DOE/RW-0160

Chapter 8

Nuclear Waste Policy Act
(Section 113)

Section 8.2

K

Consultation Draft

ISSUES

Site Characterization Plan

Yucca Mountain Site, Nevada Research and Development Area, Nevada

Volume IV

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8.2 ISSUES TO BE RESOLVED AND INFORMATION REQUIRED DURING SITE CHARACTERIZATION

As described in Section 8.1, the concept of the issues hierarchy is one of the two themes underlying the site characterization program that has been developed for the Yucca Mountain site. The key issues, making up the highest tier in the hierarchy, are the key issues identified in the Mission Plan (DOE, 1985b). Statements of these issues, which are derived from the four system guidelines of the DOE general siting guidelines (10 CFR Part 960), are provided in Table 8.2-1. Key Issue 1 addresses the requirements related to containment and isolation; Key Issue 2 covers protection of the general public and workers from radiological exposures; Key Issue 3 addresses the protection of the quality of the environment; and Key Issue 4 covers the DOE concerns that the mined geologic disposal system is cost effective and can be constructed, operated, closed and decommissioned on the basis of reasonably available technology. The key issues address the primary NRC postclosure requirements for containment and isolation, and the preclosure radiological safety requirements.

8.2.1 ISSUES TO BE RESOLVED

The issues within each key issue in the Office of Geologic Repositories (OGR) Issues Hierarchy (DOE, 1986d) represent the current DOE understanding of the questions that should be answered in order for the key issue to be resolved. Issues are often correlated with the principal NRC requirements addressing a specific repository design or site feature, and thus final resolution of an issue may be confirmed only at the time of licensing. As described in Section 8.1.2, issue resolution strategies have been developed for each issue in the issues hierarchy. From these strategies, preliminary site-specific data needs have been derived and a site characterization program has been designed to obtain sufficient data to satisfy the information requirements. The issues in Key Issue 3 are not included in the SCP, because the definition of site characterization in the Nuclear Waste Policy Act (NWPA) excludes socioeconomic, transportation, and environmental studies. Details of the information requirements for environment-related topics will be presented in other DOE documents.

Table 8.2-2 lists all performance and design issues associated with Key Issues 1, 2, and 4, arranged by issue. Site-specific information needs, relevant to resolution of each issue are also presented in Table 8.2-2. Identification of these information needs is described later in this section.

Figures 8.2-1, 8.2-2, and 8.2-3 display the relationships between the regulatory requirements of 10 CFR Part 60, 10 CFR Part 20, 40 CFR 191, Subpart A, and 10 CFR Part 960 and the performance and design issues. These relationships are explained more fully in DOE (1986d). A site is not expected to receive a license from the NRC if the key issues and issues cannot be answered affirmatively.

In parallel with the development of issue resolution strategies for each of the issues, the physical elements of the repository system were defined. This system definition is called the Yucca Mountain mined geologic disposal

Table 8.2-1. Statements of the key issues in the Office of Geologic Repositories issues hierarchy

Issue	Statement of key issue
Key Issue 1	Will the mined geologic disposal system at Yucca Mountain isolate the radioactive waste from the accessible environment after closure in accordance with the requirements set forth in 40 CFR Part 191, 10 CFR Part 60, and 10 CFR Part 960?
Key Issue 2	Will the projected releases of radioactive materials to restricted and unrestricted areas and the resulting radiation exposures of the general public and workers during repository operation, closure and decommissioning at Yucca Mountain, meet applicable safety requirements set forth in 10 CFR Part 20, 10 CFR Part 60, 10 CFR Part 960, and 40 CFR Part 191?
Key Issue 3	Can the mined geologic disposal system at Yucca Mountain be sited, constructed, operated, closed, and decommissioned, and can the associated transportation system be sited, constructed, and operated so that the quality of the environment will be protected and waste-transportation operations can be conducted without causing unacceptable risks to public health or safety?
Key Issue 4	Will the construction, operation (including retrieval), closure, and decommissioning of the mined geologic disposal system be feasible at Yucca Mountain on the basis of reasonably available technology, and will the associated costs be reasonable in accordance with the requirements set forth in 10 CFR Part 960?

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Table 8.2-2. Site-specific information needs for the Yucca Mountain site (page 1 of 9)

Issues	Information Need #	Statement of information need
	KEY ISSUE 1	
Performance issues		
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?	1.1.1	Site information needed to calculate releases to the accessible environment
	1.1.2	A set of potentially significant release scenario classes that address all events and processes that may affect the geologic repository
	1.1.3	Calculational models for predicting releases to the accessible environment attending realizations of the potentially significant release scenario classes
	1.1.4	Determination of the radionuclide releases to the accessible environment associated with realizations of potentially significant release scenario classes
	1.1.5	Probabilistic estimates of the radionuclide releases to the accessible environment considering all significant release scenarios
Issue 1.2: Will the mined geologic disposal system meet the requirements for limiting individual doses in the accessible environment as required by 40 CFR 191.15?	1.2.1	Determination of doses to the public in the accessible environment through liquid pathways
	1.2.2	Determination of doses to the public in the accessible environment through gaseous pathway
Issue 1.3: Will the mined geologic disposal system meet the requirements for the protection of special sources of ground water as required by 40 CFR 191.16?	1.3.1	Determination whether any Class 1 or special sources of ground water exist at Yucca Mountain, within the controlled area, or within 5 km of the controlled area boundary
	1.3.2	Determine for all special sources whether concentrations of waste products in the ground water during the first 1,000 years after disposal could exceed the limits established in 40 CFR 191.16.

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Table 8.2-2. Site-specific information needs for the Yucca Mountain site (page 2 of 9)

Issues	Information Need #	Statement of information need
		KEY ISSUE 1 (continued)
Performance issues (continued)		
Issue 1.4: Will the waste package meet the performance objective for containment as required by 10 CFR 60.113?	1.4.1	Waste package design features that affect the performance of the container
	1.4.2	Material properties of the container
	1.4.3	Scenarios and models needed to predict the rate of degradation of the container material
	1.4.4	Estimates of the rates and mechanisms of container degradation in the repository environment for anticipated and unanticipated processes and events, and calculation of the failure rate of the container as a function of time
	1.4.5	Determination of whether the requirement for substantially complete containment of the waste packages is met for anticipated processes and events
Issue 1.5: Will the waste package and repository engineered barrier systems meet the performance objective for limiting radionuclide release rates as required by 10 CFR 60.113?	1.5.1	Waste package design features that affect the rate of radionuclide release
	1.5.2	Material properties of the waste form
	1.5.3	Scenarios and models needed to predict the rate of radionuclide release from the waste package and engineered barrier system
	1.5.4	Determination of the release rates of radionuclides from the waste package and engineered barrier system for anticipated and unanticipated events
	1.5.5	Determination of the amount of radionuclides leaving the near-field environment of the waste package

CONSULTATION DRAFT

Table 8.2-2. Site-specific information needs for the Yucca Mountain site (page 3 of 9)

Issues	Information Need #	Statement of information need
		KEY ISSUE 1 (continued)
Performance issues (continued)		
Issue 1.6: Will the site meet the performance objective for prewaste-emplacement ground-water travel time as required by 10 CFR 60.113?	1.6.1	Site information and design concepts needed to identify the fastest path of likely radionuclide travel and to calculate the ground-water travel time along that path
	1.6.2	Calculational models to predict ground-water travel times between the disturbed zone and the accessible environment
	1.6.3	Identification of the paths of likely radionuclide travel from the disturbed zone to the accessible environment and identification of the fastest path
	1.6.4	Determination of the prewaste-emplacement ground-water travel time along the fastest path of likely radionuclide travel from the disturbed zone to the accessible environment
	1.6.5	Boundary of the disturbed zone
Issue 1.7: Will the performance-confirmation program meet the requirements of 10 CFR 60.137?		Information needs to be determined
Issue 1.8: Can the demonstrations for favorable and potentially adverse conditions be made as required by 10 CFR 60.122?		No additional information needs identified
Issue 1.9: (a) Can the higher-level findings required by 10 CFR Part 960 be made for the qualifying condition of the postclosure system guideline and the disqualifying and qualifying conditions of the technical guidelines for geohydrology, geochemistry, rock characteristics, climate changes, erosion, dissolution, tectonics, and human interference; and (b) can the comparative evaluations required by 10 CFR 960.3-1-5 be made?		No information needs identified.

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Table 8.2-2. Site-specific information needs for the Yucca Mountain site (page 4 of 9)

Issues	Information Need #	Statement of information need
		KEY ISSUE 1 (continued)
Design issues		
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 for the resolution of the performance issues?	1.10.1	Design information needed to comply with postclosure criteria from 10 CFR 60.135 (a) for consideration of the interactions between the waste package and its environment
	1.10.2	Reference waste package designs
	1.10.3	Reference waste package emplacement configurations
	1.10.4	Postemplacement near-field environment
Issue 1.11: Have the characteristics and configurations of the repository and 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?	1.11.1	Site characterization information needed for design
	1.11.2	Characteristics of waste package needed for design of the underground facility
	1.11.3	Design concepts for orientation, geometry, layout, and depth of the underground facility to contribute to waste containment and isolation, including flexibility to accommodate site-specific conditions
	1.11.4	Design constraints to limit water usage and potential chemical changes
	1.11.5	Design constraints to limit excavation-induced changes in rock mass permeability
	1.11.6	Repository thermal loading and predicted thermal and thermomechanical response of the host rock
	1.11.7	Reference postclosure repository design
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?	1.12.1	Site, waste package, and underground facility information needed for design of seals and their placement methods
	1.12.2	Materials and characteristics of seals for shafts, drifts, and boreholes
	1.12.3	Placement method for seals for shafts, drifts, and boreholes
	1.12.4	Reference design of seals for shafts, drifts, and boreholes

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Table 8.2-2. Site-specific information needs for the Yucca Mountain site (page 5 of 9)

Issues	Information Need #	Statement of information need
	KEY ISSUE 2	
Performance issues		
Issue 2.1: During repository operation, closure, and decommissioning (a) will the expected average radiation dose received by members of the public within any highly populated area be less than a small fraction of the allowable limits and (b) will the expected radiation dose received by any member of the public in an unrestricted area be less than the allowable limits as required by 10 CFR 60.111, 40 CFR 191 Subpart A, and 10 CFR Part 20?	2.1.1	Site and design information needed to assess preclosure radiological safety
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?	2.2.1	Determination of radiation environment in surface and subsurface facilities due to natural and man-made radioactivity
	2.2.2	Determination that projected worker exposures and exposure conditions under normal conditions meet applicable requirements
Issue 2.3: Can the repository be designed, constructed, operated, closed, and decommissioned in such a way that credible accidents do not result in projected radiological exposures of the general public at the nearest boundary of the unrestricted area, or workers in the restricted area, in excess of applicable limiting values?	2.3.1	Determination of credible accident sequences and their respective frequencies applicable to the repository
	2.3.2	Determination of the predicted releases of radioactive material and projected public and worker exposures and exposure conditions under accident conditions and that these meet applicable requirements

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Table 8.2-2. Site-specific information needs for the Yucca Mountain site (page 6 of 9)

Issues	Information Need #	Statement of information need
	KEY ISSUE 2	
Performance issues (continued)		
Issue 2.4: Can the repository be designed, constructed, operated, closed, and decommissioned so that the option of waste retrieval will be preserved as required by 10 CFR 60.111?	2.4.1	Site and design data required to support retrieval
	2.4.2	Determination that access to the waste emplacement boreholes can be provided throughout the retrievability period for normal and credible abnormal conditions
	2.4.3	Determination that access to the waste packages can be provided throughout the retrievability period for normal and credible abnormal conditions
	2.4.4	Determination that the waste can be removed from the emplacement boreholes for normal and off-normal conditions
	2.4.5	Determination that the waste can be transported to the surface and delivered to the waste-handling surface facilities for normal and credible abnormal conditions
	2.4.6	Determination that the retrieval requirements set forth in 10 CFR 60.111(b) are met using reasonably available technology
Issue 2.5: Can the higher-level findings required by 10 CFR Part 960 be made for the qualifying condition of the preclosure system guideline and the disqualifying and qualifying conditions of the technical guidelines for population density and distribution, site ownership and control, meteorology, and offsite installations and operations?		No additional information needs identified

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Table 8.2-2. Site-specific information needs for the Yucca Mountain site (page 7 of 9)

Issues	Information Need #	Statement of information need
		KEY ISSUE 2 (continued)
Design issues		
Issue 2.6: Have the characteristics and configurations of the waste packages been adequately established to (a) show compliance with the preclosure design criteria of 10 CFR 60.135 and (b) provide information for the resolution of the performance issues?	2.6.1	Design information needed to comply with preclosure criteria from 10 CFR 60.135(b) for materials, handling, and identification of waste packages
	2.6.2	Design information needed to comply with preclosure criteria from 10 CFR 60.135(c) for waste forms
	2.6.3	Waste acceptance specifications
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?	2.7.1	Determination that the design criteria in 10 CFR 60.131 through 60.133 and any additional appropriate design objectives pertaining to radiological protection have been met
	2.7.2	Determination that the design criteria in 10 CFR 60.131 through 60.133 and any additional appropriate design objective pertaining to the design and protection of structures, systems, and components important to safety have been met
	2.7.3	Determination that the design criteria in 10 CFR 60.131 through 60.133 and any appropriate additional design objectives pertaining to criticality control have been met
	2.7.4[a]	Determination that the design criteria in 10 CFR 60.131 through 60.133 and any appropriate additional design objectives pertaining to compliance with mining regulations have been met
	2.7.5[a]	Determination that the design criteria in 10 CFR 60.131 through 60.133 and any appropriate additional design objectives pertaining to waste treatment have been met

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Table 8.2-2. Site-specific information needs for the Yucca Mountain site (page 8 of 9)

Issues	Information Need #	Statement of information need
	KEY ISSUE 4	
Performance issues		
Issue 4.1: Can the higher-level findings required by 10 CFR Part 960 be made for the qualifying condition of the preclosure system guideline and the disqualifying and qualifying conditions of the technical guidelines for surface characteristics, rock characteristics, hydrology, and tectonics?		No additional information needs identified
Design issues		
Issue 4.2: Are the repository design and operating procedures developed to ensure nonradiological health and safety of workers adequately established for the resolution of the performance issues?	4.2.1	Site and performance assessment information needed for design
Issue 4.3: Are the waste package production technologies adequately established for the resolution of the performance issues?	4.3.1	Identification and evaluation of production technologies for fabrication, closure, and inspection of the waste package
Issue 4.4: Are the technologies of repository construction, operation, closure, and decommissioning adequately established to support resolution of the performance issues?	4.4.1	Site and performance assessment information needed for design
	4.4.2	Characteristics and quantities of waste and waste packages needed for design
	4.4.3	Plan for repository operations during construction, operation, closure, and decommissioning
	4.4.4	Repository design requirements for construction, operation, closure, and decommissioning
	4.4.5	Reference preclosure repository design
	4.4.6	Development and demonstration of required equipment
	4.4.7	Design analyses, including those addressing impacts of surface conditions, rock characteristics, hydrology, and tectonic activity

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Table 8.2-2. Site specific information needs for the Yucca Mountain site (page 9 of 9)

Issues	Information Need #	Statement of information need
	KEY ISSUE 4 (continued)	
Design issues (continued)	4.4.8	Identification of technologies for surface facility construction, operation, closure, and decommissioning
	4.4.9	Identification of technologies for underground facility construction, operation, closure, and decommissioning
	4.4.10	Determination that the seals for shafts, drifts, and boreholes can be emplaced with reasonably available technology
Issue 4.5: Are the costs of the waste packages and the repository adequately established for the resolution of the performance issues?	4.5.1	Estimate the costs of the reference and alternative waste packages
	4.5.2	Estimate the costs of the reference and alternative repository designs
	4.5.3	Estimate the life cycle costs of the reference and alternative total system design

[a]Information need does not require site-specific data.

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KEY ISSUE 1
(POSTCLOSURE PERFORMANCE)

	REGULATION		ISSUE: PERFORMANCE									(POSTCLOSURE) DESIGN		
			1.1 TOTAL SYSTEM PERFORMANCE	1.2 INDIVIDUAL PROTECTION	1.3 GROUND-WATER PROTECTION	1.4 WASTE PACKAGE CONTAINMENT	1.5 EBS RELEASE RATE	1.6 GROUND-WATER TRAVEL TIME	1.7 PERFORMANCE CONFIRMATION	1.8 NRC SITING CRITERIA	1.9 DOE GUIDELINE FINDINGS	1.10 WASTE PACKAGE CHARACTERISTICS	1.11 UNDERGROUND FACILITIES	1.12 SEAL CHARACTERISTICS
10 CFR 960	960.3-1-6	SITE EVALUATIONS									●			
10 CFR 960	960.4-1	POSTCLOSURE SYSTEM									●			
10 CFR 960	960.4-2-1	GEOHYDROLOGY									●			
10 CFR 960	960.4-2-2	GEOCHEMISTRY									●			
10 CFR 960	960.4-2-3	ROCK CHARACTERISTICS									●			
10 CFR 960	960.4-2-4	CLIMATIC CHANGES									●			
10 CFR 960	960.4-2-5	EROSION									●			
10 CFR 960	960.4-2-6	DISSOLUTION									●			
10 CFR 960	960.4-2-7	TECTONICS									●			
10 CFR 960	960.4-2-8	HUMAN INTERFERENCE									●			
10 CFR 60	60.112	SYSTEM PERFORMANCE OBJECTIVE	●											
10 CFR 60	60.113	SUBSYSTEM PERFORMANCE OBJECTIVES				●	●	●						
10 CFR 60	60.122	SITING CRITERIA								●				
10 CFR 60	60.133	UNDERGROUND FACILITY DESIGN CRITERIA											●	
10 CFR 60	60.134	SEAL DESIGN CRITERIA												●
10 CFR 60	60.135	WASTE PACKAGE DESIGN CRITERIA										●		
10 CFR 60	60.137	PERFORMANCE CONFIRMATION REQUIREMENTS							●					
40 CFR 191	191.13	CONTAINMENT REQUIREMENTS	●											
40 CFR 191	191.15	INDIVIDUAL PROTECTION REQUIREMENTS		●										
40 CFR 191	191.16	GROUND-WATER PROTECTION REQUIREMENTS			●									

Figure 8.2-1. Correlation of performance and design issues for Key Issue 1 (postclosure performance) with regulatory requirements.

KEY ISSUE 2
(PRECLOSURE RADIOLOGICAL SAFETY)

	REGULATION	ISSUE: 2.1 PUBLIC RADIOLOGICAL EXPOSURES–NORMAL CONDITIONS (PERFORMANCE)	2.2 WORKER RADIOLOGICAL SAFETY–NORMAL CONDITIONS (PERFORMANCE)	2.3 ACCIDENTAL RADIOLOGICAL RELEASES (PERFORMANCE)	2.4 RETRIEVABILITY (PERFORMANCE)	2.5 DOE GUIDELINE FINDINGS-RADIOLOGICAL SAFETY (PERFORMANCE)	2.6 WASTE PACKAGE CHARACTERISTICS (PRECLOSURE)	2.7 REPOSITORY DESIGN CRITERIA FOR RADIOLOGICAL SAFETY (PRECLOSURE) DESIGN
10 CFR 960	960.5-1 PRECLOSURE SYSTEM–RADIOLOGICAL SAFETY					●		
10 CFR 960	960.5-2-1 POPULATION					●		
10 CFR 960	960.5-2-2 SITE OWNERSHIP					●		
10 CFR 960	960.5-2-3 METEOROLOGY					●		
10 CFR 960	960.5-2-4 OFFSITE INSTALLATIONS					●		
10 CFR 60	60.111 RADIOLOGICAL PROTECTION AND RETRIEVABILITY	●	●		●			
10 CFR 60	60.131 GENERAL DESIGN CRITERIA							●
10 CFR 60	60.132 PRECLOSURE RADIOLOGICAL DESIGN							●
10 CFR 60	60.133 UNDERGROUND FACILITY DESIGN CRITERIA							●
10 CFR 60	60.135 WASTE PACKAGE DESIGN CRITERIA						●	
	40 CFR 191, SUBPART A STANDARDS FOR MANAGEMENT	●						
	10 CFR 20 RADIATION PROTECTION STANDARDS	●	●					

Figure 8.2-2. Correlation of performance and design issues for Key Issue 2 (preclosure radiological safety) with regulatory requirements.

KEY ISSUE 4
(PRECLOSURE PERFORMANCE)

	REGULATION		PERFORMANCE	DESIGN			
			4.1 DOE GUIDELINE FUNDINGS-PRECLOSURE	4.2 NONRADIOLOGICAL HEALTH AND SAFETY	4.3 WASTE PACKAGE PRODUCTION TECHNOLOGIES	4.4 PRECLOSURE DESIGN AND TECHNICAL FEASIBILITY	4.5 TOTAL SYSTEM COSTS
10 CFR 960	960.5-1	PRECLOSURE SYSTEM-EASE AND COST	●	●	●	●	●
	960.5-2-8	SURFACE CHARACTERISTICS	●				
	960.5-2-9	ROCK CHARACTERISTICS	●				
	960.5-2-10	HYDROLOGY	●				
	960.5-2-11	TECTONICS	●				

Figure 8.2-3. Correlation of performance and design issues for Key Issue 4 (preclosure performance) with regulatory requirements.

system (MGDS) (Figure 8.2-4) and serves as a basis for a functional description of the repository. The physical elements of the Yucca Mountain MGDS are the natural site features, engineered features, and institutional features arranged in a hierarchical format. These elements are the components of the system that are used as the basis for developing issue resolution strategies. As shown in Figure 8.2-4, the highest level categorization of the MGDS results in elements related to either the preclosure or postclosure waste disposal systems. Within the preclosure element, the next level in the hierarchy is composed of three elements--site, repository, and waste emplacement package. At a similar level within the postclosure waste disposal element are natural barriers, engineered barriers, and institutional barriers. Further subdivisions of the MGDS are shown in Figure 8.2-4.

As described in Section 8.1.2, the first step in developing an issue resolution strategy for a performance or design issue is to select the system element upon which reliance will be placed. As a part of issue resolution, performance allocation has been used as a means for focusing site characterization on acquisition of data that will be most useful in demonstrating that reliance on a particular element of the MGDS will result in acceptable repository designs and performance. Refer to Sections 8.2.2.1 through 8.2.2.3 for summaries of the resolution strategies for performance and design issues associated with Key Issues 1, 2, and 4. Sections 8.3.2 through 8.3.5 provide complete discussions of each issue resolution strategy summarized in this section.

8.2.1.1 Site-specific issues hierarchy

Table 8.2-2 provides the NNWSI Project site-specific information needs within the context of the OGR issues hierarchy. Information needs were developed as convenient categories of data, parameters, and other information items necessary to support resolution of performance and design issues. Information needs include calculational models, descriptions of processes, and information about conditions and characteristics of the site and the engineered repository system. Those information needs requiring site data are described in detail in Sections 8.3.2 through 8.3.5. Site data will be, in turn, provided by site programs described in Sections 8.3.1.2 through 8.3.1.17.

8.2.1.2 Other issues

The wording of the OGR issues (DOE, 1986d) differs slightly from the wording of issues in the DOE Mission Plan (DOE, 1985b). A correlation matrix provided in Figure 8.2-5 shows that all issues in the DOE Mission Plan are addressed by one or more of the OGR issues.

Although this site characterization plan has been developed and is organized on the basis of the OGR issues, specific technical concerns related to site suitability for repository development and repository performance that have been raised by the public and the NRC have been addressed. The

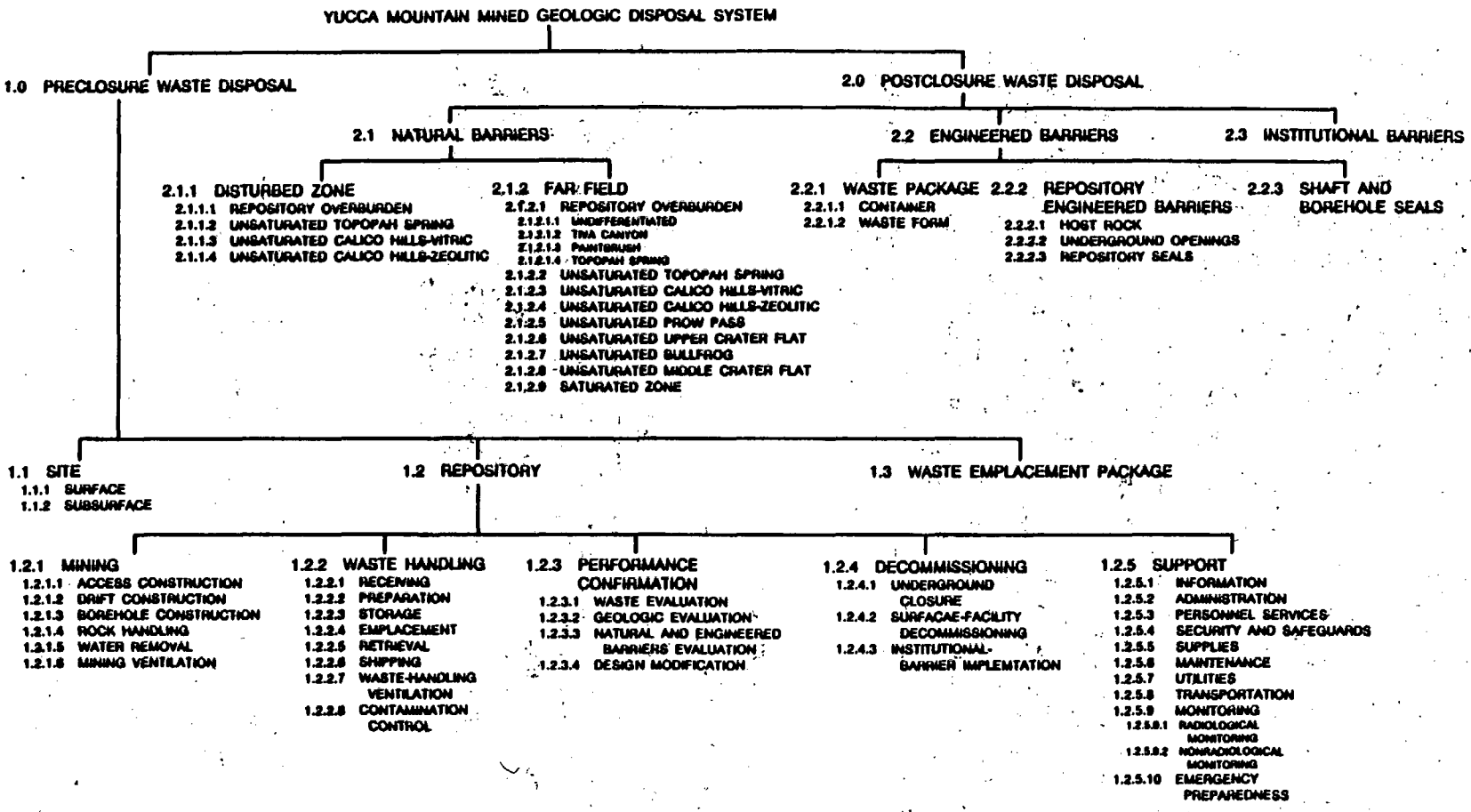

Figure 8.2-4. Hierarchy of functions and components that make up the Yucca Mountain mined geologic disposal system.

OGR ISSUES	MISSION PLAN ISSUES	1.1 GEOHYDROLOGY	1.2 GEOCHEMISTRY	1.3 ROCK CHARACTERISTICS	1.4 EROSION	1.5 CLIMATE	1.6 DISSOLUTION	1.7 TECTONICS	1.8 HUMAN ACTIVITIES	1.9 WASTE PACKAGE & ENGINEERED BARRIER SYSTEM	2.1 RADIOLOGICAL SAFETY: PUBLIC	2.2 METEOROLOGY	2.3 OFFSITE ACTIVITIES	2.4 WORKER RADIOLOGICAL SAFETY	4.1 WASTE PACKAGE COST EFFECTIVENESS	4.2 SURFACE CHARACTERISTICS	4.3 ROCK THERMAL & MECHANICAL CHARACTERISTICS	4.4 PRECLOSURE HYDROLOGY	4.5 PRECLOSURE TECTONICS	4.6 OVERALL REPOSITORY COST-EFFECTIVENESS	4.7 COST-EFFECTIVE CLOSURE
1.1	RELEASES TO ACCESSIBLE ENVIRONMENT	●	●			●		●	●	●											
1.2	INDIVIDUAL PROTECTION	●																			
1.3	GROUND-WATER PROTECTION	●																			
1.4	WASTE PACKAGE CONTAINMENT									●											
1.5	RELEASE RATE		●							●											
1.6	GROUND-WATER TRAVEL TIME	●																			
1.7	PERFORMANCE CONFIRMATION									●							●				
1.8	NRC SITING CRITERIA	●	●	●	●	●	●	●	●												
1.9	DOE GUIDELINE FINDINGS - POSTCLOSURE	●	●	●	●	●	●	●	●	●											
1.10	WASTE PACKAGE		●					●		●							●				
1.11	REPOSITORY	●		●				●									●				
1.12	SEALS	●																●			
2.1	PUBLIC SAFETY-NORMAL OPERATION										●	●	●								
2.2	WORKER SAFETY											●	●	●							
2.3	PUBLIC SAFETY DURING ACCIDENTS										●	●	●	●							
2.4	RETRIEVABILITY			●										●			●				
2.5	DOE GUIDELINE FINDINGS - RADIOLOGICAL SAFETY										●	●	●	●							
2.6	WASTE PACKAGE DESIGN		●												●						
2.7	REPOSITORY DESIGN										●	●	●	●		●	●	●	●		
4.1	DOE GUIDELINE FINDINGS - AVAILABLE TECHNOLOGY														●	●	●	●	●	●	●
4.2	NONRADIOLOGICAL WORKER SAFETY															●	●	●	●		
4.3	WASTE PACKAGE PRODUCTION									●					●						
4.4	ADEQUACY OF TECHNOLOGY											●			●	●	●	●	●	●	●
4.5	COSTS														●	●	●	●	●	●	●

Figure 8.2-5. Correlation of the Department of Energy Mission Plan issues and Office of Geologic Repositories (OGR) issues.

matrices in Tables 8.2-3 and 8.2-4 provide a correlation to the appropriate section in this document where specific technical concerns are addressed.

8.2.2 APPROACH TO ISSUE RESOLUTION

As explained in Sections 8.1.1 and 8.1.2, the performance and design issues were used as a convenient framework for structuring this document. Each of the sections in Section 8.3 covering a performance or design issue contains an issue resolution strategy explaining the performance allocation developed for the issue and describing the site data needed to resolve the issue. The site data needs identified by the performance and design issues are also categorized into a series of specific site programs. Section 8.2.2.4 summarizes the site characterization programs that are presented in detail in Sections 8.3.1.2 through 8.3.1.17. Each program section is divided into a number of site investigations containing related studies and activities. Details of the testing programs to obtain site data are provided in study plans, according to an agreement between the DOE and the NRC.

Summaries of the resolution strategies for performance and design issues are provided in Sections 8.2.2.1 through 8.2.2.3, organized according to key issues. Detailed discussions of the issue resolution strategies can be found in Sections 8.3.2 through 8.3.5. Table 8.2-5 provides an overview of the arrangement of the performance and design issues and the site programs in Section 8.3. This table should allow a reader to more readily locate information of interest.

8.2.2.1 Key Issue 1

8.2.2.1.1 Performance Issues for Key Issue 1

8.2.2.1.1.1 Summary for 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?

Regulatory background

Issue 1.1 (discussed in Section 8.3.5.13) addresses the requirements for releases of radioactive material to the accessible environment following permanent closure. These requirements are stated in the NRC's Overall System Performance Objective (proposed amendment to 10 CFR 60.112 to conform 10 CFR Part 60 to the requirements of 40 CFR 191 (NRC, 1986a)) as follows:

> The geologic setting shall be selected and the engineered barrier system and the shafts, boreholes and their seals shall be designed: (a) So that, for 10,000 years following permanent closure, cumulative releases of radionuclides to the accessible environment, from

Table 8.2-3. Correlation of site-related technical concerns and site characterization plan (SCP) sections where concerns are addressed (page 1 of 30)

Source	Comment ID number	Major concern	Specific concern	SCP cross-reference	Content
			HYDROLOGY		
EA CRD[a]	3.1.1.3	Hydraulic features	Impacts of hydraulic features on system performance	2.2.2 Mechanical properties of discontinuities in rocks	Covers fractures, joints, and effects of water
				8.3.1.4.2 Spatial distribution of thermal and mechanical properties	References thermal and mechanical properties needed for other information needs
EA CRD	3.1.1.4	Intention of guidelines	Technical approach	8.3.5.6, 8.3.5.7, 8.3.5.18 Technical basis for DOE higher level findings issues 1.9, 2.5, 4.1	Technical basis addressed individually for issues throughout Chapter 8
EA CRD	5.3	Matrix and fracture flow	Proportion of fractures vs matrix flow unknown	3.9.2.2.2 Transmissivity and hydraulic conductivity	Contains existing material on fracture vs matrix flow

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Table 8.2-3. Correlation of site-related technical concerns and site characterization plan (SCP) sections where concerns are addressed (page 2 of 30)

Source	Comment ID number	Major concern	Specific concern	SCP cross-reference	Content
			HYDROLOGY (continued)		
				8.3.1.2.1.3 Characterization of regional ground-water flow system	Activities including fracture vs matrix flow
EA CRD	5.4	Basin boundary	Effects of climatic on hydrologic conditions due to boundary conditions of basins	1.1 Geomorphology	Discusses basin geology
ISTP(1)[b]	1.5	Effects on ground water	Natural changes affecting ground-water flow	8.3.1.5.2.2 Climatic effects on hydrology	Studies on the effects of climate on hydrologic characteristics
EA CRD	3.1.3.2	Unsaturated zone hydrology	Unsaturated zone data base is inadequate	3.9 Site hydrogeologic system	Includes unsaturated zone monitoring and characteristics
	4.1.2.2	Ground-water travel time	Tritium analyses	8.3.1.2.2.1 Characterization of unsaturated zone infiltration	Studies include hydrologic characteristics and future infiltration

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Table 8.2-3. Correlation of site-related technical concerns and site characterization plan (SCP) sections where concerns are addressed (page 3 of 30)

Source	Comment ID number	Major concern	Specific concern	SCP cross-reference	Content
			HYDROLOGY (continued)		
	4.1.2.2	Ground-water travel time	Determine flux value		
	8.3	Perched water	Improve data base on perched water		
NRC comment Final EA[c]	7	Uniform infiltration	Uniform infiltration does not allow for preferential paths		
	7	Flux values	Adequate evaluation of flux values		
NRC comment draft EA[d]	3	Ground-water travel time	Uncertainties, alternate models		
EA CRD	5.1	Saturated and unsaturated zone hydrology	Further characterization of the saturated and unsaturated zone hydrology	3.6 to 3.8 Hydrology	Includes existing information on regional ground water of the site

Table 8.2-3. Correlation of site-related technical concerns and site characterization plan (SCP) sections where concerns are addressed (page 4 of 30)

Source	Comment ID number	Major concern	Specific concern	SCP cross-reference	Content
			HYDROLOGY (continued)		
	5.1	Ghost Dance fault	Potential for Ghost Dance fault as a fluid conduit	8.3.1.2 Geohydrology (postclosure)	Contains studies of the regional, unsaturated, and saturated zones of the site
	5.1	Water table	Water table profile		
	7.2	Ground-water basins	Further characterization of Devils Hole basin	8.3.1.16.3 Ground-water conditions	Includes studies for moisture content and perched water
PHPR[e]	1.02.02	Hydrologic system	Identify ground-water flow paths, rates, and fluxes		
ISTP(1)	1.1	Hydrology	Nature of present hydrology		
NRC comment Final EA	4	Hydrothermal activity	Hydrothermal activity affecting flow paths	1.5.2.1 Effects of faulting	Potential effects of faulting
PHPR	1.02.03	Hydrologic system	Effects of fractures and structural features on flow paths	3.7.2 Principal ground-water flow paths	Covers existing material on ground-water flow paths Activities include tectonic and igneous characteristics

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Table 8.2-3. Correlation of site-related technical concerns and site characterization plan (SCP) sections where concerns are addressed (page 5 of 30)

Source	Comment ID number	Major concern	Specific concern	SCP cross-reference	Content
			HYDROLOGY (continued)		
				8.3.1.8.3 Studies of changes in hydrology due to tectonic processes	
				8.3.1.8.3.1 Effects of igneous activity on hydrologic characteristics	Studies cover effects of igneous activities on hydrology
				8.3.1.3.2 Mineralogy, and petrology, rock chemistry	
				8.3.1.3.3 Stability of minerals	
				8.3.1.9.2, 8.3.1.9.3 Natural resource evaluation and exploitation	
EA CRD	4.1.2.2	Aquifers	Flow between aquifers	3.6 Regional hydrology	Includes existing information on hydrogeologic units

Table 8.2-3. Correlation of site-related technical concerns and site characterization plan (SCP) sections where concerns are addressed (page 6 of 30)

Source	Comment ID number	Major concern	Specific concern	SCP cross-reference	Content
			HYDROLOGY (continued)		
NRC comment Final EA	7(4)	Hydrogeologic properties	Interrelationships of hydrogeologic properties	8.2 Information required for site characterization	and their inter-relationships
PHPR	1.02.04	Aquifer flow	Flow between aquifers	8.3.1.2.1 Regional hydrology	Includes studies for hydraulic head and gradient
PHPR	1.02.05	Discharge and recharge	Location of natural discharge and recharge areas	3.7.1 Identification of discharge and recharge areas	
1.02.09	Amargosa Valley	Hydrologic relation-	ship with the Amargosa Valley River system	8.3.1.2 Studies of of the hydrologic system	Includes studies of discharge and recharge areas
PHPR	1.02.06	Flow paths and rates	Identify the flow paths and rates to the accessible environment	3.7 Regional ground-water flow system Assessment of ground-water travel time	
	1.02.11	Hydrology transport model	Information necessary for the hydrologic transport model		

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Table 8.2-3. Correlation of site-related technical concerns and site characterization plan (SCP) sections where concerns are addressed (page 7 of 30)

Source	Comment ID number	Major concern	Specific concern	SCP cross-reference	Content
			HYDROLOGY (continued)		
	1.02.29	Tectonic alteration	Potential for tectonic alteration of ground-water flow path		
PHPR	1.02.07	Seismic effects on ground-water travel time	Effects of seismicity on ground-water travel time	1.5.2.1 Effects of faulting 8.3.1.5 Assessment of ground-water travel timePHPR	Discusses the potential effects of faulting
1.02.08	Effects of	exploration	Effects of exploratory drilling on ground-water travel time	3.7 Regional ground-water flow system 8.2 Information required for site characterization	Describes flow system
	1.02.18	Human intrusion	Potential of mining intrusion of repository	8.3.1.9.3 Human interference	Studies exploration effects on hydrology

Table 8.2-3. Correlation of site-related technical concerns and site characterization plan (SCP) sections where concerns are addressed (page 8 of 30)

Source	Comment ID number	Major concern	Specific concern	SCP cross-reference	Content
			HYDROLOGY (continued)		
ISTP(1)	1.6	Human intrusion	Effects of human intrusion on hydrology	8.3.5.13.5 Probabilistic radiation releases	Radiological releases from anticipated and unanticipated scenarios
PHPR	1.02.10	Radionuclide transport	Potential for radionuclide transport through the flow system	3.9 Site hydrology system	
				8.3.5.13.3 Calculational model	Assess radiological releases to accessible environment
PHPR	1.09.11	Site characterization information	Benefit of site characterization information to surrounding area	Chapters 1 to 5 contain existing site information	
	1.11.04	Site characterization activities	Detailed descriptions of site characterization activities	8.3.1. Contains site information needed	
	1.12.01	Detailed information	Development of detailed site information		

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Table 8.2-3. Correlation of site-related technical concerns and site characterization plan (SCP) sections where concerns are addressed (page 9 of 30)

Source	Comment ID number	Major concern	Specific concern	SCP cross-reference	Content
			HYDROLOGY (continued)		
	1.12.03	Issue resolution	Description of issues to be resolved during site characterization		
PHPR	1.02.01	Site-qualifying hydrologic issues	Identify site-qualifying hydrologic issues examined during site characterization	Chapter 3 Hydrology	Current information on hydrology
				8.3.5.18 Higher-level findings	Findings required for technical guidelines
PHPR	1.02.17	Pluvial conditions	Effects of pluvial climate on unsaturated zone	5.2.2 Future climate variation	Includes climate prediction and model validation
ISTP(1)	1.3	Natural changes	Natural (climatic) changes altering ground-water flow	8.3.1.5 Climatic change	Includes effects of climate on site elements
PHPR	1.02.27	Ground-water migration	Ground-water migration in the Great Basin	1.1 Geomorphology	Discusses Great Basin geology
				8.3.1.2.1.3 Regional ground-water flow system	Includes recharge and potentiometric level studies

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Table 8.2-3. Correlation of site-related technical concerns and site characterization plan (SCP) sections where concerns are addressed (page 10 of 30)

Source	Comment ID number	Major concern	Specific concern	SCP cross-reference	Content
			GEOLOGY: MECHANICS		
PHPR	1.02.28	Radionuclide migration	Characterization of radionuclide migration in the unsaturated zone	8.3.5.13.5 Probabilistic radiological releases to the accessible environment	Radiological releases from anticipated and unanticipated scenarios
EA CRD	3.4.1.4	Porosity	Large-scale porosity tests	2.4.2.4 Porosity and density	Provides existing information on porosity and density
				8.3.1.15.1.1 Density and porosity characterization	Includes studies characterizing rock density and porosity
EA CRD	3.4.1.4	Fracturing	Thermally induced fracturing	2.4 Thermal and thermomechanical properties--intact rock	Provides existing information on thermal properties of intact rock
				8.3.1.15.1.6 Thermal properties from in situ experiments	Thermal properties from in situ experiments

Table 8.2-3. Correlation of site-related technical concerns and site characterization plan (SCP) sections where concerns are addressed (page 11 of 30)

Source	Comment ID number	Major concern	Specific concern	SCP cross-reference	Content
			GEOLOGY: MECHANICS (continued)		
EA CRD	4.1.1	Regional stress regime	Lack of information on the regional stress regime	2.6 Existing stress regime	Regional and site stress regime
	8.2	Rock properties	In situ rock properties and stress	8.3.1.15 Ambient stress	
				8.3.1.15.2 Ambient stress	Studies cover in situ stress testing
EA CRD	5.3	Thermo-mechanic properties of rock	Limitations of models	2.4 to 2.5 Thermal and thermomechanical properties of rock	Includes existing material on thermo-mechanical properties of rock
			Effects of percentages of lithophysae on thermomechanical properties of the in situ rock	8.3.1.15.1 Thermal and mechanical properties of rock	Studies to determine the thermal and mechanical properties of the in situ rock

Table 8.2-3. Correlation of site-related technical concerns and site characterization plan (SCP) sections where concerns are addressed (page 12 of 30)

Source	Comment ID number	Major concern	Specific concern	SCP cross-reference	Content
			GEOLOGY: MECHANICS (continued)		
EA CRD	8.2	Rock properties	Topopah Spring vs Grouse Canyon rock properties	1.8.2.1 Relation of geology to repository design	Includes repository operations
PHPR	1.01.08	Tuff properties	Integrity of tuff maintained during repository operations	Chapter 2 Geoengineering 8.2 Information required for site characterization 8.3.1.15.1 Thermal and mechanical properties	Provides existing material on large scale rock properties
PHPR	1.02.30	Characterization effects	Effects of characterization on the integrity host rock	8.3.3.2 Borehole seals 8.3.5.12.3 Disturbed zone ground-water travel time	Designs for borehole seals Ground-water travel time resulting from characterization

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Table 8.2-3. Correlation of site-related technical concerns and site characterization plan (SCP) sections where concerns are addressed (page 13 of 30)

Source	Comment ID number	Major concern	Specific concern	SCP cross-reference	Content
			GEOLOGY: SURFACE CONDITIONS (continued)		
			GEOLOGY: SURFACE CONDITIONS		
EA CRD	4.1.1	Surface conditions	Soil conditions, wind and water erosion	1.1.3.2 Erosion rates	Provides information on average erosion rates at the site
				8.3.1.14.2 Soil and bedrock properties	Studies include physical properties of soil
				8.3.1.6.2.1 Future climatic conditions on the nature and rate of erosion	Studies include wind and water erosion
				8.3.1.6 Erosion	States erosion will not affect the minimum burial depth
EA CRD	5.4	Erosion	Further data on erosion rates needed	1.1.3.2 Erosion rates	Existing material on erosion rates of site and area

Table 8.2-3. Correlation of site-related technical concerns and site characterization plan (SCP) sections where concerns are addressed (page 14 of 30)

Source	Comment ID number	Major concern	Specific concern	SCP cross-reference	Content
			GEOLOGY: SURFACE CONDITIONS (continued)		
EA CRD	4.1.2.1	Flooding	Maximum probable flood	3.2.1 Floods	Contains flood history and potential for future flooding
	8.1	Flooding	Probable maximum flood	8.3.1.16.1 Flood recurrence levels and intervals	Includes studies for the characterization of flood potential
EA CRD	4.1.3.3	Precipitation and evapotranspiration	Annual precipitation and evapotranspiration rates and variations	3.9.3.3 Recharge and discharge	Includes information on evapotranpiration and precipitation
				8.3.1.2.1 Regional hydrology	Contains studies for precipitation and evapotranspiration data
EA CRD	4.1.3.3	Climatic regime	Detail of the climatology and meteorology of the site	5.1 to 5.2 Recent and long-term climate and meteorology	Provides existing information on climatic regime
	7.2	Climatic regime	Further study of the climatic regime	8.3.1.5.1 Future climatic conditions	

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Table 8.2-3. Correlation of site-related technical concerns and site characterization plan (SCP) sections where concerns are addressed (page 15 of 30)

Source	Comment ID number	Major concern	Specific concern	SCP cross-reference	Content
			GEOLOGY: SURFACE CONDITIONS (continued)		
				8.3.1.12.1 Meteorological conditions at the site	
EA CRD	6.3	Meteorology	Data on extreme weather conditions	5.1 to 5.2 Recent and long-term meteorology and climate	Provides existing information on meteorological conditions
				8.3.1.12.1 Meteorological conditions at the site	Includes studies on extreme weather
				8.3.1.12.4 Recurrence intervals of extreme weather	
EA CRD	4.1.3.7	Background radiation	Radiation levels in soil and water	4.1.2.6 Background radioactivity	Includes information on ground-water background radioactivity
	6.5	Natural radiation	Natural radiation hazard	8.3.5.4.1 Natural radiation environment	References studies to determine the natural radiation environment

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Table 8.2-3. Correlation of site-related technical concerns and site characterization plan (SCP) sections where concerns are addressed (page 16 of 30)

Source	Comment ID number	Major concern	Specific concern	SCP cross-reference	Content
			GEOLOGY: SURFACE CONDITIONS (continued)		
EA CRD	4.1.3.1	Land use	Detailed studies of land use	8.3.1.11.1.2 Land ownership and control	Includes interactions with the Department of Interior and Bureau of Land Management
EA CRD	5.8	Future communities	Development of future communities	8.3.1.10 Population patterns and forecasts	Includes studies on population pattern development
PHPR	1.02.25	Drainage patterns	Effects of alteration of drainage pattern	3.1 Surface hydrology	
ISTP(1)	1.2	Surface water	Nature of present surface water system	8.3.1.2.1 Descriptions of surface hydrology	Includes recharge and discharge flooding
			GEOLOGY: TECTONICS AND MINERALOGY		
EA CRD	5.7	Seismic patterns	Increase seismic pattern data base	1.4 Seismology of the site	Provides existing material on seismic patterns of the area

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Table 8.2-3. Correlation of site-related technical concerns and site characterization plan (SCP) sections where concerns are addressed (page 17 of 30)

Source	Comment ID number	Major concern	Specific concern	SCP cross-reference	Content
		GEOLOGY: TECTONICS AND MINERALOGY (CONTINUED)			
				8.3.1.17.4.1 Seismology	Contains seismologic data compilation
EA CRD	5.6	Secondary volcanism	Significance of secondary volcanic processes	1.3.2.1 Volcanic history	Includes the volcanic history and petrology of the site
				8.3.1.8.1 Studies on releases resulting from volcanic activity	
EA CRD	5.2	Lateral and vertical extent	Inadequate information on the usability of areas outside the primary area	1.2 Stratigraphy and lithology	Provides existing material on stratigraphy and lithology
				8.3.1.4.2 Stratigraphy and structure	Contains activities on the extent of lithologic units
EA CRD	5.2	Fracture mineralogy	Lack of information on fracture mineralogy	4.1.1.3.1.2 Mineralogy of fractures	Contains existing information on fracture mineralogy

Table 8.2-3. Correlation of site-related technical concerns and site characterization plan (SCP) sections where concerns are addressed (page 18 of 30)

Source	Comment ID number	Major concern	Specific concern	SCP cross-reference	Content
		GEOLOGY:	TECTONICS AND MINERALOGY (CONTINUED)		
EA CRD	3.1.3.2	Postclosure tectonics	Tilting and warping rates and directions	1.1.3 Geomorphic processes	Covers significant late Quaternary geomorphic processes
NRC comment Final EA	1	Fault activity	Movement of north trending faults within the last 1,000 yr	1.3.2.2.2. Structure of Yucca Mountain	
	2	Northeast trending faults	Relationship of northeast trending faults to younger basaltic activity	8.3.1.17.4.5 Detachment faults	
NRC comment Draft EA	1	Northeast trending and fault activity	Northeast trending faults and fault activity	8.3.1.17.4.7 Geometry of faults 8.3.1.8.1.2 Effects of eruptions	
EA CRD	3.4.1.8	Seismic hazards	Site-specific estimates of seismic hazards	1.4.1.5 Seismic hazards at the candidate site	Provides existing information on seismic hazards

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Table 8.2-3. Correlation of site-related technical concerns and site characterization plan (SCP) sections where concerns are addressed (page 19 of 30)

Source	Comment ID number	Major concern	Specific concern	SCP cross-reference	Content
		GEOLOGY:	TECTONICS AND MINERALOGY (CONTINUED)		
PHPR	1.01.03	Seismic activity	Potential for and associated uncertainties of seismic activity	8.3.1.17.4 Quaternary faulting	
	1.01.04	Seismic disruption	Estimated potential for seismic disruption of the repository	8.3.1.8.1.2 Effects of eruptions	
	1.01.05	Distance to fault	Determine a safe distance to a fault	8.3.1.8.2 Tectonic processes	8.3.1.17 Studies include estimates of the probability of future earthquakes and faulting
				8.3.1.17.2 Potential fault movement	Studies include probabilities of rupture
NRC comment Draft EA	2	Volcanism and hydrothermal activity	Origin of calcite/silicate vein deposits	8.3.1.3.2.1 Fracture mineralogy	Contains activity on determining fracture mineralogy

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Table 8.2-3. Correlation of site-related technical concerns and site characterization plan (SCP) sections where concerns are addressed (page 20 of 30)

Source	Comment ID number	Major concern	Specific concern	SCP cross-reference	Content
		GEOLOGY: TECTONICS AND MINERALOGY (CONTINUED)			
				8.3.1.5.2 Future climate	Contains studies on calcite and silicates
				1.3.2.2.2 Structure of Yucca Mountain	
EA CRD	5.3	Fault density	Actual fault density	1.5.2.1 to 1.5.2.3 Faulting effects, likelihood, and relation to weapons tests	Contains information on fault types, locations, and effects
NRC comment Final EA	3	Detachment faulting	Potential for the presence of detachment faults and other fault movement	8.3.1.17.3 Ground motion	
		Faulting styles	Fault movement styles of Yucca Mountain	8.3.1.17.4.6 Quaternary faulting	
NRC comment Draft EA	1	Detachment faulting	Studies addressing detachment faulting	8.3.17.4.7 Geometry of faults	

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Table 8.2-3. Correlation of site-related technical concerns and site characterization plan (SCP) sections where concerns are addressed (page 21 of 30)

Source	Comment ID number	Major concern	Specific concern	SCP cross-reference	Content
		GEOLOGY:	TECTONICS AND MINERALOGY (CONTINUED)		
PHPR	1.01.06	Fault source	Faulting resulting from weapons tests	8.3.1.13.2 Impact of nearby installations and operations	Includes effects of weapons testing
PHPR	1.07.03	Dust generated	Potential for hazardous fibers within dust	4.1 Geochemistry of the host rock	Discusses mineralogy of host rock
				8.3.1.3.2 Mineralogy petrology, chemistry of the host rock	Determines material constituency of host rock
EA CRD	5.8	Mineral resource	Further mineral resource evaluations	1.7 Mineral and hydrocarbon resources	Provides existing information on mineral resources
		Geothermal	Potential for extraction of geothermal resources	8.3.1.9.2 Value of resources	Includes studies on resource value
NRC Comment Final EA	5	Economic deposits	Potential for economic deposits associated with Calderas	8.3.1.9.3 Effects of exploiting natural resources	

Table 8.2-3. Correlation of site-related technical concerns and site characterization plan (SCP) sections where concerns are addressed (page 22 of 30)

Source	Comment ID number	Major concern	Specific concern	SCP cross-reference	Content
		GEOLOGY:	TECTONICS AND MINERALOGY (CONTINUED)		
		Breccia deposits	Potential for economic deposits associated with breccias	8.3.1.9.2.1 Present and future value of natural resources	
NRC comment Draft EA	2	Natural resources	Potential for undiscovered mineral resources	8.3.1.5.2 Future climate	Contains studies on calcite and silicate deposits
PHPR	1.01.07	Mineral resources	Presence of mineral resources	8.3.1.16.2 Identification of water supplies	Includes identification, assessment, and effects of water supply exploitation
ISTP(1)	1.4	Ground-water withdrawal	Water resource development		
PHPR	1.01.01	Site-qualifying geology issues	Determine site-qualifying issues examined during site characterization	Chapter 1 Geology	Chapter 1 contains current geology material
ISTP(5)[f]	5.1	Geologic system	Present nature of geologic system	8.3.5.18 Higher level findings	

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Table 8.2-3. Correlation of site-related technical concerns and site characterization plan (SCP) sections where concerns are addressed (page 23 of 30)

Source	Comment ID number	Major concern	Specific concern	SCP cross-reference	Content
		GEOLOGY:	TECTONICS AND MINERALOGY (CONTINUED)		
	5.2	Future geology	Future changes altering geology		
	5.3	Geologic system	Human-induced changes altering geology		
	5.4	Geologic system	Repository-induced geologic alterations		
	5.5	Future geology	Natural changes affecting future geology		
	5.6	Future geology	Future human-induced changes altering geology		
	5.7	Future geology	Future repository-induced alterations to geology		
PHPR	1.01.09	Physical processes	Physical processes in the unsaturated zone affecting repository behavior	1.8.2.1 Relation of geology to repository design	

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Table 8.2-3. Correlation of site-related technical concerns and site characterization plan (SCP) sections where concerns are addressed (page 24 of 30)

Source	Comment ID number	Major concern	Specific concern	SCP cross-reference	Content
		GEOLOGY: TECTONICS AND MINERALOGY (CONTINUED)			
				8.2 Information required for site characterization	
				8.3.1.2 Includes processes occurring in the unsaturated zone	
				8.2 Information required for site characterization	
				8.3.1.2 Includes processes occurring in the unsaturated zone	
EA CRD	5.1	Ground-water chemistry	Unsaturated vs saturated zone chemistry	4.1.2 Ground-water geochemistry	Contains existing information on ground-water geochemistry
				8.3.1.3.1 Water chemistry	Development includes model of unsaturated and saturated zone water composition

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Table 8.2-3. Correlation of site-related technical concerns and site characterization plan (SCP) sections where concerns are addressed (page 25 of 30)

Source	Comment ID number	Major concern	Specific concern	SCP cross-reference	Content
		GEOLOGY: TECTONICS AND MINERALOGY (CONTINUED)			
EA CRD	4.2.2	Vadose water	Analysis of vadose water	8.3.1.2.2 Description of the unsaturated zone	
EA CRD	5.6	Dissolution	Equilibrium of mineralogy and aqueous chemistry		
		Topopah Spring Member	Dissolution potential of Topopah Spring Member	4.1.2 Ground-water geochemistry	Provides existing material on ground-water chemistry
				8.3.1.7.1 Dissolution rates	
EA CRD	5.1	Sorption	Sorption and varying water compositions	4.1.3.3. Sorption	Provides current information on sorption
				8.3.1.3.4.1 Geochemistry sorption	Includes studies of sorption as a function of ground-water composition

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Table 8.2-3. Correlation of site-related technical concerns and site characterization plan (SCP) sections where concerns are addressed (page 26 of 30)

Source	Comment ID number	Major concern	Specific concern	SCP cross-reference	Content
		GEOLOGY: TECTONICS AND MINERALOGY (CONTINUED)			
EA CRD	5.1	Particulates, colloids, complexes	Formation and transport of particulates, colloids, and complexes	4.1.2.7 Particulates and colloids	Provides existing information on particulates and colloids
				4.1.3.5 to 4.1.3.6 Diffusion and radionuclide transport	Provides existing information on diffusion and transport
				8.3.1.3.4.1.4 Sorption on particulates and colloids	
				8.3.1.3.5.2 Colloid behavior	
				8.3.1.3.6.1.5 Filtration	
EA CRD	5.2	Actinide complexes	Effects of carbon-rich waters on actinide complexing	4.1 Geochemistry	Contains geochemistry background information

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Table 8.2-3. Correlation of site-related technical concerns and site characterization plan (SCP) sections where concerns are addressed (page 27 of 30)

Source	Comment ID number	Major concern	Specific concern	SCP cross-reference	Content
		GEOLOGY: TECTONICS AND MINERALOGY (CONTINUED)			
				8.3.1.3.5 Studies for radionuclide retardation	Contains studies and activities on carbonate waters and actinide speciation
EA CRD	4.1.1	Gaseous radionuclide	Gaseous transport of radionuclide	4.1.3.6 Radionuclide transport	Includes radionuclide transport by gas
				8.3.1.3.8.2 Retardation of gaseous radionuclides	
EA CRD	3.4.1.3	Geochemistry data base	Insufficient geochemistry data base	4.1 Geochemistry of the host rock and surrounding units	Provides background on site geochemistry
	7.1.1	Geochemistry	Composition of percolating waters	8.3.1.2.1.3.5 Regional hydrochemical test and analyses	
NRC comment Draft EA	3	Geochemical environment	Oxidation-reduction conditions	8.3.1.2.3 Characterization of site hydrochemistry	

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Table 8.2-3. Correlation of site-related technical concerns and site characterization plan (SCP) sections where concerns are addressed (page 28 of 30)

Source	Comment ID number	Major concern	Specific concern	SCP cross-reference	Content
		GEOLOGY: TECTONICS AND MINERALOGY (CONTINUED)			
ISTP(3)[g]	3.1	Geochemistry	Present geochemistry		
NRC comment Draft EA	8	Radionuclide transport	Radionuclide transport increases due to geohydrologic changes resulting from climatic alterations	3.7 Regional groundwater flow system 8.3.1.5.2 Climatic effects on hydrologic characteristics 8.3.1.3.7.1 Retardation sensitivity	Provides existing information on recharge systems
NRC comment Final EA	6	Matrix retardation	Can matrix retardation overcome increases in groundwater flow due to climate change	4.1.3.5 Matrix diffusion 8.3.1.3.7.1 Retardation sensitivity analysis	
NRC comment Draft EA	6	Retardation	Retardation of radionuclides	8.3.1.3.6.1 Dynamic transport column experiments	

Table 8.2-3. Correlation of site-related technical concerns and site characterization plan (SCP) sections where concerns are addressed (page 29 of 30)

Source	Comment ID number	Major concern	Specific concern	SCP cross-reference	Content
		GEOLOGY: TECTONICS AND MINERALOGY (CONTINUED)			
NRC Comment Final EA	8	Retardation	Value of matrix diffusion and colloid sorption on the retardation of radionuclides	8.3.1.3.6.2 Diffusion 8.3.1.3.4.1.4 Sorption on particulates and colloids	
ISTP(3)	3.3	Retardation	Future geochemistry effecting retardation		
PHPR	1.05.02	Water courses	Chemical composition of water courses	4.1 Geochemistry of the host rock	Discusses mineralogy and retardation
				8.3.1.3.2 Mineralogy, petrology, chemistry, of the host rock	Includes material along water courses
				8.3.1.3.4-8 Radionuclide retardation	Studies the chemical composition along flow paths

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Table 8.2-3. Correlation of site-related technical concerns and site characterization plan (SCP) sections where concerns are addressed (page 30 of 30)

Footnotes

[a]EA CRD = site specific comment response document for the environmental assessment for the Yucca Mountain site (DOE, 1986b).

[b]ISTP(1) = Draft Issue-Oriented State Technical Position (ISTP) for Nevada Nuclear Waste Storage Investigations (NNWSI) Project - Hydrology (NRC, 1984).

[c]NRC comment = NRC Comments on the Final Environment Assessment, Yucca Mountain site (Kale, 1986).

[d]NRC comment = NRC comments on the draft environmental assessment for the Yucca Mountain site (NRC, 1987).

[e]PHPR = These comments are taken from the Public Hearings Panel Report, NVO 263, dated November 1983 (DOE/NVO, 1983).

[f]ISTP(5) = Draft ISTP for NNWSI Project--Geology/Geophysics, (NRC, 1984).

[g]ISTP (3) = Draft ISTP for NNWSI Project--Geochemistry, (NRC, 1984).

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Table 8.2-4. Correlation of engineered system related technical concerns and site characterization plan (SCP) sections where concerns are addressed (1 of 10)

Source	Comment ID number	Major concern	Specific concern	SCP cross-reference	Content
EA CRD[a]	4.1.1	Seismic effects	Potential effects of seismic activity on repository operation and performance	8.3.2.1.4 Repository modeling	Includes design considerations for seismic activity
EA CRD	5.4	Sealing program	Detailed description of sealing program	6.2.8 Shaft and borehole seals	Contains existing material on shaft and borehole seals
ISTP(4)[b]	4.6	Seal design	Will seal design meet 10 CFR 60.112	8.3.2.5.10 Construction of seals	States the results from other seals development tests
				8.3.3.1. Seal system	Contains planned seals design and modeling
EA CRD	5.11	Radionuclide releases to ground water	Predicted radionuclide releases to accessible environment at 100,000 yr	6.4. Design issues	Covers preliminary analysis of repository performance
				8.3.5.13.2 Post-closure system performance	Includes design concepts and calculational models for releases

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Table 8.2-4. Correlation of engineered system related technical concerns and site characterization plan (SCP) sections where concerns are addressed (2 of 10)

Source	Comment ID number	Major concern	Specific concern	SCP cross-reference	Content
EA CRD	5.11	Waste package corrosion	Corrosion testing	7.4 Waste package design and geochemical interactions	Provides existing material on waste package design
PHPR[c]	1.02.12	Water chemistry	Water chemistry and effect on corrosion	8.2 Information required for site characterization	
	1.02.14	Ground-water effects	Effects of ground water on repository components	8.3.1.2 Hydrologic system	
				8.3.1.3 Geochemistry	
				8.3.5.9-10 Assessment of containment within waste package	Contains waste package design information and containment assessment
NRC Comment Draft EA[d]	10	Waste package	Detailed materials plan	7.2-7.3 Waste package design basis, reference designs, and alternative designs	
ISTP(2)[e]	2.5	Waste package	Waste package releases within 10 CFR 20	8.3.4.3 Waste package	

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Table 8.2-4. Correlation of engineered system related technical concerns and site characterization plan (SCP) sections where concerns are addressed (3 of 10)

Source	Comment ID number	Major concern	Specific concern	SCP cross-reference	Content
	2.6	Waste package	Waste package retrievability design		
	2.7	Waste package	Waste package design		
	2.9	Waste package	Waste package monitoring	8.3.5.9 Assessment of containment within waste package	Contains waste package design and modeling accounting for the performance objective for the waste package Contains waste package design information and containment assessment
PHPR	1.01.13	Resulting radiation doses	Potential for radiation releases to jeopardize individuals	8.3.5.13.5 Probabilistic radiation releases	Radionuclide releases from anticipated and unanticipated scenarios

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Table 8.2-4. Correlation of engineered system related technical concerns and site characterization plan (SCP) sections where concerns are addressed (4 of 10)

Source	Comment ID number	Major concern	Specific concern	SCP cross-reference	Content
ISTP(4)	4.1	10 CFR 60.111	Repository design to maintain 10 CFR 60.111	8.3.5.14 Doses to individuals	Describes allowable doses
PHPR	1.03.13	Weapons testing	Safety factors provided against weapons testing or impact	6.1.2 Reference repository design	
				8.3.1.13.2 Offsite installations	Provides offsite impact data to repository data base
	1.08.03	Weapons testing	Compatibility of weapons testing and waste disposal		
PHPR	1.02.20	Flood protection	Identify flood protection measures for repository (surface)	8.3.2.5.8 Technology of surface facility construction	Design parameters include climate and flooding
PHPR	1.03.14	Nuclear criticality	Potential for waste to go critical	7.2.2 Waste forms	Describes considerations of waste form
				8.3.4.3.2 Waste form criteria	

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Table 8.2-4. Correlation of engineered system related technical concerns and site characterization plan (SCP) sections where concerns are addressed (5 of 10)

Source	Comment ID number	Major concern	Specific concern	SCP cross-reference	Content
PHPR	1.03.19	Integrity of openings	Engineering methods used to maintain openings	6.1.1 Repository design requirements	Includes operation and decommissioning as design requirements
				8.3.2.5.9 Techniques for underground construction	Includes construction of safe openings
PHPR	1.03.20	Mining effects	Potential for continual mining affecting emplaced waste	6.4.10.2.2 Repository operations	Discusses expected repository operations
	1.03.23	Repository stability	Stability of repository maintained during coupled effects of excavation and thermal stress from emplaced waste	8.3.2.5.3 Repository operations plan	Includes considerations for operation during construction
ISTP(2)	2.8	Stability	Vicinity conditions affecting waste criticality		

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Table 8.2-4. Correlation of engineered system related technical concerns and site characterization plan (SCP) sections where concerns are addressed (6 of 10)

Source	Comment ID number	Major concern	Specific concern	SCP cross-reference	Content
PHPR	1.03.21	Weapons testing	Effects of weapons-induced seismicity on the repository	6.1.2 Reference repository design basis	
				8.3.2.5.4 Repository design requirements	Includes requirements from 10 CFR 60 and 10 CFR 960
PHPR	1.03.25	Interaction effects	Results of long-term interaction between the barrier and host rock	8.3.5.13 Assessment of postclosure system performance	Includes models and scenarios of postclosure performance
PHPR	1.03.26	Waste package degradation	Degradation of waste package adversely altering the waste package environment	7.4.1 Waste package environment modification	Discusses interaction of waste package with emplacement environment
ISTP(2)	2.2	Waste package	Ground-water penetration of waste package	8.3.4.2.4 Post-emplacement near field	Studies the changes in the near field
ISTP(3)[f]	3.2	Waste package environment	Changes in geochemistry due to waste package	8.3.2.1.2 Coupled-interaction tests	Studies include interactions between waste package and environment

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Table 8.2-4. Correlation of engineered system related technical concerns and site characterization plan (SCP) sections where concerns are addressed (7 of 10)

Source	Comment ID number	Major concern	Specific concern	SCP cross-reference	Content
PHPR	1.03.27	Backfilling	Complications due to backfilling	6.2.7 Backfilling	Discusses backfilling and techniques
ISTP(2)	2.1	Backfill	Ground-water penetration of backfill	8.3.2.2.7 Postclosure repository design	Includes backfill degradation
ISTP(4)	4.3	Backfill	Retardation ability of backfill		
	4.4	Backfill	Does backfill compromise waste package		
	4.5	Backfill	Does backfill control radiological releases		
PHPR	2.04.02	Suitability	Suitability of Yucca Mountain resulting from factual evidence	8.3.5.18 Assessment of postclosure system and technical guidelines	
	3.01.03	Human engineering	Replacement of nonexistent favorable geologic conditions with engineered components		

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Table 8.2-4. Correlation of engineered system related technical concerns and site characterization plan (SCP) sections where concerns are addressed (8 of 10)

Source	Comment ID number	Major concern	Specific concern	SCP cross-reference	Content
PHPR	3.04.18	Existing technology	The use of existing international experience with waste disposal	Chapters 6,7 Conceptual design and waste package	Contain existing information and technology on repository and waste package design
				8.3.2.1.3 Design optimization	Studies improving the design to better meet performance objectives
PHPR	3.03.03	Storage	Long-term storage experiments	8.3.4.1 Waste package program	Includes waste form testing
PHPR	1.03.17	Licensing requirements	Identify the licensing requirements for the repository and their limitations	8.1.1 to 8.1.2 Derivation of site characterization and issue resolutions strategy	
				8.2 Issues to be resolved through site characterization	

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Table 8.2-4. Correlation of engineered system related technical concerns and site characterization plan (SCP) sections where concerns are addressed (9 of 10)

Source	Comment ID number	Major concern	Specific concern	SCP cross-reference	Content
PHPR	1.01.10	Model uncertainties	Level of confidence of uncertainties in models	6.4.10.3 Planned work for model validation	
				8.3.2.5 Adequate techniques	Assigns level of confidence
PHPR	1.03.05	Waste package performance	Long-term performance characteristics of the waste package	7.4.2.3 Degradation modes of waste package materials	
	1.03.06	Waste package performance	Waste package integrity under corrosive or thermal conditions	8.3.4.1.3 Waste package designs	Describes performance objectives of waste package
	1.03.22	Waste package design	Methods for waste stabilization	8.3.4.2.2 Reference waste package designs	Includes long-term corrosive and thermal properties
NRC EA Final[g]	9	Waste package performance	Uncertainties in performance models or parameters of waste package design		

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Table 8.2-4. Correlation of engineered system related technical concerns and site characterization plan (SCP) sections where concerns are addressed (10 of 10)

Source	Comment ID number	Major concern	Specific concern	SCP cross-reference	Content
ISTP(2)	2.3	Waste package releases	Radiological release rates from waste package		
	2.4	Waste package releases	Radiological migration rates through failed waste package		
ISTP(4)	4.2	Retrieval	Will underground facility allow retrieval	8.3.5.2 Issue resolution strategy for Issue 2.4; retrievability	

[a]EA CRD = site specific comment response document for the environmental assessment for the Yucca Mountain site (DOE, 1986b).

[b]ISTP(4) = Draft ISTP for NNWSI Project--Geologic Repository Operations Area Design/Rock Mechanics, (NRC, 1984).

[c]PHPR = These comments are taken from the Public Hearings Panel Report, NVO 263, dated November 1983 (DOE/NVO, 1983).

[d]NRC Comment = NRC comments on the draft environmental assessment for the Yucca Mountain site (NRC, 1985a).

[e]ISTP(2) = Draft ISTP for NNWSI Project--Waste Package, (NRC, 1984).
[f]ISTP(3) = Draft ISTP for NNWSI Project--Geochemistry, (NRC, 1984).
[g]NRC Comment = NRC comments on the Final Environmental Assessment, Yucca Mountain site (Kale, 1986).

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Table 8.2-5. Overview of contents of Section 8.3 showing order of presentation of site programs and performance and design issues within major programs

Section 8.3.2 Repository Program	Section 8.3.3 Seal Program	Section 8.3.4 Waste Package Program	Section 8.3.5 Performance Assessment Program	Section 8.3.1 Site Program
8.3.2.2 Configuration of underground facilities (postclosure), Issue 1.11	8.3.3.2 Seal characteristics (postclosure), Issue 1.12	8.3.4.2 Waste package characteristics (postclosure), Issue 1.10	8.3.5.2 Waste retrievability, Issue 2.4	8.3.1.2 Geohydrology
8.3.2.3 Repository design criteria for radiological safety, Issue 2.7		8.3.4.3 Waste package characteristics (preclosure), Issue 2.6	8.3.5.3 Public radiological exposures--normal conditions, Issue 2.1	8.3.1.3 Geochemistry
8.3.2.4 Nonradiological health and safety, Issue 4.2		8.3.4.4 Waste package production technologies, Issue 4.3	8.3.5.4 Worker radiological safety--normal conditions, Issue 2.2	8.3.1.4 Rock characteristics
8.3.2.5 Preclosure design and technical feasibility, Issue 4.4			8.3.5.5 Accidental radiological releases, Issue 2.3	8.3.1.5 Climatic change
			8.3.5.6 Higher level findings--preclosure radiological safety, Issue 2.5	8.3.1.6 Erosion
			8.3.5.7 Higher level findings--preclosure system and technical guidelines, Issue 4.1	8.3.1.7 Dissolution
			8.3.5.9 Waste package containment, Issue 1.4	8.3.1.8 Postclosure tectonics
			8.3.5.10 Engineered barrier system release rates, Issue 1.5	8.3.1.9 Human interference
			8.3.5.12 Ground-water travel time, Issue 1.6	8.3.1.10 Population density
			8.3.5.13 Total system performance, Issue 1.1	8.3.1.11 Site ownership
			8.3.5.14 Individual protection, Issue 1.2	8.3.1.12 Meteorology
			8.3.5.15 Ground-water protection, Issue 1.3	8.3.1.13 Offsite installations
			8.3.5.16 Performance confirmation, Issue 1.7	8.3.1.14 Surface characteristics
			8.3.5.17 NRC Siting Criteria, Issue 1.8	8.3.1.15 Thermal and mechanical rock properties
			8.3.5.18 Higher-level findings--postclosure system and technical guidelines, Issue 1.9	8.3.1.16 Hydrology
				8.3.1.17 Preclosure tectonics

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all anticipated and unanticipated processes and events, shall:
(1) Have a likelihood of less than one chance in 10 of exceeding the quantities calculated in accordance with Section 60.115.
(2) Have a likelihood of less than one chance in 1,000 of exceeding ten times the quantities calculated in accordance with Section 60.115.

"Accessible environment" is understood by the DOE to mean the atmosphere, land surfaces, surface waters, oceans, and the portion of the lithosphere that is outside the controlled area. Likewise, the term "anticipated processes and events" is understood to mean "those natural processes and events that are reasonably likely to occur during the period the intended performance objective must be achieved", assuming that the "processes operating in the geologic setting during the Quaternary Period continue to operate but with the perturbations caused by the presence of emplaced waste superimposed thereon." "Unanticipated processes and events" are understood to be those processes and events "that are judged not to be reasonably likely to occur during the period the intended performance objective must be achieved, but which are nevertheless sufficiently credible to warrant consideration."

The proposed 10 CFR 60.115 (NRC, 1986a) presents a table that lists the maximum release to the accessible environment allowable for each radionuclide species. These release limits are based on the EPA containment standard (40 CFR 191.13) and the release limits, stated in 40 CFR 191 Appendix A.

Technical background and licensing strategy

The DOE plans to demonstrate compliance with the total system performance objective by conducting performance assessments. Consistent with the requirements of 10 CFR 60.21(c)(1)(ii)(C), these performance assessments will (1) identify all significant processes and events, both anticipated and unanticipated, that may affect the geologic repository, (2) evaluate the effects of these processes and events on the amount of radionuclides released to the accessible environment, (3) to the extent practicable combine the release estimates into an overall probability distribution displaying the likelihood that the amount of radioactive material released to the accessible environment will not exceed the regulatory limits, and (4) compare the numerical predictions with the performance objective, evaluating the importance of any uncertainties on conclusions from this comparison.

The identification of significant processes and events which are to be taken into account in these performance assessments will be accomplished by developing scenarios that each specify a sequence of processes and events potentially resulting in significant impacts on the variables of the system important to waste isolation. Scenarios will be developed for undisturbed conditions, i.e., those due to likely natural events, and for disturbed conditions, which although due to unlikely natural events and processes are sufficiently credible to warrant consideration.

The repository system consists of the natural barriers and the engineered barriers, including the waste package and the shaft and borehole seal system. For the Yucca Mountain site, the proposed location of the repository is in the unsaturated Topopah Spring welded tuff unit, about 250 meters above

the water table and 200 to 300 meters below the ground surface. The present and future characteristics of the engineered and natural barrier systems will be evaluated to determine their effectiveness in limiting radionuclide releases to the accessible environment.

There are two aspects of isolation that must be considered: the rate of release of radionuclides from the engineered barrier system must be predicted and the transport of radionuclides through the natural barrier system to the accessible environment must be evaluated. The evaluation of the release of radionuclides from the engineered barrier system will take into account the assessments of performance of the engineered barrier system for Issues 1.4 and 1.5 (SCP Sections 8.3.5.9 and 8.3.5.10). The overall system performance assessment for Issue 1.1 will use the results of the engineered barrier system performance assessments to develop a radionuclide source term for the evaluation of radionuclide transport through the natural barriers and to the accessible environment.

There are three possible radionuclide transport modes from the engineered barriers through the natural barriers to the accessible environment. One of these modes, direct release, results from the direct mechanical transport of radioactive material to the accessible environment due, for example, to igneous extrusion or as the result of human intrusion. The other two modes are liquid transport and gas transport. The geohydrologic, geochemical and rock characteristics of the elements of the natural barrier system determine the effectiveness of the natural barriers in limiting the liquid and gaseous transport of radionuclides from the engineered barrier system to the accessible environment. These characteristics include such variables as percolation flux, fracture density, stratigraphic unit thickness and bulk porosity. During the next 10,000 years, certain events and processes could occur that would alter the characteristics of the elements of the natural barrier system and possibly the engineered barrier system elements. Sequences of these processes and events, referred to as scenarios, could alter present conditions in such a way that the isolation capabilities of the site would be adversely affected.

The strategy for the resolution of this issue is to determine the contribution to total radionuclide releases to the accessible environment for the scenarios that are likely to occur during the next 10,000 years as well as for those scenarios that are unlikely, yet sufficiently credible to warrant consideration. Generic lists of processes and events that could affect a repository system are evaluated together with site-specific information to identify the significant processes and events. Significant processes and events are those that could have a significant impact on the variables of the system important to waste isolation, and that are sufficiently credible to warrant consideration. Scenarios are then developed, based on the set of significant processes and events. Scenarios will be developed for both undisturbed and disturbed conditions. Undisturbed conditions are the natural processes and events that are likely to occur, coupled with perturbations that result from repository construction and waste emplacement. Disturbed conditions are the natural processes and conditions and human activities that are considered unlikely yet sufficiently credible to warrant consideration.

To evaluate the effects of the scenarios on repository performance, mathematical models are constructed. To reduce the number of mathematical

models required to assess the effects of the scenarios, the scenarios are grouped into "scenario classes". The nominal scenario class include all the scenarios that are associated with undisturbed performance. The scenarios associated with disturbed performance are grouped into scenario classes according to the manner in which the repository system would be effected if they were to occur. A preliminary set of eight scenario classes has been identified. These classes have been grouped into five supercategories: nominal performance, direct releases, partial failure of the engineered barrier system, partial failure of unsaturated zone barriers, and partial failure of saturated zone barriers. The scenarios are grouped such that the scenario classes are exhaustive and mutually exclusive in their coverage of the scenarios and significant events and processes. The preliminary set of scenario classes and the supercategories are shown in Table 8.2-6.

As discussed, mathematical models for each scenario class are constructed. The independent variables of each scenario class model are the state variables needed to determine initial conditions and boundary conditions. The dependent variable of each scenario class model is the contribution to the total cumulative normalized release that would result from the occurrence of the scenarios of the jth scenario class. This dependent variable is used as a partial performance measure, M_j, and is defined mathematically by

$$M_j = \sum_i \frac{Q_{ij}}{L_i} \qquad (8.2\text{-}1)$$

where j indexes the scenario class being considered, and Q_{ij} is the cumulative release of radioactivity in curies released to the accessible environment in the 10,000-year period following disposal, in the form of the ith radionuclide species, through the realization of one or more of the scenarios included in the jth scenario class. The quantity L_i is the release limit for the ith radionuclide as specified in the standards (40 CFR Part 191, Appendix A). Since the scenario classes are constructed to be exhaustive and mutually exclusive,

$$M = \Sigma M_j \qquad (8.2\text{-}2)$$

where M is the total cumulative normalized release from the repository system. M serves as a performance measure for the total repository system.

Available information can be used to obtain an estimated value for the expected partial performance measure for a scenario class. A scenario or scenario class can be eliminated if it can be shown via the estimated expected partial performance parameter that the scenario or scenario class would have low relative or absolute consequences. Also, the models of the scenario classes that remain can be simplified by the elimination of insensitive independent variables through sensitivity analyses.

The mathematical models for the scenario classes will be implemented by computer codes. These codes can be exercised for deterministic point estimates of the release or to develop an overall probability distribution. In the later case the values for the performance measures are obtained by Monte Carlo sampling from a joint probability distribution of values for the

Table 8.2-6. Preliminary set of scenario classes for resolution of Issue 1.1

Nominal performance of all barriers.

(E) Undisturbed performance of all natural barriers: (matrix flow predominates in unsaturated zone barriers, some carbon-14 released in gas phase)

Disturbed performance of barriers.

(A) Direct Releases:

1) direct release in an extrusive magmatic event;
2) direct release associated with human intrusion.

(B) Partial failure of engineered barrier system (included in (C) and (D))

(C) Partial failure of unsaturated zone barriers:

1) accelerated releases to the water table attending increased flux from sources above the repository;

2) accelerated releases to the water table attending a rise in the water table (foreshortening of unsaturated zone);

3) accelerated releases to the water table attending changes in unsaturated zone rock-hydrologic properties or geochemical properties.

(D) Partial failure of saturated zone barriers:

1) accelerated releases to the accessible environment owing to appearance of discharge points within 5 km downgradient of controlled area (foreshortening of the saturated zone).

2) accelerated releases to the accessible environment owing to increased linear water velocity in the saturated zones, changed rock-hydrologic properties, or changed geochemical properties.

dependent variables of the system. By repeated sampling, a distribution of calculated releases can be generated. This distribution can then be used to construct the overall probability distribution for normalized cumulative release.

The results of the preliminary performance allocation for this issue are summarized in Table 8.2-7 and is based upon preliminary evaluation of cumulative release using available information. Performance measures and goals are selected in terms of the scenario classes specified in Table 8.2-6. Column 1 lists the general categories of scenario classes identified in Table 8.2-6. (Section 8.3.5.13 gives the bases for these classes and discussion to support the table entries.) Column 2 indicates the mode(s) of radionuclide transport to the accessible environment that are appropriate for each scenario class. Column 3 shows the preliminary assignment of the barriers for which credit will be taken in meeting the performance goals, which are described in Section 8.3.5.13. Possible back-up barriers are also indicated.

Column 4 shows the component(s) of the primary barrier that are believed to contribute most to the achievement of the performance goal. Column 5 gives the process or condition characteristic of the primary barrier which is being relied on to limit transport.

The elements in this table help to orient the testing program toward the information needed to support the calculation of cumulative release to the accessible environment for the resolution of Issue 1.1. The testing will focus on the barriers and processes identified in this table. Goals for the testing program in terms of specific site characteristics to be evaluated and parameter values that would contribute to a favorable resolution of the issue are identified in the detailed strategies discussed in Section 8.3.5.13.

8.2.2.1.1.2 Summary for individual protection -- Issue 1.2: Will the mined geologic disposal system meet the requirements for limiting individual doses in the accessible environment as required by 40 CFR 191.15?

Regulatory background

Issue 1.2, which is discussed in Section 8.3.5.14, addresses the EPA requirements of 40 CFR 191.15 that limit the annual dose equivalent from the repository system to any member of the public in the accessible environment following permanent closure. The regulations require that, for 1,000 years after disposal and assuming undisturbed performance of the repository system, the annual dose equivalent to any member of the public in the accessible environment shall not exceed 25 mrems to the whole body or 75 mrems to any critical organ. All potential pathways associated with undisturbed performance from the repository to people shall be considered, and it shall be assumed that individuals consume 2 L/day of drinking water from any significant source of ground water outside the controlled area.

The EPA defines "undisturbed performance" as meaning the predicted behavior of the disposal system, including consideration of the uncertainties

Table 8.2-7. Primary performance allocation for Issue 1.1 (page 1 of 2)

Release scenario class	Pathway	Primary barriers	Primary barrier components	Primary processes or conditions
Nominal case E	Water	Unsaturated zone; saturated zone, EBS[a] as backup	Combined facies of Calico Hills; other units (backup)	Equivalent-porous-media transport through matrix with adsorptive retardation
	Gas	EBS; overburden as backup	Cladding and structural components	Limited rapid release of carbon-14 as carbon dioxide
Direct releases A-1, A-2	(No allocation: See Section 8.3.5.13 for explanation)			
Failure of unsaturated zone barriers C-1	Water	Repository overburden	Paintbrush Tuff unit and Topopah Spring	Flooding-pulse delay times less than 10,000 yr
	Gas	None	None	None
C-2	Water	Unsaturated zone; saturated zone, EBS as backup	Combined facies of Calico Hills	Equivalent-porous-media transport, with adsorptive retardation
	Gas	EBS; overburden as backup	Cladding and structural components	Limited rapid release of carbon-14 as carbon dioxide
C-3	Water	Saturated zone; EBS and residual unsaturated zone as backup	Saturated zone to boundary of AE[b] (or discharge points)	Equivalent-porous-media transport with adsorptive retardation

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Table 8.2-7. Primary performance allocation for Issue 1.1 (page 2 of 2)

Release scenario class	Pathway	Primary barriers	Primary barrier components	Primary processes on conditions
Failure of saturated zone barriers	Gas	None	None	None
D-1	Water	Residual saturated zone + residual unsaturated zone, EBS as backup		Equivalent-porous-media transport with adsorptive retardation
D-2	Water	Residual saturated zone + residual unsaturated zone, EBS as backup		Equivalent-porous-media transport with adsorptive retardation

[a]EBS = engineered barrier system.
[b]AE = accessible environment.

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in predicted behavior, if the disposal system is not disrupted by human intrusion or the occurrence of unlikely natural events. The term "accessible environment" means (1) the atmosphere, (2) land surfaces, (3) surface waters, (4) oceans, and (5) all the lithosphere that is beyond the controlled area, a surface location that encompasses no more than 100 km and extends horizontally no more than 5 km in any direction from the outer boundary of the original location of the radioactive wastes in a disposal system.

Technical background and licensing strategy

Radionuclides may be released from the waste container via several mechanisms. Under undisturbed conditions no radionuclides will be released from the waste container in solid form (e.g., direct releases due to human intrusion). The only other mechanism for release of radionuclides from the solid waste form and waste package are through formation of gaseous species (e.g., carbon dioxide containing carbon-14) and through dissolution in ground water that comes in contact with the waste form.

Once released from the waste container, there are only two significant mechanisms for transport of the radionuclides from the waste package to humans in the accessible environment under undisturbed conditions, i.e., ground-water transport and gas-phase transport. The probable flow paths for each transport mechanism lead to quite different and separate exposure sources for any released radionuclides and will, therefore, be treated separately. The strategy for resolving Issue 1.2 for the ground-water transport is to determine whether any exposure to the public will occur during the 1,000-yr period following permanent closure. For gas-phase transport, the reference case will examine whether the upper bounding value of the exposure to the public will be less than the 25 and 75 mrem/yr dose limits based on the amount of the carbon-14 inventory that can be released in gaseous form. Alternatively, it may be possible to show that gaseous carbon-14, the only potentially important gaseous release, may never reach the accessible environment during the 1,000-yr period.

Ground-water transport

Under undisturbed conditions, no significant amounts of liquid water are expected to be present in or adjacent to the emplacement borehole for at least 300 years after disposal. For 300 to 1,000 years after disposal, a limited amount of water (less than 5 liters per year per package) may be available to contact some waste containers, although most of the containers are expected to remain in a dry environment for well over 1,000 years (Section 8.3.4). Under very conservative assumptions, however, up to 20 percent of the waste containers may be breached and radionuclides may be released and transported via ground water downward through the unsaturated zone and laterally through the saturated zone before reaching the accessible environment. Non-sorbing radionuclides would not travel faster than the ground-water itself along the path of likely radionuclide travel, and sorbing species of the radionuclides would travel slower than the ground-water because of retardation. Thus, for ground-water transport, this issue will be resolved if it can be established with high confidence that the ground-water travel time, and therefore radionuclide transport time, along any likely and significant path of radionuclide travel to the accessible environment exceeds 1,000 years. Current estimates on the ground-water travel time show a mean

value of about 43,000 yr with a standard deviation of 13,000 yr (Sinnock et al., 1986) thus providing an initial level of confidence that the contaminant transport time will be substantially longer than 1,000 yr.

Gas-phase transport

There are three radionuclides that could be transported as gaseous species under the expected conditions at Yucca Mountain: carbon-14, tritium, and krypton-85. Of these, only carbon-14 is readily available for rapid release from a breached waste container. The other radionuclides, both of which have short half-lives, are expected to be contained within the waste form (Sections 8.3.5.9 and 8.3.5.10). Both spent fuel and glass waste forms contain carbon-14. Most of the carbon-14 in the spent fuel is locked inside the UO_2 fuel pellets, Zircaloy cladding, and fuel assemblies and will be released slowly after the containment is breached. Only a small fraction of the total carbon-14 inventory, that is contained in the oxidized skin of the Zircaloy cladding of the spent fuel, could be rapidly released by reaction of the oxygen in the pore spaces of the unsaturated host rock with the carbon in the cladding oxidation layer (Oversby and McCright, 1985). Oversby and McCright (1985) estimate that no more than one percent of the carbon-14 inventory in spent fuel could be rapidly released in this way during the first 100 to 1,000 years following closure when high temperature and gamma radiation are expected (Section 8.3.5.9). There is no mechanism for rapid release of carbon-14 from glass waste forms, which have smaller carbon-14 inventories than spent fuel. A bounding calculation for the carbon-14 releases is presented in Section 8.3.5.14.

The carbon-14 released from the spent fuel during the initial breach of the container is expected to be in the form of gaseous carbon dioxide, which will move upward through air-filled pores in the unsaturated tuffs. In the course of the upward movement of carbon-14 dioxide, isotopic exchange of carbon-14 with the normal carbon of the carbon dioxide gas in the pore space will occur, thus retarding the movement of the carbon-14 to the atmosphere above the repository. In addition, precipitation of calcite ($CaCO_3$), if it occurs, will irreversibly remove carbon-14 from the system. If the residence time of the carbon-14 in the overburden is established with high confidence to exceed 1,000 years, this part of Issue 1.2 will be resolved. Actual residence times of carbon-14 in the pore spaces of the repository overburden could, in principle, be estimated by solving a transport equation that takes the isotope exchange and chemical models into account. However, site-specific data that would permit realistic estimates of the carbon-14 residence time are presently lacking.

For the resolution of Issue 1.2, a bounding-value calculation will be used. The inventory of carbon-14 available for rapid release, a total of 200 Ci for 1,000 years, is relatively small compared with an average release of 5 to 10 Ci/yr into the atmosphere from each operating nuclear power plant (boiling water and pressurized water reactors) and with the design-basis release of approximately 800 Ci/yr from a 1,500-MTHM (metric tons of heavy metal)-per-yr fuel-reprocessing plant. Because the dose consequences expected from the assumed release of carbon-14 through the repository overburden are very small, bounding calculations will be done for a hypothetical maximally exposed individual on the ground surface above the repository assuming a ground-level release of the total 200 Ci in one year.

Internal dose due to ingestion has not been calculated because of the lack of site-specific data. This dose is, however, expected to be significantly smaller than the inhalation dose because of the lack of vegetation at the Yucca Mountain site.

A preliminary performance allocation for this issue, for both ground-water and gas-phase transport, is summarized in Table 8.2-8. Because Issue 1.2 is concerned with only the undisturbed performance of the disposal system, it is appropriate to allocate performance against the expected transport pathways. The table shows the primary barriers that will be relied upon to limit radionuclide transport along each pathway. Also shown are the measures that will be used to evaluate the performance of the barriers. More detailed performance measures are used for the gaseous pathway than for the ground-water pathway. For the gaseous pathway, possible doses can be received externally, as well as internally by either inhalation or ingestion. For the ground-water pathway, only an ingestion dose is possible. For the gaseous pathway, however, no significant individual external dose is expected through the skin from the weak, carbon-14 beta radiation. The only significant pathways for internal dose are through inhalation of carbon-14 dioxide in breathing air and by ingestion of food items grown in the area that contain carbon-14.

Goals for the testing program in terms of specific site characteristics to be evaluated and parameter values that would contribute to a favorable resolution of this issue are identified in the detailed strategies discussed in Section 8.3.5.13. Identification of primary barriers and performance measures and associated goals and parameters helps to orient the testing program toward obtaining the information to resolve this issue.

Table 8.2-8. Transport pathways, barriers, and performance measures for Issue 1.2 (individual protection)

Transport mode	Primary barriers	Performance measure
Ground water	Unsaturated zone and saturated zone	Individual dose (whole body)
Gas phase	Waste container and overburden	Individual dose (whole body)
		External
		Internal Inhalation Ingestion

8.2.2.1.1.3 Summary of ground-water protection -- Issue 1.3: Will the mined geologic disposal system meet the requirements for the protection of special sources of ground water as required by 40 CFR 191.16?

Regulatory background

Issue 1.3, which is discussed in Section 8.3.5.15, addresses the U.S. EPA requirements of 40 CFR 191.16 that limit the concentrations of radioactive waste products allowed in special sources of ground water. The regulations require that, for 1,000 years after disposal and considering undisturbed performance, the average annual radionuclide concentration in water withdrawn from a special source of ground water shall not exceed:

1. 5 picocuries per liter of radium-226 and radium-228.

2. 15 picocuries per liter of alpha-emitting radionuclides.

3. The combined concentrations of radionuclides that emit either beta or gamma radiation that would produce an annual dose equivalent to the total body, or any internal organ, greater than 4 millirems per year if an individual consumed 2 liters per day of water.

If the average annual concentration of radionuclides in a special source of ground water exceeds these limits before construction of the repository system, then the repository system may not cause an increase in the average annual concentration of radionuclides greater than these limits.

"Special source of ground water" is defined in 40 CFR 191 as a Class I ground water source that (1) is located within the boundaries of the controlled zone or less than 5 km from the controlled zone boundary, (2) is supplying drinking water for thousands of persons as of the date that Yucca Mountain was chosen for site characterization, and (3) is irreplaceable in that no reasonable alternative source of drinking water is available to that population.

"Undisturbed performance" means the predicted behavior of the disposal system, including consideration of the uncertainties in predicted behavior, if the disposal system is not disrupted by human intrusion or the occurrence of unlikely natural events.

Technical background and licensing strategy

Three sources of ground water exist within 5 km of the controlled zone boundary. They are (in stratigraphic order) the valley-fill aquifer, the tuff aquifer, and the lower carbonate (Paleozoic) aquifer. Preliminary hydrologic and demographic water-use data presented in Chapter 3 suggest that none of these aquifers meet all three special-source criteria. All the aquifers meet the criterion for location (criterion 1). But only the valley-fill aquifer was serving a population of thousands at the time Yucca Mountain was chosen for site characterization (criterion 2). Also, only the lower carbonate aquifer supplies baseflow to a critical habitat and is therefore considered to be irreplaceable (criterion 3).

Presently, none of the three aquifers is considered vulnerable to contamination within 1,000 years of waste emplacement, on the basis of the hydrologic and geochemical characteristics of the unsaturated zone within which the repository would be located. In addition to being protected by the unsaturated zone, the lower carbonate aquifer has a higher potentiometric head than does the overlying tuff aquifer, in the vicinity of the site. Therefore, the potential flow direction is upward from the lower carbonate aquifer rather than downward into it.

A dual licensing strategy will be used in resolving Issue 1.3, either element of which can be used to demonstrate that the issue is resolved. The first part of the strategy consists of demonstrating with a high level of confidence that ground-water sources do not meet the three criteria and, therefore, that no special sources of ground water exist, in the vicinity of the site. The second part of the strategy is to show that the concentrations of radionuclides in any of the ground-water sources during the first 1,000 yr after disposal will not exceed the limits specified in 40 CFR 191.16.

Site investigations planned within the geohydrology and human interference programs will aid in establishing with a high level of confidence whether any of the three aquifers meet all the criteria for special-source status. Demonstrating that the EPA limits will not be exceeded will be done only if (1) it is not possible to show with a high level of confidence that no special sources of ground water exist, or (2) a special source of ground water is in fact identified in the vicinity of the site. The approach will be to calculate the quantity of waste products that could be released and transported to a special source of ground water during the first 1,000 years after disposal. This will be demonstrated by using an assessment similar to that used by Issue 1.1 (total system performance). The difference between the assessments is that the parameters and scenarios to be considered by Issue 1.3 will cover only the first 1,000 years after disposal under expected conditions, whereas Issue 1.1 examines releases over 10,000 years under both normal and disturbed conditions.

Table 8.2-9 summarizes the system elements and performance measures associated with both possible strategies for resolving Issue 1.3. Goals for the testing program in terms of specific site characteristics to be evaluated and parameter values that would contribute to a favorable resolution of this issue are identified in the detailed strategy discussed in Section 8.3.5.13. Identification of primary barriers and performance measures and associated goals and parameters helps to orient the testing program toward obtaining the information to resolve this issue. The required site data will be compiled and evaluated through the geohydrology and human interference characterization programs.

Table 8.2-9. Performance measures and parameters

System element	Performance measure
Saturated zone	Existence of special source of ground water
Engineered barrier system with unsaturated zone as backup	Waste concentration in special source aquifer within 1,000 yr after disposal

8.2.2.1.1.4 Summary of waste package containment -- Issue 1.4: Will the waste package meet the performance objective for containment as required by 10 CFR 60.113?

Regulatory background

Issue 1.4 addresses the requirement for containment by the set of waste packages as required by 10 CFR 60.113. In addition, Issues 1.1 (total system performance) and 1.5 (engineered barrier system release rates) require information developed under this issue as input to their analyses. Section 8.3.5.9 provides a detailed discussion of the regulatory basis and resolution strategy for Issue 1.4.

The NRC regulations, specifically 10 CFR 60.113, address the performance of the waste package during the period when temperatures and radiation levels are highest. This regulation states in part

> the engineered barrier system shall be designed, assuming anticipated processes and events, so that: (A) Containment of 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.

The NRC does not define substantially complete containment.

Technical background and licensing strategy

One of the first steps in the discussion of this issue involves interpretation of the regulatory term "substantially complete containment." A precise interpretation depends to a great degree on the level of waste package performance needed at the site. This cannot be determined until additional information regarding site conditions and the characteristics of alternative materials and waste package designs subject to these site conditions is available. For the purpose of the SCP, tentative design

objectives have been developed to guide the testing and design programs. Information developed during site characterization may dictate both the need for additional testing and design activities and for other design objectives to guide these activities. Therefore, the design objectives may evolve during the site characterization program.

The following three design objectives have been set as current program goals for substantially complete containment:

1. By virtue of the intrinsic properties and design of the waste package components subjected to the range of conditions anticipated in the underground facility, 80 percent or more of the waste packages will retain all their radioactivity for a containment period of 1,000 yr after permanent closure of the repository.

2. At any time during the containment period, at least 99 percent of the radioactivity resulting from the original waste emplaced in the underground facility will be retained within the set of waste packages.

3. Any releases from the waste packages that occur during the containment period should be gradual such that releases from the engineered barrier system in any one year during this period should not exceed one part in 100,000 of the total inventory of radionuclide activity present in the geologic repository system in that year.

The components of the waste package, together with the near-field environment as altered through engineering design, has been chosen as the basis for the strategy to achieve and demonstrate that the substantially complete containment performance objective has been met. The system elements relied upon in the reference case to achieve and demonstrate the performance objective are (1) the container, (2) the engineered environment, and (3) the waste form.

The first design objective for substantially complete containment, i.e., that more than 80 percent of the containers will remain unbreached, will be achieved by selecting a proper container material and design such that the time to loss of substantially complete containment is longer than 1,000 years. The approach to projecting the time to loss of substantially complete containment utilizes a series of computational models representing the container degradation modes and the environmental conditions.

The second design objective would be automatically met if the third design objective is met, since the engineered barrier system boundary release and the waste package release are the same under the current engineered barrier system design and performance allocation. The third objective is more stringent than the second because it restricts the amount of release on an annual basis. In addition, the dominance of the total inventory by the gap and grain boundary elements during early periods forces the performance allocation to meet the third objective on a radioisotope specific basis. It is believed that reliance on the three system elements stated earlier will be sufficient to demonstrate that the second and third objectives are met.

The resolution of Issue 1.4, therefore, hinges on two important considerations, i.e., degree of containment and duration of containment for ensemble of waste packages, which are closely interrelated. Projections of both the duration and the degree of containment will determine if the objectives for substantially complete containment have been met.

Breach of a container does not necessarily constitute the loss of containment. Thus, container integrity alone does not determine the degree of containment. Breaching of a container is a necessary condition for release of radionuclides from the waste form, but not a sufficient condition for this release, except for the release of radionuclides in the form of gas which could occur for any carbon-14 that exists on the surface of spent-fuel cladding and other assembly hardware.

The period of concern is the first 1,000 years after closure of the repository, when the temperatures and radiation levels are high. During this period, the containers will continuously degrade, the environmental conditions will continuously change, and the specific radionuclides that dominate the repository inventory will change significantly due to differing decay rates.

The projection of degradation of the metal container and releases from the waste package over such a long time period (1,000 years) will involve considerable uncertainty. Information regarding the characteristics of container materials and degradation modes, and information from Issue 1.5, such as the models for radionuclide release from the waste package, will be used to estimate the distribution of times to loss of substantially complete containment of the ensemble of waste packages under anticipated processes and events, taking into account the uncertainties in such estimates. This result will be used in the resolution of the issue.

The duration of containment depends on the integrity of the waste container. An investigation of container materials will be conducted to determine which will provide the characteristics desired for the container. At present, six candidate materials from two alloy groups are being considered. They are, from the copper alloy group, high-purity oxygen-free copper (CDA 102), aluminum bronze (CDA 613), and 70/30 copper-nickel (CDA 715), and, from the austenitic alloy group, AISI type 304L and 316L stainless steel and nickel-based Alloy 825. Material selection criteria will be developed, taking into account factors such as material degradation, predictability of material behavior, interaction with other system elements, fabricability, and uncertainties. Note that no container material has been selected yet, although 304L stainless steel has served the function of a reference material only to provide necessary information for the waste package and repository design analysis. In an unlikely event that no metal from the six candidates or other metal alloy group could be chosen to satisfy the requirements, an alternative ceramic-lined container will be evaluated. Currently, alumina (Al_2O_3) is being considered as the prime candidate, although other ceramic materials will also be considered.

Factors important to the metal degradation that will be considered in the above investigation include low temperature corrosion, general aqueous corrosion, hydrogen effects, localized attack such as pitting and crevice

corrosion, intergranular and transgranular attack, stress corrosion cracking, and other metallurgical and mechanical effects. The results will be used in developing models needed to predict the rate of degradation of the container material, which in turn will be used in selecting the container material and in estimating the performance of the container in the repository environment for significant processes and events.

The results of these evaluations will be used to predict the distribution of failure times for the containers. The time estimated for failure of 20 percent of the containers will address the question of the duration of containment with respect to objective 1. The percentage of containers estimated to have failed within any given interval of time will provide the basis for estimates of releases from failed packages in addressing objectives 2 and 3, which relate to the degree of containment.

The degree of containment depends on the inventory and distribution of radionuclides present inside the waste form and the factors influencing the release of the radionuclides. These factors include the condition of the container, the condition of the waste form (e.g., cladding and state of UO_2 oxidation), and the environment (quantity and quality of water contacting the containers).

During the early years after closure (zero to approximately 100 years, when the number of failed packages is expected to be low), the waste package and near-field rock will experience temperatures exceeding the boiling point of water. As a result, although there may be some adverse effects of these temperatures in this period (e.g., oxidation of fuel within failed cladding), the environment will be dry for the majority of the waste packages, thus precluding the possibility of liquid water contacting these packages. The dominant contribution to the total radioactivity during this period comes from only four radionuclides with relatively short half-lives. These include Cs-137 and Sr-90, and their very short-lived daughter products, Ba-137m and Y-90. Cs, and to a lesser extent Sr, can migrate during reactor operation to grain boundaries and the pellet-cladding gap in the fuel, where they are readily accessible and releasable when contacted by water. In addition, there are significant quantities of the radionuclides Kr-85 and H-3 present in the spent fuel. A small percentage of the Kr-85 may be available for immediate release in gaseous form from the pellet-cladding gap. This period is also characterized as the period when a significant amount of oxidation of the UO_2 fuel may occur in the failed containers with failed cladding due to the high temperature and the availability of oxygen in the repository air-steam environment. The oxidation of UO_2 has two significant effects: (1) to increase the fraction of gap and grain boundary elements available for rapid release in water and (2) to increase the fraction of Kr-85 inventory in such oxidized fuel to be released rapidly as a gas.

During the next two hundred years (approximately 100 to 300 years after closure), the inventory of Kr-85 and H-3 will have decayed to an insignificant level, and the inventory of gap and grain boundary radionuclides (Cs, Sr, and their short-lived daughters), will have decayed to a small percentage of the total activity. The percentage of the inventory accounted for by the actinides rises during this period and the inventory is dominated by the Am and Pu isotopes 300 years after closure. Borehole temperatures will be

considerably lower than in the first 100 years but will still in most instances exceed the boiling temperature of water. The rate of fuel oxidation will be slower than the rate during the first 100 years since temperatures in the emplacement boreholes will be decreasing. These temperatures are expected to remain above the boiling point of water for most waste packages, however. Therefore, the possibility of container and cladding corrosion will still be relatively low.

From 300 to 1,000 years after closure, slow cooling of the repository will continue. Nevertheless, a substantial fraction of the waste packages could remain above the boiling point of water throughout this period. During this period, the total inventory decreases significantly, and Am and Pu continue to dominate the inventory. By 300 years after closure, the makeup of the gap and grain boundary inventory has changed significantly from earlier times. The contribution of Tc-99 to the fraction available for rapid release is comparable to that Cs and Sr at 300 yr and becomes the dominant radioactivity in this fraction by 1,000 yr. The C-14 inventory remains essentially constant during this period so that relative contribution of carbon-14 to the total inventory increases with time. Fuel temperatures are expected to drop to a value at which oxidation of UO_2 fuel proceeds quite slowly.

Because of the different radionuclide compositions, different potential release characteristics and the continuously changing environment at different time intervals previously discussed, the licensing strategy for Issue 1.4 is to allocate different performance levels to system elements at different time intervals. Table 8.2-10 shows the system elements relied on to resolve Issue 1.4 and the associated performance measures. Goals for the testing program, in terms of specific characteristics to be evaluated and parameter values that would contribute to a favorable resolution of this issue, are identified in the detailed strategy discussed in Section 8.3.5.13. Because of the difference in behavior of the glass and spent fuel waste forms, different performance parameters are assigned to them. Identification of elements and performance measures, and associated goals and parameters, helps to orient the testing program toward obtaining the information to resolve this issue.

Activities for Issue 1.4 concentrate on the metal container performance. The quantity of releases and the mechanisms of release during the containment period are closely tied to the assessment of releases during the post-containment period (Issue 1.5). Discussion of all activities related to waste-form characterization and performance, such as matrix dissolution, cladding degradation, and UO_2 fuel oxidation, are discussed in the strategy for Issue 1.5. Resolution of both Issues 1.4 and 1.5 depends on the engineered environment discussed in the strategy for Issue 1.10.

Table 8.2-10. System elements and performance measures to resolve Issue 1.4

System element	Performance measure
Container	Fraction of containers that have failed
Engineered environment	Quantity of liquid water that can contact the container
	Quality of liquid water that can contact the container
Waste form	Release rate of radionuclides from the ensemble of breached packages

8.2.2.1.1.5 Summary of the engineered barrier system release rates -- Issue 1.5: Will the waste package and repository engineered barrier systems meet the performance objective for radionuclide release rates as required by 10 CFR 60.113?

Regulatory background

Issue 1.5 (discussed in Section 8.3.5.10) addresses the requirement for gradual release from the engineered barrier system as required by 10 CFR 60.113. In addition, the resolution strategies for Issues 1.1 (total system performance) and 1.9 (postclosure higher-level findings) require information which is developed under the strategy for this issue. Section 60.113 states in part that the engineered barrier system shall be designed so that, assuming undisturbed performance of the geologic repository, "Any release of radionuclides from the engineered barrier system shall be a gradual process which results in small fractional releases to the geologic setting over long times" and

> The release rate of any radionuclide from the engineered barrier system following the containment period shall not exceed one part in 100,000 per year of the inventory of that radionuclide calculated to be present at 1,000 years following permanent closure, or such other fraction of the inventory as may be approved or specified by the Commission; provided that this requirement does not apply to any radionuclide which is released at a rate less than 0.1% of the calculated total release rate limit. The calculated total release rate limit shall be taken to be one part in 100,000 per year of the inventory of radioactive waste, originally emplaced in the underground facility, that remains after 1,000 years of radioactive decay.

The question of whether a part of the host rock is included in the engineered barrier system has not yet been resolved. For the purpose of the SCP, the following interpretation for the EBS boundary has been adopted:

> The boundary for evaluation of releases from the engineered barrier system relative to the requirements of 10 CFR 60.113 is . . . conservatively chosen to coincide with the surfaces of the excavations within the underground facility. In making this evaluation, the release rates calculated are those corresponding to the net flux of radionuclides transported into the host rock.

Technical background and licensing strategy

Issue 1.5 deals with the release from the engineered barrier system (EBS) boundary as interpreted in the regulatory background description. The requirements for the EBS annual release are isotope-specific and based on the inventory of each radionuclide present at 1,000 years after permanent closure. Radionuclides released at a rate less than 0.1 percent of the calculated total release rate limit are excluded from this requirement. This reduces the number of radionuclide species that need to be considered.

For most radionuclides, the rates of release from the EBS depends primarily on (1) the quantity and quality of the water contacting the waste form and transporting the dissolved radionuclides to the EBS boundary, and (2) the release characteristics of the waste form itself. The quantity and quality of water are discussed in the strategy to resolve Issue 1.10 (Section 8.3.4.2). The strategy to resolve Issue 1.5 uses information developed for the resolution of Issue 1.10 and concentrates on the waste form performance.

The projection of the release rate for long times into the future will necessarily involve considerable uncertainty. Models developed through the activities to resolve Issue 1.5, including the EQ3/6 geochemical model, together with information regarding container degradation and the waste package environment from the strategy for resolving Issues 1.4 and 1.10, will be used to determine the release rates of radionuclides from the waste package and the EBS boundary.

An additional investigation is included in the activities for Issue 1.5 to determine the amount of radionuclides leaving the near-field environment of the waste package. The purpose of this investigation is to provide information to predict a source term for use in Issue 1.1, as well as for use in the comparative evaluations of the sites required by 10 CFR Part 960.

The strategy for resolving Issue 1.5 is based on (1) present knowledge of the repository emplacement environment, (2) the data gathered on waste form performance in environments that can be related to the projected repository environment, and (3) the use of models to assess the performance of various system elements. The primary system elements that are relied on and associated performance measures are shown in Table 8.2-11.

Because the candidate repository horizon is in the unsaturated zone, only a negligible amount of water is expected to come into contact with the majority of the waste packages. Strategies are developed, however, for both

Table 8.2-11. Performance measures and parameters for waste form for Issue 1.5 (engineered barrier system performance)

System element	Performance measure
Engineered environment	Quantity of liquid water that can contact the container
	Quality of liquid water that can contact the container
Waste form	Release rate from bare waste form inside failed containers

the expected case (no liquid water) and the bounding case, in which all containers are allowed to experience a bounding water flux even though this is not expected to occur.

Under the expected conditions (i.e., no liquid water), the only radionuclide of concern would be the carbon-14 on the exterior of cladding and assembly components, which could be released in a gaseous state. Data are insufficient at present to assess the rapid release of carbon-14 dioxide from spent fuel. However, because of the lower gamma fluxes and temperatures in the controlled release period, the present data suggest that the release rate will be sufficiently low to meet the requirement of 10 CFR 60.113. Because of the uncertainties in the release rates, mechanisms, and locations of carbon-14, alternative approaches to carbon-14 control have been developed in Section 8.3.5.10.

Although incomplete, data presently available regarding the dissolution of the actinides and fission products in the whole matrix show that their individual dissolution rate can meet the 1×10^{-5} per year requirement on individual isotopes. Most of these elements are limited by their solubilities. In addition, the release rate may be constrained by the rate of dissolution of the waste form. The results of activities for Issue 1.5 will be used to develop models for the waste form dissolution and water flow into and out of a breached container.

Under the bounding case where all containers can experience a bounding flux of liquid water, the actinides and other matrix elements will be controlled by the limitations in their dissolution and precipitation as discussed above. Radionuclides present in the gap and grain boundary inventory both from oxidized (but not wet during the containment period) fuels and from unoxidized fuel (that breached during the post-containment period) could be released in an amount such that the release rate limit is exceeded in the bounding case. Additional system elements, such as cladding, and the dilution resulting from the accumulation of liquid water in the container through

a long period of time will be relied upon for the gap and grain boundary element control. The existing information is not sufficient, however, to allow selection of the specific system elements to be relied on and to allocate quantitative performance goals for these elements. Detailed strategy for the bounding case will evolve as more waste-form testing data and information from site characterization become available.

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

Regulatory background

Issue 1.6, which is discussed in Section 8.3.5.12, addresses the NRC performance objective for pre-waste-emplacement ground-water travel time along the fastest path of likely radionuclide travel from the disturbed zone to the accessible environment. As stated in 10 CFR 60.113(a)(2), this travel time should be "at least 1,000 years or such other travel time as may be approved or specified by the Commission." The disturbed zone is defined in 10 CFR 60.2 as that portion of the controlled area where the physical or chemical properties have changed as a result of underground facility construction or as a result of heat generated by the emplaced radioactive wastes such that performance of the repository may be significantly affected. The accessible environment is defined as the atmosphere, the land surface, surface water, oceans and the portion of the lithosphere that is outside the controlled area. The controlled area as defined in 40 CFR 191.12(g) is the surface location and the underlying subsurface that encompasses no more than 100 km^2 and extends horizontally no more than 5 km in any direction from the outer boundary of the original location of the radioactive wastes in a disposal system.

Technical background and licensing strategy

A repository at Yucca Mountain would be located in the unsaturated zone at distances ranging from about 150 to 400 m above the water table. The simplest conceptual model for the paths for likely radionuclide travel has two parts between the disturbed zone and the accessible environment. One part is generally vertically downward through the unsaturated zone to the water table, and the second part is generally horizontal through the saturated zone to the accessible environment boundary. The activities to resolve this issue (described in Section 8.3.5.12) are designed to provide the information necessary to determine distribution of pre-waste-emplacement ground-water travel times along the fastest path of likely radionuclide travel from the disturbed zone to the accessible environment. Ground-water travel time is assumed to be the time that it would take inert tracer particles released at the disturbed zone to reach the accessible environment. This is a valid approach since, statistically, the rate of motion for some water molecules and hence for any entrained species may be greater than the bulk rate of ground-water flow. The important consideration relative to 60.113 is the

rate of radionuclide travel along the fastest such path, ignoring sorption or other contaminant retardation processes. Both dispersion and diffusion will tend to spread travel times.

Current understanding of ground-water travel through the unsaturated zone suggests that it is practical to consider two general modes of flow: matrix and fracture. Matrix flow is through pores in the rock matrix. Fracture flow is defined for this issue as continuous flow through fractures or faults, which may occur in instances where water is laterally diverted to a fault, or as the result of episodic high-intensity infiltration events or other means that cause the local flux to exceed the saturated hydraulic conductivity of the matrix. Under current moisture flux conditions in the unsaturated zone at the site, matrix flow with potential discontinuous localized regions of flow through fractures is expected to predominate in the unsaturated zone. In the saturated zone, the dominant mode of water movement is expected to be fracture flow.

The strategy for demonstrating compliance with the NRC's ground-water travel time performance objective is to rely on each of several hydrogeologic units as a barrier to flow. Within each unit, different types of processes will be operating (e.g., dispersion and advection in rock pores, fracture flow, and diffusion) that will affect the flow. These processes, as well as uncertainties with respect to flow pathways, flow mechanisms, and the spatial distribution of rock characteristics, are specifically addressed in the strategy.

Six steps are recognized in the performance allocation phase of the resolution strategy for Issue 1.6. These are (1) the identification of the hydrogeologic units along potential flow paths to the accessible environment, (2) the identification of processes acting within each unit, (3) the prioritization of hydrogeologic units and flow processes within these units as primary, secondary, and auxiliary contributors to meeting the 1,000-year ground-water travel time requirement, (4) the establishment of measures of performance for each unit, (5) the assignment of goals to each performance measure, and (6) the identification of parameters judged sufficient to predict the performance measure with reasonable assurance for each of the hydrogeologic units.

Table 8.2-12 lists the hydrogeologic units that are to be considered in the evaluation of the ground-water travel time, starting with the Topopah Spring welded unit and proceeding downward to the saturated zone. Prioritization of the hydrogeologic units is presented in the second column of Table 8.2-12, and the flow processes expected to act within the units are indicated in the third column. The performance measure for each hydrogeologic unit given in the last column is the ground-water travel time through the unit. The goals for the performance measures and the parameters needed to evaluate the travel times are discussed in detail in Section 8.3.5.12. Identification of barriers and performance measures, and associated parameters and goals, helps to orient the testing program toward obtaining the information to resolve this issue.

Table 8.2-12. Summary of performance allocation for Issue 1.6

Components	Reliance priority	Process	Performance measure
Topopah Spring welded unit	Secondary	Darcy flow[a]	GWTT[b]
Calico Hills vitric unit	Primary	Darcy flow	GWTT
Calico Hills zeolitic unit	Primary	Darcy flow	GWTT
Prow Pass welded unit	Auxiliary[c]	Darcy flow	GWTT
Prow Pass nonwelded unit	Auxiliary	Darcy flow	GWTT
Bullfrog welded unit	Auxiliary	Darcy flow	GWTT
Bullfrog nonwelded unit	Auxiliary	Darcy flow	GWTT
Saturated zone	Secondary	Darcy flow	GWTT

[a]Darcy flow with both advection, dispersion and diffusion will be relied upon if substantial continuous fracture flow is identified during characterization.
[b]GWTT = ground-water travel time.
[c]Classed as auxiliary if a significant thickness of the unit occurs along the flow path.

A series of activities will be conducted to support resolution of this issue. Evaluations will be conducted to determine the appropriate calculational models for the hydrologic flow system and for identifying the fastest likely flow path within that system. The location of this path will be determined, and flow characteristics along the path will be established. The nature and availability of calculation models will be assessed to help determine the relative importance of the various parameters to the calculation of travel times. Finally, the cumulative distribution of pre-waste-emplacement ground-water travel times along the fastest likely path will be predicted. An evaluation will also be conducted to establish the boundaries of the disturbed zone, which must serve as the origin for the travel time calculation. A complete discussion of the resolution strategy for Issue 1.6 is given in 8.3.5.12.

8.2.2.1.1.7 Summary of performance confirmation -- Issue 1.7: Will the performance confirmation program meet the requirements of 10 CFR 60.137?

Regulatory background

Issue 1.7, discussed in Section 8.3.5.16, addresses the NRC requirements for performance confirmation. Section 60.137 of 10 CFR Part 60 requires that the repository be designed to permit implementation of a performance confirmation program in accordance with the requirements of Subpart F of 10 CFR Part 60. Subpart F gives both general and specific requirements for a program directed toward confirming that the actual performance of the repository is within the limits assumed in the license application.

As defined in 10 CFR Part 60.2, "performance confirmation means the program of tests, experiments, and analyses conducted to evaluate the accuracy and adequacy of the information used to determine with reasonable assurance that the performance objectives for the period after permanent closure will be met." The DOE understands the intent of Subpart F to be the confirmation, where practicable, that site and design conditions and the performance of engineered and natural barriers are within the ranges predicted in the license application. The DOE considers that the repository conditions and design assumptions integral to demonstrating compliance with the performance objectives should be the subject of the performance confirmation program. The testing and monitoring program for performance confirmation is one part of the DOE's confirmation and monitoring program.

The DOE confirmation and monitoring program is composed of two aspects: preclosure monitoring and confirmation, and postclosure performance confirmation. The preclosure monitoring and confirmation program consists of those activities associated with the preclosure performance objectives of 10 CFR 60.111. Both aspects are included under one larger program because the baseline information (description follows) and the testing and monitoring activities for both programs share many common components. Because Issue 1.7 is concerned with the confirmation of postclosure performance as outlined in 10 CFR Part 60, Subpart F, the remainder of the discussion here will focus on the postclosure performance confirmation program.

Technical background and licensing strategy

The postclosure performance confirmation program is essentially the program of testing and monitoring activities associated with the confirmation of the performance assessment calculations presented in the license application. These calculations will provide reasonable assurance that the repository will meet the NRC's postclosure performance objectives. The purpose of the confirmation program is to supply added confidence beyond that supplied in the license application that the repository will meet the long-term performance objectives for containment and isolation.

During site characterization, information is gathered to select a site, to develop a suitable design, and to make defensible performance assessments to establish with reasonable assurance that the performance objectives will be met. The postclosure performance issues have been designed to address the

NRC's performance objectives. Through the resolution of these issues (Issues 1.1 through 1.6), information will be made available to demonstrate compliance with the performance objectives. The issue resolution process is an iterative loop of testing and analyses. When sufficient information is gathered to prepare defensible performance assessments for the license application, the issue resolution process with respect to site characterization is complete. The information supporting the resolution of performance issues, and thus demonstrating compliance with the performance objectives, is included in the license application. This information then becomes the subject of postclosure performance confirmation program testing and monitoring. Plans for the confirmation of the license application predictions will be available at the time of the license application.

The testing and monitoring activities of the postclosure performance confirmation program are developed in parallel with the issue resolution process. The resolution of Issue 1.7, therefore, is linked closely to the resolution of Issues 1.1 through 1.6. The performance assessments and issue resolution strategies developed during site characterization to support issue resolution in the license application will determine the detailed content of the postclosure performance confirmation program. At the beginning of site characterization, only very general plans for the program can be defined, which will mature in parallel with the development of assessments needed for the license application. Preliminary design provisions for accommodating performance confirmation testing and monitoring in the repository are given in the SCP Conceptual Design Report (SNL, 1987). Early interactions with the NRC before the license application will define the general scope of the program. As issues are resolved, the testing and monitoring needed for the confirmation can be more clearly defined. By the time of license application submittal, these testing and monitoring activities should be well defined. More formal interactions with the NRC during the license application review may further develop the plans in response to the NRC concerns at these times. Results of the testing and monitoring program are to be reviewed by the NRC as part of the license amendment for permanent closure.

As stated previously, Issue 1.7 focuses on the postclosure performance confirmation program responding to Subpart F of 10 CFR Part 60. Based on the content of Subpart F, the objectives to be met by the postclosure performance confirmation program can be described as follows:

1. Develop baseline information -- develop information on subsurface conditions important to the performance assessments to be given in the license application and those aspects of design integral to the assessments. Predict changes in this information as a result of construction and operation.

2. Confirm baseline information -- confirm that actual subsurface conditions and the changes in those conditions resulting from construction and operation are within the limits described in the license application.

3. Confirm barrier and seal performance -- confirm that natural and engineered systems and components that are designated or assumed to operate as barriers after permanent closure are functioning as intended and anticipated within the limits described in the license application.

Table 8.2-13 shows the sequencing of activities in the performance confirmation program relative to the stages of the overall repository program. The program is divided into the baseline and confirmation phases, with the docketing of the license application serving as a convenient demarcation line between phases. Before the license application, baseline data on conditions, predicted changes in those conditions as a result of construction and operation, and performance predictions are developed based on site characterization testing. With the docketing of the license application, the DOE begins the formal licensing process with the NRC.

The two-fold division of the confirmation phase corresponds to the license application review period and the construction and operation period of repository development. During license application review, the DOE will continue to conduct testing around the site and in the exploratory shaft facility. This testing will serve to confirm baseline conditions and support the predictions of changes to these conditions. Once construction and operation take place, predicted changes in conditions as well as performance can be confirmed by the testing and monitoring programs.

The baseline phase of the performance confirmation program extends up to the docketing of the license application. The testing conducted during site characterization will provide the baseline data needed for performance confirmation. As the issue resolution strategies evolve during site characterization, additional baseline data may be found necessary to satisfy the requirements of performance confirmation.

Performance confirmation activities during the baseline phase will consist of those activities necessary to develop baseline information that, except for the performance confirmation requirements, would not otherwise have been conducted. However, all the baseline information necessary on parameters and natural processes pertaining to the geologic setting that may be changed by site characterization, construction, and operational activities is expected to be collected during site characterization activities necessary to support the license application. If any additional information is required, it will be collected under the baseline phase of the postclosure performance confirmation program during site characterization. Some baseline testing will extend beyond the license application docketing date because of the nature of the testing. For these tests, the distinction between the baseline and the confirmation phases is somewhat artificial.

Site characterization activities in support of the license application will (1) establish conditions important to performance, (2) predict changes in these conditions due to repository construction and operation, and (3) validate models. The baseline phase performance confirmation program will produce plans for the confirmation of the accuracy and adequacy of the information used to determine that the performance objectives will be met.

Table 8.2-13. Phases of the performance confirmation program

Objectives of performance confirmation	Baseline phase	Confirmation phase: Interim confirmation	Confirmation phase: Construction and operation confirmation
1. Develop baseline and predicted changes in baseline	X		
2. Confirm baseline conditions and changes		X	X
3. Confirm barrier and seal performance			X
	Site characterization/ site selection License Application	License Application Review	Construction and operation

PHASES OF THE OFFICE OF GEOLOGIC REPOSITORY PROGRAM

CONSULTATION DRAFT

Both the postclosure performance confirmation program and the preclosure monitoring and confirmation program, associated with preclosure performance objectives, draw upon baseline data collected during site characterization. This baseline data, some of which are common to both programs, determines the extent of the testing and monitoring activities needed for the pre- and postclosure programs. During the baseline phase, details of the performance confirmation program will evolve in parallel with the development of the performance assessments. In the license application, the final assessments of site performance are presented, accompanied by information that describes the testing, monitoring, and any remaining model validation work needed to evaluate the accuracy and adequacy of the information used in those assessments. The repository design given in the license application will also contain any features (test rooms, monitoring stations, etc.) determined necessary for the testing and monitoring described by the plan. To design the repository facilities needed to support the confirmation testing and monitoring, the content of the performance confirmation program must be well developed at the license application stage.

The confirmation phase follows the baseline phase. During the confirmation phase, predictions of baseline conditions and the changes caused by repository construction and operation are to be confirmed, along with barrier and seal performance. As shown on Table 8.2-13, the confirmation phase consists of two divisions: the interim confirmation period (the period after the license application docketing until issuance of the construction authorization) and the construction and operation period (beginning with repository construction). During the confirmation phase, objectives 2 and 3 (Table 8.2-13) will be achieved as described in the following paragraphs.

As mentioned previously, postclosure performance is predicted based on the results of modeling calculations that extrapolate data into the postclosure time frame. To confirm these performance assessments, surrogates for the barrier performance must be defined, that can be measured by field and laboratory testing. These surrogates are appropriately referred to as confirmation measures. These measures are not substitutes for performance but rather testable measures that, if they achieve target values or goals, will give confidence that the performance objectives will be met. These measures are then the focus of the testing, monitoring, and analysis efforts designed to confirm their predicted behavior. For example, corrosion rates could be used as a confirmation measure for the waste-package containment performance objective.

The identification of confirmation measures will likely have a genetic relationship to the original performance allocation process begun during site characterization. The confirmation measures will probably be closely related to some of the performance measures developed through the performance allocation process and used in the performance assessments in the license application. Confirmation measures will be derived, at a minimum, for waste package containment, engineered barrier release, and backfill and seals behavior. Based on site-specific needs, additional measures may be required. Testing to confirm the predicted values of confirmation measures may be initiated as early as site characterization, but will most likely take place in the construction/operation phase.

Postclosure performance predictions are largely based on numerical modeling and therefore a program for the verification of the codes and validation of the models is an important part of the confirmation program. The models of concern to the performance confirmation program are those used in the license application to predict the values of the confirmation measures and extrapolate to long-term performance. Validation of these models will have begun during the site characterization period and will continue until permanent closure, as needed, until the relevant models are considered validated.

8.2.2.1.1.8 Summary of Siting Criteria -- Issue 1.8: Can the demonstrations for favorable and potentially adverse conditions be made as required by 10 CFR 60.122?

Regulatory background

Issue 1.8 (discussed in Section 8.3.5.17) addresses the NRC Siting Criteria. These criteria, set forth in 10 CFR 60.122, are given in terms of two sets of conditions associated with various human activities and natural characteristics. The NRC states that these conditions, if present at a site, could affect the site's ability to isolate waste. The first set lists 8 favorable conditions that could enhance isolation. The second set lists 24 potentially adverse conditions that could adversely affect isolation.

The Siting Criteria consist of requirements for the demonstrations that must be made for each of these conditions. For each potentially adverse condition, it must be shown that

(i) The potentially adverse human activity or natural condition has been adequately investigated, including the extent to which the condition may be present and still be undetected, taking into account the degree of resolution achieved by the investigations; and

(ii) The effect of the potentially adverse human activity or natural condition on the site has been adequately evaluated using analyses which are sensitive to the potentially adverse human activity or natural condition and assumptions which are not likely to underestimate its effect; and

(iii)(A) The potentially adverse human activity or natural condition is shown by analysis pursuant to paragraph (a)(2)(ii) of this section not to affect significantly the ability of the geologic repository to meet the performance objectives relating to isolation of the waste, or

(B) The effect of the potentially adverse human activity or natural condition is compensated by the presence of a combination of the favorable characteristics so that the performance objectives relating to isolation of the waste are met, or

(C) The potentially adverse human activity or natural condition can be remedied.

The demonstration requirements given for the favorable conditions in 10 CFR 60.122(a)(1) state that

> a geologic setting shall exhibit an appropriate combination of the ...(favorable conditions)...so that, together with the engineered barrier system, the favorable conditions present are sufficient to provide reasonable assurance that the performance objectives relating to isolation of the waste will be met.

As discussed, for the favorable and potentially adverse conditions, the effects on isolation must be evaluated. Isolation is defined by the NRC in 10 CFR 60.2 as "inhibiting the transport of radioactive material so that amounts and concentrations of this material entering the accessible environment will be kept within prescribed limits." The release of radioactive material to the accessible environment during the postclosure period is addressed by the Overall System Performance Objective of 10 CFR 60.112. The NRC postclosure performance objectives for particular barriers, 10 CFR 60.113, state performance requirements for the engineered barrier system and the ground-water travel time. 10 CFR 60.122 requires that it be demonstrated that the potentially adverse conditions do not have a significant effect on the ability of the geologic repository to meet the performance objectives. Investigations related to the favorable conditions are needed only to the extent that existence of these conditions could be expected to lend confidence to the assessment of compliance with the performance objectives and in some way compensate, if necessary, for the effects on waste isolation of potentially adverse conditions.

Technical background and licensing strategy

The technical background for resolving Issue 1.8 is essentially the same as that for Issue 1.1 (Section 8.3.5.13). Both issues must consider the natural processes and human-induced effects operating on the site in order to evaluate the site's performance. Therefore, both issues are interdependent and interactive. They do not, however, have to be structured identically. Although each of the two issues will require both quantitative and qualitative arguments for resolution, the DOE expects that the resolution of Issue 1.8 will rely more heavily on expert geotechnical judgment. The resolution of Issue 1.1 will result in a definitive quantitative demonstration of compliance by the construction of the cumulative complementary distribution function; it will rely on qualitative reasoning primarily for the justification of the conceptual models it uses and for showing the reasonable assurance required by 10 CFR 60.101. Because 10 CFR 60.122 makes explicit reference to meeting the waste-isolation performance objectives, the resolution of Issue 1.8 cannot be wholly qualitative. It can, however, be a forum for full expression of sound qualitative technical judgment on the site's ability to isolate waste. The DOE expects that frequently such judgments can be made without recourse to complex calculations of releases to the accessible environment; for example, modeling of ground-water flow may be used to address increases in water-table elevations and in infiltration.

Issue 1.8 calls for an examination of the natural conditions and processes that exist, or may exist, at the site relative to their potential effects on performance. The potential effects of human interference are also included in the conditions listed in 10 CFR Part 60.122. As with Issue 1.1,

these conditions are included in scenario analyses used to evaluate the effects on performance of the potentially adverse and favorable conditions. The scenarios to be evaluated in Issue 1.1 are based on current understanding of the site. This understanding was developed by considering the natural processes and conditions embodied in the 10 CFR Part 60.122 siting criteria, including both favorable and potentially adverse conditions. The scenarios considered in Issue 1.1, for both nominal (undisturbed) conditions and disturbed conditions, should include all the conditions, processes, and events contained in the siting criteria. As site characterization proceeds, this assumption will be confirmed by the program of geologic investigations to be conducted in and around the site. The characterization investigations will examine the processes and conditions at the site in an iterative fashion with the assessments of performance (Issue 1.1). In this way, any scenarios not initially described will be identified and included in the quantitative performance assessments of Issue 1.1.

Issues 1.1 and 1.8 are therefore interactive in that the qualitative and quantitative analyses of subsystem performance done in Issue 1.8 serve as a confirmation that the quantitative total system performance assessments of Issue 1.1 include all the significant conditions and processes important to site performance. In turn, the identification of the major system performance parameters and their interrelationships in Issue 1.1 serves as a guide to focus and bound the site studies concerned with conditions and processes operative at the site. In developing the program of site characterization testing and analyses, each of the siting criteria has been examined to assume that the data needed to evaluate its presence or absence and potential effects on performance are included in the issues concerning postclosure performance.

Logically, if all concerns of the potentially adverse conditions that are present or could be present at the site are addressed by the performance assessment scenario set, then the effects of the potentially adverse conditions on postclosure repository performance will be evaluated in the performance assessment. The assessment will rely on favorable site characteristics and the repository system design in determining if compliance with the overall system performance objective can be demonstrated. Upon completion of the performance assessment, the effects on postclosure performance of the scenarios associated with the potentially adverse conditions and the way that these effects, if significant, were compensated for will be obtained from the performance assessment. This information is expected to be sufficient for the demonstrations required by 10 CFR 60.122 for the potentially adverse conditions.

The investigation of the favorable conditions of the Siting Criteria is inherent in the overall system performance assessment. The performance assessment evaluates the geohydrologic, geochemical, and rock characteristics of the site. This evaluation will look at the favorable characteristics of the site and assess the potential for these characteristics to enhance isolation and, if necessary, compensate for any adverse effects of the disruptive scenarios that could occur at the site during the postclosure period. The

investigation of the site's favorable characteristics during the overall system performance assessment and the evaluation of the effects of these characteristics on postclosure performance are therefore expected to be sufficient for the demonstrations required for the favorable conditions of 10 CFR 60.122.

More detailed descriptions of the issue resolution strategies for Issues 1.8 and 1.1 are provided in Sections 8.3.5.17 and 8.3.5.13, respectively. The results of the performance allocation of Issue 1.1 identifies the performance parameters, associated goals, and levels of confidence required to address the characteristics of the repository system and the disruptive scenarios. These parameters, goals, and confidence levels are given in Section 8.3.5.13. The parameters needed to address the potentially adverse and favorable conditions of 10 CFR 60.122 are a subset of those for Issue 1.1 and are shown in Section 8.3.5.17.

8.2.2.1.1.9 Summary of issue resolution strategy for postclosure siting guidelines -- Issue 1.9: (a) Can the higher-level findings required by 10 CFR Part 960 be made for the qualifying condition of the postclosure system guideline and the disqualifying and qualifying conditions of the technical guidelines for geohydrology, geochemistry, rock characteristics, climate changes, erosion, dissolution, tectonics, and human interference; and (b) can the comparative evaluations required by 10 CFR 960.3-1-5 be made?

The DOE has established a set of siting guidelines to be used as a basis for evaluating the suitability of potential repository sites during the site selection process. Part (a) of Issue 1.9 addresses those guidelines that are concerned with the postclosure performance of the repository system. These siting guidelines are set forth in 10 CFR Part 960.4. The manner in which the siting guidelines must be addressed during the siting process is described by the Implementation Guidelines (10 CFR Part 960.3).

Part (b) of Issue 1.9 addresses the two evaluations required by the DOE to predict radionuclide releases to the accessible environment under expected conditions during the next 100,000 years (10 CFR 960.3-1-5). These evaluations will be used to compare the expected postclosure performance of acceptable sites. The first comparison will emphasize the performance of the natural barriers; the second will emphasize the performance of the total system. Because of the differences between the guidelines and the comparative evaluations, this issue will be described in two parts. Issue 1.9 is fully described in Section 8.3.5.18.

Regulatory background for Issue 1.9(a)

The postclosure guidelines consist of a system guideline and eight technical guidelines. The system guideline is concerned with the effect of the geologic setting of a site on postclosure performance of the repository system. Each technical guideline is concerned with the effect of some specific

aspect of the setting on postclosure performance. Each guideline has a qualifying condition that must be met for a site to be acceptable. In addition, five of the technical guidelines have at least one disqualifying condition. A site is unacceptable if any one of the disqualifying conditions is found present. The technical guidelines also identify favorable conditions and potentially adverse conditions that describe characteristics of the setting that, if present, could contribute to or detract from the postclosure performance of a site.

The Implementation Guidelines require that the qualifying and disqualifying conditions of the system and technical guidelines be evaluated and that specific findings be made for each condition at principal decision points in the siting process. These findings are stated in 10 CFR Part 960, Appendix III. There are four levels of findings (Table 8.2-14). Lower-level findings (Levels 1 and 3) must be made to determine if a site may be nominated as suitable for characterization or recommended as a candidate site for characterization. Higher-level findings (Levels 2 and 4) must be made to determine if a site may be recommended for the development of a repository. Disqualifying conditions require Level 1 and Level 2 findings, and qualifying conditions require Level 3 and Level 4 findings. Each level has both a positive finding and a negative finding associated with it.

The findings that have already been made and the evidence supporting these findings are given in the NNWSI Project environmental assessment (DOE, 1986b). The available evidence was sufficient to support positive higher-level findings for the qualifying and disqualifying conditions of the dissolution technical guideline and positive lower-level findings for the qualifying and disqualifying conditions of the other technical guidelines and the postclosure system guideline. To determine if the Yucca Mountain site is suitable for the development of a repository, therefore, higher-level findings must be made for the the remaining qualifying and disqualifying conditions.

The DOE Siting Guidelines do not require any findings similar to lower-level or higher-level findings to be made for the favorable or potentially adverse conditions of the technical guidelines. As stated in the Overview of the Guidelines section of the Supplementary Information (DOE, 1984c) for 10 CFR Part 960, these conditions were intended to be used to predict the suitability of a site and provide a preliminary indication of system performance before the start of detailed site characterization studies. These conditions were considered and used in the identification of potentially acceptable sites and in the nomination and recommendation of sites as suitable for characterization. By the completion of site characterization, however, sufficient data will be available to directly evaluate site performance against the qualifying conditions of the system and technical guidelines. Therefore, the favorable and potentially adverse conditions will not be considered in specific terms as they were for the environmental assessment.

Technical background and issue resolution strategy (Issue 1.9(a))

To resolve Issue 1.9(a), sufficient evidence must be available to support either a positive or negative higher-level finding for each qualifying

Table 8.2-14. Findings for qualifying and disqualifying conditions

Disqualifying condition -- lower-level findings		
Level 1	(a)	The evidence does not support a finding that the site is disqualified.
	(b)	The evidence supports a finding that the site is disqualified.
Disqualifying condition -- higher-level findings		
Level 2	(a)	The evidence supports a finding that the site is not disqualified on the basis of that evidence and is not likely to be disqualified.
	(b)	The evidence supports a finding that the site is disqualified or is likely to be disqualified.
Qualifying condition -- lower-level findings		
Level 3	(a)	The evidence does not support a finding that the site is not likely to meet the qualifying condition.
	(b)	The evidence supports a finding that the site is not likely to meet the qualifying condition, and therefore the site is disqualified.
Qualifying condition -- higher-level findings		
Level 4	(a)	The evidence supports a finding that the site meets the qualifying condition and is likely to continue to meet the qualifying condition.
	(b)	The evidence supports a finding that the site cannot meet the qualifying condition or is unlikely to be able to meet the qualifying condition, and therefore the site is disqualified.

and disqualifying condition associated with postclosure repository performance. Each of the qualifying conditions makes reference to regulatory requirements of the NRC (specifically, 10 CFR Part 60). To support higher-level findings for the qualifying conditions, evidence must show that the geologic setting was taken into consideration in the evaluations of compliance with the associated NRC regulatory requirements and that the geologic setting as a whole (for the system guideline) and the various aspects of the setting (for the technical guidelines) will not prevent compliance with the NRC regulations. The disqualifying conditions are also related to NRC regulations, but not always as explicitly as the qualifying conditions.

The first step is to eliminate from further consideration the qualifying and disqualifying conditions for which higher-level findings have already been made. This is true for the qualifying and disqualifying conditions of the dissolution technical guideline. Next, for each remaining condition, it is determined whether evidence presently available is sufficient to support a higher-level finding. This evidence consists of the information presented in the NNWSI Project environmental assessment (DOE, 1986b) and in Chapters 1 through 7 of the SCP.

For the qualifying and disqualifying conditions for which the available evidence is not adequate, the planned site characterization studies are reviewed to determine if the conditions will be investigated. For most of the conditions, this is accomplished by evaluating the resolution strategies of the other postclosure performance issues (Issues 1.1 through 1.6 and Issue 1.8). These other performance issues are responsible for assessing the ability of the site to comply with the postclosure regulatory requirements of the NRC. As previously discussed, most of the qualifying and disqualifying conditions reference NRC regulatory requirements, and evidence to support a higher-level finding must show that the condition does not prevent compliance with the referenced requirements. Therefore, if the conditions are being considered in the assessments of compliance, the assessments are expected to make the evidence available to support higher-level findings. Higher-level findings for the remaining conditions (e.g., the disqualifying condition for the erosion guidelines which requires a repository depth of at least 200 meters) will be based on available site and design information.

If the evidence shows that a negative higher-level finding must be made for any one of the conditions, i.e., that a disqualifying condition is present or that a qualifying condition is not present, then the site is disqualified. This evaluation continues until positive higher-level findings can be supported for all the conditions or until a negative higher-level finding must be made.

If, in evaluating the results of the assessments, it is found that the information is insufficient to support a higher-level finding for a qualifying or disqualifying condition, the resolution strategies of the appropriate performance issues are again reviewed to determine if, in fact, the condition was considered. If not, the strategy is revised to incorporate the condition, new information needs are identified as necessary, and compliance is reassessed.

Regulatory background for Issue 1.9(b)

Following the characterization of candidate sites and before recommending a site for repository development, the DOE will require comparisons of the postclosure performance of the repository systems proposed for each candidate site. The Implementation Guidelines, in 10 CFR 960.3-1-5, provide rules for these site comparisons. The guidelines state that these comparisons will "evaluate predicted releases of radionuclides to the accessible environment." These releases will be evaluated by combining "releases of different radionuclides ... by the methods specified in Appendix A of 40 CFR Part 191."

Two evaluations are required to predict releases for the 100,000-year period following repository closure. First, the sites shall be compared with emphasis placed on the natural barrier system of each site. The second comparison will evaluate the expected performance of the total repository system, including both the natural and engineered barrier systems. In making the comparative evaluations, only those natural processes and events that are considered likely to occur or exist at the site over the next 100,000 years need to be taken into account.

Technical background and issue resolution strategy (Issue 1.9(b))

The resolution of Issue 1.9(b) will rely on the activities of Issue 1.1 (Section 8.3.15.13). Issue 1.1 addresses the NRC's overall system performance objective (10 CFR 60.112). For the resolution of Issue 1.1, an assessment of the total system performance is made to predict the performance of the total repository system over the next 10,000 years. This assessment will consider both expected conditions and disruptive conditions.

To resolve 1.9(b), a few modifications will be made to the strategy of Issue 1.1. The set of conditions expected during the 10,000 year period will be expanded to include any additional conditions that may be expected over the 100,000-year period. Some of the conditions that were considered unexpected over the 10,000-year period will therefore be included. The same total system model and submodels used to resolve Issue 1.1, however, will be adequate to address Issue 1.9(b).

Preliminary evidence indicates that the only conditions that need to be added to the 10,000-year expected case to address the 100,000-year expected case are those associated with climatic changes. Such changes could affect aspects of the repository system, including water table altitudes, percolation flux, and gradients in the saturated zone. These changes could have a significant effect on releases to the accessible environment. Information to assess these conditions in the 100,000-year calculation will be made available through the Climate program.

A complete discussion of both parts of Issue 1.9 can be found in Section 8.3.5.18.

8.2.2.1.2 Design issues for Key Issue 1

8.2.2.1.2.1 Summary of waste package characteristics (postclosure) -- 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 for the resolution of the performance issues?

Regulatory background

In addition to providing information on the postemplacement environment and waste package designs to support resolution of several performance

issues, Issue 1.10 (discussed in 8.3.4.2) is concerned with ensuring compliance with the postclosure design criteria given in 10 CFR 60.135. These criteria specify that the waste package shall be designed so that its properties and its interactions with the emplacement environment do not compromise the function of the package, or the performance of the underground facility or the geologic setting. The design criteria recognize that the inherent characteristics of high-level waste will impact both the package and the surrounding environment. These characteristics include high levels of radiation and the heat generated within the waste form resulting from radioactive decay, especially during the early containment period.

In addition to the impact of the emplacement of the waste package, the environment surrounding the waste package is also impacted by repository construction and operation. To ensure that the functions of the waste package and its environment are not compromised, it is necessary to understand the condition of the surrounding environment before waste emplacement and the interaction between the waste package and the environment over time. Such an understanding of the waste package and its environment will allow the development of a waste package design that will consider the effect of these interactions.

Technical background and licensing strategy

The waste package, which consists of highly radioactive waste inside of a metal container, is to be placed in a hole bored out of tuff in the repository horizon. The radiation field from the waste, mostly neutrons and gamma radiation, will penetrate through the waste package and interact with the environment. Neutrons can damage material by displacing atoms as a result of atomic collisions. Such radiation damage in the container materials, and host rock minerals, and the effect on the water chemistry are expected to be small at the radiation flux levels that would be present. Gamma radiation interacts with matter by ionization mechanisms. The effect of gamma interaction with tuff will largely be transient and is not expected to cause significant change in the rock or mineral properties. However, gamma radiation can cause changes in water chemistry due to the production of radiolytic species. Gamma radiation may also enhance the oxidation of C-14 in the surface layers of Zircaloy cladding during the containment period.

The thermal load imposed by the waste on the near-field environment will be a function of the waste type. The actual thermal output from the waste will depend on burnup, the time since discharge from a reactor, and the quantity of waste stored in the containers. The heat generated by the waste will result in a rise in temperature that could alter the local hydrologic system, causing the pore water contained in rock in the vicinity of waste packages to vaporize. In this case, following dehydration, rehydration of the near-field environment could occur as heat generation declines and the temperature drops. Performance of the containment barrier and the waste form is closely tied to the quantity of water that contacts the packages and to the flow mechanisms operating in the vicinity of the waste packages. The elevated temperature in the host rock could also affect the water chemistry.

The waste package environment, upon initial emplacement of the package, will depend on the ambient conditions at the repository horizon and on the way in which those conditions are altered by repository construction and

operation. The environment following emplacement will depend on the initial emplacement conditions and on how those conditions are altered by the waste package characteristics. There is, therefore, an interactive process of design and environment characterization. The design is initially based on the ambient conditions and a prediction of how those conditions will be altered 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. On the basis of those tests and subsequent analyses, designs may be modified and the test and analysis cycle repeated.

The performance measures of the system elements for resolving Issue 1.10 that deal with the interaction between the waste package and the surrounding environment are shown on Table 8.2-15. These measures form the basis for the activities necessary to characterize the ambient, preemplacement environment and the attributes of the environment that may be influenced by waste package emplacement. Each system element has a function or a characteristic for which a process or condition must be well understood. Issue resolution is accomplished by using models to describe the interactions of concern and incorporating these into waste package design considerations. The waste package environment model uses a number of submodels to define water quality, water quantity, and mechanical and thermal loading. Each model uses a series of input parameters that will be quantified through various characterization activities described in Section 8.3.4.2. Goals for the testing program in terms of specific site characteristics to be evaluated and parameter values that would contribute to a favorable resolution of this issue are identified in the detailed strategy discussion in Section 8.3.4.2. Identification of barriers and performance measures and associated goals and parameters helps to orient the testing program toward obtaining information to resolve this issue.

8.2.2.1.2.2 Summary of configuration of underground facilities (postclosure) -- Issue 1.11: Have the characteristics and configurations of the repository and 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?

Regulatory background

Issue 1.11 (discussed in Section 8.3.2.2) is concerned with those aspects of underground facility design that have implications for the postclosure behavior of the repository, particularly as expressed in 10 CFR 60.133, additional design criteria for the underground facility. The additional design criteria of 10 CFR 60.133 specify that the underground facility and the engineered barrier system be designed to (1) contribute to the containment and isolation of radionuclides, (2) incorporate sufficient flexibility to accommodate site specific conditions identified through in situ monitoring, testing, or excavation, and (3) assist the geologic setting in

Table 8.2-15. Performance measures and parameters to resolve Issue 1.10 (waste package characteristics -- postclosure)

System element	Performance measure
Engineered environment	Rock-induced load on waste package
	Temperature vs. time in waste package environment
	Water quality and quantity
	Tectonic Processes
Waste package	Select waste package material to contribute to containment
	Constrain waste handling operations so as to not degrade isolation and containment performance of the waste package

meeting the performance objectives. There are two design criteria that specifically address the potential for creating fractures in the rock mass and the attendant possibility of creating preferential pathways for ground-water movement and radionuclide migration to the accessible environment. These design criteria require that the underground openings be designed to reduce the potential for deleterious rock movement or fracturing of overlying or surrounding rock. Such fracturing or rock movement could lead to the creation of potential paths for groundwater flow or radionuclide migration, which could impact the ability of a site to comply with the postclosure performance objectives of waste package containment, engineered barrier system release rate, and the overall system compliance with the standard for releases at the accessible environment boundary. Finally, 10 CFR 60.133 has an additional postclosure design criterion that specifically requires the consideration of the predicted thermal and thermomechanical response of the host rock, surrounding strata and groundwater system.

Technical background and licensing strategy

The regulatory basis for this issue, as identified in the design criteria of 10 CFR 60.133, covers both the design of the underground facility and the design of any engineered barriers that are part of the underground facility. Such engineered barriers include the drift seals that are intended to control ground-water movement into or through the underground facility. The activities related to design of drift seals (components of the engineered barrier system) and those related to design of shaft and borehole seals

(components separate from the engineered barrier system) will be similar, even though the related performance objectives may be different. The strategy and investigations for seal design have, therefore, been combined and are discussed under Issue 1.12 (Section 8.3.3.2). Issue 1.11 is concerned only with the criteria that relate directly to the design of the underground facility.

The strategy for resolution of this issue involves repetitive examination of an evolving design to ensure that the final design meets the design criteria. Performance measures and goals are set consistent with the desire to meet the design criteria. The licensing strategy is based upon evaluation of the performance measures which address the general functions that the repository design is expected to achieve in order that compliance with the intent of the postclosure aspects of 10 CFR 60.133 can be achieved.

The four functions that the postclosure waste disposal system must perform were chosen so that there is a direct correlation between the functions and the design criteria expressed in 10 CFR 60.133. These functions can be described as follows: (1) underground layout should contribute to containment and isolation, (2) limit water usage and potential chemical changes so as not to adversely affect postclosure performance, (3) limit excavation induced permeability changes to avoid adverse impacts on performance, and (4) select thermal loads so that performance objectives will be met, considering thermomechanical responses.

The first function that the postclosure waste disposal system must perform involves contributing to containment and isolation through the postclosure effects of underground layout selection. A repository at Yucca Mountain would be located in a welded tuff that is at an average distance of 250 m above the water table and which is therefore only partially saturated. The geometry, orientation, layout, and depth of the repository have been considered in the development of the current repository conceptual design. Because the repository at Yucca Mountain would be in the unsaturated zone, the distance above the water table is considered as important as the overall depth of the facility. Orientation of the repository relative to existing fracture and principal stress directions is of importance for long-term stability of the excavations and creation of potential flow or migration paths. The repository orientation relative to stress and fracture directions, depth, and inclination could result in certain fractures opening and others closing. The goal of Issue 1.11 from this perspective is to ensure that the repository layout contributes to containment and isolation or, at least, does not detract from it. It is not possible, however, to orient each drift excavation optimally, and the functional requirements of operations also must be considered in repository layout.

The repository underground facility design is also required to incorporate flexibility to accommodate site specific conditions identified through testing, monitoring, or excavation. At Yucca Mountain, requirements for flexibility will probably be related to the subsurface character of faults, particularly the presence and amount of water and difficulties, if any, in excavation and ground control. Accommodation of these conditions, if found, could involve offsets of waste package emplacement holes from water bearing fractures or faults, or possible avoidance of faults with obvious

recent movement. Alternately, subsurface investigations could demonstrate no impediment to mining or waste emplacement in areas of suspected or possible faults. Demonstration that the repository area could be extended laterally would provide additional flexibility to deal with site specific conditions.

A second function of the postclosure waste disposal system is to limit water usage and potential chemical changes so as not to adversely affect postclosure performance. There are two criteria in 10 CFR 60.133 that require the design of the engineered barrier system to contribute to isolation and containment and to assist the geologic setting in meeting the performance objectives for the period following permanent closure. For a repository at Yucca Mountain, several approaches to implement these criteria are being investigated. The location of the repository in the unsaturated zone has led to design considerations to limit the amount of water contacting the waste packages to lengthen the effective containment period and inhibit radionuclide transport during the isolation period. The repository has been designed to include a slight incline to permit natural drainage of free water to the lowest point of the repository. The temperature of the waste canister itself also can contribute to containment; in a partially saturated medium, the rock adjacent to the emplacement holes will dry out as the interstitial moisture vaporizes. Other mechanisms through which an underground facility design could assist the geologic setting in achieving the performance objectives involve material control. Adding as little water as is practicable to the engineered barrier system or site during construction and carefully selecting and perhaps controlling the quantities and types of materials that could chemically interact with waste container or waste form materials also act to avoid degrading containment and isolation.

A third function that the postclosure waste disposal system must accomplish is to limit excavation induced permeability changes. Two of the design criteria deal with the creation of fractures and potential flow paths for radionuclide migration. One criterion is concerned with fractures induced by the excavation method. For a repository at Yucca Mountain, the current conceptual design incorporates site-specific controlled-blast procedures; techniques limiting damage during emplacement-hole drilling will also be investigated. The other criterion on fracturing is concerned with opening or creating fractures in the overlying or surrounding rock that could lead to creation of potential flow and migration paths to the accessible environment. The extraction ratio for the facility, as well as drift span dimensions, are the primary mechanisms for control of rock mass movements in a hard rock facility such as that at Yucca Mountain.

The remaining function that the postclosure waste disposal system must accomplish is to use a thermal loading that does not preclude meeting the performance objectives. Evaluation of the performance objectives of 10 CFR Part 60 also requires explicit consideration, in the design, of the thermal and thermomechanical responses of the host rock and surrounding strata. For a repository at Yucca Mountain, specific rock mass technical concerns involve surface uplift and the associated creation or opening of fractures. Also of concern for temperature-induced responses are those that could possibly impact the ground-water regime, including fluid state in the unsaturated zone. Also specific to Yucca Mountain is a question of whether temperature-induced stresses, when superposed on the existing stress regime at Yucca Mountain, could affect tectonics at the site in such a way as to impact

compliance with the postclosure performance objectives. The design goal is to maintain a thermal load that is low enough not to lead to tectonic or hydrologic impacts on compliance.

Performance allocation for Issue 1.11 results in the identification of site data to be acquired by the characterization program, as well as requirements on the design and specific design products to be used to resolve the issue. The former information is used in the characterization program, while the latter is considered in the strategy for Issue 4.4 (Section 8.3.2.5). Issue 4.4 addresses preparation of a repository design that satisfies the requirements of all design and performance issues. Figure 8.3.2.1-1 illustrates the relationships between Issue 4.4 and the other issues that introduce design requirements.

Slightly more detail about the functions relevant to the issue resolution strategy for Issue 1.11 can be found in Tables 8.2-16, -17, -18 and -19. These tables list, for each function, the processes available to ensure that the function requirement is accomplished, and also indicate whether primary reliance is placed on the process or if it serves as a backup. The performance measures for each process are defined in the last column of the tables.

The performance allocation for Issue 1.11, as well as details on performance goals and relevant parameters, can be found in Section 8.3.2.2. Identification of measures and associated goals and parameters helps to orient the testing program toward obtaining the information to resolve this issue.

8.2.2.1.2.3 Summary 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?

Regulatory background

The regulation from which Issue 1.12 (discussed in Section 8.3.3.2) is derived is concerned with those activities required to develop designs and evaluate performance of seals to be placed in shafts, ramps, and boreholes associated with the development and closure of a repository.

There are several sections in 10 CFR Part 60 that specifically relate to sealing; 10 CFR 60.134 requires seals for shafts and boreholes to be designed so that following permanent closure they do not become pathways that compromise the ability of the geologic repository to meet the performance objectives for the period following permanent closure. That section further requires that materials and placement methods for seals be selected to reduce, to the extent practicable, (1) the potential for creating a preferential pathway for ground water, or (2) radioactive waste migration through existing pathways.

Table 8.2-16. Performance measures for underground facility location and layout function -- Issue 1.11 (configuration of underground facilities -- postclosure)

Function	Process: Possible	Process: Relied on	Performance measures
Select orientation, geometry, layout, and depth of underground facility to contribute to containment and isolation, taking into account flexibility to accommodate site-specific conditions	Vary depth, dip, orientation, and lateral extent of underground facility to provide host rock with favorable containment and isolation characteristics	Yes	Usable area; is usable area adequate for 70,000 MTU of waste
	Select emplacement borehole orientation and design to limit potential for adverse effects	Backup	Performance measures as defined by Issues 1.1, 1.6, and 1.10 will be used as part of choosing borehole orientation
	Limit the amount of water in contact with container to provide favorable isolation and containment environment	Yes	Regions of dehydration and condensation and drainage pattern
	Skip and isolate unfavorable areas	Yes	Ground quality (technical feasibility performance measure)
			Extent of change in saturation and water chemistry
			Distance from ground with unfavorable properties
	Adjust thermal load to accommodate local conditions	Yes	Temperature (to limit potential for adverse geochemical, etc. effects on the host rock)
			Postclosure rock movements within acceptable limits under thermal loads

Table 8.2-17. Performance measures for function limiting water use and chemical change -- Issue 1.11 (configuration of underground facilities -- postclosure)

Function	Process		Performance measures
	Possible	Relied on	
Limit water usage and potential chemical changes	Limit adverse chemical changes by using acceptable materials and fluids	Yes	Type and quantity of materials (including materials for seals) Quantity of concrete Quantity of shotcrete Quantity of grout for bolt anchors Quantity of organics
	Limit the amount of water used in construction, operation, emplacement of seals, and decommissioning to provide favorable containment and isolation environment	Yes	Net water from operations that remains in host rock at emplacement

Table 8.2-18. Performance measures for function limiting potential excavation effects -- Issue 1.11 (configuration of underground facilities -- postclosure)

Function	Process: Possible	Process: Relied on	Performance measures
Limit potential for excavation-induced changes in rock mass permeability	Limit magnitude and extent of blast-induced permeability change by blast control	Backup	Permeability change due to blasting should not cause a change in disturbed zone boundary (compare Issue 1.6, Section 8.3.5.12) or unnecessarily complicate seal evaluation and emplacement
	Limit potential for subsidence by limiting extraction ratio and drift size	Backup	Extraction ratio Drift spans
	Backfill drifts at decommissioning	Backup	Amount of fill

Table 8.2-19. Performance measures for design thermal loading -- Issue 1.11 (configuration of underground facilities -- postclosure)

Function	Process: Possible	Process: Relied on	Performance measures
Design thermal loading taking into account performance objectives and thermomechanical response of host rock	Limit temperature changes in selected barriers	Backup	Temperature
	Limit deleterious rock movement or preferred pathways	Backup	Potential for significant displacement (see Issue 1.1, Section 8.3.5.13)
	Limit impact on surface environment	Backup	Temperature
			Surface uplift
	Vary borehole and drift spacing to control thermal loading and container temperature	Yes	Thermal loading
			Borehole wall temperature
			Rock mass temperature
	Limit potential for borehole collapse	Yes	Stress, deformation, factor of safety, and potential rock fall
	Limit corrosiveness of container environment	Yes	Time container is above boiling temperature of water (see Issue 1.10, Section 8.3.4.2)

Section 60.112 of 10 CFR Part 60 addresses the overall system performance for the geologic repository after permanent closure. The section requires the geologic setting to be selected and the engineered barrier system and the shafts, boreholes, and their seals to be designed to ensure that releases of radioactive materials to the accessible environment following permanent closure conform to release standards.

Technical background and licensing strategy

The primary objective of the NNWSI Project repository sealing program is to design seals that will ensure that water will not compromise the containment and isolation of radionuclides from the accessible environment. The regulatory basis limits the concern of this issue to shaft and borehole seals. However, since many of the activities associated with resolution of this issue would also pertain to the design of drift seals, which are considered to be part of the engineered barrier system, drift seal design will also be addressed here. Certain repository design criteria of 10 CFR 60.133 are therefore applicable to development of the strategy and information requirements for this issue. The design of drift seals must also address any requirements placed on the drift seal components of the engineered barrier system in meeting the performance objective of 10 CFR 60.113.

The strategy for resolving this issue involves repetitive examination of an evolving design to ensure that the final design meets the design criteria. Performance measures and goals are set consistent with the current strategy for meeting these criteria. The resolution strategy is based upon an evaluation of those aspects of seal performance related to these performance measures. The performance measures address three general functions that the design is expected to achieve in order that the intent of the sealing aspects of 10 CFR 60.133, 10 CFR 60.134, 10 CFR 60.112, and 10 CFR 60.113 can be met. The three components of the sealing system are (1) shaft and ramp sealing functions, (2) borehole sealing functions, and (3) underground facility sealing functions.

To meet the functional requirements for shaft and ramp sealing, the components of the seals being considered are surface cover, shaft collar cores, anchor-to-bedrock plug and seal, settlement plugs, shaft fill, and the repository station seal. Section 6.2.8 presents a further discussion of the components. For the Yucca Mountain site, ramps are planned (in addition to shafts) as a means of repository access. The seal components for the ramps are similar to those for the shafts. For the current concepts, the principal component of the seals for the boreholes is the seal in the portion of the borehole that penetrates the tuffaceous beds of Calico Hills; the remainder of the borehole may be filled with a granular material or a cementitious material. Further, not all boreholes in the vicinity of the site are expected to require sealing (e.g., boreholes that are upgradient or long distances from the repository). The decisions on the need to seal will be made independently for each specific borehole near the site.

To address the functional requirements for repository seals, the principal concern is related to options for sealing a discrete fault or fracture zone that may contain water. Options under consideration are discussed in Section 8.3.3.2 for a wide range of inflow. The determination

of whether or not such inflow is credible at the Yucca Mountain site is one of the reasons for tests to be conducted in the exploratory shaft relative to structural features (Ghost Dance fault, Drill Hole Wash). Potential components for these options range from excavating a channel in a drift floor to constrain flow, to placing small dams in drifts to impede lateral flow of water, to emplacing of physical barriers of bentonite, clay, or cementitious materials on each side of the flow to divert the flow downward and away from the waste packages.

The sealing program is somewhat different from other design-related activities because of the timing of the activities. The repository surface facilities, the accesses, and portions of the underground facility will be constructed shortly after the construction is authorized; the waste packages and the remainder of the underground facilities will be constructed during repository operations. The seals, on the other hand, will not generally be installed until the repository is decommissioned. This delay in emplacing seals is partly a result of the anticipated hydrology at the site; specifically, the lack of aquifers above the waste emplacement horizon at the Yucca Mountain site makes it unnecessary to install any of the permanent shaft or ramp seal components during access construction.

The site hydrology (described in Chapter 3) is the dominant aspect of the environment for the seals. The partially saturated nature of the Topopah Spring Member in which the repository would be located, the anticipated relatively low water flux through the unit, and the potential for flow through discrete fractures or faults are important hydrologic aspects of the functions that the seal system is required to perform. Other aspects of the seal environment that must be considered are related to surface rainfall and the potential for flooding, the stress and temperature fields to which the seals would be exposed, the bulk chemistry of the formation, the chemistry of the ground water, the potential for seismically induced forces or motion, and the flow-related characteristics of the regions in the saturated zone below the repository (principally for the borehole seals).

Specific site information needed for the design and evaluation of the seals is identified in Section 8.3.3.2.1. Information such as the saturated hydraulic conductivity, gravitational analyses, compressibility of shaft fill, borehole construction, and geologic logs associated with specific boreholes will support the design process in the selection of the appropriate methods to emplace sealing components. Site information needed to validate analytical methods may include hydrological characterization of the Topopah Spring welded unit. Specific properties required are unsaturated matrix properties and the drainage capacity of the Topopah Spring welded unit. Prevalence of water-producing zones, if any, and the hydrologic nature of the Ghost Dance fault, the area underlying Drill Hole Wash, and the rock matrix will all be important site information needed to select the most appropriate sealing designs. The description of data needed in support of establishing or confirming the seal environment is based in part upon the analysis work completed to date and the seal design concepts being used; these analyses and designs are summarized in Sections 6.4.3.2 and 6.2.8, respectively.

More detail about the functions relevant to the issue resolution strategy for Issue 1.12 can be found in Tables 8.2-20, -21 and -22. These tables

Table 8.2-20. Functions, processes, material properties, and performance measures for the shaft and ramp sealing component

Shaft and ramp seals			
Function	Process	Material properties	Performance measure
Reduce amount of water that could potentially reach the waste disposal rooms	Water entering the upper portion of the shaft or ramp	Permeability	Quantity of water
Reduce the potential for human intrusion into the repository	Penetrability through sealing components	To be determined through design trade-off studies	Physical presence
Reduce the amount of water that could potentially reach the waste disposal rooms	Infiltration of surface and subsurface waters reaching the base of the shafts	Permeability of fill	Quantity of water
Reduce the air flow up through shafts	Air flow up through the shaft due to convective air movement	Permeability of fill to air	Percentage of gaseous radionuclides preferentially exiting shafts
Reduce the potential for human intrusion into the repository	Penetrability through sealing components	To be determined through design trade-off studies	Physical presence
Reduce the amount of water that could potentially reach the waste disposal rooms	Water passage from the base of shaft to the waste emplacement drifts	Permeability	Quantity of water
Encourage drainage from base of shafts	Flow through the bulk rock, at base of shaft, both lined and unlined cases	Bulk rock hydraulic conductivity	Drainage capacity

Table 8.2-21. Functions, processes, material properties, and performance measures for the underground facility sealing component

Underground facility seals			
Function	Process	Material properties	Performance measure
Retain and drain water entering emplacement drifts where water entry occurs	Lateral migration of water in drifts	Permeability	Quantity of water
Retain and drain water entering nonemplacement drifts	Lateral migration of water in drifts	Permeability	Quantity of water
Retain and drain water entering drifts	Drainage through bulk rock in floor of drift	Bulk permeability of rock at floor of drift	Quantity of water
Divert water away from waste emplacement areas	Drainage through fill	Permeability of fill	Quantity of water
Reduce the amount of water entering horizontal emplacement boreholes	Infiltration through fault system	Permeability	Quantity of water
Reduce the potential for subsidence	Failure of rock mass above drifts	To be determined through design trade-off studies	Amount of fill
Reduce the potential of human intrusion into the repository	Penetrability through sealing components	To be determined through design trade-off studies	Physical presence

Table 8.2-22. Functions, processes, material properties, and performance measures for the exploratory borehole sealing component

Exploratory borehole seals			
Function	Process	Material properties	Performance measure
Reduce the potential for water-transported radionuclides to be preferentially transported through boreholes	Preferential ground-water flow through the repository, Calico Hills unit and the saturated zone	Equivalent hydraulic conductivity of the borehole systems	Percentage of flow

[a]The borehole system includes the borehole seals, the interface zone, and the modified permeability zone surrounding the borehole seal.

list, for each function, the processes available to ensure that the functional requirement is accomplished. Relevant natural properties and the performance measures for each process are also defined.

The performance allocation for Issue 1.12, as well as details on performance goals and relevant parameters, can be found in Section 8.3.3.2. Identification of processes and measures and associated goals and parameters helps to orient the testing program toward obtaining the information to resolve this issue.

8.2.2.2 Key Issue 2

8.2.2.2.1 Performance issues for Key Issue 2

8.2.2.2.1.1 Summary of public radiological exposures: normal conditions -- Issue 2.1: During repository operation, closure, and decommissioning (a) will the expected average radiation dose received by members of the public within any highly populated area be less than a small fraction of the allowable limits and (b) will the expected radiation dose received by any member of the public in an unrestricted area be less than the allowable limits as required by 10 CFR 60.111, 40 CFR 191 Subpart A, and 10 CFR Part 20?

Regulatory background

Issue 2.1 (discussed in Section 8.3.5.3) is concerned with the radiation exposure to the general public associated with normal conditions during operation, closure, and decommissioning of the repository. As stated in this issue, the allowable exposure limits are those specified in 10 CFR 60.111, 40 CFR Part 191 Subpart A, and 10 CFR Part 20. 10 CFR 60.111 actually only requires conformance with 10 CFR Part 20 and "such generally applicable environmental standards for radioactivity as may have been established by the Environmental Protection Agency" (i.e., 40 CFR Part 191 Subpart A). No additional requirements are imposed by 10 CFR 60.111; therefore, the only directly applicable regulatory requirements are those in 10 CFR Part 20 and 40 CFR Part 191 Subpart A.

The objective of 10 CFR Part 20 is to limit the radiation dose that members of the public in unrestricted areas may receive to less than 0.5 rem per year to the whole body and to establish limits for particular organs. In addition, 10 CFR Part 20 states that exposures should be maintained as low as reasonably achievable (ALARA).

EPA's 40 CFR Part 191 requires that "management and storage of spent nuclear fuel or high-level or transuranic radioactive wastes at all facilities regulated by the Commission or by Agreement States shall be conducted in such a manner as to provide reasonable assurance that the combined annual dose equivalent to any member of the public in the general environment resulting from: (1) discharges of radioactive material and direct radiation from such management and storage and (2) all operations covered by Part 190; shall not exceed 25 millirems to the whole body, 75 millirems to the thyroid, and 25 millirems to any other critical organ."

In addition, there are other sections of 10 CFR Part 60 that require compliance with 10 CFR 60.111 and 10 CFR Part 20; these sections, however, do not contain any additional exposure limits relevant to this issue.

Technical background and licensing strategy

Issue 2.1 is concerned with the radiation exposure to the general public from the normal operation, closure, and decommissioning of the repository. The issue is divided into two parts: (a) the exposure to members of the public in a highly populated area (a highly populated area is defined in 10 CFR 960.2), and (b) the maximum exposure to any member of the public. The lower radiation dose limit stated in part (a) is intended to reduce the total man-rem exposure and, thus, the cumulative risk to the public as a whole. To address part (a) of this issue, the locations of the highly populated areas must be determined in relation to the repository site. To address part (b) of this issue, the dose to individuals in the vicinity of the site must be evaluated. The assessment of the potential doses will allow an evaluation of the impact of the operation, closure, and decommissioning of the repository on the surrounding population. The assessments will be conducted periodically (i.e., at each design phase) throughout the design of the repository to provide feedback to the design process. A monitoring program will provide verification of the results of the analyses. The "as low as reasonably achievable" (ALARA) criterion will be applied in designing the repository to minimize the potential radiation dose to the public. DOE is presently

evaluating how the limits in 40 CFR Part 191 relate to the ALARA criterion. Any decisions will be incorporated in the issue resolution strategies for this issue.

The strategy for resolving this issue involves repetitive examination of an evolving design to ensure that the final design meets the design criteria, expressed as performance measures and associated goals, that are derived from performance criteria. These goals are the direct result of a preliminary performance allocation concerned with the expected average radiation doses received by members of the public within any highly populated area or in an unrestricted area in accordance with 10 CFR Part 960, 10 CFR 60.111, 40 CFR Part 191, Subpart A, and 10 CFR Part 20. The licensing strategy for this issue is concerned only with normal operating conditions. Accident conditions are dealt with under Issue 2.3 (Section 8.3.5.5); worker radiologic safety is dealt with under Issues 2.2 (Section 8.3.5.4) and 2.3. The aspects of repository facility performance that are relevant to public radiologic health and safety under normal conditions are grouped into five functions that the repository design is expected to perform in order to comply with the intent of the preclosure public health and safety aspects of the applicable regulations. Issue resolution corresponds to the acceptance of the arguments in support of compliance by the NRC.

A complete logic diagram of the iterative design and assessment process required to obtain resolution of this issue may be found in Section 8.3.5.3. A portion of this process, the performance allocation, is responsible for the five repository functional groupings just mentioned. Table 8.2-23 lists these repository system functions, along with the activities or processes required to perform these functions and the measure that will be used to assess the level of success in performing the functions.

The first function of the repository design necessary for public health and safety is to provide a remote location. This is simply accomplished by locating the repository in a low population area. Success is measured by the population density of the area. Yucca Mountain is located in Nye County, which has an average population density of 0.5 persons per square mile. This is significantly lower than the continental U.S. average of 76 persons per square mile. The remaining functions are less obvious but are still relatively easy to understand.

The second and third functions are related to the natural environment surrounding the repository and its effects on the dispersion and transport of radionuclides to the public. These functions require analyses of the atmospheric and environmental transport mechanisms that operate in the area of the repository. The measures used to assess these two functions are the predicted and measured radionuclide concentrations in environmental media and the predicted individual public doses.

Environmental transport mechanisms are not expected to be significant because of the small amount of food production and absence of perennial surface water sources available in the desert-like environment. Preliminary meteorological measurements in the area indicate that the transport and dispersion characteristics should aid in reducing radiation exposures to the public. These measurements indicate high average annual wind speeds, which favor effective dispersion. The region surrounding the site experiences some

Table 8.2-23. Functions, performance measures, and performance goals for Issue 2.1 (public radiological exposures--normal conditions)

Function	Process or activity	Performance measure
Provide remoteness from highly populated areas and members of the public	Locate repository in a low population area	Population density
Provide dispersion and transport of routine radioactive releases to the unrestricted area through water pathways, crops, and animals	Analyze dilution, transportation, bioaccumulation of radionuclides in rivers, streams, and food stuffs	Radionuclide concentrations in environmental media and individual doses
Provide transport, dispersion, and diffusion of routine airborne radioactive effluents to the unrestricted area	Analyze atmospheric transport by wind and convection, including dispersion and diffusion	Radionuclide concentrations in environmental media and individual doses
Provide containment of potential sources of radiation to the unrestricted area	Limit releases of routine gaseous, liquid, and solid radioactive effluents	Radionuclide concentrations in environmental media and individual doses
Verify that there are no nuclear (uranium) fuel cycle facilities that need to be considered in assessing the public dose	Locate and analyze nearby nuclear (uranium) fuel cycle facilities	Number of nuclear (uranium) fuel cycle facilities requiring consideration in assessing the public dose

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of the deepest atmospheric mixing layers in the United States, a condition favorable to atmospheric mixing and dispersion (DOE, 1986b).

The fourth function of the repository with respect to the public health and safety is to provide containment of potential sources of radiation. This function is performed by limiting releases of routine gaseous, liquid, and solid effluents containing radionuclides. Again, success is measured in terms of the predicted and measured radionuclide concentrations in environmental media and the predicted individual public doses. Certain features of the conceptual design already provide some means of limiting releases of radioactive materials. These include filtration systems on ventilation exhausts to remove most airborne particulates and plans for radiation monitoring systems to promptly warn of increased levels of radiation levels in repository effluents, and thereby allow prompt corrective actions.

The final function of the design relevant to public health and safety under normal conditions is to verify that there are no other nuclear fuel cycle facilities in the area that could contribute to the predicted public dose. This is performed simply by locating any nuclear fuel cycle facilities in the area and analyzing the available data for normal releases from these facilities. The measure of success in this instance is the number of nearby nuclear fuel cycle facilities that could affect the public dose. It is expected that there are no other nuclear fuel cycle facilities in the area of Yucca Mountain that could contribute significantly to the public dose. Currently, no other nuclear fuel cycle facilities have been located in the area of Yucca Mountain.

More details about the performance allocation for Issue 2.1 including tentative goals for performance measures, parameters needed to evaluate performance measures, and goals and expected values of these parameters are contained in Section 8.3.5.3.

8.2.2.2.1.2 Summary of 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?

Regulatory background

Issue 2.2 (discussed in Section 8.3.5.4) is concerned with the radiation exposure to workers at the repository under normal conditions during construction, operation, closure, and decommissioning.

While this issue refers to the requirements of both 10 CFR 60.111(a) and 10 CFR Part 20 for limiting radiological exposure to workers, 10 CFR 60.111(a) simply refers to 10 CFR Part 20 and 40 CFR 191, Subpart A. Because 40 CFR 191, Subpart A is only applicable to members of the public, 10 CFR Part 20 (Standards For Protection Against Radiation) is the only regulation directly relevant to worker protection and, thus, this issue. 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.

Sections 21, 131, 132, and 133 of 10 CFR Part 60 specifically address effluent control and monitoring, ventilation and repository design in terms of the protection requirements of 10 CFR Part 20.

The regulation 10 CFR Part 20 specifies the requirements for control of occupational radiation exposure. The concept and application of "as low as reasonably achievable" (ALARA) also applies to worker radiation exposure. In addition to the requirement that worker doses be maintained less than regulatory limits and the recommendation that they adhere 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 maintained below allowable limits. Design criteria for radiological safety are established under Issue 2.7 (Section 8.3.2.3). Issue 2.7 uses the performance criteria established in this issue in developing the design criteria.

Regulations 10 CFR Part 20 and Part 60 also require a monitoring program during repository operations that ensures area radiation levels, airborne activity concentrations, contamination levels, and criticality controls are known and routinely verified. These operational requirements necessitate including systems to perform the verification of the design and operation of the facility. To ensure that the occupational radiation doses from the operation of the repository are less than the allowable levels, regulatory requirements must be known, both by designers to produce a compatible design and by evaluators to ensure that requirements are met by the design and operating procedures.

Technical background and licensing strategy

Issue 2.2 addresses the radiological safety of workers during normal operations. To resolve this issue, the mined geologic disposal system will be designed to limit the normal radiation doses to workers during construction, operation, closure, and decommissioning of the repository to less than the limits specified in 10 CFR Part 20. The design process will be an iterative process as the design proceeds through the various phases. Design criteria and assumptions will be needed for both repository system operation and worker radiation safety. Many of the same parameters will apply to both areas and will require appropriate input from design development. Further, the policy to maintain radiation doses as low as reasonably achievable (ALARA) imposes additional iterations on the design in order to implement the differential cost-benefit analyses for the ALARA process. In these iterative design activities, DOE and other guidelines will be used in designing for repository worker radiation safety. For any operational activities for which design features are not able to preclude the possibility of dose rates to personnel above the guidelines, administrative procedures will be required to limit personnel exposure.

The NRC requirements for verification of radiological performance necessitate special considerations for radiation measuring and monitoring systems. These requirements include "each licensee shall make or cause to be made such surveys as (1) may be necessary for the licensee to comply with the regulations in this part and (2) are reasonable under the circumstances to evaluate the extent of radiation hazards that may be present," (10 CFR 20.201(b)) and "the effluent monitoring systems shall be designed to measure

the amount and concentration of radionuclides in any effluent with sufficient precision to determine whether releases conform to the design requirements for effluent control" (10 CFR 60.132(c)(2)). In addition, a "means to monitor and control the dispersal of radioactive contamination" (10 CFR 60.113(a)(4)) and "a radiation alarm system to warn of significant increases in radiation levels, concentrations of radioactive material in air, and of increased radioactivity in effluents" (10 CFR 60.131(a)(6)) are required. Radiological measurement and monitoring systems that will be required for performance verification include air monitoring systems, criticality monitoring systems, gaseous effluent monitoring and sampling systems, and liquid effluent monitoring and sampling systems. The criteria for the testing, operation, and performance of these systems are found in documents issued by various organizations responsible for setting standards.

The strategy for resolving this issue involves repetitive examination of an evolving design to ensure that the final design meets the design criteria, expressed as performance measures and associated goals, that are derived from performance criteria. These goals are the direct result of a preliminary performance allocation concerned with the radiation exposure to workers at the repository under normal conditions in accordance with 10 CFR Part 60 and 10 CFR Part 20. The licensing strategy for this issue is concerned with normal operating conditions. Accident conditions are dealt with under Issue 2.3; public radiologic safety is dealt with under Issues 2.1 and 2.3. The aspects of repository facility performance that are relevant to worker radiologic health and safety under normal conditions are grouped into three general functions that the repository design is expected to achieve in order to comply with the intent of the preclosure worker health and safety aspects of the applicable regulations. Issue resolution corresponds to acceptance of the arguments in support of compliance by the NRC.

A complete logic diagram of the iterative design and assessment process required to obtain resolution of this issue is presented in Section 8.3.5.4. A portion of this process, the performance allocation, is responsible for the repository functional grouping mentioned previously. Table 8.2-24 lists these repository system functions, along with the activities or processes required to perform these functions and the measure that will be used to assess the level of success in performing these functions.

The first function necessary to ensure the health and safety of the workers under normal conditions is related to the natural environment surrounding the repository surface facilities and its effects on the dispersion and transport of radionuclides. As in Issue 2.1, this function requires analyses of the atmospheric transport mechanisms and the resulting doses to workers from radionuclides outside the repository facilities. In this instance, the performance measures are the transport characteristics of the surrounding atmosphere and the predicted and measured doses to the workers. Preliminary meteorological measurements in the area indicate that the transport and dispersion characteristic should aid in reducing radiation exposures to the public. These same characteristics should contribute to reducing exposure to workers. These measurements indicate high average annual wind speeds, which favor effective dispersion. The region surrounding the site experiences some of the deepest atmospheric mixing layers in the United States, a condition favorable to atmospheric mixing and dispersion (DOE, 1986b).

Table 8.2-24. Functions, processes or activities, and performance measures for Issue 2.2 (worker radiological safety--normal conditions) (page 1 of 2)

Function	Processes or activity	Performance measure
Provide transport, dispersion, and diffusion of routine airborne radioactive effluents within site boundaries	Analyze atmospheric transport, dispersion, and diffusion characteristics within the site boundaries	Transport characteristics of atmosphere within site boundaries
	Analyze worker doses from outdoor airborne radionuclides within site boundaries	Doses resulting from airborne radionuclide concentrations around repository facilities
Provide assurance that doses to workers underground are not excessive	Analyze shielding of workers from direct radiation using properties of the host rock	Effective attenuation of direct radiation by host rock
	Analyze the natural radiation released in the underground facilities	Release rates and concentrations of naturally occurring radionuclides
	Analyze radiation levels from miscellaneous sources of radiation such as calibration and testing sources	Direct radiation and contamination levels from miscellaneous sources
Provide containment of radiation and limit radiation doses to repository workers	Analyze direct radiation levels in all areas of the repository	Direct radiation levels in all areas of the repository
	Analyze high-level waste containment and handling operations	Doses due to worker occupancy in direct radiation areas

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Table 8.2-24. Functions, processes or activities, and performance measures for Issue 2.2 (worker radiological safety--normal conditions) (page 2 of 2)

Function	Processes or activity	Performance measure
	Analyze site-generated waste containment, handling, and treatment operations	Doses due to worker occupancy in direct radiation areas
Provide containment of radiation and limit radiation doses to repository workers	Analyze radiation levels from miscellaneous sources of radiation such as calibration and testing sources	Direct radiation and contamination levels from miscellaneous sources
	Analyze shielding provided by structures, containments, equipment, and waste packages	Effective attenuation of direct radiation levels
	Analyze ventilation and filtration of repository airstreams	Contamination and airborne radionuclide concentrations in repository airstreams

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The second function relates to the underground facilities of the repository and is to provide assurance that doses to workers underground are not excessive. Performing this function requires three analyses: (1) an analysis of the effectiveness of the host rock in shielding workers from direct radiation from the emplaced waste packages, (2) an analysis of the natural radiation released in the underground facilities, and (3) an analysis of the radiation levels from miscellaneous sources of radiation underground. The performance measure for the first analysis is simply the effective attenuation of direct radiation by the host rock. Although it is not yet known just how effective the host rock is as a radiation shield, the rock is expected to provide some shielding of the workers from the emplaced waste. For the second analysis, the performance measures are the release rates and concentrations of naturally occurring radionuclides in the underground openings. Preliminary measurement of radon levels in underground openings near the site indicate that while radon can build up in unventilated openings, release rates should be low enough that radon levels can be controlled through normal ventilation. Finally, the performance measures for the third analysis are the direct radiation levels and contamination levels from the miscellaneous radiation sources. The use of radiation sources in construction is now relatively commonplace. No difficulties are foreseen in controlling these sources of radiation through established safety procedures.

The third function of the repository is to provide containment of radiation and limit radiation doses to repository workers. This function requires six analyses be performed to assess its performance. The first of these analyses is the determination of direct radiation levels in all areas of the repository, and its performance measure is simply direct radiation levels. Preliminary estimates of expected direct radiation levels in the repository (Dennis, et al., 1984a; Stinebaugh and Frostenson, 1987) indicate that all areas can be made safe by using shielding or remote handling equipment. The next two analyses involve the investigation of high-level and site-generated waste operations, and the performance measures are the predicted and measured doses to workers from these operations. Preliminary estimates of expected worker exposures from waste-handling operations indicate that there are no expected problems in keeping worker exposures below design levels (Dennis, et al., 1984a; Stinebaugh and Frostenson, 1987).

The fourth analysis is an analysis of the radiation levels from miscellaneous sources. In this instance, the performance measure is the radiation levels from the miscellaneous sources. The use of radiation sources in construction is now relatively commonplace. No difficulties are foreseen in controlling these sources of radiation through established safety procedures. The last two analyses deal with the shielding of workers and the ventilation and filtration of repository airstreams. Performance measures are simply the effective attenuation of direct radiation levels by repository structures and the contamination and airborne concentration levels in the repository airstream. Numerous other facilities for handling radioactive materials have been designed, built, and safely operated using technology similar to that proposed for use in the repository.

More details about the performance allocation for Issue 2.2 including tentative goals for performance measures, parameters needed to evaluate performance measures, and goals and expected values of these parameters are contained in Section 8.3.5.4.

8.2.2.2.1.3 Summary of preclosure accidental radiological releases -- Issue 2.3: Can the repository be designed, constructed, operated, closed, and decommissioned in such a way that credible accidents do not result in projected radiological exposures of the general public at the nearest boundary of the unrestricted area, or workers in the restricted area, in excess of applicable limiting values?

Regulatory background

Issue 2.3 (discussed in Section 8.3.5.5) is concerned with the radiation exposure to the general public and workers under credible accident conditions during construction, operation, closure, and decommissioning. Although Issue 2.3 states that radiation exposures resulting from credible accidents must be maintained below applicable limits, there presently are no specified limits for radiation exposures to either members of the public or repository workers from accidents at a repository. The DOE is developing a regulatory position on what the accident dose limit for the general public should be and will seek the agreement of the NRC. There are regulatory criteria relevant to radiological protection of the repository workers and the general public under accident conditions.

The NRC, 10 CFR 60.2, defines structures, systems, and components important to safety as "those engineered structures, systems, and components essential to the prevention or mitigation of an accident that could result in a radiation dose to the whole body, or any organ, of 0.5 rem or greater at or beyond the nearest boundary of the unrestricted area at any time until the completion of permanent closure." The regulation does not, however, provide criteria for what constitutes a credible accident and does not specify accident dose limits for members of the public or workers. Criteria for what constitutes a credible accident will be developed as part of the preclosure risk assessment methodology (PRAM) described in Section 8.3.5.1.

Technical background and licensing strategy

Resolution of this issue requires the assurance that during the preclosure period the repository will not pose any undue radiological risk to the health and safety of the public and repository workers as a result of credible accidents. This will be initially established by an analysis documenting the adequacy of structures, systems, and components provided for the prevention of accidents and mitigation of consequences. The structures, systems, and components to be analyzed are those that will be presented to the NRC in the safety analysis report (SAR) of the license application.

The strategy for resolving this issue involves repetitive examination of an evolving design to ensure that the final design meets the design criteria, expressed as performance measures and associated goals, that are derived from performance criteria. These goals, established to orient the testing program toward obtaining the information to resolve this issue, are the direct result of a preliminary performance allocation concerned with projected radiological exposures to the general public in the unrestricted area or workers in the restricted area as a result of credible accidents. Exposures under normal conditions are dealt with under Issues 2.1 and 2.2 (Sections 8.3.5.3 and 8.3.5.4). The aspects of repository facility performance that are relevant

to public and worker radiological health and safety under credible accident conditions are grouped in three general functions that the repository design is expected to achieve in order to comply with the intent of the preclosure worker and public health and safety aspects of the applicable regulations. Issue resolution corresponds to the acceptance of the arguments in support of compliance by the NRC.

A complete logic diagram of the iterative design and assessment process required to obtain resolution of this issue is presented in Section 8.3.5.5. A portion of the process, the performance allocation, is responsible for the repository functional grouping mentioned previously. Table 8.2-25 lists these repository system functions along with the activities or processes required to perform these functions, and the measures that will be used to assess the level of success in performing these functions.

The first function of the repository is to provide a location that assists in limiting potential radiation exposure to the public and workers from accidents. There are four analyses that are needed to assess the performance of this function. First, the remoteness of the site must be analyzed. This is relatively straightforward and the measure used to assess remoteness is the population density of the region. Yucca Mountain is surrounded by Nye County, which has an average population density of 0.5 persons per square mile. This is significantly lower than the continental United States average of 76 persons per square mile. Second, the frequencies and consequences of initiating events caused by natural or site-related phenomena need to be analyzed. This is an important aspect of the site and the repository. The measure applied to this activity is the consequences of credible site-related initiating events. Consequences will be evaluated mainly in terms of radiation exposure; however, consequences can also include other types of "damage" to the repository, the environment, and people. A preliminary study (Appendix F of the Site Characterization Plan-Conceptual Design Report (SCP-CDR) has indicated that there are few credible accidents with consequences that could be considered serious. Further, this study also identified some changes that could be made to eliminate some of these credible accidents.

The last two analyses needed to assess the performance of the first function are really required to determine initiating event consequences. These are an analysis of the short-term public and worker radiation exposure mitigation features of the site and an analysis of the long-term public and worker radiation exposure mitigation features of the site. Short-term radiation exposures are dominated by the quick-acting radiation transport mechanisms such as atmospheric dispersion, dilution, and transport of radionuclides. The atmospheric transport characteristics of the site are the measures used to evaluate the short-term radiation exposure mitigation features of the site. Preliminary meteorological measurements in the area indicate that the transport and dispersion characteristic should aid in reducing radiation exposures to the public. These measurements indicate high average annual wind speeds, which favor effective dispersion. The region surrounding the site experiences some of the deepest atmospheric mixing layers in the United States, a condition that is favorable to atmospheric mixing and dispersion (DOE, 1986b).

Table 8.2-25. Functions, processes or activities, and performance measures for Issue 2.3 (page 1 of 2)

Function	Processes or activity	Performance measure
Provide location that assists in limiting potential radiation exposure to the public and workers from accidents	Analyze "remoteness" of repository location	Population density of region
	Analyze probabilities and consequences of initiating events caused by natural or site-related phenomena	Consequences of credible site-related initiating events
	Analyze short-term public and worker radiation exposure mitigation features of the site	Quick-acting dispersion, dilution, and transport characteristics of the site
	Analyze long-term public and worker radiation exposure mitigation features of the site	Long-term dispersion, dilution, diffusion, and bioaccumulation characteristics of the site
Provide prevention, containment, and mitigation of accident consequences and limit radiation exposures to workers and public	Analyze probabilities and consequences of design-related initiating events	Consequences of credible design-related initiating events
	Analyze design for vulnerability to effects of natural, site-related, and design-related initiating events	Sensitivity of repository design to possible accidents
	Analyze design for effectiveness of preventive features	Effectiveness of preventive design features

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Table 8.2-25. Functions, processes or activities, and performance measures for Issue 2.3 (page 2 of 2)

Function	Processes or activity	Performance measure
	Analyze design for effectiveness of mitigative features	Effectiveness of mitigative design features
Provide assurance that repository and workers are safe from effects of offsite accidents	Analyze vulnerability of repository and workers to effects of offsite accidents	Consequences of credible off-site accidents that could affect repository and workers

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Long-term radiation exposures are dominated by the slow-acting radiation transport mechanisms such as transport of radionuclides through the surface water and food chain pathways. The long-term dispersion, dilution, diffusion, and bioaccumulation characteristics of the site are the measures used to evaluate the site's ability to limit long-term exposures. The long-term pathways at Yucca Mountain are expected to be a small contributor to worker and public dose because of the small amount of food production and limited surface water sources available in its desert-like environment.

The second function of the repository design related to this issue is to prevent accidents, contain radioactive materials, mitigate accident consequences and limit radiation exposures to workers and the public through design features. This function also requires four analyses to assess its performance. The first is an analysis of the frequencies and consequences of design-related initiating events. This analysis is similar to the analysis of site-related initiating events mentioned previously. Again, the measure applied to this aspect of the repository is the consequences of credible design-related initiating events. The second analysis is actually a subset of the initiating event consequence analyses. It is an analysis of the design for vulnerability to the effects of natural, site-related, and design-related initiating events. The measure applied here is the sensitivity of the repository to all these credible accidents. This analysis will use both probabilistic methods and deterministic methods in a complementary manner. Some important results that could arise from this analysis include the refinement of the NNWSI Project Q-list (items important to safety portion only) and the development of a set of design-basis accidents to use in the repository safety analysis report (SAR).

The last two analyses are evaluations of the effectiveness of preventive and mitigative design features. These analyses will most likely be implemented as part of the deterministic design-basis accident analyses. The obvious measure of these analyses is effectiveness; effectiveness itself is measured in many different ways. These analyses will ensure that the design of the repository will exhibit the necessary response when subjected to design-basis accidents. Numerous other facilities for handling radioactive materials have been designed, built, and safely operated using technology similar to that proposed for use in the repository.

Finally, the third function of the repository design related to this issue is to provide assurance that both the repository and workers are safe from the effects of offsite accidents. The function requires only the analysis of the vulnerability of the repository and the workers to offsite accident consequences, and the measure used to assess the function is the consequences of credible offsite accidents to the repository and to the workers. There are few facilities of any kind in the area of Yucca Mountain. Offsite accidents that could adversely affect the repository or workers are not expected, however, possible offsite accidents associated with the nearby Nellis Air Force Range or the Nevada Test Site will be considered. The current policy of the DOE Nevada Operations Office requires the removal of workers from underground mines within about 80 km of an underground test of approximately 80 kilotons or larger (Vortman, 1980). Because the DOE exercises control over the schedule of activities at the NTS, compatible arrangements for nuclear testing and repository construction-operation activities can be made. The removal of workers from the underground

repository facility would be a standard industrial practice to guarantee the safety of workers. Other preparations might include the purging of contaminated hot-cell atmospheres or the securing of waste disposal containers and spent fuel assemblies. Plans for the evacuation of facilities that are judged particularly sensitive could also be developed, if warranted, although this is not considered to be a likely situation.

More details about the performance allocation for Issue 2.3 including tentative goals for performance measures, parameters needed to evaluate performance measures, and goals and expected values of these parameters are contained in Section 8.3.5.5.

8.2.2.2.1.4 Summary of waste retrievability -- Issue 2.4: Can the repository be designed, constructed, operated, closed, and decommissioned so that the option of waste retrieval will be preserved as required by 10 CFR 60.111?

Regulatory background

Issue 2.4, which is discussed in Section 8.3.5.2, is concerned with the ability to retrieve emplaced waste as required by 10 CFR 60.111(b). As a result, this issue must ensure that the repository is designed, constructed, operated, and maintained with the option to retrieve any or all of the emplaced waste. The regulations concerning the retrieval of high-level radioactive waste from geologic repositories, as specified by the Nuclear Waste Policy Act (NWPA, 1983) are contained in the NRC regulation 10 CFR Part 60.

The principal NWPA reference to retrieval is contained in Section 122, and requires any repository to be designed and constructed to permit the retrieval of any spent nuclear fuel during an appropriate period of operation of the facility. Retrieval could be required for reasons pertaining to public health and safety, the environment, or the recovery of the economically valuable contents of such spent fuel.

The principal NRC reference to retrievability is in Section 111(b) of 10 CFR Part 60, which requires the geologic repository operations area to be designed to preserve the option of waste retrieval throughout the period during which wastes are being emplaced and, thereafter, until the completion of a performance confirmation program and NRC review of the information obtained from such a program. To satisfy this objective, the geologic repository operations area will be designed so that any or all of the emplaced waste could be retrieved on a reasonable schedule starting at any time up to 50 years after waste emplacement operations are begun.

Technical background and licensing strategy

The strategy for resolving this issue involves repetitive examination of an evolving design to ensure that the final design (developed in Issue 4.4) meets the design criteria, expressed as performance measures and associated goals, that are derived to ensure retrieval. These goals directly result from a preliminary performance allocation concerned with maintaining the

option to retrieve any or all of the emplaced waste. The licensing strategy is based upon evaluation of aspects of the repository design that are relevant to the requirement of maintaining the capability to retrieve the waste from the repository should it become necessary or desirable.

A complete logic diagram of the iterative design and assessment process required to resolve this issue is presented in Section 8.3.5.2. A portion of this process, the performance allocation, has resulted in identification of the four functions that must be performed for retrievability:

1. Provide access to the emplacement boreholes.
2. Provide access to the waste packages.
3. Remove waste package from the emplacement borehole.
4. Transport and deliver the waste to the surface facilities.

Table 8.2-26 lists the processes or activities required to perform these functions and the performance measures that will be used to assess the level of success in performing these functions. These four functions are the organizing principle upon which the retrieval discussions, information needs, and plans for future evaluations are based.

The first function is to provide a safe and reliable access from the surface facilities to the emplacement boreholes. To do this, the underground openings must be usable and the environment within them must be acceptable under normal and credible abnormal conditions. A time period of at least 84 years has been selected as the period for which drifts and accesses must remain usable. This time period is a significant and potentially severe restriction that impacts the design, construction, and operation of the repository. For example, the materials selected for the rock-support system, the necessity for a continual, long-term monitoring and maintenance program for the underground openings, the timing for backfilling operations, and the selection of an acceptable emplacement mode are all significantly impacted by this time period. Evaluations of the thermal and mechanical effects on stability of shafts, ramps, and drifts have been the focus of about 15 reports and studies; a synopsis is given in Section 6.4.10.2. The common preliminary conclusions drawn from the multiple approaches used to date are that the openings are predicted to remain stable during preclosure and that excavation-induced effects would be expected to be similar to those in the Grouse Canyon tuff in G-tunnel on the Nevada Test Site. Substantial additional information on drift and support system behavior is expected to be gathered as part of the exploratory shaft facility observations. To help ensure the feasibility of retrieval operations, design constraints have been established to ensure that the temperature in selected drifts will remain below 50°C for the first 50 years after waste emplacement. Similarly, the drifts are not planned to be backfilled until after the retrieval period. Preliminary analyses indicate that the requirements for providing adequate ventilation can be met for inspection and retrieval operations using currently available equipment. More detailed evaluations, planned for future design phases, will evaluate the effects of specific particulates, humidity, and selected potential contaminants. Particular emphasis will be placed on evaluating the potential presence and consequences of credible abnormal conditions that may occur in the openings.

Table 8.2-26. The functions, processes or activities, and performance measures involved in providing the ability to retrieve waste--Issue 2.4 (waste retrievability) (page 1 of 3)

Function	Process or activity	Performance measure
Provide access to the emplacement boreholes for normal and credible abnormal conditions	Design and construct the accesses and drifts to be usable throughout the retrievability period for normal and credible abnormal conditions	Time during which the drifts and accesses will remain usable
	Develop rock support concepts that ensure maintainability	Amount of spall, opening displacement, and frequency of maintenance
	Develop backfill removal concepts (if needed)	Time and level of effort for backfill removal
	Monitor drifts and accesses to determine maintenance needs	Localized rock and rock support displacement
	Design for a specific temperature and air quality environment with the accesses and drifts	Drift temperature and air quality
	Verify environment for maintenance and retrieval operations	Air quality
	Modify environment (as necessary)	Time required to modify the environment for retrieval

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Table 8.2-26. The functions, processes or activities, and performance measures involved in providing the ability to retrieve waste--Issue 2.4 (waste retrievability) (page 2 of 3)

Function	Process or activity	Performance measure
Provide access to the waste package	Design waste emplacement envelope to allow access to the waste package throughout the retrievability period for normal and credible abnormal conditions	Borehole usability (rockfall, displacement of borehole wall, borehole liner lifetime, displacement and curvature radius)
	Assess the condition of the emplacement envelope and waste package before removal (as required)	Borehole liner displacement
	Perform corrective actions (as required)	Time required to perform corrective actions
Remove the waste package	Design the waste package and transporter with the option to remove the waste for normal and credible abnormal conditions	Radiation protection Time required to perform waste removal Removal latch and pull strength Structural strength of the waste package or dolly
	Verify conditions of equipment and waste package	Waste package structural failure detection Removal equipment checks
	Verify operator training	Operator competency certification

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Table 8.2-26. The functions, processes or activities, and performance measures involved in providing the ability to retrieve waste--Issue 2.4 (waste retrievability) (page 3 of 3)

Function	Process or activity	Performance measure
Transport and deliver waste to the surface facilities	Design the transporter with the ability to transport the waste to the surface for normal and credible abnormal conditions	Transporter design characteristics (braking ability, maximum speed, cornering ability, radiation protection) Time required to transport the waste to the surface
	Design the surface waste-handling building and the transporter with the ability to unload waste at the surface facilities for normal and credible abnormal conditions	Time required to unload waste Radiation protection Transporter unloading capability
	Assess the ability to transport the waste to the surface facilities	Transporter drive system performance Operator competency certification
	Assess the ability to unload the waste at the waste handling building	Transporter unloading system performance Surface facility unloading system Operator competency certification

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The second function necessary for retrieval is to provide a safe and reliable access to the waste packages. The waste emplacement envelope (borehole, liner, shield plug, and collar) must, therefore, be designed to allow for retrieval of emplaced waste packages under normal and credible abnormal conditions. Borehole usability is one of the principal performance measures for this function; specifically, goals have been established that seek to limit rockfall, rock displacement, and liner curvature and to establish the needed lifetime of the liner. Preliminary analyses (see Section 6.4.2.10) indicate that under normal conditions waste emplacement boreholes are predicted to remain stable during preclosure, although, for horizontal waste emplacement, some potential exists for negligible amounts of rock to fall on the liner. For credible abnormal conditions, substantial additional work remains to be done particularly as related to evaluating effects of tectonic events.

The third and fourth functions are related to the waste-handling operations of removing the package from the emplacement borehole and delivering the waste to the surface facilities. The principal site-related concern relative to these functions is determination of shielding characteristics of the host rock to ensure that design limits for worker doses are not exceeded. Nonsite-related concerns are focused upon designing and evaluating the equipment necessary to perform the functions. Equipment concepts and designs are presented in various sections of the SCP and SCP-CDR (Section 8.3.5.2 provides a directory of related discussions). Even though the equipment designs use currently available technology, the usage will generally be unique to a repository. Removing the waste package under normal conditions will use the same technology and equipment as the emplacement operations. However, the ability to perform this function for credible abnormal conditions could be among the most difficult repository operations because of the high temperatures, the radioactive environment, and uncertainties regarding the condition of the boreholes and containers. Proof-of-principle demonstrations will probably be done for selected pieces of equipment.

More details about the performance allocation for Issue 2.4 (waste retrievability), including tentative goals for the performance measures, parameters needed to evaluate performance measures, and goals and expected values of these parameters are presented in Section 8.3.5.2. Identification of these measures, parameters, and associated goals helps to orient the testing program toward obtaining the information to resolve this issue.

8.2.2.2.1.5 Summary of preclosure radiological safety higher-level findings -- Issue 2.5: Can the higher-level findings required by 10 CFR Part 960 be made for the qualifying condition of the preclosure system guideline and the disqualifying and qualifying conditions of the technical guidelines for population density and distribution, site ownership and control, meteorology, and offsite installations and operations?

Regulatory background

The DOE has established a set of siting guidelines to be used as a basis for evaluating the suitability of potential repository sites during the site

selection process. These siting guidelines are set forth in 10 CFR Part 960. The siting guidelines are separated into two categories: those that address postclosure conditions (10 CFR 960.4) and those that address preclosure conditions (10 CFR 960.5). The DOE Implementation Guidelines (10 CFR 960.3) describe the manner in which the siting guidelines must be addressed during the siting process.

Issue 2.5 (discussed in Section 8.3.5.6) is concerned with the DOE's preclosure guidelines that relate to preclosure radiologic safety under normal and anticipated operating conditions. These guidelines consist of a system guideline and four technical guidelines. The system guideline is concerned with the expected performance of the repository system as a whole during the period before permanent closure, while each technical guideline is concerned with the effect of some specific aspect of the site on the preclosure performance. Each preclosure technical guideline has one qualifying condition that must be met for a site to be acceptable. In addition, two of the technical guidelines have one or more disqualifying conditions. A site is unacceptable if any one of the disqualifying conditions is found to be present. The technical guidelines also identify favorable conditions and potentially adverse conditions that describe characteristics of the setting that, if present, could benefit or detract from preclosure radiological safety.

The Implementation Guidelines require that the qualifying and disqualifying conditions of the system and technical guidelines be evaluated and that specific findings be made for each condition at principal decision points in the siting process. There are four levels of findings (Table 8.2-14). Disqualifying and qualifying conditions both require a lower-level and a higher-level finding. Lower-level findings must be made to determine if a site may be nominated as suitable for characterization or recommended as a candidate site for characterization (Levels 1 and 3). Higher-level findings must be made to determine if a site may be recommended for the development of a repository (Levels 2 and 4). Thus, disqualifying conditions require Level 1 and Level 2 findings, and qualifying conditions require Level 3 and Level 4 findings. Each level has both a positive finding and a negative finding associated with it.

The DOE siting guidelines do not require any findings similar to lower-level or higher-level findings to be made for the favorable or potentially adverse conditions of the technical guidelines. As stated in the Supplementary Information (DOE, 1984c) for 10 CFR Part 960, these conditions were intended to be used to predict the suitability of a site and provide a preliminary indication of system performance before the start of detailed site characterization studies. These conditions were considered and used in the identification of potentially acceptable sites, and in the nomination and recommendation of sites as suitable for characterization. By the completion of site characterization, however, sufficient data will be available to directly evaluate site performance against the qualifying conditions of the system and technical guidelines. Therefore, the favorable and potentially adverse conditions will not be considered in specific terms as they were for the environmental assessment.

Technical background and issue resolution strategy

To resolve Issue 2.5, sufficient evidence must be available to support either a positive or negative higher-level finding for each qualifying and disqualifying condition associated with preclosure radiologic safety. Each of the qualifying conditions refers to regulatory requirements of the NRC (specifically, 10 CFR Part 60). To support higher-level findings for the qualifying conditions, evidence must show whether the preclosure radiological releases under normal and projected operating conditions will be within the limits set by the NRC and the EPA, given the conditions that exist at the site. The system guideline looks at the site conditions as a whole, while the technical guidelines are concerned with the effects of specific site conditions. The disqualifying conditions are also related to NRC regulations, but not always as explicitly as the qualifying conditions.

The findings that have been made previously for the preclosure radiological safety guideline qualifying and disqualifying conditions and the evidence supporting these findings are given in the NNWSI Project environmental assessment (DOE, 1986b). The available evidence was sufficient to support a positive higher-level finding for two of the three disqualifying conditions of the Population Density and Distribution technical guideline, and positive lower-level finding for the other qualifying and disqualifying conditions. To determine if the Yucca Mountain site is suitable for the development of a repository, therefore, higher-level findings must be made for the remaining qualifying and disqualifying conditions.

The information necessary to support higher-level findings will be made available through the resolution strategies of other issues. For each condition, available evidence is evaluated to determine if it is sufficient to support a higher-level finding for any of the conditions. For the qualifying and disqualifying conditions for which there is not sufficient evidence available, the planned site characterization studies are reviewed to determine if the conditions will be investigated. This is accomplished by evaluating the resolutions strategies of other preclosure radiological safety performance issues (Issues 2.1 and 2.2) that assess the ability of the site to comply with the NRC's preclosure radiological safety regulatory requirements. If the concerns of the conditions are being considered in the resolution strategies of the other issues, it can be expected that the evidence to support higher-level findings for these conditions will be available.

8.2.2.2.2 Design issues for Key Issue 2

8.2.2.2.2.1 Summary of waste package characteristics (preclosure) -- Issue 2.6: Have the characteristics and configurations of the waste packages been adequately established to (a) show compliance with the preclosure design criteria of 10 CFR 60.135 and (b) provide information for the resolution of the performance issues?

Regulatory background

In addition to providing information on the waste package designs and the integration of those designs into the repository system to support requirements derived from several performance issues, Issue 2.6 (discussed in Section 8.3.4.3) is concerned with ensuring compliance with the design criteria established in 10 CFR 60.135. In addition to general design criteria for waste package design, specific design criteria are provided for the waste package and the waste form. The amount of explosive, pyrophoric, and chemically reactive materials and the quantity of free liquids are limited to the extent that the performance of the waste package will not be compromised. The radioactive waste is to be in solid form, and the availability and generation of particulates is to be limited. There are also criteria covering requirements for handling and identification of the waste packages.

Technical background and licensing strategy

This issue involves the actual development of the waste package designs and the integration of the designs into the repository system. Highly radioactive wastes are received at the repository surface facilities where they are handled and processed for disposal. The wastes are placed in containers to produce waste packages that then must be handled and emplaced in the underground facilities. These operations continue while the underground facilities are filled over a period of several years. Requirements and constraints are placed on the waste form, the container, and the waste package assembly during this preclosure period. It is important that containment of the waste is maintained both during processing and after emplacement. During this period, it is also important that the waste form and container are not subjected to conditions that could impact their performance during the postclosure period.

Issue 2.6 is closely related to Issues 1.10 (waste package characteristics--postclosure) and 4.3 (waste package production technologies). The tasks to be undertaken for these three issues are closely related to issues discussed in several other sections of this document. Requirements and constraints are imposed on the waste package designs by the postclosure regulatory performance objectives for containment and for releases from the engineered barrier system. The performance issues that address these objectives (Issue 1.4, waste package containment, and Issue 1.5, engineered barrier system release rates) provide the properties of the waste forms and container materials that are needed to design the packages. The waste package designs are closely coupled to the repository designs because the repository must accommodate the fabrication, assembly, emplacement, and disposal of the waste packages.

In one important respect, the division of the waste package design issues into preclosure and postclosure categories is somewhat artificial. Although the requirements and constraints on the package designs differ for the two time frames, there will only be one set of package designs. After emplacement, the environment that the packages will experience does not strongly depend on whether the repository is operational or closed.

The approach used in resolving this issue involves combining the requirements of Issue 2.6 with those of Issue 1.10 and developing a consolidated design. Specific features of this design are then evaluated for consistency with the performance requirements of these issues. In this framework, the design criteria and constraints that are derived within Issue 2.6 from the preclosure functional requirements through the performance allocation process are consolidated with the requirements and other design inputs developed in Issue 1.10 (Section 8.3.4.2). An integrated document, the waste package design requirements document, will be compiled and will provide the definitive guidance for development of the designs.

A significant product of the waste package design effort will be the specification of the production processes to be used in the fabrication, closure, and inspection of the containers. A direct supporting element to the design process is therefore identified separately in Issue 4.3 (Section 8.3.4.4), where the evaluation and testing of these production technologies are described.

The performance allocations to the system elements for resolution of Issue 2.6 are defined in Table 8.2-27 which lists the major preclosure functions or characteristics that are derived from the regulatory criteria. Information on the physical characteristics of the spent fuel and high-level waste that is to be accepted into the disposal system will be provided to the NNWSI Project by other elements of the DOE Office of Civilian Radioactive Waste Management (OCRWM) in the form of waste acceptance specifications, receipt rate projections by waste type and characteristics, and other descriptions. Information on other materials used in the waste package will be obtained from published sources or through various tests.

None of the information needed to address the preclosure waste package design criteria mentioned previously requires the acquisition of site characterization data, as it primarily involves information about, or restrictions on, the waste forms and specific criteria for characteristics of the waste packages. Therefore, no site specific parameters have been identified for characterization. The following nonsite-related parameters must be addressed in the design as required by 10 CFR 60.135:

1. Explosive, pyrophoric, and chemically reactive materials.
2. Free liquids.
3. Containment during transportation, emplacement, and retrieval.
4. Unique identification.

An analysis of the designs, including the waste forms, and the repository operations will be required to show that classes of materials in items 1 and 2 will not be present or, if present, the quantities will not exceed the criteria. An analysis of the containment capability of the waste packages under both normal and abnormal loads will be performed. Also, an assessment of the alternatives available for complying with the identification requirement and an analysis of the selected method will be performed.

Table 8.2-27. Performance allocation for Issue 2.6 (preclosure waste package characteristics)

System element	Function or characteristic	Performance measure
Waste package	Contain waste during repository operations	Fraction of containers intact at end of preclosure
	Limit potential criticality in waste packages	Effective neutron multiplication factor
	Provide unique identification of packages	Identification legible at end of preclosure
Waste form	Comply with Nuclear Regulatory Commission criteria for acceptance	Waste form characteristics
Container	Capable of being handled by repository systems	Package handling fixtures

8.2.2.2.2.2 Summary for 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?

Regulatory background

The regulatory bases for addressing Issue 2.7 (Section 8.3.2.3) arise primarily from two sources: (1) 10 CFR Part 60 provides the repository design criteria, in Sections 60.131 through 60.133 and (2) Issues 2.1, 2.2, and 2.3, which address radiological exposures to the workers and public under normal and accident conditions, impose criteria upon the design of the repository as a result of EPA, NRC, and DOE-imposed limits on the exposures to the public and workers. These two bases for Issue 2.7 will be treated individually in the discussions that follow.

In 10 CFR Part 60, the NRC has laid out design criteria for the geologic repository, which are found in Sections 60.130 through 60.135. In addition to the brief statement of the general scope of the design criteria given in 60.130, the sections of particular importance to design of surface and underground facilities with respect to radiological safety, containment, and waste isolation are 60.131 through 60.133. Section 60.134 addresses the design

criteria for shaft and borehole seals which are not part of the underground facility or the engineered barrier system; these criteria are addressed by Issue 1.12 (Section 8.3.3.2). Section 60.135 addresses design criteria for the waste package, which are covered under Issue 2.6 (Section 8.3.4.3). General design criteria for the geologic repository operations area are given in 10 CFR 60.131. This section covers two main topics: (1) methods of radiological protection and (2) systems, structures, and components important to safety. Additional design criteria for the surface facilities are given in 60.132, and additional design criteria for the underground facilities are given in 60.133.

Technical background and licensing strategy

Not all the design criteria stated in these sections are related to preclosure radiological safety; some are related to postclosure containment and isolation. Therefore, not all these design criteria are addressed in Issue 2.7. The division of responsibility and relationships between the design issues are described in Section 8.3.2.1 (see Figure 8.3.2.1-1), and the specific issues responsible for addressing each criterion stated in 10 CFR 60.131 through 60.133 are presented in Table 8.3.2.3-1. In addition, the table also indicates which criteria require site parameters to accomplish the design and analyses needed to address the criteria. Only those criteria that result in the need for site data will be addressed in detail in the SCP. A full consideration of all criteria, as well as the plans to account for all criteria in the design of the repository, will be provided in the repository design plan.

This issue is concerned with the features (i.e., characteristics and configurations) of the repository that relate to radiological safety. These features consist of a subset of the total set of engineered systems and components that make up the repository. The features also address some aspects of the natural setting (i.e., the site) by accounting for the impact of these aspects on the engineered systems and components. For example, the presence of radon in the rock at the site, and its release into the mined openings, should be accounted for in the design of the ventilation system.

The role and responsibilities of this issue in addressing the features of the repository related to radiological safety must be placed in context with the roles of other issues. An illustration of the relationship of Issue 2.7 to the other issues with which it is directly tied is illustrated in Figure 8.3.2.1-1. That figure defines the ties among these issues by indicating what major information items are transferred, as well as the connection of these issues with the site characterization program. A strong tie between Issue 2.7 and Issue 4.4 is indicated and, in particular, the reliance of Issue 2.7 upon Issue 4.4 for development of the design and supporting analyses is depicted.

This issue requires that the repository design incorporate the general design criteria specified in 10 CFR 60.131 through 60.133 such that the preclosure performance objectives identified in 10 CFR 60.111 can be met. The general objective of these criteria is to ensure that the geologic repository operations area will be designed in such a way that the general public and repository workers are adequately protected from both routine and

accidental releases of radioactive material during repository operation, including retrieval operations. The primary means of resolving this issue is by reflecting the preclosure design criteria of 10 CFR 60.131 through 60.133 in the design of the geologic repository operations area and by demonstrating through analyses that the performance objectives of 10 CFR 60.111 will be met. As stated in 10 CFR 60.130, the design criteria specified in 10 CFR 60.131 through 60.133 are a minimum set. Other design criteria that are consistent with and compliment the criteria in 10 CFR 60.131 through 60.133 could be specified. The information needed to resolve this issue is primarily design information. Very little site characterization data is required to perform the design functions of this issue. Site data that is required pertains mainly to the identification of design-basis accidents and to the use of the properties of the site to aid design features in enhancing radiological safety. The resolution of Issue 2.7 will be complete when it has been demonstrated that each item listed in 10 CFR 60.131 through 60.133 has been adequately addressed in the license application design. The analysis of additional design features will provide added assurance of radiological safety beyond the regulatory requirements. Note that Issue 2.7 will ensure that radiation safety design criteria are met while Performance Issues 2.1 through 2.3 will ensure that regulatory limits are met.

The strategy for resolving this issue involves repetitive examination of an evolving design to ensure that the final design meets the design criteria, expressed as performance measures and associated goals. These goals directly result from a preliminary performance allocation concerned with the preclosure radiological design criteria of 10 CFR 60.131 through 10 CFR 60.133. The licensing strategy is based upon the evaluation of aspects and safety features in the design of specific facility features of the geologic repository operations areas. These aspects are grouped into five general categories, referred to as functions in the following text, that the design is expected to achieve in order to comply with the intent of the preclosure design aspects of 10 CFR 60.131 through 10 CFR 60.133. Issue resolution corresponds to acceptance of the arguments in support of compliance by the NRC.

The five functions that the geologic repository operations area facilities must perform in order that this issue be resolved were selected such that there is a direct correlation between the functions and the preclosure design criteria of 10 CFR 60.131 through 60.133. The functions are (1) radiation protection, (2) design and protection of structures systems and components important to safety, (3) criticality control, (4) compliance with mining regulations, and (5) waste treatment.

A complete logic diagram of the iterative design and assessment process required to obtain resolution of this issue may be found in Section 8.3.2.3. A portion of this process, the performance allocation, is responsible for the repository functional groupings just mentioned. The activities or processes required to perform these functions and the measures that will be used to assess the level of success in performing the functions have been identified through the performance allocation process. Goals for the testing program, in terms of specific site characteristics to be evaluated and parameter values that would contribute to a favorable resolution of this issue, were

also identified. Identification of the processes and measures and associated goals and parameters helps to orient the testing program toward obtaining the information to resolve this issue.

The first major function of the repository design is radiation protection. Radiation protection is further subdivided into ten subfunctions (Table 8.2-28). These subfunctions are derived from 10 CFR 60.131 through 60.133 design criteria, and they are the necessary functions of radiation protection. The first two subfunctions include limiting concentrations of radioactive materials in air and limiting the time required to perform work in the vicinity of radiation sources. The measures used to assess these subfunctions are the predicted and measured concentrations of radioactive material in air, time to perform tasks, and doses to workers in the vicinity of radiation sources. Another necessary subfunction is to provide shielding for workers to protect them from direct radiation exposures. Measures of this subfunction include dose reduction factors and radiation attenuation factors.

An important subfunction of radiation protection is to monitor and control the dispersal of radioactive contamination. This can be accomplished in various ways, including the use of stationary monitors, portable monitors, personnel dosimeters, access control mechanisms, ventilation control and cleanup methods, decontamination procedures, and the collection and treatment of waste generated onsite. Measures used to assess radiation control and monitoring include measured contamination levels and personnel doses.

Radiation alarm systems are to be provided both for the workers and worker areas and for the repository effluents. These alarm systems will alert workers to levels of radiation in work areas or repository effluents that exceed established design levels. The alarms will be both visual and audible. Measures for alarm systems include accuracy, reliability, and noticeability (both visibility and loudness).

Ventilation systems that protect against radiation exposure are also to be provided in the repository facilities. This can be accomplished by providing separate ventilation systems for waste-handling areas and non-waste-handling areas both on the surface and underground. If necessary close-capture ventilation system can be provided in areas where the potential to generate airborne radionuclides exists. Ventilation filtration is a standard method of ensuring clean air and decontaminating airstreams, and filtration will be used where prudent. Another method of controlling exposure through ventilation is to design flow pattern such that potential contamination is always carried away from personnel.

All of these subfunctions and some others are necessary to perform the major function of radiation protection. Table 8.2-28 contains a more detailed list of these subfunctions along with their required processes or activities and their performance measures.

The development of the conceptual design has led to identifying numerous means of limiting releases. For the surface facilities, these include compartmentalization of surface facility operations, design of hot cells for negative-pressure operation, shielding selected operations, and zoned ventilation systems in the surface buildings. In addition, filtration

Table 8.2-28. The subfunctions, processes or activities, and performance measures involved in providing the radiation protection function (Issue 2.7, repository design criteria for radiological safety) (page 1 of 5)

Subfunction	Process or activity	Performance measure
Limit concentrations of radioactive materials in air	Monitor concentrations of radioactive material in repository airstream	Concentrations of radioactive materials in repository airstreams
	Filter exhaust air from potentially contaminated areas	Concentrations of radioactive materials in repository airstreams
	Maintain gaseous radionuclides in repository airstreams below acceptable levels	Concentration of radioactive materials in repository airstreams
Limit time required to perform work in the vicinity of radioactive materials	Limit time of occupancy for tasks in radiation field greater than 0.5 mrem/hr	Time required to perform tasks in radiation fields greater than 0.5 mrem/hr
	Provide remote-handling capability for long-term task in radiation fields greater than 0.5 mrem/hr	Dose reduction due to use of remote-handling equipment
Provide suitable shielding materials	Provide shielding to reduce radiation fields to below 0.5 mrem/hr in normally occupied work areas	Radiation fields in normally occupied work areas
	Use shielding properties of the host rock in limiting exposure of workers to direct radiation	Dose reduction factor attributable to host rock shielding properties

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Table 8.2-28. The subfunctions, processes or activities, and performance measures involved in providing the radiation protection function (Issue 2.7, repository design criteria for radiological safety) (page 2 of 5)

Subfunction	Process or activity	Performance measure
Monitor and control the dispersal of radioactive contamination	Monitor contamination by using	Contamination levels outside of contamination areas
	stationary radiation monitoring systems	
	portable radiation monitors	Contamination levels outside of contamination areas
	personnel dosimetry	Contamination on personnel
	Control dispersal of contamination by	
	providing access control to potential contamination areas	See access control function
	providing ventilation control and cleanup of airstreams	See ventilation functions
	decontamination of contaminated items	Residual contamination
	collection of site-generated waste	Residual contamination due to site-generated waste

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Table 8.2-28. The subfunctions, processes or activities, and performance measures involved in providing the radiation protection function (Issue 2.7, repository design criteria for radiological safety) (page 3 of 5)

Subfunction	Process or activity	Performance measure
Control access to high radiation areas	Provide signs and personnel barriers to prevent access by unauthorized personnel	Visibility of signs Distribution and location of signs Effectiveness of personnel barriers
	If necessary, provide guards to prevent access by unauthorized personnel	Effectiveness of guard
	Provide procedural requirements to control access to high radiation areas	Effectiveness of procedures
Provide radiation alarm systems for work protection	Provide visual alarm systems to alert workers if radiation levels exceed established design levels	Visibility of alarm systems Accuracy and reliability of alarm system
	Provide audible alarm systems to alert workers if radiation levels exceed established design levels	Loudness and noticeability of alarm Accuracy and reliability of alarm system
Monitor and control radioactive materials in repository effluents	Detect radioactive materials in repository effluent	Ability to detect radioactive materials in repository effluent streams

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Table 8.2-28. The subfunctions, processes or activities, and performance measures involved in providing the radiation protection function (Issue 2.7, repository design criteria for radiological safety) (page 4 of 5)

Subfunction	Process or activity	Performance measure
	Detect radioactive materials in repository effluent streams	Ability to control radioactive materials in repository effluent streams
Provide radiation alarm systems for repository effluents	Provide visual alarm systems to alert workers if radiation levels in effluents exceed established design levels	See worker radiation alarm function
	Provide audible alarm systems to alert workers if radiation levels in effluents exceed established design levels	See worker radiation alarm function
Provide safe handling and temporary storage of waste whether awaiting emplacement or being retrieved	See function to limit work time in vicinity of radioactive materials	See function to limit work time in vicinity of radioactive materials
	See function to provide suitable shielding	See function to provide suitable shielding
	Maintain combined individual worker doses from all sources of radiation below annual design objective	Combined annual individual worker doses from all sources of radiation

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Table 8.2-28. The subfunctions, processes or activities, and performance measures involved in providing the radiation protection function (Issue 2.7, repository design criteria for radiological safety) (page 5 of 5)

Subfunction	Process or activity	Performance measure
Provide repository facility ventilation systems that will protect against radiation exposure	Maintain airflow in direction from areas of lower contamination potential to areas of higher contamination potential	Pressure differentials between radiation zones Potential for accidental flow reversals Flow rate in high contaminated areas
	Separate ventilation systems of surface waste-handling areas and other surface areas	Leakage between systems Pressure differential between separate systems
	Separate ventilations systems of underground waste-handling and emplacement areas and mining development areas	Leakage between systems Pressure differential between separate systems
	Provide close-capture ventilation exhaust systems when necessary	System capture efficiency
	Filter airstream and exhausts when necessary	Decontamination factor (DF) Number of filter banks
	Flow pattern of ventilation should direct potential contamination away from personnel	Flow patterns of ventilation system

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systems for gaseous effluents, strippable wall coatings in selected areas, removable liners from selected equipment, and automated systems where possible are used in the current design. Placement of the waste-handling building and its effluent exhaust systems has considered the prevailing wind direction as a means of limiting contamination of other surface facilities. Access control is also provided for the surface facilities. Collection and treatment of site-generated waste is reflected in the current design as are specified areas for decontamination activities.

Ventilation systems and design are the primary means of limiting releases in the underground facilities. In the ventilation system, filters are provided on the underground exhaust building, and a positive-pressure differential will exist between the development and waste emplacement areas to ensure leakage is always toward the emplacement side. For the equipment program, shielding is installed in the transporter cask, transporter cab, and shield plugs designed for the waste emplacement boreholes. Additionally, speed limitations and braking criteria have been established for the transporter as a means of limiting the consequences of potential accidents. Assess control is provided.

Many of the planned repository operations have established means of limiting releases. For example, operations are sequenced so that workers should not be consistently downstream from waste emplacement operations. Similarly, airflow related to muck removal from the development area will be exhausted along the tuff ramp, thereby having minimal potential for ingestion by workers. Extensive inspections are planned for waste upon arrival and during processing. Where possible maintenance operations are being designed to be conducted outside the hot cells, although some maintenance will require using remote systems.

The second major function of the repository is the design and protection of structures, systems, and components important to safety (Table 8.2-29). Structures, systems, and components important to safety must be protected from a number of events, including natural phenomena, environmental conditions, dynamic effects of equipment failures, fires, and explosions. This can be accomplished by designing housing structures, systems, and components important to safety in buildings or structures (1) to withstand credible natural phenomena and environmental conditions, (2) to withstand the dynamic effects of equipment failures and similar events, (3) with fire and explosion detection and suppression systems, and (4) to respond adequately to design-basis accidents. The design of structure, systems, and components important to safety must also provide for the (1) maintenance of control of radioactive materials, (2) prompt termination of unessential operations, and (3) evacuation of personnel during emergencies. During emergencies, utilities that are important to safety must be able to continue their safety functions during emergencies, and timely backup power must be available for structures, systems, and components important to safety. Finally, structures, systems, and components important to safety must be designed to facilitate inspection, testing, and maintenance. The processes and activities necessary to perform all these functions and performance measures for these functions are shown in Table 8.2-29.

Table 8.2-29. The subfunctions, processes or activities, and performance measures involved in providing the function of design and protection of structures, systems and components important to safety (Issue 2.7, repository design criteria for radiological safety) (page 1 of 3)

Subfunction	Process or activity	Performance measure
Protect structures, systems, and components important to safety against natural phenomena and environmental conditions	Structures, systems, and components important to safety are housed in buildings designed to withstand credible natural phenomena and environmental conditions	Effects of credible natural phenomena and natural conditions on structures, systems, and components important to safety
Protect structures, systems, and components important to safety against dynamic effects of equipment failure and similar events	Structures, systems, and components important to safety are housed in structures designed to withstand dynamic effects of equipment failures and similar events	Response of structures, systems, and components important to safety to dynamic effects of equipment failure and similar events
Protect structures, systems, and components important to safety against fires and explosions	Structures, systems, and components important to safety are housed in structures with fire and explosion detection and suppression equipment	Effects of fires, explosions, and suppression systems on structures, systems, and components important to safety
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 emergencies	Structures, systems, and components important to safety are designed to maintain control of radioactive material during emergencies	Maintenance of control of radioactive material during design-basis accidents

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Table 8.2-29. The subfunctions, processes or activities, and performance measures involved in providing the function of design and protection of structures, systems and components important to safety (Issue 2.7, repository design criteria for radiological safety) (page 2 of 3)

Subfunction	Process or activity	Performance measure
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 emergencies	Structures, systems, and components important to safety are designed to permit prompt shutdown of nonsafety related operations during an emergency	Time to shutdown nonsafety related operations during all design-basis accidents
	Structures, systems, and components important to safety are designed so that they facilitate the evacuation of personnel from the repository during an emergency	Effects of structures, systems, and components important to safety on evacuation of personnel during design-basis accidents
Ensure that utilities important to safety will continue their safety functions during emergencies	Utilities important to safety are designed to continue their safety functions during conditions anticipated during an emergency	Ability of utilities important to safety to continue safety functions during all design-basis accidents
Ensure that structures, systems, and components important to safety will facilitate inspection, testing, and maintenance	Structures, systems, and components important to safety are designed to facilitate inspection, testing, and maintenance	Complexity of inspection operations for structures, systems, and components important to safety Complexity of testing operations for structures, systems, and components important to safety

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Table 8.2-29. The subfunctions, processes or activities, and performance measures involved in providing the function of design and protection of structures, systems and components important to safety (Issue 2.7, repository design criteria for radiological safety) (page 3 of 3)

Subfunction	Process or activity	Performance measure
		Complexity of maintenance operations for structures, systems, and components important to safety
Provide timely backup power to structures, systems, and components important to safety when needed and during emergencies	Design power systems with backup power capability (diesel generators or other suitable means)	Capacity of backup power supply Time for backup power supply to become operable
Provide instrumentation and control systems to monitor and control structures, systems, and components important to safety for all anticipated ranges of operation	Design structures, systems, and components with instrumentation and control system	Range of operation of monitoring instrumentation Range of operation of control instrumentation Ability to control structures, systems, and components important to safety

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The third major function of the repository design relevant to radiological health and safety is criticality control (Table 8.2-30). Three main factors can be used to control criticality. The first, and easiest to manipulate, is geometry. The geometry in which the spent fuel is placed in containers, stored, and emplaced can be easily dictated by design, and so configurations unfavorable to criticality can be maintained. The second factor is critical mass or total fissile content. A critical mass is the smallest amount of fissile material that could attain criticality under the most favorable conditions. If assemblies and containers are kept below a critical mass, then a criticality incident is not possible. In many instances, however, the critical mass may be too small to be practical; therefore, in general, combinations of factors affecting criticality are used to ensure that a criticality incident is not possible. The third factor used to control criticality is neutron moderation (slowing down neutrons to speeds where the fission reaction is possible). Light (low atomic weight) materials such as water or graphite are used to moderate neutrons. Controlling the introduction of these light materials into waste arrays is an effective way of controlling criticality.

Another way to control criticality events is by introducing neutron absorbers into the waste arrays. This is the same principle that is used to control power reactors. Reactor control rods are simple neutron absorbers that "steal" neutrons from the fuel and shut off the fission reactions. This method of control is not currently under consideration; however, it will be considered if such measures are needed. The processes and activities necessary to maintain criticality control are contained in Table 8.2-30.

Compliance with the relevant mining regulations is the fourth major function of the repository mentioned earlier (Table 8.2-31). 10 CFR 60.131(b)(9) requires that the repository design "include such provisions for worker protection as may be necessary to provide reasonable assurance that all structures, systems, and components important to safety can perform their intended safety functions." This means that those workers that are assigned specific safety functions must be able to perform those functions, and if protection is required, it must be provided. Those workers that do not perform assigned safety functions are evacuated during emergencies and therefore do not require protection beyond that normally provided.

The final major function of the repository is waste treatment. There are three basic activities associated with waste treatment: (1) collection of site-generated waste, (2) treatment and stabilization of collected waste, and (3) packaging of treated site-generated waste for disposal. These activities along with their performance measures are contained in Table 8.2-32.

More details about the performance allocation for Issue 2.7, including tentative goals for performance measures, parameters needed to evaluate performance measures, goals, and expected values of these parameters, are contained in Section 8.3.2.3.

Table 8.2-30. The subfunctions, processes or activities, and performance measures involved in the criticality control function (Issue 2.7, repository design criteria for radiological safety) (page 1 of 2)

Subfunction	Process or activity	Performance measure
Criticality control	Maintain control of geometry of waste configurations in all phases of waste handling and disposal	Geometry of waste storage arrays
		Geometry of waste package configurations
		Geometry of emplaced waste
		Possibility of accidental disruption of waste geometry leading to unfavorable configuration
	Maintain subcritical assemblies and masses of fissile material in all phases of waste handling and disposal	Mass/fissile content of waste storage arrays
		Mass/fissile content of waste package configuration
		Possibility of accidental disruption of waste leading to unfavorable concentrations of fissile materials
	Control the introduction of any neutron moderating materials to waste containing areas	Moderating materials in or around waste storage arrays
		Moderating materials in or around waste package configurations

CONSULTATION DRAFT

Table 8.2-30. The subfunctions, processes or activities, and performance goals involved in the criticality control function (Issue 2.7, repository design criteria for radiological safety) (page 2 of 2)

Subfunction	Process or activity	Performance measure
Criticality control (continued)		Moderating materials in or around emplaced waste
		Possibility of accidental introduction of moderating materials into areas containing waste
	Neutron multiplication	K_{eff} of fissile materials

CONSULTATION DRAFT

Table 8.2-31. The subfunctions, processes or activities, and performance measures involved in providing the function of compliance with mining regulations (Issue 2.7, repository design criteria for radiological safety)

Subfunction	Process or activity	Performance measure
Compliance with mining regulations	Protection of workers who perform assigned safety functions	Ability of workers to perform assigned safety function

CONSULTATION DRAFT

Table 8.2-32. The subfunctions, processes or activities, and performance measures involved in providing waste treatment function (Issue 2.7, repository design criteria for radiological safety)

Subfunction	Process or activity	Performance measure
Waste treatment	Collect secondary site-generated generated radioactive waste handling areas	Fraction of site-generated waste collected
	Treat and stabilize or recycle secondary site-generated waste collected	Fraction of site-generated waste treated and stabilized or recycled
	Package treated and stabilized secondary site-generated waste for disposal offsite	Fraction of treated and stabilized site-generated waste packaged

CONSULTATION DRAFT

8.2.2.3 Key Issue 4

8.2.2.3.1 Performance issues for Key Issue 4

8.2.2.3.1.1 Summary of the ease and cost of higher-level findings -- Issue 4.1: Can the higher-level findings required by 10 CFR Part 960 be made for the qualifying condition of the preclosure system guideline and the disqualifying and qualifying conditions of the technical guidelines for surface characteristics, rock characteristics, hydrology, and tectonics?

Regulatory background

The DOE has established a set of siting guidelines to be used as a basis for evaluating the suitability of potential repository sites during the site selection process. These siting guidelines, set forth in 10 CFR Part 960, are separated into two categories: those that address postclosure conditions (10 CFR 960.4) and those that address preclosure conditions (10 CFR 960.5). The DOE Implementation Guidelines (10 CFR 960.3) describe the manner in which the siting guidelines must be addressed during the siting process.

Issue 4.1 (discussed in Section 8.3.5.7) is concerned with the DOE's preclosure guidelines that relate to ease and cost of construction. These guidelines consist of a system guideline and four technical guidelines. The system guideline is concerned with the technical feasibility and relative cost of siting, constructing, operating, and closing a repository at a given site. Specific concerns are (1) whether special engineering measures beyond those provided by reasonably available technology may be necessary for repository construction, operation, and closure, and (2) whether the cost of repository construction, operation, and closure may be unreasonable in comparison with other repository siting options if a large number of special measures are necessary for these phases. Each technical guideline is concerned with the effect of some specific aspect of site conditions on the concerns expressed in the system guideline. Each technical guideline has one qualifying condition that must be met for a site to be acceptable. In addition, three of the technical guidelines have a disqualifying condition. A site is unacceptable if any one of the disqualifying conditions is found to be present. The technical guidelines also identify favorable conditions and potentially adverse conditions that describe characteristics of the setting that, if present, could benefit or adversely affect the ease or cost of constructing, operating, or closing a repository.

The implementation guidelines require that the qualifying and disqualifying conditions of the system and technical guidelines be evaluated and that specific findings be made for each condition at principal decision points in the siting process. There are four levels of findings (Table 8.2-14). Disqualifying and qualifying conditions both require a lower-level and a higher-level finding. Lower-level findings must be made to determine if a site may be nominated as suitable for characterization or recommended as a candidate site for characterization (Levels 1 and 3). Higher-level findings must be made to determine if a site may be recommended for the development of a repository (Levels 2 and 4). Thus, disqualifying conditions require Level 1

and Level 2 findings, and qualifying conditions require Level 3 and Level 4 findings. Each level has both a positive finding and a negative finding associated with it.

The DOE siting guidelines do not require any findings similar to lower-level or higher-level findings to be made for the favorable or potentially adverse conditions of the technical guidelines. As stated in the Overview of the Guidelines section of the Supplementary Information (DOE, 1984c) for 10 CFR Part 960, these conditions were intended to be used to predict the suitability of a site and provide a preliminary indication of system performance before the start of detailed site characterization studies. These conditions were considered and used in the identification of potentially acceptable sites and in the nomination and recommendation of sites as suitable for characterization. By the completion of site characterization, however, sufficient data will be available to directly evaluate site performance against the qualifying conditions of the system and technical guidelines. Therefore, the favorable and potentially adverse conditions will not be considered in specific terms as they were for the environmental assessment.

Technical background and issue resolution strategy

To resolve Issue 4.1, sufficient evidence must be available to support either a positive or negative higher-level finding for each qualifying and disqualifying condition associated with ease and cost of repository siting, construction, and operation. Each of the qualifying conditions references requirements for technical feasibility based on reasonably available technology and reasonable costs relative to other siting options. In making higher-level findings for the qualifying and disqualifying conditions, specific aspects of the geologic setting must be considered in the evaluations of these requirements.

The findings that have been made previously for the qualifying and disqualifying conditions related to ease and cost, and the evidence supporting these findings, are given in the NNWSI Project environmental assessment (DOE, 1986b). The available evidence was sufficient to support a positive lower-level finding for each of the qualifying and disqualifying conditions. To determine if the Yucca Mountain site is suitable for the development of a repository, therefore, higher-level findings must be made for the qualifying and disqualifying conditions.

The information necessary to support higher-level findings will be made available through the resolution strategies of other issues. For each condition, available evidence is evaluated to determine if it is sufficient to support a higher-level finding for any of the conditions. For the qualifying and disqualifying conditions for which there is not sufficient evidence available, the planned site characterization studies are reviewed to determine if the concerns of the conditions will be investigated. This is accomplished by evaluating the resolution strategies of Issues 4.2 through 4.5, the preclosure design issues that are relevant to the evaluation of Performance Issue 4.1. If the concerns of the conditions are being considered in the resolution strategies of the other issues, the evidence to support higher-level findings for these conditions should be available.

8.2.2.3.2 Design issues for Key Issue 4

8.2.2.3.2.1 Summary of nonradiological health and safety -- Issue 4.2: Are the repository design and operating procedures developed to ensure nonradiological health and safety of workers adequately established for the resolution of the performance issues?

Regulatory background

Issue 4.2 (discussed in Section 8.3.2.4) is concerned with those aspects of underground facility design that have an implication for the preclosure nonradiological health and safety of repository workers. The DOE, in the preclosure system guideline for ease and cost of repository development (10 CFR 960.5-1(a)(3)), requires a demonstration that repository construction, operation, and closure be technically feasible. The technical guidelines related to this system guideline require that the characteristics and conditions at the site do not necessitate the use of engineering measures beyond the bounds of reasonably available technology for repository development and protection of worker safety. The strategy for resolving this issue considers worker nonradiological health and safety to be a significant element in the demonstration of feasibility using reasonably available technology.

Technical background and licensing strategy

Although not cited in the DOE guidelines that are the basis for this issue, the NRC requires, in 10 CFR 60.131, that the design of the geologic repository operations area should include provisions for worker protection adequate to ensure that structures, systems, and components important to safety can perform their intended functions. For the underground facility, such provisions are to comply with Mine Safety and Health Administration (MSHA) regulations for mine safety. The question of worker nonradiological health and safety in 10 CFR 60.131 is strictly concerned with how such safety measures can provide reasonable assurance that all systems, structures, and components important to safety can perform their intended functions. The DOE and the MSHA have signed a memorandum of understanding (dated December 23, 1986) to formalize a working arrangement whereby the MSHA will assist the DOE by inspecting repository operations so that the DOE can implement its policy of compliance with MSHA standards as though the repository were a commercial mine.

The strategy for resolving this issue involves repetitive examination of an evolving design to ensure that the final design meets the design criteria, expressed as performance measures and associated goals. These goals are the direct result of a preliminary performance allocation concerned with the preclosure nonradiological health and safety design criteria. The licensing strategy is based upon evaluating the functions of repository design that are relevant to preclosure nonradiological health and safety. Nine general groupings of functional requirements for the repository design have been identified in order to ensure compliance with the intent of the preclosure nonradiological safety concerns of the DOE guidelines for ease and cost of repository development.

The resolution of this issue requires that designs and operating procedures that ensure worker nonradiological health and safety during the preclosure period be selected and implemented. Certain aspects of the designs must also be demonstrated to verify that the design approach produces designs that are safe. Design aspects that must be demonstrated are related to the designs of the underground system elements located within the underground areas heated by the emplaced waste; this heating presents a unique design environment. The overall design process is described in Issue 4.4.

The relationship of Issue 4.2 to Issue 4.4 is graphically described in Figure 8.3.2.1-1. In Issue 4.2, those aspects of the overall design that impact worker health and safety are defined, goals necessary to meet the regulatory requirements are designed, and the design goals are transmitted to Issue 4.4 for incorporation into the overall design.

The goal of Issue 4.4 is to ensure that the design, construction, and operation of the repository can be accomplished with reasonably available technology. The implication of Issue 4.4 is that the repository will be able to draw upon an existing experience base in the design and the development of procedures for ensuring worker nonradiological heath and safety. To this end, Issue 4.2 will draw upon regulatory requirements to establish goals for the design and operation to ensure worker health and safety. These goals will be imposed on Issue 4.4 in the form of requirements and constraints on the overall design and operating procedures.

The nine general groupings of functional design requirements address specific elements of the mined geologic disposal system at Yucca Mountain. The specific system elements of concern are drifts and access, emplacement boreholes, retrieval, mining and waste ventilation, nonradiological monitoring, maintenance, and underground closure. The functions and processes that the various system elements must accomplish are frequently similar for several system elements. Accordingly, the relevant aspects of the site characteristics and licensing strategy that are presented in the following text often address groups of system elements.

The major factors that impact worker safety are associated with the underground facilities. These factors are opening stability and ventilation. At the Yucca Mountain site, ground-water inflow sufficient to cause a worker safety problem is not expected (Issue 4.8, Section 8.3.1.16). The natural rock temperature at Yucca Mountain does not present a concern, but the rock temperatures and hence the work environment during retrieval could be of concern. Equipment-related accidents should not be caused by restrictive site conditions. Accesses and drifts will be sized to allow adequate room for maneuvering of equipment without endangering personnel. To ensure rock stability, the characteristics of the rock must be known and a design procedure must be established to accommodate conditions expected in construction, waste emplacement, and waste retrieval.

Opening stability is an important aspect of access and drift construction, retrieval, and maintenance. The strata within which a repository at Yucca Mountain would be constructed have some characteristics that could be favorable with regard to opening stability. Chapter 6 describes the current conceptual design, and the rock support system that has been selected based on currently available data. Attributes of the site that are important to

the licensing strategy are reflected in that design. The repository construction would take place primarily in welded tuff that is relatively competent and jointed. The repository would be relatively shallow and neither high stresses, high temperature, and dangerous gases are not expected. The primary support system envisioned for the repository is rock bolts and wire mesh.

The goals of worker nonradiological health and safety are completely consistent with design goals to maintain stable openings with minimal maintenance for at least up to 84 years, should retrieval be necessary. Current NTS underground opening support practice includes a small amount of development in a welded fractured tuff that is similar in many respects to the horizon in which the repository would be constructed. The currently planned support system, with primary emphasis on rock bolts and wire mesh, is consistent with current NTS practice. Furthermore, the planned excavation support can be increased by adding extra or longer bolts and shotcrete.

An evaluation of potential excavation hazards to underground workers in a repository at Yucca Mountain was presented in the NNWSI Project environmental assessment (DOE, 1986b). That evaluation was based upon experience at the NTS in weapons-effect testing tunnels. The data presented by DOE (1986b) clearly indicated a significantly better safety record for NTS tunneling operations than is typical of commercial mining industry practice. NTS practice heavily emphasizes worker safety. It incorporates the concepts of MSHA, California Department of Mines safety orders, and DOE order 5480.4 on safety and uses the most stringent governing standards from these regulations. The weapons-effect tunnels at NTS are designed and constructed for long-term serviceability and stability. Information relevant to resolution of this issue will be developed with that relevant experience that can be drawn from existing NTS practice.

There are ventilation and induced-temperature concerns relevant to worker nonradiological safety and thus to resolution of this issue. The NRC in 10 CFR 60.133(g) requires a separation of the ventilation circuitry for the excavation and waste emplacement areas. The current conceptual design calls for the circuitry to be separate and to meet MSHA standards and ACGIH (American Conference of Governmental Industrial Hygienists) standards. The design goals for ventilation, with respect to worker nonradiological health and safety, include two independent systems for the underground ventilations facility, one for the waste emplacement operations area and one for the development area. Redundancy in the ventilation fans for each area is planned. In addition, a forcing circuit is planned for the development area, and an exhausting circuit is planned for the emplacement area. The pressure differential thus established should ensure that any leakage would be away from the development areas.

Temperature of the working environment is of concern for worker nonradiological health and safety. Current design goals directly address the question of temperature-induced rock stress and potential instabilities. Also, the design criteria introduced for retrieval considerations place temperature limits on the workings that directly relate to worker nonradiological health and safety.

More detail about the functions relevant to the issue resolution strategy for Issue 4.2 can be found in Table 8.2-33. For each system element, this table lists the functions and processes available to ensure that the functional requirement is accomplished. The performance allocation for Issue 4.2, as well as details on performance goals and relevant parameters, can be found in Section 8.3.2.4. Goals for the testing program, in terms of specific site characteristics to be evaluated and parameter values that would contribute to a favorable resolution of this issue are identified. Identification of processes, measures, and associated goals and parameters helps to orient the testing program toward obtaining the information to resolve this issue.

8.2.2.3.2.2 Summary for waste package production technologies -- Issue 4.3: Are the waste package production technologies adequately established for the resolution of the performance issues?

Regulatory background

Issue 4.3 (discussed in Section 8.3.4.4) arises from the provision of the preclosure system guideline for ease and cost of repository development 10 CFR 960.5-1(a)(3), which requires that repository operations shall be demonstrated to be feasible on the basis of reasonably available technology. The waste packages are a necessary element of repository operations and, therefore, must be technically feasible on the same basis.

Technical background and issue resolution

In addition to questions of technical feasibility, the processes selected for producing the waste packages affect the design of the packages, the design and operation of the repository surface facilities where they are assembled, and the performance of the packages after they are emplaced in the repository underground facilities. Rather than differentiate among technical feasibility, waste package and facility design, and waste package performance aspects of the production processes and describe the plans for each separately, the planned activities to provide information for all production-related requirements are addressed in this issue.

The waste packages consist of several components that must be fabricated and assembled according to requirements imposed to ensure containment of the waste form for 1,000 years. It is estimated that approximately 30,000 waste packages will be required to contain the 70,000 MTHM of waste to be emplaced in the first repository. Fabricating and assembling components in these quantities must be done with well understood and predictable techniques.

The parameters of Issue 4.3 involving fabrication technologies include process criteria definition, process identification, process testing and evaluation, process selection, and prototype fabrication and testing. Fabrication includes all processes required to produce the package components other than the waste form.

For a waste package using metal containers, the components include an internal basket, the container body, and a top closure. The processes to be

Table 8.2-33. System elements, functions and processes, and performance measures pertinent to Issue 4.2 (nonradiological health and safety)

System element	Function and process	Performance measure
Access construction	Underground facility access and egress	Safe access to underground facilities (usable access for 100 yr) Limit overbreak Limit blast induced fracture extent Access closure (combined performance of rock and opening support) Closure rate in shafts and ramps Total closure in ramps Total closure in shafts Maximum rock fall size (rockfall in ramps contained by support system Average shaft liner space (all rockfall or liner spall to be retained (by supplemental support or liner system) (shafts)) Acceptable maintenance frequencies Minor maintenance (continuing basis) Major maintenance frequency Access sizes and grades compatible with requirements for personnel and material transport and utility routing Waste ramp grade Tuff ramp grade Minimum diameter Roadway width Clearance between ramp or ramp equipment

Table 8.2-33. System elements, functions and processes, and performance measures pertinent to Issue 4.2 (nonradiological health and safety) (continued)

System element	Function and process	Performance measure
Access construction (continued)	Underground facility access and egress (continued)	Tuff ramp diameter adequate for conveyor-movement of equipment
	Removal of broken rock	Compliance with 30 CFR 57 Clearance for rock removal equipment Presence of safety systems (conveyors) Barriers and guards Heat sensors Slack sensors Back run preventers Dust suppression
	Ventilation supply and exhaust	Pressure drops in accesses Accesses sized to limit air velocities and to accommodate future changes in air demands < 3,000 ft/min in shafts < 1,500 ft/min in ramps > 60 ft/min in all accesses
	Emergency egress	Compliance with 30 CFR 57 Accesses designed to provide safe egress during emergencies
Drift construction	Underground facility access	Safe and usable access for 100 yr Limit overbreak Limit blast-induced fracture extent Drift closure (combined performance of rock and opening support system) Rate of closure in mains and access drifts Rate of closure in waste emplacement drifts Total closure

Table 8.2-33. System elements, functions and processes, and performance measures pertinent to Issue 4.2 (nonradiological health and safety) (continued)

System element	Function and process	Performance measure
Drift construction (continued)	Underground facility access (continued)	Rockfall quantity and retention Maximum rock or slab size Rockfall retained by support system
		Acceptable maintenance frequencies Inspection and minor maintenance performed on a continuing basis
		Major maintenance frequencies
		Drift size and grades for personnel and material transport and utility routing Drift size wider than equipment Drift grades
	Removal of broken rock	Compliance with 30 CFR 57
		Adequate clearance
		Safety systems (conveyors) Barriers and guards Heat sensors Slack sensors
		Dust control and suppression
	Ventilation supply and exhaust	Pressure drop in drifts
		Drifts sized to limit air velocities and to cover changes in future air needs
	Emergency egress	Compliance with 30 CFR 57 Ventilated emergency escapeways present

Table 8.2-33. System elements, functions and processes, and performance measures pertinent to Issue 4.2 (nonradiological health and safety) (continued)

System element	Function and process	Performance measure
Borehole construction	Construct borehole	Compliance with 30 CFR 57 and ACGIH[a] (1986)
		Air quality compliance with 30 CFR 57 and threshold limit values (TLVs) and bioindices specified in ACGIH (1986) Concentrations of SiO_2, O_2, CO, and radon daughters Personnel radon exposure Air cooling power
Mining ventilation	Provide adequate quantity of air to all work areas	Air quantity compliance with 30 CFR 57 Adequate quantity Minimum air
	Provide quality air to all work areas	Air quality compliance with 30 CFR 57 and TLVs and bioindices specified in ACGIH (1985-86) Concentrations of SiO_2, O_2, CO, and radon daughters Personnel radon exposure Air cooling power
Retrieval	Provide access to emplacement borehole	Temperature in retrieval area Surface rock temperature in shafts and ramps Temperature in access drifts Air temperature during retrieval

Table 8.2-33. System elements, functions and processes, and performance measures pertinent to Issue 4.2 (nonradiological health and safety) (continued)

System element	Function and process	Performance measure
Retrieval (continued)	Provide access to emplacement borehole (continued)	Rock movement Rock and support movement in accesses Rock movement in access drifts Rock movement in emplacement drifts Total closure in shafts Total closure in ramps and drifts Rockfall in ramps and drifts Maximum rock or slab size Rockfall amount in shaft (all rockfall to be retained by support system) Maintenance Inspection and minor maintenance will be done on a continuing basis Major maintenance frequency
Waste ventilation	Air quality	Air cooling power
	Cooldown of rock for reentry of emplacement drifts to perform heavy maintenance or retrieval	Rock surface temperature
Underground closure	Backfill of drifts and installation of post-closure seals	Temperature Air cooling power Rock surface temperature Air temperature Compliance with 30 CFR 57 and ACGIH (1985-86) Concentrations of SiO_2, O_2, CO, and radon daughters Personnel radon exposure

Table 8.2-33. System elements, functions and processes, and performance measures pertinent to Issue 4.2 (nonradiological health and safety) (continued)

System element	Function and process	Performance measure
Maintenance	Access (shaft and ramps) maintenance	Closure and rockfall Rock movement Amount of rockfall Maximum rock or slab size (rockfall retained by support system)
	Drift maintenance	Usability for 100 yr Inspection and maintenance will be done on a continuing basis Major maintenance frequency
Nonradiological monitoring	Monitor usability of shafts, ramps, and drifts during construction, operation, retrieval, closure, and decommissioning	Items important to operational safety monitored and displayed in repository control center Temperature Rock movement Rock support system (visual) Air quality Water inflow Seismic activity

[a]ACGIH: American Conference of Governmental Industrial Hygienists.

used for assembling this waste package may include rolling, welding, casting, forging, extruding, heat treating, and nondestructive testing.

Since the performance of the waste package can be impacted by the production technology used, it is crucial that processes are selected that will minimize these impacts and that allow these impacts to be mitigated through proper treatment. Welding processes are particularly important in this regard. Proper resolution of this issue is considered of equal importance to the other waste package issues.

The approach to resolving this issue will involve a set of studies directed at identifying and evaluating production processes in each of the

technology areas. Selection criteria for each technology will be established. Candidate processes will be identified and evaluated against the selection criteria, and the leading candidate processes will be used to produce representative test specimens. These test specimens will be analyzed to determine their properties and the properties will be compared with the criteria derived from the performance requirements. Process selection will then be made on bases that will include performance, as well as other criteria such as reliability, adaptability to repository facility operations, and cost. The final step in the analyses will be the use of the selected processes to produce full-scale prototype components, assembly of these components, and testing of the prototypes to demonstrate both feasibility and compliance with the requirements.

8.2.2.3.2.3 Summary for preclosure design and technical feasibility -- Issue 4.4: Are the technologies of repository construction, operation, closure, and decommissioning adequately established to support resolution of the performance issues?

Regulatory background

Issue 4.4 (discussed in Section 8.3.2.5) is concerned with the question of whether or not the repository can be designed, constructed, operated, and closed using reasonably available or proven technologies given the characteristics of the site. The regulatory basis for addressing this issue and its subsidiary information needs is expressed in the preclosure guidelines related to ease and cost of repository development.

Technical background and licensing strategy

Issue 4.4 questions whether the repository can be designed, constructed, operated, and closed using reasonably available or proven technology or whether it will be necessary to extrapolate beyond current techniques in order to perform the functions identified by this issue. An additional constraint imposed on this issue by Key Issue 4 is that the cost for construction, operation, and closing of the repository be reasonable.

In addition to consideration of design concerns related to the preclosure guidelines which are the basis for this issue, a decision has been made to make Issue 4.4 the focus for repository design activities. To serve this purpose, Issue 4.4 must be concerned with design constraints developed directly by and for resolution of the issue as stated; it must also be concerned with design and performance-derived design constraints developed under other issues, which address the performance and design criteria of 10 CFR Part 60. Postclosure design constraints developed under Issue 1.11 (configuration of underground facilities--postclosure) and Issue 1.12 (seal characteristics) are factored into the design developed under Issue 4.4. Similarly, preclosure constraints for worker and public radiological health and safety developed under Issues 2.1, 2.2, 2.3, and 2.7 and worker nonradiological health and safety considerations developed under Issue 4.2 are factored into the design developed under Issue 4.4. Additionally, retrieval objectives developed under Issue 2.4 are considered in the design developed under Issue 4.4.

The strategy for resolving this issue involves development of an evolving design that meets the design criteria, expressed as performance measures and associated goals developed jointly with several design-related issues. Those goals are the direct result of a preliminary performance allocation concerned with the design criteria of 10 CFR Part 60 and 10 CFR Part 960. The licensing strategy is based upon evaluations about the reasonable availability of technologies, consistent with the design goals being achieved. The conclusion that the repository can be constructed, operated, closed, and decommissioned using reasonably available technology will be based on the technology requirements for each system element. The technology requirements will be developed by a design process for the element that includes configuration determination, design analysis (requiring site or nonsite data), and material selection to meet the performance goals for that element. The assessment that the technology is reasonably available will be based on criteria that includes (1) the previous successful demonstration elsewhere of construction or design techniques, (2) the ability to demonstrate new technology applications before license application, and (3) combinations of empirical, observational, and analytical procedures to provide reasonable assurance of the success of the design.

The current conceptual design of the repository is described in Chapter 6. Relevant technical aspects of the design include development of the underground facility at relatively shallow depth (approximately 335 m) in a welded tuff formation. The relatively shallow depth permits ramp access to the repository horizon; separate ramps are currently planned for waste emplacement activities and construction activities. The ramps are augmented by shafts for ventilation, personnel and materials handling; separate ventilation circuits are planned for construction and waste emplacement activities. The repository horizon at Yucca Mountain would be in the unsaturated zone; ground water is not expected to be a major factor in facility construction. Additionally, the repository horizon is currently planned to slope toward the northeast, both to develop the repository in rock strata of expected similar properties and to enhance drainage away from waste packages should isolated zones of perched water be encountered. A relatively dry underground facility is expected to be conducive to lengthened waste package lifetimes. Previous excavation experience in tuff formations at the nearby Nevada Test Site lends confidence to the expectation that stable openings can be developed and maintained with reasonably available technology.

Twelve groups of functional requirements have been identified that are relevant to resolution of this issue. These functional requirements are associated with specific elements of the Yucca Mountain mined geologic disposal system. The specific functional requirements addressed in the design developed for resolving this issue originate, for the most part, in the issue resolution strategies for other issues. Issue 4.4, as has been pointed out previously, has as its primary responsibility the development of the repository design for a facility at Yucca Mountain. As such, it must incorporate the site specific postclosure design concerns of Issues 1.11, 1.12, and 1.10 (Sections 8.3.2.2, 8.3.3.2, and 8.3.4.2). Issue 4.4 must also address the site specific concerns of the issue resolution strategies of the design issues concerned with radiologic health and safety, specifically Issues 2.6 and 2.7 (Sections 8.3.4.3 and 8.3.2.3). Functional requirements originating from retrieval concerns (from Issue 2.4, Section 8.3.5.2) are also addressed in the design prepared for resolution of Issue 4.4. Finally,

functional requirements for the design originate in the issue resolution strategy for the nonradiologic health and safety issue, Issue 4.2 (Section 8.3.2.4). The relationships and interfaces between the various design issues are illustrated in Figure 8.3.2.1-1. That figure also illustrates the manner in which performance assessment related concerns are conveyed to Issue 4.4 for treatment in the design.

Information about the 12 functional areas relevant to the issue resolution strategy for Issue 4.4 can be found in Table 8.2-34. This table lists, for each system element, the functions and processes that are relevant to a viable repository design. The complete performance allocation for Issue 4.4, as well as details on goals for the performance measures and relevant parameters, can be found in Section 8.3.2.5.

8.2.2.3.2.4 Total system costs -- Issue 4.5: Are the costs of the waste packages and the repository adequately established for the resolution of the performance issues?

Regulatory background

To make the higher-level findings required for the related performance issue (Issue 4.1), the DOE must develop comparable cost estimates for construction, operation (including maintaining the retrieval option), closure, and decommissioning of a repository at the Yucca Mountain site and at each of the candidate sites that have been characterized. Cost estimates must also be developed for design and fabrication of the waste packages to be used at each site. Estimating costs for a specific site requires that the designs for the waste packages and repository be developed to a suitable level of detail, that the procedures for waste-package fabrication and for repository construction and operation be adequately identified, and that there be a model available to evaluate the associated costs. For the eventual comparative evaluation of costs to be valid, the basis for estimating the costs for each site must be similar.

Issue 4.5 addresses the need to provide the information necessary to satisfy the second requirement of the preclosure system guideline related to ease and cost of siting, construction, operation, and closure (10 CFR 960.5-1(a)(3)): the costs associated with repository siting, construction, operation, and closure shall be demonstrated to be reasonable relative to other available and comparable siting options. The results of this evaluation will support the requirement to make a higher-level finding for the qualifying condition of this system guideline for the Yucca Mountain site, and will be considered in selecting a site for recommendation for development as a repository. The comparative evaluation of costs will be based on waste package and repository designs developed to meet the applicable performance objectives and design criteria specified or referenced in 10 CFR Part 60. These designs must be deemed to be feasible on the basis of reasonably available technology and developed to accommodate those site characteristics identified in the related technical guidelines (10 CFR 960.5-2-8 to 960.5-2-11) that may affect design, and hence overall system costs.

Table 8.2-34. System elements, functions and processes, and performance measures pertinent to Issue 4.4 (preclosure design and technical feasibility) (Page 1 of 8)

System element	Function and process	Performance measure
Surface	Provide sufficient area for surface facilities	Space to accommodate surface facilities (with contingency) Area for central surface facility Area for material storage Area for underground access location
	Provide usable access for waste delivery vehicles	Grades for rail and truck delivery Road grades Rail grades
	Provide facility sites (including underground accesses) that are not jeopardized by natural or man-made phenomena	Location above floodplain Location for surface facilities Important to safety (FITS) Not over potentially active geological structures Potential for vibratory ground motion Potential for volcanic eruption at surface facilities Design basis ash fall thickness at surface facility locations (including shaft and ramp portals)
	Provide facility sites (including underground accesses) that have acceptable soil and rock conditions	Soil and rock conditions under static and dynamic conditions Stable foundations on soil and rock under static load conditions (for FITS) Stable retaining walls on soil and rock under static load conditions Stable slopes for static and dynamic loading conditions Hydraulic related soil conditions Volume change in soils

Table 8.2-34. System elements, functions and processes, and performance measures pertinent to Issue 4.4 (preclosure design and technical feasibility) (Page 2 of 8)

System element	Function and process	Performance measure
Surface (continued)	Protection and confinement of operational activities	Facilities adequate to withstand natural weather phenomena without damage to functional capability
	Provide proper environment for personnel and equipment	Proper environment for personnel and equipment under normal weather extremes Heating and cooling design values
Subsurface	Provide adequate area for distributing waste (with contingency) and required overburden	Area for 70,000 metric tons of waste and overburden >200 m
	Provide underground sites (including accesses) that are not jeopardized by natural or manmade phenomena	Sites for underground facilities Not located in areas of potentially active faults Potential for fault activity Potential for volcanic activities Acceptable potential for vibratory ground motion Levels of vibratory ground motion in underground facility Potential for volcanic eruption through underground facility
	Provide host rock thickness for drift construction and waste emplacement	Thickness for drift construction and waste emplacement
	Provide physical properties adequate for construction and operation of stable (safe) underground accesses, drifts, emplacement boreholes, and support facilities for normal and credible abnormal conditions	Usable openings of required size

Table 8.2-34. System elements, functions and processes, and performance measures pertinent to Issue 4.4 (preclosure design and technical feasibility) (Page 3 of 8)

System element	Function and process	Performance measure
Subsurface (continued)	Dissipate heat from emplaced waste	Waste package temperature
	Provide adequate water for water for repository operations	Available water
Access construction	Underground facility access for personnel, support materials, waste-handling systems during construction, operation (including retrieval), and decommissioning	Accesses (shafts and ramps) usable for 100 yr with rea-reasonable maintenance Compliance with 10 CFR 60.133f Limit overbreak Limit extent of fracturing of intact rock Access closure (combined performance of rock and opening support system) In accesses (shafts and ramps) Total closure in ramps Total closure in shafts Rockfall Amount Maximum size of rock or slabfall Rockfall contained by support system (ramps) No rockfall to disrupt or damage waste transporter (ramp) Rockfall or liner spall in shafts Maintenance frequency Inspection and minor maintenance done on continuing basis Major maintenance frequency

Table 8.2-34. System elements, functions and processes, and performance measures pertinent to Issue 4.4 (preclosure design and technical feasibility) (Page 4 of 8)

System element	Function and process	Performance measure
Access construction (continued)	Underground facility access (continued)	Access sizes and grades compatible with requirements for personnel and material transport and utility routing Shaft diameter Waste ramp roadway width Vehicle clearance Clearance for conveyor, movement of equipment Waste ramp grade Tuff ramp grade
	Ventilation routing (supply and exhaust)	Pressure drop in shafts and ramps Shaft and ramp size Ramp air velocities Shaft air velocities
	Sealing	Shafts and ramps compatible with requirements for repository sealing Material type Construction methods capability to remove exploratory shaft-1 liner Penetration into Calico Hills Water storage capacity at base of shafts
Drift construction	Underground facility access for personnel, support materials, waste handling systems during construction, operation (including retrieval) and decommissioning	Drifts usable for 100 yr with reasonable maintenance
		Compliance with 10 CFR 60.133f Limit overbreak Limit extent of fracturing in intact rock
		Drift closure (combined performance of rock and rock support system) Rates in main and access drifts Rates in waste emplacement drifts Total closure

Table 8.2-34. System elements, functions and processes, and performance measures pertinent to Issue 4.4 (preclosure design and technical feasibility) (Page 5 of 8)

System element	Function and process	Performance measure
Drift construction (continued)	Underground facility access (continued)	Rockfall (performance of rock support system) Quantity (rockfall contained by support system) Maximum size of rock or slab fall Disruption of or damage to waste transporter
		Acceptable maintenance frequency Inspection and minor maintenance on a continuing basis Major maintenance frequency
		Drift sizes and slopes compatible with requirements for personnel and material transport and utility routing Drift cross section size Drift grade
	Ventilation routing (supply and exhaust)	Pressure drop in drifts Drift size
	Sealing	Drifts (underground layout) compatible with repository sealing Water drainage to designated locations
Borehole	Provide for emplacement	Constructability of usable borehole for waste disposal envelope Borehole length Borehole diameter
	Provide waste emplacement envelope	Installation of borehole liner
Rock handling	Removal of mined rock	Ability to remove mined rock at rate of generation

Table 8.2-34. System elements, functions and processes, and performance measures pertinent to Issue 4.4 (preclosure design and technical feasibility) (Page 6 of 8)

System element	Function and process	Performance measure
Water removal	Removal of process water	All process water removed Removal capacity
	Removal of natural water	Removal rate equal to rate of inflow Removal capacity
	Removal of water resulting from condensation in ventilation returns (potential during operations)	Removal rate equal to rate of condensation Removal capacity Potential rate of condensation
Mining ventilation	Supply quality air to working area (considering: temperature, humidity, dust content, and other pollutants)	Compliance with 30 CFR Part 57 Ventilation horsepower Compliance with threshold limit values and biological exposure indices specified in ACGIH[a] (1986) Air cooling power Quantity of air per worker Minimum air velocity in work areas Concentration of SiO_2, O_2, and radon daughters Personnel exposure to radon daughters
	Provide flexibility to allow changes in air quantities and routing	System design flexibility to allow changes in air quantities and routing
	Provide safe escape routes for work force	Ventilated escape routes available for all active work areas
	Provide independence between ventilation systems	Compliance with 10 CFR 60.133g Independence of systems Leakage from mining ventilation to waste emplacement ventilation system

Table 8.2-34. System elements, functions and processes, and performance measures pertinent to Issue 4.4 (preclosure design and technical feasibility) (Page 7 of 8)

System element	Function and process	Performance measure
Emplacement	Transport waste to emplacement location	Ability to transport the required number of waste packages per day using methods which will ensure personnel safety Number of waste packages Compliance with ALARA[5] Compliance with other requirements relating to worker radiation dose
Retrieval	Retrieval of emplaced waste	Access to emplacement borehole Access to waste package Rock temperature at borehole wall Borehole liner deformation Liner corrosion
	Waste retrieval	Retrieval time Emplacement time Construction time Operator safety Radiation dose rate
	Waste transport	Operator safety
Waste	Supply air to waste disposal areas during emplacement and retrieval	Compliance with threshold limit values and biological exposure indices specified in ACGIH (1985-86) Air cooling power Quantity of air per worker Minimum air velocity in work areas Concentration of SiO_2, O_2, and radon daughters Personnel exposure to radon daughters Air cooling power for retrieval preparation

Table 8.2-34. System elements, functions and processes, and performance measures pertinent to Issue 4.4 (preclosure design and technical feasibility) (Page 8 of 8)

System element	Function and process	Performance measure
Waste (continued)	Radiological safety	Detection of airborne radioactive material
		Reduction and redirection of ventilation flows in the event that airborne radioactive particulate is detected
	Provide flexibility to allow changes in air quantities and routing necessary to accommodate changes in requirements	System design flexibility to allow changes in air quantities and routing
	Provide safe escape routes for work force	Ventilated escape routes available for all active work areas
	Provide independence between ventilation systems	Compliance with 10 CFR 60.133g Independence of systems Leakage from mining ventilation to waste emplacement ventilation system
Underground closure	Removal of repository structures	Compliance with requirements for decommissioning
	Installation of seals	Compliance with requirements for postclosure seals
	Installation of surface markers	Marker permanence
	Construction of diversion structures or water flow barriers	Construction according to sealing requirements
	Installation of backfill	Filling of all underground openings

[a]ACGIH = American Conference of Governmental Industrial Hygienists.
[b]ALARA = as low as reasonably achievable.

Technical background and issue resolution strategy

The requirement of the system guideline to estimate and compare the costs for repository siting, construction, operation, closure, and decommissioning for the various siting options was addressed in the environmental assessment (EA) for the Yucca Mountain site (DOE, 1986b). In that document, a preliminary, total-system life-cycle cost (TSLCC) estimate for a repository at the Yucca Mountain site was presented in Chapter 6 and compared with the TSLCC estimates made for the other nominated sites in Chapter 7. Updated TSLCC estimates for all nominated sites were used in the multiattribute utility analysis that led to recommendation of the three candidate sites for characterization (DOE, 1987d). In both instances, the estimates were developed, using the same methodology for each site, as part of the DOE's annual evaluation of the adequacy of the fee paid to the Nuclear Waste Fund to cover the costs of disposal services (DOE, 1985). These estimates were developed on the basis of the available preconceptual design information for the repository and waste package for each site and do not represent final cost estimates. The TSLCC estimate for the Yucca Mountain site was 8.5 billion 1984 dollars; the range of cost estimates presented in the EAs for the three sites selected for characterization was 8.5 to 12.3 billion dollars. These cost estimates have since been superseded by repository cost estimates prepared for the three recommended sites presented in annual reevaluations of the total system life cycle costs (DOE/RW-0047, 1986). The current TSLCC estimates combine the cost elements in a manner different from that used in the EAs. A detailed comparison of changes in the TSLCC estimates is beyond the scope of the SCP. The uncertainty assigned to these estimates is based on engineering judgment and is plus-or-minus 35 percent of the total cost. This uncertainty, coupled with a 10 to 40 percent contingency built into the estimate, reflects the preliminary nature of the design from which the costs estimates were derived.

The TSLCC estimates presented in the EA and those used in the multiattribute utility analyses were derived from evaluations of the two major cost components of the repository development program:

1. Development and evaluation (D&E) costs, which include costs for all activities, other than final design and construction that are conducted before the start of repository operation (e.g., siting, land acquisition, design development, testing, and regulatory and institutional activities).

2. Construction, operation, closure, and decommissioning (COCD) costs, which include costs for final design, construction, operation, and maintenance of repository facilities; for final design and fabrication of waste packages; and for closure and decommissioning of repository facilities.

Different methods were used to estimate the life cycle costs for each component. The D&E cost component for the Yucca Mountain site was derived from that portion of the total OCRWM Program D&E cost due to development work for the first repository. Cost estimates were developed on the basis of the most recent program budget projections available, the current schedule of program milestones, and a series of assumptions about the conduct of work activities throughout the D&E period. The portion of the first repository

D&E cost attributable to the Yucca Mountain site before site selection, plus all D&E costs allocated to repository development following site selection, were summed to give the D&E costs used in the TSLCC analysis. Note that D&E costs attributed to three candidate sites for activities before site selection would be incurred regardless of which site is ultimately selected for development as a repository.

The COCD component for the Yucca Mountain site was estimated using the REPCOST spreadsheet (DOE, 1985a). This spreadsheet details the costs for repository design (final procurement and construction and Title III) construction, operation (including emplacement, caretaker, and backfill periods), closure, and decommissioning. These costs are accumulated in a multilevel matrix of cost accounts that provides a cost breakdown by repository facilities and related activities for each period in the repository life cycle. The major cost account groupings are

1. Surface facilities.
2. Waste packages.
3. Shafts and ramps.
4. Underground development and operation.

Costs for each account during each phase were estimated from the product of labor, material, or equipment requirements, and the associated unit costs and subsequent buildup factors. Contingency factors of 10 to 40 percent were applied to these estimates, as indicated previously (DOE, 1985a). Costs were summed by account and phase to arrive at the total COCD costs.

To make the higher-level findings required for the related performance issue (Issue 4.1), the DOE will develop a TSLCC estimate for construction, operation (including maintenance of the retrieval option), closure, and decommissioning of a repository at each of the candidate sites that have been characterized and for design and fabrication of the waste packages to be used at each site. In developing the basis for cost estimates and providing for the site selection decision, the impact of site characteristics on the technological requirements and on the complexity of design and operating procedures will be a primary consideration.

For the eventual cost comparisons to be valid, the basis for estimating the TSLCC for each site must be similar, and the degree of uncertainty associated with the various design and operational requirements must be reduced to a reasonable level. To resolve this issue, the DOE intends to rely on refinements of the procedure and model already in use for estimating TSLCC (e.g., DOE/RW-0024, 1985; DOE/RW-0047, 1987a), with TSLCC used as the performance measure. To ensure comparability of information used for each site, the basis for the TSLCC estimate will be the advanced conceptual design (ACD) for each repository and its associated waste package(s), developed in accordance with specified ACD information requirements (DOE, 1987a). The ACD plan contains a physical subsystem structure and code of accounts (PSS-COA) that will be used to establish requirements for the ACD effort, and to estimate costs for the ACD. Additional information requirements from the early stages of license application design (LAD) development may also be considered, as appropriate.

The experience gained from construction of the exploratory shafts and underground testing facility and the results of site characterization activities that provide input to the design process will be relied on to provide an acceptable level of confidence in the bases for and estimates of the costs associated with construction, operation, decommissioning, and closure of a repository at the Yucca Mountain site. By the end of site characterization, the impacts of site characteristics on the major design choices that have a significant effect on cost will have been determined, and there will be adequate information to support a reasonable estimate of costs for comparative evaluation of the available siting alternatives. Since the TSLCC estimates will be based on COCD costs developed for ACD studies, possibly augmented by LAD studies, and on D&E costs estimated from program budget information, no specific information is required from site characterization for the sole purpose of supporting resolution of this issue. Site information that may be needed to support ACD and LAD development is identified under other design issues, such as 1.11, 2.7, 4.2, and 4.4 (Sections 8.3.2.2 through 8.3.2.5).

Repository and waste package cost estimates will be prepared for COCD costs during ACD development. The ACD cost estimates for the Yucca Mountain site will be developed following general DOE cost guidelines that will be applied in estimating costs that are presently scheduled for each site. The specific methods used to develop detailed cost data and buildup factors for the site may vary slightly from those used to develop cost data for the other siting options due to differences in the cost-estimating procedures used by the architect-engineer firms responsible for each design effort. The cost estimates for the Yucca Mountain site will be structured according to a common format to be specified in the DOE cost guidelines. The cost accounts will be based on the physical-subsystem structure provided in the ACD Plan. Costs will be estimated for design, construction, operation, closure, and decommissioning, in a detailed breakdown of cost accounts corresponding to various repository facilities, the waste package, and related activities. The general DOE cost guidelines will specify the cost reporting requirements, assumptions, account definitions, and suggested factors to be used in developing these cost estimates. As the estimates are developed for the Yucca Mountain site, the DOE will monitor the progress through the review process. This will ensure comparability among the projects with regard to the bases used to develop the required cost data. These reviews will identify key differences between candidate sites, ensure that the assumptions made for each are reasonable and consistent, and check for comprehensiveness and conformity in addressing the cost guidelines. This process is expected to lead to comparable estimates of TSLCC for all sites, while allowing the Yucca Mountain site to independently develop its own cost data and the related supporting documentation.

The cost guidelines developed initially for ACD are expected to continue to evolve as the program matures, as a result of site characterization and design studies, so that the final ACD cost guidelines will build upon those currently under development. COCD cost estimates at the time of site selection may provide more detail than is presently envisioned.

Costs for development and evaluation activities for the Yucca Mountain site will be developed in a manner similar to that used to estimate D&E costs for the EAs, as described previously (see DOE/RW-0047, 1987a, for the most recent description of the methodology). Comparable bases for the D&E costs for each project are ensured through the normal DOE schedule review and budget formulation processes. Once determined, these D&E costs will be added to the COCD costs to produce the TSLCC estimates for development of a repository at the Yucca Mountain site and to provide the information needed to support resolution of this issue.

8.2.2.4 Summaries of specific site characterization programs

The site characterization programs are made up of investigations that will provide a general understanding of the Yucca Mountain site and the specific data needed to resolve the performance and design issues. The investigations are organized into 16 site-specific programs. Brief summaries of the site data being obtained and the investigations to be conducted under each program are provided in the following sections.

8.2.2.4.1 Summary of the geohydrology program

The details of the geohydrology characterization program are presented in Section 8.3.1.2. The program is designed to provide an overall understanding of the geohydrology of the Yucca Mountain site, as well as to supply specific geohydrologic information required to resolve the performance and design issues. The overall approach to satisfying the performance and design information requirements is to conduct investigations that will result in a valid geohydrologic model.

Summary of performance and design requirements for geohydrologic information

The purpose of the geohydrologic characterization program is to provide information regarding the geohydrologic characteristics, processes, and conditions necessary to support resolution of the performance and design issues. Figure 8.2-6 provides an overview of the performance and design issues that depend on the geohydrologic characterization program for information, and the geohydrologic investigations planned to acquire the site data.

The primary performance issues relying on geohydrologic data include those for the cumulative release of radionuclides from the mined geologic disposal system (Issue 1.1, Section 8.3.5.13), and the pre-waste-emplacement ground-water travel time (Issue 1.6, Section 8.3.5.12). Compliance with the requirements for waste package containment (Issue 1.4, Section 8.3.5.9) and limiting releases from the engineered barrier system (EBS) (Issue 1.5, Section 8.3.5.10) also depend on a knowledge of the geohydrology. For the waste package, the moisture content of the emplacement environment is one of the critical parameters influencing the predicted performance of the container. For releases from the EBS, estimating the amount of water in the waste package environment is the basis for predicting radionuclide release.

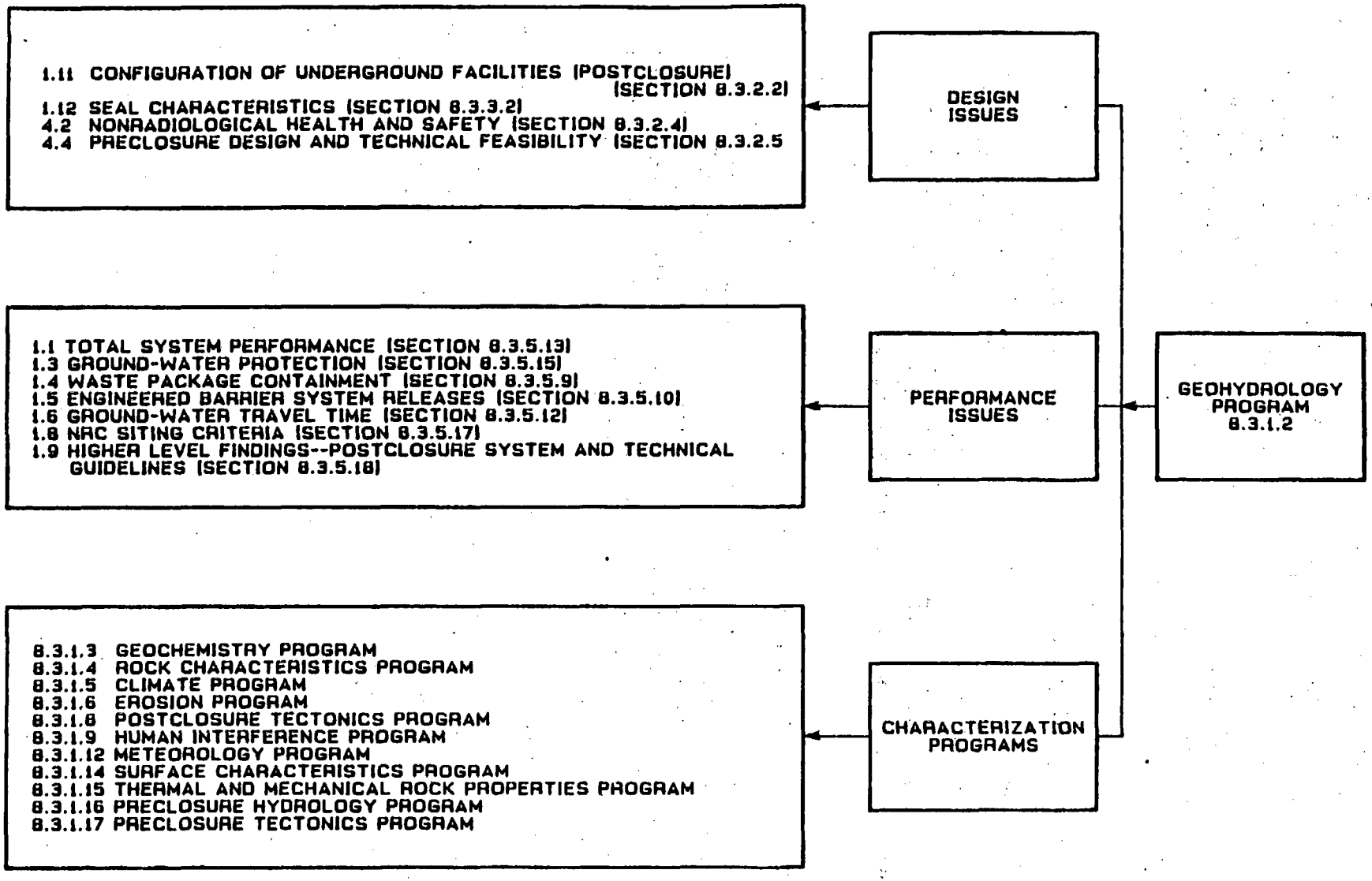

Figure 8.2-6. Interface of the geohydrology program with design and performance issue and other characterization programs.

The geohydrologic characterization program also provides data to resolve Issue 1.3 (Section 8.3.5.15), which addresses the potential for impacts on special sources of ground water.

The design issue relying on geohydrologic data is Issue 4.4 (Section 8.3.2.4), which concerns hazards such as the intersection of ramps or drifts with perched water. These data will be obtained as a part of the geohydrology program but will be evaluated under the preclosure hydrology program (Section 8.3.1.16). Issue 1.4 (Section 8.3.5.9) relies on the geohydrologic characterization program from a design as well as a performance perspective because it addresses features of the waste package design affecting performance of the containment barrier.

In addition, the geohydrologic characterization program will supply data to assist in evaluating the NRC siting criteria (Issue 1.8, Section 8.3.5.17), as well as the higher level findings (Issue 1.9, Section 8.3.5.18) required by DOE in their siting guidelines (10 CFR Part 960).

Approach to satisfy performance and design requirements

The general approach to satisfying the performance and design requirements is to develop a credible geohydrologic model. The geohydrologic model will have three components: the unsaturated zone model, the saturated zone model, and the surface-water model. The unsaturated-zone hydrologic model will be developed only for the near-site vicinity (i.e., site scale), whereas the surface-water and saturated-zone hydrologic models will be developed at both site and regional scales. The geohydrologic model will then be combined with the geochemical model and thermal-mechanical model to produce the site model. Each of these three models will be developed using conceptual and descriptive models as well as numerical models. Components of the numerical models include a complete and accurate description of the geologic and hydrologic framework, initial and boundary conditions, processes at work within the geologic and hydrologic framework, and a hypothesis describing their interrelationships.

Summary of geohydrologic investigations

The geohydrologic investigations that will be conducted to obtain the data necessary to build the geohydrologic model are described in Section 8.3.1.2. Three investigations are planned, focusing on the three hydrologic systems to be characterized. The investigation described in Section 8.3.1.2.1 will develop a description of the regional hydrologic system. Section 8.3.1.2.2 describes studies to investigate the site unsaturated zone system, while the investigation presented in Section 8.3.1.2.3 will provide a description of the saturated zone system at the site. Table 8.2-35 lists the general parameters to be provided by each geohydrologic investigation.

8.2.2.4.2 Summary of the geochemistry program

The details of the geochemistry characterization program are presented in Section 8.3.1.3. The program is designed to provide the information necessary for developing a site geochemical model, as well as to supply specific geochemical information required to address performance and design issues. The overall approach to satisfying the performance and design

Table 8.2-35. Major parameters provided by investigations in Geohydrology Program 8.3.1.2.

Section number	Investigation	Major parameters
8.3.1.2.1	Description of the regional hydrologic system	Rainfall and temperature Water chemistry Runoff Drainage basin and channel characteristics Debris transport characteristics Hydraulic conductivity Storage coefficients and porosities Isotope ratios Hydraulic heads and gradients - regional Evapotranspiration rates Recharge and discharge locations and rates Regional hydrologic properties Water flux Fracture characteristics
8.3.1.2.2	Description of the unsaturated zone hydrologic system at the site	Effective porosity Fracture and matrix permeabilities Hydraulic conductivity Tortuosity Transmissivity Moisture-retention curves Porosity Dispersivity Diffusion coefficients Hydrochemistry Evapotranspiration rates Flow paths Flow velocities Volumetric flux Infiltration Water potential Matric potential Pneumatic potential Moisture content Saturation profiles

Table 8.2-35. Major parameters provided by investigations in Geohydrology Program 8.3.1.2 (continued)

Section number	Investigation	Major parameters
8.3.1.2.3	Description of the saturated zone hydrologic system at the site	Hydraulic conductivity Storage coefficient Transmissivity Effective porosity Dispersion coefficient Temperature Hydraulic heads and gradients Water flux Fracture system characteristics

information requirements is to conduct investigations that will evaluate, synthesize, and integrate site and experimental data to show the combined effects of physical, thermal, and chemical processes.

Summary of performance and design requirements for geochemical information

Compliance with the performance and design requirements for a geologic repository will require information about the geochemistry of the Yucca Mountain site. This program provides the geochemical data and data on geochemical processes that are needed to support assessments of site performance and waste package design analyses. Performance assessment calculations of radionuclide transport (Issue 1.1) require specific data about the geochemical behavior of waste elements at the Yucca Mountain site. In addition, the NRC siting criteria addressed by Issue 1.8 include favorable and potentially adverse geochemical conditions that must be evaluated. Figure 8.2-7 graphically displays the performance and design issues requesting geochemical information and the investigations planned to supply this site data.

Approach to satisfy performance and design requirements

As described in Section 8.1.1, a process of performance allocation was used in the performance and design issues to determine the information and data needs required from the geochemistry program. The primary data requested as a result of performance allocation may not be a measurable quantity, and therefore supporting data are necessary to derive the primary information. The studies required to provide the primary and supporting data often involve multiple tests because of the high degree of coupling of the geochemical and physical processes that are the basis for radionuclide retardation. Furthermore, secondary and supporting data may be required to

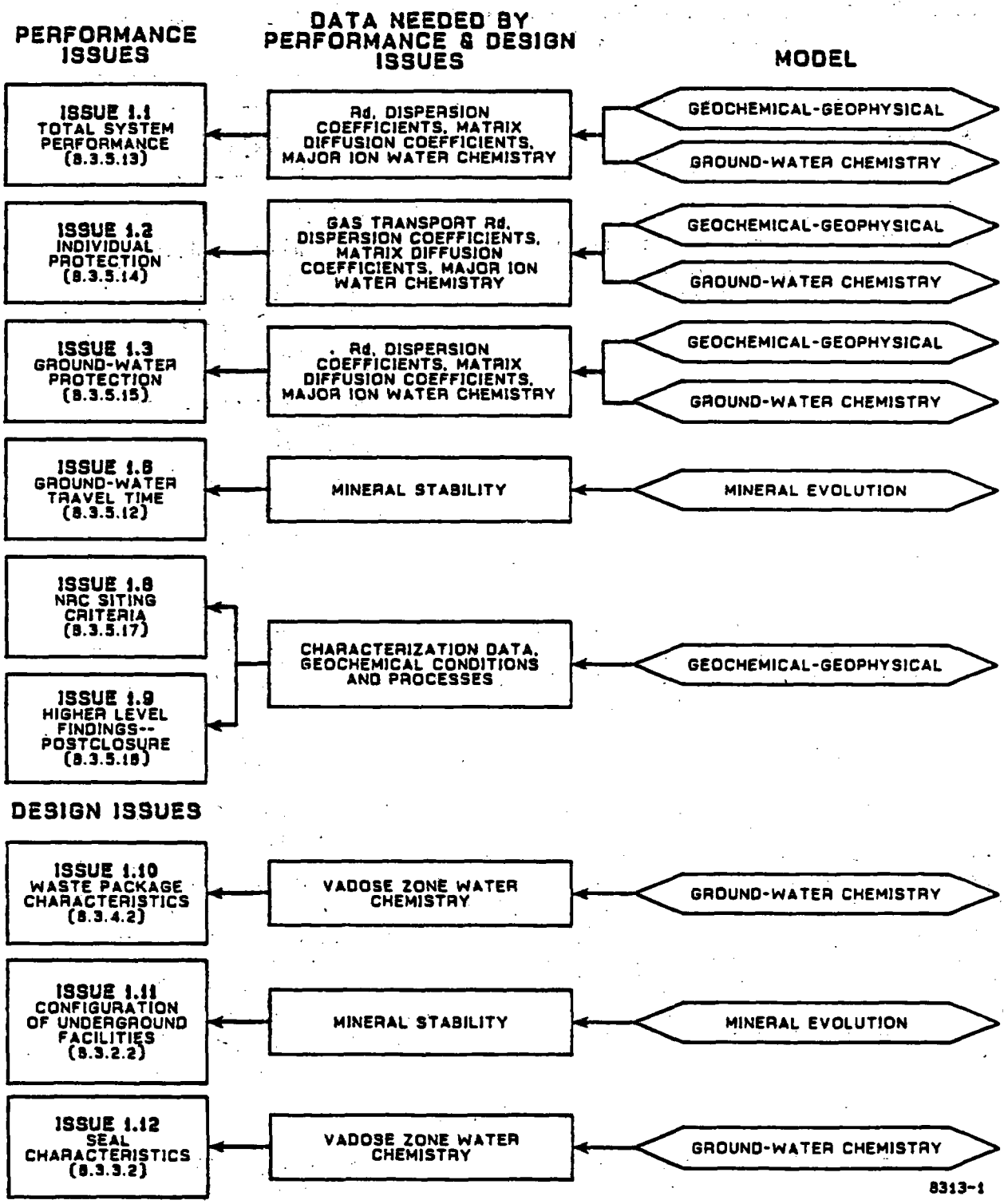

Figure 8.2-7. Parameter calls and corresponding model from geochemistry test program.

provide the level of confidence requested by the performance and design issues.

Table 8.2-36 lists the primary parameters provided by the geochemistry program. The parameters listed in the table reflect the primary data required to satisfy the performance or design needs. Data synthesis will be required to identify and quantify the following higher level parameters that are required by the performance and design issues: coupling and retardation factors, distribution coefficients, liquid constrictivity and tortuosity, and hydrodynamic dispersion. These higher-level parameters, in conjunction with other parameters listed in Table 8.2-36, will be used in model validation of coupling factors, source term determination for the waste package, and model calibration and validation for gas-phase transport. The results of these models will be used in determining the effects of climate and human interference on the baseline geochemical conditions, and in determining controls on ground-water composition. The geochemistry program relies upon the investigation described in Section 8.3.1.3.7 (retardation by all processes) to evaluate, synthesize, and integrate the geochemical site and experimental data to show the coupled effects that might not be evident if the geochemical or physical process data were considered separately.

Development of a site geochemical model requires data on liquid constrictivity-tortuosity factors for the rock matrix, fracture networks, fault zone rock mass, and distribution coefficients for radionuclide species for all rock units within the controlled zone. The characterization program addresses this data need by integrating the results of sorption studies with dynamic transport and diffusion studies. Calculations of total system releases (Issue 1.1) require information on the specific discharge field in saturated-zone units and values for hydrodynamic dispersion. This information will be provided by determining the dispersion characteristics for crushed tuff and obtaining hydrodynamic dispersion data for solid rock and fractured tuff. Requests for model validation-coupling factors in the saturated and unsaturated zone units will be satisfied by permeability information from unsaturated tuff column experiments. Solubility limits of chemical species associated with the liquid and gas-phase radionuclides will be used to establish potential source terms for the waste packages. Section 8.3.1.3.5 describes an investigation that will provide dissolved species concentration limits and information on colloid formation and stability will support the source term estimates. Major-ion water chemistry and gas-phase carbon-14 transport in the overburden also provide information for model calibration and validation. The ground-water chemistry model described in Section 8.3.1.3.1, together with gaseous radionuclide transport calculations, provide integrated information to the performance assessment program.

The waste package postclosure design requires information on the composition of the vadose water for particular elements most affecting the waste package stability (Issue 1.10). The ground-water chemistry model being developed in this program will serve as a tool for evaluating present ground-water conditions as a basis for predicting future changes in ground-water chemistry.

The total system performance issue (Issue 1.1) identifies climatic changes and human intrusion scenarios that might increase the flux thus affecting the ground-water chemistry. Information must be provided on the

Table 8.2-36. Major parameters provided by investigations in Geochemistry Program 8.3.1.3

Section number	Investigation	Major parameters
8.3.1.3.1	Studies to provide the information on water chemistry within the potential emplacement horizon and along potential flow paths	Unsaturated-zone fluid dispersive properties Unsaturated-zone fluid diffusive properties Unsaturated-zone fluid sorptive properties Unsaturated-zone fluid chemistry Unsaturated-zone fluid temperature Unsaturated-zone fluid rock chemistry
8.3.1.3.2	Studies to provide information on mineralogy, petrology, and rock chemistry within the potential emplacement horizon and along potential flow paths	Rock-unit mineralogy and petrology Fracture-filling mineralogy and physical properties Rock chemistry
8.3.1.3.3	Studies to provide information on stability of minerals and glasses.	Rock-unit mineralogy and petrology Rock chemistry
8.3.1.3.4	Studies to provide information required on radionuclide retardation by sorption processes along flow paths to the accessible environment	Unsaturated-zone fluid sorptive properties Saturated-zone sorptive properties
8.3.1.3.5	Studies to provide the information required on radionuclide retardation by precipitation processes along flow paths to the accessible environment	Unsaturated-zone geochemical properties (solubilities) Saturated-zone geochemical properties (solubilities)
8.3.1.3.6	Studies to provide the information required on radionuclide retardation by dispersive, diffusive and advective transport processes along flow paths to the accessible environment	Saturated-zone geochemical properties Effective diffusivities Major ion chemistry Dispersion characteristics Unsaturated-zone dispersion characteristics

Table 8.2-36. Major parameters provided by investigations in Geochemistry Program 8.3.1.3. (continued)

Section number	Investigation	Major parameters
8.3.1.3.7	Studies to provide the information required on radionuclide retardation by all processes along flow paths to the accessible environment	Retardation sensitivity analyses Physical and chemical processes affecting transport Geochemical and geophysical model of Yucca Mountain and integrated geochemical transport calculations Transport models Application determinations of laboratory data to repository transport calculations
8.3.1.3.8	Studies to provide the information required on retardation of gaseous radionuclides along flow paths to the accessible environments	Gaseous radionuclide transport calculations and measurements Physical transport mechanisms and rates Retardation mechanisms and transport with retardation Gas transport measurements

potential magnitude of change in the distribution coefficients based on changing water compositions. The investigation described in Section 8.3.1.3.7 will provide bounding calculations on radionuclide transport using sorption and no sorption. The ground-water chemistry model, the conceptual model of mineral evolution, and data on sorption as a function of solid phase composition will be used in sensitivity analyses to establish the factors controlling water composition.

Summary of the planned geochemical investigations

As shown in Figure 8.2-7, eight investigations are included in the geochemical characterization program. The investigation described in Section 8.3.1.3.1 addresses water chemistry within the potential emplacement horizon and along flow paths to the accessible environment. This investigation will incorporate the existing ground-water chemistry data for the saturated zone and data from the unsaturated zone chemistry activities described in Section 8.3.1.2.2 into the ground-water chemistry model. This model will be used to

better understand factors influencing present ground-water chemistry in order to predict future variations in ground-water chemistry. The investigation described in Section 8.3.1.3.2 addresses mineralogy, petrology, and rock chemistry within the potential emplacement horizon and along flow paths to the accessible environment. Section 8.3.1.3.3 describes studies addressing the stability of minerals and glasses. A conceptual model of mineral and glass evolution at Yucca Mountain will be developed to predict future mineral evolution by natural processes and repository induced thermal loading. Section 8.3.1.3.4 provides the data base on radionuclide retardation by sorption processes along flow paths to the accessible environment. This investigation will evaluate sorption in the far field (beyond the disturbed zone) at Yucca Mountain. Laboratory data will be collected on sorptive behavior and a sorption model (isotherms) will be developed to improve the understanding of the expected sorption at the Yucca Mountain site.

Section 8.3.1.3.5 describes an investigation addressing radionuclide Retardation by precipitation along flow paths to the accessible environment. Solubility measurements and models will be used to provide limits on the concentrations of dissolved waste elements and on natural colloid concentrations under expected site conditions. Section 8.3.1.3.6 addresses radionuclide retardation by dispersive, diffusive, and advective transport processes along the flow paths to the accessible environment. This investigation will determine experimentally the rate of movement and effective retardation of radionuclides by dispersive, diffusive, and advective processes, and will provide support for the applicability of data produced in saturated systems to unsaturated systems. Radionuclide retardation by all processes along flow paths to the accessible environment is addressed in Section 8.3.1.3.7. This investigation uses three-dimensional transport models and other multidimensional process codes to determine, characterize, and quantify the cumulative effects of all significant processes, physical and geochemical, acting on or controlling radionuclide transport at Yucca Mountain. Finally, Section 8.3.1.3.8 addresses retardation of gaseous radionuclides along flow paths to the accessible environment. Potential retardation mechanisms for gaseous radionuclide species will be identified and used to estimate rates of transport.

8.2.2.4.3 Summary of postclosure rock characteristics program

The details of the postclosure rock characteristics program are presented in Section 8.3.1.4. The program is designed to obtain geologic and geophysical site data needed to develop a three-dimensional physical property model, as well as to supply specific data on rock characteristics required by performance and design issues. The overall approach to satisfying the performance and design information requirements is to conduct investigations that will supply the information needed to develop a data base to provide a computer-based representation of the physical properties of the rocks at the site.

Summary of performance and design requirements for rock characteristics information

Compliance with performance and design requirements for a geologic repository will require information about the rock characteristics of the Yucca Mountain site. This information will be used to support assessments of site performance related to ground-water travel time, radionuclide releases to the accessible environment, and the NRC siting criteria (10 CFR 60.122). Design criteria for the underground facility, seals for shafts and boreholes, and waste packages are also evaluated in the context of the natural rock properties of the site. Figure 8.2-8 provides an overview of the performance and design issues that depend on the rock characteristics program for information.

Approach to satisfy performance and design requirements

A summary of the site information requested by performance and design issues is provided in Table 8.2-37. These data needs were derived by applying performance allocation to the performance and design issues described in Sections 8.3.2 through 8.3.5.

The geologic and geophysical site characterization activities provide information needed to develop a three-dimensional physical property model that will relate the geologic framework to the material properties of rocks at the Yucca Mountain site. The data base developed for the model will contain the spatial distribution of parameter values for physical properties within property-dependent rock units. An important function of the computer-based model will be to provide input for numerical computer analyses involving hydrologic, thermal, thermomechanical, and geochemical processes.

To develop the physical property model, four categories of information are necessary: (1) material properties, (2) geometry, (3) assumptions and hypotheses, and (4) initial and boundary conditions. The model will allow predictions of how a physical property changes spatially within and across the boundaries of the model, where the boundaries represent distinct changes in a property. The location of the physical property boundaries will be based on three sources of information: (1) geologic studies, (2) geophysical studies, and (3) the physical property data from core samples. The geologic complexity of the Yucca Mountain site may cause large uncertainties in the variation of the properties between sample locations. Various interpolation methods can be used to estimate the variation in the value of a rock property between sample locations. The ultimate use of specific rock property data determines the precision required in determining the lateral and vertical variability of a particular property at distances away from the sample location. Thus, the nature and number of site sampling activities and characterization studies will be determined by the level of confidence required by the numerical models using the physical properties.

The planned geologic and geophysical studies are intended to identify correlations between the properties of interest that can be directly measured and properties of interest that must be estimated. The results of the geologic studies will therefore be used to calibrate the geophysical data and provide additional sources for correlating parameter information.

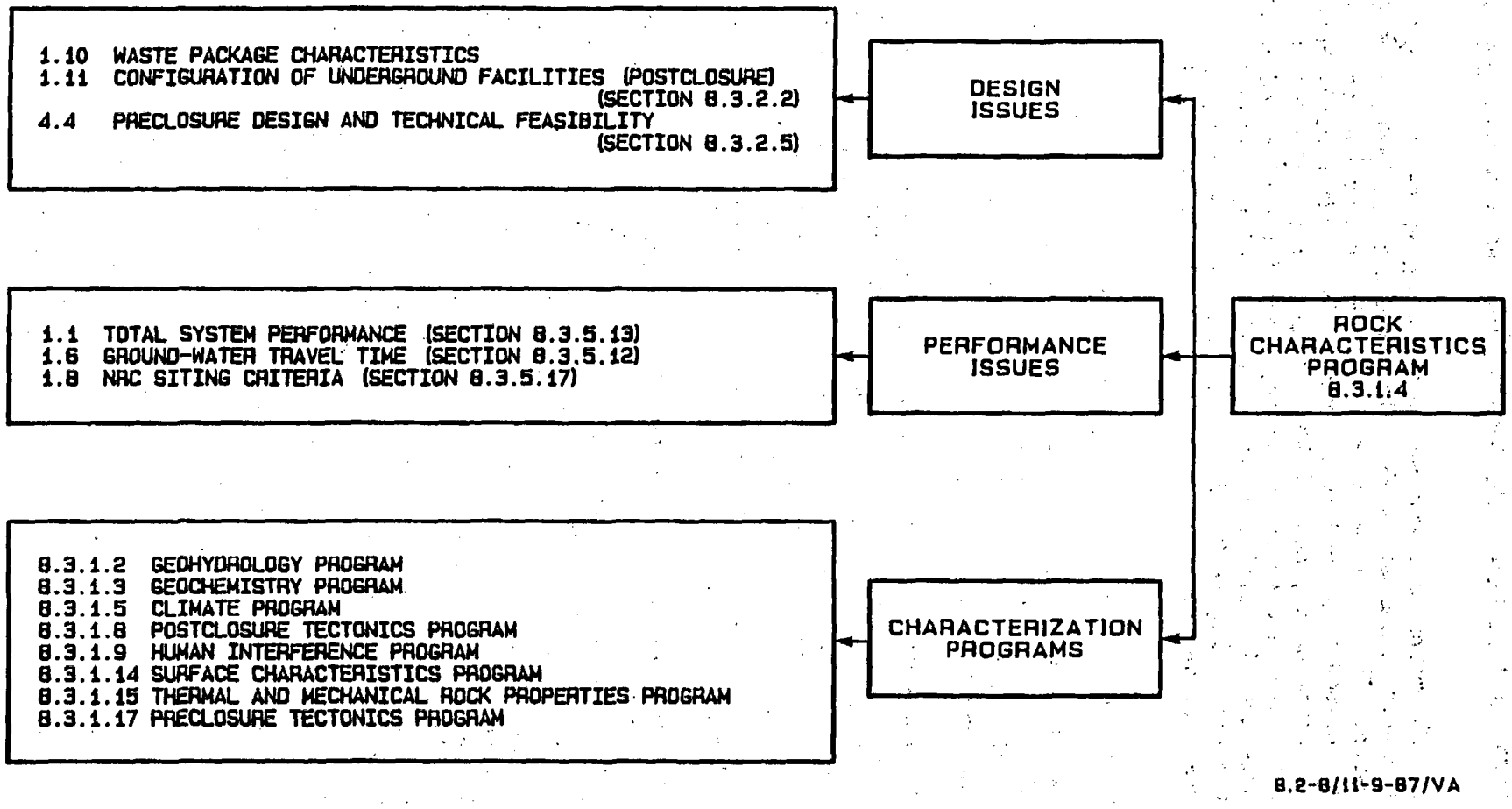

Figure 8.2-8. Interface of the rock characteristics program with design and performance issues and other characterization programs

Table 8.2-37. Major parameters provided by investigations in Postclosure Rock Characteristics Program 8.3.1.4

Section number	Investigation	Major parameters
8.3.1.4.1	Development of an NNWSI Integrated Drilling Program	Development of drilling practices to be followed for site characterization Yearly development of integrated drilling plans for site characterization
8.3.1.4.2	Geologic framework of the Yucca Mountain site	Rock unit contact location and configuration Rock unit lateral and vertical variability Rock unit mineralogy and petrology Rock unit depositional and diagentic history Fault location, length, and width Fault orientation Fault displacement Fault zone mineralogy and physical properties Fracture orientation Fracture distribution Fracture aperature Fracture length Fracture-filling mineralogy and physical properties
8.3.1.4.3	Development of three-dimensional models of rock characteristics at the repository site	Computer-based three-dimensional physical property model Compiled systematic drilling information Contour maps and cross sections for various site parameters

Summary of planned rock characteristics investigations

As shown in Table 8.2-37, three investigations are planned for the rock characteristics program. The first investigation (Section 8.3.1.4.1) will develop a plan for integrating the NNWSI Project drilling activities for the

entire site characterization program. The second investigation (Section 8.3.1.4.2) will provide primary data on the lateral and vertical variation in structure and stratigraphy in support of design and performance assessment analyses. The third investigation (Section 8.3.1.4.3) will focus on developing a three-dimensional model of the rock characteristics at the Yucca Mountain site. The purpose of this model is to summarize, in a coherent fashion, the geologic, hydrologic, geochemical and thermal mechanical information and to provide a mechanism for transfer of this information to the design and performance assessment issues.

8.2.2.4.4 Summary of the climate site program

The details of the climate characterization program are presented in Section 8.3.1.5. The program is designed to provide the climate information needed to resolve performance and design issues. The overall approach to satisfy the performance and design issues involves building a model that simulates future climate. By using the results of the future-climate model to define the boundary conditions for hydrologic models, the effects of future climate on the hydrologic system can be determined.

Summary of performance and design requirements for climate information

The climate program consists of investigations designed to (1) provide data on past, present, and future climate conditions (Investigation 1.16.1) and (2) determine the effects of climate change on surface hydrology, unsaturated zone hydrology, and saturated zone hydrology (Investigation 1.16.2). Figure 8.2-9 shows the flow of information from the climate program to the performance or design issues requesting the information, as well as the characterization programs relying on climatic data. The climate program will use hydrologic system models developed in the geohydrology program to simulate future hydrologic conditions due to climate change. Thus the geohydrology program also provides information to the climate program.

As shown in Figure 8.2-9, the major performance and design issues requesting climate data are: (1) total system performance (Issue 1.1); (2) NRC siting criteria (Issue 1.8); (3) higher-level findings (Issue 1.9a); (4) prediction of climate over the next 100,000 yr (Issue 1.9b); and (5) postclosure waste package design (Issue 1.10). Postclosure repository design considerations (Issue 1.11, Section 8.3.2.2) and characteristics of seals (Issue 1.12, Section 8.3.3.2) also consider future climatic conditions as design constraints. It has been determined that the climate information needed to satisfy Issue 1.1 will be sufficient to address Issues 1.8, 1.9a, and 1.10, and the other design issues requesting climate information. Additional data and new analytical techniques are necessary to satisfy Issue 1.9b because of the need for predicting expected climatic conditions over the next 100,000 years.

Summary of climatic investigations

The investigations, studies, and activities within the climate program are designed to predict of the effects of future climate change on hydrologic conditions and to estimate the ranges of future climatic conditions to

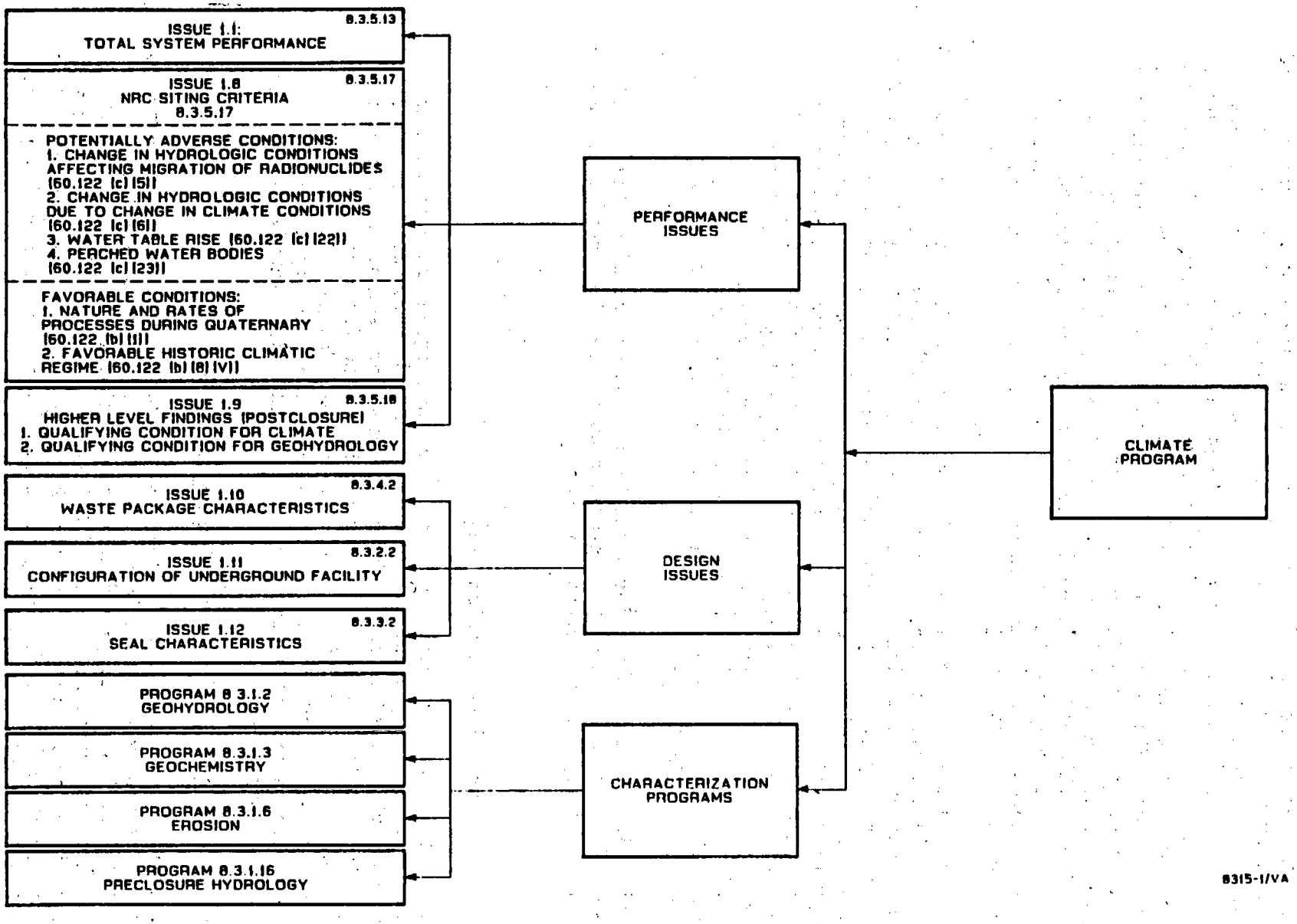

Figure 8.2-9. General logic diagram showing ties between climate program and other characterization programs, design issues, and performance issues.

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satisfy the performance and design issues. The analysis of paleoclimate and paleoenvironment (Study 8.3.1.5.1.5) is a synthesis activity using data generated by two previous studies and is necessary to assess the long-term variability of paleoclimate, as well as to provide the basis for the estimation of future climatic episodes. This analysis also provides the basis for determining the potential effects of future climatic conditions on hydrologic characteristics. The determination of the nature, probability and timing of future climate scenarios will be derived from a linked global-regional modeling approach, a separate empirical modeling approach, or both (Study 8.3.1.5.1.6). This model will be developed and validated using the paleoclimate and paleoenvironmental information and will be calibrated using present-day meteorological data generated in collaboration with the meteorology program (8.3.1.12).

Section 8.3.1.5.2 describes the investigation to determine the potential effects of future climate change on hydrologic conditions. Paleoclimate and paleoenvironment information established in Section 8.3.1.5.1 will be used in the paleohydrology studies to better understand the Quaternary regional ground-water flow systems. Understanding paleohydrologic and paleoclimate relationships will serve as a basis for predicting hydrologic responses (i.e., changes in infiltration and recharge) initiated by future climate. Hydrologic system models developed in the geohydrology program (8.3.1.2) will be used to determine baseline present hydrologic conditions. Future hydrologic conditions will be modeled on the basis of estimated climate changes. The result will be an estimate of the impact of future climate on the overall hydrologic system.

Table 8.2-38 lists the major parameters to be generated by the climate program. These parameters must be provided at the level of confidence needed for input to design and performance issues.

8.2.2.4.5 Summary of the erosion program

The details of the erosion characterization program are presented in Section 8.3.1.6. The program is designed to provide information on geomorphic processes and conditions at the site needed for design, as well as to supply site-specific erosion data required by the performance issues. The overall approach to satisfying the performance and design information requirements is to conduct investigations that will identify areas of active erosion and deposition at Yucca Mountain and that will quantify these rates for the postclosure period.

<u>Summary of design and characterization requirements</u>

The erosion program will provide the site-specific information regarding geomorphic processes and conditions that is required to satisfy Design Issues 4.4 (preclosure design and technical feasibility, Section 8.3.2.5) and 1.12 (seal characteristics, Section 8.3.3.2), and to provide information to the human interference program (Section 8.3.1.9). Figure 8.2-10 graphically shows the relationship of the design issues and the characterization program requesting information from the erosion program. Issue 4.4 requires data on

Table 8.2-38. Major parameters provided by investigations in Climate Program 8.3.1.5

Section number	Investigation	Major parameters
8.3.1.5.1	Develop model of future climatic change	Synoptic climate and variations
		Estimates of past changes in effective moisture and their chronology
		Estimates of past precipitation, temperature, and evaporation
		Climatic implications of terrestrial paleoecology
		Quaternary regional paleoenvironment estimate
		Chronology of paleoclimate/paleoenvironment episodes
		Soil properties
		Nature, probability, and timing of future climate scenarios
8.3.1.5.2	Effects of future climate on hydrologic conditions	Characteristics of Eolian deposits
		Change in unsaturated zone, saturated zone, and surface hydrologic systems due to climate change
		Characteristics of paleofloods
		Hydrochemistry of unsaturated zone
		Characteristics of past discharge

Table 8.2-38. Major parameters provided by investigations in Climate Program 8.3.1.5 (continued)

Section number	Investigation	Major parameters
		Recharge properties and characteristics
		Properties of hydrogenic deposits

the erosional and depositional processes to identify the most suitable locations for the warning system markers for the repository. Issue 1.12 requires data on bedrock erosion rates that is needed for seal design. The human interference program requires similar information to evaluate the long-term survivability and the future legibility of the markers. As indicated in Figure 8.2-10, these data will be used by Issue 1.1 (total system performance) to aid in assessing the probability for human interference during the 10,000-yr postclosure period by providing information on long-term marker survivability.

Approach to satisfy the design requirements

Because erosion is not believed to pose a hazard to waste isolation at Yucca Mountain, only three field activities are planned. The remaining regulatory requirements will be satisfied through analysis and further evaluation of geomorphic data that will be obtained through investigations in support of this program, the meteorology program (Section 8.3.1.12), and the hydrology program (Section 8.3.1.16). These data will be used to develop topical reports that will address (1) the expected effects of tectonism and climate changes on erosion, (2) the expected effects of erosion on the baseline characteristics at the site, and (3) the siting guidelines of 10 CFR Part 960. These topical reports also will provide the technical data base and analyses needed to address the requirements of 10 CFR Part 60.

Summary of erosion investigations

As shown on Figure 8.2-10, four investigations are planned. Many of the necessary parameters have been obtained and evaluated as part of the ongoing scientific studies at the NTS in support of the weapons testing program. In most instances, data are not site specific, and therefore, not adequate to satisfy the performance and design issues. Studies will be carried out during site characterization to satisfy these remaining data needs. Table 8.2-39 lists the major parameters provided by the erosion program. Existing geomorphic data will be used in conjunction with new data to provide the level of confidence required in these parameters.

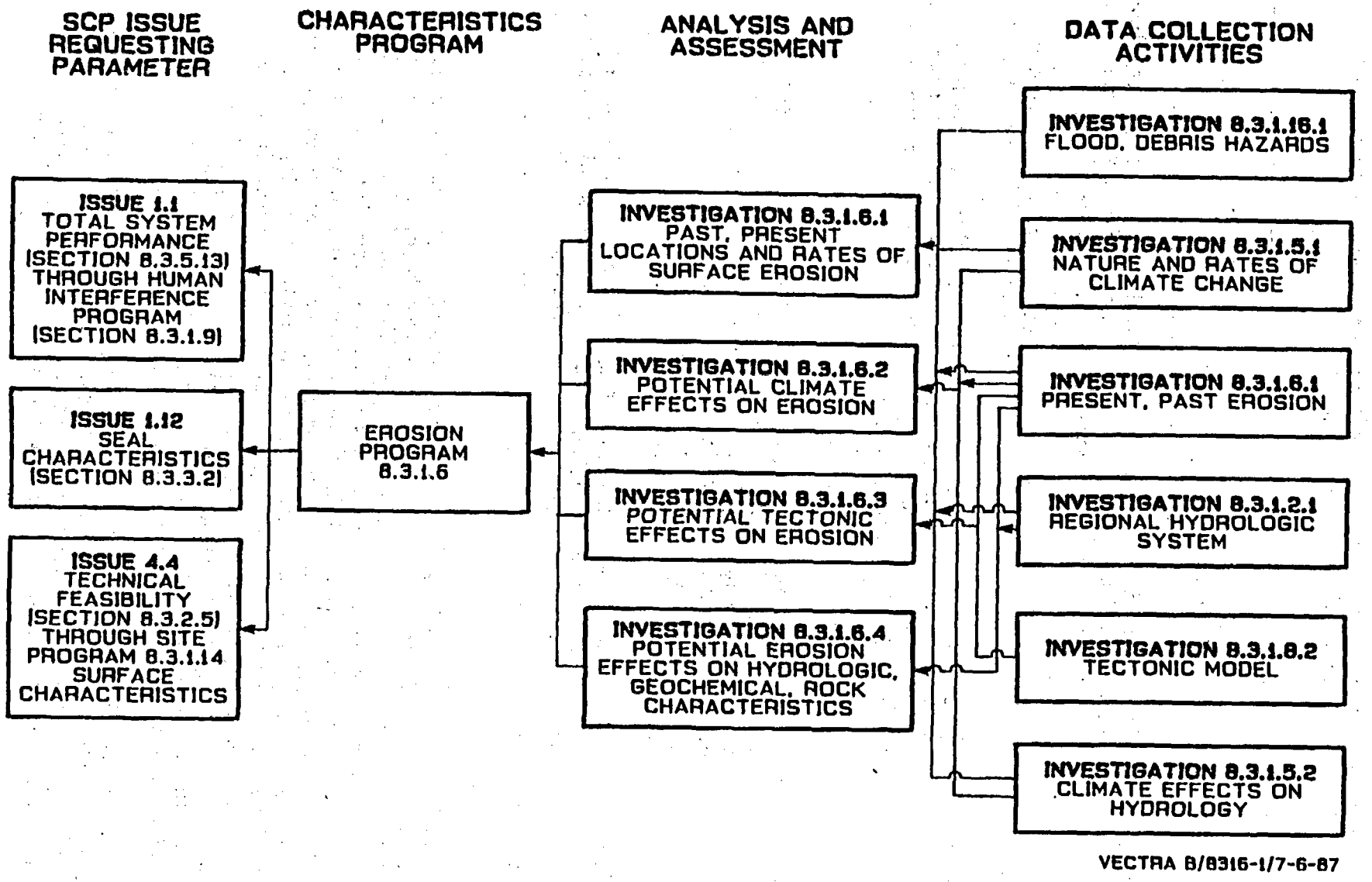

Figure 8.2-10. Relationship between erosion program and investigations.

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Table 8.2-39. Major parameters provided by investigations in Erosion Program 8.3.1.6.

Section number	Investigation	Major parameters
8.3.1.6.1	Studies to provide the information needed to determine present locations and rates of erosion	Development of a geomorphic map of Yucca Mountain Analysis of hillslope erosion Analysis of downcutting history of Fortymile Wash
8.3.1.6.2	Studies to provide the information needed to determine the potential effects of future climatic conditions on locations and rates of erosion	Impact of future climatic conditions on locations and rates of erosion
8.3.1.6.3	Studies to provide the information required to determine the potential effects of future tectonic activity on locations and rates of erosion	Effects of future uplift or subsidence and faulting on erosion at Yucca Mountain
8.3.1.6.4	Potential effects of erosion on hydrologic, geochemical, and rock characteristics	Effects of erosion on the baseline conditions at Yucca Mountain

Investigation 8.3.1.6.1 will collect site-specific data on Quaternary erosion and stream incision rates, which will be used to calculate average erosion rates on Yucca Mountain and to develop a history of the downcutting episode(s) of Fortymile Wash. Investigation 8.3.1.6.2 includes studies to assess the potential effects of future climatic changes on locations and rates of erosion. Previously established regional erosion rates suggest that future changes in the climatic regime will not significantly affect upland and hillslope erosion rates. Local erosion data on Yucca Mountain and an evaluation of the relationship of increased runoff in Fortymile Canyon, Fortymile Wash, and their tributaries to localized stream incision rates are needed for Information Need 2.7.1 (Section 8.3.2.3.1). Investigation 8.3.1.6.3 will evaluate the effects of tectonic activity on rates of erosion.

Investigation 8.3.1.6.4 addresses the potential effects of erosion on the baseline hydrologic, geochemical, and rock characteristics at Yucca Mountain. Data obtained from these investigations will be analyzed to provide the information necessary to support the higher-level finding required

by Issue 1.8. These topics will be addressed in a topical report, which will present the discussion supporting termination of the erosion program.

8.2.2.4.6 Summary of the rock dissolution program

Because the findings on rock dissolution made for the environmental assessment (DOE, 1986b) are adequate to meet the requirement for higher-level findings in the siting guidelines, no additional studies are planned for issue resolution. Studies on mineral stability described under the geochemistry program (Section 8.3.1.3) are being conducted to assess geochemical retardation along flow paths to support performance assessment studies for Issue 1.1 (Section 8.3.5.13).

8.2.2.4.7 Summary of the postclosure tectonics site program

The details of the postclosure tectonics program are presented in Section 8.3.1.8. The purpose of the tectonic characterization program is to supply data on the probability and effects of tectonic "initiating events" that could alter existing conditions at Yucca Mountain and potentially have adverse effects on repository performance. Figure 8.2-11 shows the interfaces to the performance and design issues that require information from the tectonic characterization program and the investigations planned to provide the site data.

Summary of performance and design requirements for postclosure tectonics information

Issue 1.1 (Section 8.3.5.13) requires data on the probability and effects of potentially significant tectonic release-scenario classes addressing both anticipated and unanticipated conditions. These data are needed for performance assessment calculations of radionuclide releases to the accessible environment. The tectonic characterization program also supplies data required to perform the analysis to determine the degree to which each of several favorable and potentially adverse conditions listed in 10 CFR 60.122 contributes to or detracts from isolation (Issue 1.8, Section 8.3.5.17). The program also will provide the information needed to make the higher level findings (Issue 1.9, Section 8.3.5.18) required by the DOE in their siting guidelines (10 CFR Part 960). Tectonics information will also be used to accommodate site-specific tectonic conditions in design concepts for the geometry, layout, and emplacement borehole locations of the underground facility (Issue 1.11, Section 8.3.2.2).

Approach to satisfy performance and design requirements

The general approach to satisfying the performance and design requirements is to conduct investigations to provide the additional detail necessary to accurately characterize the effects of tectonic processes operating at or near the site and to measure the rates at which these processes operated during the Quaternary. This information will then be used to provide the

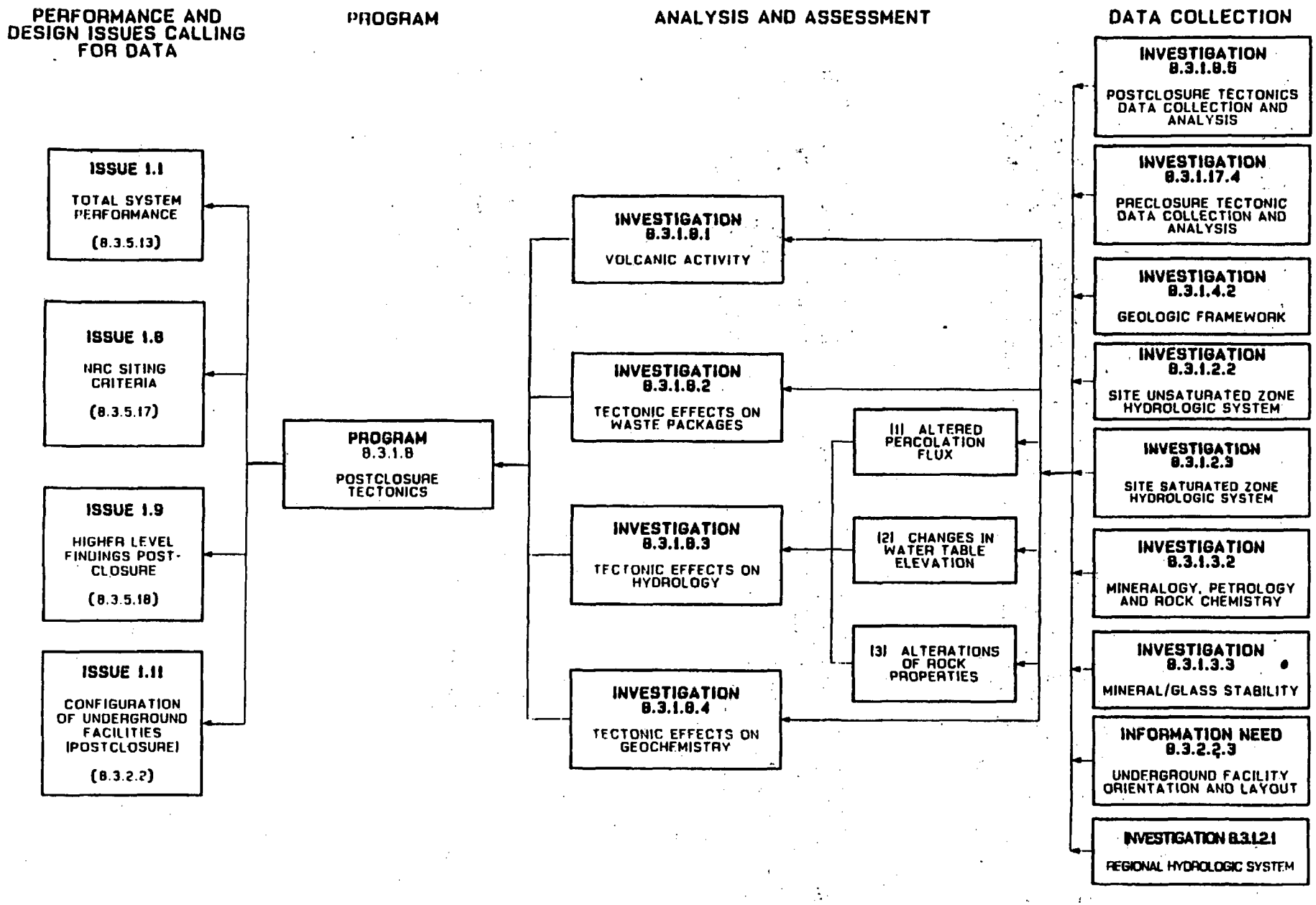

Figure 8.2-11. Relationships between the postclosure tectonics program, investigations, and performance design issues.

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predictions of future rates necessary to satisfy the requirements of the performance and design issues. The tectonic processes that will be evaluated are volcanism, igneous intrusion, faulting, folding, and uplift and subsidence. The tectonics program will estimate the probability of occurrence of significant tectonic events related to these processes during the postclosure time period and evaluate the effects of these events on possible direct releases related to the event, the lifetime of waste packages, and on the possible alteration of hydrologic and geochemical parameters that govern radionuclide transport times and release rates.

A variety of sources of information will be used to evaluate tectonic processes and events including earthquake observations, fault measurements, geologic mapping, drilling, gravity and magnetotelluric surveys, and other geophysical data. Alternative interpretations of the data will be explored and evaluated with respect to implications for repository performance. Multiple interpretations will be refined to the extent necessary to provide the degree of confidence that is specified by the performance and design issues.

Summary of postclosure tectonic investigations

Table 8.2-40 lists the major parameters provided by the investigations and studies to be conducted as part of this program. As shown in Figure 8.2-11, five investigations are planned under this program. The first four investigations are related to the initiating events and their associated data requirements (performance parameters) needed to evaluate the scenarios identified in Issue 1.1. The studies and activities connected with these investigations provide the analysis and assessment of site geologic data necessary to characterize the probability and effects of tectonic initiating events. Because the analysis and interpretation activities for different tectonic initiating events repeatedly call for the same type of data, data gathering activities were grouped separately under a fifth investigation that feeds data as required to the analysis activities associated with the postclosure tectonics program.

8.2.2.4.8 Summary of the human interference program

The details of the human interference program are presented in Section 8.3.1.9. The program is designed to identify, analyze, and evaluate the potential human activities that could adversely affect long-term repository performance, or that could lead to inadvertent intrusion into the repository. Identification, analysis, and evaluation of potential human activities will provide the data required by the design and performance issues. The overall approach to satisfying the performance and design information needs is to identify all credible anthropogenic disruption scenarios, assess their potential consequences, and provide this information as input to a model that will be used to determine total system releases to the accessible environment (Issue 1.1) caused by inadvertent human activities.

Table 8.2-40. Major parameters provided by investigations in Postclosure Tectonics Program 8.3.1.8

Section number	Investigation	Major parameters
8.3.1.8.1	Studies to provide information required on direct releases resulting from volcanic activity	Probability of a volcanic eruption penetrating the repository Effects of volcanic eruption penetrating the repository
8.3.1.8.2	Studies to provide information required on rupture of waste packages	Probability of underground displacement
8.3.1.8.3	Studies to provide information required on changes in unsaturated and saturated zone hydrology	Effects of tectonic processes and events on flux rates, on water table elevation, and on local fracture permeability and effective porosity
8.3.1.8.4	Studies to provide information required on changes in rock geochemical properties	Effects of tectonic processes and events on rock geochemical properties
8.3.1.8.5	Studies to provide the general tectonic information required by the analysis and assessment investigations	Characteristics of volcanic features, igneous intrusive features, and folds in Miocene and younger rocks

Summary of performance and design requirements for information related to human interference

The purpose of the human interference characterization program is to provide information regarding the likelihood that the activities of humans in the vicinity of Yucca Mountain over the next 10,000 years will influence the performance of the repository. Information regarding the long-term survivability of the surface marker warning system, the natural resource potential of the site, and the potential effects of future resource exploration or extraction will be provided by the human interference characterization program. Figure 8.2-12 displays the performance and design issues requesting information and the investigations of the human interference program that will provide the information.

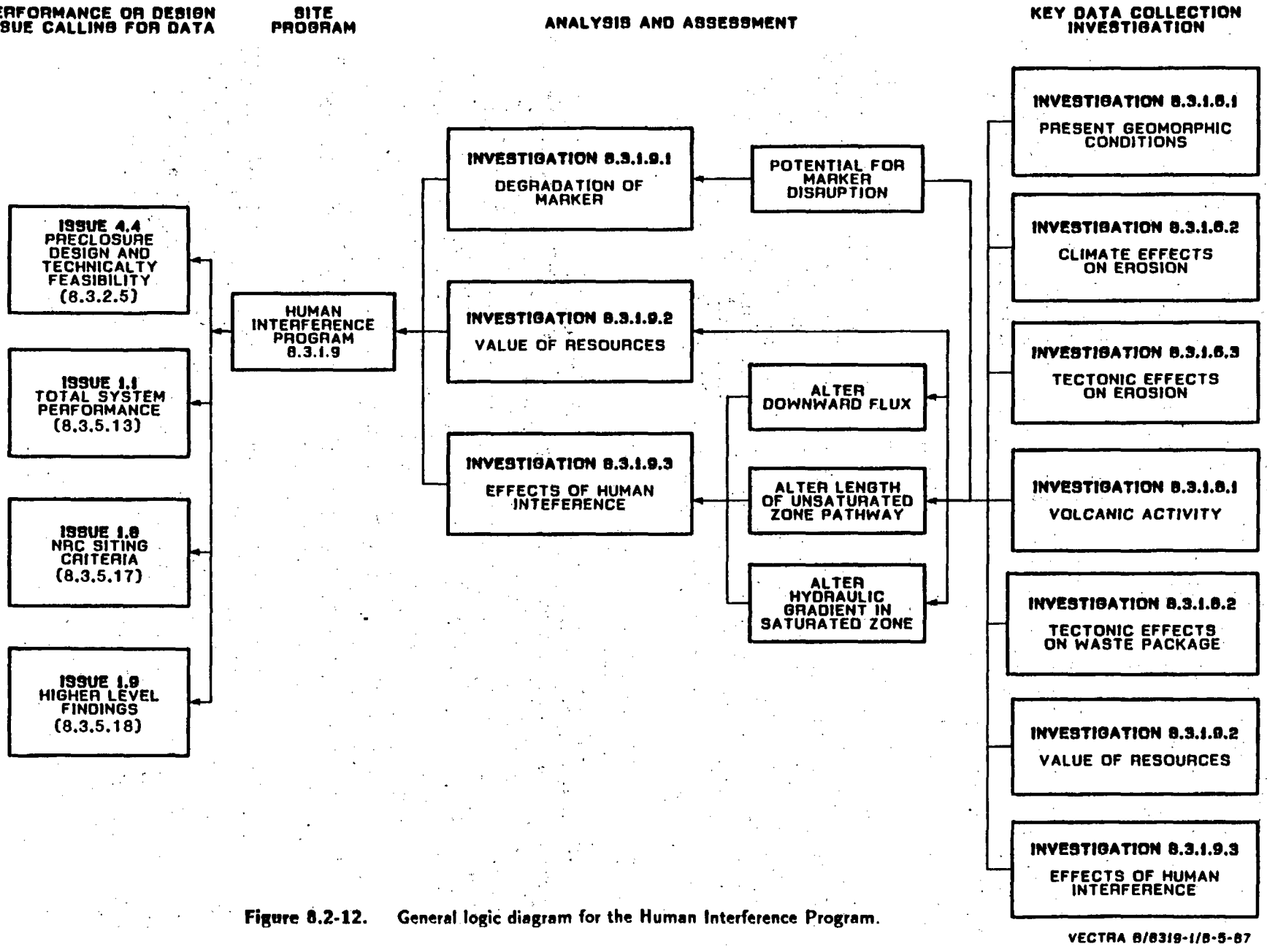

Figure 8.2-12. General logic diagram for the Human Interference Program.

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As shown in Figure 8.2-12, the performance issues that rely on information from the human interference program include the cumulative releases from the repository (Issue 1.1, Section 8.3.5.13), and the demonstration that the site meets the NRC siting criteria (Issue 1.8, Section 8.3.5.17). These issues require information regarding the potential for human interference at the site during the 10,000-yr postclosure period.

The only design issue requesting information from the human interference program is Issue 4.4 (preclosure design and technical feasibility). This issue requests site-specific information on natural processes that could affect the long-term survivability of the surface markers. The data obtained through the human interference program will be used to identify the most suitable locations for the surface markers.

Approach to satisfy performance and design requirements

The general approach to satisfying the performance and design requirements is to conduct investigations that will provide the basis for developing credible human intrusion scenarios. The investigations will provide information about the site and about the survivability of the warning system that can be used to assess the likelihood of occurrence of specific human activities at and near the site. The probability that specific human activities will occur, and the potential influence that such activities might have on repository performance will be determined. These data will provide the information necessary to satisfy the performance and design issue requirements.

Summary of human interference investigations

Table 8.2-41 summarizes the major parameters and the investigations planned for the human interference program. The first investigation (Section 8.3.1.9.1) identified for this program determines all events, both natural and anthropogenic, that could destroy or degrade the surface markers and monuments. Because most anthropogenic factors have been considered and incorporated into the marker design, only three specific data needs are identified, all of which will be provided from other investigations. The magnitudes and locations of fault rupture and seismically induced ground motion (Section 8.3.1.8.2); the rates, magnitudes, and locations of potential igneous activity (Section 8.3.1.8.1); and the potential effects of tectonic activity and future climatic conditions on locations and rates of erosion and deposition (Sections 8.3.1.6.2 and 8.3.1.6.3) will aid in determining the best locations for the surface markers and monuments.

The second investigation (Section 8.3.1.9.2) will identify all resources at the site with current markets, or those that could potentially be marketable in the future. These resources will be described in terms of physical factors such as tonnage and grade. Once resources and reserves are identified, they will be delineated and quantified (Study 8.3.1.9.2.1) and the impact of their presence will be addressed in Studies 8.3.1.9.3.1 and 8.3.1.9.3.2).

Ground water currently is the only commodity classified as a resource in the immediate vicinity of the site. Exploitation of this resource is

Table 8.2-41. Major parameters provided by investigations in Human Interference Program 8.3.1.9

Section number	Investigation	Major parameters
8.3.1.9.1	Studies to provide the information required on natural phenomena and human activities that might degrade surface markers and monuments	Parameter synthesis of tectonic, seismic, and volcanic hazards data for assessing marker survivability Parameter synthesis of geomorphic data for assessing marker survivability
8.3.1.9.2	Studies to provide the information required on present and future value of energy, mineral, land, and ground-water resources	Geochemical assessment of Yucca Mountain in relation to the potential for mineralization Geophysical and geological assessment of Yucca Mountain relative to mineral resources Geothermal resource assessment of Yucca Mountain Mineral and energy resource analog modeling of Yucca Mountain Projected trends in local and regional ground-water development Estimated ground-water withdrawal rates in southern Nevada proximal to Yucca Mountain
8.3.1.9.3	Studies to provide the information required on potential effects of exploiting natural resources on hydrologic, geochemical, and rock characteristics	Data evaluation to support the assessment calculation of the potential for human interference and intrusion Potential effects of resource exploration and extraction on the hydrologic conditions at the site Evaluation of initiating events related to human interference

expected to become economically feasible in the near future. Study 8.3.1.9.2.2 will integrate existing scientific and institutional data with information obtained during characterization of the saturated zone (Section 8.3.1.2.3) to (1) quantify and qualify the ground-water resources proximal to the site, (2) assess the current and future value of the resource, and (3) project the probable rates and locations of ground-water exploitation in the reasonably foreseeable future. These parameters will be considered in calculating the probability for human interference (Section 8.3.1.9.3.1) and in assessing the potential effects of ground-water exploitation on the baseline conditions at the site (Section 8.3.1.9.3.2).

The final investigation (Section 8.3.1.9.3) examines the potential effects of resource extraction on the baseline hydrologic, geochemical, and rock characteristics. The parameters that have been identified are (1) the specific resources determined in Investigation 8.3.1.9.2, (2) the baseline conditions at the site, and (3) the extraction methods that would be used for the specific resources under consideration. The parameters obtained for this investigation will be analyzed and evaluated to determine whether the potential effects of resource exploitation can change the baseline characteristics of the site such that repository performance would be affected.

The second part of Investigation 8.3.1.9.3 will focus on the initiating events of the release scenarios that relate to human activities and their potential effects on long-term repository performance. The parameters defined for this investigation are the initiating events identified in Issue 1.1 (total system performance) that may not be considered sufficiently credible to warrant further consideration because of the improbability of their occurrence. These parameters will be evaluated to establish with a high level of confidence whether they are sufficiently credible or significant to warrant further consideration within Issue 1.1.

8.2.2.4.9 Summary of population density and distribution program

The population density and distribution program is described in Section 8.3.1.10. This program provides references and information to support the resolution of performance and design issues related to preclosure radiological safety. These requirements are derived from 10 CFR Part 20, 10 CFR Part 60, 40 CFR Part 191, and DOE orders. The data requirements necessary to comply with these regulations are addressed in the performance and design issues.

Collection of population density and distribution data is not considered a site characterization activity as defined in the Nuclear Waste Policy Act. Therefore, details for data collection activities are not in this document. However, population density and distribution remains an important component of the program of preclosure radiological safety of members of the general public whether through normal operations or as a result of accident conditions (Issues 2.1 and 2.3, Sections 8.3.5.3 and 8.3.5.5). The data base established through this program will contribute to Issue 2.5 (Section 8.3.5.6), which addresses higher level findings on the qualifying and disqualifying conditions of DOE's siting guideline on population density and distribution (10 CFR 960.5-2-1).

The distribution of future populations in highly populated areas and in unrestricted areas is a significant factor in defining preclosure radiological safety programs. Preparation of a radiological monitoring plan will help to establish the data base required to resolve of performance and design issues related to radiological safety.

8.2.2.4.10 Summary of site ownership site program

The land ownership and mineral rights program is described in Section 8.3.1.11. This program is derived from the requirements of 10 CFR Part 960 and 10 CFR Part 60. The provisions of 10 CFR 60.121 require that

> Both the geologic repository operations area and the controlled area shall be located in and on lands that are either acquired lands under the jurisdiction and control of DOE, or lands permanently withdrawn and reserved for its use.

This provision further requires that (1) such lands shall be held free and clear of all encumbrances, (2) the DOE shall exercise any jurisdiction and control over surface and subsurface estates necessary to prevent adverse human actions that could significantly reduce the repository's ability to achieve isolation, and (3) the DOE shall also have obtained water rights as may be needed to satisfy the requirements of the repository operations area.

The plans and procedures for conducting the land ownership and mineral rights program are not considered site characterization activities as defined by the Nuclear Waste Policy Act (NWPA, 1983). The regulatory requirements just listed are an essential component of the repository program in that they provide for a controlled site, which in part addresses preclosure radiological safety aspects of the program. Thus, performance and design issues concerning radiological dose calculations to the public and workers performed in Issues 2.1, 2.2, 2.3, and 2.7 and discussed in Sections 8.3.5.3 through 8.3.5.5 and 8.3.2.3 can be addressed with the knowledge that actions will be taken to withdraw and control the appropriate portion of land in accordance with applicable regulations. In addition, compliance with these requirements will support Issue 2.5 (Section 8.3.5.6), which addresses higher level findings on the qualifying and disqualifying conditions of the site ownership and control guidelines in 10 CFR 960.

If the Yucca Mountain site is recommended and approved for development as a repository following site characterization, it will be necessary, pursuant to 10 CFR 60.121, for the DOE to withdraw the land that would comprise the repository operations area and controlled area and reserve this land for its use. Such a withdrawal action, under current law, must be made pursuant to applicable implementing regulations. The Federal Land Policy Management Act of 1976 (FLPMA) and the implementing regulations define the data and information required to be provided at the time of application to Congress to support the review of the application for withdrawal. Much of the required data and information will be collected as part of the site characterization activities or other programmatic activities planned by the DOE. A similar requirement to recognize and address withdrawal requirements also exists for additional DOE activities directed at assessing the suitability of the Yucca Mountain site under 10 CFR Part 960 and preparing input

to the environmental impact statement required by the NWPA and the National Environmental Policy Act (NEPA, 1970).

8.2.2.4.11 Summary of meteorology site program

The details of the meteorology site program are presented in Section 8.3.1.12. The program is designed to provide a complete understanding of the meteorology of the area, as well as to supply specific information on climatologically average and extreme weather phenomena required by design and performance issues. The overall approach to satisfying the design and performance information requirements is to conduct investigations that will address the preclosure radiological safety aspects of the mined geologic disposal system under normal and accident conditions.

Summary of performance and design requirements for meteorological information

The purpose of the meteorological program is to provide data required to resolve performance and design issues. The types of data requested fall into two categories: (1) data needed in calculating radiological doses resulting from releases from the repository and (2) information required for design of surface facilities. Figure 8.2-13 is a logic diagram summarizing the programs and issues requesting meteorological information.

Approach to satisfy performance and design requirements

As summarized in Figure 8.2-13, the meteorology program establishes (1) regional meteorological conditions (Section 8.3.1.12.1), (2) atmospheric and meteorological phenomena at potential locations of surface facilities (Section 8.3.1.12.2), (3) locations of population centers relative to wind patterns in the general region of the site (Section 8.3.1.12.3), and (4) potential extreme weather phenomena and their recurrence intervals (Section 8.3.1.12.4).

The investigations were created so that a complete understanding of the meteorology of the area, including both climatologically average and extreme phenomena, would be gained. Such an understanding will require looking at data from sites throughout the region and relating and comparing these data to site-specific conditions.

Meteorological data will be used by performance and design issues that assess the preclosure radiological safety aspects of the mined geologic disposal system under normal and accident conditions as shown in Figure 8.2-13. The investigation that deals with population centers relative to wind patterns will be a part of the radiological assessment because wind is the primary transport mechanism by which airborne radionuclides would reach these population centers. Finally, characterization of potential extreme weather phenomena (e.g., tornadoes, hurricanes, extreme wind speeds, temperature and humidity extremes, precipitation extremes, and obstructions to visibility) will provide input to design criteria issues relative to radiological safety. Data collected as part of this program will also provide input to investigations associated with the geohydrology program and will be used, for example, in developing storm trajectories through the area.

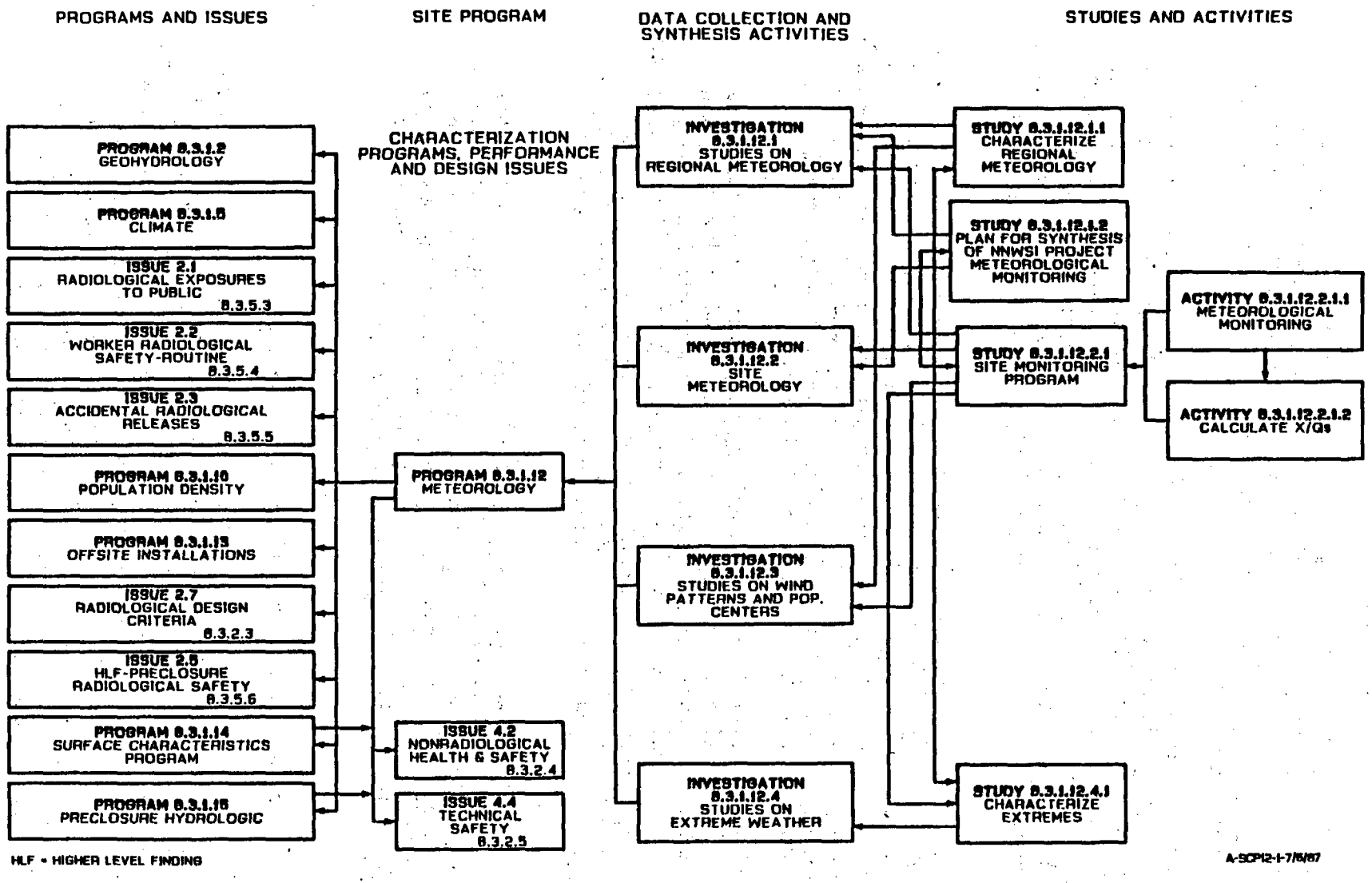

Figure 8.2-13. General logic diagram for meteorology program.

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Summary of meteorology investigations

As just described, the investigations planned for the meteorology program fall into two general categories: (1) those concerned with only site-specific data and (2) those associated with regional meteorological conditions. Table 8.2-42 lists the major parameters to be acquired by the meteorology investigations.

To gain an understanding of the regional meteorological conditions, existing data bases will be evaluated and their applicability to Yucca Mountain determined (Investigation 8.3.1.12.1). These data, in combination with data from the site monitoring program will then be assimilated into a data set that represents the regional meteorological conditions. Part of this investigation will also be to coordinate monitoring efforts needed for other issues or programs with the data being collected through the meteorology program.

A site monitoring program consisting of five towers has been implemented at Yucca Mountain. Although this network was initially established to support environmental permitting and licensing activities, the parameters being monitored will be used as input in evaluating preclosure radiological impacts as well. The data being collected will be input to predictive models for dose calculations to ensure that radiological safety is not compromised as a result of meteorological characteristics of the site.

The studies identified for characterizing wind patterns relative to population centers will consist of providing data on and analyses of wind parameters that will be used in conjunction with the population density program identified in Section 8.3.1.10. Together, these results will provide a clear understanding of wind transport patterns relative to population centers and will be used in determining if the patterns would or would not preferentially carry radioactive material released to the air toward these centers.

The existing data bases and technical publications reviewed in characterizing the regional meteorology will also provide data on the extreme weather phenomena that may be experienced at the site. Because extreme weather can affect design and can initiate an accident during repository operation and transportation of waste to the site, the occurrence of such phenomena and their recurrence interval must be determined.

8.2.2.4.12 Summary of offsite installations site program

The offsite installations and operations program is described in Section 8.3.1.13. This program provides technical data required to address preclosure radiological safety requirements for the repository. The investigations derived from these issues address the following topics: (1) the data base necessary to assess the potential offsite accident initiators, (2) possible radioactive releases from other sites that affect the site's ability to comply with radiological requirements, (3) location and adequacy of the transportation access routes, and (4) the agricultural and cultural data required for analysis of the public ingestion-dose pathway.

Table 8.2-42. Major parameters provided by investigations in Meteorology Program 8.3.1.12

Section number	Investigation	Major parameters
8.3.1.12.1	Studies to provide data on regional meteorological conditions	Characterization of meteorological conditions Synthesis of meteorological monitoring data
8.3.1.12.2	Studies to provide data on atmospheric and meteorological phenomena at potential locations of surface facilities	Site meteorological monitorological monitoring Data summary for input to dose assessments
8.3.1.12.3	Studies to provide data on the location of population centers relative to wind patterns in the general region of the site	Frequency distribution of wind speed and direction Persistence of wind speed and direction Diurnal wind speed and direction Atmospheric dispersion associated with wind speed and direction
8.3.1.12.4	Studies to provide data on potential extreme weather phenomena and their recurrence intervals	Frequency of severe storms Magnitude and frequency of extreme wind speeds Extremes of temperature and and humidity Precipitation extremes and their recurrence intervals Frequency and intensity of fog

Summary of performance and design requirements for offsite installations and operations information

The offsite installation program requires the identification of all offsite operations that could impact the site. Potential impacts of offsite operations are determined to support the calculation of ingestion doses and exposures to the public and workers for Issues 2.1, 2.2, and 2.3 discussed in Sections 8.3.5.3 through 8.3.5.5.

The data base established in this program will be used in an evaluation of the higher level findings required for the qualifying condition in the offsite installations technical guideline (10 CFR Part 960), and for the qualifying condition for the preclosure radiological safety system guideline (Section 8.3.5.6).

Approach to satisfy performance and design requirements

The data base presented in the environmental assessment (DOE, 1986b) describes the nearby offsite installations and operations that could potentially affect repository operations. Further information required to support resolution of design and performance issues related to radiological safety include the following:

1. An evaluation of offsite accident initiators, their probabilities and potential impacts, and the parameters required for calculation of public ingestion dose to support Issues 2.1 and 2.3 (Sections 8.3.5.3 and 8.3.5.5).

2. An assessment of releases from all nuclear fuel cycle operations to support Issues 2.3 and 2.5 (Sections 8.3.5.5 and 8.3.5.6).

3. An assessment of the onsite impact of nonrepository-related routine and potential accidental releases of radioactive material to support Item 1 and to support the resolution of Issues 2.3 and 2.5.

4. An evaluation of the adequacy of proposed transportation site access routes to support resolution of Issues 2.3 and 2.5.

5. The collection of agricultural and cultural data to support the calculation of the dose to the public through the ingestion pathway from releases at the Yucca Mountain site and to support resolution of Issues 2.1 and 2.3.

Summary of investigations

The first investigation developed for this program addresses the requirement to document the presence of all nearby industrial, transportation, and military installations and operations, both nuclear and nonnuclear (Investigation 8.3.1.13.1). The second investigation requires an evaluation of the potential impacts of those nearby installations and operations (Investigation 8.3.1.13.2).

The investigations identified for nearby industrial, transportation, and military installations and operations (both nuclear and nonnuclear) consist of identifying the nearby site operations, nuclear fuel cycle facilities, and nonnuclear fuel cycle facilities in the area. Once these operations have been identified, the impacts of those facilities will be assessed.

Certain agricultural and cultural data are necessary for assessing radionuclide dose calculations to the public. This information will not be collected as part of this program because this type of data is not considered part of site characterization activities as defined in the Nuclear Waste Policy Act. However, this data is an essential component of the program of

calculating doses to the public through the ingestion dose pathway and will be presented as part of the environmental program planning process within the NNWSI Project.

8.2.2.4.13 Summary of surface characteristics program

The details of the surface characteristics program are presented in Section 8.3.1.14. The program reflects requirements of the DOE, the NRC, and the EPA that the surface facilities, including openings to the underground, must ensure public health and safety, be technically feasible, and have reasonable costs. This program contains three investigations pertinent to preclosure design and performance issues: (1) topography (Section 8.3.1.14.1), (2) soil and bedrock conditions (Section 8.3.1.14.2), and (3) meteorological conditions (Section 8.3.1.14.3).

Summary of performance and design requirements for surface characteristics information

The interfaces between the surface characteristics program, other characterization programs and design and performance issues that require surface characteristics information are presented in Figure 8.2-14. As shown in the figure, surface characteristic information such as topographic contours will be used to locate and design repository surface facilities (Issue 4.4, preclosure design and technical feasibility) and to determine probable flood levels at potential surface facility locations. Topographic contour maps will be used to locate shaft and ramp entrances and other sensitive structures such as waste handling facilities above potential flood levels.

Surface topographic characteristics will also be required for certain underground design and performance studies. Topographic contour maps will be used to determine the usable repository horizon area while maintaining the required amount of overburden (Sections 8.3.5.17 and 8.3.5.18). In addition, in-situ stresses are influenced, in part, by local topography (Sections 8.3.1.4 and 8.3.1.15). Surface characteristics of the alluvial soil and rock at or near the surface influence the location and design of the surface facilities and their costs. This is especially true for sensitive structures, such as the waste handling facilities, which may experience earthquake loading (Section 8.3.1.17). Even for static loading conditions, the soil and rock conditions at the site will influence the selection of the surface facility location and its foundation design. Local meteorological conditions at the site will also impact the location and design of the surface facilities. Meteorological conditions, such as extreme wind or precipitation, must be considered in the design and performance of the surface facilities. These conditions are addressed in the meteorological program (Section 8.3.1.12).

Approach to satisfy performance and design requirements

The general approach to satisfying the performance and design requirements is to obtain and evaluate surface characterization information to determine whether the information is adequate to resolve the performance and design issues. Close collaboration between engineering and geotechnical experts is planned to allow timely development of the repository design. The

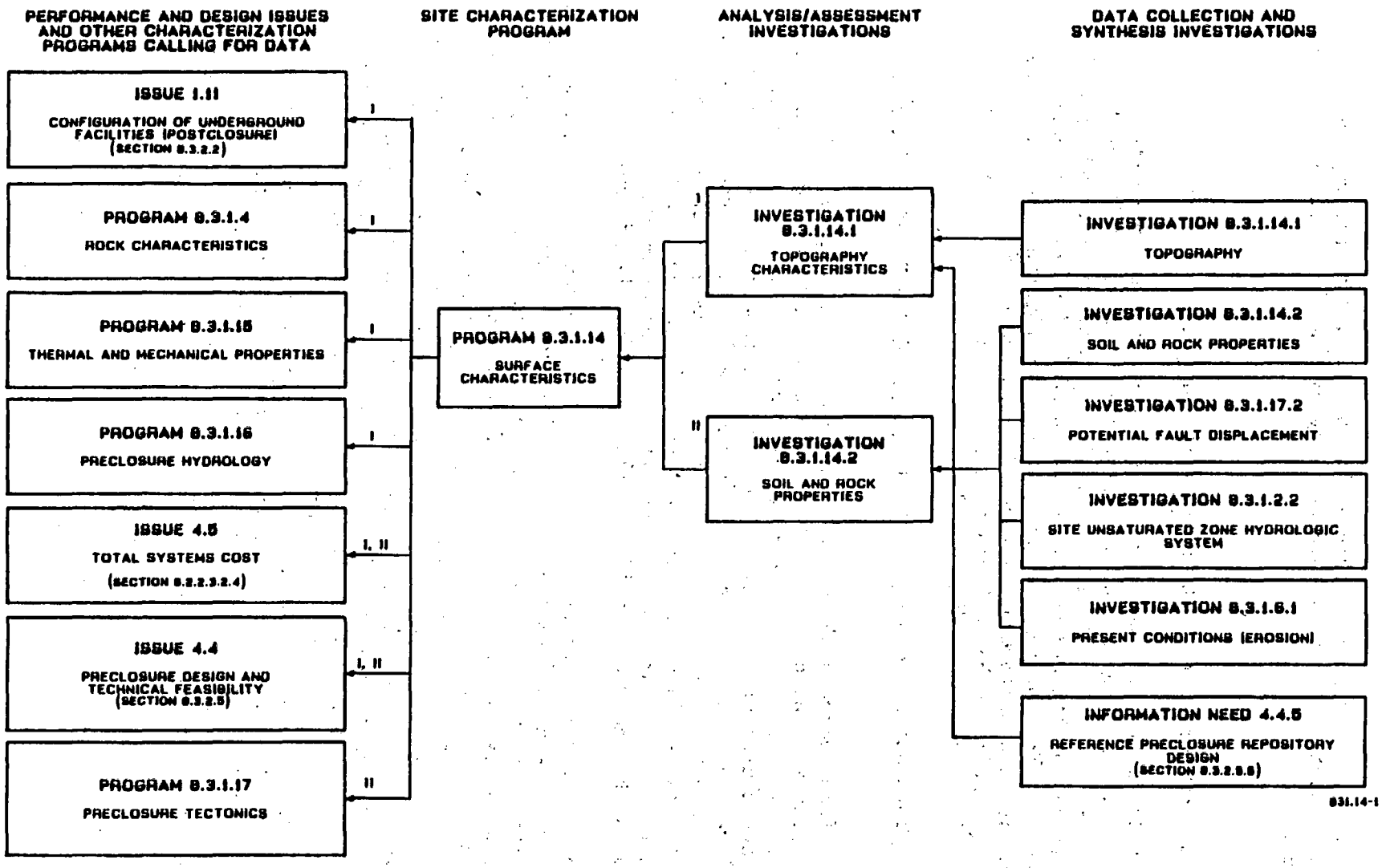

Figure 8.2-14. Logic diagram for Program 8.3.1.14, surface characteristics. Roman numerals indicate data flow.

major elements defining the required surface characteristics information include topography, soil and bedrock properties, and meteorologic conditions. The facility designer will use the surface site characteristics data to design surface structures and their foundations, shaft and ramp portals, roads, drainage systems, and flood control structures. These designs will also consider abnormal conditions such as maximum probable floods, high wind loads, and dynamic loading conditions caused by earthquakes and man-induced explosions. To satisfy these requirements, the appropriate surface characteristics information must be obtained.

New investigations are planned for soil and bedrock properties and meteorological conditions but no new studies are needed for topography, because requirements for this investigation have been satisfied. The recommended studies to address the requirements for soil and bedrock properties consist of an exploratory program, laboratory testing program, and a field testing and measurement program. The exploratory program will utilize various methods and techniques to investigate and characterize the subsurface soil and rock strata beneath the reference conceptual site. The laboratory test program will test undisturbed samples (minimal disturbance) obtained from the exploratory program and determine the soil or rock physical and mechanical material properties. The results from the field test and measurement program will further enhance the characterization of the subsurface conditions that may influence or impact surface facilities performance and design.

Summary of surface characteristics investigations

A summary of the information to be provided by the soil and bedrock property investigation is provided in Table 8.2-43. The topography investigation provides no further data because adequate contour maps are available. As previously indicated, any description of studies and activities associated with the meteorological condition investigation will be addressed in the meteorology program (Section 8.3.1.12).

8.2.2.4.14 Summary of thermal and mechanical rock properties program

The thermal and mechanical rock properties program is described in Section 8.3.1.15. Compliance with performance and design criteria for a geologic repository requires information about the rock characteristics of the Yucca Mountain site. This program provides the site information needed on thermal and mechanical rock properties and on ambient stress and temperature conditions required to support assessments of site performance and design criteria for the underground facility, seals, and waste packages.

Summary of performance and design requirements for thermal and mechanical rock properties information

Information requirements of the performance and design issues can be divided into four categories. First, Issues 1.1, 1.12, and 4.4 (Sections 8.3.5.13, 8.3.3.2, and 8.3.2.5) require data on thermal and mechanical properties of the rock for repository design analysis. Second, data on thermal properties of the rock for use in analysis of the disturbed zone are also

Table 8.2-43. Major parameters to be provided by investigations in Surface Characteristics Program 8.3.1.14

Section number	Investigation	Major parameters
8.3.1.14.1	Studies to provide the topographic characteristics of potential locations of surface facilities	Ground surface elevation as a function of geographic position
8.3.1.14.2	Studies to provide soil and rock properties of potential locations of surface facilities	Laboratory tests and material property measurements Physical property and index laboratory tests Mechanical and dynamic laboratory property tests Physical property field tests and characterization measurements Mechanical property field tests Geophysical field measurements

required for Issue 1.6 (Section 8.3.5.12). Third, Issue 2.7 (Section 8.3.2.3) requests information on bulk properties and radon emanation rates for use in analysis of radiologic safety. Finally, data on ambient in situ stress and temperature conditions to serve as initial and boundary conditions for repository design are required for Issues 1.11, 1.12, and 4.4 (Sections 8.3.2.2, 8.3.3.2, and 8.3.2.5). Figure 8.2-15 shows the interfaces between the performance assessment and design issues, and the characterization programs, and the investigations planned to acquire data on thermal and mechanical rock properties.

Approach to satisfy performance and design requirements

Performance allocation has been used to establish performance goals for the design and performance assessment issues requesting information from this program. These performance goals are then used to define the thermal and mechanical data necessary to determine whether the goals are met. In this program characterization goals represent quantitative estimates of the maximum variability in a parameter that can be tolerated without necessitating a change in the existing design. Required confidence levels are a measure of how important it is that the specified limits are met. Both characterization goals and confidence levels have been estimated for performance assessment and design issues based on limited sensitivity studies or on expert judgment. When more than one issue requires a given parameter, the issue that poses the

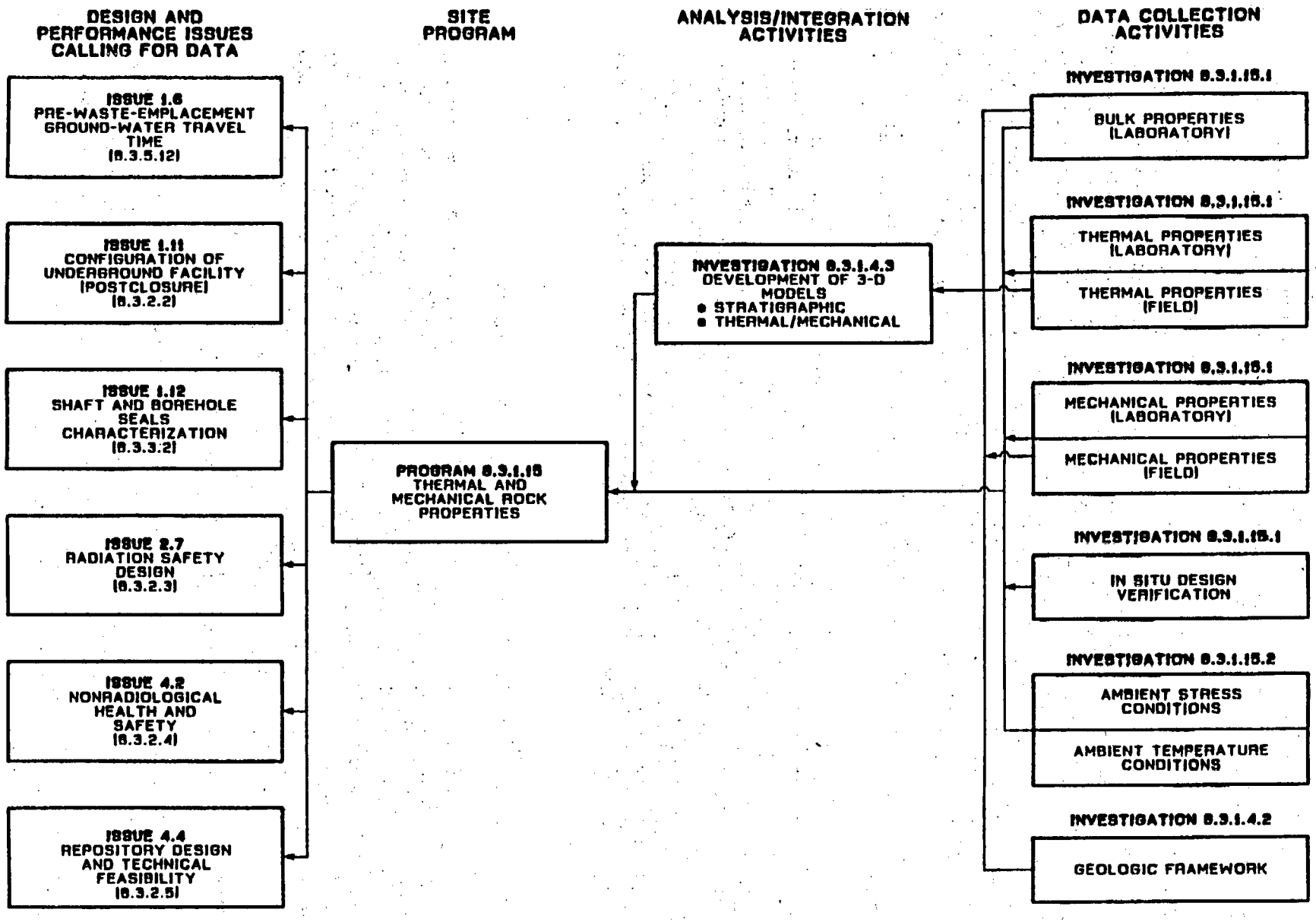

Figure 8.2-15. Relationship between data acquistion for rock properties and issues requiring the data.

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greatest constraint will be used in planning site studies and activities to obtain values for the parameter. A summary of the major parameters provided by this program is presented in Table 8.2-44.

As site characterization proceeds, some site data values may be found to fall outside the specified range for the characterization goal. If this occurs, the portions of the design or of the performance assessment programs affected by these data will be reevaluated to assess the impact. New ranges for these data may be specified, and additional data will be collected if necessary. In addition the possibility exists that not all necessary data have been identified or that the specified ranges are invalid because of the preliminary or nonexistent sensitivity studies. In these instances, additional data may be requested or the specified ranges for a requested parameter may be changed. Either situation might lead to a modification to the site characterization program outlined in Sections 8.3.1.15.1 and 8.3.1.15.2.

Summary of the planned investigations for the thermal and rock properties program

Two investigations and nine studies are planned to collect the required rock characteristics data. The studies consist of those related to laboratory determination of thermal and mechanical properties, to in situ experiments in the exploratory shaft, and to characterization of ambient stress and thermal conditions. Three categories of in situ experiments are planned: (1) experiments related to evaluation of the effects of excavation, (2) mechanical property experiments, and (3) thermomechanical property experiments. Characterization of ambient stress and thermal conditions will include measurements of stress and temperature in new exploratory holes and in the exploratory shaft.

8.2.2.4.15 Summary of the preclosure hydrology program

The details of the preclosure hydrologic characterization program are presented in Section 8.3.1.16. This program is designed to provide the site-specific hydrologic information needed to meet the information requirements of Issue 4.4 (preclosure design and technical feasibility, Section 8.3.2.5), Issue 4.2 (nonradiological health and safety, Section 8.3.2.4), Issue 1.11 (configuration of underground facilities, Section 8.3.2.2), and Issue 1.12 (seal characteristics, Section 8.3.3.2). The overall approach is to obtain data on surface and subsurface hydrologic characteristics that will aid in finalizing the surface and subsurface facility designs.

Summary of design requirements for hydrologic information

The purpose of the preclosure hydrologic characterization program described in Section 8.3.1.16 is to provide the information regarding hydrologic characteristics, processes, and conditions required for repository design. Figure 8.2-16 shows the design issues that depend on the hydrologic characterization program for information, and the investigations that will be performed to satisfy the design requirements.

Table 8.2-44. Major parameters provided by investigations in Thermal and Mechanical Rock Properties Program 8.3.1.15 (Page 1 of 2)

Section number	Investigation	Major parameters
8.3.1.15.1	Studies to provide the required information for spatial distribution of thermal and mechanical properties	Laboratory determination of rock properties characterization of density and porosity - Characterization of volumetric heat capacity - Characterization of thermal conductivity - Thermal expansion testing - Compressive mechanical properties of intact rock at baseline conditions - Effects of variable environmental conditions on compressive mechanical properties - Tensile strength of unit TSw2[a] Fracture properties - Mechanical properties of fractures at baseline conditions - Effects of variable environmental conditions on mechanical properties of fractures Excavation investigations - Spatial variability of rockmass deformation - Spatial variability of horizontal in situ stress - Deformation in tuff caused by excavation of repository-sized rooms - Extent of increased fractures - Stress changes due to excavations In situ thermomechanical properties - Thermal conductivity, heat capacity, and thermal expansion coefficients for TSw1[b] and TSw2 - Deformation modulus - Joint wall compressive strength - Joint roughness coefficient - Measurement of thermally-induced stress - Rock-mass deformation

Table 8.2-44. Major parameters provided by investigations in Thermal and Mechanical Rock Properties Program 8.3.1.15 (Page 2 of 2)

Section number	Investigation	Major parameters
8.3.1.15.1 (continued)	Studies to provide the required information for spatial distribution of thermal and mechanical properties (continued)	Estimate of region in which stress state is changed by temperature elevation Rib stress change Ground-support loading and deformation Temperature dependence of measured parameters In situ mechanical properties Plate loading tests Rock-mass strength In situ design verification Evaluation of mining methods Monitoring of ground support systems Monitoring of drift stability Air quality and ventilation requirements
8.3.1.15.2	Studies to provide the required information for spatial distribution of ambient thermal and stress conditions	Anelastic strain recovery in core holes In situ stress Spatial variability of in situ stress Ambient temperature Spatial variability of ambient temperature

[a]Tsw2 = Topopah Spring welded tuff nonlithophysal unit.
[b]Tsw1 = Topopah Spring welded tuff lithophysal unit.

The design issues require three types of hydrologic data that will be used in the final design of the surface and subsurface facilities. These data include information on the hazards associated with flooding and debris flows; the location of adequate and alternate water supplies for the construction, operation, and closure of the repository and the surface facilities; and information on the subsurface hydrologic conditions within and above the host horizon. These data will be used to finalize the surface facility design and the shaft and seals designs.

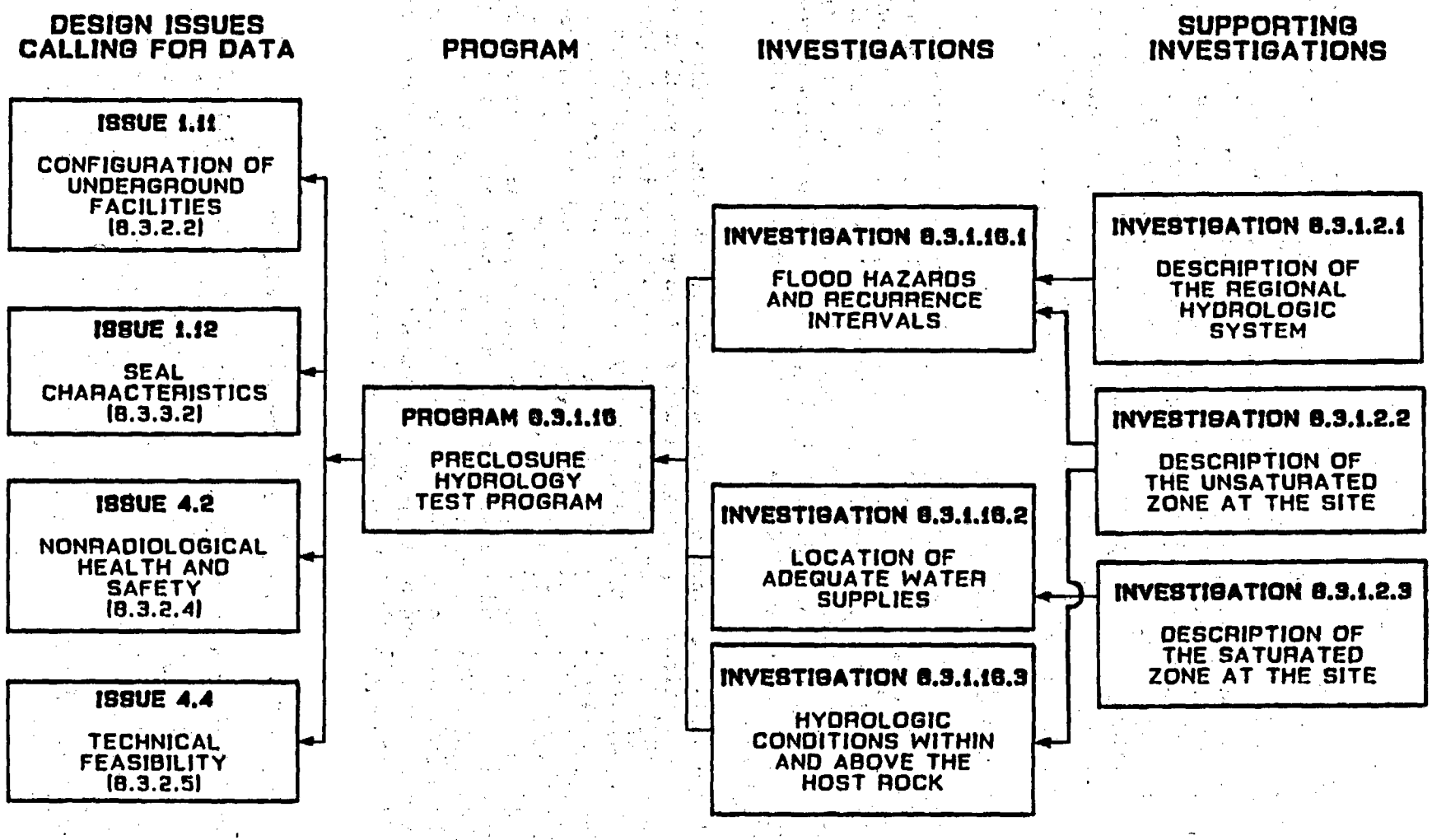

Figure 8.2-16. Relationship between the preclosure hydrology test program and its investigations.

Approach to satisfy the design requirements

The general approach to satisfying the design requirements is to conduct investigations that will provide values for the specific hydrologic parameters requested. Data regarding the surface hydrologic conditions will be obtained through flood and debris hazard studies and will be used in conjunction with data obtained from regional hydrology investigations (Section 8.3.1.2.1) to determine the values necessary for design. The investigation described in Section 8.3.1.16.2 will evaluate existing water well data and obtain new site-specific data in order to ensure the availability of sufficient water supplies for repository construction and operation. Detailed information on the conditions and characteristics of the unsaturated zone within and above the repository horizon will be obtained and evaluated through the geohydrologic program (Sections 8.3.1.2.1 through 8.3.1.2.3).

Summary of hydrologic investigations

A general list of parameters provided by this program is shown in Table 8.2-45. The site data will be obtained at the level of confidence needed for input to design analyses. For determining the values of parameters that are not readily amenable to measurement or analysis, multiple approaches will be used. More detailed information on the parameters provided by this program is provided in Section 8.3.1.16, and the investigations necessary to satisfy the design requirements are described in detail in Sections 8.3.1.16.1 through 8.3.1.16.3.

The three different types of data required will be obtained from three different investigations. Each investigation focuses on the specific type of data to be collected. The investigation described in Section 8.3.1.16.1 addresses the aspects of surface hydrology related to flood and debris hazard, the investigation described in Section 8.3.1.16.2 addresses the hydrologic and economic requirements of water supply, and the investigation described in Section 8.3.1.16.3 describes the subsurface conditions of the unsaturated zone that must be known to design the repository access ramps, underground facilities, and seals. These data are required by the design issues to determine (1) the technical feasibility of constructing a repository in the unsaturated zone, (2) the compatibility of repository-related activities with the geohydrologic setting, and (3) if the repository can be constructed using available technology and at a reasonable cost.

8.2.2.4.16 Summary of the preclosure tectonics program

The preclosure tectonics program described in Section 8.3.1.17 is intended to provide an understanding of and to characterize the tectonic events that could reasonably impact the operations of structures, systems, or components considered important to safety for the proposed Yucca Mountain repository through the operational phase until permanent closure is achieved. In addition, characterization of tectonic processes and events will be developed for consideration in the design and operation of certain structures, systems, and components required for exercising the retrieval option.

Table 8.2-45. Major parameters provided by investigations in Preclosure Hydrology Program 8.3.1.16

Section	Investigation	Major parameters
8.3.1.16.1	Flood recurrence intervals and levels at potential locations of surface facilities	Surface-water runoff characteristics Surface-water debris transport characteristics
8.3.1.16.2	Location of adequate water supplies	Cost, feasibility, and adequacy of wells J-12 and J-13 for use as alternate water supply Identify primary water supply for the mined geologic disposal system Identify alternate water supply for MGDS Identification and evaluation of effects of ground-water withdrawals on flow system
8.3.1.16.3	Ground-water conditions within and above the potential host rock	Data syntheses: preclosure hydrologic characteristics of the unsaturated zone

Summary of performance and design requirements for preclosure tectonics information

Performance and design issues requiring data from the preclosure tectonics program are indicated in the left half of Figure 8.2-17; the right half of the figure indicates investigations that provide the requested data. The primary requirements come from Issue 4.4, which addresses the preclosure repository design and technical feasibility for repository construction, operation, closure, and decommissioning and is discussed in Section 8.3.2.5. Investigations of technical feasibility that include data requirements from four additional performance and design issues are also noted in the figure. These four issues are repository design criteria for radiological safety (Issue 2.7, Section 8.3.2.3), accidental radiological releases (Issue 2.3, Section 8.3.5.5), waste retrieval ability (Issue 2.4, Section 8.3.5.2), and seal characteristics (Issue 1.12, Section 8.3.3.2). In addition, data are also requested by the postclosure tectonics program (Section 8.3.1.8).

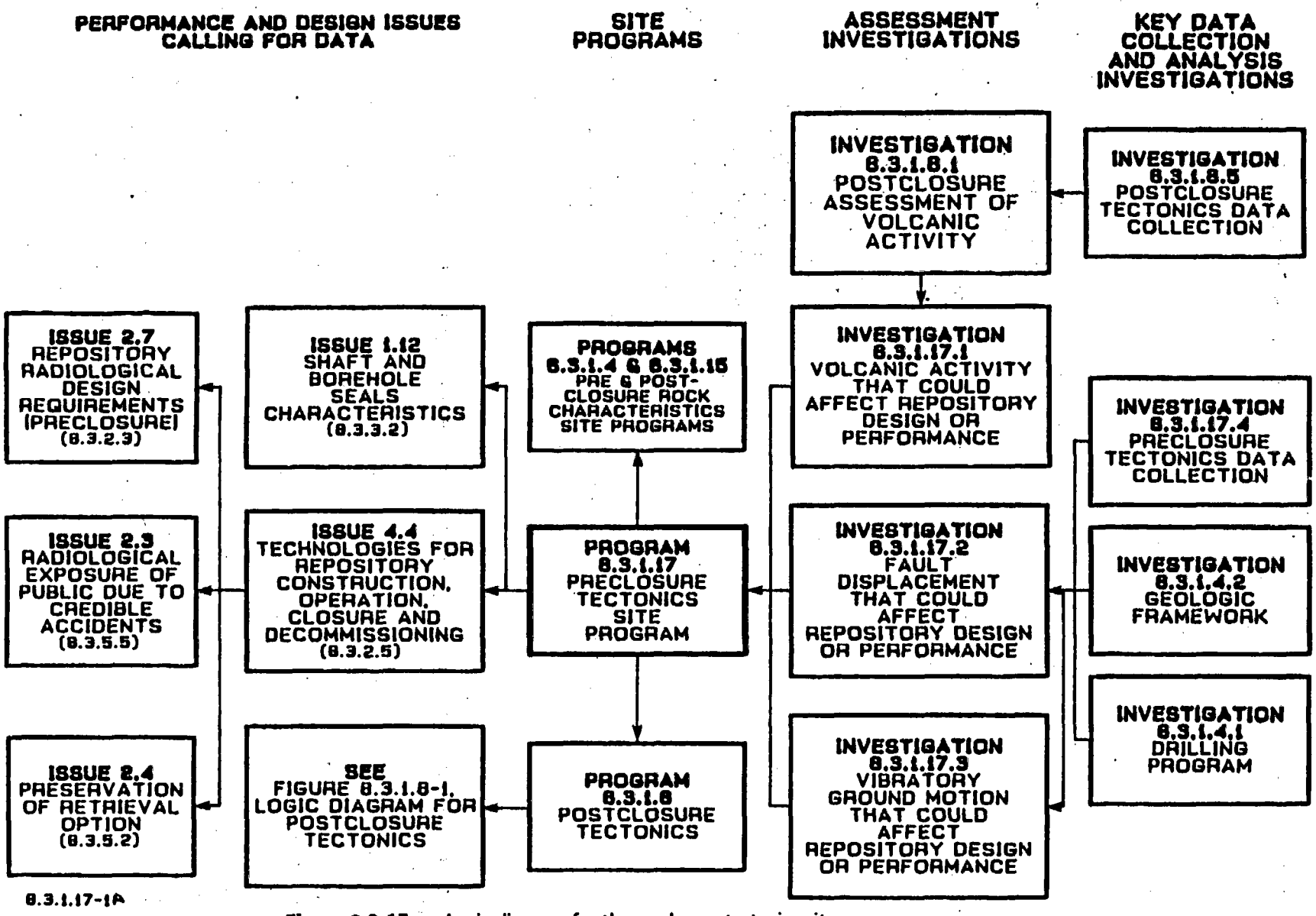

Figure 8.2-17. Logic diagram for the preclosure tectonics site program.

Approach to satisfy performance and design requirements

The approach that has been developed to satisfy performance and design requirements is based on current knowledge and uncertainties about the local tectonic environment, and consideration has been given to state-of-the art capabilities for resolving or bounding the effects of these uncertainties. The performance and design requirements are organized in this program by the type of tectonic event involved (volcanic, faulting, and vibratory ground motion). Two analyses are made for each type of event, one for surface facilities and one for underground facilities.

Both deterministic and probabilistic methods will be used for analyzing the effects of tectonic events during the preclosure period. The deterministic approach will be used to model cause-and-effect mechanisms and to develop particular tectonic event scenarios in greater detail than is typically provided by probabilistic methods. In addition, all final results for volcanic, faulting, and ground-motion events will be evaluated using probabilistic methods to ensure that the full range of identifiable tectonic processes, including uncertainties, is adequately considered and to help identify those processes that are key to parametric characterizations.

Summary of preclosure tectonic investigations

Table 8.2-46 provides a list of the major parameters and principal studies associated with this program. As shown in Figure 8.2-17 the program is divided into four investigations. The first three investigations provide the analysis and assessment of geologic data necessary to satisfy performance and design requirements. Each of these investigations considers a tectonic process that could possibly be significant in the location or design of surface or underground facilities. The data gathering activities that supply the basic geologic field data required by the analysis and assessment investigations are grouped together in the fourth investigation.

8.2.3 ISSUE TRACKING

As described in Section 8.2.1, the performance and design issues were derived from NRC and DOE requirements. The information needs that have been identified under each issue represent the site data and other technical information to be used to support the resolution of the issue. The site programs summarized in Section 8.2.2.4 were structured to acquire the data on present and expected site characteristics, processes, and events needed to develop site descriptions and to support the resolution of the performance and design issues. The general plan for issue tracking and resolution is depicted schematically in Figure 8.2-18. Site information, obtained from tests in the exploratory shaft facility and from surface-based site studies, will be used as required to design a suitable waste package and the surface and underground repository facilities. On the basis of the engineered system designs and the site characteristics and conditions, performance assessment calculations will be made to predict preclosure performance for normal and

Table 8.2-46. Major parameters provided by investigations in Preclosure Tectonics Program 8.3.1.17

Section number	Investigation	Major parameters
8.3.1.17.1	Studies to provide information on volcanic activity that could affect repository design or performance	Ashfall potential Literature survey: Quaternary silicic volcanic centers of the Great Basin Potential ash-fall thickness Particle density and size distribution of ash fall
8.3.1.17.2	Studies to provide information on fault displacement that could affect repository design or performance	Faulting potential at the repository Faulting potential at surface facility locations Potential for displacement on faults intersecting the repository
8.3.1.17.3	Studies to provide required information on vibratory ground motion that could affect repository design or performance	Identification of relevant earthquake sources Characterization of exceptional earthquakes for relevant seismogenic sources Range of underground nuclear explosion (UNE) sources Determination of maximum UNE sources Determination of ground motion from UNEs Empirical models for earth-quake ground motion Empirical models for UNEs Effects of local site geology on surface and subsurface motions Site effects from ground-motion recordings Site-effects model using wave properties of the local geology Identification of controlling seismic events Characterization of controlling seismic events Ground motion at the site from controlling seismic events Evaluation of earthquake sources Ground-motion probabilities

Table 8.2-46. Major parameters provided by investigations in Preclosure Tectonics Program 8.3.1.17 (continued)

Section number	Investigation	Major parameters
8.3.1.17.4	Preclosure tectonics data collection and analysis	Historical earthquake record Current seismicity Potential for induced seismicity Faulting potential near prospective surface facility locations Identification of Midway Valley trench locations and conduct exploratory trenching Crustal structure and subsurface expression of Quaternary faults crossing the Furnace Creek and Walker Lane zones Evaluation of Quaternary faults within 100 km of Yucca Mountain Evaluation of the Cedar Mountain earthquake of 1933 and its bearing on wrench tectonics of the Walker Lane within 100 km of the site Evaluation of the Bare Mountain fault zone Evaluation of structural domains and characterize the Yucca Mountain region with respect to regional patterns of faults and fractures Evaluation of Quaternary faulting proximal to the site within northeast-trending fault zones including Rock Valley, Cane Spring, and Mine Mountain fault systems and the Stagecoach Road fault zone Evaluation of the significance of the Miocene-Paleozoic contact in the Calico Hills area to detachment faulting within the site area Evaluation of postulated detachment faults in the Beatty-Bare Mountain area Evaluation of the potential relationship of mega-breccia within and south of Crater Flat to detachment faulting

Table 8.2-46. Major parameters provided by investigations in Preclosure Tectonics Program 8.3.1.17 (continued)

Section number	Investigation	Major parameters
8.3.17.4 (continued)	Preclosure tectonics (continued)	Evaluation of postulated detachment faults in the Specter Range and Camp Desert Rock areas Evaluation of the age of detachment faults using radiometric ages Evaluation of Quaternary geology and potential Quaternary faults at Yucca Mountain Evaluation of age and recurrence of movement on suspected and known Quaternary faults Evaluation of subsurface geometry and concealed extensions of Quaternary faults at Yucca Mountain Evaluation of intermediate depth (to 2 to 3 km) reflection and refraction methods and plan potential application of these methods within the site area Detailed gravity survey of the site area Detailed aeromagnetic survey of the site area Detailed ground magnetic survey of specific features within the site area Evaluation of surface geoelectric methods and plan potential applications of these methods within the site area Evaluation of methods to detect buried faults using gamma ray measurements, and plan potential application of these methods within the site area Evaluation of thermal infrared methods and plan potential applications of these methods within the site area Evaluation of shallow seismic reflection (Mini-Sosie) methods and if appropriate conduct surveys of selected structures at and proximal to the site area

Table 8.2-46. Major parameters provided by investigations in Preclosure Tectonics Program 8.3.1.17 (continued)

Section number	Investigation	Major parameters
8.3.1.17.4 (continued)	Preclosure tectonics (continued)	Evaluation of present stress field within the site area Evaluation of and test shallow borehole hydrofrac and triaxial strain recovery methods for the determination of in situ stress, and if appropriate, plan potential application of these methods within and proximal to the site Evaluation of published and unpublished data on paleostress orientation at and proximal to the site and assess the relevance of these data to Quaternary tectonics Evaluation of theoretical stress distributions associated with potential tectonic settings (wrench fault, normal fault, detachment fault setting, etc.) of the site Geomorphic evaluation of age and extent of tectonically stable areas at and near Yucca Mountain Evaluation of extent of areas of Quaternary uplift and subsidence at and near Yucca Mountain Evaluation of variations in the nature and intensity of Quaternary faulting within 100 km of Yucca Mountain through morphometric and morphologic analysis Geodetic leveling Relevel base-station network, Yucca Mountain and vicinity Global positioning satellite survey selected base stations, Yucca Mountain and vicinity Analysis of existing releveling data, Yucca Mountain and vicinity Characterization of regional lateral crustal movement Tectonic models and synthesis Evaluation of tectonic processes and tectonic stability at the site

Table 8.2-46. Major parameters provided by investigations in Preclosure Tectonics Program 8.3.1.17 (continued)

Section number	Investigation	Major parameters
	Preclosure tectonics (continued)	Tectonic models Tectonic disruption sequences

accident conditions, and to predict postclosure performance under both nominal (undisturbed) and disturbed conditions. The DOE will use these predictions as a part of the basis for selecting the first repository site according to the process described in 10 CFR Part 960. The repository designs and the performance assessment predictions will also serve as the basis for determinations of compliance with the NRC requirements for permanent disposal of high-level radioactive waste as specified in 10 CFR Part 60.

As shown in Figure 8.2-18, site investigation reports will document the completion of various site activities. These reports will continue to update and extend the data base available for use in repository design and performance assessment activities. When designs and calculations are sufficiently mature, a variety of topical reports, and finally, issue resolution reports will document the preliminary basis upon which the DOE will seek NRC's concurrence with various regulatory and technical requirements. Thus, by acquiring of the site data and other information necessary to support resolution of the performance and design issues, the DOE will systematically establish the information necessary to support demonstrations of compliance with the major technical and regulatory requirements.

An integrated system for monitoring and tracking progress toward issue resolution is under development. The technical basis derived from Section 8.3 provides the list of site activities planned to develop the data base for use in repository and waste package design and performance assessment calculations. Study plans for the site activities will describe the tests and experiments in more detail. Descriptions of repository and waste package design activities that do not require site data will be provided in other documents. These activities will also be monitored through the issue resolution tracking system. As site information and results of design analyses and activities become available, the baseline information will be updated. This process will continue until final designs have been developed and credible performance assessment predictions have been prepared on the basis of those designs. Resolution of those issues that address the DOE's siting guidelines (10 CFR Part 960) will occur when DOE makes a determination that the requirements of these guidelines have been met in support of the site-selection process. Resolution of those issues that address the NRC's

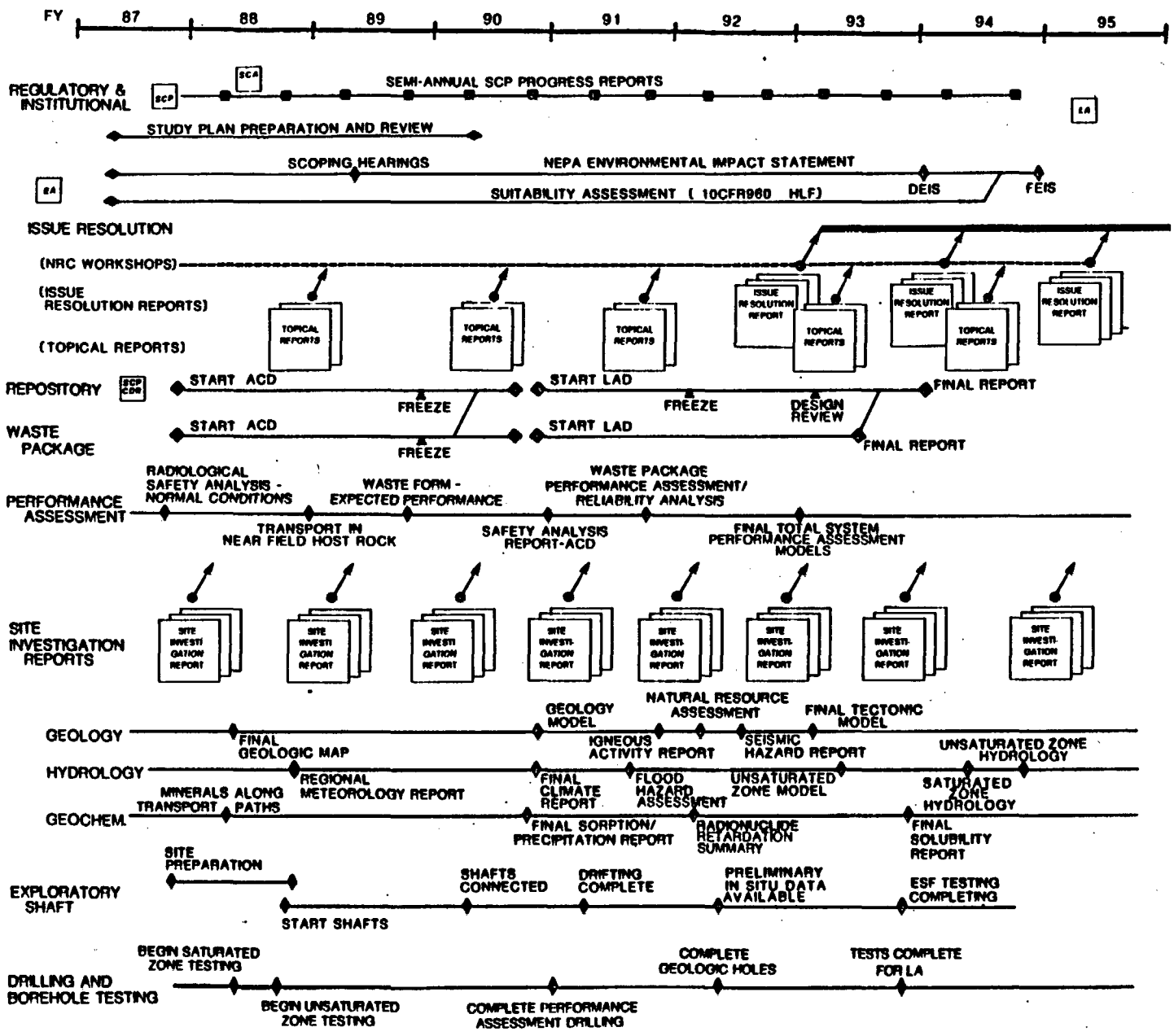

Figure 8.2-18. Schematic diagram showing utilization of site data by performance assessment and design, and finally for preparation of regulatory documents.

requirements for repository performance and issuance of construction authorization cannot occur until the NRC determines that there is reasonable assurance, at that time, that all requirements are likely to be met.