctions, which are shown in Table 3-2 along with the related regulatory requirements.

Table 3-2. Subfunctions of the Design of Structure, Systems, and Components Important to Safety Function and Associated Regulatory Requirements

10 CFR Part 60 Citation No.	Description
11. 131(b)(1)	Protect structures, systems, and components important to safety against natural phenomena and environmental conditions
12. 131(b)(2)	Protect structures, systems, and components important to safety against dynamic effects of equipment failure and similar events
13. 131(b)(3)	Protect structures, systems, and components important to safety against fires and explosions
14. 131(b)(4)(i)	Ensure that structures, systems, and components important to safety will maintain control of radioactive materials, permit prompt termination of operations, and allow evacuation of personnel during an emergency
15. 131(b)(5)	Ensure that utilities important to safety will continue their safety functions during emergencies
16. 131(b)(6)	Ensure that structures, systems, and components important to safety will facilitate inspection, testing, and maintenance
17. 131(b)(5)	Provide timely backup power when needed and during emergencies
18. 131(b)(8)	Provide instrumentation and control systems to monitor and control structures, systems, and components important to safety for all anticipated ranges of operation

Site data on the frequency and magnitude of natural phenomena and other accident events are needed to determine accident probabilities and consequences for subfunctions 11, 15, and 18 of this function.

Criticality control

The third function, criticality control, provides assurance that all systems for processing, transporting, handling, storing, retrieving, emplacing, and isolating radioactive material are designed to ensure that a criticality accident is not credible, per 10 CFR 60.131(b)(7). Site data are needed to address this function. For this function, 13 performance measures have been defined that concern the fissile material inventory, moderator inventory, geometry, and possibilities of accidents. Site data regarding disruptive events and accidents are needed to assess function performance to determine the possibility of disruption of waste leading to unfavorable concentrations of fissile materials, accidental introduction of moderating materials into areas containing waste, and accidental disruption of waste geometry leading to unfavorable configurations. Other site data, including the bulk density, elemental composition, and water content of the host rock, are needed to determine the neutron multiplication factor k_{eff}, and the effect of moderating materials around the emplaced waste.

Compliance with mining regulations

The fourth function, compliance with mining regulations, ensures that the requirements of 30 CFR Chapter I, Subchapters D, E, and N that are applicable to protection of workers who perform a safety function will be incorporated into the repository design, per 10 CFR 60.131(b)(9). A single performance measure is defined for this function, i.e., the ability of workers to perform their assigned safety functions. This performance measure does not require site data.

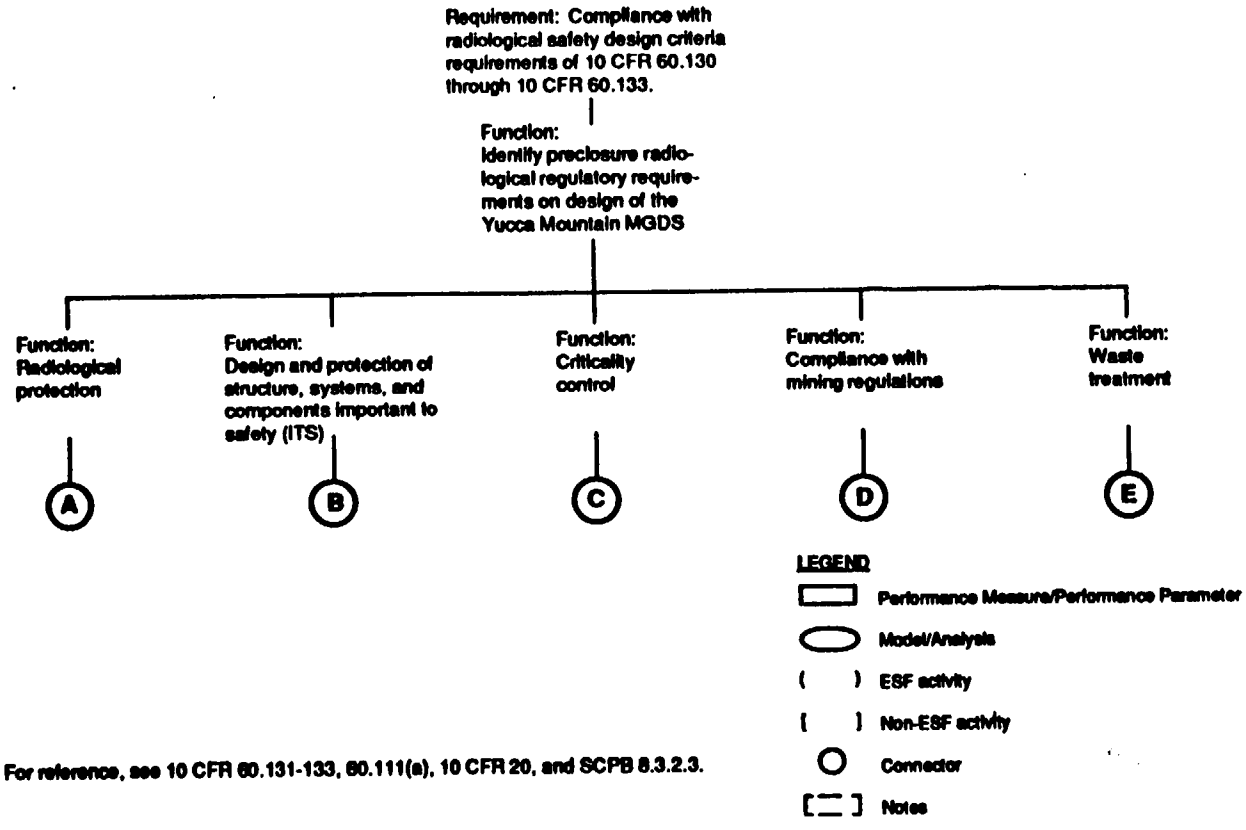
Waste treatment

The fifth function, waste treatment, ensures that waste treatment facilities are designed to permit safe offsite disposal of site-generated waste in accordance with applicable regulations, per 10 CFR 60.132(d). Three performance measures have been defined for this function:

- The fraction of site-generated waste collected,
- The fraction of treated and stabilized site-generated waste that is packaged, and
- The fraction of site-generated waste that is treated and stabilized or recycled.

No site data are needed to measure the performance of this function.

FIGURE 3-10 ISSUE 2.7*: REPOSITORY DESIGN CRITERIA FOR RADIOLOGICAL SAFETY



* For reference, see 10 CFR 60.131-133, 60.111(a), 10 CFR 20, and SCPB 8.3.2.3.

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FIGURE 3-10 (cont.) ISSUE 2.7: REPOSITORY DESIGN CRITERIA FOR RADIOLOGICAL SAFETY

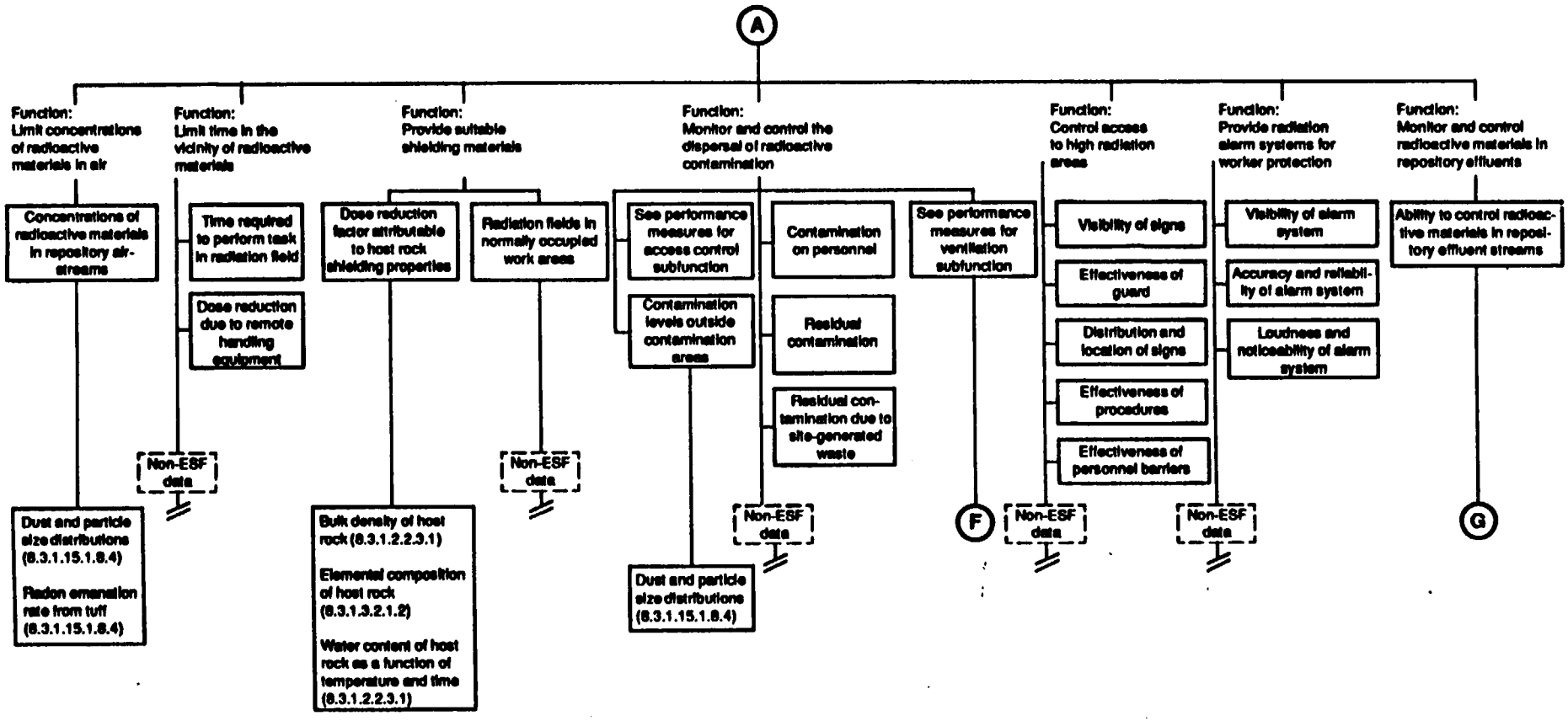

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FIGURE 3-10 (cont.) ISSUE 2.7: REPOSITORY DESIGN CRITERIA FOR RADIOLOGICAL SAFETY

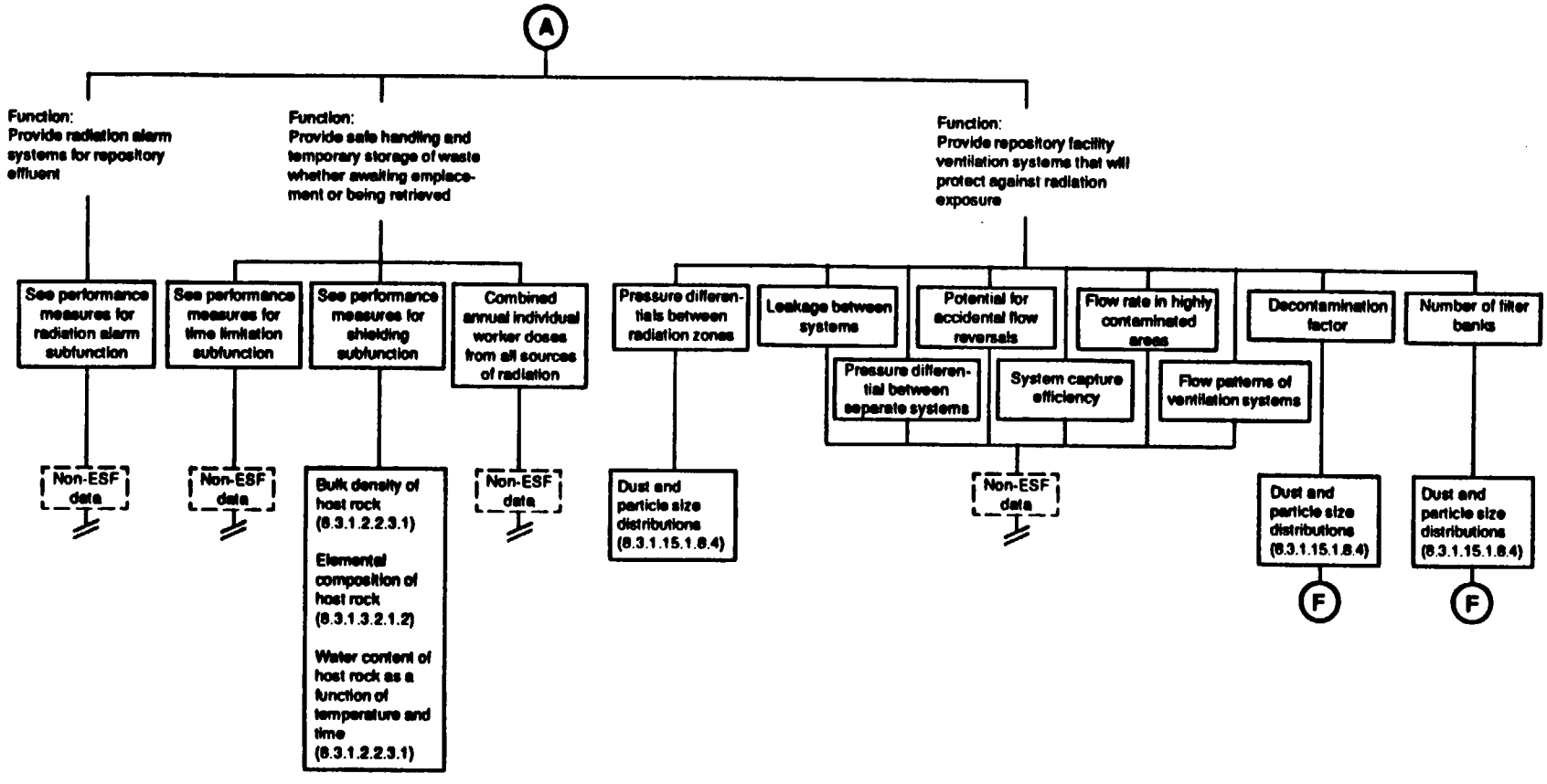

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FIGURE 3-10 (cont.) ISSUE 2.7: REPOSITORY DESIGN CRITERIA FOR RADIOLOGICAL SAFETY

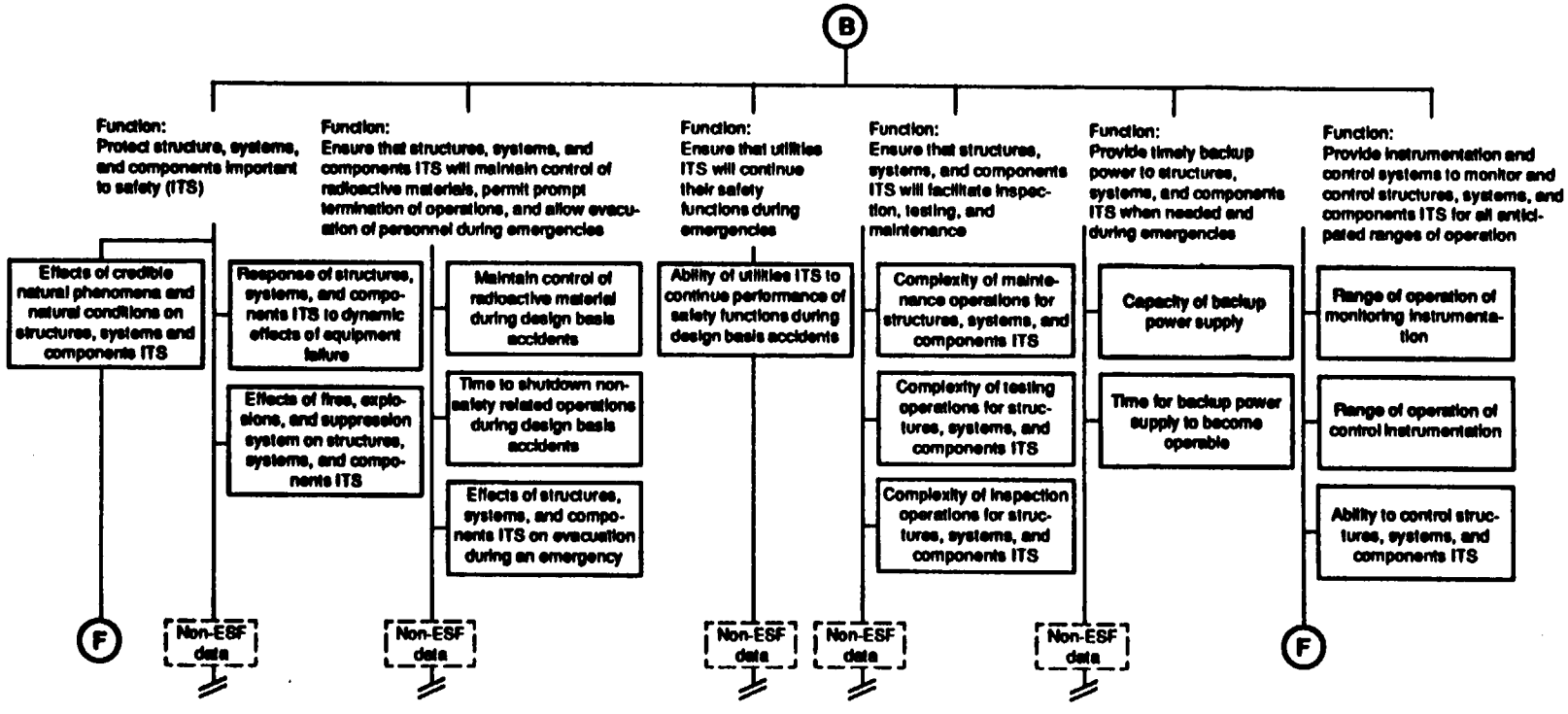

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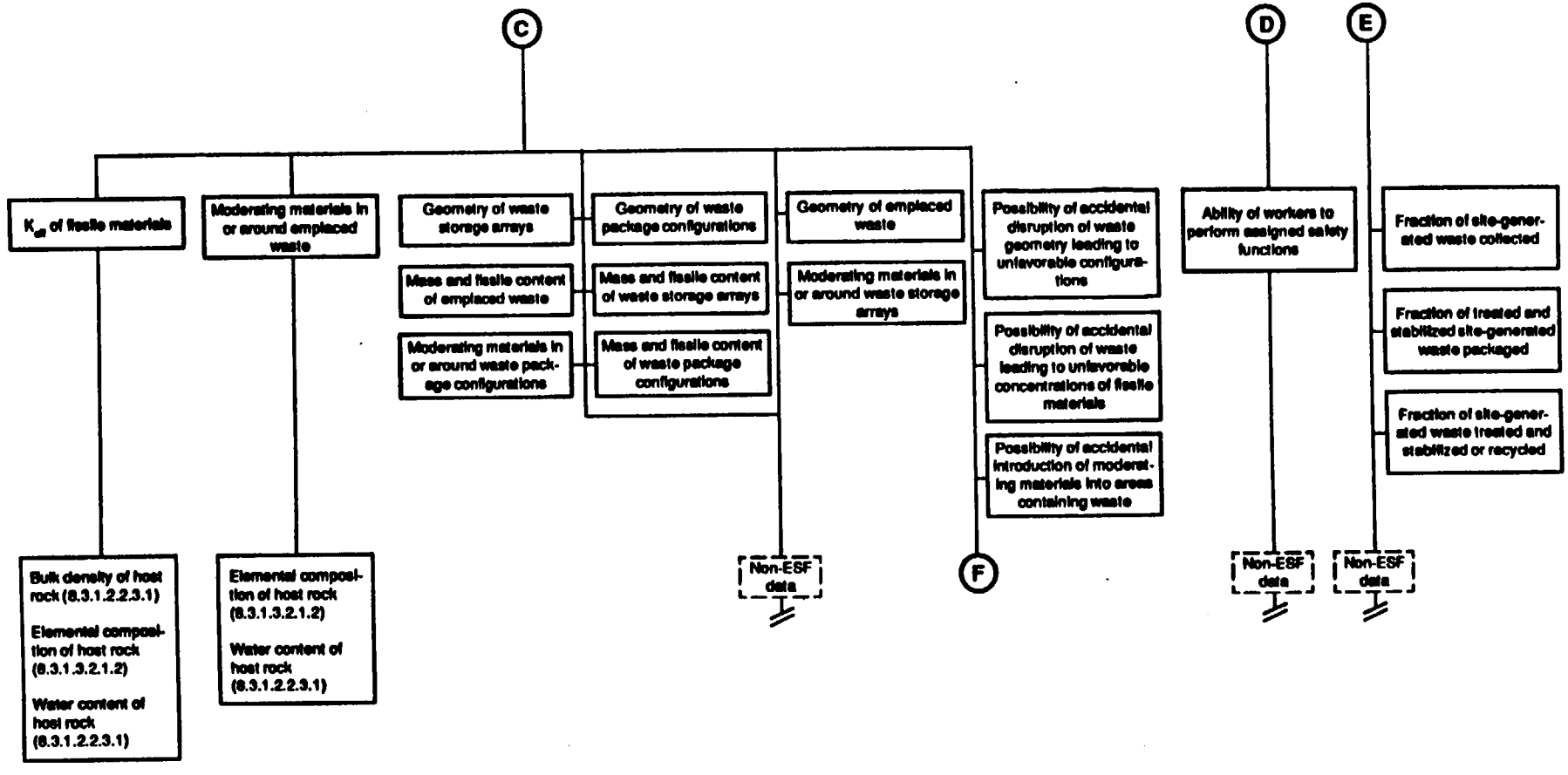
FIGURE 3-10 (cont.) ISSUE 2.7: REPOSITORY DESIGN CRITERIA FOR RADIOLOGICAL SAFETY



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F

Frequency and magnitudes of:

- Tornadoes [8.3.1.12]
- Cloud-to-ground lightning strikes [8.3.1.12]
- Sandstorms//windstorms [8.3.1.12]
- Snowfall/ice storms [8.3.1.12]
- Repository surface flooding [8.3.1.16]
- Surface and subsurface seismic events (8.3.1.17)
- Fault movement within the repository (8.3.1.17)
- Drift roof fall/collapse/failure (8.3.2.4)
- Landslides [8.3.1.14]
- Volcanic ash fall (8.3.1.17)
- Nearby brush fires [8.3.1.13]
- Aircraft crashes [8.3.1.13]
- Criticality events [8.3.5.5]
- Other potential accidents [PRAM Program]

G

Wind speeds	[8.3.1.12]
Wind direction	[8.3.1.12]
Atmospheric stability	[8.3.1.12]
Mixing layer depth	[8.3.1.12]
Average ambient temperature	[8.3.1.12]
Atmospheric moisture	[8.3.1.12]
Precipitation: type, amount intensity, etc.	[8.3.1.12]
Barometric pressure	[8.3.1.12]
Size and distance of topographic features from release points	[Literature]
Bioaccumulation of radionuclides in terrestrial flora	[8.3.1.13]
Bioaccumulation of radionuclides in terrestrial fauna	[8.3.1.13]
Types of crops raised	[8.3.1.13]
Amounts of crops raised	[8.3.1.13]

Types of crops consumed	[8.3.1.13]
Amounts of crops consumed	[8.3.1.13]
Types of animals raised	[8.3.1.13]
Amounts of animals raised	[8.3.1.13]
Types of animals consumed	[8.3.1.13]
Amounts of animals consumed	[8.3.1.13]
Animal consumption of forage	[8.3.1.13]
Forage storage time	[8.3.1.13]
Grazing yield and period	[8.3.1.13]
Radius of crop and animal area	[8.3.1.13]
Volumetric flow of surface water to water bodies	[8.3.1.13]
Recreational uses of water bodies	[8.3.1.13]

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3.9 ISSUE 4.4, PRECLOSURE DESIGN AND TECHNICAL FEASIBILITY

Issue 4.4: Are the technologies of repository construction, operation, closure, and decommissioning adequately established for the resolution of the performance issues?

3.9.1 Introduction

The preclosure design and technical feasibility issue addresses the requirements of 10 CFR 60.133 and 10 CFR Part 960 for preclosure design. For example, 10 CFR 60.133(b) states that "the underground facility shall be designed with sufficient flexibility to allow adjustments when necessary to accommodate site-specific conditions identified through in situ monitoring, testing, or excavation." Some of these adjustments might be required because of technology limitations such as the ability to predict rock behavior over the long life of the repository. Similarly, 10 CFR 60.133(f) states that "the design of the underground facility shall incorporate excavation methods that will limit the potential for creating a preferential pathway to the accessible environment." This requirement places a potential constraint on the construction methods. These potential limitations and constraints will be continually determined and revised during construction and subsequent testing in the exploratory studies facility.

The preclosure siting guidelines in 10 CFR Part 960 identify the potentially adverse condition, "In situ characteristics and conditions that could require engineering measures beyond reasonably available technology in the construction of the shafts and the underground facility." The preclosure design and technical feasibility issue addresses this condition and design questions related to the preclosure technical guidelines for surface and rock characteristics, hydrology, and tectonics. Postclosure requirements for design are addressed in Issue 1.11, Configuration of the Underground Facility.

A major assumption in developing the testing requirements for preclosure design and technical feasibility relates to options for testing in the Calico Hills unit. Based on the recommendations of the Calico Hills Risk Benefit Analysis, ["Plan for Risk/Benefit Analysis for Alternative Strategies for Characterizing the Calico Hills Unit at Yucca Mountain", Revision 0, Document # YMP/90-3, Yucca Mountain Project, 5-31-1991] the option for testing in the Calico Hills unit will be maintained in the design of the Exploratory Shaft Facility, but full excavation for the recommended testing strategies is not justified at this time. Specific testing requirements for the Calico Hills unit will be defined as our understanding of the potential impacts on waste isolation and the sufficiency of data required for adequate site characterization improve during site characterization. Therefore, the testing requirements defined in this section do not include tests in the Calico Hills unit.

3.9.2 Logic

The approach used to identify ESF testing requirements for preclosure design and technical feasibility is shown graphically in the logic diagram for Issue 4.4 (Figure 3-11). This approach proceeds through the following steps:

1. The systems elements of the mined geologic disposal system that are pertinent to preclosure design and technical feasibility were identified. These include the site systems elements,

both surface and subsurface, because these elements provide input to preclosure design considerations and could potentially require the use of advanced technology. In addition, the systems elements – mining, waste handling, and decommissioning – were included because they address the bulk of the construction and operational activities and are also potential candidates for the use of advanced technology. Performance confirmation and support systems elements are not considered to require advanced technology; thus they are not considered in this section. Systems elements that may require technology development but do not require site-specific data will be addressed in the repository design plan, as shown in the logic diagram for Issue 4.4.

2. For the design activities (e.g., drift construction), functions or processes considered pertinent to design and the assessment of technical feasibility are identified. For these elements, the functions listed are those things that the element must do or provide for the repository to meet its required operational and functional goals. The list of functions is not all-inclusive. Only those functions that establish the technology requirements within the specific system elements and require site-specific data to assess the need for new technology or technology development are identified. The following criteria were used to determine if a function plays a role in establishing technology requirements:

   - Has the function been repeatedly demonstrated in normal industrial practice?
   - Does the function depend only on engineered structures and equipment of predictable capabilities?
   - Does the function have potential impact on worker health and safety?

3. For each subelement, performance measures were identified to define the required performance of the systems element. Typical performance measures are temperature, rock movement, air flow, and maintenance frequency.

4. For each performance measure, performance and/or design parameters are identified. These parameters are needed to assess whether or not the performance measure can be met.

5. Some performance and/or design parameters require data from the site characterization program; these site data will be acquired from the rock characteristics, the surface characteristics, the thermal and mechanical rock properties, and the tectonics programs (SCPB Sections 8.3.1.4, 8.3.1.14, and 8.3.1.15, respectively). The final step in the logic diagram for Issue 4.4 (Figure 3-11) is to identify the performance and/or design parameter that requires data/parameters from the site characterization program. For each of the performance and/or design parameters that require site data from testing in the ESF, specific parameters and the associated test are listed.

Site parameters

The logic diagram for Issue 4.4 (Figure 3-11) identifies site-related parameters that are required to address preclosure design and technical feasibility. These required data are derived from design analyses, reference design development, equipment program needs, the operations plan, subsystems design requirements, and assessments of reasonably available technology. Both surface and subsurface data that have potentially significant effects on design and performance will be included. This section briefly presents the justification for specifying the parameters identified in the logic diagram that will be collected in tests in the ESF.

The properties and behavior of the host rock, surrounding strata, and groundwater systems at Yucca Mountain are important for the preclosure and postclosure period design requirements of the underground facilities. Hydrologic characteristics at the site are also important for the underground facilities, including seals.

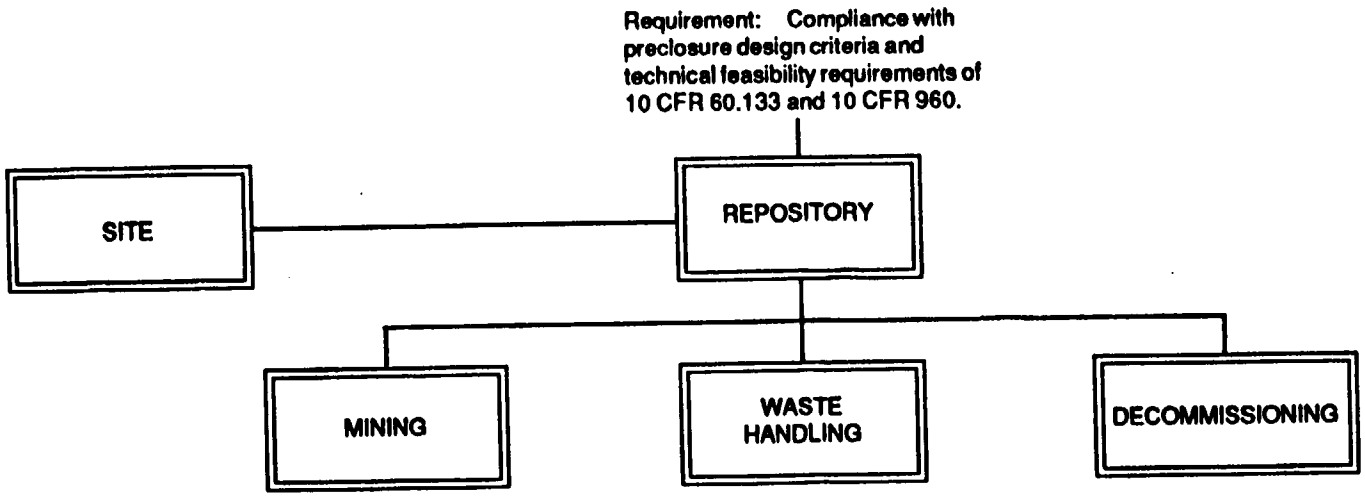
The mineability of the rock units at Yucca Mountain is being investigated through a series of mining demonstrations. The ESF will be used to demonstrate mineability; the site data needed to address this concern are collected in the mineability demonstration.

Factors important to consider for working environment considerations in design that depend on rock characteristics are drift wall temperature, drift wall wetness factor, water inflow into drifts, and air quality (dust, radon, etc.).

Data for water inflow into the drift will be used to design the drainage and pumping systems. Although significant inflows are not expected, the underground facility will be designed to accommodate anomalous conditions. The drainage system will control the flow of water so that water will not collect at places such as emplacement boreholes (a condition that would be adverse to performance). The pumping system will remove any excess water accumulating at collection points and move it to the surface.

The drift wall wetness factor is required for ventilation system design because it reflects humidity in the drifts. An assumed value is currently being used for design, and an analysis of the ESF areas will allow an assessment of whether the assumed values have correctly predicted the amount of water vapor that enters the drift. This will require monitoring air flows and humidity within the ESF.

FIGURE 3-11 ISSUE 4.4*: PRECLOSURE DESIGN AND TECHNICAL FEASIBILITY



LEGEND

- Performance Measure/Performance Parameter
- Model/Analysis
- ( ) ESF activity
- [ ] Non-ESF activity
- Connector
- Notes
- System elements

* For reference, see 10 CFR 60.133, 10 CFR 960, and SCPB 8.3.2.5.

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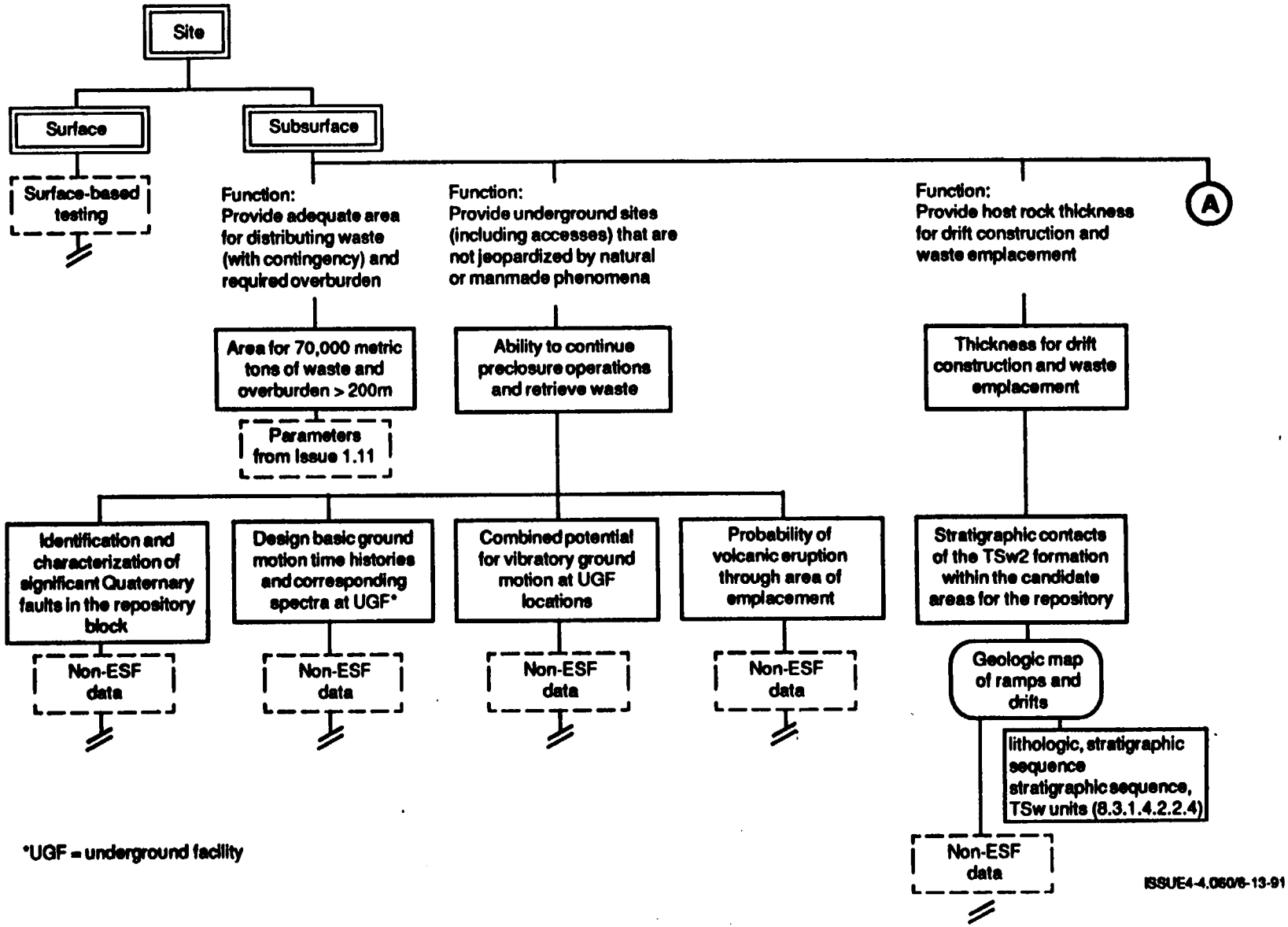
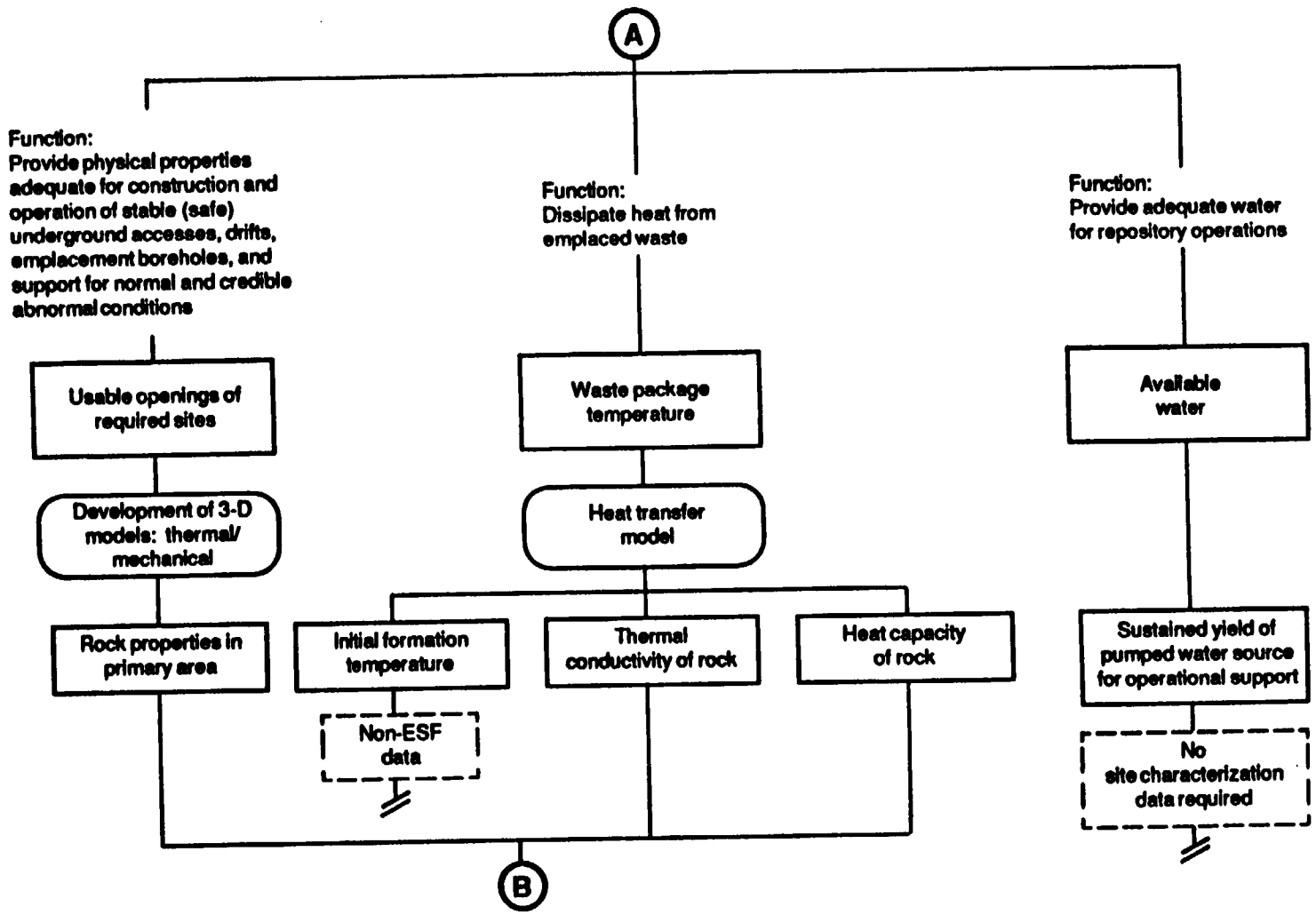
FIGURE 3-11 (cont.) ISSUE 4.4: PRECLOSURE DESIGN AND TECHNICAL FEASIBILITY



*UGF = underground facility

FIGURE 3-11 (cont.) ISSUE 4.4: PRECLOSURE DESIGN AND TECHNICAL FEASIBILITY



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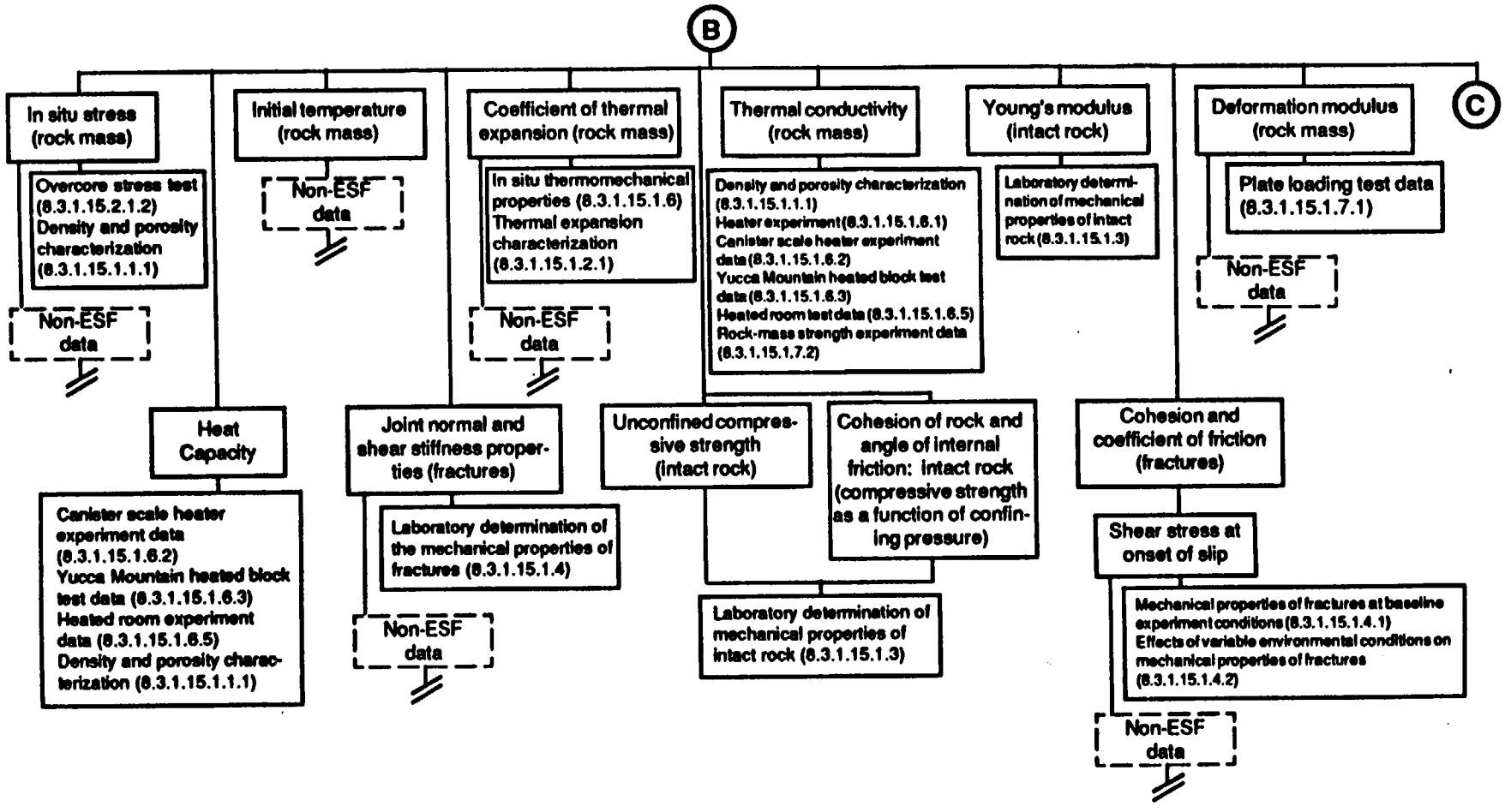

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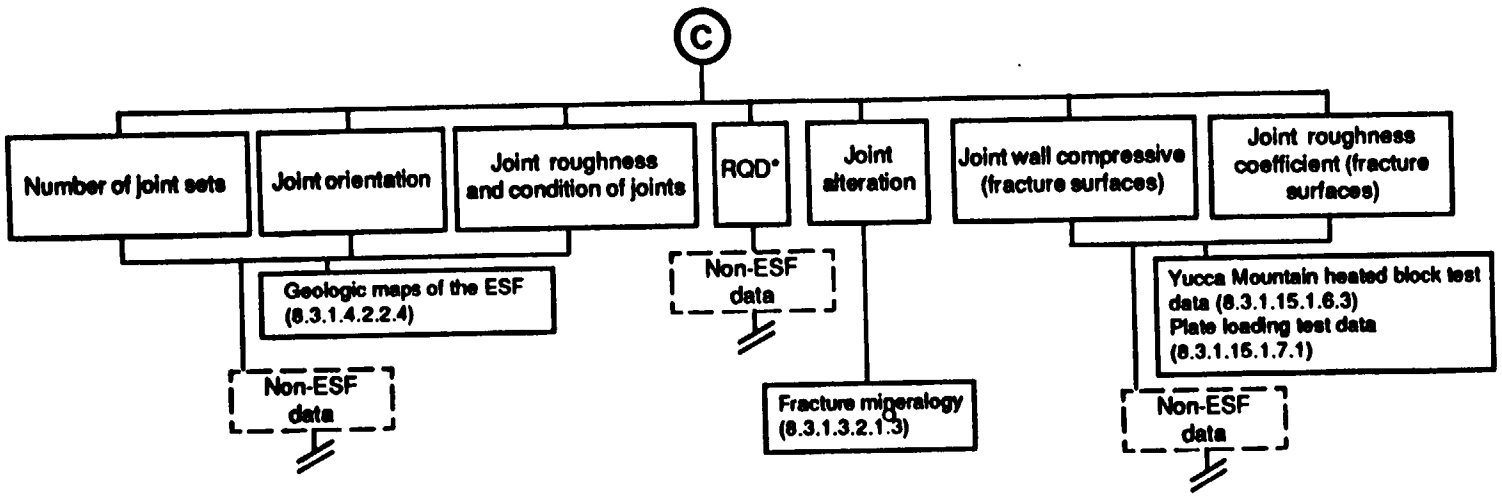
FIGURE 3-11 (cont.) ISSUE 4.4: PRECLOSURE DESIGN AND TECHNICAL FEASIBILITY



* RQD = Rock Quality Designation

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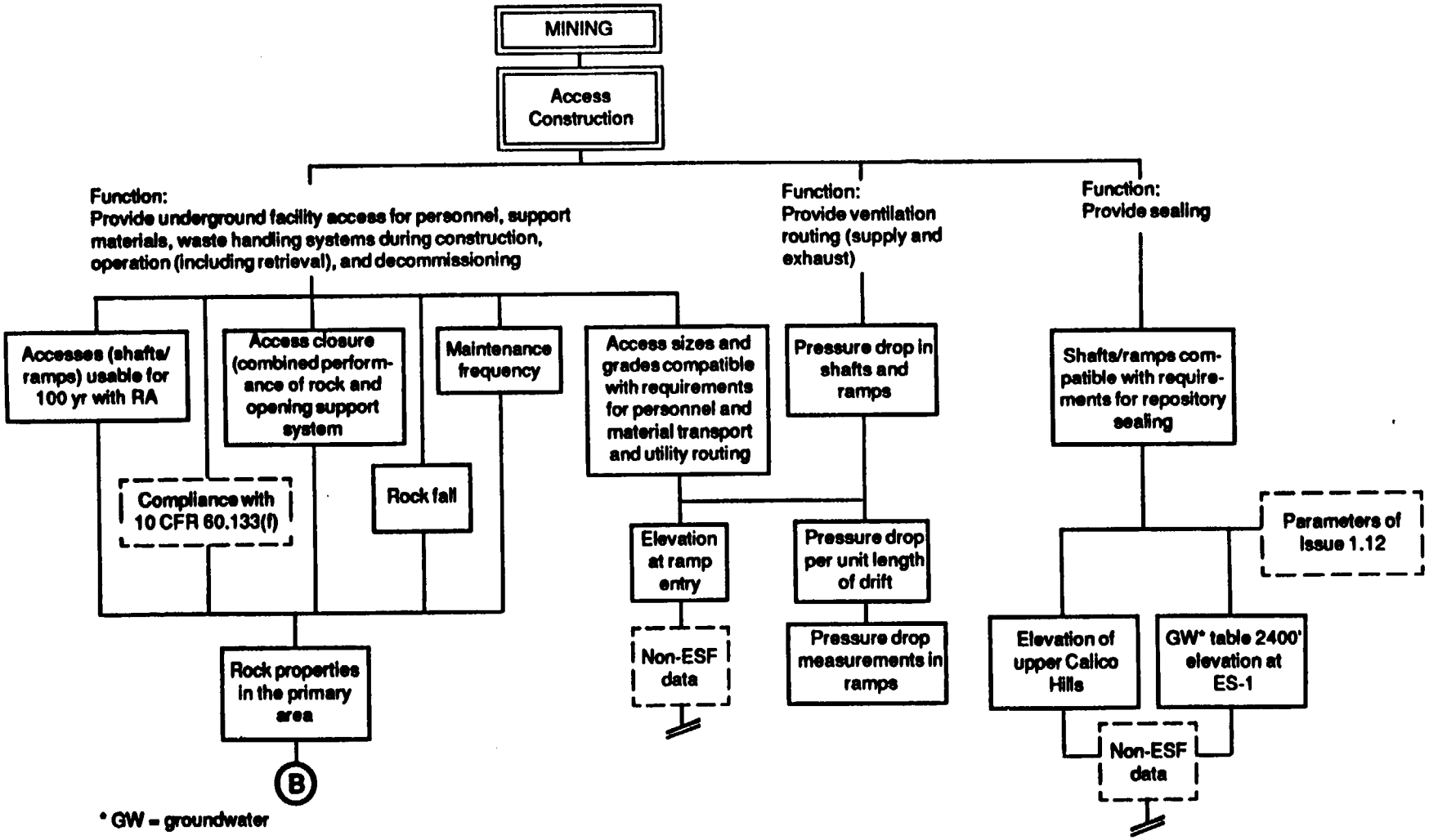

* GW = groundwater

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FIGURE 3-11(cont.) ISSUE 4.4: PRECLOSURE DESIGN AND TECHNICAL FEASIBILITY

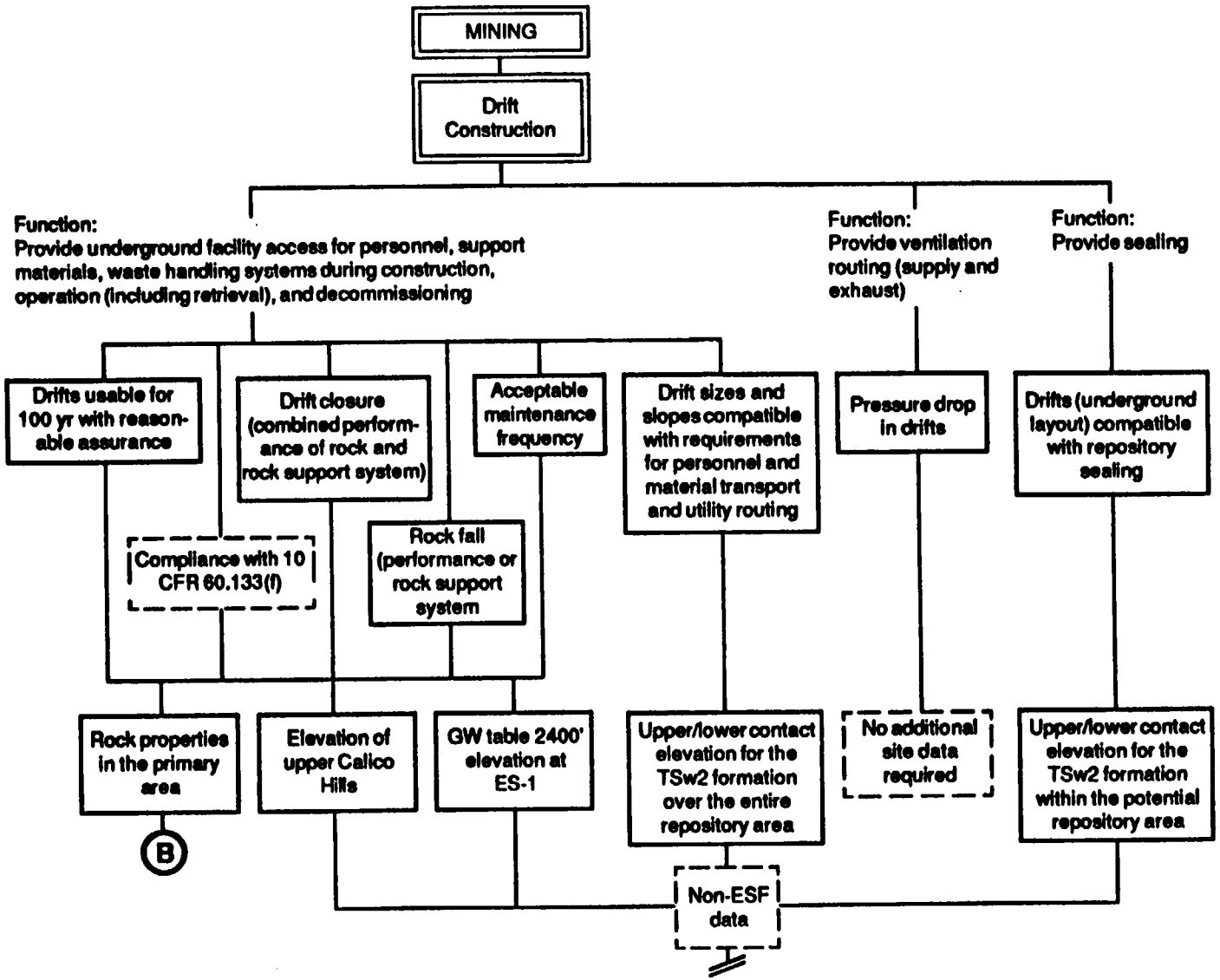

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FIGURE 3-11(cont.) ISSUE 4.4: PRECLOSURE DESIGN AND TECHNICAL FEASIBILITY

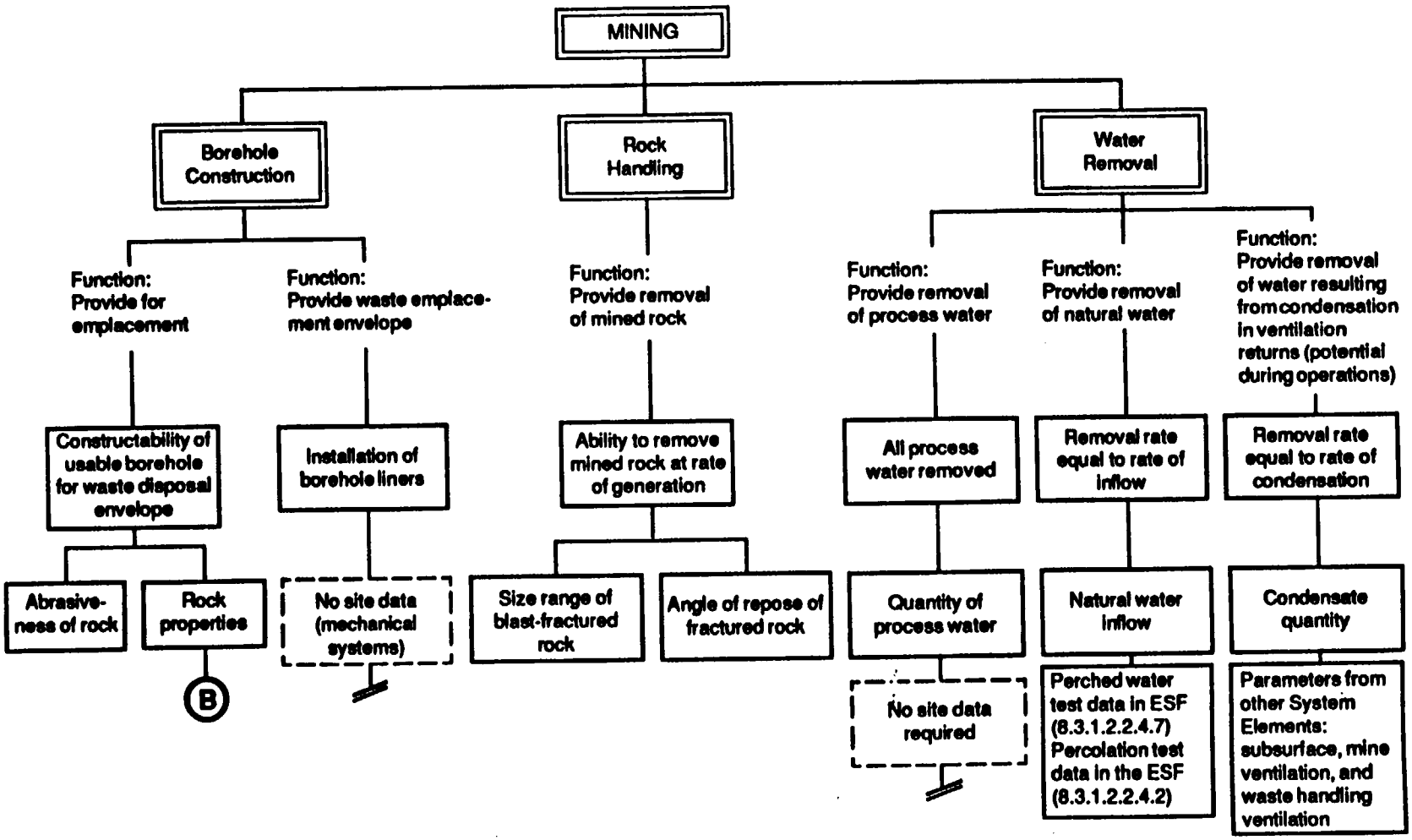

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FIGURE 3-11(cont.) ISSUE 4.4: PRECLOSURE DESIGN AND TECHNICAL FEASIBILITY

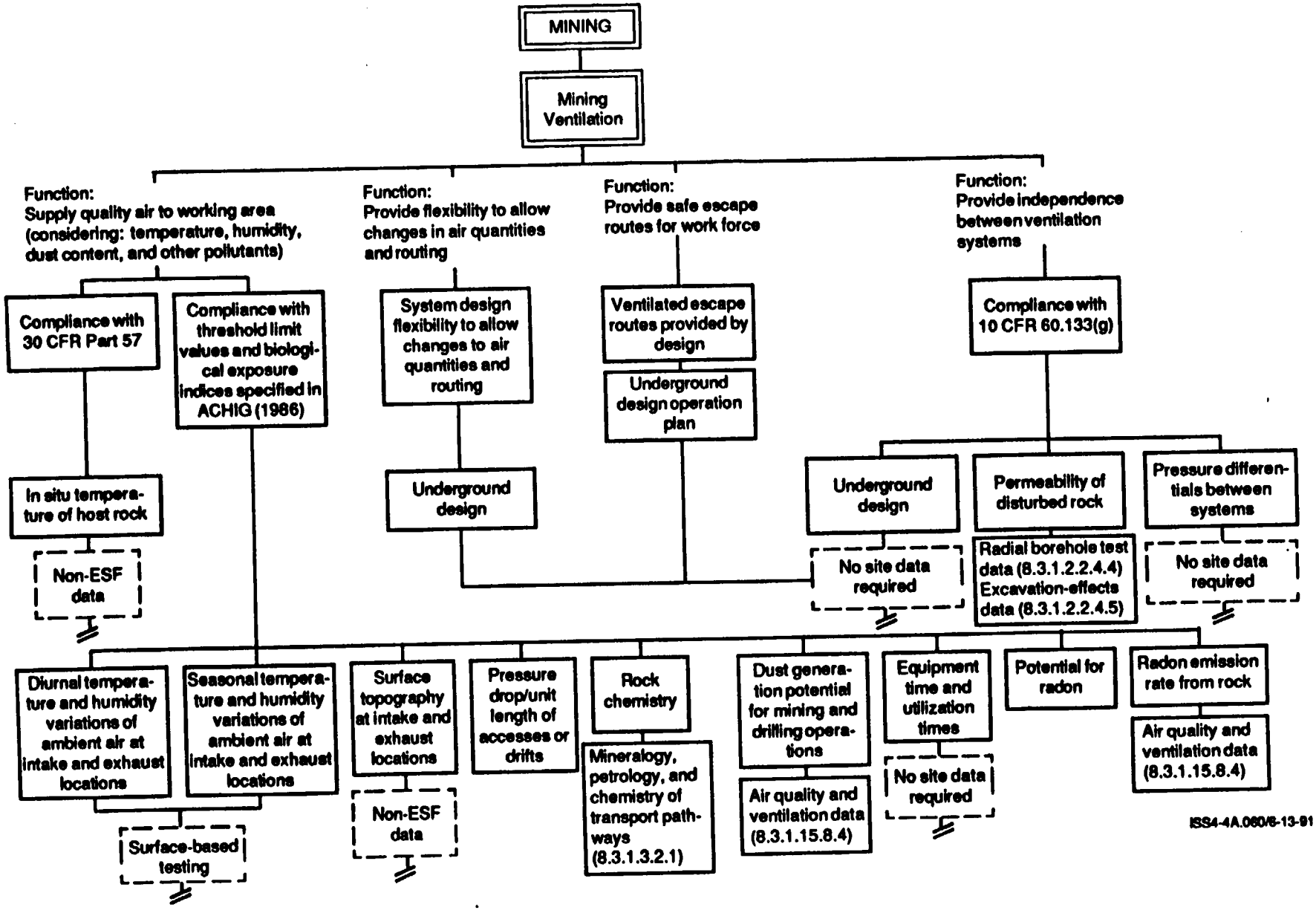

FIGURE 3-11(cont.) ISSUE 4.4: PRECLOSURE DESIGN AND TECHNICAL FEASIBILITY

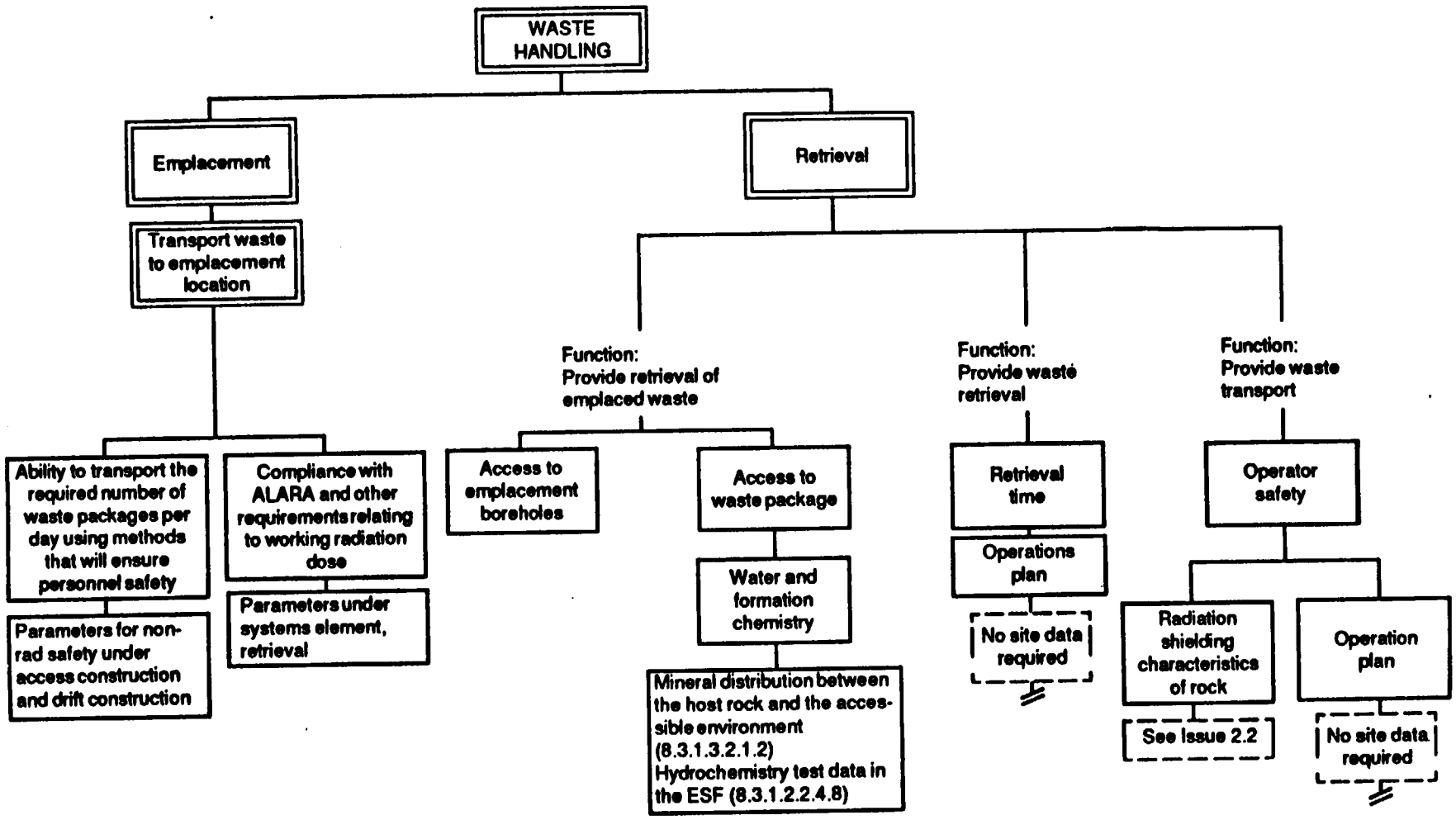

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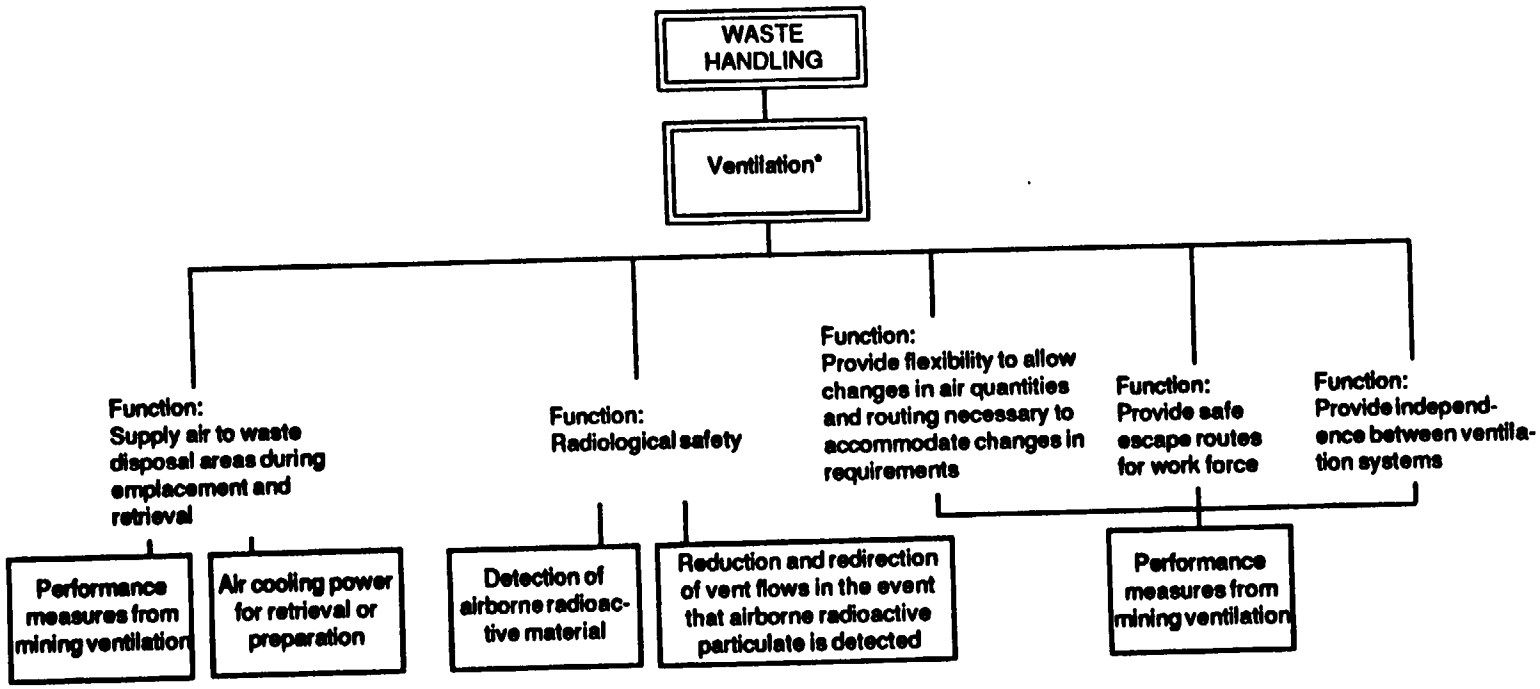
FIGURE 3-11(cont.) ISSUE 4.4: PRECLOSURE DESIGN AND TECHNICAL FEASIBILITY



*Site data for this system element is the same as the data required by system element, mining ventilation.

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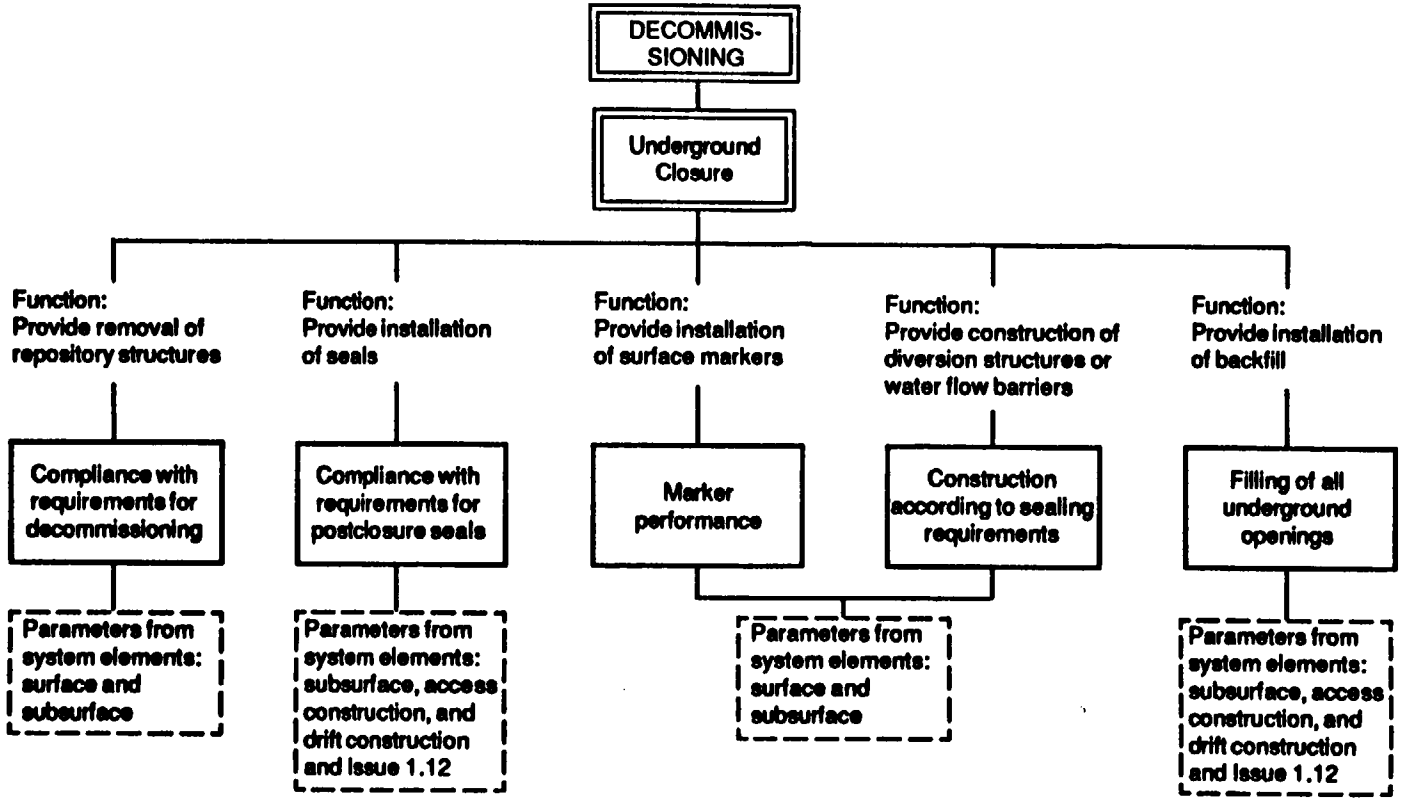
FIGURE 3-11(cont.) ISSUE 4.4: PRECLOSURE DESIGN AND TECHNICAL FEASIBILITY



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4.0 ESF ACTIVITY DESCRIPTIONS

This section contains a brief description of each ESF activity identified on the logic diagrams in Section 3.0. Table 4-1 (page G-137) provides a cross reference of these ESF activities with the SCPB issues.

4.1 SCPB ACTIVITY 8.3.1.2.2.2.1 CHLORIDE AND CHLORINE-36 MEASUREMENTS OF PERCOLATION AT YUCCA MOUNTAIN

4.1.1 Activity Description

These measurements will be made at various depths to determine the rate of water movement downward through the unsaturated-zone tuffs using the chloride/chlorine-36 concentration ratio. Large bulk samples from the ESF will be collected, packaged, and labeled for laboratory analysis. Because of the requirement to extract pore water to conduct the chlorine-36 test, several hundred pounds of samples may be needed at each sampling location. In the event that perched water is encountered, perched water samples will also be used for this activity.

4.1.2 Parameters Derived from This Activity

- Bromide concentration
- Chemistry, vadose water
- Chloride concentration
- Isotopes, chlorine
- Precipitation measurements
- Dry chloride fallout
- Fracture morphology in Paintbrush tuff
- Site hydrology and hydrochemistry.

4.1.3 Test Requirements

- The ability should exist to collect rock samples, bulk or cores, up to 4 inch in diameter and rock samples approximately 40 lb/location.

Perched water samples will be collected, whenever encountered. In the event that blasting is used, then precautions will have to be taken to ensure that the blast-produced chemicals do not contaminate the samples obtained. Water to be used in the Exploratory Studies Facility (ESF) should contain tracers to determine change in the samples by construction activity.

4.2 SCPB ACTIVITY 8.3.1.2.2.3.1 MATRIX HYDROLOGIC PROPERTIES TESTING

4.2.1 Activity Description

The purpose of the matrix hydrologic properties tests is to develop a comprehensive database on matrix flux properties in the unsaturated-zone tuffs at Yucca Mountain. This activity includes collecting bulk and/or core samples from the ESF. The collected samples will be packaged, labeled, and sent to an off-site laboratory for various analyses.

Samples are required from various geologic formations intercepted during the construction of accesses to the Topopah Spring member and excavation made in the Topopah Spring member.

4.2.2 Parameters Derived from This Activity

- Density, bulk
- Density, grain
- Metric potential
- Matrix permeability, liquid-saturated
- Matrix permeability, gas-saturated
- Moisture-retention relations
- Porosity
- Relative-permeability relations
- Spatial variability of matrix hydrologic properties
- Water content, gravimetric
- Water content, volumetric
- Water potential.

4.2.3 Test Requirements

Large sizes (estimated to be large enough not to pass a 1-ft mesh) and cores may be required for some samples. Contamination of samples from water during construction should be minimized.

4.3 SCPB ACTIVITY 8.3.1.2.2.4.1 INTACT-FRACTURE TEST IN THE ESF

4.3.1 Activity Description

The intact-fracture test will be used to evaluate fluid-flow and chemical transport properties and mechanisms in relatively undisturbed and variably stressed fractures to enhance understanding of physics of flow and for flow modeling.

Fracture-sampling locations will be selected on the basis of detailed fracture maps. A small pilot hole will be drilled across fractures to be recovered, rock bolt anchors installed, the pilot hole overcored, and the sample withdrawn. The sample will be packaged, labeled, and transported to an off-site laboratory for intact-fracture analyses.

The samples will be collected from different rock types, locations, and orientations in the unsaturated zone of the ESF. The samples collected shall represent natural fractures in the unsaturated zone of the ESF.

4.3.2 Parameters Derived from This Activity

- Density, bulk
- Dispersion (tracers), breakthrough curve
- Dispersivity, fracture and fracture network
- Effective porosity, fractures (rock matrix)
- Flux, fractures
- Fracture, fractal dimensions
- Fracture origin and type, natural or artificial
- Fracture roughness coefficient, surface profile
- Fracture tortuosity
- Fracture-filling, mineralogy, alteration, and chemistry
- Fracture-filling, physical characteristics
- Permeability, effective, hydraulic, f (saturation, matric potential, stress)
- Permeability, effective, pneumatic, f (saturation, water potential, stress)
- Permeability, relative, aqueous, fractures
- Permeability, relative, aqueous, rock matrix
- Permeability, relative, pneumatic, rock matrix
- Porosity, total, rock matrix
- Pressure head, matric potential, rock matrix
- Rock compressive strength, shear strength, rock matrix
- Water content (faults), hydraulic potential
- Young's modulus.

4.3.3 Test Requirements

Sample locations will be chosen by the principal investigator (PI) after mapping information is available.

Flexibility in sampling location is required. Drilling and overcoring will be done using dry methods.

4.4 SCPB ACTIVITY 8.3.1.2.2.4.2 PERCOLATION TESTS IN THE ESF

4.4.1 Activity Description

Percolation tests will be used to observe and measure fluid flow through a network of fractures under controlled in situ conditions in order to characterize and quantify important flow processes in fractured welded tuff. The test is planned to use a large, isolated block of rock of about 6 ft on a side in the Topopah Spring member. The block will be instrumented to detect fluid flow under physical conditions that can be mechanically controlled and systematically varied. Tracer-tagged water will be introduced from a trickle system/sand bed on the surface of the block.

4.4.2 Parameters Derived from This Activity

- Unsaturated hydraulic conductivities to air and water as functions of bulk water saturation and matric potential (including the determination of critical saturation)
- Effective porosities of the matrix and fractures
- Volumetric flux and travel time through the rock mass
- Fracture spacings, orientations, connectivity, and apertures.

4.4.3 Test Requirements

Two parallel drifts will be excavated so that the block can be cut from the pillar between the drifts.

Flexibility in location of the block excavation is required because of the need to have high-fracture-density spacing in the block. Orientation is not considered critical. Excavation disturbances should be limited so that the rock mass is not excessively damaged during excavation and preparation. Hence, the zone of hydrologic or geochemical influence will not extend beyond the isolated test block. Stress redistribution around the experiment drift will extend approximately two drift diameters from the drift boundaries.

Provision for data collection by the Integrated Data System (IDS) must be available prior to beginning this test.

4.5 SCPB ACTIVITY 8.3.1.2.2.4.3 BULK-PERMEABILITY TEST IN THE ESF

4.5.1 Activity Description

The purpose of the bulk-permeability test activity is to assess the fluid transport properties in relatively large volumes of minimally disturbed tuff. Tests are planned at various separate locations in the ESF, at Calico Hills nonwelded unit and at the lower breakout zone in the Topopah Spring welded unit, selected on the basis of detailed fracture maps. At each location, a small-diameter hole, 100 to 200 ft deep, will be air-cored (dry-drilled) and logged. Air permeability will then be measured in packed-off intervals. If the rock is deemed suitable for the test based on the preliminary results, three additional holes, nonparallel (frustrum configuration) to the first, will be air-cored, logged, and instrumented.

Cross-hole air permeability (injection) tests will be conducted. Pressure, temperature, and humidity sensors will be installed in experiment boreholes. Selected holes will then be pressurized, and the air movement outward to sensors in the other holes will be monitored. The measurements will be repeated as required by using positive or negative pressures in the boreholes.

4.5.2 Parameters Derived from This Activity

- Atmospheric moisture, humidity
- Atmospheric pressure, barometric
- Borehole locations, characteristics
- Diffusion coefficient, rock matrix
- Dispersion (tracers), breakthrough curve
- Effective porosity, rock matrix
- Flux, fault zones
- Flux, fracture-matrix interface
- Flux, velocity
- Fracture dimensions
- Fracture intersection, connectivity
- Fracture orientation
- Fracture-filling, physical characteristics
- Head, fluids
- In situ temperature
- Moisture content, rock matrix
- Moisture-retention curves
- Permeability, effective, hydraulic, f (saturation, matric potential, stress)
- Permeability, relative, aqueous, rock matrix
- Permeability, relative, pneumatic, fractures
- Pneumatic flux, unsaturated zone
- Porosity, total, fault zones
- Porosity, total, rock matrix
- Pressure head, matric potential, fault zones
- Pressure head, matric potential, rock matrix
- Water content (faults), hydraulic potential.

4.5.3 Test Requirements

Each test location will require an IDS alcove that can accommodate a Data Acquisition Station. Provision for data collection by the IDS must be available prior to beginning this test. Flexibility of location and orientation are required because both the fracture geometry and the orientation relative to the test holes are important. Test areas must be outside the hydrologic zones of influence of other tests or mining activities. Water usage shall be minimized in the test area.

Test holes for each test will be dry-drilled deep enough (approximately 150 ft) into the rock mass so that the cross-hole permeabilities can be measured in undisturbed rock (outside the stress-altered zone of the excavations). Gas-phase pressure pulses may occur as much as 100 ft away from the centerline of the cross-hole frustrum configuration. Test holes may penetrate the rock mass to 150 ft. Thus, a zone of influence extends along the four-hole frustrum out to 150 ft longitudinally and radially to approximately 100 ft. The air injected for this test will contain a tracer to allow discrimination between the natural gas in pore spaces and the injected air. Hence, no interference caused by air injection between this test and any other test is expected. No significant mechanical, hydrologic, thermal, or chemical alteration to the rock mass is expected to result from this activity.

4.6 SCPB ACTIVITY 8.3.1.2.2.4.4 RADIAL BOREHOLE TESTS IN THE ESF

4.6.1 Activity Description

The radial borehole tests will investigate vertical and lateral movement of gas, water, and vapor on and across hydrologic contacts and within the various units, and will evaluate near-field excavation effects on hydrologic properties.

Radial borehole tests will be conducted at geologic contacts. At each contact boreholes will be drilled using air as the drilling fluid. Orientation of the radial boreholes at each location will be determined by analyzing fracture data collected during access wall mapping. Core will be collected, packaged, labeled, and transported to an off-site laboratory for hydrologic analyses (fracture and matrix properties). The holes will be logged and surveyed for fracture and moisture data. Air-permeability tests in packed-off intervals will be conducted to obtain gas permeability data. Across stratigraphic contacts, cross-hole permeability tests will be run with both gas and water. Long-term monitoring of matrix water potential, pressure, and temperature will also be conducted; formation gases will be sampled periodically.

4.6.2 Parameters Derived from This Activity

- Atmospheric pressure, barometric
- Chemistry, formation pore fluid
- Concentration of stable isotopes, liquid
- Density, bulk
- Density, grain
- Diffusion coefficient, fractures
- Fracture alteration
- Fracture dimensions
- Fracture frequency
- Fracture tortuosity
- Fracture-filling, physical characteristics
- Hydraulic characteristics (fractured rock)
- Hydrogeologic stratigraphy, contact location
- In situ temperature
- Isotopes
- Moisture content, fault zones
- Moisture-retention curves
- Permeability, pneumatic, change due to underground facility excavation
- Permeability, relative, aqueous, fractures
- Permeability, relative, aqueous, rock matrix
- Permeability, relative, pneumatic, fractures
- Permeability, relative, pneumatic, rock matrix
- Pneumatic potential, f (time)
- Porosity
- Porosity, distribution
- Porosity, total, fault zones

- Porosity, total, rock matrix
- Pressure head, matric potential, fault zones
- Pressure head, matric potential, fractures
- Pressure head, matric potential, rock matrix
- Water content (faults), hydraulic potential.

4.6.3 Test Requirements

The boreholes will be dry-drilled. The facility design and operational constraints shall allow periodic access to the test locations.

Provision for data collection by the IDS must be available at each location. The radial boreholes will be drilled deep enough to be beyond the expected zone of mechanical and hydrologic influence of the openings. The holes will be used to monitor the movement of any construction water from the opening in order to measure the hydrologic zone of influence resulting from shaft construction. These monitoring activities require no special constraints, nor do they alter the hydrologic or geochemical state of the rock mass. However, at the stratigraphic contacts, cross-hole permeability tests will be run with both gas and water. The water injected under low pressure is estimated to influence a zone extending 10 m from the test location. Geochemical effects are not expected to extend beyond the zone of influence resulting from water movement. The air injected for this test will contain a tracer to allow discrimination between the natural gas in pore spaces and the injected air. No thermal or mechanical alterations to the rock mass will result from this test.

4.7 SCPB ACTIVITY 8.3.1.2.2.4.5 EXCAVATION-EFFECTS TEST IN THE ESF

4.7.1 Activity Description

The excavation effects test performed at the high lithophysal zone in the access and in the Topopah Spring member will measure stress changes in the near-field wall rock as the ESF is excavated, and will measure air-permeability changes that result from the stress redistribution.

This test requires multiple small-diameter holes drilled but set back at a selected distance from the unexcavated area. All holes are planned to be air-drilled/cored, logged, and surveyed; some of the holes will be instrumented to monitor stress changes and some to monitor permeability changes as the excavation is advanced. Stress and permeability data will be taken in drill holes extended beyond the excavation. Long-term permeability measurements will be made, and temperature and moisture data will be collected. Additional holes may be drilled to handle the instrumentation packages if they are determined to be necessary during prototype testing.

4.7.2 Parameters Derived from This Activity

- Borehole locations, characteristics
- Density, bulk
- Fracture development, in situ, due to underground facility excavation
- Fracture dimensions
- Fracture frequency
- Fracture orientation
- In situ stress, magnitude, orientation
- Moisture content, fault zones
- Permeability, relative, pneumatic, fault zones
- Porosity, total, fault zones
- Saturation, f (depth, lateral location, pressure).

4.7.3 Test Requirements

Instrument leads at the test location shall be protected from damage.

Flexibility is the only significant constraint identified for this test. It is required for locating drill holes for tests. The instrument holes will be drilled at distances up to 50 ft from the excavation. They will extend as much as 100 ft beyond the excavation creating a zone of potential mechanical interference. No thermal, chemical, or hydrologic alteration of the rock mass is expected as a result of this activity.

4.8 SCPB ACTIVITY 8.3.1.2.2.4.7 PERCHED-WATER TEST IN THE ESF

4.8.1 Activity Description

The purposes of the perched-water test are to detect the occurrence, and delineate the lateral and vertical extent, of perched-water zones (if encountered) during excavation, to identify perching mechanism(s), and to sample the water for chemical analyses. Because there is significant uncertainty regarding the likelihood of encountering perched water, the perched-water test is categorized as a "contingency test." This test will be performed wherever in the ESF perched water is detected.

If perched water is encountered during excavation, one or more small-diameter hole(s) will be drilled to enhance drainage, facilitate collection of water samples, and allow flow and/or pressure measurements to be made. The hole(s) will also be instrumented and sealed during testing to obtain data on hydraulic pressure and water potential over time.

4.8.2 Parameters Derived from This Activity

- Chemistry of perched water
- Concentration of stable isotopes, liquid
- Flux, perched-water zones
- Groundwater discharge, perched-water zones, springs and seeps
- Hydraulic conductivity, perched-water zones
- Hydraulic conductivity, rock matrix
- Isotopes
- Pneumatic flux, unsaturated zone
- Porosity, perched-water zones
- Pressure head, matric potential, fault zones
- Storage coefficient, perched-water zones
- Transmissivity, perched-water zones
- Water quality.

4.8.3 Test Requirements

All moisture or free water observed in the ESF will be sampled.

All boreholes will be drilled dry. Grouting in the ESF will require a chemical tracer to be added to the grout. Because of the uncertain nature and location of perched water, no special constraints on the layout or operation of the ESF are imposed by this experiment.

4.9 SCPB ACTIVITY 8.3.1.2.2.4.8 HYDROCHEMISTRY TESTS IN THE ESF

4.9.1 Activity Description

The hydrochemistry tests will determine the chemical composition, reactive mechanisms, and age of water and gas in pores, fractures, and perched-water zones within the unsaturated tuffs accessible from the ESF and/or affiliated coreholes. The ESF will provide access for the collection of gas, rock, and possibly perched-water samples.

Samples for this test will be collected from the radial borehole tests (performed in the access and Topopah Spring member) and from the mine rubble or cores from the unsaturated zone.

4.9.2 Parameters Derived from This Activity

- Age of groundwater
- Age of in situ gas
- Anion and cation concentrations
- Chemistry of gas
- Chemistry, formation pore fluid
- Chemistry, water
- Groundwater flow paths, locations
- Isotope age
- Isotopes
- Moisture, loss
- Pneumatic flux, unsaturated zone
- Water quality.

4.9.3 Test Requirements

All water used in the ESF will be traced. No chlorides or chlorination should occur until all the samples for chloride/chlorine-36 have been procured. All compressed air used in coring or drilling will be tagged with sulfur hexafluoride (SF_6) as tracer. Suitable space for gas sampling activities and equipment will be provided at each radial borehole location. Large rock samples (bulk) or core (HQ size:2.5 inches) will be required from various locations in the ESF. Core samples shall be dry and bulk shall have minimal disturbance to moisture content.

4.10 SCPB ACTIVITY 8.3.1.2.2.4.9 MULTIPURPOSE-BOREHOLE TESTING

4.10.1 Activity Description

One or more multipurpose boreholes (MPBHs) will be drilled using dry-drilling and spot-coring techniques, to the extent practicable. The borehole(s) will be located such that they do not penetrate within a distance of two diameters, as appropriate, of any underground openings. Exact location of the boreholes is yet to be established. The borehole(s) will be drilled to depths approximately equal to the corresponding opening, with walls as smooth as practical to maximize the quality of geophysical logging and provide adequate packer seats. The drilling activities are planned to be completed and monitoring begun before ESF construction.

4.10.2 Parameters Derived from This Activity

- Anion and cation concentrations
- Borehole locations, characteristics
- Chemistry of perched water
- Chemistry, formation pore fluid
- Flux, perched-water zones
- Fracture alteration
- Fracture frequency
- Fracture orientation
- Head, hydraulic, perched-water zones
- Hydraulic conductivity, perched-water zones
- Hydrogeologic stratigraphy, contact location
- In situ temperature
- Isotopes, formation water
- Lithostratigraphy, lithologic classification
- Moisture content, fault zones
- Moisture content, fractures
- Permeability, relative, aqueous, rock matrix
- Storage coefficient, perched-water zones
- Transmissivity, perched-water zones.

4.10.3 Test Requirements

Periodic geophysical logging and pneumatic testing will be conducted in the MPBHs to monitor conditions during and after excavation.

Boreholes will be drilled dry and will be completed prior to excavation of the ESF. A gas tracer will be used. Baseline hydraulic testing and hydrochemical sampling will be completed prior to construction of the ESF.

Boreholes will be located such that they do not penetrate within a distance of two opening diameters of any underground excavation.

4.11 SCPB ACTIVITY 8.3.1.2.2.4.10 HYDROLOGIC PROPERTIES OF MAJOR FAULTS ENCOUNTERED IN THE ESF

4.11.1 Activity Description

This activity is designed to provide hydrologic information in parallel with a portion of SCPB Activity 8.3.1.4.2.2.4. All faults encountered in the ESF will be characterized geologically under the geologic mapping activity. Hydraulic properties of major faults encountered in the ESF will be determined in this activity. The major faults or fault zones expected to be tested are the Ghost Dance fault, a suspected fault in Drill Hole Wash, the imbricate fault zone, and the Solitario Canyon fault. Other faults will be tested if they are considered hydrologically significant or if water flow is observed.

On the basis of the identification of major faults by the geologic mapping activity, a hydrologic testing program will be implemented. This program will consist primarily of tests conducted in boreholes drilled through fault zones and tests on cores collected. Air permeability tests will be conducted between boreholes to determine the permeability to air of the fault zones. Some boreholes will be instrumented to determine in situ conditions of the rock mass and monitored for any changes in these conditions over time. Other sets of boreholes will be used for cross-hole water-injection tests. One borehole at each location will be used for geothermal measurements. All water used for injection will be tagged with a tracer. Core recovered from the holes will be tested to provide a water-content profile across the fault zone. This profile may provide information relative to any recent moisture occurrence in the fault zone.

This test will be conducted wherever faults with flow are observed in the ESF and the major suspected faults in the Topopah Spring and Calico Hills formation such as Ghost Dance fault, Imbricate fault, and Solitario Canyon fault.

4.11.2 Parameters Derived from This Activity

- Atmospheric moisture, humidity
- Borehole locations, characteristics
- Density, bulk
- Density, grain
- Flux, velocity
- Fracture dimensions
- Fracture intersection, connectivity
- Fracture orientation
- Fracture orientation, lithostratigraphic variation
- Fracture-filling, physical characteristics
- Head, hydraulic, rock mass
- Hydrogeologic stratigraphy, contact location
- In situ temperature
- Moisture content, fault zones
- Moisture content, fractures
- Moisture-retention curves

- Permeability, effective, hydraulic, f (saturation, matric potential, stress)
- Permeability, effective, pneumatic, f (saturation, water potential, stress)
- Permeability, intrinsic, fault zones
- Permeability, intrinsic, rock matrix
- Permeability, relative, aqueous, rock matrix
- Permeability, relative, pneumatic, fractures
- Pneumatic potential, f (time)
- Porosity
- Pressure head, matric potential, rock matrix
- Water content (faults), hydraulic potential
- Water content, in situ.

4.11.3 Test Requirements

Geothermal holes: One hole will be air-cored, near horizontally, at each location at about 45° to the opening as soon after identification of the fault as possible. These holes will be minimum of 200 ft long. Hydrologic holes: Approximately four holes will be air-cored at each location. Each location will require access to the IDS.

The hydrologic boreholes shall not be drilled until the PI has determined that the effects of ventilation in the opening have been detected in the geothermal borehole at that location and therefore that drilling of the hydrologic holes can proceed.

4.12 SCPB ACTIVITY 8.3.1.2.2.5 DIFFUSION TESTS IN THE ESF

4.12.1 Activity Description

The diffusion tests will take place in specially constructed alcoves in the zeolitic and the vitric zones of the Calico Hills unit and in the Topopah Spring member. Each test will require boreholes dry-drilled, vertically downward, or subhorizontally in each alcove. Each hole will be approximately 4 in in diameter for the upper 30 ft and about 1.5 in in diameter for the bottom 18 ft. The bottom of each hole will serve as a source region for the tracer diffusion tests. The core removed from the bottom of each hole will be examined for fractures. In addition, the boreholes will be examined for fractures using a downhole borescope.

About 10 ml of solution containing a suite of tracers will be placed at the bottom of the 1.5 in-diameter hole. One of the tracers will be bromide. The 4 in-diameter hole will be sealed with an inflatable packer to isolate the bottom of the hole from air pressure and humidity changes in the alcove while diffusion occurs. The hole will then be overcored, and the bottom portion of the core will be sectioned and analyzed for tracer concentration as a function of position.

The results of the diffusion experiments will be used to estimate the effective diffusion coefficients of conservative radionuclides in the unsaturated zone. Two sets of experiments will be performed for each zone (vitric and zeolitic) in the Calico Hills unit. The initial experiment (3 months) will be performed to establish the length of time required and the size and type of overcoring needed to effect the transport rate via diffusion through the unsaturated tuff unit. Then a period of 1 year will be required to conduct a conclusive experiment to be reported in a milestone report.

4.12.2 Parameters Derived from This Activity

- Diffusivity, hydraulic
- Lithostratigraphy, subunits.

4.12.3 Test Requirements

The locations require an area large enough to accommodate the drilling equipment with any needed attachments, the sample injection system, the packer system, and any appropriate equipment and instrumentation to effect these tests in the ESF. A minimum alcove area of approximately 18 ft diameter and a depth of 25 ft is needed for each diffusion test.

The test requires that all the boreholes be drilled dry. These tests will require dry-drilling equipment and equipment to emplace tracer solution in the bottom of the boreholes as well as the ability to recover the core into which the lithium bromide tracers have diffused. No additional construction or experiment to be conducted within one opening diameter.

4.13 SCPB ACTIVITY 8.3.1.3.2.1.1 PETROLOGIC STRATIGRAPHY OF TOPOPAH SPRING MEMBER

4.13.1 Activity Description

The goal for this activity is to determine the petrologic variability within the devitrified Topopah Spring member at Yucca Mountain and to define the stratigraphic distribution of this variability. Studies of the distribution of phenocyst and rock matrix textures in this member have been shown to be useful for defining stratigraphic position. Analysis will be conducted with X-ray diffraction. Chemical analyses will also be used to determine variability.

This activity requires collecting samples from the Topopah Spring member. Detailed sampling will depend on the features encountered. Samples will be collected in the drifts in order to assess the lateral variability within a stratigraphic location.

4.13.2 Parameters Derived from This Activity

- Descriptions of the Topopah Spring member from core samples, from outcrop, and from the ESF.

4.13.3 Test Requirements

No special requirements are imposed by the test on the design of the ESF. The ability should exist to obtain oriented samples and to transport samples from underground to the surface.

This activity involves sample collection and identification of the samples by the geologist. Drilling may be required, depending on the excavation method.

4.14 SCPB ACTIVITY 8.3.1.3.2.1.2 MINERAL DISTRIBUTIONS BETWEEN THE HOST ROCK AND THE ACCESSIBLE ENVIRONMENT

4.14.1 Activity Description

This activity will provide a three-dimensional description of the distribution and abundances of major minerals for potential flow paths between the repository and accessible environment. Statistical evaluation of the three-dimensional distribution will be part of this activity to estimate natural variability and sample density requirements and to extrapolate between boreholes. Data collected by this activity are quantitative X-ray diffraction (XRD) determinations of mineral abundances, X-ray fluorescence and/or other chemical methods to determine major and trace element abundances in bulk rock, and electron microprobe analyses of mineral composition. Rock samples for this activity are obtained from the accesses, the main test level (MTL), and the Calico Hills formation.

4.14.2 Parameters Derived from This Activity

- Groundmass textural variations by modal petrography
- Major, minor, and trace element chemistry of whole rocks, mineral separates, and fracture coatings by x-ray fluorescence, atomic absorption spectrophotometry, and neutron activation analysis
- Mineral chemistry by electron microprobe analysis
- Mineral identifications, abundances, and distributions in bulk rocks and fractures by x-ray diffraction
- Textural relationships of minerals in fractures by scanning electron microscope.

4.14.3 Test Requirements

Ability should exist to obtain oriented samples and to transport samples from the underground to the surface. Drilling may be required to obtain samples for laboratory analysis.

4.15 SCPB ACTIVITY 8.3.1.3.2.1.3 FRACTURE MINERALOGY

4.15.1 Activity Description

The fracture mineralogy studies will be conducted to determine mineralogic variability throughout the ESF to establish the time and conditions of fracture mineralogy deposition alteration, and to identify fracture-coating mineral types, sorptive characteristics, and health hazard potential of fibrous zeolites.

In addition to mineralogic sampling by drilling cores and collecting samples from walls and at the working face in the ESF and drifts, samples may be collected on the surface from the muck removed. The samples will be packaged and labeled for shipment to offsite laboratory for detailed analyses, including age determinations.

This activity requires gathering samples from the entire ESF (including the Calico Hills formation). Detailed sampling of anomalous features will depend on the features encountered. In addition, one or two oriented samples from altered intervals and from lower candidate host rock to upper vitrophyre, and two or three oriented samples from lower TSw zeolitized nonwelded tuff and from Calico Hills tuff will be procured.

4.15.2 Parameters Derived from This Activity

- Fracture-filling, mineralogy, alteration, and chemistry
- Lithostratigraphy, mineralogy and petrography
- Mineralogy, morphology, crystallinity
- Rock chemistry, qualitative, quantitative
- Distribution and identity of mineral species.

4.15.3 Test Requirements

No special requirements are imposed by the test on the design of the ESF. The ability should exist to obtain oriented samples and to transport samples from underground to the surface.

This activity essentially requires collecting samples. Samples will be identified by the PI.

4.16 SCPB ACTIVITY 8.3.1.3.2.2.1 HISTORY OF MINERALOGIC AND GEOCHEMICAL ALTERATION OF YUCCA MOUNTAIN

4.16.1 Activity Description

This study will include petrologic analysis of alteration sequences and structures. Mineral growth sequences will be studied using an electron microprobe. Ages of alteration events will be estimated using potassium-argon dating of clays and zeolites and electron spin resonance dating of quartz and calcite.

Samples will be collected from the bottom of the Topopah Spring member and the Calico Hills unit. The ESF samples will provide large, oriented samples of alteration products. Detailed sampling will depend on the features encountered. Any natural gels found in the ESF will be sampled.

4.16.2 Parameters Derived from This Activity

- Stable isotope data from authigenic minerals
- Uranium-thorium and rubidium-strontium isotopic data for authigenic minerals
- Uranium-series and uranium-trend ages of authigenic minerals
- Model of unsaturated zone hydrologic flow
- Model of saturated zone hydrologic flow.

4.16.3 Test Requirements

No special requirements are imposed by the test on the design of the ESF. The ability should exist to obtain oriented samples and to transport samples from underground to the surface.

This activity involves sample collection. Samples will be identified by the PI. Drilling may be required, depending on the excavation method.

4.17 SCPB STUDY 8.3.1.3.4.2 BIOLOGICAL SORPTION AND TRANSPORT

4.17.1 Study Description

Underground operations will introduce microorganisms into the environment. This study will address the effects of these organisms on retardation (either positive or negative) of radionuclides. This study will determine the growth of microorganisms in fluids used in excavation and drilling, evaluate the influence of microorganisms on actinide mobility, and determine binding constants of microorganisms to actinides. Indigenous populations and introduced organisms must be characterized.

Microorganisms will be cultured from samples collected by drilling and from the ESF. These organisms will then be cultured in the presence of fluids expected to be introduced to examine their growth. These microorganisms will also be used to examine actinide sorption characteristics.

This activity requires collecting fluid samples from the Topopah Spring member. Samples must be collected aseptically to prevent further contamination.

4.17.2 Parameters Derived from This Activity

- Groundwater chemistry
- Sorption of actinides on crushed tuff
- Types and quantities of microorganisms.

4.17.3 Test Requirements

No special requirements are imposed by the test on the design of the ESF. The ability should exist to obtain samples and to transport samples from underground to the surface.

This activity involves fluid sample collection. Samples will be identified by the PI.

4.18 SCPB STUDY 8.3.1.3.7.2 DEMONSTRATION OF APPLICABILITY OF LABORATORY DATA TO REPOSITORY TRANSPORT CALCULATIONS

4.18.1 Study Description

The tests will be conducted in eight alcoves in the Calico Hills unit. Dual breakout rooms will be required for these tests. The main room below is where sampling instruments will be located. The upper room will contain equipment to apply water and tracers to the intervening block. Access will need to be maintained to this room in order to service equipment.

During room excavation, samples will be collected from the alcove area for laboratory characterization of hydrologic and chemical properties. A geologic map of the test block will need to be compiled.

Tests will involve increasing water content of the test block by either ponding or sprinkling water on top. Both reactive and nonreactive tracers will be used. The slow response of the system will require that tracers be injected during the wetting phase of the experiment rather than bringing the block to a steady-state water content. Water content will be measured in the block, and water flux will be determined by effluent collection. Tracer concentrations and total mass will be measured in the effluent. For reactive tracers that have not broken through, a sampling program will be undertaken once the flux part of the experiment is considered complete.

4.18.2 Parameters Derived from This Activity

- TBD

4.18.3 Test Requirements

A total of eight alcoves, each alcove 30 ft x 30 ft, is requested. Two alcoves in each of the zeolitic and vitric facies of the Calico Hills, two alcoves at the interface between the vitric and zeolitic facies, and two alcoves at the interface of the Topopah Springs and Calico Hills members.

The test will require the ability and experience to inject reactive and nonreactive tracers. The tests may utilize geophysical techniques, neutron probe, or time domain reflectometry to assure water content and distribution. Tracers will be added to the water.

These tests should be located away from other tests involving water or other liquids. The alcove should be mined dry and located a sufficient distance from ramps/shafts and or drifts so that other activities will not interfere with the test. The test is expected to operate for approximately 1 to 10 years.

4.19 SCPB ACTIVITY 8.3.1.4.2.2.4 GEOLOGIC MAPPING OF THE ESF

4.19.1 Activity Description

Geologic mapping and photogrammetry will be used to document lithologic and fracture variability throughout the vertical and horizontal extent of the underground excavations, to investigate structural features, and to provide siting data to confirm (or modify) planned test locations within the underground excavations. It is planned that all of the excavations in the ESF be mapped.

A complete stereophotographic record will be obtained of all the excavations including accesses to the Topopah Spring member (TSw) and the Calico Hills formation (CHn). Where stratigraphic contacts occur or where geologic anomalies are encountered, the mapping detail will be comparable in all accesses.

4.19.2 Parameters Derived from This Activity

- Contact altitude
- Fault geometry, orientation, attitude, strike and dip
- Fault tectonic style, classification
- Fault-zone physical properties
- Fracture dimensions
- Fracture frequency
- Fracture orientation
- Fracture roughness coefficient, surface profile
- Fracture-filling, mineralogy, alteration, and chemistry
- Hydrogeologic stratigraphy, contact location
- Lithostratigraphy, lithologic classification
- Lithostratigraphy, lithophysae
- Lithostratigraphy, mineralogy, and petrography
- Lithostratigraphy, subunits
- Stratigraphic orientation, attitude
- Stratigraphic thickness
- Aperture roughness
- Fracture persistence
- Mineralogy
- Relative ages
- Spatial distribution
- Lateral variability.

4.19.3 Test Requirements

Unless safety considerations dictate to the contrary, the mapping will be done prior to installation of ground support. The area to be mapped should be cleaned to expose geologic features. Cleaning of the area, if required, is expected to be accomplished by washing the walls with a minimal amount of water (less than that used to control mining dust). Surveying of benchmarks to a level-three

precision as defined by appropriate project procedures is required. Securable underground space is required to store mapping equipment. A storage and staging trailer or building of at least 200 sq ft with necessary amenities is required on the surface. A photographic laboratory (light-tight) approximately 8 x 13 ft with necessary amenities and one 220-V, 30-A circuit are also required.

4.20 SCPB ACTIVITY 8.3.1.4.2.2.5 SEISMIC TOMOGRAPHY/ VERTICAL SEISMIC PROFILING

4.20.1 Activity Description

The purpose of the seismic tomography and vertical seismic profiling activity is to remotely characterize subsurface fracture networks.

This activity requires access to walls of the entire excavated ESF. A vertical environment (shaft) will require the drilling of short boreholes in which geophones will be emplaced to obtain information on fracture characteristics. A horizontal or subvertical environment will require access only to competent rock. After the instruments have been installed, seismic stimuli will be initiated by using either small explosives charges or vibrations.

4.20.2 Parameters Derived from This Activity

- Geophysical signatures of discontinuities/fractures
- Induced polarization (geophysical), lithologic correlation
- Seismic motion, response spectra (spectral amplitude, frequency, duration, and seismic moment)
- Seismic motion, velocity
- Wave propagation characteristics.

4.20.3 Test Requirements

No specific design support is required for this activity. This activity may use surface-drilled boreholes, and short boreholes in the underground excavations for installation of seismic sensors if in a shaft. The PI will identify the exact location for the drill holes, if used.

Because the purpose of this test is to measure ground vibration caused by the introduction of energy from a specific source controlled by the seismic-test team, other loud noises or equipment or machinery-induced vibration in or near the facility are not allowed while tests are in progress. No other special constraints are required to include this activity in the ESF testing, and no additional perturbation to natural conditions (stress, temperature, moisture, etc.) will result from this activity (i.e., no significant zone of influence results from this activity).

4.21 SCPB INVESTIGATIONS 8.3.1.15.1 STUDIES TO PROVIDE THE REQUIRED INFORMATION FOR SPATIAL DISTRIBUTION OF THERMAL AND MECHANICAL PROPERTIES

4.21.1 Investigation Description

The laboratory geoengineering properties test will provide bulk, thermal, and mechanical properties data for evaluations of opening stability and related design and performance studies and/or modeling. Data from the laboratory test will also support analyses of the geomechanical and thermomechanical field tests planned in the ESF. The ESF activities are basically the collection, packaging, and labeling of the selected bulk samples taken from the shafts or drifts.

This activity primarily consists of collecting rock samples from the accesses, main test level, and Calico Hills formation.

4.21.2 Parameters Derived from This Investigation

- Volumetric heat capacity
- Heat capacity, rock matrix
- Heat flow, regional
- Thermal conductivity, in situ
- Thermal conductivity, rock matrix
- Thermal expansion coefficient
- Poisson's ratio
- Rock compressive strength, shear, rock matrix
- Young's modulus
- Rock-matrix cohesion
- Rock-matrix friction angle
- Fracture cohesion
- Fracture friction coefficient
- Fracture stiffness, normal, shear
- Matrix porosity
- Grain density
- In situ bulk density.

4.21.3 Test Requirements

There are no special requirements. The capability should exist to extract cores of various sizes up to 15 inches in diameter. The capability to drill cores or collect samples and transport them to the surface for shipment to laboratories is necessary.

4.22 SCPB ACTIVITY 8.3.1.15.1.5.1 ACCESS CONVERGENCE

4.22.1 Activity Description

Access convergence tests are required to monitor rock-mass deformation around the accesses.

Rock-mass deformation around the accesses will be monitored at measurement stations using multiple-point borehole extensometers (MPBXs) placed at 120° intervals around the opening. The MPBXs consist primarily of anchors installed at depth. Movement in the rock mass is recorded as the anchors move. Deformations will be measured across the access at multiple locations. In addition to MPBX measurements, deformations will be measured with rod extensometers. Extensometer measurements will be made along diameters of the opening and at 60° from the MPBX heads. The tests will be located at various locations in each access at stratigraphic horizons of TSw2, and in the Calico Hills.

Each station will also include hydraulic pressure cells in the liner to monitor radial stress changes over time as the excavation continues below the test location.

4.22.2 Parameters Derived from This Activity

- Borehole locations, characteristics
- Borehole stability, casing
- Deformation
- In situ stress, magnitude, orientation.

4.22.3 Test Requirements

The tests should be installed soon after the excavation passes the proposed test location. No constraint on construction is imposed by this test. It is not necessary that the stations be instrumented immediately after the test location has been exposed. No drilling will be allowed near the MPBX and pressure cell stations.

4.23 SCPB ACTIVITY 8.3.1.15.1.5.2 DEMONSTRATION BREAKOUT ROOMS

4.23.1 Activity Description

The demonstration breakout room (DBR) tests will be used to demonstrate constructibility and stability of the underground openings in the upper lithophysal zone of the Topopah Spring member (TSw1) in the upper demonstration breakout room (UDBR) and in welded fractured tuff (TSw2) on the main test level in the lower demonstration breakout room (LDBR).

The size of the DBR openings shall be consistent with the maximum width for repository openings. The excavation techniques for the DBRs should be similar to the excavation techniques to be used for the repository openings. This test will evaluate mining techniques and rock support requirements. The rock-mass response will also be measured in the DBR excavations by using extensometers and convergence anchors.

4.23.2 Parameters Derived from This Activity

- Deformation rate, in situ, due to underground facility excavation
- Excavation methods, efficiency
- Fracture development, in situ, due to underground facility excavation
- Rock-support system loading.

4.23.3 Test Requirements

The instrument heads of the extensometers will be placed within a recess to be provided at the walls of the excavation.

Flexibility in the orientation of the rooms is required to ensure that the desired alignment relative to local geologic features, such as the prevailing joint structure, is achieved. Adequate flexibility must exist to rotate the orientation of the DBRs, depending on the geology of the test location. Other constraints include a requirement that no other mining be performed to within a distance of approximately 50 ft from the deepest MPBX anchors installed in the walls of the opening while the test is in progress.

It is preferred that the main test LDBR be mined before any significant mining occurs at the main test level. The mining sequence will be controlled; after excavation has reached 35 ft, the bulk of the instrumentation installation will commence in conjunction with mining. This room cannot be used for any other function.

4.24 SCPB ACTIVITY 8.3.1.15.1.5.3 SEQUENTIAL DRIFT MINING

4.24.1 Activity Description

The purpose of the sequential drift mining activity in the Topopah Spring member MTL is to measure deformational response of a repository-size opening as the opening is being excavated. This is accomplished by installing instruments from adjacent drifts into a rock mass and subsequently excavating the instrumented rock mass.

Instruments installed in boreholes will monitor stress change caused by excavation. Tests of bulk permeability changes will be conducted, and deformation will be measured. To measure rock-mass response to mining, data will be obtained before mining of the center parallel drift. Air and water permeability in boreholes adjacent to the new drift opening will be measured after mining.

4.24.2 Parameters Derived from This Activity

- Deformation rate, in situ, due to underground facility excavation
- Excavation methods, efficiency
- In situ stress, change due to underground facility excavation
- Permeability, hydraulic, rock matrix.

4.24.3 Test Requirements

The orientation will coincide with either of the two orthogonal orientations planned for the conceptual repository design, with the flexibility for orientation adjustment between two limits depending on the dominant fracture orientation and the in situ stress conditions at each DBR location.

Convergence measurements will be made as construction of each DBR proceeds to assess the effects of excavation of the rooms themselves.

The DBR tests will be performed early in the construction of the MTL to minimize the effects of ground disturbance from unrelated excavations.

Provision for data collection by the IDS must be available prior to excavation of each room beyond 35 ft.

Two parallel drifts approximately 14 ft high, 16 ft wide, and 180 ft long are required to install the instruments. The center-to-center distance between the two drifts should be approximately 110 ft. After the instruments have been installed, a central drift approximately 19 ft high, 25 ft wide, and 180 ft long will be excavated using the same technique as that used to excavate the MTL. A 10-ft by 15-ft alcove should be provided to install a Data Acquisition System (DAS).

No mining, except to excavate each DBR, will be allowed within 50 ft of any MPBX anchor until MPBX readings are no longer being taken. Because MPBX anchors can be 50 ft from the DBR rib, this constraint effectively provides an exclusion envelope of 100 ft from the DBR ribs.

4.25 SCPB ACTIVITY 8.3.1.15.1.6.1 HEATER EXPERIMENT IN UNIT TSw1

4.25.1 Activity Description

The heater experiment measures thermomechanical and thermally induced hydrologic responses in high-lithophysal rock to verify scaling relationships needed for repository design and performance calculations.

In the upper demonstration breakout room (UDBR) in TSw1, a heater-emplacement hole will be drilled approximately 8 ft into the drift wall. Several instrumentation holes parallel to the heater hole will be drilled, and then the heater and instruments (MPBXs and thermocouples) will be installed. In a borehole near the heater, neutron logs will be run before, during, and after the heating cycle to monitor moisture content changes. After the heater has been started, the rock response to thermal loading, heat flow, and moisture changes will be monitored.

4.25.2 Parameters Derived from This Activity

- Borehole locations, characteristics
- Heat capacity, rock matrix
- Thermal conductivity, rock matrix
- Thermal expansion coefficient.

4.25.3 Test Requirements

Sufficient flexibility should be provided to locate the test so that other activities in the UDBR are not adversely affected. This test should be located about 30 ft away from the next nearest test, and in an area of low traffic. Heat from this test cannot be allowed to interfere with other tests.

4.26 SCPB ACTIVITY 8.3.1.15.1.6.2 CANISTER-SCALE HEATER EXPERIMENT

4.26.1 Activity Description

The canister-scale heater experiment will monitor thermomechanical and hydrothermal responses in the repository host rock for design and performance modeling, for assessment of retrievability, and for monitoring radon emanation as a function of heating. During the tests, heat fluxes will be increased so that temperatures near the canister heater exceed design limits. This phase of the test is to aid in determining limits on waste-emplacement borehole stability.

At a location within the MTL in the TSw2, a heater hole and parallel small-diameter instrumentation holes will be drilled. Baseline moisture data in neutron probe holes will be recorded. A heater and instrumentation (thermocouples, MPBXs, borehole deformation gages, and radon monitors) will be installed. After instruments have been installed, the heater will be initiated, and thermal, thermomechanical, and hydrothermal phenomena, and radon release rates, will be monitored at increasing heat loads.

4.26.2 Parameters Derived from This Activity

- Borehole locations, characteristics
- Heat capacity, rock matrix
- Moisture content, f (time)
- Repository radon emanation rate, underground facilities
- Thermal conductivity, rock matrix
- Thermal expansion coefficient.

4.26.3 Test Requirements

To limit the influence of drift openings (1) on the stresses near the heater and (2) on the temperatures produced in the rock formation, the heater should be located 30 ft from drifts or alcoves running parallel to the axis of the heater.

Uninterrupted power is required for the heater and IDS. The experiment needs to be located in a low traffic area.

Water usage and spillage must be kept to a minimum within a 50-ft radial distance from the test centerline.

4.27 SCPB ACTIVITY 8.3.1.15.1.6.3 YUCCA MOUNTAIN HEATED BLOCK TEST

4.27.1 Activity Description

The Yucca Mountain heated block experiment, at the main test level in TSw2, will (1) measure three-dimensional deformation and temperature changes; (2) measure relationships among fracture permeability, stress, and temperature; (3) monitor moisture movement relative to temperature; and (4) evaluate cross-hole measurement methods in large blocks of welded tuff. Results from 1, 2, and 3 will be used in modeling.

At a selected location in the dedicated test area, an alcove will be mined and an area of rock 6 ft by 6 ft will be defined within the alcove. Baseline fracture permeabilities will be measured, reference survey pins will be established, and cross-hole ultrasonic measurements will be made. Next, slots will be cut on each side of the block approximately 6 ft deep and flatjacks will be inserted. An array of heaters will be installed in holes on opposite sides of the block. Other instrumentation holes will be drilled and instrumented with thermocouples, MPBXs, and deformation gages. Finally, cyclic tests will be conducted at various mechanical loads (imposed using flatjacks) and thermal loads (imposed using heaters). The rock responses and permeability changes under induced conditions will be monitored.

4.27.2 Parameters Derived from This Activity

- Fracture roughness coefficient, surface profile
- Heat capacity, rock matrix
- Moisture content as function of time
- Rock compressive strength, shear, rock matrix
- Thermal conductivity, rock matrix
- Thermal expansion coefficient.

4.27.3 Test Requirements

An experimental alcove with nominal dimensions of approximately 27 ft x 27 ft and a height of 14 ft is required for this test. The test will require drilling and coring of holes. An uninterrupted power source for the heaters and IDS will be needed.

Flexibility in location of the test alcove is required to ensure that the block contains joint spacing and orientation that are reasonably representative of the repository horizon. The experiment should be located in a low traffic area so that dust and vibrations from other construction and testing do not interfere with sensitive displacement measurements being made as the block is loaded.

The thermal zone will extend approximately 20 ft beyond the test alcove in a direction normal to the lines of heaters. Within the thermal zone, the 100°C isotherm will attain a maximum distance of approximately 3 ft radially from the centerline of the heaters. Because of the small volume of rock dehydrated, the hydrologically altered zone is likely to be less than the estimated 40-ft maximum.

4.28 SCPB ACTIVITY 8.3.1.15.1.6.4 THERMAL STRESS MEASUREMENTS

4.28.1 Activity Description

These tests will measure thermal stresses in a relatively large volume of jointed rock and relate the stress changes to thermomechanical displacement for numerical modeling. The specific numbers and locations of these experiments have not been determined. These measurements will be performed in the LDBR at the TSw2.

4.28.2 Parameters Derived from This Activity

- In situ stress, change due to thermal load
- Temperature, ambient
- Thermal expansion coefficient.

4.28.3 Test Requirements

An uninterrupted power source for the heaters and IDS will be needed.

No mining should be performed within a two-drift-diameter standoff region until the test is completed. The test should be located in a drift that can be isolated from normal mine traffic.

4.29 SCPB ACTIVITY 8.3.1.15.1.6.5 HEATED ROOM EXPERIMENT

4.29.1 Activity Description

The heated room experiment remains in early stages of design and is intended to measure thermomechanical responses in fractured welded tuff at a drift-size scale to acquire data for evaluating both preclosure and postclosure design. Measurements will also be used to support the validation phase of both empirical and numerical design methods. This experiment will be performed in the TSw2 MTL. The rock around the central drift of the sequential drift mining experiment will be heated to temperatures representative of those expected in the repository.

4.29.2 Parameters Derived from This Activity

- Borehole locations, characteristics
- Deformation modulus
- Heat capacity, rock matrix
- In situ stress, magnitude, orientation
- In situ temperature
- In situ thermal gradient
- Land-surface temperature
- Moisture content, f (time)
- Rock-support system loading
- Temperature, ambient
- Thermal conductivity, rock matrix
- Thermal expansion coefficient.

4.29.3 Test Requirements

Flexibility integral to the sequential drift mining experiment in location and orientation of the experiment is a constraint. Because it will be approximately 2 to 3 years after heating begins before data are available, the heated room test should begin as soon as possible. Special doors and thermal barriers may be required to control the ventilation and heat flow from the area.

No other test alcoves or test drifts will be planned within a standoff zone 150 ft laterally from the centerline of the center drift and 50 ft longitudinally beyond the ends of the center drift.

4.30 SCPB ACTIVITY 8.3.1.15.1.7.1 PLATE LOADING TESTS

4.30.1 Activity Description

The plate loading test loads parallel, diametrically opposed surfaces of rock for the purpose of deformation measurements. Experimental results can be used to calculate rock mass modulus and interpret the depth of the disturbed zone. These tests will be conducted in alcoves extending from each access, within the MTL, and within the Calico Hills. The alcoves will be approximately 15 ft wide by 6 ft tall. Between 12 and 20 of these tests are expected.

4.30.2 Parameters Derived from This Activity

- Borehole locations, characteristics
- Fracture dimensions
- Fracture orientation
- Fracture-filling, physical characteristics
- In situ stress
- In situ stress, change due to underground facility excavation
- Rock deformation modulus.

4.30.3 Test Requirements

Surfaces in the vicinity of the plate loading test should be relatively free of blast damage. Testing will impede traffic; therefore, test alcoves should be provided out of the way.

4.31 SCPB ACTIVITY 8.3.1.15.1.7.2 ROCK-MASS STRENGTH EXPERIMENT

4.31.1 Activity Description

The rock-mass strength activity evaluates the mechanical behavior of the rock mass. Experiments will obtain information on the mechanical response of single joints and multiple jointed volumes of rock. This experiment will be conducted in several areas that are representative of the range of conditions encountered in the main accesses, in the main test level of TSw2, and in the Calico Hills. The information will evaluate scale effects between laboratory and in situ conditions, provide data to evaluate empirical design criteria, and provide data to evaluate and validate jointed-rock models.

Most of these experiments will be conducted at the main test level (TSw2) in a test alcove. Certain of these test will be performed in alcoves along the main accesses and within the Calico Hills. Specifically, in situ tests for strength and deformability would be conducted in the Calico Hills if the rock mass were fractured or heterogeneous.

4.31.2 Parameters Derived from This Activity

- Borehole locations, characteristics
- Deformation
- Fracture shear strength, peak, residual, compressive
- Fracture stiffness, normal, shear
- In situ stress
- Rock deformation modulus
- Rock-mass strength, in situ
- Stratigraphic alteration near basaltic intrusions.

4.31.3 Test Requirements

This test must be performed in a location that has not been affected by other testing. Provision for data collection by the IDS must be available prior to beginning this test.

No special constraints exist other than ensuring that the tests are not conducted in regions that have been altered by other activities. The location of the test will be determined after the drifts in the dedicated test area are mined. The experiment will be similar to the plate loading test in that only a small region of rock (approximately 30 to 90 ft^3) will be directly loaded and the effects of the loading will likely extend only a distance of a few times the width of the area over which the load is applied. No permanent alteration to the local hydrologic, chemical, or thermal conditions will result from this test. No significant zone of influence will result from the rock-mass loading imposed in this activity.

4.32 SCPB ACTIVITY 8.3.1.15.1.8.1 EVALUATION OF MINING METHODS

4.32.1 Activity Description

These tests will monitor and evaluate mining methods for access and underground openings, with emphasis on rock responses in a variety of lithologic and structural settings that may be encountered in the long exploratory drifts. This activity will be to develop recommendations for mining in the repository. Mining investigations will include particle velocity measurements, segmented blasting rounds, and examination of blast-induced damage in boreholes, as appropriate.

This activity will occur at all locations deemed appropriate by the PI. This includes all major accesses, drifts within TSw2, and Calico Hills.

4.32.2 Parameters Derived from This Activity

- Borehole stability, casing
- Excavation methods, efficiency
- Repository safety, mining, and ground support requirements
- Rock stability, underground blasting design

4.32.3 Test Requirements

No specific requirements have been identified for this test.

4.33 SCPB ACTIVITY 8.3.1.15.1.8.2 MONITORING OF GROUND SUPPORT SYSTEMS

4.33.1 Activity Description

This activity will develop recommendations for a ground support system in drifts of a potential repository, based on evaluations of the ground support techniques used in the underground excavations, and on experimentation with other ground support configurations. This activity will be carried out at the MTL. The selection, installation, and performance of the support systems used will be monitored. Experimentation with ground supports will include pull tests on rock bolts. Observations will be made of unsupported rock, strength measurements will be taken on shotcrete cores, and trials of alternative ground support configurations from those prescribed for the ESF will be performed. The effects of heat on ground support will be considered in the heated room experiment.

4.33.2 Parameters Derived from This Activity

- Fracture frequency
- Fracture orientation
- Fracture-filling, physical characteristics
- Ground support system stress, concrete, shotcrete
- Ground support system stress, underground facilities
- In situ stress, in situ, underground facilities
- Lithostratigraphy, texture, fabric, and grain size
- Repository ground support systems
- Rock-support system design.

4.33.3 Test Requirements

No specific requirements have been identified for this test.

4.34 SCPB ACTIVITY 8.3.1.15.1.8.3 MONITORING OF DRIFT STABILITY

4.34.1 Activity Description

These tests will monitor drift convergence throughout the ESF, along accesses, and in the Calico Hills. This activity involves monitoring drift convergences and drift maintenance activities. The PI will select convergence measurement stations. In the long drifts, convergence measurements will be taken in a continuous manner; if practical, rock-mass relaxation will be investigated in repository-scale portions of the long drifts using MPBXs. Rock falls and maintenance activities will be documented.

4.34.2 Parameter Derived from This Activity

- Deformation rate, in situ, due to underground facility excavation.

4.34.3 Test Requirements

Field observations of ground conditions will be necessary before final locations of measurement stations can be specified. The design of service hardware in the drifts (such as ventilation ducts, cable trays, etc.) must accommodate these measurements. MPBXs and tape extensometer anchors should be installed as close as possible to the advancing face. Provision for data collection by the IDS must be available prior to beginning this test.

4.35 SCPB ACTIVITY 8.3.1.15.1.8.4 AIR QUALITY AND VENTILATION EXPERIMENT

4.35.1 Activity Description

The purpose of the air quality and ventilation experiments is to assess the impact of site characteristics on ventilation requirements to ensure a safe working environment. This activity consists of (1) measurements of radon emanation; (2) surveys of air-flow and pressure, temperature, and humidity; (3) determinations of air resistance factors; and (4) dust characterization. The radon emanation measurements will be made in a dead-end drift that has been sealed with a bulkhead at equilibrium conditions and at various rates of airflow. Radon concentrations might also be measured in a borehole. The air quality and ventilation measurements are not expected to interfere significantly with other underground activities.

These experiments will be conducted throughout the ESF after construction is completed. The end section of the drift to the Ghost Dance fault will be sealed with a bulkhead to allow measurement of radon gas emanation.

4.35.2 Parameters Derived from This Activity

- Atmospheric moisture, humidity
- Atmospheric pressure, barometric
- Basaltic volcanism, controls and geochemical patterns
- Chemistry of gas
- Dust generation (drilling and mining)
- Dust, chemistry, types
- Pneumatic flux, unsaturated zone
- Repository radon emanation rate, underground facilities
- Temperature, ambient
- Underground-facility ventilation, air resistance.

4.35.3 Test Requirements

This experiment requires only periodic air sampling, no special constraints are required to include this activity in the ESF testing, and no additional perturbation to natural conditions (stress, temperature, moisture, etc.) will result from this activity.

4.36 SCPB ACTIVITY 8.3.1.15.2.1.2 OVERCORE STRESS EXPERIMENTS IN THE ESF

4.36.1 Activity Description

The overcore stress experiments will be performed in the ESF accesses at the Topopah Spring welded tuff MTL and in the Calico Hills formation, to determine the in situ state of stress above, within, and below the repository horizon, in that portion of the unsaturated zone penetrated by the ESF, to determine the extent of excavation-induced stress changes, and to relate stress parameters to rock-mass heterogeneities.

Soon after access is available, small-diameter holes will be drilled to prescribed orientations and lengths (longer than three times the opening diameter). A deformation sensor will then be installed, and the instrumented center hole will be overcored in stages. Strain data will be taken as the instrumentation of each stage is overcored.

4.36.2 Parameters Derived from This Activity

- Borehole locations, characteristics
- In situ stress, magnitude, orientation
- Poisson's ratio
- Rock deformation modulus
- Young's modulus.

4.36.3 Test Requirements

A mobile rock-testing facility (to be supplied by the test organization) will require an assigned space at the surface and utility hookups.

The test should be separated from the nearest thermal test by a minimum of 50 ft or should be completed before the heaters are energized. Flexibility in location of the tests is required because intact segments of core are required. Thus, the location, distribution, orientation, and apertures of fractures need to be examined before tests are conducted. No mining, testing, or construction should take place in such a way as to influence the in situ stresses at the bottom of the test holes. Test holes should not be drilled near other instrument holes. Tests will be conducted within the approximately 50-ft-long boreholes extending downward and horizontally from the end of the excavation.

4.37 SCPB INFORMATION NEED 4.4.6: 8.3.2.5.6 DEVELOPMENT AND DEMONSTRATION OF REQUIRED EQUIPMENT

4.37.1 Information Need Description

This SCPB information need was originally proposed for the purpose of development and demonstration of special equipment. Further specific equipment needs have not been identified to date.

If these tests are conducted, a designated room on the main test level of TSw2 will be required.

4.37.2 Parameters Derived from This Information Need

- Fracture characteristics of host rock
- Abrasiveness of host rock
- Rock-cutting characteristics, including dependence on in situ stresses
- Existence of free water in the rock mass
- Normal and abnormal conditions of drifts and borehole.

4.37.3 Test Requirements

No specific requirements have been identified for this test.

4.38 SCPB STUDY 8.3.3.2.2.3 IN SITU TESTING OF SEAL COMPONENTS

4.38.1 Study Description

The seal tests have not been developed in sufficient detail to evaluate their impact on excavation of the underground facilities. Additional evaluations will be required before defining appropriate field tests for seal components. The most important needs will be the characterization of the repository environment and results of laboratory studies on seal material properties.

While particular experiments are not yet defined, the three general categories of field-test operations are expected to provide some constraints on the test location. For example, if testing is performed to verify emplacement techniques, this operation may involve a significant amount of equipment, as well as construction operations that may require physical separation from other more sensitive tests. Tests will be performed in the accesses, in TSw2, and in the Calico Hills formation.

4.38.2 Parameters Derived from This Study

Parameters to be determined.

4.38.3 Test Requirements

The mechanical zone of influence from sealing tests is likely to be within the zone created as a result of the related excavation. Initial tests would most likely be done without heating so that no thermal zone of influence is expected. Hydrologic considerations may, however, be significant. If testing of sealing systems is needed under simulated flooding scenarios, a significant amount of water may be required. If this is required, then a hydrologic zone of influence may result. If this zone of influence were to become unacceptably large or the test were to significantly increase uncertainties relative to postclosure performance, an alternative test could possibly be conducted either in the laboratory or in an alternative field location removed from the ESF. The geochemically altered zone would depend on the types of materials tested and upon the total amount of water used in each test. When these tests are defined, this test and associated constraints and performance-related impacts will be described in semiannual progress reports.

4.39 SCPB STUDY 8.3.4.2.4.3 MECHANICAL ATTRIBUTES OF THE WASTE PACKAGE ENVIRONMENT

4.39.1 Study Description

The test will be conducted in alcoves mined in the nonlithophysal portion of the Topopah Spring tuff unit away from major faults. The test will require dry drilling of boreholes up to approximately 30 inches in diameter.

This study is designed to characterize the geomechanical response of the rock in the near-field environment to the changing environmental conditions expected to occur over the lifetime of the repository. Some tests will study the effect of a heating/cooling cycle on the stability of rock. Other tests will assess the potential for spalling or other types of borehole breakout that may occur due to the heating/cooling cycle and associated changes in the rock/fracture properties.

For each test, instruments will be installed to measure temperature, stress, and displacement as a function of time and location. Rock cores and blocks will also be obtained before and after the thermal cycles for laboratory determination of thermal-mechanical properties.

The heaters in the test will be cycled through heating and cooling stages and in some cases temperatures and/or stresses may be imposed on the rock which are higher than those expected in the potential repository. The intent of testing at these higher temperatures and stresses will be to accelerate the rate at which rock deformation mechanisms occur. This may serve to bound the estimates of geomechanical deformation over time.

4.39.2 Parameters Derived from this Study

- Emplacement configuration
- Repository layout
- Mechanical properties of rock in repository horizon (TSw2), including for example, Young's modulus, Poisson's ratio, deformation modulus, coefficient of thermal expansion, and strength-related properties
- Fracture (joint) characteristics of rock in repository horizon (TSw2), including for example, shear and normal stiffness, orientation, and frequency and degree of persistence.

4.39.3 Test Requirements

The test requires the ability to lift up to 1.5 tons in the ESF.

4.40 SCPB ACTIVITY 8.3.4.2.4.4.1 REPOSITORY HORIZON NEAR-FIELD HYDROLOGIC PROPERTIES

4.40.1 Activity Description

This activity consists of conducting a series of heater tests and infiltration tests in the non-lithophysal portion of the Topopah Spring tuff unit away from major faults as prototype tests in the ESF. The tests are designed to investigate moisture movement and saturation conditions in the host rock during heating and cooling periods of waste storage and to investigate the scale effects of the heater hole on the measured parameters. Some tests will measure the parameters during the thermal cycle using ambient moisture as the initial condition. The other tests will include a simulated percolation event to examine the effect of water percolating or diffusing through the rock mass.

For each of the tests, instruments will be installed in the rock mass around the heaters to measure temperature, moisture content, gas and liquid pressure, stress change, and displacement as a function of time and location. Various geophysical probes will be used to measure the moisture content in the rock before, during, and after thermal cycling. Rock cores will be obtained before and after the thermal cycles for mineralogic and geochemical analyses. Laboratory measurements of hydrologic properties and thermal-mechanical properties will be made on similar samples.

The heaters in the test will be cycled through heating and cooling stages. The duration of the period during which the heater is at maximum power and the initial thermal loading for the heater are based on the criteria that the boiling conditions encompass a sufficiently large volume of rock to include several fractures within the dry hot region. Scoping calculations will be used to determine the initial power of heating and the duration of heating at the maximum power.

4.40.2 Parameters Derived from this Activity

- Degree of liquid water saturation
- Relative permeability
- Matric potential
- Fluid flow pathways
- Fluid flow rates
- Fracture characteristics
- Thermal loading
- Mechanical and thermal properties of the rock.

4.40.3 Test Requirements

This activity requires approximately 900 feet of drift. There are two sets of drift: emplacement and instrumentation drift. These two sets of drift will be separated by at least 25 feet vertically. In addition, two instrument alcoves approximately 12 ft x 12 ft each and two storage alcoves approximately 12 ft x 12 ft each will be needed. In addition, no roof bolts will be installed in the area covered by the heater plus 5 feet.

The test will require dry-drilled heater holes 4 inches, 12 inches, and 30 inches in diameter. The test will also require:

- Transporting ability to move, lift, and load at least 1.5 tons
- Infiltration water: untracered, unchlorinated J-13 water, about 500 gal/week.

4.41 SCPB ACTIVITY 8.3.4.2.4.4.2 REPOSITORY HORIZON ROCK-WATER INTERACTION

4.41.1 Activity Description

This activity is to obtain large-diameter (6- to 8-inch) dry-drilled cores or dry-mined blocks of sample from the lithophysal zone of Topopah Spring tuff at the contact of Tiva Canyon and Topopah Spring, the Topopah Spring welded unit, the Basal Vitrophyre of Topopah Spring, and the top of the Vitric Calico Hills unit. They will be used for laboratory tests to evaluate rock-water interactions at high temperatures. The rock types to be studied include the lithophysal Topopah Spring tuff at the contact between the Tiva Canyon and Topopah Spring units, the welded Topopah Spring, the Basal Vitrophyre of the Topopah Spring, and the top of the Vitric Calico Hills unit.

4.41.2 Parameters Derived from this Activity

- Temperature
- Temperature gradient
- Water chemistry
- Mineralogic changes.

4.41.3 Test Requirements

No specific requirements have been identified for this test.

Table 4-1 Cross Reference of ESF Activities and SCPB Issues

APP. G SECTION	INVEST./ STUDY/ ACTIVITY	ISSUES 1.1	1.4/ 1.5	1.6	1.10	1.11	1.12	2.2	2.7	4.4
4.1	8.3.1.2.2.2.1			X					X	
4.2	8.3.1.2.2.3.1			X						
4.3	8.3.1.2.2.4.1			X						X
4.4	8.3.1.2.2.4.2	X		X						
4.5	8.3.1.2.2.4.3			X						
4.6	8.3.1.2.2.4.4	X		X		X				X
4.7	8.3.1.2.2.4.5	X		X		X				X
4.8	8.3.1.2.2.4.7	X		X						X
4.9	8.3.1.2.2.4.8	X		X		X				X
4.10	8.3.1.2.2.4.9	X		X						
4.11	8.3.1.2.2.4.10	X		X						
4.12	8.3.1.2.2.5.1					X				
4.13	8.3.1.3.2.1.1	X			X			X	X	X
4.14	8.3.1.3.2.1.2	X								X
4.15	8.3.1.3.2.1.3	X								
4.16	8.3.1.3.2.2.1	X								
4.17	8.3.1.3.4.2	X								
4.18	8.3.1.3.7.2	X								
4.19	8.3.1.4.2.2.4			X		X				X
4.20	8.3.1.4.2.2.5	X		X						
4.21	8.3.1.15.1				X		X			4
4.22	8.3.1.15.1.5.1				1	2	3			
4.23	8.3.1.15.1.5.2				1	2	3			
4.24	8.3.1.15.1.5.3				1	2	3			
4.25	8.3.1.15.1.6.1				1	2	3			
4.26	8.3.1.15.1.6.2				1	2	3	X		X
4.27	8.3.1.15.1.6.3				1	2	3			X
4.28	8.3.1.15.1.6.4				1	2	3			
4.29	8.3.1.15.1.6.5				1	2	3			X
4.30	8.3.1.15.1.7.1				1	2	3			X
4.31	8.3.1.15.1.7.2				1	2	3			X
4.32	8.3.1.15.1.8.1				1	2	3			
4.33	8.3.1.15.1.8.2				1	2	3			
4.34	8.3.1.15.1.8.3				1	2	3			
4.35	8.3.1.15.1.8.4				1	2	3		X	
4.36	8.3.1.15.2.1.2									X
4.37	8.3.2.5.6*						5			
4.38	8.3.3.2.2.3									
4.39	8.3.4.2.4.3				6					
4.40	8.3.4.2.4.4.1	X			X					
4.41	8.3.4.2.4.4.2				X					

X - Denotes that the specified activity has been explicitly identified for that particular issue.
1 - 8.3.1.15.1 is explicitly identified under issue 1.10; hence, by implication, all its studies and activities.
2 - 8.3.1.15 is explicitly identified under issue 1.11; hence, by implication, all its investigations, studies and activities.
3 - 8.3.1.15.1 is explicitly identified under issue 1.12; hence, by implication, all its investigations, studies and activities.
4 - 8.3.1.15.1.1.1, 8.3.1.15.1.2.1, 8.3.1.15.1.3, 8.3.1.15.1.4, 8.3.1.15.1.4.1, and 8.3.1.15.1.4.2 are explicitly identified under issue 4.4.
5 - 8.3.3.2.2.3 is a study within 8.3.3.2.2 which is explicitly identified under issue 1.12.
6 - 8.3.4.2.4.3 contains 8.3.4.2.4.3.1 which is explicitly identified under issue 1.11.
* - 8.3.2.5.6 - Development and Demonstration of Required Equipment, is pending.

APPENDIX H

TRACEABILITY OF ESF MISSION TO "DISPOSAL OF WASTE" REQUIREMENTS

APPENDIX H

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2 1.0 OVERVIEW 1

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4 DISPOSE OF WASTE REQUIREMENTS 4

5 3.0 COMPLETE SET OF PERFORMANCE MEASURES FROM THE
6 "DISPOSE OF WASTE" REPORT 16

1.0 OVERVIEW

This appendix describes the relationships between the performance measures for the resolution of issues involving subsurface based activities, which are defined in the Site Characterization Program Baseline (SCPB), to the set of performance measures established for the "Dispose of Waste" physical system functions, which are defined in the Dispose of Waste document. Figure 1 illustrates schematically the relationship between the two documents.

In the functional decomposition analysis for the "Dispose of Waste" function, subfunctions were systematically defined to progressively more detailed and functional specificity. Externally-imposed regulatory requirements were then assigned as constraints upon individual functions using a unique identification system. As an example, "1.4.2.2.2-C2" refers to the second performance constraint (10 CFR 60.113(a)(2)) assigned to function 1.4.2.2.2 - "Limit Release of Radionuclides to Accessible Environment."

The SCPB utilizes an Issues Hierarchy as an organizing principle to address site characterization needs and regulatory requirements. Each of the Issues is directly related to one or more regulatory requirements. Planned activities in the Exploratory Studies Facility will contribute to the resolution of the Issues identified in Table 2-1 of Appendix G. The following ten Issues require primary data from the ESF. These data can also be used to meet some of the data needs of the remaining Issues except Issues 2.6 and 4.3.

Issue Number	Issue Title
1.1	Total System Performance
1.4	Waste Package Containment
1.5	EBS Release Rate
1.6	Groundwater Travel Time
1.10	Waste Package Characteristics
1.11	Configuration of Underground Facilities (Postclosure)
1.12	Seal Characteristics
2.2	Worker Radiological Safety - Normal Conditions
2.7	Repository Design Criteria for Radiological Safety
4.4	Preclosure Design and Technical Feasibility

The logic for resolving each of these Issues is summarized elsewhere in this document and shows the functions or process elements established for resolving the Issue, the performance measures defined for each of these elements, and the parametric data needs associated with these performance measures. Other portions of this document describe planned subsurface testing activities and their relationship to the acquisition of data for each of the parameter types.

It is important to note the distinction between the two sets of related performance measures which have been discussed. Performance measures defined through the "Dispose of Waste" functional analysis describe how well a repository function must perform to comply with regulatory requirements. Performance measures defined for an SCPB Issue included in the ESF Mission Analysis document, however, describe how well a process must perform to adequately resolve the concerns expressed by an Issue statement.

Following the schematic figure illustrating the relationship between repository requirements and the ESF is a series of matrix diagrams showing the correlation between the performance measures defined for each of the ten Issues and the Dispose of Waste requirements which are related to each Issue. With few exceptions, it is clear from these diagrams that: (1) all of the SCPB Issue-based performance measures can be associated with at least one of the regulatory requirements identified in the "Dispose of Waste" functional analysis, and (conversely) (2) all of the "Dispose of Waste" requirements, dependent upon ESF data for evaluation, can be associated with at least one of the performance measures contained in the resolution logic for one of

the ten Issues identified above. The exceptions are summarized and discussed below.

For Issue 1.12, constraint 1.4.3.1.3C1 (10 CFR 60.142) is not addressed by the Issue resolution strategy directly, because this requirement for implementing a program for in situ testing of various features is programmatic in nature. For Issue 2.2, six of the constraining requirements, including: 1.4.1.4.2.6C1 (10 CFR 60.131(a)(1)), 1.4.1.4.2.6C2 (10 CFR 60.131(a)(4)), 1.4.1.4.2.6C3 (10 CFR 60.131(a)(6)), 1.4.1.4.2.6C5 (10 CFR 60.132(c)), 1.4.1.4.1.1C2 (10 CFR 60.133(g)), and 1.4.1.2I2 (10 CFR 60.133(g)(3)) are not directly addressed by the Issue resolution strategy, because this Issue establishes design goals, which are transferred to other Issues for the development of design criteria and design products. Demonstration of regulatory compliance will be based on the evaluation of these design products. Finally, a number of the "Dispose of Waste" constraints associated with Issue 4.4 refer to site recommendation guidelines in 10 CFR 960. While the issue resolution strategy for Issue 4.4 treats some of the guidelines, others do not depend directly on the acquisition of site characterization data. Regulatory compliance for the latter will be measured using socioeconomic, environmental monitoring, and other similar data.

A number of requirements considered in the functional analysis of the "Dispose of Waste" function do not appear in these diagrams for similar reasons. Programmatic requirements, for example, are not directly associated with the operational physical system that will be used to perform the assigned functions. Certain requirements will be addressed by other Issues, including those involving laboratory, surface-based, or other non-ESF testing activities. Other requirements apply to either the operation of the facility or the integration/conversion of the facility for use in a potential repository. Requirements which are related to Issue 1.7 (Performance Confirmation), for example, and those which relate to the possibility of emplacing waste packages in the ESF for testing purposes, are not shown. Finally, certain requirements apply specifically to the operation of a repository itself, and are not directly associated with the functioning of an ESF.

This is shown in more detail in the Dispose of Waste performance measure tables which follow the matrix diagrams. Grouped by Dispose of Waste function is a list of the requirements assigned to that function and the performance measures defined in the Dispose of Waste document associated with each requirement. Each Dispose of Waste requirement has been annotated to indicate the relationship to ESF activities. The six annotation types used include the following: (1) "Included in Issue X.X" - directly associated with resolution of Issue X.X; (2) "Related to Issue X.X" - Dispose of Waste performance measure is identical or closely similar to the performance measures defined in the ESF Mission Analysis for Issue X.X; (3) "No ESF data required" - self explanatory, performance measurement for this requirement will not rely on subsurface data acquired in the ESF; (4) "Covered by all Issues" - generic requirements which apply to the conduct of all issue resolution activities; (5) "Related to Issue 1.7" - requirements applicable to the performance confirmation program, which is the subject of Issue 1.7 and which may utilize the data acquired in the ESF; and (6) "ESF placeholder" - requirements associated with preclosure waste package monitoring, which has not been precluded from the ESF Mission.

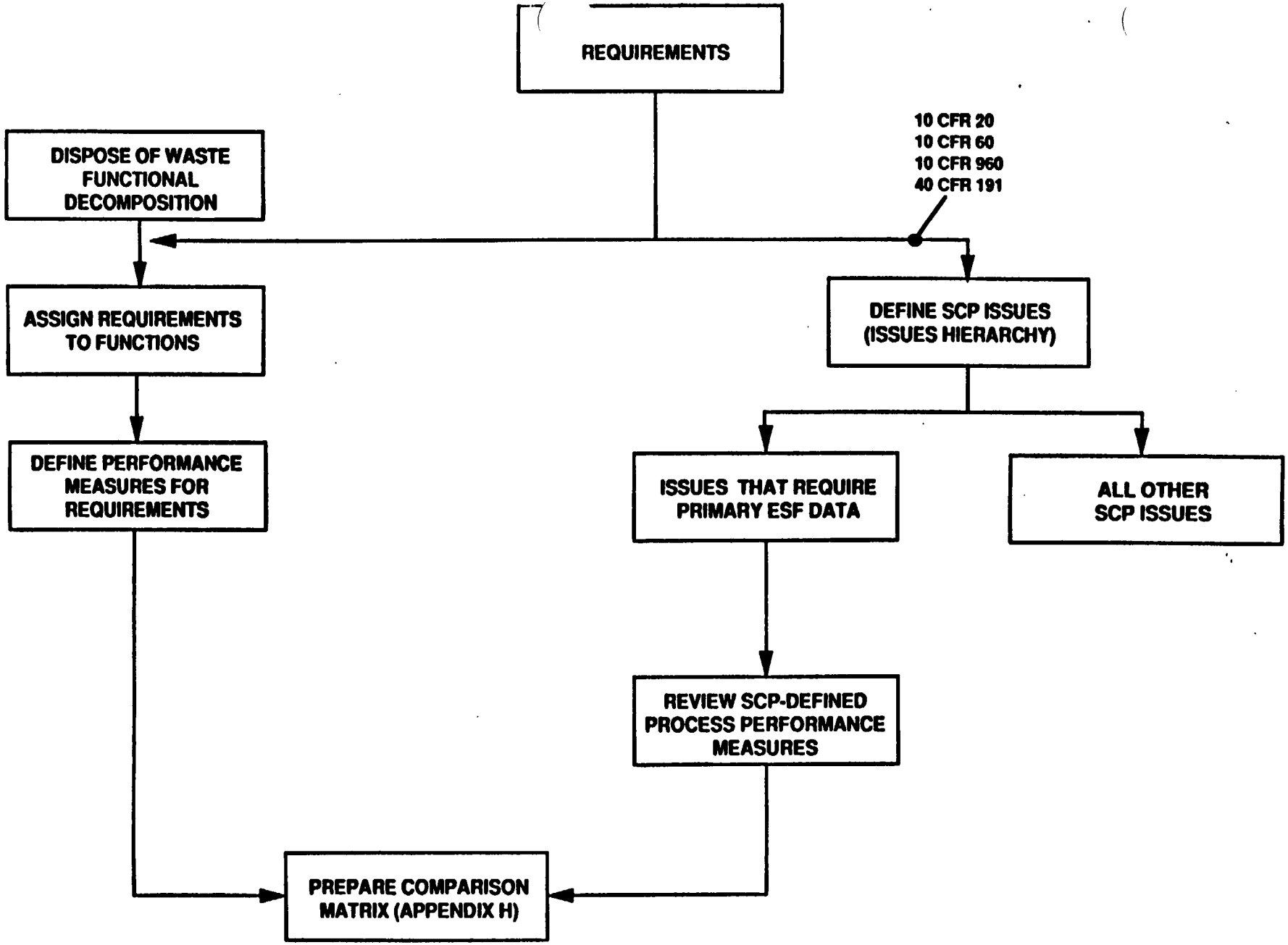

Figure 1. Relationship Between Repository and ESF Site Characterization Performance Measures

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2.0 CORRELATION OF PERFORMANCE MEASURES FROM ISSUES AND DISPOSE OF WASTE REQUIREMENTS

Issue 1.1 - Total System Performance

Dispose of Waste Requirement	ESF Mission Analysis Performance Measures: Predicted Distribution (CCDF) of Releases to Accessible Environment
1.403b	X
1.4.204a	X

Issue 1.4/1.5 - Waste Package Containment and EBS Release Rate

Dispose of Waste Requirement	ESF Mission Analysis Performance Measures: Release Rate From EBS	Container Breach Statistics
1.4.2.2.102	X	
1.4.2.1C1		X

Issue 1.6 - Ground Water Travel Time (GWTT)

Dispose of Waste Requirement	ESF Mission Analysis Performance Measures: Unsaturated Zone GWTT	Saturated Zone GWTT
1.4.2.2.2C2	X	X
1.4.2C13	X	X

Issue 1.10 - Waste Package Characteristics

Dispose of Waste Requirement	ESF Mission Analysis Performance Measures: Near-field/Waste Package Water Quality	Near-field Water Quantity	Borehole Stability
1.4.2.1C2	X	X	X
1.4.2.1C3		X	X

Issue 1.11 - Postclosure Design Criteria

PM	ESF Mission Analysis Performance Measures
A1	Is usable area adequate for 70,000 MTU of Waste?
A2	Performance Measures of Issues 1.1, 1.6, and 1.10
A3	Regions of dehydration or condensation and drainage pattern
A4	Ground quality
A5	Extent of change in saturation and water chemistry
A6	Distance from ground with unfavorable properties
A7	Temperature (to limit adverse effects)
A8	Postclosure rock movements under thermal load
B1	Type, quantity, and location of construction materials
B2	Net water from operations that remains in host rock at emplacement
C1	Permeability change due to blasting (vis a vis disturbed zone and seals)
C2	Extraction ratio
C3	Drift spans
C4	Amount of fill
D1	Time container is above boiling temperature of water
D2	Temperature (changes in barriers)
D3	Thermal loading
D4	Temperature (surface)
D5	Surface uplift
D6	Potential for significant displacement
D7	Stress, deformation, factor of safety, and potential rockfall
D8	Borehole wall temperature
D9	Rock mass temperature

Dispose of Waste Requirement	ESF Mission Analysis Performance Measures																					
	A								B		C				D							
	1	2	3	4	5	6	7	8	1	2	1	2	3	4	1	2	3	4	5	6	7	8	9
1.4.2C3	X	X	X	X	X	X	X	X	X	X													
1.4.1.2C2	X			X		X																	
1.4.2C7									X	X													
1.4.1.2.1C1												X	X	X									
1.4.1.2.1C2											X	X	X	X									
1.4.2C6											X	X	X	X									
1.4.1.2C6																	X		X	X	X		
1.4.2C8															X	X	X	X		X	X	X	X

Issue 1.12 - Seal Characteristics

PM ESF Mission Analysis Performance Measures

A Shaft and Ramp Seals
- 1 Quantity of water
- 2 Physical presence
- 3 Percentage of gaseous radionuclides preferentially exiting shafts
- 4 Drainage capacity

B Exploratory Borehole Seals
- 1 Quantity of water
- 2 Percentage of gaseous radionuclides preferentially exiting boreholes
- 3 Percentage of flow

C Underground Facility Seals
- 1 Quantity of water
- 2 Quantity of water
- 3 Amount of fill
- 4 Physical presence

ESF Mission Analysis Performance Measures

Dispose of Waste Requirement	A 1	2	3	4	B 1	2	3	C 1	2	3	4
1.4.204a		X	X			X					X
1.4.2.1C1			X			X					
1.4.2.2.102			X			X					
1.4.2C9	X				X			X	X		
1.4.1.3.1.3C2				X			X			X	X
1.4.3.1.3C1*											

* In situ testing is a programmatic requirement.

Issue 2.2 - Worker Radiological Safety - Normal Conditions

PM ESF Mission Analysis Performance Measures
(From SCP Table 8.3.5.4-1)

Surface:

A Transport characteristics of atmosphere within site boundaries

B Doses resulting from airborne radionuclide concentrations around repository facilities

Subsurface:

C Effective attenuation of direct radiation by host rock

D Release rates and concentrations of naturally occurring radionuclides

E Direct radiation and contamination levels from miscellaneous sources

Repository:

F Direct radiation levels in all areas of the repository

G Doses due to worker occupancy in direct radiation areas

H Doses due to worker occupancy in direct radiation areas

I Direct radiation and contamination levels from miscellaneous sources

J Effective attenuation of direct radiation levels

K Contamination and airborne radionuclide concentrations in repository airstreams

ESF Mission Analysis Performance Measures (Relation to SCP Performance Measures)

Surface:	Underground:
Worker Dose (B,G,H,J)	Worker Dose (C,D,E,G,H,J)
Radiation conc. isopleths (A,K)	Radiation levels (C,D,E,F,I)
Radiation levels (A,F,I)	Radon radiation levels (C,D,I)
Radiation contam. level (A,K)	Radiation contam. level (E,I,K)

Dispose of Waste Requirement	ESF Mission Analysis Performance Measures A	B	C	D	E	F	G	H	I	J	K
1.4.1C2	X	X	X	X	X	X	X	X	X	X	X
1.4.1.4.2.6C1*											
1.4.1.4.2.6C2*											
1.4.1.4.2.2C1	X							X			
1.4.1.4.2.6C3*											
1.4.1.4.2.6C5*											
1.4.1.4.1.1C2*											
1.4.1.2I2*											
1.4.104a	X	X	X	X	X	X	X	X	X		X

* Notes:

[1] - Issue 2.2 establishes design goals, which are transferred to other issues for development of design criteria and design products. Compliance with these requirements will be based on an evaluation of these design products.

[2] - 1.4.1.4.2.8C1 and 1.4.1.4.4C1 have the same performance measures as 1.4.1.4.2.6C5.

Issue 2.7 - Repository Design Criteria for Radiological Safety

Functions of Issue 2.7

A- Radiological Protection
B- Design/Protection of IITS
C- Criticality Control
D- Compliance w/mining regs.
E- Waste Treatment

Function	PM	ESF Mission Analysis Performance Measures
A	1	Concentrations of radioactive materials in repository air streams
	2	Time required to perform task in radiation field
	3	Dose reduction due to remote handling equipment
	4	Dose reduction factor attributable to host rock shielding properties
	5	Radiation fields in normally occupied work areas
	6	See A12-16
	7	Contamination levels outside contamination areas
	8	Contamination on personnel
	9	Residual contamination
	10	Residual contamination due to site-generated waste
	11	See A26-34
	12	Visibility of signs
	13	Effectiveness of guard
	14	Distribution and location of signs
	15	Effectiveness of procedures
	16	Effectiveness of personnel barriers
	17	Visibility of alarm system
	18	Accuracy and reliability of alarm system
	19	Loudness and noticeability of alarm system
	20	Ability to detect radioactive materials in repository effluent streams
	21	Ability to control radioactive materials in repository effluent streams
	22	See A17-19
	23	See A2-3
	24	See A4-5
	25	Combined annual individual worker doses from all sources of radiation
	26	Pressure differentials between radiation zones
	27	Leakage between systems
	28	Pressure differential between separate systems
	29	Potential for accident flow reversals
	30	System capture efficiency
	31	Flow rate in highly contaminated areas
	32	Flow pattern of ventilation systems
	33	Decontamination factor
	34	Number of filter banks

(Continued)

Issue 2.7 - Repository Design Criteria for Radiological Safety

Functions of Issue 2.7

A- Radiological Protection
B- Design/Protection of IITS
C- Criticality Control
D- Compliance w/mining regs.
E- Waste Treatment

Function	PM	ESF Mission Analysis Performance Measures
B	1	Effects of credible natural phenomena and natural conditions on structures, systems, and components important to safety (ITS)
	2	Response of structures, systems, and components ITS to dynamic effects of equipment failure
	3	Effects of fires, explosions, and suppression system on structures, systems, and components ITS
	4	Maintain control of radioactive material during design basis accidents
	5	Time to shut down non-safety related operations during design basis accidents
	6	Effects of structures, systems, and components ITS on evacuation during an emergency
	7	Ability of utilities ITS to continue performance of safety functions during design basis accidents
	8	Complexity of maintenance operations for structures, systems, and components ITS
	9	Complexity of testing operations for structures, systems, and components ITS
	10	Complexity of inspection operations for structures, systems, and components ITS
	11	Capacity of backup power supply
	12	Time for backup power supply to become operable
	13	Range of operation of monitoring instrumentation
	14	Range of operation of control instrumentation
	15	Ability to control structures, systems, and components ITS
C	1	K_{eff} of fissile materials
	2	Moderating materials in or around emplaced waste
	3	Geometry of waste storage arrays
	4	Mass and fissile content of emplaced waste
	5	Moderating materials in or around waste package configuration
	6	Geometry of waste package configurations
	7	Mass and fissile content of waste storage arrays
	8	Mass and fissile content of waste package configurations
	9	Geometry of emplaced waste
	10	Moderating materials in or around waste storage arrays
	11	Possibility of accidental disruption of waste geometry leading to unfavorable configurations
	12	Possibility of accidental disruption of waste leading to unfavorable concentrations of fissile materials
	13	Possibility of accidental introduction of moderating materials into areas containing waste

(Continued)

Issue 2.7 - Repository Design Criteria for Radiological Safety

Functions of Issue 2.7

A- Radiological Protection
B- Design/Protection of IITS
C- Criticality Control
D- Compliance w/mining regs.
E- Waste Treatment

Function	PM	ESF Mission Analysis Performance Measures
D	1	Ability of workers to perform assigned safety functions
E	1	Fraction of site-generated waste collected
	2	Fraction of treated and stabilized site-generated waste packaged
	3	Fraction of site-generated waste treated and stabilized or recycled

ESF Mission Analysis Performance Measures

Dispose of Waste Requirements	A1	A2	A3	A4	A5	A6	A7	A8	A9	A10	A11	A12	A13	A14	A15	A16	A17	A18	A19	A20	A21	A22	A23	A24	A25	A26	A27	A28	A29	A30	A31	A32	A33	A34
1.4.1.4.2.6C1	X																																	
1.4.1.C2		X	X	X	X	X	X	X	X	X		X	X	X	X	X																		
1.4.1.4.2.6C3																	X	X	X	X	X		X	X										
1.4.1.4.2.6C5*																				X	X													
1.4.1.1C1											X														X	X	X	X	X	X	X	X	X	X
1.4.1.4.1.1C1*																										X	X	X	X	X	X	X	X	X
1.4.1.4.1.1C2																												X						
1.4.1.2I2																																		
1.4.1C3																																		
1.4.1.4.2.8C1																																		
1.4.1.4.2C1																																		
1.4.1.4.1C1																																		
1.4.1.4.2.3C2																																		
1.4.14.2.3C3																																		
1.4.C4																																		
1.4.1C5																																		
1.4.1.4.4C2																																		

Dispose of Waste Requirements	B1	B2	B3	B4	B5	B6	B7	B8	B9	B10	B11	B12	B13	B14	B15	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13	D1	E1	E2	E3
1.4.1.4.2.6C1																																
1.4.1.C2																																
1.4.1.4.2.6C3																																
1.4.1.4.2.6C5*																																
1.4.1.1C1																																
1.4.1.4.1.1C1*																																
1.4.1.4.1.1C2																																
1.4.1.2I2	X	X	X																													
1.4.1C3	X	X	X				X	X	X	X	X	X	X	X																		
1.4.1.4.2.8C1			X																													
1.4.1.4.2C1							X																									
1.4.1.4.1C1							X				X	X	X	X																		
1.4.1.4.2.3C2								X	X	X																						
1.4.14.2.3C3													X	X																		
1.4.C4																X	X	X				X	X	X	X		X	X				
1.4.1C5																													X			
1.4.1.4.4C2																															X	X

* Notes:

1 - 1.4.1.4.2.6C1 and 1.4.1.4.4C1 have the same performance measures as 1.4.1.4.2. 6C5.

2 - 1.4.1.4.2.6C4 has the same performance measures as 1.4.1.4.1.1C1

safetypm8

Issue 4.4 - Preclosure Design and Technical Feasibility

ESF Mission Analysis Performance Measures

A. Surface:*
- 1 Space
- 2 Grades
- 3 Location re floodplain
- 4 Location surface facilities
- 5 Soil and Rock
- 6 Natural weather
- 7 Personnel/Equip environment

B. Subsurf:
- 1 Area for 70 kMTU
- 2 Ability to operate
- 3 Drift thickness
- 4 Usable opening
- 5 WP temperature
- 6 Available water

C. Access/drift construct:
- 1 Usable access
- 2 Compliance with 60.133f
- 3 Access closure
- 4 Rockfall
- 5 Maint. Freq.
- 6 Access compatibility
- 7 Pressure drop
- 8 Sealing compatibility

D. Borehole construct:
- 1 constructibility
- 2 liner installation

E. rock handling:
- 1 rock removal

F. water removal:
- 1 remove process water
- 2 removal = inflow
- 3 removal = condensation

G. mining ventilation:
- 1 comply w/ 30 CFR 57
- 2 comply w/ ACGIH
- 3 vent flex
- 4 escape route
- 5 comply w/ 60.133g

H. emplacement:
- 1 transportability
- 2 comply w/ ALARA
- 3 worker rad safety

I. retrieve:
- 1 access to emplacement
- 2 access to WP
- 3 retrieval time
- 4 operator safety

J. waste handling:
- 1 mining ventilation
- 2 air cooling power
- 3 radionuc.detection
- 4 redirect vent flow

K. underground closure:
- 1 comply w/ decomm
- 2 comply w/ seals
- 3 marker perm
- 4 seal construct
- 5 fill underground opening

* Note: Performance Measures for the Surface Element are not shown in the ESF Mission Analysis report, because only surface-based data is needed.

Dispose of Waste Requirement	A1	A2	A3	A4	A5	A6	A7	B1	B2	B3	B4	B5	B6	C1	C2	C3	C4	C5	C6	C7	C8	D1	D2	E1	F1	F2	F3	G1	G2	G3	G4	G5	H1	H2	H3	I1	I2	I3	I4	J1	J2	J3	J4	K1	K2	K3	K4	K5
1.4.1.2C1	X	X	X	X	X	X	X	X	X		X							X	X		X		X																						X			
1.4.1.2C2*								X		X			X									X																										
1.4.1.2C3									X					X							X	X	X													X	X	X	X		X							
1.4.1.2C4																									X	X	X																		X		X	
1.4.1.2C5										X				X		X								X							X		X	X	X													
1.4.1.2C6											X	X																																				
1.4.1.2.1C1										X						X	X																															
1.4.1.2.1C2															X																																	
1.4.1.4.1.1C2																			X									X	X	X	X	X								X		X	X					
1.4.1.C20										X				X		X	X																															
1.4.2C7																					X																								X			X
1.4.2C8											X																																					
1.4.1C9	X		X		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X				X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
1.4.1C10*																																																
1.4.1C11*																																																
1.4.1C12*							X																					X	X												X							
1.4.1C13*																																																
1.4.1C14		X																																														
1.4.1C15	X		X			X	X																																									
1.4.1C16					X			X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X				X	X	X	X	X				X	X	X	X	X	X	X	X	X	X	X	X	X
1.4.1C17*			X		X							X													X	X	X																					
1.4.1C18				X					X																																							
1.4.1O4b																																		X	X				X				X					
1.4.1O4c*																																		X	X				X				X					
1.4.1O5b																																		X	X				X				X					
1.4.1O5c*	X																																															
1.4.1O5d						X	X																																									
1.4.1O5e*																																																

(Column groups: ESF Mission Analysis Performance Measures)

A - Surface
B - Subsurface
C - Access/Drift Construction
D - Borehole Construction
E - Rock Handling
F - Water Removal
G - Mining Ventilation
H - Emplacement
I - Retrieval
J - Waste Handling
K - Closure

*Notes:

[1] 1.4.1C19 has the same performance measures as 1.4.1.2C2.

[2] 1.4.1C10 through 1.4.1C13 refer to site recommendation guidelines of 10 CFR 960 which concern population density and distribution, offsite installations and operations, environmental quality, and socioeconomic impacts. Information needed to demonstrate compliance with these guidelines does not depend directly on the acquisition of site characterization data.

[3] 1.4.1.2C4 has the same performance measures as 1.4.1C17

[4] 1.4.1O4c, 1.4.1O5c, and 1.4.1O5e refer to site recommendation guidelines of 10 CFR 960 which concern population density and distribution, offsite installation and operations, environmental quality, and socioeconomic impacts. Information needed to demonstrate compliance with these guidelines does not depend directly on the acquisition of site characterization data.

Issue 4.4 - Preclosure Design and Technical Feasibility

3.0 COMPLETE SET OF PERFORMANCE MEASURES FROM THE "DISPOSE OF WASTE" REPORT

Table 1. Performance Measures for "Dispose of Waste" (Function 1.4)

- 1.4-C1 [NWPA sec. 111(b)(1)] (No ESF data required.)
  PM1-Environmental Impact (constructed scale)
  PM2-Public Impact (constructed scale)
- 1.4-C2 [NWPA sec. 114(d)] (Related to Issue 1.1)
  PM1-Quantity of Spent Fuel (MTHM)
  PM2-Quantity of Solidified High-Level Waste (MTHM)
- 1.4-C3 [NWPA sec. 122] (Related to Issue 4.4)
  PM1-Retrieval Capability (yes/no)
  PM2-Retrieval Period (years)
- 1.4-C4 [10 CFR 60.131(b)(7)] (Included in Issue 2.7)
  PM1-Calculated Effective Multiplication Factor (K_{eff})
- 1.4-C5 [10 CFR 60.151] (No ESF data required.)
  PM1-QA Capability with Q-List (scope of QA program)
- 1.4-C6 [10 CFR 60.152] (No ESF data required.)
  PM1-Implementation of QA Program (yes/no)
- 1.4-C7 [10 CFR 960.3-4] (No ESF data required.)
  PM1-Environmental Impacts
  PM2-Environmental Mitigation
- 1.4-P1 (This requirement intentionally left blank.)
- 1.4-P2 [DOE/RW-0247]1(No ESF data required.)
  PM1-Start date of repository operations (year)
- 1.4-I1 (No ESF data required.)
  PM1-SNF Receipt Rate (MTHM/year or equivalent)
- 1.4-I2 (No ESF data required.)
  PM1-CHLW Receipt Rate (MTHM/year or equivalent)
- 1.4-I3 (No ESF data required.)
  PM1-DHLW Receipt Rate (MTHM/year or equivalent)
- 1.4-O2 [40 CFR 191.03(a)] (Related to Issue 4.4)
  PM1-Combined Annual Dose to Any Member of the Public (mrem to various organs) [Note: Preclosure]
- 1.4-O3a [40 CFR 191.03(a)] (Related to Issue 4.4)
  PM1-Combined Annual Dose to Any Member of the Public (mrem to various organs) [Note: Preclosure]
- 1.4-O3b [40 CFR 191.13(b)] (Included in Issue 1.1)
  PM1-Cumulative Radionuclide Release to Accessible Environment (curies of various isotopes)
  PM2-Probability of Exceeding Limit
  PM3-Estimated Partial Performance Measure (curies of various isotopes)
  PM4-Quantity of Waste (MTHM)
- 1.4-O3c [960.4-2-3(a)] (Related to Issues 1.4 and 1.5)
  PM1-Radionuclide Release to Accessible Environment (frac. of 1000 yr inven.)
  PM2-Radionuclide Release from EBS (frac. of 1000 yr. inven.)
  PM3-Thermal Stresses of Host Rock & Surrounding Units (ksi)
  PM4-Chemical Stresses of Host Rock & Surrounding Units (ksi)
  PM5-Mechanical Stresses of Host Rock & Surrounding Units (ksi)
  PM6-Radiation Induced Stresses of Host Rock & Surrounding Units (ksi)

Table 2. Performance Measures for "Operate Geologic Repository" (Function 1.4.1)

- 1.4.1-C1 [10 CFR 60.111(b)] (Related to Issue 4.4)
  PM1-Quantity of Waste To Be Retrieved (MTHM)
  PM2-Retrieval Schedule (MTHM/year)
  PM3-Retrieval Period (years)
- 1.4.1-C2 [10 CFR 60.131(a)] (Included in Issues 2.2 and 2.7)
  PM1-Radiation Doses in Restricted Areas (mrem)
  PM2-Levels of Radioactive Material in Restricted Areas (microcuries)
  PM3-Concentration of Radioactive Material in Restricted Areas (microcuries/cc)
- 1.4.1-C3 [10 CFR 60.131(b) (1)-(4), (6), (8)] (Included in Issue 2.7)
  PM1-Probability of Disruption
  PM2-Consequences of Disruption
  PM3-Time to Recover (years)
- 1.4.1-C4 (This requirement intentionally left blank.)
- 1.4.1-C5 [10 CFR 60.131(b)(9)] (Included in Issue 2.7)
  PM1-Deviation from Mining Regulations (yes/no)
- 1.4.1-C6 [10 CFR 60.137] (Related to Issue 1.7)
  PM1-Capability to Confirm Performance (yes/no)
- 1.4.1-C7 [10 CFR 60.160] (No ESF data required.)
  PM1-Training and Certification of Records (yes/no)
- 1.4.1-C8 [10 CFR 60.162] (No ESF data required.)
  PM1-Employee Health Qualifications (yes/no)
- 1.4.1-C9 [10 CFR 960.5-1(a)(2)&(3)] (Included in Issue 4.4)
  PM1-Public Hazards (constructed scale)
  PM2-Environmental Hazards (constructed scale)
  PM3-Availability of Technology (yes/no)
  PM4-Costs (dollars)
- 1.4.1-C10 [10 CFR 960.5-2-1(d)] (Included in Issue 4.4)
  PM1-Population Density (#/sq. mile)
  PM2-Population (#)
  PM3-Deviation from Regulation (yes/no)
- 1.4.1-C11 [10 CFR 960.5-2-4(a)(1) & (d)] (Included in Issue 4.4)
  PM2-Schedule Interruption (yes/no)
- 1.4.1-C12 [10 CFR 960.5-2-5(a)&(d)] (Included in Issue 4.4)
  PM1-Unmitigated Environmental Impacts (constructed scale)
- 1.4.1-C13 [10 CFR 960.5-2-6(a)&(d)] (Included in Issue 4.4)
  PM1-Unmitigated Social Impacts (constructed scale)
  PM2-Unmitigated Economic Impacts (constructed scale)
  PM3-Unmitigated Quality of Water Impact (constructed scale)
  PM4-Unmitigated Quantity of Water Impact (volume)
- 1.4.1-C14 [10 CFR 960.5-2-7(a)] (Included in Issue 4.4)
  PM1-Unmitigated Construction Impacts (constructed scale)
- 1.4.1-C15 [10 CFR 960.5-2-8(a)] (Included in Issue 4.4)
  PM1-Availability of Technology (yes/no)
  PM2-Costs (dollars)
  PM3-Surface Characteristics
- 1.4.1-C16 [10 CFR 960.5-2-9(a)&(d)] (Included in Issue 4.4)
  PM1-Availability of Technology (yes/no)
  PM2-Costs (dollars)
  PM3-Host Rock Characteristics

Table 2. (Cont'd)

- 1.4.1-C17 [10 CFR 960.5-2-10(a)&(d)] (Included in Issue 4.4)
  PM1-Availability of Technology (yes/no)
  PM2-Costs (dollars)
  PM3-Ground Water Conditions
- 1.4.1-C18 [10 CFR 960.5-2-11(a)&(d)] (Included in Issue 4.4)
  PM1-Availability of Technology (yes/no)
  PM2-Costs (dollars)
  PM3-Tectonic Phenomena
- 1.4.1-C19 [10 CFR 60.133(b)] (Included in Issue 4.4)
  PM1-Flexibility of Underground Facility Design
- 1.4.1-C20 [10 CFR 60.133(c)] (Included in Issue 4.4)
  PM1-Deleterious Rock Movement or Fracturing of Overlying or Surrounding Rock
- 1.4.1-I1 (No ESF data required.)
  PM1-SNF Receipt Rate (MTHM/year or equivalent)
- 1.4.1-I2 (No ESF data required.)
  PM1-CHLW Receipt Rate (MTHM/year or equivalent)
- 1.4.1-I3 (No ESF data required.)
  PM1-DHLW Receipt Rate (MTHM/year or equivalent)
- 1.4.1-O4a [10 CFR 60.111(a)] (Included in Issue 2.2)
  PM1-Radiation Exposures in Unrestricted Areas (mrem)
  PM2-Radiation Levels in Unrestricted Areas (mrem)
  PM3-Releases of Radioactive Materials to Unrestricted Areas (microcuries)
  PM4-Radiation Doses in Restricted Areas (mrem)
  PM5-Levels of Radioactive Material in Restricted Areas (microcuries)
  PM6-Concentration of Radioactive Material in Restricted Areas (microcuries/cc)
- 1.4.1-O4b [10 CFR 960.5-1(a)(1)] (Included in Issue 4.4)
  PM1-Radiological Exposures of the General Public (mrem/yr)
  PM2-Releases of Radioactive Materials to Restricted Areas (curies of various isotopes)
  PM3-Releases of Radioactive Materials to Unrestricted Areas (curies of various isotopes)
- 1.4.1-O4c [10 CFR 960.5-2-1(a)] (Included in Issue 4.4)
  PM1-Radiation Dose to Members of Public (mrem to various organs)
  PM2-Radiation Dose to Any Member of Public (mrem to various organs)
- 1.4.1-O5a [10 CFR 60.111(a)] (Related to Issue 2.2)
  PM1-Radiation Exposures in Unrestricted Areas (mrem)
  PM2-Radiation Levels in Unrestricted Areas (mrem)
  PM3-Releases of Radioactive Materials to Unrestricted Areas (microcuries)
  PM4-Radiation Doses in Restricted Areas (mrem)
  PM5-Levels of Radioactive Material in Restricted Areas (microcuries)
  PM6-Concentration of Radioactive Material in Restricted Areas (microcuries/cc)
- 1.4.1-O5b [10 CFR 960.5-1(a)(1)] (Included in Issue 4.4)
  PM1-Radiological Exposures of the General Public (mrem/yr)
  PM2-Releases of Radioactive Materials to Restricted Areas (curies of various isotopes)
  PM3-Releases of Radioactive Materials to Unrestricted Areas (curies of various isotopes)
- 1.4.1-O5c [10 CFR 960.5-2-2] (Included in Issue 4.4)
  PM1-Acquisition of Ownership, Surface and Sub-Surface Rights, and Control of Access (yes/no)
  PM2-Radioactive Releases to Unrestricted Areas (microcuries)

Table 2. (Cont'd)

- 1.4.1-O5d [10 CFR 960.5-2-3] (Included in Issue 4.4)
  PM1-Meteorological Conditions
  PM2-Radioactive Releases to Unrestricted Areas (microcurie)
- 1.4.1-O5e [10 CFR 960.5-2-4(a)(2)] (Included in Issue 4.4)
  PM1-Radionuclide Releases to Unrestricted Areas from Combined Facilities (microcuries)
- 1.4.1-O11a [30 USC 801 et.seq. sec. 813] (No ESF data required.)
  PM1-Accident Investigation Process (yes/no)
  PM2-Record Verification (yes/no)
- 1.4.1-O11b [30 USC 801 et.seq. sec. 813(h)] (No ESF data required.)
  PM1-Maintenance of Records (yes/no)
  PM2-Availability of Records (yes/no)

Table 3. Performance Measures for "Handle Waste" (Function 1.4.1.1)

- 1.4.1.1-C1 [10 CFR 60.132(a)] (Included in Issue 2.7)
  PM1-Pre-Emplacement Surface Handling Safety
  PM2-Post-Retrieval Handling Safety
- 1.4.1.1-C2 [10 CFR 60.135(b)(2)] (No ESF data required.)
  PM1-Concentration of Free Liquids (volume %)
- 1.4.1.1-C3 [10 CFR 60.135(b)(3)] (No ESF data required.)
  PM1-Containment During Waste Package Handling
- 1.4.1.1-C4 [10 CFR 60.135(b)(4)] (No ESF data required.)
  PM1-Unique Identification (yes/no)
  PM2-Predictions of Legibility through Retrieval (yes/no)
  PM3-Consistency with Permanent Written Records (yes/no)
  PM4-Waste Package Integrity Compromise by Identification
    a. Containment Period (years)
    b. Induced Stress (ksi)
    c. Induced Microstructural Changes (yes/no)
- 1.4.1.1-I1 (No ESF data required.)
  PM1-SNF Receipt Rate (MTHM/year or equivalent)
- 1.4.1.1-I2 (No ESF data required.)
  PM1-CHLW Receipt Rate (MTHM/year or equivalent)
- 1.4.1.1-I3 (No ESF data required.)
  PM1-DHLW Receipt Rate (MTHM/year or equivalent)
- 1.4.1.1-O6 [10 CFR 60.71(b)] (No ESF data required.)
  PM1-Sufficiency of Information in Records of the Receipt, Handling, and Disposition of Radioactive Waste at a GROA.
  PM2-Retention and Useability of the Above Records

Table 4. Performance Measures for "Receive Waste" (Function 1.4.1.1.1)

- 1.4.1.1.1-C1 [10 CFR 60.3(a)] (No ESF data required.)
  PM1-Issuance of License to Receive Nuclear Material (yes/no)
- 1.4.1.1.1-I1 (No ESF data required.)
  PM1-SNF Receipt Rate (MTHM/year or equivalent)
- 1.4.1.1.1-I2 (No ESF data required.)
  PM1-CHLW Receipt Rate (MTHM/year or equivalent)
- 1.4.1.1.1-I3 (No ESF data required.)
  PM1-DHLW Receipt Rate (MTHM/year or equivalent)

Table 5. Performance Measures for "Inspect Cask/Transfer Custody to Repository" (Function 1.4.1.1.1.1)

- 1.4.1.1.1.1-I1 (No ESF data required.)
  PM1-SNF Receipt Rate (MTHM/year or equivalent)
- 1.4.1.1.1.1-I2 (No ESF data required.)
  PM1-CHLW Receipt Rate (MTHM/year or equivalent)
- 1.4.1.1.1.1-I3 (No ESF data required.)
  PM1-DHLW Receipt Rate (MTHM/year or equivalent)

Table 6. Performance Measures for "Store Waste" (Function 1.4.1.1.2.2)

- 1.4.1.1.2.2-C1 [10 CFR 60.102(b)(3)] (No ESF data required.)
  PM1-Use of GROA for Storage of HLW (yes/no)

Table 7. Performance Measures for "Containerize Waste" (Function 1.4.1.1.2.3)

- 1.4.1.1.2.3-O3a [10 CFR 60.135(b)(1)&(2)] (No ESF data required.)
  PM1-Concentration of Explosive, Pyrophoric, and Chemically Reactive Materials (weight %)
  PM2-Concentration of Free Liquids (volume %)
- 1.4.1.1.2.3-O3b [10 CFR 60.135(c)(1),(2)&(3)] (No ESF data required.)
  PM1-Inspection (yes/no)
  PM2-Particle Size (microns)
  PM3-Combustibility (flashpoint)

Table 8. Performance Measures for "Store Containerized Waste" (Function - 1.4.1.1.2.4)

- 1.4.1.1.2.4-C1 [10 CFR 60.102(b)(3)] (No ESF data required.)
  PM1-Use of GROA for Storage of HLW (yes/no)

Table 9. Performance Measures for "Transfer Containerized Waste Underground" (Function - 1.4.1.1.3)

- 1.4.1.1.3-C1 [10 CFR 60.131(b)(10)] (No ESF data required.)
  PM1-Identification of Items Important to Safety (yes/no)
  PM2-Hoist Design Review Criteria
    a. Hoist Cage Free Fall
    b. Hoist Cage Location System Reliability
    c. Hoist Interlocks
    d. Hoist Transfer Indicator Duality

Table 10. Performance Measures for "Develop Subsurface Openings" (Function 1.4.1.2)

- 1.4.1.2-C1 [10 CFR 60.133(a)] (Included in Issue 4.4)
  PM1-Confirmation of Underground Facility
  PM2-Confirmation of EBS
  PM3-Underground Facility Credible Events
  PM4-Containment Period (years)
  PM5-Release Rate from EBS (frac. of 1000 yr. inven.)
  PM6-Depth of Underground Facility (feet)
  PM7-Waste Area (sq. miles)
- 1.4.1.2-C2 [10 CFR 60.133(b)] (Included in Issue 4.4)
  PM1-Flexibility of Underground Facility Design
- 1.4.1.2-C3 [10 CFR 60.133(c)] (Included in Issue 4.4)
  PM1-Retrieval from Underground Facility (yes/no)
- 1.4.1.2-C4 [10 CFR 60.133(d)] (Included in Issue 4.4)
  PM1-Water/Gas Intrusion to U.G. Facility (cc/yr)
- 1.4.1.2-C5 [10 CFR 60.133(e)(1)] (Included in Issue 4.4)
  PM1-Underground Facility Operational Safety
  PM2-Retrieval from Underground Facility (yes/no)
- 1.4.1.2-C6 [10 CFR 60.133(i)] (Included in Issues 1.11 and 4.4)
  PM1-Thermal Response of Host Rock
  PM2-Thermal Response of Surrounding Strata
  PM3-Thermal Response of Groundwater System
  PM4-Thermomechanical Response of Host Rock
  PM5-Thermomechanical Response Surrounding Strata
  PM6-Thermomechanical Response of Groundwater System
- 1.4.1.2-C7 [10 CFR 60.142(c)&(d)] (Related to Issues 1.11 and 1.12)
  PM1-Backfill Test Section (yes/no)

Table 10. (Cont'd)

- 1.4.1.2-C8 [10 CFR 960.4-2-3(a)] (Related to Issues 1.4 and 1.5)
  PM1-Radionuclide Release to Accessible Environment (frac. of 1000 yr. inven.)
  PM2-Radionuclide Release from EBS (frac. of 1000 yr. inven.)
  PM3-Thermal Stresses of Host Rock & Surrounding Units (ksi)
  PM4-Chemical Stresses of Host Rock & Surrounding Units (ksi)
  PM5-Mechanical Stresses of Host Rock & Surrounding Units (ksi)
  PM6-Radiation Induced Stresses of Host Rock & Surrounding Units (ksi)
- 1.4.1.2-C9 [10 CFR 960.4-2-5(d)] (Related to Issue 1.11)
  PM1 Depth of Underground Facility (feet)
- 1.4.1.2-I2 [10 CFR 60.133(g)(3)] (Included in Issues 2.2 and 2.7)
  PM1- Ventilation Separation (yes/no)
- 1.4.1.2-O4 [10 CFR 60.133(g)(3)] (Included in Issue 2.2)
  PM1- Ventilation Separation (yes/no)
- 1.4.1.2-O5 [10 CFR 60.72(a)&(b)] (No ESF data required.)
  PM1-Record Verification (yes/no)
  PM2-Record Maintenance (yes/no)

Table 11. Performance Measures for "Construct Subsurface Openings" (Function 1.4.1.2.1)

- 1.4.1.2.1-C1 [10 CFR 60.133(e)(2)] (Included in Issues 1.11 and 4.4)
  PM1-Underground Opening Stability (yes/no)
- 1.4.1.2.1-C2 [10 CFR 60.133(f)] (Included in Issues 1.11 and 4.4)
  PM1-Damaged Zone
  PM2-Containment Period (years)
  PM3-Radionuclide Release Rate (frac. of 1000 yr. inven.)
  PM4-Permeability (cm/sec)
  PM5-Subsidence (inches/yr)

Table 12. Performance Measures for "Excavate Subsurface Openings" (Function 1.4.1.2.1.1)

- 1.4.1.2.1.1-O2 [30 USC 801 et.seq., sec. 844] (Related to Issue 4.4)
  PM1-Approved Dust Control Method (yes/no)
  PM2-Approved Repository Equipment (yes/no)

Table 13. Performance Measures for "Emplace Backfill" (Function 1.4.1.2.5.2)

- 1.4.1.2.5.2-C1 [10 CFR 60.142(c)] (Related to Issue 1.12)
  PM1-Backfill Test Section (yes/no)

Table 14. Performance Measures for "Close Geologic Repository" (Function 1.4.1.3)

- 1.4.1.3-C1 [10 CFR 60.51(b)] (No ESF data required.)
  PM1-Environmental Impacts (constructed scale)

Table 15. Performance Measures for "Backfill Subsurface Openings" (Function 1.4.1.3.1.2)

- 1.4.1.3.1.2-C1 [10 CFR 60.142(c)] (Related to Issue 1.11)
  PM1-Backfill Test Section (yes/no)

Table 16. Performance Measures for "Emplace Seals" (Function 1.4.1.3.1.3)

- 1.4.1.3.1.3-C1 [10 CFR 60.72(a)&(b)] (No ESF data required.)
  PM1-Record Verification (yes/no)
  PM2-Record Maintenance (yes/no)
- 1.4.1.3.1.3-C2 [10 CFR 60.134(b)] (Included in Issue 1.12)
  PM1-Seal Effectiveness (cc/yr)
- 1.4.1.3.1.3-C3 [10 CFR 60.142(d)] (Related to Issue 1.12)
  PM1-Backfill Test Section (yes/no)

Table 17. Performance Measures for "Decommission Surface Facilities" (Function 1.4.1.3.2)

- 1.4.1.3.2-C1 [10 CFR 60.132(e)] (No ESF data required.)
  PM1-Surface Facility Decontamination & Decommissioning

Table 18. Performance Measures for "Establish Institutional Barriers" (Function 1.4.1.3.3)

- 1.4.1.3.3-C1 [10 CFR 60.51(a)(2)] (No ESF data required.)
  PM1-Land Use
  PM2-Archived Record Lifetime (years)
  PM3-Monument Lifetime (years)

Table 19. Performance Measures for "Establish Passive Controls" (Function 1.4.1.3.3.2)

- 1.4.1.3.3.2-C1 [10 CFR 60.21(c)(8)] (No ESF data required.)
  PM1-Description of Controls (yes/no)

Table 20. Performance Measures for "Provide Utility Services" (Function 1.4.1.4.1)

- 1.4.1.4.1-C1 [10 CFR 60.131(b)(5)] (No ESF data required.)
  PM1-Utility Service Operational Safety

Table 21. Performance Measures for "Provide Ventilation (HVAC)" (Function 1.4.1.4.1.1)

- 1.4.1.4.1.1-C1 [10 CFR 60.132(b)] (Included in Issue 2.7)
  PM1-Surface Ventilation Radiation Control
- 1.4.1.4.1.1-C2 [10 CFR 60.133(g)] (Included in Issues 2.2, 2.7,and 4.4)
  PM1-Underground Facility Ventilation

Table 22. Performance Measures for "Provide Communications" (Function 1.4.1.4.1.2)

- 1.4.1.4.1.2-C1 [10 CFR 73.50(e)] (No ESF data required.)
  PM1-Central Alarm System Characteristics
  PM2-Telephone Services re: Law Enforcement Agencies
  PM3-Capability for 2-Way Radio Communication (yes/no)
  PM4-Communications Capability re: Independent Power Source (yes/no)

Table 23. Performance Measures for "Supply/Control Water" (Function 1.4.1.4.1.3)

- 1.4.1.4.1.3-C1 [33 USC 1251 et.seq., sec. 1252] (No ESF data required.)
  PM1-Reservoir Stream Flow Regulation
- 1.4.1.4.1.3-C2 [42 USC 300f et.seq., sec. 300g-6] (No ESF data required.)
  PM1-Water System Inspection Criteria
  PM2-Water System Design Review Criteria
  PM3-Water System Procurement Criteria
- 1.4.1.4.1.3-C3 [42 USC 300f et.seq., sec. 300j-4] (No ESF data required.)
  PM1-Record Verification
- 1.4.1.4.1.3-C4 [42 USC 300f et.seq. sec. 300 j-6] (No ESF data required.)
  PM1-Verification of Compliance with Federal Water Regulations (yes/no)
  PM2-Verification of Compliance with State Water Regulations (yes/no)
  PM3-Verification of Compliance with Local Water Regulations (yes/no)

Table 24. Performance Measures for "Provide Protective Services" (Function 1.4.1.4.2)

- 1.4.1.4.2-C1 [10 CFR 60.131(b)(4)(ii)] (Included in Issue 2.7)
  PM1-Radiation Emergency Controls of Items Important to Safety
  PM2-GROA Emergency Response
- 1.4.1.4.2-C2 [10 CFR 73.50(d)] (No ESF data required.)
  PM1-Location of Alarms re: Emergency Exits & Vital Areas
  PM2-Alarm Characteristics re: Performance, Reliability, Operation

Table 25. Performance Measures for "Safeguard Radioactive Material" (Function 1.4.1.4.2.1)

- 1.4.1.4.2.1-C1 [10 CFR 73.40(a)] (No ESF data required.)
  PM1-Approved Security Plan (yes/no)
  PM2-Protection Against Radiological Sabotage
  PM3-Protection Against Theft of Special Nuclear Material
- 1.4.1.4.2.1-C2 [10 CFR 73.40(b)&(c)] (No ESF data required.)
  PM1-Approved Safeguards Contingency Plan (yes/no)
  PM2-Record Maintenance (yes/no)
  PM3-Availability and Functionality of Safeguards (yes/no)
  PM4-Safeguards Training Complete (yes/no)

Table 26. Performance Measures for "Provide Physical Security" (Function 1.4.1.4.2.2)

- 1.4.1.4.2.2-C1 [10 CFR 60.131(a)(5)] (Included in Issue 2.2)
  PM1-Concentration of Radioactive Material in Restricted Areas (microcuries/cc)
- 1.4.1.4.2.2-C2 [10 CFR 73.40(a)] (No ESF data required.)
  PM1-Approved Security Plan (yes/no)
  PM2-Protection Against Radiological Sabotage
  PM3-Protection Against Theft of Special Nuclear Material
- 1.4.2.2-C3 [10 CFR 73.40(d)] (No ESF data required.)
  PM1-Approved Safeguards Contingency Plan (yes/no)
  PM2-Record Maintenance (yes/no)
  PM3-Availability and Functionality of Safeguards (yes/no)
  PM4-Safeguards Training Complete (yes/no)
  PM5-Annual Safeguards Review (yes/no)
- 1.4.1.4.2.2-C4 [10 CFR 73.50(c)] (No ESF data required.)
  PM1-Identification and Authorization for Protected Access (yes/no)
  PM2-Implementation of Search and Escort Controls (yes/no)
  PM3-Use of Picture Badge Identification System (yes/no)
  PM4-Special Area Access and Alarms (yes/no)
  PM5-Visitor Escort Controls (yes/no)
  PM6-Record Maintenance (yes/no)
  PM7-Prohibition of Non-Emergency Personnel Vehicles
  PM8-Key Control

Table 27. Performance Measures for "Provide Inspection/Testing Services" (Function 1.4.1.4.2.3)

- 1.4.1.4.2.3-C1 [10 CFR 60.75(c)] (No ESF data required.)
  PM1-Provision of Rent-Free Office Space and Utilities (yes/no)
  PM2-Office Location and Access
  PM3-Office Privacy
  PM4-ONMSS Approval (yes/no)
- 1.4.1.4.2.3-C2 [10 CFR 60.131(b)(6)] (Included in Issue 2.7)
  PM1-Inspection Testing of Items Important to Safety
- 1.4.1.4.2.3-C3 [10 CFR 60.131(b)(8)] (Included in Issue 2.7)
  PM1-Instrumentation and Control of Systems Important to Safety
- 1.4.1.4.2.3-C4 [DOE Order 3790.1A, page I-2, (1)] (No ESF data required.)
  PM1-Content of Health Hazard Notification (yes/no)
  PM2-Posting of Health Hazard Notification (yes/no)

Table 28. Performance Measures for "Provide Emergency Medical Treatment" (Function 1.4.1.4.2.4)

- 1.4.1.4.2.4-C1 [DOE Order 3790.1A, page VIII-5] (No ESF data required.)
  PM1-Federal Employee Occupational Medicare Program (yes/no)

Table 29. Performance Measures for "Provide Fire/Explosion Protection (Function 1.4.1.4.2.5)

- 1.4.1.4.2.5-C1 [10 CFR 60.131(b)(3)(iii)] (Included in Issue 2.7)
  PM1-GROA Explosion/Fire Detection/Alarm/Suppression

Table 30. Performance Measures for "Provide Radiological Protection" (Function 1.4.1.4.2.6)

- 1.4.1.4.2.6-C1 [10 CFR 60.131(a)(1)] (Included in Issues 2.2 and 2.7)
  PM1-Means to Limit Concentration of Radioactive Material in Restricted Areas (yes/no)
- 1.4.1.4.2.6-C2 [10 CFR 60.131(a)(4)] (Included in Issue 2.2)
  PM1-Means to Monitor and Control the Dispersal of Radioactive Contamination in Restricted Areas (yes/no)
- 1.4.1.4.2.6-C3 [10 CFR 60.131(a)(6)] (Included in Issues 2.2 and 2.7)
  PM1-Radiological Alarm System for GROA (yes/no)
  PM2-Provisions for Calibration and Testing of the GROA Radiological Alarm System (yes/no)
- 1.4.1.4.2.6-C4 [10 CFR 60.132(b)] (Included in Issue 2.7)
  PM1-Surface Ventilation Radiation Control

Table 30. (Cont'd)

- 1.4.1.4.2.6-C5 [10 CFR 60.132(c)] (Included in Issues 2.2 and 2.7)
  PM1-Effluent Control and Monitoring
- 1.4.1.4.2.6-C6 [DOE Order 3790.1A, Page I-2, (5)] (No ESF data required.)
  PM1-Health Hazard Monitoring

Table 31. Performance Measures for "Provide Non-Radiological Protection" (Function 1.4.1.4.2.7)

- 1.4.1.4.2.7-C1 [30 USC 801 et.seq., sec. 844] (Related to Issue 4.4)
  PM1-Approved Dust Control Method (yes/no)
  PM2-Approved Respiratory Equipment (yes/no)
- 1.4.1.4.2.7-C2 [DOE Order 3790.1A, page I-2, (5)] (No ESF data required.)
  PM1-Health Hazard Monitoring

Table 32. Performance Measures for "Provide Environmental Protection" (Function 1.4.1.4.2.8)

- 1.4.1.4.2.8-C1 [10 CFR 60.132(c)] (Included in Issues 2.2 and 2.7)
  PM1-Effluent Control and Monitoring

Table 33. Performance Measures for "Administer General Support Services" (Function 1.4.1.4.3)

- 1.4.1.4.3-C1 [10 CFR 60.43(b)(6)] (No ESF data required.)
  PM1-Administrative Controls to Assure Safety and Conformity with the License Specifications (yes/no)

Table 34. Performance Measures for "Maintain Records" (Function 1.4.1.4.3.1)

- 1.4.1.4.3.1-C1 [29 USC 651 et.seq., sec. 657] (No ESF data required.)
  PM1-Verification of Compliance with Occupational Safety (yes/no)
  PM2-Record Verification (yes/no)
  PM3-Record Maintenance (yes/no)
- 1.4.1.4.3.1-C2 [30 USC 801 et.seq., sec. 813(h)] (No ESF data required.)
  PM1-Maintenance of Records (yes/no)
  PM2-Availability of Records (yes/no)
- 1.4.1.4.3.1-C3 [30 USC 801 et.seq., sec. 813(d)] (No ESF data required.)
  PM1-Accident Investigation Process (yes/no)
  PM2-Record Verification (yes/no)

Table 34. (Cont'd)

- 1.4.1.4.3.1-C4 [30 USC 801 et.seq., sec. 825(c)] (No ESF data required.)
  PM1-Record Verification (yes/no)
  PM2-Record Maintenance (yes/no)
- 1.4.1.4.3.1-C5 [42 USC 300f et.seq., sec. 300j-4] (No ESF data required.)
  PM1-Record Verification (yes/no)
- 1.4.1.4.3.1-C6 [60.4(b)] (No ESF data required.)
  PM1-Record Verification (yes/no)
  PM2-Record Maintenance (yes/no)
- 1.4.1.4.3.1-C7 [10 CFR 60.44(b)] (No ESF data required.)
  PM1-Maintenance of Records of Changes in the GROA (yes/no)
  PM2-Maintenance of Records of Tests and Experiments (yes/no)
  PM3-Safety Evaluation (yes/no)
  PM4-Furnish the Report to NRC (yes/no)
  PM5-Records Made Part of the Public Records of the Licensing Proceedings (yes/no)
- 1.4.1.4.3.1-C8 [10 CFR 60.71(a)&(b)] (No ESF data required.)
  PM1-Preparation and Maintenance of Records
  PM2-Sufficiency of Information in Records of the Receipt, Handling, and Disposition of Radioactive Waste at a GROA.
  PM3-Retention and Usability of the Above Records
- 1.4.1.4.3.1-C9 [60.72(a)&(b)] (No ESF data required.)
  PM1-Record Verification (yes/no)
  PM2-Record Maintenance (yes/no)
- 1.4.1.4.3.1-C10 [DOE Order 3790.1A, page VII-8] (No ESF data required.)
  PM1-Record Maintenance (yes/no)

Table 35. Performance Measures for "Provide for Human Resources" (Function 1.4.1.4.3.3)

- 1.4.1.4.3.3-C1 [29 USC 651 et.seq., sec. 657(c)] (No ESF data required.)
  PM1-Verification of Compliance with Occupational Safety (yes/no)
  PM2-Record Verification (yes/no)
  PM3-Record Maintenance (yes/no)
- 1.4.1.4.3.3-C2 [30 USC 801 et.seq., sec. 819(a)] (No ESF data required.)
  PM1-Respirable Dust Monitoring
  PM2-Respirable Dust Control

Table 36. Performance Measures for "Provide Training" (Function 1.4.1.4.3.3.1)

- 1.4.1.4.3.3.1-C1 [30 USC 801 et.seq., sec. 825] (No ESF data required.)
  PM1-Approved Health and Safety Training Program (yes/no)
- 1.4.1.4.3.3.1-C2 [30 USC 801 et.seq., sec. 825 (1)-(5)] (No ESF data required.)
  PM1-Health and Safety Training Program (yes/no)
- 1.4.1.4.3.3.1-C3 [30 USC 801 et.seq., sec. 825(c)] (No ESF data required.)
  PM1-Record Maintenance (yes/no)
  PM2-Record Verification (yes/no)
- 1.4.1.4.3.3.1-C4 [10 CFR 60.161] (No ESF data required.)
  PM1-Implementation of Training Program (yes/no)
- 1.4.1.4.3.3.1-C5 [DOE Order 3790.1A, page V-1] (No ESF data required.)
  PM1-OSHA Training Program/Content
- 1.4.1.4.3.3.1-C6 [DOE Order 3790.1A, page VIII-5(k)] (No ESF data required.)
  PM1-Training for Collateral Duty Safety Personnel (yes/no)

Table 37. Performance Measures for "Provide Personnel Services" (Function 1.4.1.4.3.3.2)

- 1.4.1.4.3.3.2-C1 [DOE Order 3990.1A, page I-2, (1)] (No ESF data required.)
  PM1-Content of Health Hazard Notification (yes/no)
  PM2-Posting of Health Hazard Notification (yes/no)
- 1.4.1.4.3.3.2-C2 [DOE Order 3990.1A, page VIII-3(a)-(j)] (No ESF data required.)
  PM1-Federal Employee Occupational Medicare Program (yes/no)

Table 38. Performance Measures for "Process Site-Generated Waste" (Function 1.4.1.4.4)

- 1.4.1.4.4-C1 [10 CFR 60.132(c)] (Included in Issues 2.2 and 2.7)
  PM1-Effluent Control and Monitoring
- 1.4.1.4.4-C2 [10 CFR 60.132(d)] (Included in Issue 2.7)
  PM1-Radioactive Waste Treatment

Table 39. Performance Measures for "Maintain Operating Equipment" (Function 1.4.1.4.5.1)

- 1.4.1.4.5.1-C2 [10 CFR 60.21 (c)(15)(v)] (No ESF data required.)
  PM1-Information on GROA Activities in License Application (yes/no)
    a. Organization Structure of DOE
    b. Identification of Key Positions for Safety
    c. Personnel Qualifications and Training
    d. Startup Activities and Testing Plans
    e. Maintenance, Surveillance, and Testing of Items ITS Plans
    f. Permanent Closure, Decontamination or Dismantlement Plans
    g. Effects of Use of GROA for Purposes Other Than Disposal
- 1.4.1.4.5.1-C1 [10 CFR 73.50(f)] (No ESF data required.)
  PM1-Security Tests
  PM2-Security Maintenance
  PM3-Security System Schedules

Table 40. Performance Measures for "Isolate Waste" (Function 1.4.2)

- 1.4.2-C1 [10 CFR 60.21(c)(1)(ii)(D)] (Related to Issues 1.4 and 1.5)
  PM1-Effectiveness of Engineered Barriers
  PM2-Effectiveness of Natural Barriers
  PM3-Effectiveness of Barriers that are not Part of the GROA
  PM4-Evaluation of Alternatives to the Major Design Features that are Important to Waste Isolation
  PM5-Evaluation of Alternatives that Provide Longer Radionuclide Containment
  PM6-Evaluation of Alternatives that Provide Longer Radionuclide Isolation
- 1.4.2-C2 (This requirement intentionally left blank.)
- 1.4.2-C3 [10 CFR 60.133(a)(1)] (Included in Issue 1.11)
  PM1-Containment Period (years)
  PM2-Release Rate from EBS (frac. of 1000 yr. inven.)
  PM3-Depth of the Underground Facility (feet)
  PM4-Waste Area (sq. miles)
- 1.4.2-C4 (This requirement intentionally left blank.)
- 1.4.2-C5 (This requirement intentionally left blank.)
- 1.4.2-C6 [10 CFR 60.133(f)] (Included in Issue 1.11)
  PM1-Containment Period (years)
  PM2-Radionuclide Release Rate
  PM3-Permeability (cm/sec)
  PM4-Subsidence (inches/yr)
- 1.4.2-C7 [10 CFR 60.133(h)] (Included in Issues 1.11 and 4.4)
  PM1-Set of Engineered Barrier Performance Measures

Table 40 (Cont'd)

- 1.4.2-C8[10 CFR 60.133(i)] (Included in Issues 1.11 and 4.4)
  PM1-Set of Performance Objectives
  PM2-Temperature of Host Rock (°C)
  PM3-Temperature of Surrounding Strata (°C)
  PM4-Temperature of Groundwater System (°C)
  PM5-Stress/Strain of Host Rock (ksi/%)
  PM6-Stress/Strain of Surrounding Strata (ksi/%)
- 1.4.2-C9 [10 CFR 60.134 (a) & (b)] (Included in Issue 1.12)
  PM1-Set of Performance Objectives
  PM2-Quantity of Water (cc/year)
  PM3-Permeability (cm/sec)
- 1.4.2-C10 [10 CFR 60.135(b)] (No ESF data required.)
  PM1-Concentration of Explosive, Pyrophoric, and Chemically Reactive Materials (weight %)
  PM2-Concentration of Free Liquids (volume %)
- 1.4.2-C11 [10 CFR 60.135(c)] (No ESF data required.)
  PM1-Inspection (yes/no)
  PM2-Particle Size (microns)
  PM3-Combustibility (flashpoint)
- 1.4.2-C12 [10 CFR 960.4-1(a)] (Related to Issue 1.1)
  PM1-Complete Set of NRC & EPA Postclosure Measures
- 1.4.2-C13 [10 CFR 960.4-2-1(d)] (Related to Issue 1.6)
  PM1-Prewaste Emplacement Groundwater Travel Time (years)
- 1.4.2-C14 (This requirement intentionally left blank.)
- 1.4.2-C15 [10 CFR 960.4-2-6(d)] (Related to Issues 1.4 and 1.5)
  PM1-Solubility
- 1.4.2-C16 [10 CFR 960.4-2-7(d)] (Related to Issues 1.4 and 1.5)
  PM1-Tectonic Processes
- 1.4.2-C17 [10 CFR 60.133(d)] (Included in Issue 4.4)
  PM1-Control of Water or Gas Intrusion
- 1.4.2-O4a [10 CFR 60.112] (Included in Issues 1.1 and 1.12)
  PM1-Releases of Radioactive Materials to the Accessible Environment (curies of various isotopes)
- 1.4.2-O4b [10 CFR 960.4-2-1(a)] (Related to Issues 1.4 and 1.5)
  PM1-Radionuclide Release to Accessible Environment (frac. of 1000 yr. inven.)
  PM2-Radionuclide Release from EBS (frac. of 1000 yr. inven.)
  PM3-Availability of Technology (yes/no)
  PM4-Geohydrological Characteristics
- 1.4.2-O4c [10 CFR 960.4-2-2(a)] (Related to Issues 1.4 and 1.5)
  PM1-Containment Period (years)
  PM2-Radionuclide Release to Accessible Environment (frac. of 1000 yr. inven.)
  PM3-Radionuclide Release from EBS (frac. of 100 yr. inven.)
  PM4-Geochemical Characteristics
  PM5-Availability of Technology (yes/no)

Table 40 (Cont'd)

- 1.4.2-O4d [10 CFR 960.4-2-3(a)] (Related to Issues 1.4 and 1.5)
  PM1-Radionuclide Release to Accessible Environment (frac. of 1000 yr. inven.)
  PM2-Radionuclide Release from EBS (frac. of 1000 yr. inven.)
  PM3-Thermal Stresses of Host Rock & Surrounding Units (ksi)
  PM4-Chemical Stresses of Host Rock & Surrounding Units (ksi)
  PM5-Mechanical Stresses of Host Rock & Surrounding Units (ksi)
  PM6-Radiation Induced Stresses of Host Rock & Surrounding Units (ksi)
- 1.4.2-O4e [10 CFR 960.4-2-4(a)] (Related to Issues 1.4 and 1.5)
  PM1-Radionuclide Release to Accessible Environment (frac. of 1000 yr. inven.)
  PM2-Radionuclide Release from EBS (frac. of 1000 yr. inven.)
  PM3-Future Climatic Conditions
- 1.4.2-O4f [10 CFR 960.4-2-5(a)] (Related to Issues 1.4 and 1.5)
  PM1-Radionuclide Release to Accessible Environment (frac. of 1000 yr. inven.)
  PM2-(Predictive) Rate of Erosion (f(time, location))
  PM3-Radionuclide Release from EBS (frac. of 1000 yr. inven.)
- 1.4.2-O4g [10 CFR 960.4-2-6(a)] (Related to Issues 1.4 and 1.5)
  PM1-Radionuclide Release to Accessible Environment (frac. of 1000 yr. inven.)
  PM2-Radionuclide Release from EBS (frac. of 1000 yr. inven.)
  PM3-Rate of Subsurface Rock Dissolution
- 1.4.2-O4h [10 CFR 960.4-2-7(a)] (Related to Issues 1.4 and 1.5)
  PM1-Radionuclide Release to Accessible Environment (frac. of 1000 yr. inven.)
  PM2-Radionuclide Release from EBS (frac. of 1000 yr. inven.)
  PM3-Tectonic Processes

Table 41. Performance Measures for "Contain Waste" (Function 1.4.2.1)

- 1.4.2.1-C1 [10 CFR 60.113(a)(1)(ii)(A)] (Included in Issues 1.4, 1.5, and 1.12)
  PM1-Containment Period (years)
- 1.4.2.1-C2 [10 CFR 60.135(a)(1)] (Included in Issue 1.10)
  PM1-In Situ Waste Package Properties
  PM2-Waste Package Environment
  PM3-Near-field Waster Quality
  PM4-Set of Waste Package Performance Measures
  PM5-Set of Underground Facility Performance Measures
- 1.4.2.1-C3 [10 CFR 60.135(a)(2)] (Included in Issue 1.10)
  PM1-Solubility
  PM2-Oxidation/Reduction Reactions
  PM3-Corrosion
  PM4-Hydriding
  PM5-Gas Generation
  PM6-Thermal Effects
  PM7-Mechanical Strength
  PM8-Mechanical Stress
  PM9-Radiolysis

Table 41. (Cont'd)

PM10-Radiation Damage
PM11-Radionuclide Retardation
PM12-Leaching
PM13-Fire & Explosion Hazard
PM14-Thermal Loads
- 1.4.2.1-C4 [10 CFR 60.135(b)(2)] (No ESF data required.)
PM1-Concentration of Free Liquids (volume%)
- 1.4.2.1-C5 [10 CFR 60.135(b)(4)] (No ESF data required.)
PM1-Unique Identification (yes/no)
PM2-Predictions of Legibility through Retrieval (yes/no)
PM3-Consistency with Permanent Written Records (yes/no)
PM4-Waste Package Integrity Compromised by Identification
  a. Containment Period (years)
  b. Induced Stress (ksi)
  c. Induced Microstructural Changes (yes/no)

Table 42. Performance Measures for "Inhibit Degradation of Waste Form" (Function 1.4.2.1.2)

- 1.4.2.1.2-I4 [10 CFR 60.135(c)(1),(2)&(3)] (No ESF data required.)
PM1-Inspection (yes/no)
PM2-Particle Size (microns)
PM3-Combustibility (flashpoint)

Table 43. Performance Measures for "Limit Release of Radionuclides" (Function 1.4.2.2)

- 1.4.2.2-O1 [40 CFR 191.15] (Related to Issues 1.4 and 1.5)
PM1-Annual Dose Equivalent to Any Member of Public (mrem/Yr)
- 1.4.2.2-O2 [40 CFR 191.16] (Related to Issues 1.4 and 1.5)
PM1 Radionuclide Concentration in Water Withdrawn (curies/cc of various isotopes)
PM2-Annual Dose Equivalent (mrem/yr)

Table 44. Performance Measures for "Limit Release of Radionuclides from EBS" (Function 1.4.2.2.1)

- 1.4.2.2.1-O2 [10 CFR 60.113(a)(1)(ii)(B)] (Included in Issues 1.4, 1.5, and 1.12)
PM1-Cumulative Radionuclide Release from the EBS (curies of various isotopes)

Table 45. Performance Measures for "Limit Release of Radionuclides to Accessible Environment" (Function 1.4.2.2.2)

- 1.4.2.2.2-C2 [10 CFR 60.113(a)(2)] (Included in Issue 1.6)
  PM1-Prewaste Emplacement Groundwater Travel Time (years)

Table 46. Performance Measures for "Limit Incompatible Human Activities" (Function 1.4.2.3)

- 1.4.2.3-C1 [10 CFR 60.121(a),(b)&(c)] (No ESF data required.)
  PM1-Land Control
    a. GROA and Controlled Area Location
    b. DOE Ownership of Control (yes/no)
    c. Removal of Encumbrances (yes/no)
  PM2-External Controls
    a. Appropriate Mitigation Controls External to Controlled Area (yes/no)
  PM3-Water Rights
- 1.4.2.3-C2 [10 CFR 960.4-2-8-1(a)&(d)] (Related to Issues 1.4 and 1.5)
  PM1-Cumulative Radionuclide Release to Accessible Environment (curies of various isotopes)
  PM2-Predicted Utilization of Natural Resources
  PM3-Value of Natural Resources (yes/no)
  PM4-Scarcity of Natural Resources (yes/no)
  PM5-Evidence of Mining/Extraction Activities (yes/no)
  PM6-Permeability (cm/sec.)
  PM7-Quantity of Water (acre-ft)
- 1.4.2.3-C3 [10 CFR 960.4-2-8-2(a)] (Related to Issues 1.4 and 1.5)
  PM1-Cumulative Radionuclide Release to Accessible Environment (curies of various isotopes)
  PM2-Evidence of Ownership (yes/no)
  PM3-Evidence of Controls (yes/no)

Table 47. Performance Measures for "Limit Inadvertent Human Activities" (Function 1.4.2.3.1)

- 1.4.2.3.1-C1 [10 CFR 60.51(a)(2)] (No ESF data required.)
  PM1-Archived Record Lifetime (years)
  PM2-Monument Lifetime (years)

Table 48. Performance Measures for "Evaluate System Performance" (Function 1.4.3)

- 1.4.3-C1 [10 CFR 60.21 (c)(1)(i)] (Covered by all Issues.)
  PM1-Assessment of Site Impacts on Design and Performance
- 1.4.3-C2 [10 CFR 60.21 (c)(1)(ii)] (Covered by all Issues.)
  PM1-Descriptive Site Analysis: Site Characterization
  PM2-Descriptive Site Analysis: Design Performance
  PM3-Descriptive Site Analysis: Postclosure Performance
- 1.4.3-C3 [10 CFR 60.51(a)] (No ESF data required.)
  PM1-Postclosure Program Description (For License Amendment)

Table 49. Performance Measures for "Confirm Performance" (Function 1.4.3.1.)

- 1.4.3.1-C1 [10 CFR 60.74(a) & (b)] (Related to Issue 1.7)
  PM1-Capability for Regulatory/Performance Confirmation Testing Program
- 1.4.3.1-C2 [10 CFR 60.140] (Related to Issue 1.7)
  PM1-Performance Confirmation Program Content
- 1.4.3.1-C3 [10 CFR 60.141(a)] (Related to Issue 1.7)
  PM1-Geotechnical/Design Performance Confirmation
  PM2-NRC Notification of Design Changes
- 1.4.3.1-C4 [10 CFR 60.143(d)] (ESF placeholder)
  PM1-Duration of Preclosure Waste Package Monitoring Program

Table 50 . Performance Measures for "Monitor In Situ Conditions" (Function 1.4.3.1.1)

1.4.3.1.1-C1 [10 CFR 60.141(b)] (Related to Issue 1.7)
.PM1-Subsurface Monitoring
1.4.3.1.1-C2 [10 CFR 60.141(c)] (Related to Issue 1.7)
PM1-Performance Confirmation Measurement Types
1.4.3.1.1-C3 [10 CFR 60.141(e)] (Related to Issue 1.7)
PM1-Preclosure Thermomechanical Response Monitoring
1.4.3.1.1-O1 [10 CFR 60.51(a)(3)] (No ESF data required.)
PM1-Postclosure Program Description (for License Amendment)

Table 51. Performance Measures for "Monitor In Situ Waste Package and Underground Facility Conditions" (Function 1.4.3.1.1.2)

- 1.4.3.1.1.2-C1 [10 CFR 60.143(a) & (b)] (ESF placeholder)
  PM1-Representativeness of Monitored Waste Packages and Environment

Table 52. Performance Measures for "Conduct Lab/Field Tests" (Function 1.4.3.1.2)

- 1.4.3.1.2-O1 [10 CFR 60.51(a)(4)] (No ESF data required.)
  PM1-Postclosure Program Description (for License Amendment)

Table 53. Performance Measures for "Test Waste Package and Underground Facility Performance" (Function 1.4.3.1.2.3)

- 1.4.3.1.2.3-C1 [10 CFR 60.143(c)] (No ESF data required.)
  PM1-Existence of Laboratory Testing of Internal Waste Package Condition
  PM2-Representativeness of Monitored Waste Packages: Laboratory Experiments

Table 54. Performance Measures for "Conduct In Situ Experiments" (Function 1.4.3.1.3)

- 1.4.3.1.3-C1 [10 CFR 60.142] (Included in Issue 1.12)
  PM1-In Situ Emplacement Testing

Table 55. Performance Measures for "Plan Appropriate Action" (Function 1.4.3.1.4)

- 1.4.3.1.4-C1 [10 CFR 60.141(d)] (Covered by all Issues.)
  PM1-Performance Confirmation Feedback to Design
  PM2-NRC Notification of Design Changes

Table 56. Performance Measures for "Assess Environmental Compliance" (Function 1.4.3.3)

- 1.4.3.3-C1 [10 CFR 60.24(c)] (No ESF data required.)
  PM1-Environmental Impact Update
- 1.4.3.3-C2 [10 CFR 60.51(b)] (No ESF data required.)
  PM1-Environmental Impact Supplement to License Amendment

Table 57. Performance Measures for "Monitor Performance" (Function 1.4.3.4)

- 1.4.3.4-C1 [10 CFR 60.51(a)(1)] (No ESF data required.)
  PM1-Postclosure Monitoring Program Description