DOE/RW-0199

DOE/RW-0199

Nuclear Waste Policy Act
(Section 113)

Site Characterization Plan

Yucca Mountain Site, Nevada Research and Development Area, Nevada

Volume V, Part B

Chapter 8, Section 8.3.1.9, Human Interference

December 1988

U. S. Department of Energy
Office of Civilian Radioactive Waste Management

8.3.1.9 Overview of the human interference program: Description of potential future human activities at or near the site, required by performance and design issues

Summary of performance and design requirements for human interference information

The postclosure human interference test program addresses (1) the likelihood of inadvertent human intrusion into a mined geologic disposal system (MGDS), (2) interference with long-term MGDS performance due to human activities, and (3) the possible consequences of such interference events. The likelihood of these events must be very low, because the potential consequences of events of this nature may pose unacceptable risks to the public health.

The performance and design requirements for the human interference program directly reflect the regulatory requirements of the NRC, the EPA, and the DOE. These requirements, and their relationships to the human activities program can be summarized as follows:

1. Issue 1.1 (total system performance, Section 8.3.5.13) requires information that can help in estimating the probability of human intrusion and interference during the postclosure period. This will be accomplished through the development of release scenarios. The development of these scenarios will focus on relating potential specific human activities to the specific effects on the variables of the system important to waste isolation. Thus, the human interference program will focus on identifying those factors that can affect the probability of future inadvertent human interference (i.e., the presence of potential economic resources at the site, and the long-term survivability of the surface markers), and describing qualitatively and quantitatively the effects of specific human activities.

2. Issue 1.8 (NRC siting criteria, Section 8.3.5.17) addresses NRC regulations 10 CFR 60.21(c)(13), 60.122(a), 60.122(c)(2), and 60.122(c)(17) requiring that resources at the site with current markets be identified, and described in terms of net and gross values. Resources that occur in abundances that may be marketable in the future must also be identified and described in terms of physical factors such as tonnage (or other amount), grade, and quality. The evaluation of resources, including undiscovered resources, shall be conducted for the site in comparison to areas similar to the site that are representative of and are within a similar geologic setting. A complete assessment of the potential consequences of exploration activities (e.g., drilling) or resource extraction that could realistically influence the ability of the MGDS to isolate waste during the postclosure period, is required. This would include identification of human activities such as ground-water withdrawal and fluid waste injection.

3. Issue 1.9 (higher level findings - postclosure system and technical guidelines, Section 8.3.5.18) is the evaluation of the site against the qualifying and disqualifying conditions of the DOE siting

guidelines. For the site to be considered for selection as the first repository, it must be demonstrated that the site is located in an area such that natural resources at or near the site are not likely to give rise to interference activities. The presence of natural resources (whether known to be present or inferred to be present) could lead to exploration and exploitation activities by future generations that might affect long-term repository performance. Thus, information regarding the natural resource potential at and in the vicinity of the site will be obtained during the human activities program. The land ownership and mineral rights program (Program 8.3.1.11) addresses postclosure site ownership and control concerns, and discusses the only other qualifying conditions related to human interference.

4. Issue 4.4 (preclosure design and technical feasibility, Section 8.3.2.5) requires site-specific data for the design and placement of the permanent warning system. The warning system, which will consist of surface markers and monuments, will be placed along the boundary of the controlled area following repository closure and decommissioning. (The controlled area is the actual area chosen according to the 10 CFR 60.2 definition of controlled area.) Parameters relative to natural processes like erosion, deposition, ground motion, and burial by volcanic materials are required to identify the most suitable locations for the markers.

<u>Approach to satisfy performance and design requirements</u>

The consideration of inadvertent human intrusion or human interference events is based on several assumptions (10 CFR Part 60; 40 CFR Part 191, Appendix B). These assumptions, reproduced from the regulations, are as follows

> Processes and events initiated by human activities may only be found to be sufficiently credible to warrant consideration if it is assumed that (1) the monuments provided for by this part are sufficiently permanent to serve their intended purpose; (2) the value to future generations of potential resources within the site can be assessed adequately under the applicable provisions of this part; (3) an understanding of the nature of radioactivity, and an appreciation of its hazards, have been retained in some functioning institutions; (4) institutions are able to assess risk and to take remedial action at a level of social organization and technological competence equivalent to, or superior to, that which was applied in initiating the processes or events concerned; and (5) relevant records are preserved, and remain accessible, for several hundred years after permanent closure (10 CFR 60.2).
>
> The [U.S. Environmental Protection] Agency believes that the most productive consideration of inadvertent [human] intrusion concerns those realistic possibilities that may be usefully mitigated by repository design, site selection, or use of passive controls (although passive institutional controls should not be assumed to completely rule out the possibility

> of intrusion). Therefore, inadvertent and intermittent intrusion by exploratory drilling for resources (other than any provided by the disposal system itself) can be the most severe intrusion scenario assumed by the implementing agencies. Furthermore, the implementing agencies can assume that passive institutional controls or the intruders own exploratory procedures are adequate for the intruders to soon detect, or be warned of, the incompatibility of the area with their activities. (40 CFR Part 191, Appendix B.)

The approach to assessing future human activities at Yucca Mountain will be consistent with the previously presented assumptions. The program will follow the principle that highly speculative intrusion scenarios will not be included, and that only those factors and potentially adverse human activities that could directly affect waste isolation will be addressed.

Human interference presents special problems because of its dependence upon unpredictable future human activities. This anthropogenic factor makes defining the potential for radionuclide releases resulting from human activities, in quantitative or probabilistic terms, particularly difficult. For this reason, professional judgment may be required (Study 8.3.1.9.3.1) to determine the likelihood of future human intrusion or interference that could result from resource exploration or extraction.

The general approach to obtaining the required parameters from the human interference program is to identify the natural and anthropogenic parameters that are required by the design and performance issues. Table 8.3.1.9-1 lists the performance issue that requests data from this program, along with the performance and characterization parameters required by the issue.

The data requirements of Issue 1.1 primarily involve quantifying, in probabilistic terms, the site-specific factors that could contribute to unanticipated natural phenomena or anthropogenic events at or in the vicinity of Yucca Mountain. Design of the marker system (Issue 4.4) requires site-specific data to ensure strategic placement of the monuments in locations having low risk associated with the consequences of natural phenomena or human activities. Archaeological studies of ancient monuments and structures (Kaplan, 1982; Berry et al., 1984) have been used to address identifiable and potentially disruptive and destructive anthropogenic factors that could affect marker survivability. The remaining parameters, the consequences of natural phenomena, will be obtained through other site activities and evaluated in Study 8.3.1.9.1.1 as listed in Table 8.3.1.9-1.

Current information and new data acquired from site activities will be employed to assess the natural resource potential of Yucca Mountain (Investigation 8.3.1.9.2). These data will be used to describe qualitatively the various categories of potential human interference and intrusion scenarios (Study 8.3.1.9.3.2). For example, the possible presence of four natural resources (i.e., mineral, geothermal, hydrocarbon, and ground-water resources) would require that at least one category of initiating events (exploratory drilling) must be evaluated. After examining the potential for

Table 8.3.1.9-1. Initiating events, associated performance parameters, and activity parameters for the human interference program (page 1 of 7)

Issue requesting parameter	SCP section	Initiating event	Performance parameter	Activity parameter	SCP section
1.1 Total system releases	8.3.5.13	Exploratory drilling intercepts a waste package and brings up waste with core or cuttings	Presence and readability of C-area[a] markers over 10,000 yr (long-term survivability of markers)	Rates of Erosion Weathering Deposition Igneous activity Seismic activity at marker locations	8.3.1.9.1
			Expected drilling rate (no. of boreholes/km^2/yr) in R-area[b] over the next 10,000 yr	Quantities, tonnages, and grades of known or inferred resources at Yucca Mountain	8.3.1.9.2.1
			Distribution of diameters of exploratory drilling	Types of known or inferred resources at Yucca Mountain	8.3.1.9.2 and 8.3.1.9.3
			Distribution of depths of exploratory drilling	Types of known or inferred resources at Yucca Mountain	8.3.1.9.2 and 8.3.1.9.3
		Extensive ground-water withdrawal occurs near C-area	Expected magnitude of change in water-table level in the C-area due to extensive ground-water withdrawal in next 10,000 yr	Quantity, rates, well locations, and hydrostratigraphic unit sources of ground-water withdrawals	8.3.1.9.2.2 and 8.3.1.16.2.1

Table 8.3.1.9-1. Initiating events, associated performance parameters, and activity parameters for the human interference program (page 2 of 7)

Issue requesting parameter	SCP section	Initiating event	Performance parameter	Activity parameter	SCP section
1.1 Total system releases (continued)	8.3.5.13 (continued)		Expected magnitude in changes in gradient of water table under C-area due to ground-water withdrawal near C-area in next 10,000 yr	Quantity, rates, well locations, and hydrostratigraphic source of ground-water withdrawals	8.3.1.9.2.2 and 8.3.1.16.2.1
			Presence and readability of C-area markers over 10,000 yr	See the activity parameter for the exploratory drillers intercept under the initiating event column of this table	8.3.1.9.1.1
		Extensive surface or subsurface mining occurs near the C-area	Expected magnitude of change in water-table level due to mine-water use or mine dewatering near C-area over next 10,000 yr	Estimated depth of mine, cross-sectional area of mines or shafts	8.3.1.9.3.2

Table 8.3.1.9-1. Initiating events, associated performance parameters, and activity parameters for the human interference program (page 3 of 7)

Issue requesting parameter	SCP section	Initiating event	Performance parameter	Activity parameter	SCP section
1.1 Total system releases (continued)	8.3.5.13 (continued)		Expected magnitude of change in gradient under C-area due to mine-water usage or mine dewatering	Estimated water usage based on quantity of water-available, depth of mine	8.3.1.9.3.2
			Expected magnitude of changes in distribution coefficient (K_ds) of unsaturated zone (UZ) and saturated zone (SZ) due to mining activities near the C-area	No changes expected	8.3.1.9.3.2
			Presence and readability of C-area markers over next 10,000 yr	See the activity parameter for the exploratory drillers intercept under the initiating event column of this table	8.3.1.9.1.1

Table 8.3.1.9-1. Initiating events, associated performance parameters, and activity parameters for the human interference program (page 4 of 7)

Issue requesting parameter	SCP section	Initiating event	Performance parameter	Activity parameter	SCP section
1.1 Total system releases (continued)	8.3.5.13 (continued)	Large-scale surface-water impoundments are constructed near the C-area	Expected magnitude of change in water-table level due to presence of artificial lake near C-area	Area, depth, volume of surface-water impoundment; seepage rates, percolation rates and transmissivity of near-surface and subsurface materials	8.3.1.9.3.2
			Expected magnitude of changes in K_ds for UZ and SZ units due to presence of an artificial lake near C-area	No changes expected	
			Expected magnitude of changes in head gradients of the SZ in C-area due to the presence of an artificial lake near C-area	Area, depth, volume of surface-water impoundments	8.3.1.9.3.2

Table 8.3.1.9-1. Initiating events, associated performance parameters, and activity parameters for the human interference program (page 5 of 7)

Issue requesting parameter	SCP section	Initiating event	Performance parameter	Activity parameter	SCP section
1.1 Total system releases (continued)	8.3.5.13 (continued)		Expected magnitude of flux change due to presence of an artificial lake near the C-area in next 10,000 yr	Area, depth, and volume of surface water impoundment; seepage rates, percolation rates, and transmissivity of near-surface and subsurface materials	8.3.1.9.3.2
			Presence and readability of C-area markers over 10,000 yr	See the activity parameter for the exploratory drilling intercept under the initiating event column of this table	8.3.1.9.1.1
		Extensive irrigation is conducted near the C-area	Expected magnitude of change in altitude of water-table under C-area due to extensive irrigation near C-area over next 10,000 yr	Area of irrigation, crop cultivation, quantity of water used for irrigation based on quantity of water available	8.3.1.9.3.2

Table 8.3.1.9-1. Initiating events, associated performance parameters, and activity parameters for the human interference program (page 6 of 7)

Issue requesting parameter	SCP section	Initiating event	Performance parameter	Activity parameter	SCP section
1.1 Total system releases (continued)	8.3.5.13 (continued)		Expected magnitude of flux change due to extensive irrigation near the C-area over next 10,000 yr	Area of irrigation, crop cultivation, quantity of water applied, infiltration, and percolation rate	
			Expected magnitude of change in read gradients below C-area due to extensive irrigation over next 10,000 yr	Quantity of irrigation withdrawals	8.3.1.9.3.2
			Expected magnitude of changes in K_ds of UZ and SZ	No change expected	8.3.1.9.3.2
			Presence and readability of surface markers over 10,000 yr	See the activity parameter for the exploratory drilling intercept under the initiating event column of this table	8.3.1.9.1.1

Table 8.3.1.9-1. Initiating events, associated performance parameters, and activity parameters for the human interference program (page 7 of 7)

Issue requesting parameter	SCP section	Initiating event	Performance parameter	Activity parameter	SCP section
4.4 Technical feasibility	8.3.2.5	NA[c]	Surface markers located in geomorphically stable locations	Rates of deposition, igneous activity and seismic activity near C-area boundary	

[a]C-area = controlled area (i.e., the actual area chosen according to the 40 CFR 191.12 definition of controlled area).
[b]R-area = restricted area (i.e., the projection of the primary area and extensions onto the surface).
[c]NA = not applicable).

each resource, the probability of occurrence for each type of human intrusion scenario in the exploratory drilling category will be estimated. This will require the use of professional and expert opinion (Study 8.3.1.9.3.1). The probabilities obtained from this exercise will be provided to Issue 1.1 (total system performance, Section 8.3.5.13), and will be used as input parameters in predicting potential radionuclide releases to the accessible environment.

The final information that will be obtained from the human activities program is an evaluation of the potential effects that could result from resource extraction. These data will be gathered under Investigation 8.3.1.9.3. Presently, only the effects of ground-water withdrawal on the hydrologic system will be evaluated because ground water is the only commodity currently identified as a resource. If other potentially marketable resources are identified during site characterization, plans will be developed to examine the effects of their extraction on the hydrologic, geochemical, and rock characteristics.

Interrelationships of human interference investigations

The first investigation (8.3.1.9.1) identified for this program determines all factors, both natural and anthropogenic, that could destroy or degrade the surface markers and monuments. Because the 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 (Investigation 8.3.1.8.2); the rates, magnitudes, and locations of potential igneous activity (Investigation 8.3.1.8.1); and the potential effects of tectonic activity and future climatic conditions on locations and rates of erosion and deposition (Investigations 8.3.1.6.3 and 8.3.1.6.2, respectively) will aid in determining the best locations for the surface markers and monuments.

The second investigation (8.3.1.9.2) requires the identification of all resources at the site with current markets and an estimate of their gross and net value. Resources without current markets, but which are potentially marketable in the future, will be described in terms of such physical factors as tonnage (or other amount), grade, and quality. The evaluation of resources, including undiscovered resources, shall be conducted for the site in comparison to areas of similar size that are representative of and are within the geologic setting. The present assessment of commodities as presented in Chapter 1, Section 1.7 and reviewed in Section 1.8.1.7, classifies most commodities as "occurrences" and some as "undiscovered, speculative resources of subeconomic grade," using the USBM/USGS (1980) classification system. If identified resources and reserves are defined, 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 to be classified as a resource in the immediate vicinity of the site. Exploitation of this resource is expected to become economically feasible in the near future (DOE, 1985). Study 8.3.1.9.2.2 will integrate existing scientific and institutional data with information obtained during characterization of the saturated zone (Investigation 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 (Table 8.3.1.9-1) will be considered in calculating the probability for human interference (Study 8.3.1.9.3.1) and in assessing the potential effects of ground-water exploitation on the conditions at the site (Study 8.3.1.9.3.2).

The final investigation (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 the specific resources determined in Investigation 8.3.1.9.2, the conditions at the site and 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 characteristics of the site such that repository performance would be affected. Professional judgment will then be used to define the interdependence between natural resources at the site and the potential for human intrusion as a result of exploratory drilling (Study 8.3.1.9.3).

The second part of Investigation 8.3.1.9.3 will focus on the initiating events of the release scenarios (Table 8.3.1.9-1) that relate to human interference, and their potential effects on long-term repository performance. The parameters defined for this investigation are (1) 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 (e.g., large-scale surface-water impoundment above the repository zone) and (2) those potential consequences of initiating events that are not expected to significantly affect long-term repository performance. 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.

The information needed from the human interference program for the performance and design issues will be obtained from these three investigations. Table 8.3.1.9-2 lists the studies and activities that will be undertaken to obtain the required performance and design data. Figure 8.3.1.9-1 illustrates the relationships between the three investigations making up the human interference program and other issues that require input from this program.

The schedule information for Site Program 8.3.1.9 (human interference) is presented in Section 8.3.1.9.4.

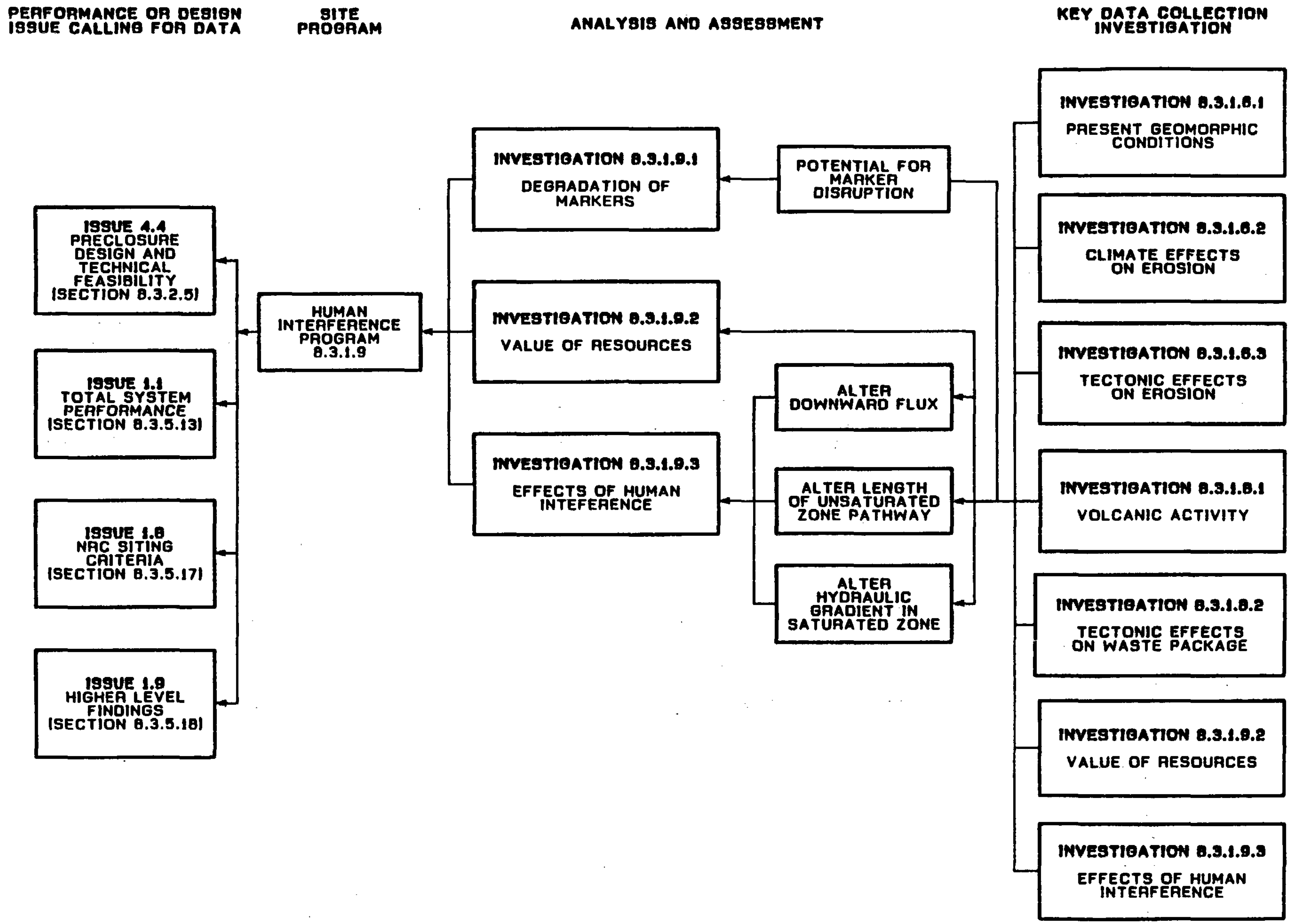

Figure 8.3.1.9-1. General logic diagram for the Human Interference Program.

Table 8.3.1.9-2. Studies and activities making up the human interference program

Study	Activity	Description
8.3.1.9.1.1		An evaluation of natural processes that could affect the long-term survivability of the surface marker system at Yucca Mountain
	8.3.1.9.1.1.1	Synthesis of tectonic, seismic, and volcanic hazards data from other site characterization activities
	8.3.1.9.1.1.2	Synthesis--evaluation of the effects of future erosion and deposition on the survivability of the marker system at Yucca Mountain
8.3.1.9.2.1		Natural resource assessment of Yucca Mountain, Nye County, Nevada
	8.3.1.9.2.1.1	Geochemical assessment of Yucca Mountain in relation to the potential for mineralization
	8.3.1.9.2.1.2	Geophysical/geologic appraisal of the site relative to mineral resources
	8.3.1.9.2.1.3	Assessment of the potential for geothermal energy at and in the vicinity of Yucca Mountain, Nevada
	8.3.1.9.2.1.4	Assessment of hydrocarbon resources at and near the site
	8.3.1.9.2.1.5	Mineral and energy assessment of the site, comparison to known mineralized areas, and the potential for undiscovered resources and future exploration
8.3.1.9.2.2		Water resource assessment of Yucca Mountain, Nevada
	8.3.1.9.2.2.1	Projected trends in local and regional ground-water development, and estimated withdrawal rates in southern Nevada, proximal to Yucca Mountain
8.3.1.9.3.1		Compilation of data needed to support an assessment of the likelihood of inadvertent human intrusion at Yucca Mountain as a result of exploration and/or extraction of natural resources

Table 8.3.1.9-2. Studies and activities making up the human activities program (continued)

Study	Activity	Description
	8.3.1.9.3.1.1	Compilation of data to support the assessment calculation of the potential for inadvertent human intrusion at Yucca Mountain
8.3.1.9.3.2		An evaluation of the potential effects of exploration for, or extraction of natural resources on the hydrologic characteristics at Yucca Mountain
	8.3.1.9.3.2.1	An analysis of the potential effects of future ground-water withdrawals on the hydrologic system in the vicinity of Yucca Mountain, Nevada
	8.3.1.9.3.2.2	Assessment of initiating events related to human interference that are considered not to be sufficiently credible or significant to warrant further investigation

8.3.1.9.1 Investigation: Studies to provide the information required on natural phenomena and human activities that might degrade surface markers and monuments

Technical basis for obtaining the information

Link to the technical data chapters and applicable support documents

Pursuant to the regulations of the EPA (40 CFR 191.14(c)) and the NRC (10 CFR 60.21(c) and 60.51(a)), a warning system composed of surface markers and monuments will be placed at the site as a means of informing future generations of the risks associated with the repository and its contents. Human activities and many natural phenomena that could contribute to the degradation, destruction, or disruption of the marker system have been evaluated and presented in Kaplan (1982) and Berry et al. (1984). These factors have been considered and are being used as criteria in the final marker design. There are some site-specific natural processes and their consequences that require further consideration because of their potential to degrade, disrupt, or destroy the marker system. These processes are (1) potentially destructive fault displacement or seismically induced ground motion, (2) potentially destructive volcanic events or volcanic burial due to hydrovolcanic eruptions, and (3) increased erosion or deposition rates resulting from tectonic activity or climatic change. The current knowledge of these processes and their potential consequences as presented in Chapters 1, 3, and 5 of this document is not adequate to thoroughly assess the potential associated risks to the surface markers and monuments.

Parameters

Three parameters will be evaluated to resolve this portion of the investigation:

1. Potential fault movement and ground motion at the site from man-made natural seismic events (Investigation 8.3.1.8.2).

2. The rates and magnitudes of potential igneous activity that could affect the site (Investigation 8.3.1.8.1).

3. The potential effects of tectonic activity and future climatic conditions on locations and rates of erosion and deposition (Investigations 8.3.1.6.2, 8.3.1.6.3, and 8.3.1.5.1).

Purpose and objectives of the investigation

The purpose of Investigation 8.3.1.9.1 is to obtain the site-specific information on the occurrence and consequences of natural phenomena needed to satisfy the parameter requests of the performance and design issues. The objective of the investigation is to compile and evaluate these data so that they can provide information directly to the performance and design issues.

The information needed to satisfy Issue 1.1 is an estimate of the long-term survivability of the warning system. Data on the consequences of natural phenomena such as erosion, deposition, volcanic activity, and strong ground motion are needed to assess the possible damage to the warning system that might occur during the 10,000-yr postclosure period. The probability of inadvertent human intrusion and interference will be influenced by the effectiveness of the marker system to warn intruders of the potential hazards of the mined geologic disposal system (MGDS). Thus, bounds on the probability that the markers will be effective over the 10,000-yr postclosure period will provide input to the total system releases calculation.

Similar information is required by Issue 4.4 (preclosure design and technical feasibility) to supplement the general warning system design developed by the Office of Nuclear Waste Isolation (Kaplan, 1982). Geologic information gathered to assess the potential hazards associated with natural phenomena in the vicinity of the controlled area boundary will aid in determining the most suitable locations for the markers.

Investigation 8.3.1.9.1 ensures that the risks associated with natural phenomena are incorporated into the final design of the warning system. Figure 8.3.1.9-2 shows the flow of data for this investigation. By maximizing the effectiveness of the passive institutional controls, the likelihood that future generations will inadvertently affect the performance of the MGDS can be reduced.

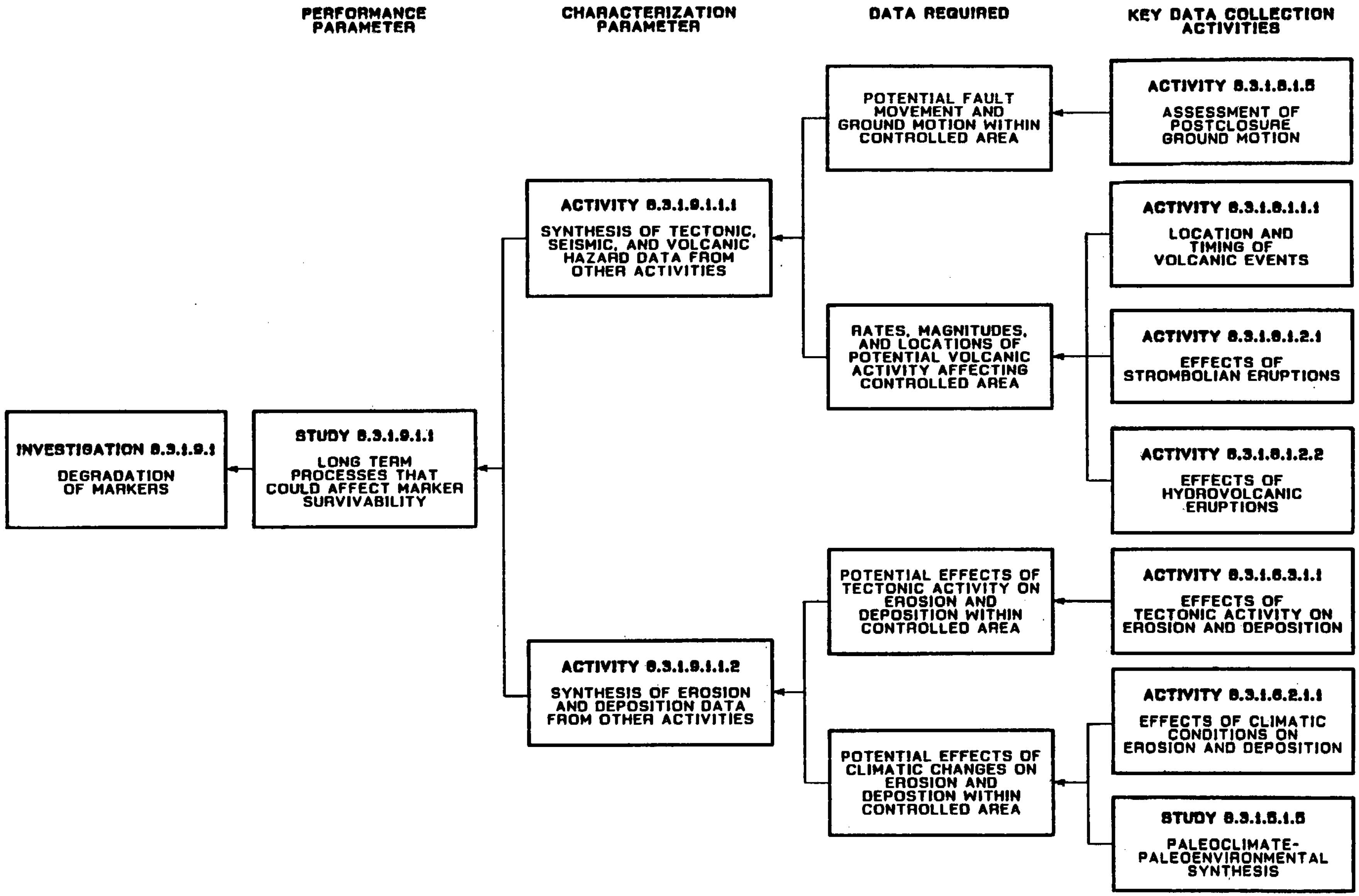

Figure 8.3.1.9-2. Logic diagram for Investigation 8.3.1.9.1.

Technical rationale for the investigation

Fault movement and ground motion at the site, whether from man-made or natural seismic events, could dislocate and damage large monuments and surface markers. Information regarding fault locations and the magnitudes of potential ground motions associated with fault rupture will aid in the placement and design of the surface marker system. Strategic placement of the markers will reduce the risk of their degradation or destruction.

Volcanic events could potentially degrade, cover, or destroy surface markers and monuments by dislocation, burial or incorporation into extruded volcanic material. Knowledge of the locations, rates, and magnitudes of potential volcanic events will aid in the placement of the markers and monuments, thereby reducing the associated risks.

Tectonic activity such as uplift or subsidence can increase erosion and deposition rates by changing the local or regional base level. Future climatic changes could potentially affect the locations and rates at which erosion and deposition occur. Erosion along the foundations of the markers could undermine their stability and result in dislocation. Deposition could result in rapid burial of the markers. Information regarding the locations and rates of potential erosion and deposition, which could contribute to marker dislocation or disruption, is needed to determine the most strategic placement of the markers and monuments.

Data that are required to satisfy the design and performance issues will be derived from studies done as part of Investigations 8.3.1.5.1, 8.3.1.6.2, 8.3.1.6.3, 8.3.1.8.1, and 8.3.1.8.2. The results obtained from these studies will be compiled and evaluated to determine the optimum locations for the surface markers.

8.3.1.9.1.1 Study: An evaluation of natural processes that could affect the long-term survivability of the surface marker system at Yucca Mountain

This study provides information on the currently or potentially active natural processes at Yucca Mountain capable of adversely affecting the long-term survivability of the surface marker system. This study will be a synthesis of data obtained from other activities to be undertaken in support of several investigations. The data will then be evaluated to determine the most suitable locations of the monuments for the surface marker system. Input for this study will be provided by Investigations 8.3.1.6.2, 8.3.1.6.3, 8.3.1.8.1, and 8.3.1.8.2. Detailed activity descriptions can be found under the appropriate investigation discussions.

8.3.1.9.1.1.1 Activity: Synthesis of tectonic, seismic, and volcanic hazards data from other site characterization activities

Objectives

The objective of this activity is to identify the potential locations of faulting and volcanic eruption or intrusion that could occur where they could affect the marker system.

Parameters

The parameters required for this activity will be derived from descriptions of the seismic, volcanic, and tectonic processes in the vicinity of the site and their associated physical consequences. These data will be taken from Studies 8.3.1.8.1.2 and 8.3.1.8.2.1.

Description

This activity will integrate all applicable data involving faulting, folding, uplift and subsidence, and volcanism. Each segment of the controlled area boundary will be examined in light of this information to determine the locations that have the lowest associated risk. The range of geologic consequences, as they might adversely affect the long-term survivability of the surface markers and monuments, will be described.

Methods and technical procedures

The methods and technical procedures for this activity are to be developed.

8.3.1.9.1.1.2 Activity: Synthesis: evaluation of the effects of future erosion and deposition on the survivability of the marker system at Yucca Mountain

Objectives

The objective of this activity is to determine the effects of future erosion and deposition on the topographic elements of the controlled area boundary at Yucca Mountain. This information will be evaluated to identify the optimum locations for the markers.

Parameters

The locations of potential future erosion surfaces identified in Activities 8.3.1.6.1.1.1 and 8.3.1.6.2.1.1 will be used as the input parameters for this activity.

Description

This synthesis activity will be aimed at identifying the locations along the controlled area boundary expected to have low rates of erosion and deposition during the postclosure period. Using this information in conjunction with results from volcanic and fault hazard analyses (Investigation 8.3.1.8.1) the tentative marker locations will be chosen.

Methods and technical procedures

The methods and technical procedures for this activity are to be developed.

8.3.1.9.1.2 Application of results

The data obtained from this study will be used to determine the most suitable locations for the surface markers and monuments. The strategic placement of the surface markers and monuments at locations unlikely to experience physical disruptions as a result of natural processes will contribute to the long-term stability of the warning system. The final locations chosen for the surface markers will be identified and evaluated in a milestone report. This report will provide input regarding marker survivability to Issue 1.1 (total system performance), which will be used in assessing the human interference scenarios.

8.3.1.9.2 Investigation: Studies to provide the information required on present and future value of energy, mineral, land, and ground-water resources

Technical basis for obtaining the information

Link to the technical data chapters and applicable support documents

A preliminary assessment of the natural resource potential at Yucca Mountain (energy, mineral, ground water, and land), based on published literature, was presented in the Yucca Mountain environmental assessment (DOE, 1986b). Sections 1.7 and 1.8.1.7 (summary) of the SCP provide additional information and an evaluation of the mineral and energy resources for the site. Section 3.8 of the SCP contains a preliminary assessment of the ground-water resources in the relevant geohydraulic basins at and in the vicinity of Yucca Mountain. Land resources have been evaluated in Sections 3.4 and 6.2 of the Yucca Mountain environmental assessment (DOE, 1986b).

Parameters

Several groups of parameters must be evaluated to determine all the factors that must be considered when assessing the future value of potential resources at Yucca Mountain. These groups of parameters include the following:

1. The assessment for the occurrences of economically attractive deposits of precious metals, base metals, strategic metals, industrial minerals, or other commodities, and energy resources including hydrocarbon or geothermal resources.

2. The projected value and future development of local ground-water resources.

Purpose and objectives of the investigation

The natural resource potential of a candidate site for an mined geologic disposal system is an important consideration in evaluating the likelihood for inadvertent human intrusion and interference. The presence of natural resources or an environment that is favorable for the occurrence of natural resources could lead to prospecting exploration within or near the controlled area, and possible subsequent resource exploitation. The exploration or extraction of resources could result in direct releases of radionuclides to the accessible environment or could modify the hydrologic, geochemical, and rock characteristics at the site (Investigation 8.3.1.9.3) by possibly shortening travel paths to the accessible environment. Thus, a complete evaluation of the natural resource potential of the Yucca Mountain site is essential in determining the likelihood for inadvertent human intrusion and interference.

Technical rationale for the investigation

The potential occurrence of precious- and base-metal deposits, other metallic or nonmetallic deposits, and ground-water, geothermal, or hydrocarbon resources at Yucca Mountain will play an important role in determining the likelihood for future exploratory drilling within the boundaries of the controlled area. This knowledge will provide the basis for Investigation 8.3.1.9.2 as outlined in Figure 8.3.1.9-3, and additionally will provide input to Investigation 8.3.1.9.3 by identifying those resources that may attract exploration or may potentially be exploited, and thus could affect the long-term waste isolation ability of the Yucca Mountain site. Figure 8.3.1.9-3 shows the flow of data for this investigation.

To assess the potential for resource exploration or exploitation over the next 10,000 yr, it will be necessary to identify all resources at or near the site with current markets and provide an estimate of their gross and net values. Resources without current markets, but which could potentially be marketable in the future, will be described in terms of physical factors such as tonnage (or other amount), grade, and quality. The discussion of commodities, as presented in Section 1.7 and reviewed in Section 1.8.1.7, classifies most commodities as "other occurrences" and some as "undiscovered, speculative resources of subeconomic grade," using the USBM/USGS (1980) classification system. It is extremely unlikely that drilling or mining will occur in the area unless commodities that are presently valued or may be valued in the future are found in amounts that greatly exceed the average crustal abundance (Section 1.7). Identified resources and reserves 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.

The relative value of the ground-water resources that are located proximal to the site is known to be low at the present time. The depth to these resources, and the distances over which transport would be required, currently preclude economic exploitation (Sinnock and Fernandez, 1982). Through time, these economic conditions may change, and ground-water

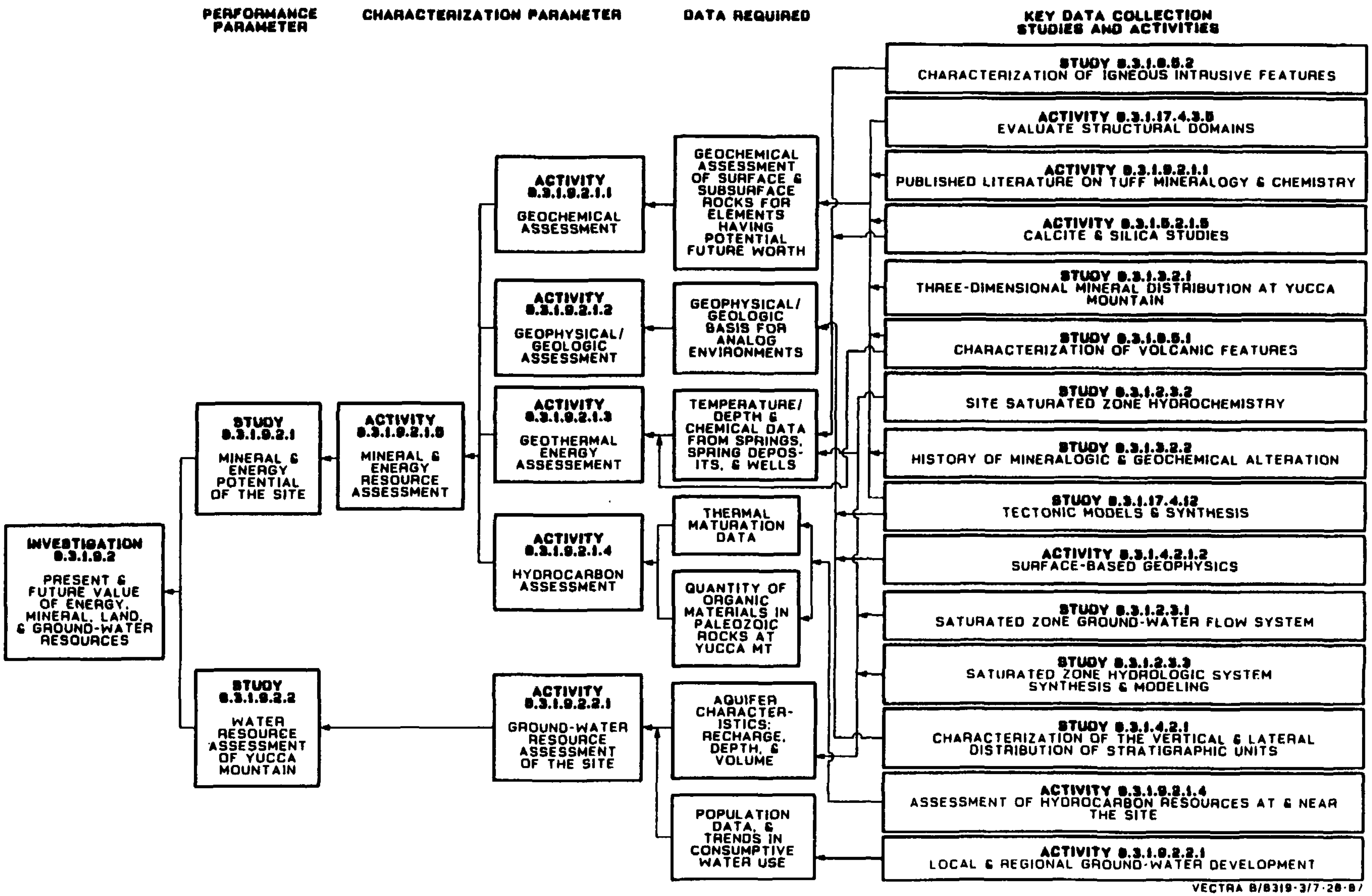

Figure 8.3.1.9-3. Logic diagram for Investigation 8.3.1.9.2.

development and exploitation may occur as a result. As discussed in the previous section, ground-water development and exploitation proximal to the site could affect the geohydrologic system. Such effects must be evaluated in Investigation 8.3.1.9.3. The projections of the probable future withdrawal rates that will be obtained from activities conducted in support of this investigation will be used as an input parameter for Investigation 8.3.1.9.3.

Sections 3.4 and 6.2 of the environmental assessment for Yucca Mountain (DOE, 1986b) suggest that the use of the land surface as a resource is highly unlikely for the following reasons:

1. The sparse vegetation within the boundaries of the controlled area has historically precluded this land from being used for grazing purposes. Other, better-suited areas are available nearby and throughout southern Nevada that would likely be preferred in the future.

2. Community settlement historically has occurred within valleys where water resources are more accessible. Yucca Mountain and the surrounding controlled area are physiographically poorly suited for community development because of the rough terrain, the absence of surface water, and the great depth to ground water.

3. There is low potential for agricultural development within the boundaries of the controlled area because of the poorly developed soils, the lack of surface water, the depth to ground water, and the variable topographic relief.

The scarcity of vegetation, wildlife, and water has historically precluded using the land within the controlled area for recreational purposes. Thus, based on the historical use of this land, there is little chance that it will ever be considered suitable for recreational use. Information will be used from climate prediction studies (Section 8.3.1.5.1.6) to assess the value of the land within the proposed controlled area. A topical report will be prepared that addresses present and future land use in the Yucca Mountain area. This topical report will be prepared in response to the human interference program, the Yucca Mountain Project environmental program planning efforts, and the environmental impact statement process, as required for the repository construction and operation phases of the Project.

The probability that natural resources occur at the Yucca Mountain site is a required input parameter for evaluating the probability that future exploratory drilling will occur. This probability will be evaluated by an expert panel and incorporated into a subjective probability that describes the likelihood of future exploratory drilling (Study 8.3.1.9.3.1).

Two studies are planned to address Investigation 8.3.1.9.2. The studies consist of activities designed to obtain data from the existing literature and from site characterization. Through these activities, an evaluation will be made of (1) the geochemical characteristics of the site (Activity 8.3.1.9.2.1.1), (2) the geophysical-geologic characteristics of the site (Activity 8.3.1.9.2.1.2), (3) the potential for future occurrences of geothermal resources in the vicinity of Yucca Mountain (Activity 8.3.1.9.2.1.3), (4) the potential for hydrocarbon resources at the site (Activity 8.3.1.9.2.1.4) and water resources (Activity 8.3.1.9.2.2.1) at the site, and (5) a summary assessment of the mineral and energy potential (Activity 8.3.1.9.2.1.5) and water-resource potential (Study 8.3.1.9.2.2) of the site.

Alternative Conceptual Models

As discussed in the Overview of the site characterization program (Section 8.3.1.1), hypothesis-testing tables have been constructed where appropriate to summarize (1) the current hypotheses regarding how the site can be modeled and how modeling parameters can be estimated; (2) the uncertainty associated with this current understanding, including alternative hypotheses that are also consistent with available data and which may compose an alternative conceptual model; (3) the significance of alternative hypotheses; and (4) the activities or studies designed to discriminate between alternative hypotheses or to reduce uncertainty. A hypothesis-testing table (8.3.1.9-3) for mineral and energy resources has been constructed since alternative models may be important in evaluating the present and future value of such resources.

Integration of information from different disciplines is often necessary to comprehensively evaluate alternative hypotheses. Accordingly, the hypothesis-testing tables for each site program call for information from studies and activities in other programs, as appropriate.

The hypotheses considered in Table 8.3.1.9-3 have been categorized as elements that pertain to the driving forces processes that are defined by the model. These elements are listed in column one.

The second column of the table lists the current representations for each model element in the form of hypotheses that are based on currently available data.

The third column in Table 8.3.1.9-3 provides a judged level of uncertainty designated "high," "moderate," or "low" associated with the current representation for each element. A brief rationale for the judgment is also given.

The fourth column describes alternative hypotheses to the current representation that are consistent with currently available data. As site characterization proceeds and more information becomes available, alternative hypotheses may be deleted or added or the current hypothesis may be revised and refined.

The fifth column indicates the performance measure or performance parameter that could be affected by the selection of hypotheses related to that element.

Column six gives the needed confidence in the indicated performance measure or performance parameter, as defined in the performance allocation tables.

Table 8.3.1.9-3. Current representation and alternative hypotheses for mineral and resource models for the human interference program (page 1 of 2)

Current representation: Model element	Current representation: Current representation	Uncertainty and rationale	Alternative hypothesis	Significance of alternative hypothesis: Performance measure, design or performance parameter	Significance of alternative hypothesis: Needed confidence in parameter or performance measure	Significance of alternative hypothesis: Sensitivity of parameter or performance measure to hypothesis	Significance of alternative hypothesis: Need to reduce uncertainty	Studies or activities to reduce uncertainty
				DRIVING FORCES/PROCESSES				
Ore-forming processes	Significant ore-forming processes have not occurred; no mineral resources exist at the site	Medium--some mineral resources have yet to be evaluated (e.g., Hg, Ag) or limited information is presently available (e.g., Au). Geochemical evaluation of surface and subsurface will be relied upon heavily for assessment of the present-day value of resources and for a comparison to analogs	Ore-bearing fluids derived from deep sources Ore-bearing fluids derived from lateral flow or surface flux Igneous fractionation processes produce ore or ore-bearing fluids	Types of known or inferred resources at Yucca Mountain	High	Medium--no gross features of mineralization have been observed at the surface or in drillholes, but geochemistry, petrography, etc., are yet to be done; evaluation of faults, rock alterations, etc., need to be assessed. Models for resource emplacement need to be fully evaluated; remotely possible that resources could exist within undrilled parts of domain, west of site	High	8.3.1.9.2.1.1, 8.3.1.9.2.1.2, 8.3.1.9.2.1.5, and drilling of new holes (e.g., USW G-5, USW G-6, and UE25 G-7). (Integrated Drilling Plan)
Hydrocarbon-forming processes	Significant hydrocarbon-forming processes have not occurred; no oil or gas resources exist at the site	Low--no oil or gas has been reported from the many drillholes emplaced in the tuff; potential source rocks have not been identified in the region from outcrop and subsurface information	Potential source rocks exist, thermal maturation history is favorable, and favorable reservior rocks exist	Same as above	Medium--risk for waste isolation is only from the potential for drilling	Low to medium--regional geology (oil and gas occurrences and regional stratigraphy) do not favor resource potential; thermal gradient was too high at the north end of the site; CAI[a] index from Paleozoics south of site is still in thermal range appropriate for gas generation	Medium	8.3.1.9.2.1.4, 8.3.1.9.2.1.2, 8.3.1.9.2.1.5

Table 8.3.1.9-3. Current representation and alternative hypotheses for mineral and resource models for the human interference program (page 2 of 2)

Current representation		Uncertainty and rationale	Alternative hypothesis	Significance of alternative hypothesis				Studies or activities to reduce uncertainty
Model element	Current representation			Performance measure, design or performance parameter	Needed confidence in parameter or performance measure	Sensitivity of parameter or performance measure to hypothesis	Need to reduce uncertainty	
			DRIVING FORCES/PROCESSES (continued)					
Tectonic/hydrologic processes	A low-temperature (<90°C) geothermal resource is present at the site, as is common to all of Nevada; no higher temperature resources are expected	Low--large thermal systems only can maturate slowly; small dikes, intrusions, or eruptions have limited thermal energy and, thus, would have to intrude the site to have an effect on resource extraction that could affect waste isolation; thermal waters and heat flow at site are low	Geothermal resources as a result of deep basin circulation or hot dry rock Geothermal resources as a result of igneous activity	Same as above	Low	Low--present-day temperatures and heat flow are low; depth to water table limits economic use of resources; 12 km from site a single well has heat flow of 3.1 HFU; rest of region has heat flow near or below Nevada average	Low	8.3.1.9.2.1.3, 8.3.1.9.2.1.2, 8.3.1.9.2.1.5, 8.3.1.8.5.2.3

*CAI = color alteration index.

The seventh column presents a judgment of the sensitivity of the performance parameters in column five to the selection of hypotheses in columns two and four for that element. The sensitivity is rated high if significant changes in the values of the performance parameter might occur if an alternate hypothesis were found to be the valid hypothesis for the system.

The eighth column presents a judgment on the need to reduce uncertainty in the selection of hypotheses. This judgment is based on the uncertainty in the current representation, the sensitivity of the performance parameters to alternative hypotheses, the significance and needed confidence of affected performance parameters, and the likelihood that feasible data-gathering activities could significantly reduce uncertainty.

The final column identifies the characterization studies or activities that will discriminate between alternative hypotheses or that will reduce uncertainties associated with the current representation for each model element.

8.3.1.9.2.1 Study: Natural resource assessment of Yucca Mountain, Nye County, Nevada

This study will identify and assess the natural resource potential at the proposed repository site at Yucca Mountain. Mineral and energy resources (including hydrocarbon and geothermal resources) will be included. Water resources will be evaluated under Study 8.3.1.9.2.2. The study includes a geochemical assessment of Yucca Mountain in relation to the potential for mineralization (Activity 8.3.1.9.2.1.1), a geophysical-geologic appraisal of the site relative to mineral resources (Activity 8.3.1.9.2.1.2), an assessment of the potential geothermal energy at and in the vicinity of Yucca Mountain (Activity 8.3.1.9.2.1.3), an assessment of the hydrocarbon resources of the site (Activity 8.3.1.9.2.1.4), and a mineral and energy assessment of the site, comparison to known mineralized areas, and the potential for undiscovered resources and future exploration (Activity 8.3.1.9.2.1.5). The information and data obtained in this study will provide the basis for probabilistic calculations for determining inadvertent human interference and intrusion (Study 8.3.1.9.3.1).

The consideration of the mineral, hydrocarbon, and geothermal resource potential at Yucca Mountain will not necessarily be limited to the silicic volcanic tuffs that host the proposed repository site. Various models of mineral resource genesis characteristic of the region will be considered, as required in 10 CFR Part 60. In addition, general models of resource occurrence available in the literature will also be considered. For example, the assessment of economic potential will include an evaluation of possible mineralization derived from deep or laterally adjacent hydrothermal systems, as well as systems centered in the site area. In addition, the potential for placer and other types of mineralization found in the Tertiary to Quaternary alluvial deposits will be specifically addressed. The evaluation of oil and gas resource potential will consider potential source rocks that may exist, the thermal maturation of the possible source rocks identified, the presence of reservoir rocks, and the potential for structural or stratigraphic traps. Several types of geothermal resources will be evaluated, including thermal water reservoirs resulting from (1) deep basin circulation, (2) hot-dry rock, or (3) igneous activity.

The potential impact on repository performance from exploration or development of a mineral or energy resource is a function of the three-dimensional location of the resource or expected resource, the direction of vadose-zone water movement, and the extent and nature of the specific activities with respect to the planned underground facility. Human actions that could most directly affect isolation involve those activities within the repository block that could (1) directly induce or affect fluid movement in the repository block or (2) disturb the radioactive waste and result in direct releases. Actions that would have a more indirect effect on isolation involve activities outside the repository block that could (1) affect or induce fluid movement or (2) lead to withdrawal of fluids or materials that have since become contaminated with radioactive waste. Activities in both categories include drilling, mining, the creation of surface-water impoundments, or other work performed during exploration for or development of natural resources. The differing nature of the concerns relating to direct and indirect impacts suggests two levels for evaluation of human interference potential: one for evaluating direct isolation concerns and another for evaluating indirect isolation concerns.

As site characterization activities proceed and new information is provided, evaluation boundaries will be more explicitly defined. Specifically, the assumptions used in establishing the present areas of evaluation will be assessed. This includes information concerning the geologic and geomorphic features, the potential flow paths for induced fluids or effects on natural fluid movement, the assumed stability of the present water table, and other parameters.

As a first approximation, the surface boundary for the detailed evaluation of geothermal and oil and gas resources is defined as within 5(?) km of the center of the surface projection of the perimeter drift of the repository. Energy resources outside of this area are considered to have lower significant potential to affect the performance of the site because of the expected nature of the exploration and development activities (i.e., drilling). Because of the greater potential for impacts on waste isolation in the repository block, areas immediately adjacent to the repository block deserve more scrutiny than areas more distant. As site characterization proceeds and new information is provided, the areas of evaluation will be reassessed.

The depth of the zone considered for detailed energy resource characterization may differ from the zone considered for mineral resources due to the differences in exploration and exploitation techniques (e.g., deep drilling and pumping versus shallow drilling and mining activities). Drilling would likely provide a smaller conduit for the transmission of natural fluids and a smaller potential for the introduction of fluids. As resources are located farther away from the repository or at deeper levels in the earth, exploration or extraction activities should have a diminishing potential for interacting with nuclear waste and thus, less potential for an impact on waste isolation. In addition, the assumptions on geologic structures or stratigraphy, geomorphic barriers, vadose-zone flow characteristics, and the stability of the water table that were applied to mineral resources are also generally applicable to energy resources. However, the regional and the pre-Tertiary stratigraphy and structures will be evaluated along with the tuffs and surficial deposits in the regional energy resource assessments.

The regional hydrocarbon and geothermal energy resource assessments must consider source and reservoir rocks at considerable depth below the proposed repository, because these resources are generally accessed by the drilling of deep holes. The potential for these energy resources will be evaluated by considering information obtained in the region, the immediate vicinity, the drillholes in Paleozoic rocks near the site (e.g., drillhole UE-25p#1 and planned drillhole USW G-7). Depth to Paleozoic rock under the site are generally greater than 3 km. Presently, deep drillholes (9,000 to 20,000 ft) that could intersect Paleozoic rocks are not a planned activity because any specific drilling location would be an arbitrary decision for which no reasonable geologic or geophysical information has yet been established.

During the course of site characterization, additional evidence will be gathered and the need for drilling assessed with respect to the evaluation of energy resource potential.

The potential in other pre-Tertiary rocks will be evaluated, but the level of detail planned for the characterization of their resource potential will be a function of their proximity to the site and will be undertaken as a part of the regional assessment planned (see activity descriptions under this study). For example, the regional analog comparison to Yucca Mountain will consider the general region and the various lithologies in the general region.

The likelihood and possible effects of various scenarios for human intrusion and interference resulting from resource exploration or exploitation will be evaluated as part of the resource assessment program. If a reasonable scenario is identified, a detailed study of the possible significance and effects of the scenario will be performed in Investigation 8.3.1.9.3. The results will feed the total system performance assessment calculations described in Section 8.3.5.13. As site characterization proceeds and new information is obtained, the previously described approach, the defined, detailed evaluation boundaries, and the associated assumptions will be reevaluated and changed, if necessary.

Mineral and energy resources have been discussed in Sections 1.7 and 1.8.1.7 and will be further assessed in this program. This includes information that will allow the calculation of gross and net values for any identified resources and reserves that have present markets, and the calculation of tonnage, grade, or volume for speculative, undiscovered resources (Section 1.7) that may have value in the future. These data will then be used as input to Issue 1.1.

8.3.1.9.2.1.1 Activity: Geochemical assessment of Yucca Mountain in relation to the potential for mineralization

Objectives

The overall objective of this activity is to conduct a geochemical sampling program to evaluate the potential for precious, base, and strategic metals; energy resources; and industrial mineral resources in the vicinity of Yucca Mountain. Specific objectives include:

1. Selecting a suite of elements for analysis in a geochemical sampling program. The suite will be based upon known commodities that occur in silicic tuffs and/or trace elements indicative of commodities that occur in the tuffs.

2. Developing a field program to include a systematic and biased sampling of surface materials. Using existing core, core obtained during site characterization, and other subsurface samples to evaluate the potential of mineralization at and near the site. This includes evaluation of deposits that occur along faults within breccia zones and deposits that may be hidden by alluvium.

3. Generating a first-order geochemical data base for selected elements obtained from surface and subsurface sampling within the vicinity of Yucca Mountain.

4. Evaluating the data base in conjunction with geological and geophysical data obtained from other site characterization activities to determine if additional data are needed for an evaluation of natural resources.

5. Evaluating the potential for the occurrence of natural resources in the vicinity of Yucca Mountain based on an analysis of the geochemical data. These data will be examined and evaluated statistically from anomaly and residual maps, and by comparison with calculated background levels and average elemental values found in silicic tuffs.

Information obtained from this activity will further address questions concerning the attractiveness of the site relative to the possible presence of resources (Activity 8.3.1.9.2.1.5) and the potential of future drilling or disruption (Study 8.3.1.9.3.1).

Parameters

The following list is considered to be a first approximation of the elements that are currently important commodities in silicic volcanic associations: gold, silver, copper, lead, zinc, tin, mercury, thorium, and uranium. In addition, pathfinder elements may be considered and could include antimony, fluorine, barium, arsenic, and yttrium. The methods employed for the geochemical characterization will be a function of the detection limits required to assess the potential for mineralization; for example, gold will need to be detected to the parts per billion level. Most metals will be evaluated at the ppm level. Existing chemical analyses on the tuffs of Yucca Mountain will also be used in the site geochemical assessment. Information on the occurrence, abundance, and quality of industrial minerals will be collected as sampling is performed. Additional industrial minerals or elements that could be assessed or analyzed, if necessary, will be determined from a literature search and evaluation of the mineralogy and chemistry of tuff.

Description

Geochemical sampling of surface and subsurface materials will be conducted to determine the potential for exploration in the area of the repository. It is anticipated that future exploration for mineral commodities would likely be conducted before activities such as drilling or mining (Section 1.7). On the basis of currently available data and regional comparisons (Sections 1.7 and 1.8.1.7), the mineral-resource potential of the site is considered low. Chemical analyses of surface and subsurface samples could add further confidence to the conclusion that adjacent areas with surface and subsurface anomalies (e.g., Wahmonie, Calico Hills, Bare Mountain) would prove to be more likely locations for future drilling and mining (Section 1.7.1.1). Other geochemical information (e.g., biochemical data and isotopic data) will be evaluated to determine if they would add significantly to the confidence needed to comply with 10 CFR Part 60. Methods of determining what should be considered anomalous concentrations will also be considered (e.g., Mattson, 1988). A geochemical data base will help to determine if the site is likely to remain unattractive for exploration, even with anticipated changes in exploration methods and concepts.

The approach to the geochemical sampling program and Activity 8.3.1.9.2.1.5 will be based on a review of existing literature of similar geologic environments with known mineral occurrence, data from preliminary geochemical analyses (Section 1.7), the geologic setting of Yucca Mountain and the nearby mineralized areas (Bare Mountain, Wahmonie, and Calico Hills) A comparison of the suite of elements determined for Yucca Mountain will be compared with proposed ore emplacement models found elsewhere in the literature. The geochemical sampling scheme to be developed will account for subsurface and surface variation in terrain, rock type, or soil type. The elements selected for analysis will be those that represent metallic and nonmetallic commodities known to be associated with silicic volcanic rocks and surficial deposits. Geochemical sampling also will include rocks of various types and rocks exhibiting the effects of alteration or other geological phenomena commonly associated with mineralization. In particular, geological deposits that will be included in this activity include calcite and opaline-silica deposits and breccias located along faults near Yucca Mountain (Vaniman et al., 1988; Section 8.3.1.5). Trench mapping, isotopic work, and age information obtained on these fault deposits will be integrated with the economic and geochemical information obtained under this study. In addition, analog fault-related breccias or hydrothermal breccias known to carry mineralization (Nelson and Giles, 1985; Huben and Nelson, 1988) will be compared with these deposits located near Yucca Mountain. The sampling program will not be restricted to the controlled area. Samples will also be collected and analyzed from northern Yucca Mountain, Calico Hills, and Wahmonie. This will provide a comparative base, along with chemical analyses obtained from the available literature, to compare the site with other areas in Activity 8.3.1.9.2.1.5. Identified industrial minerals or materials will be evaluated from the geochemical suite of samples, from the information obtained from studies on mineralogy and petrology (Section 8.3.1.3.2), and from appropriate data as identified.

The configuration of the surface sampling program, and the number of sample locations, will be based on the geology, known and expected mineral occurrences, topography, and configuration of the perimeter drift and controlled area. A systematic sampling system will be used. Sample spacing within the controlled area is expected to range between 250 and 750 ft. A more closely spaced grid system may be necessary for a second-order geochemical sampling program if anomalies are identified from the first-order program. Soil-survey geochemistry techniques have been widely used and discussed in the literature (e.g., Thomson, 1986; Theobold, 1987). Surface sampling will not be restricted to a grid system. Biased sampling will also be done where rock types and alteration zones or other geological phenomena commonly associated with mineralization are observed. In addition, sediment sampling within selected areas, including drainages, may be necessary at similar spacing (250 and 750 ft).

The subsurface sampling program will be carried out in a similar manner. A representative number of drillhole cores will be selected that cover the controlled area. Spacing of sampling locations of the core is expected to range between 50 and 300 ft. The program is intended to include the deep holes, including UE-25p#1, which intersect the Paleozoic rocks under Yucca Mountain. Biased samples will be taken from rock types and alteration zones commonly associated with mineralization. Additional sampling may be necessary if anomalies are identified.

Sampling intervals at the surface and of drillhole core will vary depending upon the particular element being measured. For instance, gold will require a more closely spaced sampling interval than base metals. Sampling intervals will be determined after a complete list of elements selected for analysis is finalized and a scoping assessment is made for each element.

Anomaly and residual maps will be prepared for each elemental analysis. Standard statistical analyses will be performed to characterize the background levels and spatial variability for each element, including averages and standard deviations of the results of the analyses. A comparison of background levels found in the silicic tuffs of Yucca Mountain with anomalies identified will be made. In addition, average elemental abundances found in silicic tuffs will be compared with elemental abundances found at Yucca Mountain.

This activity will generate a geochemical data base for two groups of elements. The first group will include those elements with known affinities for silicic volcanic rocks, including elements that are concentrated by primary magmatic processes, secondary weathering, or hydrothermal (mesothermal to epithermal) processes. The precious metals (gold and silver), mercury, and uranium are included in this group. The second group, the so-called pathfinder elements, such as antimony and arsenic, are usually subeconomic. Because of their solubility in alteration processes, however, these elements are useful in defining dispersion halos or detecting emanations from more deeply buried mineral deposits. Elements such as mercury are important as commodity elements (group 1) and are also excellent pathfinder elements (group 2).

Many elements can be excluded from this evaluation based on their known abundances and potential concentration factors in crystal rocks. These include cobalt, chromium, and the platinum group elements, which are known only to be associated with mafic and ultramafic rocks (Stanton, 1972). Additionally, a large body of literature exists relative to the distribution of elements in specific rock types that allow the prediction of which elements could occur in anomalous concentrations by such processes as weathering, hydrothermal activity, or magmatism. Therefore, many additional commodities and elements may be eliminated from further consideration.

Analytical methods to be used may include fire assays, atomic absorption, x-ray diffraction, x-ray fluorescence, neutron activation, or inductively coupled plasma emission spectroscopy. These methods will be evaluated based on their analytical detection limits and the projected number of samples to be analyzed. Further details and additional information will be presented in the study plans for this activity.

Methods and technical procedures

The methods and technical procedures for this activity are given in the following table.

Method	Technical procedure		
	Number	Title	Date
Geochemical sampling plan	TBD[a]	TBD	TBD
Analytical methods	TBD	TBD	TBD
Field plans	TBD	TBD	TBD

[a]TBD = to be determined.

8.3.1.9.2.1.2 Activity: Geophysical/geologic appraisal of the site relative to mineral resources

Objectives

This activity will qualitatively evaluate the available geophysical data base as it relates to Study 8.3.1.9.2.1. The existing geophysical data base (Section 1.7.1.1) will be examined to define any geophysical anomalies that may require additional exploration and possibly constrain any known geochemical anomalies (Activity 8.3.1.9.2.1.1). The geophysical data base will also be used as a basis for comparisons to analog environments of known mineralization (Activity 8.3.1.9.2.1.5). Geologic models derived from geophysical data in Section 8.3.1.17 will be evaluated for their impact on mineral resources. Further work may be planned depending on the results of studies described in Section 8.3.1.17.4 and the qualitative evaluation performed in this activity.

Parameters

Existing regional and site-specific reports on geophysical surveys, as well as reports from geophysical work planned in Section 8.3.1.17.3 will be used in this qualitative assessment. Included in this assessment will be a review of the existing aeromagnetic, gravity, and electrical (induced polarization and magnetotelluric) data. Data obtained from the site-specific gravity, ground magnetic, selected geophysical logging, and magnetotelluric surveys (Section 8.3.1.17.4.3) may also be assessed. Possible hydrothermal alteration zones may be identified through the use of remote sensing (thematic myopia) and field mapping (Section 8.3.1.17.4.4). These techniques may provide useful information to the geochemical program (Section 8.3.1.9.2.1.1). Additional parameters maybe defined during this activity.

Description

Interpretations described in the literature and derived from geophysical data may provide additional information to evaluate the geochemical data base (Activity 8.3.1.9.2.1.1) and to aid in determining which types of ore-forming models should be considered. In addition, preliminary geophysical models that have been suggested for Yucca Mountain include the possible presence of detachment faults (Scott, 1986; Scott and Rosenbaum, 1986), and the presence of a metamorphic core complex under Yucca Mountain (Robinson, 1985). These interpretations, if correct, will be assessed relative to their significance to ore-forming processes.

Other geophysical methods (Section 8.3.1.17.4) that are responsive to local, surficial, or shallow variations of the bedrock will be evaluated as potential complements possibly to constrain the site-specific geochemical survey (Activity 8.3.1.9.2.1.1). The information and data evaluated in this activity will provide the geophysical basis for the comparisons to analog environments performed in Activity 8.3.1.9.2.1.5. Further details and additional information will be presented in the study plans for this activity.

Methods and technical procedures

There are no procedures for Activity 8.3.1.9.2.1.2. Existing data will be used.

8.3.1.9.2.1.3 Activity: Assessment of the potential for geothermal energy at Yucca Mountain, Nevada

This activity will be undertaken in cooperation with Activity 8.3.1.8.5.2.3 (evaluation of regional ambient heat flow and local heat flow anomalies). Both activities are aimed at characterizing the local geothermal regime as it might relate to repository performance during the postclosure period. Activity 8.3.1.8.5.2.3 will focus on geothermal activity and heat flow calculations as they could relate to Quaternary igneous processes or events. This activity (8.3.1.9.2.1.3) assesses the geothermal regime in terms of its energy resource potential for either hydrothermal or conductive reservoir thermal systems (Section 1.7.1.5.2). Data compilation and evaluation will be done jointly through both activities.

Objectives

The overall objective of this activity is to assess the potential for a geothermal energy resource at Yucca Mountain, Nevada.

The objectives of this activity are to

1. Compile measured geothermal and calculated heat flow data at and in Yucca Mountain and vicinity to quantify vertical and horizontal geothermal gradients. The quality of these data will be assessed under this activity in conjunction and cooperation with Activity 8.3.1.8.5.2.3. Temperature and other data collected under site unsaturated zone hydrology (Section 8.3.1.2.2) and site saturated zone hydrology (Section 8.3.1.2.3) will be assessed here and in cooperation with Activity 8.3.1.8.5.2.3.

2. Compile appropriate chemical and isotopic (oxygen and deuterium) analyses of water samples from springs and wells useful for predicting subsurface temperatures. These data will be useful in comparing subsurface temperatures at the site with measured temperature profiles and heat flow data for the region.

3. Evaluate the existing data on geothermometry and heat flow necessary to adequately characterize the region for its geothermal resource potential.

4. Recommend whether additional studies may be needed, including the collection and integration of additional geothermal data from existing or planned drillholes.

5. Provide the information necessary for the final resource assessment to be performed in Activity 8.3.1.9.2.1.5.

Parameters

The parameters that will be calculated and evaluated for this activity are

1. Temperature gradient and thermal conductivity data from boreholes and similar data from the exploratory shaft facility will be used to calculate heat flow (Sections 8.3.1.8.5.3, 8.3.1.17.4.5, and 8.3.1.8.5.2).

2. Water chemistry and isotopic (oxygen and deuterium) analyses will be used in evaluating geothermometry methods (Study 8.3.1.2.3.2).

3. Temperature of ground water from springs and wells, and geological, hydrological, and structural data of the site and surrounding region will be used to assess the geothermal energy potential of Yucca Mountain (Section 8.3.1.2.3.2, 8.3.1.4.2.1, and 8.3.1.8.5.2).

Description

As discussed in Section 1.7.1.5.3, the existing heat flow calculations, temperature data, temperature gradient data, and isotopic analyses (oxygen and deuterium) for Yucca Mountain are consistent with a low-temperature (<90°C) geothermal regime.

Downhole temperature data from Yucca Mountain and temperature data obtained from nearby localities indicate that significant variations occur in temperature gradients for a single hole and between wells. Anomalous heat flow and thermal gradients are observed at localities near the site at drillhole UE-25a#3 (3.08 to 3.34 heat flow units (HFU)) located near Calico Hills, and drillhole UE-20F located at Pahute Mesa (thermal gradient is 37°C/km). These localized anomalies could be associated with several heat-flow models such as water circulation in faults, shallow magma bodies, anomalous ground-water flow, and large variations in stratigraphic thickness (thermal conductivity).

The available data for geothermal assessment have not been compiled or thoroughly evaluated for adequacy or quality. Because data were not collected systematically (in some instances, measurements were taken during or soon after drilling (Sass et al., 1983)), some of the data are of questionable quality. Thus, the available data will be evaluated for their adequacy and quality, and the acquisition of temperature and thermal conductivity data from existing or new drillholes for use in heat flow calculations may be recommended as a result of this activity. A compilation of regional data obtained from the literature will also be assessed so that a comparison can be made with the data from the Yucca Mountain area.

Chemical and isotopic data will be compiled and evaluated for their application to the geothermal assessment of Yucca Mountain (Section 1.7.1.5.2). Data will include chemical analyses of ground-water samples obtained from drillholes (Section 8.3.1.2.3.2), and springs near Yucca Mountain (Section 1.7.1.5.2). These data will be evaluated to determine whether silica geothermometer analyses may be appropriate.

All the data compiled and evaluated will be used in conjunction with geologic, structural, stratigraphic, and hydrologic data to perform the geothermal assessment. This activity will lead into the final energy and resource assessment performed in Activity 8.3.1.9.2.1.5. Further details and updated information will be provided in the study plans for this activity.

Methods and technical procedures

There are no methods and technical procedures for this activity. Existing data and data collected in support of other site characterization activities will be used.

8.3.1.9.2.1.4 Activity: Assessment of hydrocarbon resources at and near the site

Objectives

The objectives of this activity are to

1. Determine the potential for the presence or absence of suitable source rocks, reservoir rocks, and traps and seals at and near the site.

2. Determine the potential for occurrence of conventional hydrocarbon resources (crude oil and natural gas) at and near the site. This will include a review and assessment of drillholes emplaced for oil and gas exploration within the geographic area of the site. The radius of this area is expected to be on the order of tens of kilometers, but its size will depend largely on the results of the work described previously.

3. Provide necessary data for the overall mineral and energy resource assessment to be performed in Activity 8.3.1.9.2.1.5.

Parameters

Several investigative efforts and evaluation approaches are intended. First, the presence of organic matter within certain Paleozoic rocks will be ascertained. This will be based upon an examination of samples from drillholes and outcrops in the general area including core material from the one drillhole (UE-25p#1) that penetrated Paleozoic rocks close to the site. Newly obtained core or cuttings from drillholes in areas adjacent to the site will also be studied. An evaluation of the existing petroleum industry exploration drillholes in the vicinity of Yucca Mountain will be made to determine if information relevant to the site can be obtained. Outcrop material from adjacent areas such as Bare Mountain, Calico Hills, and Mine Mountain-Syncline Ridge will also be collected and evaluated.

Second, the thermal maturation of any organic matter found in these samples will be determined. Several techniques, such as kerogen elemental analysis, kerogen coloration (temperature alteration index (TAI)), rock pyrolysis, and vitrinite reflectance, are among those available for determining thermal maturation-source-bed potential. These and possibly other techniques that are based upon organic matter will be compared relative to their applicability, especially with regard to outcrop samples using the most suitable method(s).

Third, parallel consideration of another thermal maturation technique, based upon microfaunal remains (conodonts) and termed the conodont color alteration index (CAI), will be undertaken in conjunction with a literature search intended to focus upon the thermal maturation experienced by the Paleozoic carbonate strata at and near the site. Other techniques will be evaluated (e.g., fluorescence petrography for oil fluid inclusions) to determine if other information could aid in refining the time-temperature history reconstruction estimations. This will allow refinements to be made to the estimate of Lopatin's time-temperature index (Section 1.7.2.2.1) and will expand upon the work of Harris et al. (1980) and M. D. Carr et al. (1986). This will also allow the anticipated integration of the thermal history of adjacent sites (e.g., Bare Mountain) into an understanding of the thermal history of Yucca Mountain.

Other work is intended to review the stratigraphy and geologic structure of the Yucca Mountain site and of areas near the site within the context of available and future drillhole and geophysical data (Section 1.7.1.1; Study 8.3.1.17.4.4). This is intended to identify potential reservoir rocks, traps, and seals that may be present. An allied exercise will be to evaluate comparable petroleum-geology features as they are developed at known hydrocarbon occurrences within the Great Basin of Nevada, and, in particular, the highly productive trend that is present in the Railroad Valley area (e.g., Grant Canyon Field) of northeastern Nye County. The possibility that Mesozoic thrust belts with oil-bearing potential extend to southern Nevada (Scott and Chamberlain, 1987), including the area of Yucca Mountain, will also be addressed. This will provide a basis for assessing the degree to which these factors are relevant to the petroleum potential of the site (Activity 8.3.1.9.2.1.5). New data gathered by several planned geophysical surveys, such as the regional magnetotelluric, deep refraction-seismic, deep and intermediate reflection-seismic, and the ground magnetic surveys planned for fault detection (Table 8.3.1.17-10) will be assessed if applicable for evaluating oil and gas potential. Part of this effort will be conducted under Activity 8.3.1.9.2.1.2, particularly the evaluation of geophysical data, which will include an early assessment regarding the applicability of these data to the interpretation of subsurface geologic structures. Additional parameters may be defined and pursued if these several work efforts, evaluations, and literature investigations fail to provide adequate information on possible source rocks-organic matter, thermal maturation, and the integrated petroleum potential at and near the site. Among these may be a comparative evaluation of both surface hydrocarbon-prospecting techniques and indirect subsurface detection methods such as the analysis of ground water for dissolved hydrocarbon gases.

Description

To date, no hydrocarbons have been discovered at or in the vicinity of the Yucca Mountain site, although relatively few boreholes have been drilled for that purpose. Of the commercially drilled exploration holes located throughout southcentral and southeastern Nevada, none have encountered economic quantities of oil and gas. Significant shows of such hydrocarbons have similarly been lacking.

The thermal history of the general Yucca Mountain area may have been too high over an extended period of geologic time to allow any previously formed hydrocarbons to persist as either oil or gas (Section 1.7.2.2.1). However, data presented by M. D. Carr et al. (1986) suggest that CAI-based temperatures within the Silurian portion of the Paleozoic carbonate sequence as encountered in drillhole UE-25p#1 have been no greater than 180°C, and possibly no less than 140°C (CAI = 3). If these paleogeothermal data represent an accurate reflection of the thermal maturation, these rocks would not be considered overly mature, and thus technically capable of some hydrocarbon potential within the gas range, provided that the several other factors necessary to generate and entrap hydrocarbons were present.

Further refinement of the thermal history will be pursued, along with work designed to evaluate the potential for reservoir rocks, the potential for trap-seals, and the comparison with other producing trends within the Great Basin and Nevada. Analyses of any detected organic matter (as found in drillhole cores and cuttings and samples collected from selected outcrops) will be made based upon an assessment of the most applicable petroleum geochemical methods. Companion work based upon faunal remains and their indications of thermal maturation will also be made. Inclusion of geophysical and drillhole data will also be implemented to evaluate the structural geologic setting as it relates to traps and seals. Further details and additional information will be provided in the study plans for this activity.

Methods and technical procedures

The methods and technical procedures for this activity are given in the following table.

Method	Technical procedure		
	Number	Title	Date
Organic-matter sampling and sample-preparation plan	TBD[a]	TBD	TBD
Conodont sampling plan	TBD	TBD	TBD
Analytical methods-thermal maturation	TBD	TBD	TBD

[a]TBD = to be determined.

8.3.1.9.2.1.5 Activity: Mineral and energy assessment of the site, comparison to known mineralized areas, and the potential for undiscovered resources and future exploration

Objectives

The objective of this activity is to integrate the data and information collected from Activities 8.3.1.9.2.1.1 (geochemical assessment), 8.3.1.9.2.1.2 (geophysical/geologic assessment), 8.3.1.9.2.1.3 (geothermal energy assessment), and 8.3.1.9.2.1.4 (hydrocarbon assessment). Integration of these activities and the data acquired from them will allow:

1. The identification of mineral resources with current markets, as well as the calculation of gross and net values for identified resources or reserves.

2. The physical description of mineral resources with potential future markets relative to "tonnage, or other amount, grade, and quality," as described in 10 CFR 60.21(c)(13).

3. The physical description of energy resources using appropriate parameters that describe the extent and magnitude of those resources.

4. The evaluation of the resource potential of any identified or undiscovered mineral and energy resources, based upon a "representative" area of "similar size" and a comparison to the Yucca Mountain site (10 CFR 60.122(c)(17)).

5. An estimation of the potential for undiscovered deposits of those resources described in 10 CFR 60.21(c)(13). This will be accomplished using site-specific data in conjunction with evaluation of models found in the literature of economic mineralization, hydrocarbon generation and entrapping processes, and extraction-conversion methods in geothermal energy utilization.

This activity provides data necessary for the probabilistic calculations for determining future inadvertent human interference or intrusion (Study 8.3.1.9.3.2).

Parameters

Existing site-specific data and data collected under Activities 8.3.1.9.2.1.1, 8.3.1.9.2.1.2, 8.3.1.9.2.1.3, and 8.3.1.9.2.1.4 will be used to calculate grades, tonnages, or other amounts. Information obtained from the literature will allow a comparison of analog areas and literature models with the site-specific data obtained for Yucca Mountain under the activities just listed.

Description

Information from Activities 8.3.1.9.2.1.1 and 8.3.1.9.2.1.2 and other site-specific data from the literature will be used to calculate gross and net values of commodities of current commercial value and commodities that may have future commercial value. These site-specific grades, tonnages, or amounts will be compared with the average abundances in crystal rock types to determine if the site has extractable commodities that may be of commercial value, of future commercial value, or anomalous concentrations of a commodity that would attract exploration.

Information from Activities 8.3.1.9.2.1.3 and 8.3.1.9.2.1.4 and other site-specific data from the literature will be used to describe energy resource potential. More detailed assessment of energy resources will be conducted if warranted by data from this activity.

This activity will compare analog environments of known natural resources to the geological conditions present at the site. Information on selected mineral deposit analogs will be obtained from the existing literature and Activities 8.3.1.9.2.1.1 and 8.3.1.9.2.1.2. Ideally, the selected analogs will consist of similar rock types that have originated under similar geologic conditions. For example, analogs will be selected that compare the site to known areas of mineralization such as those found within calderas (Jefferson Caldera, Nevada) and on margins of calderas (Round Mountain and Goldfield, Nevada) or in deposits recently discovered in the vicinity of Yucca Mountain (Bullfrog District and northern Bare Mountain, Nevada). This approach will allow the incorporation of many mineral deposit models, including Round Mountain, Nevada as a lode gold deposit (Tingley and Berger, 1985) or as a high-volume low-grade (bulk-mineable) precious-metal deposit (Bonham, 1988). A large body of literature, including petrologic, petrogenic, structural, geophysical mineralogic, and analytical data of the rocks located at the site, will be evaluated in this comparison. This integrated information will be used to evaluate the site potential for undiscovered deposits and mineral exploration using reasonable inference based on geologic and geophysical evidence as required in 10 CFR Part 60, which states

> For resources without current markets, but which would be marketable given credible projected changes in economic or technological factors, the resources shall be described by physical factors such as tonnage or other amount, grade, and quality.

The activity will permit a final qualitative assessment of mineral resources at the site in terms of their present value, and the potential for future exploration at the site.

Information on selected geothermal analogs will also be obtained from the existing literature. This information will be compared with existing information on the geothermal resource potential of the site and with new data provided by the results of Activities 8.3.1.9.2.1.1, 8.3.1.9.2.1.2, and 8.3.1.9.2.1.3. Ideally, the selected analogs will consider geothermal resources in similar geologic environments that have originated under comparable geologic conditions. Analogs will be selected to compare the site with known areas of geothermal resources found in association with large-volume silicic caldera systems of similar age, geothermal resources associated with small-volume, intra-plate basaltic volcanism of similar age or similar geologic environments in Nevada with known geothermal resources. The available literature will be used as a source of information on the analogs, including geophysical, geochemical, and geological data. The integrated information will be used to evaluate the potential for undiscovered occurrences at the site using reasonable inferences from geologic and geophysical data. This approach will allow the incorporation of several geothermal resource models such as low-temperature resources, high-temperature fluid dominated resources, dry-steam resources, and hot-dry rock resources. The activity will permit a final qualitative assessment of geothermal resources at the site in terms of (1) the presence or absence of favorable circumstances for occurrence, (2) the present-day value if located, and (3) the potential for future exploration at the site. "For resources without current markets, but which would be marketable given credible projected changes in economic or technological factors, the resources shall be described by physical factors such as tonnage or other amount, grade, and quality" (10 CFR Part 60).

Information on selected hydrocarbon (oil and gas) analogs will be obtained from the existing literature. This information will be compared with the existing information on the hydrocarbon potential of the site and with new data provided by the results of Activities 8.3.1.9.2.1.1, 8.3.1.9.2.1.2, and 8.3.1.9.2.1.3. Ideally, the selected analogs will consider similar age rocks, depositional environments, tectonic regimes, and similar traps and seals that are anticipated in the region. Analogs will be selected to compare the site with known areas of hydrocarbons found associated with Paleozoic carbonate rocks, in similar structurally complex areas such as Grants Canyon, Nevada. The available literature will be used as a source of information on the analogs including geophysical, geochemical, and geological data. This integrated information will be used to evaluate the potential for undiscovered occurrences at the site using reasonable inference based on geologic and geophysical data. This approach will allow the incorporation of several models for source generation, structural and stratigraphic trapping, and reservoir seals. The work will provide a final qualitative assessment of the hydrocarbon resource potential at the site in terms of the presence or absence of favorable circumstances for hydrocarbon generation and entrapment, present-day value if located, and the potential for future exploration at the site.

This activity will also provide synthesized data and evaluations of those data relative to assessing any initiating events under human interference that may be potentially unworthy of further consideration (Activity 8.3.1.9.3.2.2). These data and data evaluations are anticipated to facilitate the requisite probabilistic calculations (Study 8.3.1.9.3.2), but in some instances a less rigorous treatment may be used to dismiss events if they are considered sufficiently noncredible. Further details and additional information will be presented in the study plans for this activity.

Methods and technical procedures

There are no procedures for Activity 8.3.1.9.1.5. Existing data and data obtained from Activity 8.3.1.9.2.1.1 will be used in this activity.

8.3.1.9.2.2 Study: Water resource assessment of Yucca Mountain, Nevada

Ground water is expected to be the primary mechanism by which radionuclides might be transported from the repository to the accessible environment. Ground water is the sole source of supply for residents, irrigated agriculture, and industry within the geohydrologic study area. Changes in population, economic and industrial development, and consumptive uses of water will affect ground-water depths and withdrawal rates. Future ground-water withdrawals could affect ground-water flow within the geohydrologic system. This study consists of a single activity that will use available data to estimate the future supply, demand, and value of the ground-water resource in southern Nevada, proximal to Yucca Mountain.

8.3.1.9.2.2.1 Activity: Projected trends in local and regional ground-water development, and estimated withdrawal rates in southern Nevada, proximal to Yucca Mountain

Objectives

The objectives of this activity are to (1) assess the current and projected supply and demand situation for ground water in the geohydrologic study area, and (2) estimate the value of the ground-water resource.

Parameters

Three sets of parameters are required for this activity:

1. The determinants of supply, which include quantities available from alternative sources; the cost of water by alternative source; the physical and chemical characteristics of the ground-water system (e.g., recharge, aquifer depth, volume, and salinity); and the institutional factors relating to water laws and rights (e.g., preferred beneficial uses).

2. The determinants of demand, which include population data (i.e., historical, current, and projected trends); the economic conditions, including industry, employment, and income; the trends in consumptive uses of water (i.e., domestic, commercial, industrial, and agricultural uses); climate; and price.

3. Empirical estimates of the value of water in various uses (i.e., domestic, commercial, industrial, and agricultural).

Description

Current and projected marginal supply curves for water will be estimated. The effects of various current and projected socioeconomic conditions on ground-water development, use, and allocation will be evaluated. Where sufficient price and quantity data are available, water-demand curves can be estimated, from which estimates can be made of the marginal value of the water. For a variety of reasons, market-established prices for water are not generally available. However, there are a number of alternative means of estimating the value of the ground-water resource even in the absence of markets. These include evidence of prices paid for water by a given sector as an indication of the user's willingness to pay (an example of this is the recent purchase of ground water by Nevada Power Company in the Moapa Valley area), shadow prices determined via linear programming, change in net income or value-added approaches, and alternative and opportunity cost.

Because of the degree of uncertainty in forecasting changes in those factors that will determine the future supply and demand situation for ground water, a reasonable range of plausible scenarios will be developed. This information will be used to estimate the current and future value of the ground-water resource in the geohydrologic study area and to project probable withdrawal rates and locations. Estimations will be limited to the foreseeable future (10 CFR 960.4-2-8-1) and be a function of the various supply and demand scenarios.

Methods and technical procedures

Water supply information will be obtained from a variety of sources including the Nevada Department of Natural Resources and Conservation, the Water Resources Division; the USGS; the Bureau of Reclamation; the Las Vegas Valley Water District; and Activity 8.3.1.16.2.1.2 (location of primary water supply). Water use data will be obtained from the same sources.

The supply of water is not determined solely on the basis of the physical quantity available, but on the quantities available at particular costs. The economic supply of water is a function of the quantities that are legally available for use at various levels of cost for each quantity. Supply functions will be developed for specific areas with relatively uniform quality requirements and delivery costs based upon a set of different supply scenarios. Published data on historic, current, and projected trends in population, industrial and economic growth, consumptive uses, real per capita incomes, and price will be used in estimating future water demand.

Socioeconomic data (e.g., population, industry, and income) needed for the demand assessment will be acquired from a variety of sources, including the State of Nevada Employment Security Department, the U.S. Department of Commerce, the Bureau of Census, the Bureau of Economic Analysis, and future Yucca Mountain Project socioeconomic county profiles.

Changes in population, urban development, agricultural crops and acreages, and energy costs will affect the future supply of and demand for ground water in these areas. Because of the degree of uncertainty in forecasting changes in these factors, supply and demand projections will be based on a reasonable range of plausible, area-specific scenarios.

8.3.1.9.2.3 Application of results

The information obtained from the activities of this investigation will be used in conjunction with data presented in the Yucca Mountain environmental assessment (DOE, 1986b) and Sections 1.7 and 3.8 of the SCP to determine those resources having any potential for occurrence at Yucca Mountain. These resources, and the applicable extraction and exploitation techniques, will be examined to determine the effects on the hydrologic, geochemical, and rock characteristics that could potentially result from future exploitation (Section 8.3.1.9.3).

The data from this investigation will also be considered in determining the likelihood for future exploratory drilling within the boundaries of the perimeter drift. Knowledge of the types of specific resources that could exist, based on geologic evidence and the geologic environment, can provide useful information regarding exploration techniques (e.g., random drilling and drill-bit diameter) that can be used as a logical basis for forming the assumptions for the most probable release scenarios. Thus, information obtained from these activities will be used as input parameters for Investigation 8.3.1.9.3.

8.3.1.9.3 Investigation: Studies to provide the information required on potential effects of exploiting natural resources on hydrologic, geochemical, and rock characteristics

Technical basis for obtaining the information

Links to the technical data chapters and applicable support documents

A preliminary evaluation of the resource potential of the Yucca Mountain site is presented in the Yucca Mountain environmental assessment (DOE, 1986b) and in Sections 1.7 and 3.8 of the SCP. Studies will be performed to determine the extent to which the actual or inferred presence of resources at the site might influence the exploration activities of future generations. Additional studies will establish the potential effects of resource exploitation and extraction on the hydrologic, geochemical, and rock characteristics at and in the vicinity of Yucca Mountain.

Ground water currently is the only resource being considered. However, if other economically attractive resources or reserves are identified during the natural resource assessment that is being conducted in support of Investigation 8.3.1.9.2, the potential effects of their exploitation will also be evaluated. These data will be assessed by a panel of experts to determine the probability that human intrusion into, or interference with, a mined geologic disposal system could result from the actual or inferred presence of natural resources.

Parameters

The only parameters that have been identified to date are (1) projected rates and the probable locations of future ground-water withdrawals within the geohydrologic study area, (2) the results of the resource assessment (Study 8.3.1.9.2.1), and (3) the probabilities for inadvertent human interference and intrusions.

Additional parameters that will be required if other resources are identified (Investigation 8.3.1.9.2) include the specific types, locations, distributions, and quantities (i.e., grades, tonnages, and volumes) of the materials identified. Necessary information regarding the applicable extraction and exploitation methods will be taken from the literature. Site characterization activities and the existing data base will provide the baseline information relative to the hydrologic, geochemical, and rock characteristics at the site.

Purpose and objectives of the investigation

The purpose of this investigation is to obtain the information that will be used to satisfy the parameter requests made in Issue 1.1 (total system performance). Two types of data are requested in this performance issue: (1) information on the resources presently at the site that would influence the likelihood of exploratory drilling within the controlled area, and (2) the potential effects of resource extraction on the hydrologic, geochemical, and rock characteristics at the site. The first objective of this investigation is to evaluate the data relative to the resource potential at the site, resource extraction, and marker system survivability necessary to determine the probability range for exploratory drilling. The second objective is to assess the potential effects of resource extraction for all commodities known to be present or inferred to be present at the site. Thus, this investigation will compile all the site data generated by the human interference program and pass the required parameters to Issue 1.1 (total system performance, Section 8.3.5.13).

Technical rationale for the investigation

To determine the effects of resource exploitation on the hydrologic, geochemical, and rock characteristics at the Yucca Mountain site, it will be necessary to estimate the quantities, as well as the locations and distributions, of those resources identified in the assessment. These resource parameters, together with their applicable extraction and exploitation methods, will be evaluated to determine qualitatively the effects of exploitation. For instances in which it is possible to model the effects using computer codes, such as with ground-water withdrawals, potential effects will be quantified. The data that will be collected by Studies 8.3.1.9.1.1, 8.3.1.9.2.1, and 8.3.1.9.2.2 will be evaluated to determine the likelihood for human interference and intrusion. Figure 8.3.1.9-4 shows the data flow for this investigation.

Two studies will be undertaken in fulfillment of this investigation. Study 8.3.1.9.3.1 will address factors that directly influence the amount of radionuclide releases that could result from inadvertent human interference and intrusion at the site. The studies to be undertaken to evaluate the potential effects of resource exploitation will be defined in detail when the resource assessment (Study 8.3.1.9.2.1) is completed. On the basis of the data available to date, ground water is the only resource known to be present. Specific plans for evaluating the effects of ground-water withdrawal are presented in the following sections. The second study (8.3.1.9.3.2) will present supporting discussions necessary to demonstrate that certain initiating events identified in the human interference program are not credible and, therefore, not significant.

8.3.1.9.3.1 Study: Evaluation of data needed to support an assessment of the likelihood of future inadvertent human intrusion at Yucca Mountain as a result of exploration and/or extraction of natural resources

In this study, data will be compiled and analyzed for assessing the likelihood of inadvertent human interference in the vicinity of Yucca Mountain. The initiating events for which data will be compiled include exploratory drilling for natural resources and ground-water withdrawal.

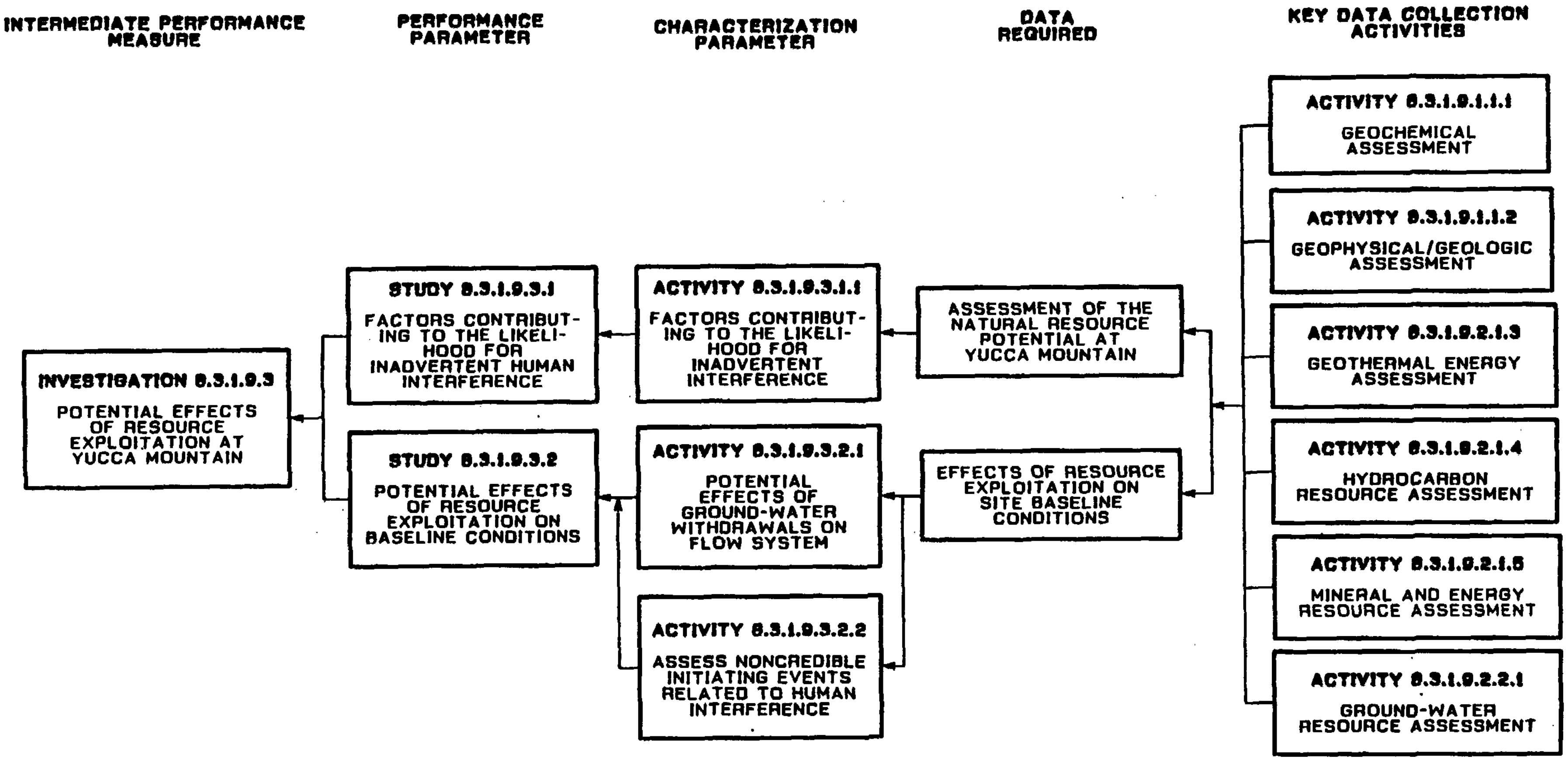

Figure 8.3.1.9-4. Logic diagram for Investigation 8.3.1.9.3.

8.3.1.9.3.1.1 Activity: Compilation of data to support the assessment calculation of the potential for inadvertent human intrusion at Yucca Mountain

Objectives

The objectives of this activity are to

1. Determine the maximum drilling density and frequency (drillholes per square kilometer per 10,000 yr) that can be reasonably assumed for a repository at Yucca Mountain.

2. Determine the extent to which future ground-water withdrawals will modify the expected ground-water flow paths.

Parameters

The parameters that will be obtained or evaluated by this activity include:

1. Expected drilling density.

2. Distribution and expected depth of drillholes.

3. Expected distribution of drillhole diameters.

4. The probabilities that human interference or intrusion will occur as a result of exploratory drilling or exploitation.

The natural resource assessment parameters for this activity will be input from Study 8.3.1.9.2.1 (assessment of the natural resource potential at Yucca Mountain) and Study 8.3.1.9.2.2 (effects of natural resource exploitation at Yucca Mountain). These data will be used to aid in estimating the likelihood of the initiating events (Table 8.3.1.9-1) for human intrusion and interference at Yucca Mountain during the postclosure period.

Description

This activity will involve compiling data to determine the anticipated maximum drillhole density, borehole diameter, and depths of the drillholes over the next 10,000 yr in the vicinity of Yucca Mountain. The results of the natural resource assessment studies (8.3.1.9.2.1 and 8.3.1.9.2.2) will be used in this activity. In addition, information on state-of-the-art exploration and drilling techniques, as well as information on expected future exploration and drilling equipment trends, will be analyzed in this activity.

Methods and technical procedures

Since this activity involves data synthesis or analysis, no technical procedures are required.

8.3.1.9.3.2 Study: An evaluation of the potential effects of exploration for, or extraction of, natural resources on the hydrologic characteristics at Yucca Mountain

This study will assess in qualitative or quantitative terms, the effects of exploiting natural resources known or believed to be present at Yucca Mountain. Consideration of the effects of resource exploitation or extraction are limited to changes in the hydrologic, geochemical, and rock characteristics.

8.3.1.9.3.2.1 Activity: An analysis of the potential effects of future ground-water withdrawals on the hydrologic system in the vicinity of Yucca Mountain, Nevada

Objectives

The objective of this activity is to determine the potential effects of future ground-water withdrawals on the hydrologic system at Yucca Mountain. Effects of the withdrawals will be defined qualitatively and quantitatively.

Parameters

The parameters required for this study are the following:

1. The time-phased estimates of ground-water withdrawals as projected from the activity described in Investigation 8.3.1.9.2.

2. The probable locations of the wells from which projected withdrawals would be made. Locations need only be accurate to within a single hydrographic area (Section 3.8.1). This parameter will also be passed from Investigation 8.3.1.9.2.

3. The appropriate hydrologic parameters (aquifer characteristics) will be obtained from Investigation 8.3.1.2.3.

Description

Various computer models, such as FEMOD (Czarnecki, 1985), will be used to analyze the potential effects of ground-water withdrawal on the local hydrologic system. The input parameters supplied from Investigation 8.3.1.9.2 when used in the computer model will allow simulation of the changes in the geohydrologic system that might occur as a result of withdrawals through break time. The results from the model will provide qualitative and quantitative information on the potential effects of ground-water withdrawals within the geohydrologic system.

Methods and technical procedures

Since this activity involves data synthesis or analysis no technical procedures are required.

8.3.1.9.3.2.2 Activity: Assessment of initiating events related to human interference that are considered not to be sufficiently credible or significant to warrant further investigation

Objectives

The objective of this activity is to demonstrate that those initiating events that have been identified (Table 8.3.1.9-1) for the human interference issue are not considered sufficiently credible or significant to necessitate additional investigation. This will be documented in a topical report.

Parameters

The parameters that will be obtained or calculated by this activity are grouped by initiating events and include the following:

1. Large-scale surface-water impoundment constructed near the controlled area.

   a. Area, depth, and volume of surface impoundment.

   b. Seepage and percolation rates, and transmissivities of near surface and subsurface materials.

2. Extensive irrigation is conducted near the controlled area.

   a. Area of irrigation.
   b. Quantity of water available for irrigation.
   c. Types of crops cultivated.
   d. Infiltration and percolation rates.
   E. Quantity of water applied for irrigation.

All initiating events will require information on the presence and readability of the markers over 10,000 yr.

Description

The results of the natural resource assessment activities along with data from the activities in Section 8.3.1.2 (geohydrology) will provide input to this activity. These data will be used to assess the credibility and significance of the initiating events of potential human interference activities at Yucca Mountain. A special panel of experts from the disciplines of natural resources exploration, geosciences, economics, social sciences, and statistics will be convened to make a qualitative assessment of the non-credible or insignificant initiating events by using their experience and the parameters listed previously. The panel's professional judgment along with previously noted data will be used to prepare topical reports on those non-credible and insignificant initiating events.

Methods and technical procedures

Since this activity involves data synthesis or analysis, no technical procedures are required.

8.3.1.9.3.3 Application of results

The information obtained from the activities supporting Investigations 8.3.1.9.1 and 8.3.1.9.2 will be assessed by a panel of experts (Study 8.3.1.9.3.1). The professional judgment of the panel members will be used to estimate the bounds on the probability of inadvertent human interference and intrusion resulting from potential exploratory activities (Louden, 1979). The information obtained in Investigation 8.3.1.9.2 will be used in Issue 1.9 (higher level findings--postclosure; Section 8.3.5.18) to demonstrate that human interference and intrusion will not likely arise due to exploration and extraction of natural resources. The information obtained from Study 8.3.1.9.3.2 will be used in Issue 1.1 (total system performance; Section 8.3.5.13) to develop the most-probable release scenarios. These data will be provided as input parameters to Issues 1.1 and 1.8 (NRC siting criteria; Section 8.3.5.17) for use in calculating total system releases and in evaluating the potentially adverse conditions.

8.3.1.9.4 Schedule and milestones for Site Program 8.3.1.9 (human interference)

The human interference program includes three investigations, which contain five studies. The schedule information for each study is summarized in Figure 8.3.1.9-5. This figure includes the study number and a brief description, as well as major events associated with each study. A major event, for purposes of these schedules, may represent the initiation or completion of an activity, completion or submittal of a report to the DOE, an important data feed, or a decision point. Solid lines on the schedule represent study durations and dashed lines show interfaces among studies as well as data transferred into or out of the human interference program. The events shown on the schedule and their planned dates of completion are provided in Table 8.3.1.9-4.

The study-level schedules, in combination with information provided in the logic diagrams for this program (Figures 8.3.1.9-1 through -4), are intended to provide the reader with a basic understanding of the relationships between major elements of the site, performance, and design programs. The information provided in Table 8.3.1.9-4 and Figure 8.3.1.9-5, however, should be viewed as a snapshot in time.

The overall program schedule presented here is consistent with the Draft Mission Plan Amendment (DOE, 1988a). The site characterization program will undergo a series of refinements following issuance of the statutory SCP. Refinements will consider factors both internal and external to the site characterization program, such as changes to the quality assurance program. Such refinements are to be considered in ongoing planning efforts, and changes that are implemented will be reflected in the semiannual progress reports. Additional schedule information for activities within site program studies is to be provided in SCP support documents. Summary schedule information for the human interference program can be found in Sections 8.5.1.1 and 8.5.6.

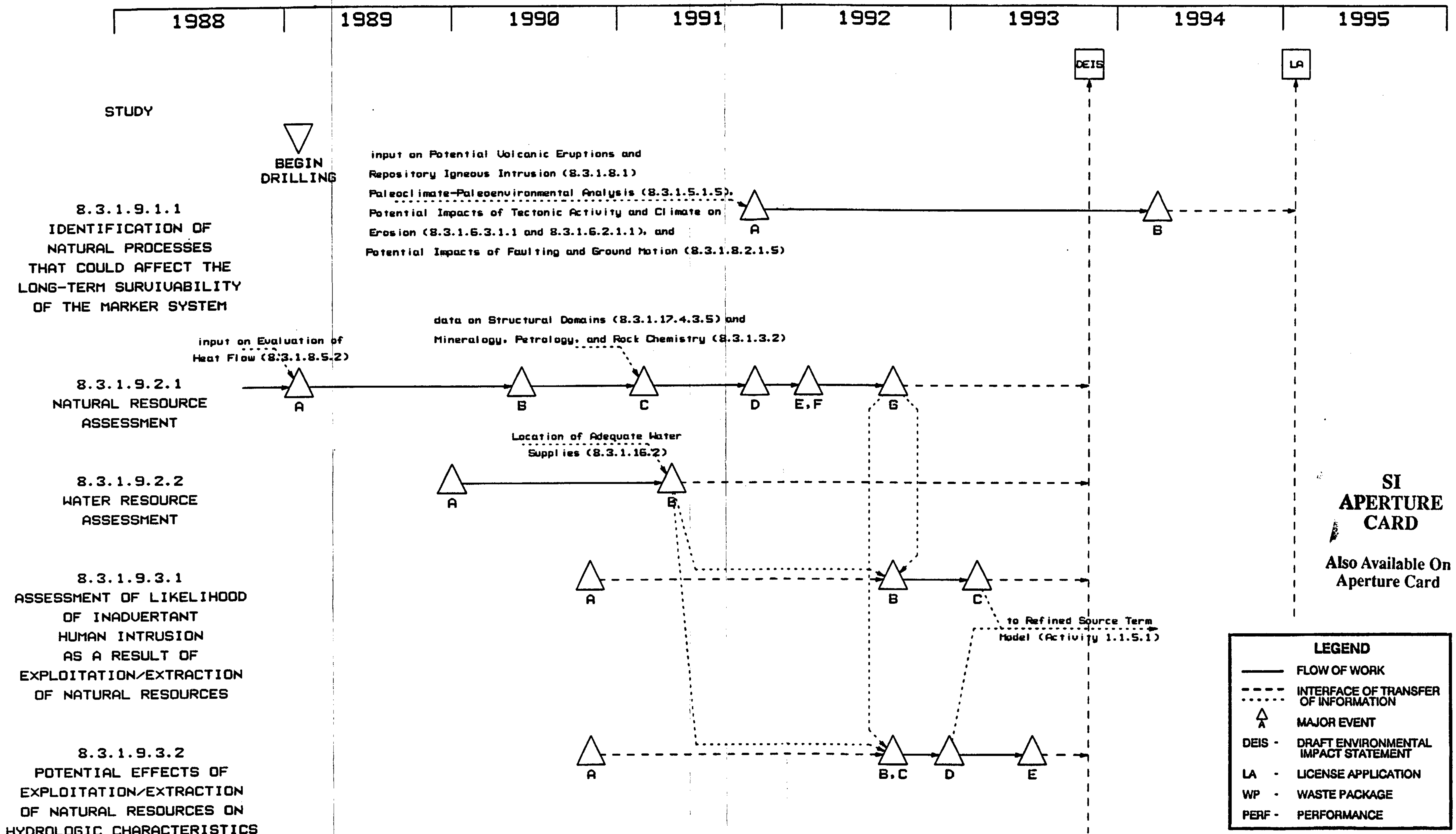

Figure 8.3.1.9-5. Schedule information for studies in Site Program 8.3.1.9 (human interference). See Table 8.3.1.9-3 for descriptions of major events. This network is consistent with the Draft Mission Plan Amendment (DOE, 1988a) schedule. Revisions will be published in semiannual site characterization progress reports as new information becomes available.

Table 8.3.1.9-4. Major events and planned completion dates for studies in the human interference program (page 1 of 3)

Study number	Brief description of study	Major event[a]	Event description	Date
8.3.1.9.1.1	Identification of natural processes that could affect the long-term survivability of the surface marker system	A	Study plan approved	10/91
		B	Report available to the U.S. Department of Energy (DOE) synthesizing data on the natural processes that could affect marker survivability	3/94
8.3.1.9.2.1 (ongoing)	Natural resource assessment	A	Initiate assessment of geothermal energy potential	1/89
		B	Draft report available to DOE on the assessment of hydrocarbons at or near the site	5/90
		C	Initiate geophysical/geological assessment of mineral resources	2/91
		D	Draft report available to DOE on the assessment of geothermal energy potential at or in the vicinity of Yucca Mountain	10/91
		E	Draft report available to DOE on the geophysical/geological assessment of mineral resources at the site	2/92
		F	Draft report available to DOE on the mineral and energy potential of the site	2/92

Table 8.3.1.9-4. Major events and planned completion dates for studies in the human interference program (page 2 of 3)

Study number	Brief description of study	Major event[a]	Event description	Date
8.3.1.9.2.1 (ongoing)	Natural resource assessment (continued)	G	Draft of final report on the evaluation of natural resource potential at the site available to DOE	8/92
8.3.1.9.2.2	Water resource assessment	A	Study plan approved	12/89
		B	Draft report available to DOE on the assessment of water resources at Yucca Mountain	4/91
8.3.1.9.3.1	Evaluation of data needed to support an assessment of the likelihood of inadvertant human intrusion as a result of exploitation/extraction of natural resources	A	Study plan approved	10/90
		B	Initiate work on the determination of factors contributing to the likelihood of human interference/ intrusion	8/92
		C	Draft report available to DOE on factors contributing to the like-lihood of human interference and intrusion at Yucca Mountain	2/93
8.3.1.9.3.2	Evaluation of the potential effects of exploitation/ extraction of natural resources on the hydrologic characteristics at Yucca Mountain	A	Study plan approved	10/90
		B	Initiate work on the determination of potential effects of exploiting ground water	8/92

Table 8.3.1.9-4. Major events and planned completion dates for studies in the human interference program (page 3 of 3)

Study number	Brief description of study	Major event[a]	Event description	Date
8.3.1.9.3.2	Evaluation of the potential effects of exploitation/ extraction of natural resources on the hydrologic characteristicst at Yucca Mountain (continued)	C	Initiate assessment of noncredible human interferences	8/92
		D	Draft report available to DOE on the potential effects of exploiting ground-water resources proximal to the Yucca Mountain site	12/92
		E	Complete assessment of noncredible human interferences	6/93

[a]The letters in this column key major events shown in Figure 8.3.1.9-5.

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Chapter 8, Section 8.3.1.10, Population Density and Distribution

December 1988

U. S. Department of Energy
Office of Civilian Radioactive Waste Management

8.3.1.10 Overview of population density and distribution program: Description of population density and distribution required by the performance and design issues

This section presents references and information to support 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 detailed link to these regulations is presented in the performance and design issues that require data from the population density and distribution program.

Collection of population density and distribution data is not considered a site characterization activity as defined in the Nuclear Waste Policy Act (NWPA, 1983). Therefore, the format and details for data collection will not be presented in this document. Population density and distribution, however, remain important components of the program of preclosure radiological safety for members of the general public, whether through normal operations or as a result of accident conditions (Issues 2.1 and 2.3). The data base established during this program will contribute to Issue 2.5, which addresses higher level findings on the qualifying and disqualifying conditions of the DOE 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 currently recognized as a significant factor in defining preclosure radiological safety programs. Preparation of a radiological monitoring plan will help to establish the data base required for resolution of performance and design issues related to radiological safety. This plan, in part, will be the mechanism for implementing the studies necessary for calculating radionuclide doses to members of the general public at varying distances from the potential repository location at Yucca Mountain. The details of the methodology to be used in analyzing the population related information will be discussed in the Radiological Monitoring Plan. The methods and procedures for collection of population data will be part of the Yucca Mountain Project socioeconomic planning process and environmental program planning effort.

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Chapter 8, Section 8.3.1.11, Land Ownership and Mineral Rights

December 1988

U. S. Department of Energy
Office of Civilian Radioactive Waste Management

8.3.1.11 Overview of land ownership and mineral rights program: Description of status and plans for land ownership and mineral rights required by the performance and design issues

The land ownership and mineral rights program derives 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 acquiring land ownership and mineral rights are not considered site characterization activities as defined by the Nuclear Waste Policy Act (NWPA, 1983). Therefore, the standard format and level of detail that is presented for other programs will not be provided in this section. However, 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. Information about postclosure site ownership and control is presented in Sections 8.3.5.18 (postclosure higher level findings) and 8.3.1.9 (human interference). The performance and design issues concerning radiological dose calculations to the public and workers (Issues 2.1, 2.2, 2.3, and 2.7, Sections 8.3.5.3, 8.3.5.4, 8.3.5.5, and 8.3.2.3, respectively) 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 Part 960. Another aspect of the land ownership program is the process by which the land is acquired and controlled, including rights to subsurface resources. This process is described in the following paragraphs.

The parameters of the controlled area are defined in 40 CFR Part 191 and are based on information about the subsurface. After tentatively identifying the outline of the proposed repository site, the information-gathering elements of the land ownership program will occur in three basic steps. The first step is to define the boundaries of the parcel for which the DOE must obtain control and seek withdrawal. Inherent in this step is applying the information gained during site characterization that would influence the boundaries at the controlled area and accessible environment.

The second step is to ascertain the status of any preexisting outside rights with respect to the land at the site. Prior investigations have identified no such rights (e.g., mineral, grazing, or water rights) at or in the immediate vicinity of Yucca Mountain. However, monitoring of these situations during site characterization will be conducted by the DOE.

The third step involves the actual process by which information will be obtained for purposes of supporting a withdrawal application as set forth in the Federal Land Management Policy Act (FLMPA) and implementing Bureau of Land Management (BLM) regulations.

As established in the environmental assessment for the Yucca Mountain site (DOE, 1986b), the land area of interest to the DOE for the repository operations area and controlled area is entirely on Federal lands controlled by three Federal agencies. These lands include the Nellis Air Force Range (NAFR) controlled by the U.S. Department of the Air Force (DAF), the Nevada Test Site (NTS) controlled by the DOE, and public lands controlled by the U.S. Department of the Interior (DOI), BLM. The Military Lands Withdrawal Act of 1986 (Public Law 99-606; MLWA, 1986), recently enacted by Congress, withdrew the 2.9 million acre NAFR for defense-related use by the DAF. Management of these lands remains the responsibility of the BLM.

The land area of interest to DOE currently under BLM control is in the public domain and has not been segregated from the operation of the public land laws. There exists, therefore, a possibility that control of surface and subsurface rights on the public lands could change as a result of rights granted under FLMPA or applicable mining laws.

The ownership and control status of the land area of interest is important to the DOE for a variety of reasons. These include the length of time required to conduct site characterization activities, the land management plans and agreements, and the public domain status of the BLM controlled lands. The DOE will monitor not only actions taken by the BLM or DAF with regard to the land areas of interest to the DOE but also the current or proposed laws and regulations that may impact land ownership and control, or the rights to access such lands.

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. To initiate a withdrawal action, FLMPA 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. 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. The programmatic activities include the repository land withdrawal and control process and the environmental program planning effort for the Yucca Mountain site. To ensure that the data and information relevant and necessary to support a withdrawal action are acquired and documented properly, site characterization activities must be reviewed and withdrawal information and documentation requirements conducted in parallel with the site characterization program. 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 (1983) and the National Environmental Policy Act (NEPA, 1969).

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Volume V, Part B

Chapter 8, Section 8.3.1.12, Meteorology

December 1988

U. S. Department of Energy
Office of Civilian Radioactive Waste Management

8.3.1.12 Overview of the meteorology program: Description of meteorological conditions required by the performance and design issues

Summary of performance and design requirements for meteorological information

The purpose of the meteorological program is to provide data required for resolving of performance and design issues. The types of data requested fall into three categories: (1) data needed in calculating radiological doses resulting from airborne releases from the repository during the preclosure operational period; (2) information required for design of surface facilities; and (3) hydrometeorological measurements for hydrologic and climatic studies. Table 8.3.1.12-1 shows the link between the design and performance parameters (information needed) and the meteorology program parameters that satisfy those needs, respectively.

Approach to satisfy performance and design requirements

The purpose of the meteorology program is to establish (1) regional meteorological conditions (Investigation 8.3.1.12.1), (2) atmospheric and meteorological phenomena at potential locations of surface facilities (Investigation 8.3.1.12.2), (3) locations of population centers relative to wind patterns in the general region of the site (Investigation 8.3.1.12.3), and (4) potential extreme weather phenomena and their recurrence intervals (Investigation 8.3.1.12.4).

The investigations were created so that an understanding of the meteorology of the area, including both average and extreme climatic 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. Parameters that are important in determining the dispersion characteristics and general regional meteorology and, hence, are important to the performance and design issues, are as follows:

1. Wind speed.
2. Wind direction.
3. Ambient temperature.
4. Atmospheric moisture.
5. Precipitation type, amount, frequency of occurrence, and intensity.
6. Atmospheric stability.
7. Mixing layer depth.
8. Barometric pressure.

These data will provide input to the performance and design issues that assess the preclosure radiological safety aspects of the mined geologic disposal system under normal and accident conditions. These issues are as follows:

Issue	Short title	SCP section
2.1	Public radiological exposures--normal conditions	8.3.5.3

Table 8.3.1.12-1. Performance allocation table for meteorology program

Issue	SCP section	Performance or design parameter	Characterization parameter	Testing basis: Current estimate	Testing basis: Current confidence	Testing basis: Needed confidence	SCP study (or activity)[a]
2.1, 2.2, 2.3, 4.2, and 4.4	8.3.5.3, 8.3.5.4, 8.3.5.5, 8.3.2.3, 8.3.2.4, and 8.3.2.5	χ/Q	Wind speed	Figures 5-3 to 5-7	Low	High	8.3.1.12.1.1--Regional meteorological conditions
			Wind direction	Tables 5-6 and 5-7	Low	High	
				Figures 5-3 to 5-7	Low	High	
				Tables 5-6 and 5-7	Low	High	8.3.1.12.2.1.1--Site meteorological monitoring program
			Temperature	Tables 5-2 and 5-3	Low	High	
			Mixing layer depth	Quiring (1968)	Low	High	
			Atmospheric stability	Table 5-11	Low	High	
			Atmospheric moisture	Tables 5-2 and 5-5	Low	High	
			Precipitation (type, amount, intensity)	Tables 5-2 and 5-4	Low	High	
2.2	8.3.5.4	Radon emanation rate from tuff	Temperature	Tables 5-2 and 5-3	Low	High	8.3.1.12.2.1.2--Data summary for input to dose assessments
			Barometric pressure	Table 5-2	Low	High	
2.3 and 4.4	8.3.5.5 and 8.3.2.5	Accident initiating events	Extreme winds and frequency of occurrence	Tables 5-2 and 5-8	Medium	High	8.3.1.12.4.1--Potential extreme weather phenomena and their reoccurrence
			Lightning strikes and frequency	Section 5.1.1.6	Medium	High	
			Precipitation extremes (snow, rain, ice, and amounts and frequency)	Tables 5-2, 5-4, and 5-10	Medium	High	
			Temperature extremes	Tables 5-2, 5-3, and 5-9	Medium	High	

[a]Studies and activities listed apply to all parameters associated with the issue.

Issue	Short title	SCP section
2.2	Worker radiological safety--normal conditions	8.3.5.4
2.3	Accidental radiological releases	8.3.5.5
2.5	Higher level findings--preclosure radiological safety	8.3.5.6
2.7	Repository design criteria for radiological safety	8.3.2.3

The investigation that deals with population centers relative to wind patterns (Investigation 8.3.1.12.3) 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. The extreme weather data will be evaluated in designing physical systems or components of the repository (e.g., wind or snow loading, heating and cooling systems, freeze protection) and must also be factored into the safety analysis in terms of the potential for extreme weather to initiate radiological accidents. Both repository operations and transportation of waste to the site will make use of the extreme weather data, and these data could be important in access route assessments.

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. The relationship of the meteorology program to design issues, performance issues, and other programs is shown on the logic diagram for the meteorology program in Figure 8.3.1.12-1. This logic diagram also indicates how the investigations planned to provide the program data are linked to the individual studies and activities.

The environmental assessment (EA) (DOE, 1986b) for the Yucca Mountain Project (formerly called Nevada Nuclear Waste Storage Investigations Project) included meteorological data and analyses from existing meteorological monitoring networks in the vicinity of Yucca Mountain. These data and analyses proved useful for the purposes of the EA in that they provided enough information to support conclusions for the favorable and potentially adverse conditions of 10 CFR Part 960 and, more importantly, to support a preliminary finding on the qualifying condition. Additional data, both regional and site specific, are necessary to support the higher-level findings on the qualifying conditions required at the time of repository site selection (Section 8.3.5.6).

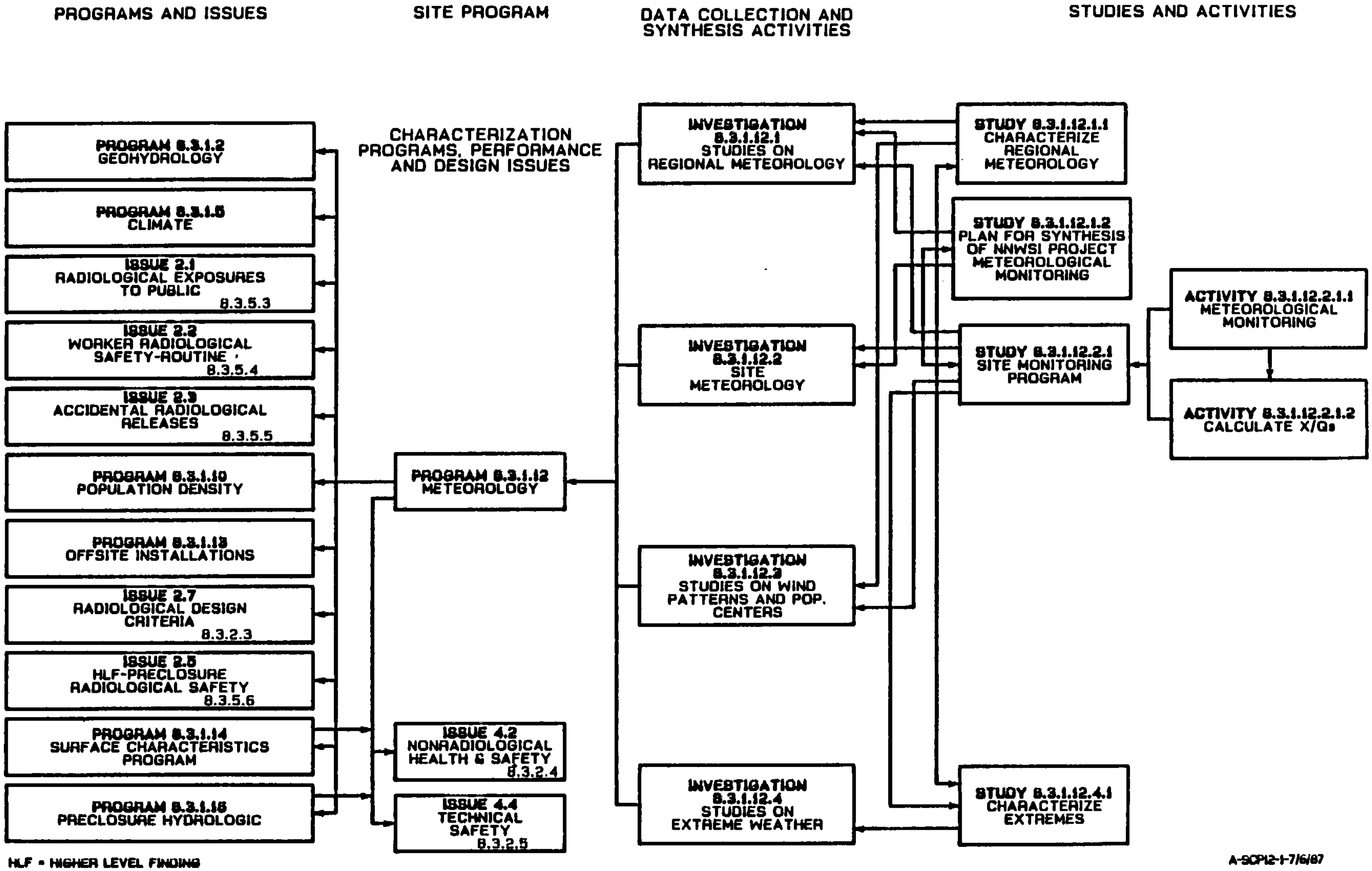

Figure 8.3.1.12-1. General logic diagram for meteorology program.

Interrelationships of meteorology investigations

The data and information developed through the meteorology program and associated investigations will have connections with the following issues, programs, investigations, and information needs:

1. Issue 2.1: Preclosure doses to members of the public in highly populated areas and members of the public within any unrestricted area. Information Need 2.1.1--site and design information (Section 8.3.5.3.1)--is linked to the meteorology program.

2. Issue 2.2: Preclosure doses to workers. Information Need 2.2.1--natural radiation environment (Section 8.3.5.4.1)--is linked to the meteorology program.

3. Issue 2.3: Accident-related doses to workers and members of the public. This issue is resolved through Information Needs 2.3.3, worker exposures under accidental conditions (Section 8.3.5.5.3) and 2.3.4, public exposures under accidental conditions (Section 8.3.5.5.3).

4. Issue 2.5: Higher level findings relative to preclosure system and technical guidelines. How the site meets and will continue to meet qualifying conditions of the technical guidelines is related to the meteorology program.

5. Issue 2.7: Design characteristics of the repository in terms of design criteria and performance issues. Information Need 2.7.1--site information for design (Section 8.3.2.3.1)--is linked to the meteorology program.

6. Program 8.3.1.10: Population density and distribution. The importance of meteorological conditions to the population density program is in determining whether winds would transport radiological emissions from the repository toward population centers.

7. Program 8.3.1.13: Offsite installations. The investigation specifically linked with the meteorology program is offsite transportation (8.3.1.13.1).

8. Program 8.3.1.14: Surface characteristics. The applicable investigation under this program is meteorological conditions at surface facility locations.

9. Program 8.3.1.16: Preclosure hydrology. Assessing preclosure hydrologic conditions in the vicinity of Yucca Mountain will rely on the characteristics of precipitation events throughout the region and the wind flow patterns associated with such events.

10. Program 8.3.1.2: Geohydrology. The investigations related to the meteorology program are Investigations 8.3.1.2.1 (description of the regional hydrologic system) and 8.3.1.2.2 (description of the unsaturated zone hydrologic system at the site).

11. Program 8.3.1.5: Climate. The climate program investigations that need meteorological input are those associated with establishing the nature of the existing climate at Yucca Mountain, and how present conditions relate to historical conditions.

The schedule information provided for information needs in this section includes the sequencing, interrelationships, and relative durations of the activities in the information need. Specific durations and start/finish dates for the activities are being developed as part of ongoing planning efforts and will be provided in the SCP at the time of issuance and revised as appropriate in subsequent semiannual progress reports.

Summary of studies

The studies planned for the meteorology program fall into two general categories: (1) those studies that are concerned with only site-specific data and (2) those studies that are associated with regional meteorological conditions.

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 (see following discussion) will then be assimilated into a data set that represents the regional meteorological conditions. This investigation will also coordinate monitoring efforts needed for other issues or programs with the data being obtained through the meteorology program.

A site monitoring program consisting of five towers has been implemented at Yucca Mountain (Investigation 8.3.1.12.2). The locations of these towers are shown in Figure 8.3.1.12-2. Although this network was initially established to support environmental permitting and licensing activities, the parameters being monitored will also be used as input in evaluating preclosure radiological impacts. The data being collected will serve as input to predictive models for dose calculations to ensure that radiological safety is not compromised as a result of the meteorological characteristics of the site.

The studies identified for characterizing wind patterns relative to population centers (Investigation 8.3.1.12.3) will consist of providing data on and analyses of wind parameters that will be used with the population density program identified in Section 8.3.1.10. 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 preferentially carry radioactive material released to the air towards 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 cause accidents during repository operation and transportation of waste to the site, the occurrence of such phenomena and their recurrence interval must be determined (Investigation 8.3.1.12.4).

Schedule information for Site Program 8.3.1.12 (meteorology) is presented in Section 8.3.1.12.5.

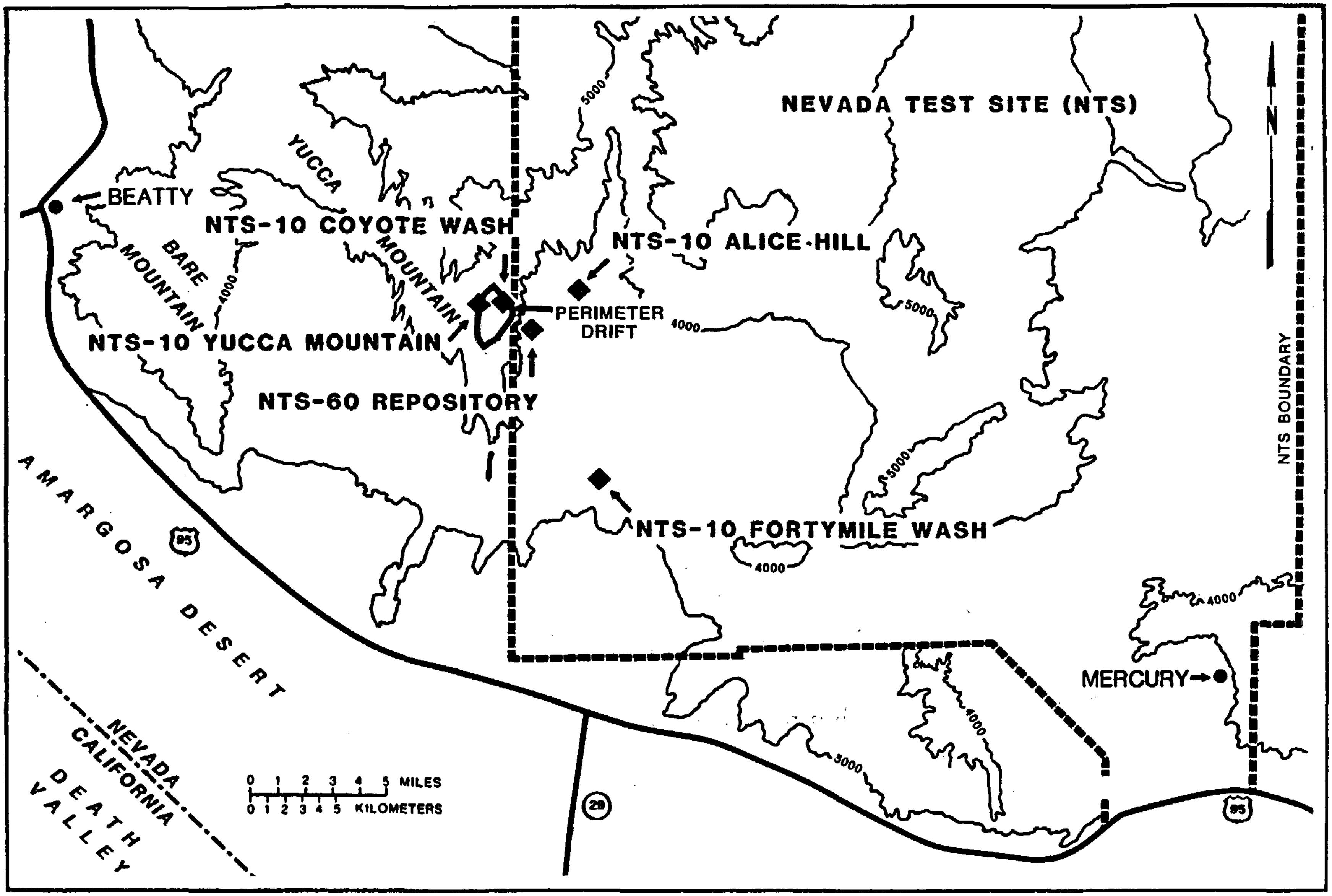

Figure 8.3.1.12-2. Meteorological monitoring sites operated as part of the Yucca Mountain Project.

8.3.1.12.1 Investigation: Studies to provide data on regional meteorological conditions

Technical basis for obtaining the information

Link to the technical data chapters and applicable support documents

Technical data summaries of regional meteorological conditions are in Chapter 5 of the SCP and in the Yucca Mountain EA (DOE, 1986b). Specifically, Section 5.1 of the SCP includes descriptive text and tables on regional meteorology appropriate to the Yucca Mountain site. Section 3.4.3 of the EA includes material on regional meteorology and related environmental materials, such as air quality and noise.

Parameters

Existing data bases will be examined to characterize regional conditions in terms of the following meteorological parameters:

1. Wind speed.
2. Wind direction.
3. Ambient temperature.
4. Atmospheric moisture.
5. Precipitation type, amount, frequency of occurrence, and intensity.
6. Atmospheric stability.
7. Mixing layer depth.
8. Barometric pressure.
9. Variability of parameters 1 through 5 at a given site and between sites.

Ideally, each data base examined would contain all of these parameters in a similar format (hourly averages). However, much of the existing data have been collected by private and governmental agencies for varying purposes and are not uniform in content, format, monitoring methodology, or quality. The data identified will, therefore, have to be carefully evaluated to determine their appropriateness to this study. Because some of the data will only be available as summaries of multiyear intervals (e.g., 5- or 10-yr climatological summaries), only general trends and averages for certain regions of the area around Yucca Mountain can be derived.

The data collected at the site (Section 8.3.1.12.2) will supplement the regional meteorology characterization and provide the relationship between the regional data and site-specific data. These data (specifically precipitation amounts used to track storm trajectories) will also serve as input to investigations associated with hydrology.

Purpose and objectives of the investigation

The purpose of this investigation is to provide data on the regional meteorological conditions in the general vicinity of Yucca Mountain, extending to Las Vegas, and to coordinate meteorology program monitoring efforts with other Yucca Mountain Project meteorological monitoring. Some of the data can then be used in calculating radiation doses to the general public and at the nearest major population center that might be caused by the proposed repository under routine and accident scenarios.

Technical rationale for the investigation

One of the major concerns in the siting of a geologic repository is to ensure that its design and performance do not result in radiological impacts, due to airborne releases, to workers and the general public that exceed established limits. Because this concern must be satisfied before the construction of the facility, predictive tools are used in estimating the impacts of postulated releases from the repository. These predictive tools are typically dispersion models, which require data on the transport mechanism (in this case the atmosphere). Impacts predicted to occur in the immediate vicinity of the release dictate the use of site-specific meteorological data. This need is covered in Section 8.3.1.12.2. However, the applicable regulations also require that impact determinations be made at distances up to 80 km (50 miles) from the source. Therefore, site-specific data must be used in conjunction with regional data. In addition, impacts at the nearest major population center must be evaluated. For Yucca Mountain, the nearest major center is Las Vegas, Nevada, which is 137 km (85 miles) by air southeast of the site.

Another aspect of the Yucca Mountain site that warrants examination of data from various locations is the terrain. Because the topography of the area is complex, data from any single location may reflect unique terrain influences. These site-specific data will be used in characterizing regional meteorology to show topographic influences on regional windflow and precipitation patterns.

The parameters listed above collectively determine how material emitted from the repository system will be transported downwind. In addition to providing a picture of the overall meteorology of the region, these parameters are required input to dispersion models that will be used in calculating impacts. Atmospheric moisture and precipitation, although not specifically needed in dispersion analyses, are other comparative tools used in determining overall weather patterns for the area. The seasonal variability of the data from any given site and the variability of parameters between sites will aid in constructing the regional meteorology. The operational life of the repository during which postulated releases could be occurring is several years. Therefore, regional data from stations that have operated for long periods of time will help establish a link between present-day meteorological conditions and long-term averages of meteorological parameters.

8.3.1.12.1.1 Study: Characterization of the regional meteorological conditions

Objectives

The objective of this study is to gather and analyze meteorological data from various locations to characterize the regional meteorology and assimilate that information into a regional summary report. This will be accomplished by determining if there are meteorological monitoring stations that have been operated in the general vicinity of the site and might be sources of information (in addition to those evaluated in Section 5.1). Comparisons between site and very-near-site data and data from these regional sources will give a more complete picture of the areal variability of conditions around the site than is presently available. This characterization will provide a regional overview of wind flow patterns and other meteorological parameters (related to atmospheric dispersion) associated with those patterns in and around Yucca Mountain.

Parameters

The parameters of interest, although many will not be available at all the monitoring locations identified, are

1. Wind speed.
2. Wind direction.
3. Ambient temperature.
4. Atmospheric moisture.
5. Precipitation type, amount, frequency of occurrence, and intensity.
6. Atmospheric stability (and method by which it was determined).
7. Mixing layer depth.
8. Barometric pressure.

Description

This study will involve contacting potential sources of meteorological data and determining what data are available in the area of interest. Potential sources of data include the National Weather Service (NWS), State of Nevada agencies (the State), the Environmental Protection Agency (EPA), the Nevada Test Site (NTS), the Nellis Air Force Range (NAFR), Desert Research Institute (DRI), and any other entities, such as private industry, recommended by these initial contacts. The State and the EPA are likely to be useful sources of meteorological data because, in addition to data from stations they operate themselves, these agencies should be able to identify private industry concerns that are collecting or have collected meteorological data to fulfill regulatory requirements. The NTS will be a source of meteorological data because of its proximity to the Yucca Mountain site, and because it has operated a number of meteorological monitoring stations in support of DOE activities. The NWS is always a valuable resource in securing meteorological data, but the density of NWS stations in southwestern Nevada is somewhat low. Organizations like the DRI may be able to identify meteorological data collected in support of research efforts that are not driven by regulations. In addition, periodicals and journals will be reviewed for articles on the meteorology of the area. Obtaining the data on magnetic tape would facilitate analysis and summarization, but much of the data may not be available in that form.

Once the data have been obtained and reviewed in terms of the period of record, the parameters available, the sampling and averaging frequency and the quality, a report on the regional meteorology will be prepared. The report will include a discussion of general wind flow patterns and their seasonality, differences and similarities between sites, general trends of any given parameter, terrain influences, and the relationship between site-specific data (Section 8.3.1.12.2) and regional characteristics.

Methods and technical procedures

The method and technical procedure for Study 8.3.1.12.1.1 is given in the following table:

Method	Technical procedure		
	Number	Title	Date
Data review and analysis	TBD[a]	Process for determining data acceptability	TBD

[a]TBD = to be determined.

8.3.1.12.1.2 Study: Plan for synthesis of Yucca Mountain Project meteorological monitoring

Objectives

The objective of this study is to develop a plan that provides for coordination of meteorological monitoring efforts proposed during site characterization by the various Yucca Mountain Project participants.

Parameters

The parameters that will be incorporated into the coordination of Yucca Mountain Project meteorological monitoring are

1. Wind speed.
2. Wind direction.
3. Ambient temperature.
4. Atmospheric moisture.
5. Precipitation type, amount, frequency of occurrence, and intensity.
6. Atmospheric stability.

7. Mixing layer depth.
8. Barometric pressure.
9. Solar and terrestrial radiation.
10. Chemical and isotopic character of precipitation.

Description

The plan that will be developed under this study will provide coordination between meteorological monitoring efforts initiated through Characterization Programs 8.3.1.12 (meteorology), 8.3.1.5 (climate), 8.3.1.2 (geohydrology), and 8.3.1.16 (preclosure hydrology). The plan will also provide for review of the various monitoring efforts proposed in terms of meteorological adeqquacy and consistency. The specific studies under these programs that are associated with meteorological monitoring are Study 8.3.1.2.1.1 (characterization of regional meteorology), Study 8.3.1.2.1.3 (characterization of regional ground-water flow), Study 8.3.1.2.2.1 (characterization of unsaturated zone infiltration), Study 8.3.1.5.1.1 (characterization of modern regional climate), and Study 8.3.1.12.2.1 (site meteorological monitoring). The preclosure hydrology program calls for meteorological data from geohydrology program Studies 8.3.1.2.1.1, 8.3.1.2.1.3, and 8.3.1.2.2.1.

Presently no single study encompasses all the meteorological monitoring needed to characterize the site because meteorological data are needed by four different programs for slightly different purposes. For example, the meteorology program needs those parameters that define atmospheric dispersion characteristics, the geohydrology program needs precipitation-related parameters, and the climate program needs meteorological characteristics that relate to regional climate. All the programs, however, need to be coordinated to avoid a duplication of monitoring efforts and to effectively make use of technical experts within each of the programs.

The plan will present a description of all the programs that call for meteorological data, a more complete explanation of why each program needs the data, the parameters that will be measured for the program, and any links between the monitoring efforts. An evaluation of each of the monitoring programs will also be conducted to ensure that adequate data are being collected to satisfy the identified needs. The plan will also include the developing of most of an integrated network of meteorological stations that will incorporate the needs of all the programs. All these efforts will be coordinated among the programs and will use the collective experience and discipline-specific needs of the participants involved. Some of the monitoring programs involved are ongoing or will be expanded as site characterization proceeds.

Methods and technical procedures

There are no specific methods or technical procedures associated with development of the plan for synthesis of project meteorological monitoring.

8.3.1.12.1.3 Application of results

The information derived from the study described previously will be used in the following information needs and investigations:

Investigation or information need	Subject
8.3.1.2.1	Description of the regional hydrologic system
8.3.1.2.2	Description of the unsaturated zone system at the site
8.3.1.5.1	Nature and rates of change in climatic conditions to predict future climates
2.1.1	Site and design information needed to assess preclosure radiological safety (Section 8.3.5.3.1)
2.1.3	Determination that public radiation exposures resulting from the releases of radioactive material from the repository combined with exposures from offsite installations and operations meet applicable requirements
2.3.4	Determination that projected public exposures and exposure conditions under accident conditions meet applicable requirements (Section 8.3.5.5.3)
2.5.1	Determination that the site is not disqualified and is not likely to be disqualified for each of the disqualifying conditions (Section 8.3.5.6.1)
2.5.2	Determination that the site meets the qualifying conditions of the technical guidelines and is likely to continue to meet the qualifying conditions (Section 8.3.5.6.2)
2.7.1	Site information needed for design (Section 8.3.2.3.1)
8.3.1.12.2	Atmospheric and meteorological phenomena at potential locations of surface facilities
8.3.1.12.3	Location of population centers relative to wind patterns in the general region of the site

8.3.1.12.2 Investigation: Studies to provide data on atmospheric and meteorological phenomena at potential locations of surface facilities

Technical basis for obtaining the information

Link to the technical data chapters and applicable support documents

None of the technical data chapters provides an in-depth description of the site meteorological monitoring program. Section 5.1 of the SCP contains a brief summary of the program, and a detailed description can be found in the Meteorological Monitoring Plan (SAIC, 1985).

Parameters

The following meteorological parameters are being monitored at the Yucca Mountain site:

1. Wind speed.

2. Wind direction.

3. Ambient temperature.

4. Atmospheric moisture.

5. Precipitation type, amount, frequency of occurrence, and intensity.

6. Atmospheric stability (calculated from either wind speed and standard deviation of wind direction or wind speed and net (solar and terrestrial) radiation).

7. Barometric pressure.

Each of these parameters is measured or calculated from measured values as required by applicable EPA monitoring guidelines (40 CFR Part 58) and NRC Regulatory Guide 1.23 (NRC, 1980) and summarized as an hourly average in monthly and quarterly data reports.

Purpose and objectives of the investigation

The purpose of this investigation is to collect site-specific meteorological data that can be used in calculating doses to workers, including workers in restricted areas, and the general public under routine and accident scenarios.

Technical rationale for the investigation

One of the primary mandates of the Nuclear Waste Policy Act and associated siting guidelines is to ensure that releases from the repository system do not result in exposures to workers or the public in excess of applicable standards. Compliance with this requirement must be demonstrated before construction of the facility and is generally accomplished through dispersion modeling as explained in Section 8.3.1.12.2.1.2. Although the information summarized for Section 8.3.1.12.1 (regional meteorological conditions) will provide a thorough understanding of the general wind flow patterns, atmospheric dispersion characteristics, temperature, and precipitation throughout the region, site-specific data from the proposed facility locations is needed to fully assess the potential impacts of releases. This is especially true for Yucca Mountain because the terrain in the immediate vicinity is quite complex, which results in micro-meteorological differences within relatively short distances. Regional conditions are, therefore, not sufficient in determining very-near-site meteorology.

To ensure that the meteorology specific to Yucca Mountain was completely evaluated, a monitoring network of five towers was installed and began operation in December 1985. The locations of these towers within the study area is shown in Figure 8.3.1.12-1. Two of the towers are located near potential facility locations: one tower is near the proposed repository surface facilities location and the other is near the proposed exploratory shaft site. If selected as a repository, the exploratory shaft at Yucca Mountain would be incorporated into the repository design as a ventilation shaft, so data from this site are quite important. Site-specific dispersion parameters, which will be used to calculate concentrations and subsequent doses, are required to satisfy this investigation.

The rationale for the meteorological monitoring program that has been implemented at Yucca Mountain, and the requirements for accuracy, calibration, auditing, reporting, and operating such a program were derived from a variety of rules, regulations, and guidelines. These governing documents are discussed in the following paragraphs.

Both the EPA and the NRC have promulgated regulations or guidelines outlining the meteorological data required to conduct certain environmental analyses, but none are specific to deep geologic repositories. The NRC regulations (10 CFR Part 60) under which a construction authorization and license for the repository would be issued have been approved, but they do not outline the scope and nature of the environmental analyses required to support those decisions. In lieu of specific guidelines concerning meteorological monitoring requirements, the Yucca Mountain monitoring program has been based on an understanding of the types of information (data and analyses) required by the NRC for licensing other nuclear facilities (e.g., reactors, reprocessing plants, spent fuel storage facilities). The primary NRC regulatory guideline that deals specifically with meteorological monitoring programs (NRC, 1980) is not repository specific but is, nonetheless, useful in helping to define the scope of the Yucca Mountain monitoring program. Sections C.2 (Siting of Meteorological Instruments), C.3 (Data Recorders), C.4 (System Accuracy), C.5 (Instrument Maintenance, Servicing Schedules, and Data Availability), and C.6 (Data Reduction and Compilation) of Regulatory Guide 1.23 (NRC, 1980) were evaluated for guidance in developing the monitoring network. To ensure that the monitoring programs implemented at Yucca Mountain would provide meteorological data acceptable for use in nonradiological regulatory permitting requirements, the program was also designed to comply with the EPA monitoring requirements for the Prevention of Significant Deterioration (40 CFR Part 58). The data these agencies require are to be used in addressing two aspects of repository development: (1) the potential for degrading the air quality in the vicinity of the repository by construction and excavation activities and (2) the role site-specific meteorological conditions would have in effectively dispersing routine operational and accidental releases from the repository.

The specific NRC regulatory guides reviewed to ensure responsiveness to evaluating expected and potential atmospheric releases are Regulatory Guides 4.17 (Standard Format and Content of Site Characterization Reports for High-Level-Waste Geologic Repositories), 4.18 (Standard Format and Content of Environmental Reports for Near-Surface Disposal of Radioactive Waste), 4.2 (Preparation of Environmental Reports for Nuclear Power Stations, Revision 2), 1.70 (Standard Format and Content of Safety Analysis Reports for Nuclear Power Plants, LWR Edition, Revision 3), and 3.8 (Preparation of Environmental Reports for Uranium Mills).

8.3.1.12.2.1 Study: Meteorological data collection at the Yucca Mountain site

The purpose of conducting meteorological monitoring at Yucca Mountain is to provide data that can be used in resolving design and performance issues associated with preclosure radiological safety. This study consists of two activities, one that deals strictly with collecting the meteorological data and the other dealing with processing the data into dispersion-specific parameters.

8.3.1.12.2.1.1 Activity: Site meteorological monitoring program

Objectives

The objective of the site monitoring program is to collect meteorological data at potential locations of surface facilities and at a sufficient number of additional locations deemed necessary to characterize the wind flow patterns in the vicinity of Yucca Mountain.

These data must be suitable for use in dispersion models that will be used in assessing radiological impacts resulting from repository operations. Discussion on the use and applicability of the output of these dispersion models is presented under Information Need 2.7.1 (Section 8.3.2.3.1). Another objective of the site monitoring program, although not related to resolution of this information need, is to provide data that are suitable for permitting and licensing activities for both site characterization and repository development.

Parameters

The following meteorological parameters are measured or calculated from measured values and summarized as hourly averages as required by EPA monitoring guidelines (40 CFR Part 58) and NRC Regulatory Guide 1.23 (NRC, 1980) at the five Yucca Mountain site locations discussed in the following description section:

1. Wind speed.
2. Wind direction.
3. Ambient temperature.
4. Atmospheric moisture.
5. Precipitation type, amount, frequency of occurrence, and intensity.
6. Atmospheric stability.
7. Barometric pressure.

Description

A detailed description of the site-monitoring activities can be found in the Meteorological Monitoring Plan (SAIC, 1985) and is summarized below. All activities are conducted in accordance with the Project Quality Assurance Program Plan (SAIC, 1986a).

Five sites in the vicinity of Yucca Mountain were chosen as monitoring locations. These sites are shown in Figure 8.3.1.12-2 and are further identified in Table 8.3.1.12-2.

The main meteorological tower (NTS-60 Repository) is located at an elevation of 1,143 m (3,751 ft) above mean sea level (MSL) near the proposed repository surface facility location. This area is bounded on the west by Yucca Mountain with peak elevation nearly 1,523 m (5,000 ft) above MSL and partially blocked from Jackass Flats to the east by three intermediate buttes with elevations of up to approximately 1,220 m (4,000 ft) above MSL. Data collected at this location will be used in assessing impacts associated with repository operations if the project proceeds to permitting activities.

The other four towers will be used to collect data on overall meteorological conditions in the area so that the site-specific data from the repository site can be interpreted more realistically. Data from these four remote sites will be particularly useful in characterizing terrain-induced perturbations that may significantly influence dispersion and transport of emissions.

The first of these remote locations is along the north-south trending ridge of Yucca Mountain approximately 3.9 km west-northwest of the main site at an elevation of 1,478 m (4,849 ft) above MSL, the highest elevation of any of the towers. This tower, NTS-10 Yucca Mountain, is 10 m high, and there are virtually no obstructions in any direction. Data from this site should be indicative of synoptic-scale weather conditions some of the time. Comparison of this data with the data from NTS-60 Repository during such times could provide insight into the relationship between synoptic-scale conditions and those that can be expected to occur at the surface facilities.

A second 10-m tower is located at the proposed site of the exploratory shaft, which is 2.7 km (1.7 miles) west-northwest of the main site at an elevation of 1,278 m (4,193 ft) above MSL. This tower is referred to as NTS-10 Coyote Wash and is located in one of the many drainages along the eastern side of Yucca Mountain. Data from this tower will be used primarily

Table 8.3.1.12-2. Meteorological monitoring sites operated by the Yucca Mountain Project

Site	UTM[a] Coordinates Zone 11 (m)	Nevada System (ft)	Latitude-longitude	Elevation (above MSL)[b]
NTS-60 Repository	550,776E 4,077,427N	569,127E 761,795N	3650'33" 11625'49"	3,751 ft 1,143 m
NTS-10 Yucca Mountain	547,660E 4,078,781N	558,862E 766,434N	3651'20" 11628'19"	4,849 ft 1,478 m
NTS-10 Coyote Wash	548,884E 4,078,689N	562,876E 766,195N	3651'17" 11627'05"	4,193 ft 1,278 m
NTS-10 Alice Hill	553,122E 4,079,787N	576,810E 769,661N	3651'51" 11624'14"	4,047 ft 1,234 m
NTS-10 Fortymile Wash	554,396E 4,068,691N	580,882E 733,230N	3645'51" 11623'27"	3,124 ft 952 m

[a]UTM = Universal Transverse Mercator.
[b]MSL = mean sea level.

to assess impacts from exploratory shaft operations, but will also be used in the overall site evaluation.

A third 10-m tower is located at Alice Hill, one of the buttes separating the project area from Jackass Flats. This site is 3.0 km (1.9 miles) northeast of the main site at an elevation of 1,234 m (4,047 ft) above MSL and is referred to as NTS-10 Alice Hill. This tower is located such that data from NTS-10 Yucca Mountain, NTS-10 Coyote Wash, and NTS-10 Alice Hill will provide a cross-section of the atmosphere in the lee of Yucca Mountain. In addition, because NTS-10 Coyote Wash and NTS-10 Alice Hill are at approximately the same elevation, comparisons with the main site can be used to evaluate the characteristics of the drainage flow that may form between the ridges.

The final 10-m tower is placed at the edge of Fortymile Wash, 9.2 km (5.7 miles) southwest of the main tower, at an elevation of 952 m (3,124 ft) above MSL. This wash is the major surface-water drainage for the area, and it is expected to influence significantly the air drainage during times when rapid nocturnal surface cooling causes air near the surface to subside. Data from NTS-10 Fortymile Wash will indicate how far down-valley repository emissions would be transported under these drainage conditions.

All monitoring equipment and stations have been designed and sited to ensure that all probes and samplers meet or exceed applicable EPA and NRC requirements and guidelines.

The meteorological sensors on the proposed 10-m towers are mounted at the top of the tower, precluding tower-induced turbulence interference. For the 60-m tower, wind speed and direction sensors will project approximately 1.8 m (5.9 ft) from the tower in the direction of the prevailing wind to minimize tower-induced turbulence effects.

The four 10-m towers are instrumented identically to measure wind speed, wind direction, sigma theta (standard deviation of horizontal wind direction) for determination of atmospheric stability, relative humidity, and temperature at the 10-m level. The 60-m meteorological tower is instrumented to measure or calculate wind speed, wind direction, and sigma theta at the 10- and 60-m levels; sigma phi (standard deviation of vertical wind direction), temperature, and relative humidity at the 10-m level; temperature difference between the 10- and 60-m levels; net radiation (solar and terrestrial) at the 3-m level; and precipitation at essentially ground level a short distance from the base of the tower. The sensors at the 10-m level satisfy the requirement of applicable monitoring guidelines for monitoring meteorological parameters at the standard exposure heights over level, open terrain. The NTS-10 Coyote Wash and NTS-10 Fortymile Wash 10-m towers will be located so as to characterize particular drainage and terrain-induced flow patterns to help define site-specific conditions. The sensors at the 60-m level will provide an indication of larger-scale wind flow patterns. Other details of the monitoring program, such as temperature sensor ventilation and shielding, net radiometer (solar and terrestrial) exposure, and precipitation gauge heating (for water equivalent measurements of snow) are all designed to be in full compliance with acceptable meteorological practice and applicable EPA and NRC regulations and guidelines.

Instrument specifications and station design. Meteorological parameters at all four remote sites will be monitored using continuous analyzers to provide hourly average wind speed, wind direction, sigma theta, relative humidity, and temperature. Power will be supplied by batteries that are trickle-charged by solar cells. Continuous recording of the data on strip charts is not feasible at these sites because of the lack of available commercial electrical power. With this exception, the meteorological equipment and methodologies will be in accord with referenced EPA and NRC rules, regulations, and guidelines.

All meteorological parameters at the main site will also be monitored using continuous analyzers. The continuously recorded meteorological parameters will be reduced and averaged (scalar and/or vector, if appropriate) to produce the following meteorological data base:

1. Hourly average wind speed (10- and 60-m levels).

2. Hourly average wind direction (10- and 60-m levels).

3. Hourly average standard deviation of horizontal wind direction (10- and 60-m levels).

4. Hourly average atmospheric stability based on Pasquill Stability Category using continuous sigma theta monitoring (with differential temperature, sigma phi, and net radiation data as backup).

5. Hourly average surface temperature at standard height for climatic comparisons and plume rise calculations.

6. Hourly average differential temperature measurements between the 10- and 60-m tower levels.

7. Hourly average dewpoint temperature.

8. Hourly average barometric pressure.

9. Hourly precipitation amounts for climatic comparisons.

Except as noted above, meteorological analyzers, equipment, and methodologies will be in accord with applicable EPA and NRC rules, regulations, and guidelines, and will be purchased, installed, and monitored in compliance with Yucca Mountain Project quality assurance requirements.

Instrument specifications will meet or exceed those given in applicable EPA and NRC rules, regulations, and guidelines. Where agency specifications differ, the more stringent specification has been used in designing the monitoring program. The specifications are as follows:

1. Wind direction: ±3° of true azimuth (including sensor orientation error) with a starting threshold of less than 0.45 m/s (1 mph).

2. Wind speed: ±0.22 m/s (0.5 mph) for speeds above the starting threshold of 0.45 m/s (1 mph) but less than 11.1 m/s (25 mph), and ±5 percent of true speed, not to exceed 2.5 m/s (5.6 mph), at speeds greater than 11.1 m/s (25 mph).

3. Sigma theta: wind vane damping ratio of between 0.4 and 0.6 (inclusive) with a 15° deflection and delay distance not to exceed 2 m.

4. Temperature: ±0.5°C (0.9°F).

5. Temperature difference (between levels): ±0.003°C (0.005°F) per meter.

6. Radiation (solar and terrestrial): ±5 percent.

7. Precipitation: resolution of 0.25 mm (0.01 in.) with recorded accuracy of ±10 percent of total accumulated catch.

8. Time: within 5 minutes of actual time for all recording devices.

These specifications apply to digital systems; analog backup systems can deviate by up to 1.5 times these values. There is no prescribed specification for barometric pressure sensors.

Data reporting. The meteorological and quality control data collected during the monitoring program will be summarized in three types of reports: monthly reports at the end of each monitoring month that will be for internal data verification only, quarterly reports prepared after each monitoring quarter, and annual reports summarizing each baseline monitoring year.

The quarterly reports will contain a quality-assured (i.e., in accordance with written, approved procedures and instructions) listing of the meteorological data collected at each site during the previous quarter by month. A discussion of the data recovery rates and significant project activities will also be included in these reports. The monthly reports will serve to track the technical aspect of the monitoring program.

The content and basic format for the monthly, quarterly, and annual data reports will be in a format and scope consistent with reporting requirements for the EPA, NRC, and the State of Nevada, and shall be in accordance with supplemental written and approved instructions. All reports will provide an indication of progress to date, a review of all site activities during the period of record, problems encountered and their resolution, percentage data recovery rates, calibration-audit reports, and other pertinent information.

The quarterly reports will also contain a summary description of the site equipment and operating methodologies and a hard copy of the hourly data listing for each parameter monitored as a second volume. A wind rose for each site showing the percent frequency distribution of wind speed and direction will also be included in each report. In addition, the quarterly reports will include a description of quality assurance and of quality control activities for the quarter.

The annual report will contain discussions and data similar to the monthly and quarterly reports but summarized for the entire monitoring year. In addition, meteorological summaries such as wind direction and speed persistence, diurnal variations, seasonal variations, and meteorological influences will be presented and discussed. Also the annual report will present a chronology of data recovery detailing the annual data recovery rates by parameter. The joint frequency of wind speed, wind direction, and atmospheric stability will be presented and discussed in terms of persistence and frequency of occurrence. These data will be in a form suitable for use in air quality modeling analyses and for modeling potential radiological impacts.

Methods and technical procedures

The methods and procedures for Activity 8.3.1.12.2.1.1 are given in the following table.

Method	Technical procedure Number	Title	Date
Collection of meteorological data	DOE/NV/10270-5 SAIC 84/7600	Meteorological Monitoring Plan	9 Jul 85
	SAIC 85/8002	Instructions for receipt, acceptance testing, and performance auditing of meteorological monitoring equipment	20 Jan 86
	SAIC 86/8000	Instructions for operation and calibration checks of meteorological monitoring equipment	30 Apr 86
	TBD[a]	Data processing instructions (in preparation)	TBD

[a]TBD = to be determined.

8.3.1.12.2.1.2 Activity: Data summary for input to dose assessments

Objectives

The objective of this activity is to process the meteorological data collected as a result of Activity 8.3.1.12.2.1.1 into a format and content that will be useful in assessing radiological impacts, as required by the design and performance issues.

Parameters

The parameters listed in Activity 8.3.1.12.2.1.1 (from one or more sites) will be used in combination with an estimate of the mixing layer depth to calculate a concentration parameter: χ/Q. This parameter is calculated using dispersion models, and represents the concentration χ over the emission rate Q. χ/Qs will be calculated for several locations at various distances from the surface facilities. Calculating χ/Qs as opposed to concentrations allows the source term Q to be varied without rerunning the model, as needed for determining doses under accident versus routine emission scenarios.

Description

The concentration (χ/Q) values will be calculated using a dispersion model that is capable of simulating the meteorological and topographical influences on material emitted to the atmosphere as it is transported and dispersed downwind. A variety of models have been developed for this purpose, but most are appropriate only for use in flat or gently rolling terrain. The topography of the Yucca Mountain site, however, warrants the use of a model that can simulate complex terrain effects. Both the EPA and the NRC have issued documents that provide guidance on the selection and use of the various models that have been developed. This guidance will help ensure that the appropriate model is used.

The NRC has issued at least four regulatory guides that either reference, provide examples of, or suggest the use of models to determine χ/Q values, but none of them were developed specifically for geologic repositories. However, some of the information in these guidelines will be applicable to a repository. These guides are (1) Regulatory Guide 1.109--Calculation of Annual Doses to Man from Routine Releases of Reactor Effluents for the Purpose of Evaluating Compliance with 10 CFR Part 50, Appendix I (NRC, 1977a); (2) Regulatory Guide 1.111--Methods for Estimating Atmospheric Transport and Dispersion of Gaseous Effluents in Routine Releases from Light-Water-Cooled Reactors (NRC, 1977c); (3) Regulatory Guide 1.145--Atmospheric Dispersion Models for Potential Accident Consequence Assessments at Nuclear Power Plants (NRC, 1982a); and (4) Regulatory Guide 3.8--Preparation of Environmental Reports for Uranium Mills (NRC, 1982b). These documents will be reviewed to ensure that the dispersion analysis done for Yucca Mountain is comprehensive enough to satisfy typical NRC requirements.

The guidance for the EPA is contained within the guideline on air quality models (EPA, 1986). The EPA has also developed and provides a magnetic tape containing a variety of the approved and most frequently used models.. Although the EPA models are aimed at assessing nonradiological impacts, χ/Q values can be calculated using these models as well.

The χ/Q values will be calculated at discrete locations, but the receptor grid is arbitrary in that no specific sites have been selected for evaluation. Instead, a radial receptor grid will be used and χ/Q values at distances of 4, 8, 16, 24, 32, 40, 48, 56, 64, 72, and 80 km from an assumed source will be calculated in each of the 16 cardinal directions for a total of 176 receptors.

To ensure responsiveness to the design and performance issues, χ/Qs representing routine and accident release scenarios must be developed. Routine releases will be evaluated by calculating an annual average χ/Q value at each of the receptors. Because the accident scenarios must be evaluated under meteorologically worst-case conditions (in terms of dispersion), one-hour χ/Q values also will be required.

Other data needed as input to a dispersion model are one year of hourly sequential meteorological data (wind speed, wind direction, temperature, mixing height, and Pasquill stability class), receptor terrain heights and their Universal Transverse Mercator (UTM) coordinates, and source characteristics (UTM coordinates, stack height, stack diameter, exit gas velocity, exit gas temperature, and building-stack configuration). Once all these data have been put in the format required by the model, the model is run. Although the basic equations used in calculating an χ/Q value are not exceptionally complex, the large number of calculations required for a year of hourly meteorological data dictates the use of a computer.

A report presenting the χ/Q values and the information used in calculating those values will be prepared at annual intervals for up to 5 yr.

Methods and technical procedures

The method and procedure for Activity 8.3.1.12.2.1.2 is given in the following table.

Method	Technical procedure		
	Number	Title	Date
Dispersion modeling	TBD[a]	Instructions for performing dispersion analyses	TBD[a]

[a]TBD = to be determined.

8.3.1.12.2.2 Application of results

The meteorological data and resultant dispersion parameters will be used in the following information needs dealing with routine and accident scenarios:

Information need	Subject	SCP section
2.1.1	Site and design information needed--public radiological exposures from normal conditions	8.3.5.3.1
2.2.2	Project worker exposures--normal conditions	8.3.5.4.2
2.3.1	Credible repository accidents	8.3.5.5.1
2.3.2	Projected accidental releases	8.3.5.5.2

In addition, the meteorological data will provide input to Investigations 8.3.1.2.1, 8.3.1.2.2, 8.3.1.5.1, and 8.3.1.14.3.

8.3.1.12.3 Investigation: Studies to provide data on the location of population centers relative to wind patterns in the general region of the site

Technical basis for obtaining the information

Link to the technical data chapters and applicable support documents

The only data contained within the SCP relative to this investigation is in Section 5.1 (recent climate and meteorology). The preliminary finding relative to the qualifying condition associated with this investigation is contained in Chapter 6 of the Yucca Mountain environmental assessment (DOE, 1986b).

Parameters

The following summaries will be calculated using data from the site monitoring program (Activity 8.3.1.12.2.1.1) or from data gathered as a result of Investigation 8.3.1.12.1, regional meteorological conditions:

1. Frequency distribution of wind speed and direction.

2. Persistence of wind speed and direction.

3. Diurnal wind speed and direction.

4. Atmospheric dispersion associated with these summaries in parameters 1, 2, and 3 (if appropriate).

Purpose and objectives of the investigation

The purpose of this investigation, similar to Investigation 8.3.1.12.1, is to provide data on wind flow patterns in the general region of Yucca Mountain. These data will then be used in estimating doses to the public and in doing so ensure that wind flow patterns would not preferentially transport material towards population centers.

Technical rationale for the investigation

The qualifying condition for meteorology (10 CFR 960.5-2-3) requires an evaluation of the potential for preferential transport of radioactive emissions toward population centers in the vicinity of the site. Although a preliminary assessment was conducted for the Yucca Mountain environmental assessment (EA) (DOE, 1986b) using existing regional data, site-specific meteorological data are needed to supplement the conclusions reached in the EA.

The population density and distribution data will be collected as part of the population density program (Section 8.3.1.10). The meteorological data gathered and summarized as part of Investigations 8.3.1.12.1 and 8.3.1.12.2 should provide sufficient data in combination with the population data for satisfying this investigation. Assimilation of the population and meteorological data into dose calculations will make use of the data generated in Activity 8.3.1.12.2.1.2 and will be completed as part of Information Need 2.5.2 (Section 8.3.5.6.2) and Issues 2.1 (Section 8.3.5.3) and 2.3 (Section 8.3.5.5).

8.3.1.12.3.1 Application of results

The information from this investigation together with the data associated with the population density program will be used in calculating doses to members of the public under routine and accident scenarios (Issues 2.1 and 2.3).

8.3.1.12.4 Investigation: Studies to provide data on potential extreme weather phenomena and their recurrence intervals

Technical basis for obtaining the information

Link to the technical data chapters and applicable support documents

Section 5.1 (recent climate and meteorology) provides a technical summary of existing data relevant to this investigation.

Parameters

The following parameters will be evaluated using existing historical data bases and technical publications:

1. Frequency of severe storms (tornadoes, hurricanes, etc.).

2. Magnitude and frequency of extreme wind speeds.

3. Extremes of temperature and humidity.

4. Precipitation extremes (including hail and snow) and their recurrence intervals.

5. Frequency and intensity of fog.

Purpose and objectives of investigation

The purpose of this investigation is to assimilate data that can be used in evaluating the impact of extreme weather phenomena on surface facilities.

Technical rationale for the investigation

Extreme weather phenomena cannot be resolved from short-term, site-specific monitoring programs. Long-term meteorological and climatological data records must be used to provide a sufficient data base upon which to develop statistical predictions of extreme events along with their recurrence intervals.

The identification of extreme conditions is necessary to provide design information for the repository surface facilities. All structures must be designed for the meteorological conditions that may be experienced over the life of the facilities. Example of how meteorological data will influence design are as follows:

1. Temperature and humidity extremes will affect the design of heating and cooling systems.

2. Precipitation extremes will provide data for the design of containment basins, diversion channels, and culverts.

3. Snow and hail data will provide input to the design of roof loadings and external facilities.

4. Extreme wind speed estimates will provide critical design criteria for surface facility structures.

5. The frequency and intensity of fog, dust storms, and other severe storms will be used to design lighting and emergency facilities and will be factored into the accident analyses relative to the repository.

8.3.1.12.4.1 Study: Characterize the potential extreme weather phenomena and their recurrence intervals

Objectives

The objective of this study will be to evaluate the existing historical meteorological and climatological records, technical publications, and other relevant information to quantify the extreme weather phenomena that may be expected at the Yucca Mountain site and determine their recurrence interval.

Parameters

1. Frequency of severe storms.
2. Magnitude and frequency of extreme wind speeds.
3. Extremes of temperature and humidity.
4. Precipitation extremes.
5. Frequency and intensity of fog.

Description

Existing data bases and technical publications will be reviewed to characterize the extreme weather phenomena that may be experienced at the site. Where necessary, calculations (e.g., statistical extrapolations) may be made to interpolate existing data to develop site-specific estimates. The data from the site-monitoring program will also be compared with the extreme data.

8.3.1.12.4.2 Application of results

The information derived from the activities described previously will be used in the following investigations for repository design:

Information need	Subject
2.2.1	Site and design information needed to assess preclosure radiological safety (Section 8.3.5.4.1)
2.7.1	Site information needed for design (Section 8.3.2.3.1)

8.3.1.12.5 Schedule for the meteorology program

The meteorology program includes four investigations, which contain four studies. The schedule information for each study is summarized in Figure 8.3.1.12-3. This figure includes the study number and a brief description, as well as major events associated with each study. A major event, for purposes of these schedules, may represent the initiation or completion of an activity, completion or submittal of a report to the DOE, an important data feed, or a decision point. Solid lines on the schedule represent study durations and dashed lines show interfaces among studies as well as data transferred into or out of the meteorology program. The events shown on the schedule and their planned dates of completion are provided in Table 8.3.1.12-3.

The study-level schedules, in combination with information provided in the logic diagram for this program (Figure 8.3.1.12-1), are intended to provide the reader with a basic understanding of the relationships between major elements of the site, performance, and design programs. The information provided in Table 8.3.1.12-3 and Figure 8.3.1.12-3, however, should be viewed as a snapshot in time. The overall program schedule presented here is consistent with the Draft Mission Plan Amendment (DOE, 1988a). The site characterization program will undergo a series of refinements following issuance of the statutory SCP. Refinements will consider factors both internal and external to the site characterization program, such as changes to the quality assurance program. Such refinements are to be considered in ongoing planning efforts, and changes that are implemented will be reflected in the semiannual progress reports. Summary schedule information for the meteorology program can be found in Section 8.5.1.1 and 8.5.6.

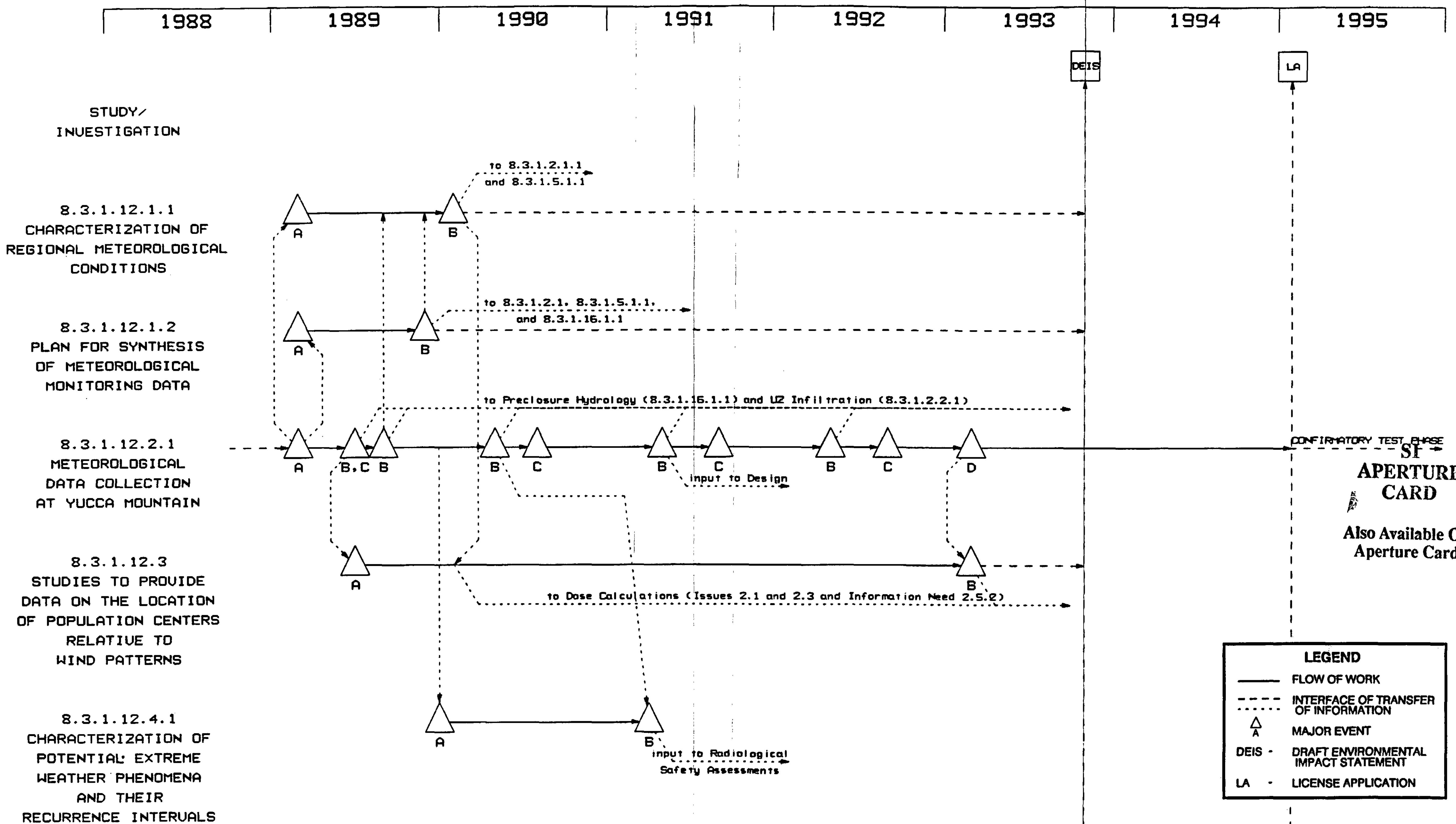

Figure 8.3.1.12-3. Schedule information for studies and investigations in Site Program 8.3.1.12 (meteorology). See Table 8.3.1.12-3 for description of major events. This network is consistent with the Draft Mission Plan Amendment (DOE, 1988a) schedule. Revisions will be published in semiannual site characterization progress reports as new information becomes available.

Table 8.3.1.12-3. Major events and completion dates for studies and investigations in the meteorology program (page 1 of 2)

Study/ investigation number	Brief description of study	Major event[a]	Event description	Date
8.3.1.12.1.1	Characterization of regional meteorological conditions	A	Monitoring ongoing; Begin characterization of regional meteorological conditions	2/89
8.3.1.12.1.2	Plan for synthesis of meteorological monitoring data	A	Monitoring ongoing; Begin development of plans for synthesis of meterological monitoring data	2/89
		B	Plan available on the synthesis of meteorological monitoring data	11/89
8.3.1.12.2.1 (ongoing)	Meteorological data collection at Yucca Mountain	A	Study plan approved	2/89
		B	Annual meteorological monitoring data reports available to DOE; precipitation and meteorological monitoring will continue as performance confirmation	6/89 8/89 4/90 4/91 4/92
		C	Summary reports available to DOE on average and unfavorable X/Q values at each designated receptor	6/89 7/90 8/91 8/92

Table 8.3.1.12-3. Major events and completion dates for studies and investigations in the meteorology program (page 2 of 2)

Study/ investigation number	Brief description of study	Major event[a]	Event description	Date
8.3.1.12.2.1	Meteorolgical data collected at Yucca Mountain	D	Draft of five-year summary report on meteorological conditions available to DOE	2/93
8.3.1.12.3	Studies to provide data on the location of population centers relative to wind patterns	A	Begin compilation of data on wind flow patterns from the site meteorological program	6/89
		B	Complete compilation of data on wind flow patterns for use in estimating doses to the public (Issues 2.1 and 2.3)	2/93
8.3.1.12.4.1	Characterization of potential extreme weather phenomena and their recurrence inter- vals	A	Start assimilation of data from regional meteorology	12/89
		B	Draft report available to DOE on extreme weather phenomena and expected recurrence intervals	3/91

[a]The letters in this column key major events shown in Figure 8.3.1.12-3.

 DOE/RW-0199

Nuclear Waste Policy Act
(Section 113)

Site Characterization Plan

Yucca Mountain Site, Nevada Research and Development Area, Nevada

Volume V, Part B

Chapter 8, Section 8.3.1.13, Offsite Installations

December 1988

U. S. Department of Energy
Office of Civilian Radioactive Waste Management

8.3.1.13 Overview of offsite installations and operations program: Description of the offsite installations and operations required by performance and design issues

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

This program provides the technical data required to support the resolution of the following performance and design issues:

Performance or design issue	Short title	SCP section
2.1	Radiological exposures to public--normal conditions	8.3.5.3
2.2	Worker radiological safety--normal conditions	8.3.5.4
2.3	Accidental radiological releases	8.3.5.5
2.5	Higher level finding--preclosure radiological safety	8.3.5.6
2.7	Repository design criteria for radiological safety	8.3.2.3

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 includes the following:

1. An evaluation of offsite accident initiators, their probabilities and potential impacts to support Issues 2.3 and 2.5.

2. An assessment of routine releases from nuclear operations to support Issues 2.1, 2.2, and 2.5.

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 resolution of Issues 2.3 and 2.5.

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

Interrelationships of offsite installations and operations 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 near-site operations, nuclear fuel cycle facilities, and nuclear facilities not associated with the nuclear fuel cycle in the area. Once these operations have been identified, the impacts of those facilities will be assessed. The planned activities for assessing impacts consist of evaluating (1) near-site operations, (2) nuclear fuel cycle facilities, (3) nuclear facilities not associated with the nuclear fuel cycle, and (4) nuclear testing induced ground motion.

Certain agricultural and cultural data are necessary for assessing radionuclide dose 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 (NWPA, 1983). However, these data are 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 Yucca Mountain Project. Specific information on these data is addressed in the Radiological Monitoring Plan.

Schedule information for Site Program 8.3.1.13 (offsite installation) is presented in Section 8.3.1.13.3.

8.3.1.13.1 Investigation: Determination of nearby industrial, transportation, and military installations and operations (nuclear and nonnuclear)

Technical basis for obtaining the information

Link to the technical data chapters and applicable support documents

The preliminary data currently available are contained in Sections 3.4.1, 3.4.7, 3.5, 3.6.1, 3.6.3, 5.3, and 6.2.1.5 of the Yucca Mountain environmental assessment (DOE, 1986b). Data for this investigation will be collected according to a transportation studies plan, a preliminary site characterization radiological monitoring plan, and a radiological monitoring plan, which are currently being developed.

Parameters

The parameters for this investigation are

1. A list of all nearby DOE, industrial, transportation, and military operations.

2. The scope and frequency of the operations in Item 1.

3. Distance to all operations listed in item 1.

4. Estimates of potential radiological releases from the operations listed in item 1.

5. Meteorological parameters (from Program 8.3.1.12).

Purpose and objectives of the investigation

The data and parameters list includes those items considered important to assess impacts from nearby DOE, industrial, transportation, and military operations. These parameters will be included in performance strategies as presented in the performance and design issues and ultimately used to address preclosure radiological safety aspects of the site.

Technical rationale for the investigation

The data collected will be used to (1) estimate the probability and magnitude of exposures caused by abnormal events and (2) estimate the magnitude of any routine radiological releases from offsite nuclear operations to determine that these releases, when combined with the release from Yucca Mountain, will be within allowable limits (40 CFR 191.03(a)). This investigation consists of three activities collecting similar data types. The activities are separated because of the differences in how the data will be collected.

The following activities will identify all current DOE, industrial, transportation, and military operations and such operations projected for the future in the Yucca Mountain area. This data will be used to provide the data base for the evaluations described in Section 8.3.1.13.2.1.

8.3.1.13.1.1 Activity: Identify near-site activities

Objectives

The objective of this activity is to identify and describe all DOE, industrial, commercial, transportation, and military operations within 8 km of the Yucca Mountain site. In addition, significant operations outside this area that could impact the site will also be evaluated. This will not include offsite radioactive materials transportation since this operation will be addressed by the Division of Systems Integration and the environmental program planning efforts of the Yucca Mountain Project. For the environmental impact statement, offsite transportation will be considered in evaluating the impact of the repository facility.

Parameters

The parameters of this activity are the description of (1) all industrial operations, (2) flight operations, (3) commercial operations, and (4) DOE operations within 8 km of the Yucca Mountain site. A radius of 8 km was chosen because of the high concentration of activities within this area. The Nevada Test Site (NTS) operations will be addressed separately under Activity 8.3.1.13.1.3.

Description

A review of military flight operations in the area is being conducted and will be documented. A list of all existing and projected commercial operations in the area will be compiled. This will include a review of all public domain land use permits in the area for mining and other operations. In addition, the DOE management will be contacted to determine NTS operations near the site. Windshield survey observations from a motor vehicle of the local area will be conducted to complete the compilation of this list. In addition, information obtained from state agencies and other sources will be used to project future operations and determine if any of those operations could have an adverse impact on repository site operations. Activity 8.3.1.13.2.1 contains further details on the evaluation of near-site activities.

Methods and technical procedures

There are no methods and technical procedures for this activity.

8.3.1.13.1.2 Activity: Characterize nuclear fuel cycle facilities in the area

Objectives

The objective of this activity is to identify all nuclear fuel cycle facilities within 80 km of the Yucca Mountain site or within Nevada areas adjacent to Las Vegas.

Parameters

The parameters for this activity are

1. A list of all nuclear fuel cycle facilities within the specified area.

2. The data base to predict magnitudes of projected normal and accidental releases of radioactivity.

Description

The regional NRC office and the State organizations with similar responsibilities will be contacted to identify any nuclear fuel cycle facilities. The routine yearly release of radioactive material from all such facilities will be available because these values are required for routine reports to the NRC and State agencies. Also, potential accidental releases from the facilities will be obtained from safety evaluations of those facilities. The radiological environmental data from Yucca Mountain will be used to identify sources of the material in addition to amounts of past releases, consistent with the limitations imposed by the need to maintain national security measures.

Methods and technical procedures

There are no methods and technical procedures for this activity.

8.3.1.13.1.3 Activity: Characterize all nuclear facilities not associated with the nuclear fuel cycle near the Yucca Mountain site

Objectives

The objective of this activity is to characterize the impacts of all radiological operations at facilities within 80 km of the Yucca Mountain site that are not part of the nuclear fuel cycle. The basis for using an 80 km radius for this activity is documented in Section 4.3.2 of the radiological monitoring plan. Because of the potential for classified information being associated with the identification of NTS operations, radionuclide concentrations in the existing environment of the Yucca Mountain area will be assumed to bound the cumulative effects of past radiological operations in the area. Attempts will be made to make corrections for global fallout and natural sources.

Parameters

For the existing environment at Yucca Mountain, radionuclide concentration and radiation levels will be assessed in (but not limited to)

1. Air (particulate form), concentration.
2. Air (gaseous form).
3. Ambient exposure rate.
4. Soil.
5. Surface water.
6. Sediments.
7. Biota.

In addition, the NTS environmental monitoring reports (produced yearly by various organizations) and any other available data will be reviewed to assess the impacts of past releases at the Yucca Mountain site and in the City of Las Vegas.

Description

All data collection will be conducted in a manner consistent with applicable regulatory guides, DOE guidance documents, and industry practices. Specific examples can be found in the Preliminary Site Characterization Radiological Monitoring Plan (SAIC, 1986b), which addresses data collection before the initiation of significant site characterization activities. The requirements for this activity are the radiological environmental monitoring and sampling equipment and services procured consistent with the studies identified. The equipment and services required include

1. Air sampling equipment.
2. Soil and water sampling equipment.
3. Ambient radiation monitoring equipment and services.
4. Laboratory analysis of air, soil, and water samples.

The radiological environmental data from Yucca Mountain will be used to identify sources of the material in addition to amounts of past releases, consistent with the limitations imposed by the need to maintain appropriate national security measures.

Methods and technical procedures

All data collection operations described for this activity will follow standard environmental radiological monitoring technical procedures. This data collection is addressed in the radiological monitoring plan.

8.3.1.13.1.4 Application of results

The data from this investigation will be used in Investigation 8.3.1.13.2 described below.

8.3.1.13.2 Investigation: Potential impacts of nearby installations and operations

Technical basis for obtaining the information

Link to the technical data chapters and applicable support documents

The preliminary data used in this activity are in Sections 3.4.1, 3.4.7, 3.5, 3.6.1, 3.6.3, 5.3, and 6.2.1.5 of the Yucca Mountain environmental assessment (DOE,1986b). Information not currently available will be collected by the activities for Investigation 8.3.1.13.1. This investigation is addressed by activities described in the Yucca Mountain Project transportation studies efforts, the Preliminary Site Characterization Radiological Monitoring Plan (SAIC, 1986b), and by the Project Radiological Monitoring Plan (DOE, 1987c).

Parameters

The parameters for this investigation are as follows:

1. A list of all accidents initiated by offsite operations that must be considered in the repository safety analyses.

2. An assessment of the potential impacts of those events on the basis of data from Investigation 8.3.1.13.1.

3. Estimates of potential exposures of the public to radiation and radioactive material from all nuclear fuel cycle activities in the area.

4. Projected radioactive airborne concentrations for existing and projected conditions at the site.

5. Other factors contributing to onsite occupational or offsite exposure.

Purpose and objectives of investigation

The information collected from Investigation 8.3.1.13.1 will be used to conduct impact assessments as a result of accidents involving any nearby installations and operations. Those accidents include radiological and nonradiological events that may have an impact on site operations. The information collected will also be used to assess compliance with 40 CFR 191.03 and to resolve Issue 2.5 (Section 8.3.5.6) for routine releases, which addresses compliance with 40 CFR 191.03, 10 CFR Part 20, and 10 CFR Part 60. The results of these assessments will provide data and analyses for use in determining the preclosure radiological safety aspects of the site as outlined in the performance and designs issues of Key Issue 2 (preclosure radiological safety).

Technical rationale for investigation

The data on potential offsite accident initiators will be used to determine if further performance analyses (Issue 2.3, Section 8.3.5.5) are required. If so, the accident data will be used to assess preclosure system performance relative to the regulations cited in Key Issue 2.

The exposure from other nuclear fuel cycle operations covered by 40 CFR Part 190 are required to assess compliance with 40 CFR 191.03(a). The limits specified are the total for all nuclear fuel cycle operations.

The surrounding facilities will be evaluated to determine the effects they could have on potential repository operations and to determine the ability of the repository to complete its mission while in compliance with the regulations cited in Key Issue 2. The surrounding facilities could, under rare circumstances, force evacuation of the facility or limit the ability of the facility to detect and thus respond to abnormal events. This type of circumstance can thus act as an accident initiator (Issue 2.3, Section 8.3.5.5). In addition, any radiation exposure received by workers while at the site, independent of its sources, affects the ability of the facility to comply with applicable radiation standards for occupational exposure (Issue 2.2, Section 8.3.5.4).

The following activities will evaluate all operations identified in Investigation 8.3.1.13.1 and assess their impact on compliance with Key Issue 2. These data will be used to provide the data base for evaluation of operations that could have an impact on Yucca Mountain repository operations and to support the resolution of Issues 2.1, 2.2, 2.3, and 2.5.

8.3.1.13.2.1 Activity: Evaluate near-site activities

Objectives

The objective of this activity is to review all commercial, DOE, DOD, and transportation operations within 8km of the site; identify those operations that could act as accident initiators; and quantify their probability and magnitude. This activity will reduce the list of activities gathered in Activity 8.3.1.13.1.1 to those that could act as accident initiators, thus generating accident scenarios for analysis in the resolution of Issues 2.3 and 2.5.

Parameters

The parameters for this activity are

1. A list of all operations within 8 km of the Yucca Mountain site.
2. A description of the operations that have the potential to act as accident initiators for the site.
3. The probability and magnitude of events with potential to initiate accidents.

Description

Flight operations in the area are being reviewed and will be documented in a report to be issued. The list of all existing and projected operations in the area collected for Investigation 8.3.1.13.1 will be reviewed by experts to determine if any operations may adversely impact site activities. The primary considerations will include the following:

1. Could this operation lead to a breach of the confinement barriers of the waste handling facilities at Yucca Mountain?
2. Could this operation require evacuation of the Yucca Mountain site or endanger site employees?
3. Could this operation cause the loss of offsite services (electrical, telephone, transportation access, etc.)?
4. Could this operation cause a disruption of the flow of waste into the site?

Any such operation will be investigated and the probability and magnitude estimated on the basis of actual technical data on flight operations and the information from Activity 8.3.1.13.1.1. This data will then be used to support the analyses associated with Issues 2.3 and 2.5 and will be documented in a report on offsite impacts.

Methods and technical procedures

Standard risk assessment methods are under consideration for this activity.

8.3.1.13.2.2 Activity: Evaluation of the impact of nuclear fuel cycle operations near the Yucca Mountain site and Las Vegas

Objectives

The objective of this activity is to project the impact of all nuclear fuel cycle operations within 80 km of the Yucca Mountain site.

Parameters

The parameters of this activity are

1. A list of all nuclear fuel cycle operations within the specified area and the magnitude of their routine and projected accident releases estimated from Investigation 8.3.1.13.1.

2. Estimates of probabilities and magnitudes of any projected releases.

Description

All nuclear fuel cycle operations within 80 km of the site will be reviewed. The routine yearly releases of radioactive material from all such facilities will be determined from safety documentation. In addition, the probability and magnitude of potential accidents at the facilities will be determined based on past technical reports and safety analyses documentation. The primary considerations will be to

1. Assess the magnitude of the routine releases of radioactive material from these facilities to determine their contribution to the nuclear fuel cycle facilities release limits (Issues 2.1 and 2.2 discussed in Section 8.3.5) specified in 40 CFR 191.03(a), if any.

2. Provide the basis for determining if the radioactive releases by these nuclear fuel cycle operations could obscure the detection of routine and accidental releases from a Yucca Mountain facility (Issues 2.1, 2.2, and 2.3).

3. Provide the basis for determining if the operation could require evacuation of the Yucca Mountain site (Issue 2.3) or expose workers to significant levels of radiation (Issues 2.2 and 2.3), which may

endanger the workers or impact compliance with the exposure limits in 10 CFR Part 20.

All models and computer programs used in these evaluations will be consistent with those used in resolving Issues 2.1, 2.2, and 2.3.

Methods and technical procedures

Standard risk assessment methods are under consideration for this activity.

8.3.1.13.2.3 Activity: Evaluate the impact of all nuclear facilities not associated with the nuclear fuel cycle near the Yucca Mountain site

Objectives

The objective of this activity is to use the data from Activity 8.3.1.13.1.3 to project airborne concentrations. The probability of such concentrations resulting from operations within 80 km of the Yucca Mountain site will then be estimated and used to predict the potential for exposure of individuals in Las Vegas, Nevada.

The primary considerations in evaluating the results for this operation will be the same as items 2 and 3 under the objective for Activity 8.3.1.13.2.2.

Parameters

The parameters of this activity include the projected airborne radionuclide concentrations and the probabilities of such concentrations for the operations impacting the site.

Description

The routine yearly releases of radioactive material from all such facilities and the existing concentrations at the Yucca Mountain site will be determined. The probability and magnitude of potential accidents will be determined, including the probability and magnitude of release near the Yucca Mountain site. The cumulative effects of past radiological operations in the area will be used to estimate the impacts and probabilities of such operations in the future.

This activity will include (1) the evaluation of resuspension of radionuclides from past operations at the Nevada Test Site (NTS) and the subsequent deposition at the site and (2) the extrapolation of NTS environmental data to Yucca Mountain using standard modeling techniques. All models and computer programs used in these evaluations will be consistent with those used in the resolution of Issues 2.1, 2.2, and 2.3.

Methods and technical procedures

Standard risk assessment methods are under consideration for this activity.

8.3.1.13.2.4 Activity: Evaluate the impact of ground motion from nuclear testing activities at the Nevada Test Site

This activity is addressed in the resolution of Investigation 8.3.1.17.3.

8.3.1.13.2.5 Application of results

The data from this investigation will be used in analyses conducted to ensure compliance with the radiological limits specified in Issues 2.1 through 2.3 and Issue 2.5. It will be used to

1. Identify credible accident scenarios that must be analyzed to ensure facility compliance with regulations. This includes consideration of loss of offsite services and evacuations that could act as accident initiators (Information Needs 2.3.1 (credible accidents, Section 8.3.5.5.1) and 2.3.2 (projected releases from credible accidents, Section 8.3.5.5.2)).

2. Assess the radiological exposures from routine operations to determine the combined offsite exposures from all activities to nearby individuals required to be considered for the qualifying condition in the technical guideline on offsite installations (Issue 2.5) and for Issue 2.1 (public radiological exposures--normal conditions).

3. Assess the radiological exposure of workers due to potential releases from other radiological facilities in the area to determine impacts on a Yucca Mountain facility (Information Need 2.2.1 (natural radiation environment, Section 8.3.5.4.1) and Issue 2.3 (accidental radiological releases).

4. Assess the impact of offsite operations that could have radiological impacts that significantly affect facility feasibility (Issue 4.4, Section 8.3.2.5).

The methods for these assessments are being developed as part of the preclosure risk assessment methodology (PRAM) program as discussed in SCP Sections 8.3.5.1 through 8.3.5.5.

8.3.1.13.3 Schedule for offsite installations

The offsite installations and operations program includes two investigations. The schedule information for each investigation is summarized in

Figure 8.3.1.13-1. This figure includes the investigation number and a brief description, as well as major events associated with each investigation. A major event, for purposes of these schedules, may represent the initiation or completion of an activity, completion or submittal of a report to the DOE, an important data feed, or a decision point. Solid lines on the schedule represent investigation durations and dashed lines show interfaces among investigations as well as data transferred into or out of the offsite installations and operations program. The events shown on the schedule and their planned dates of completion are provided in Table 8.3.1.13-1.

The investigation-level schedules are intended to provide the reader with a basic understanding of the relationships between major elements of the site, performance, and design programs. The information provided in Table 8.3.1.13-1 and Figure 8.3.1.13-1, however, should be viewed as a snapshot in time.

The overall program schedule presented here is consistent with the Draft Mission Plan Amendment (DOE, 1988a). The site characterization program will undergo a series of refinements following issuance of the statutory SCP. Refinements will consider factors both internal and external to the site characterization program, such as changes to the quality assurance program. Such refinements are to be considered in ongoing planning efforts, and changes that are implemented will be reflected in the semiannual progress reports. Summary schedule information for the offsite installations and operations program can be found in Section 8.5.1.1.

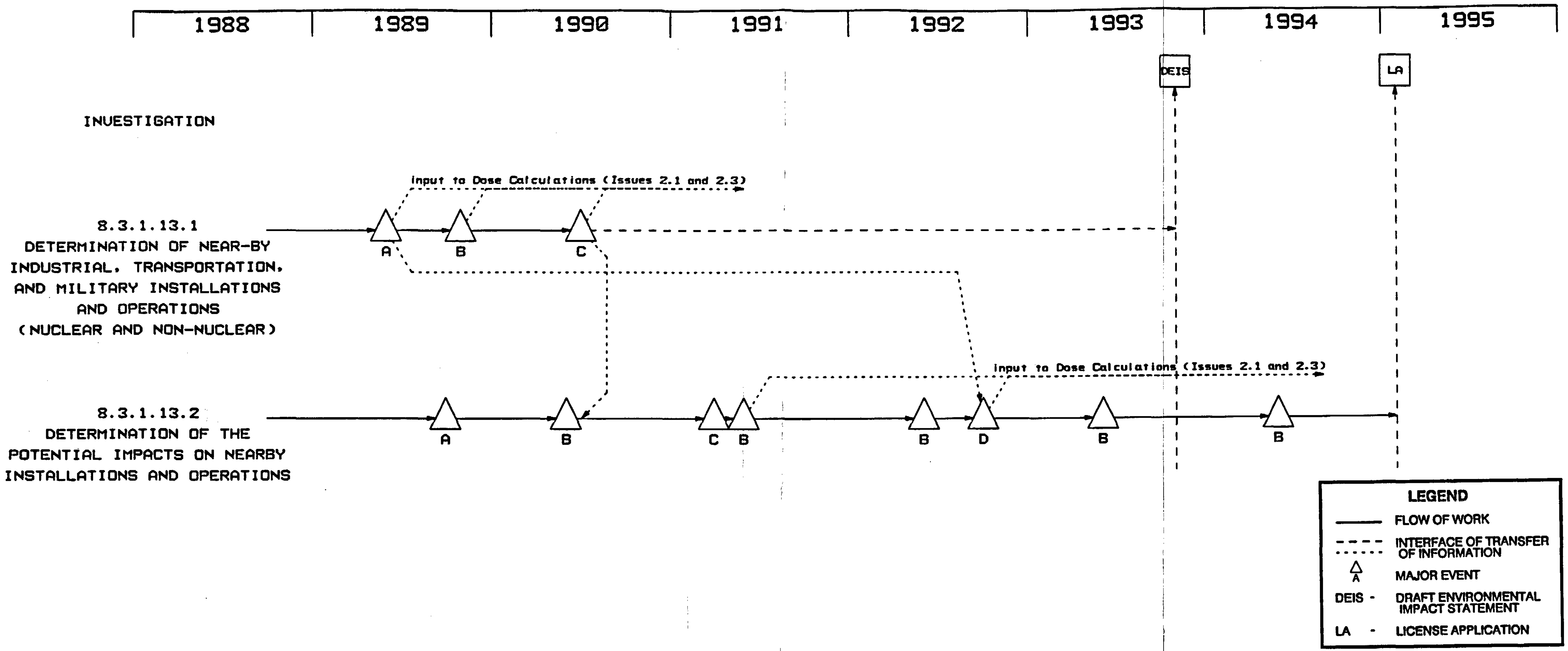

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Figure 8.3.1.13-1. Schedule information for investigations in Site Program 8.3.1.13 (offsite installations). See Table 8.3.1.13-1 for descriptions of major events. This network is consistent with the Draft Mission Plan Amendment (DOE, 1988a) schedule. Revisions will be published in semiannual site characterization progress reports as new information becomes available.

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Table 8.3.1.13-1. Main events and completion dates for investigations in the offsite installations and operations program (page 1 of 2)

Investigation number	Brief description of investigation	Major event[a]	Event description	Date
8.3.1.13.1 (ongoing)	Determination of near-by industrial, transportation, and military installations and operations (nuclear and nonnuclear)	A	Draft of 1988 environmental monitoring report available to the U.S. Department of Energy (DOE)	5/89
		B	Complete survey and evaluation of nuclear fuel cycle activities	10/89
		C	Complete identification of near-site activities (nonnuclear related)	6/90
8.3.1.13.2 (ongoing)	Determination of the potential impacts on nearby installations and operations	A	Complete analysis of over-flight hazards due to U.S. Air Force (USAF) activities	9/89
		B	Environmental monitoring data summaries available to DOE; environmental monitoring will continue beyond 1995	5/90 5/91 5/92 5/93 5/94
		C	Draft of final report on USAF overflight impacts available to DOE	3/91

Table 8.3.1.13-1. Main events and completion dates for investigations in the offsite installations and operations program (page 2 of 2)

Investigation number	Brief description of investigation	Major event[a]	Event description	Date
8.3.1.13.2 (continued)	Determination of the potential impacts on nearby installations and operations (continued)	D	Summary report documenting environmental and radiological data available to DOE	9/92

[a]The letters in this column key major events shwon in Figure 8.3.1.13-1.

 DOE/RW-0199

Nuclear Waste Policy Act
(Section 113)

Site Characterization Plan

Yucca Mountain Site, Nevada Research and Development Area, Nevada

Volume V, Part B

Chapter 8, Section 8.3.1.14, Surface Characteristics

December 1988

U. S. Department of Energy
Office of Civilian Radioactive Waste Management

8.3.1.14 Overview of the surface characteristics program: Description of the surface characteristics required by the performance and design issues

Summary of performance and design requirements for surface characteristics information

The surface characteristics program reflects requirements from the DOE, the NRC, and the EPA that the surface facilities, including openings to the underground, must ensure public health and safety, are technically feasible, and have reasonable costs. This program investigates two areas pertinent to preclosure design and performance issues:

1. Topography (Investigation 8.3.1.14.1).
2. Soil and rock conditions (Investigation 8.3.1.14.2).

A logic diagram showing what design and performance issues and what characterization programs require surface characteristics information is presented in Figure 8.3.1.14-1. A more detailed interlinking of design and performance issue parameters with characterization program parameters is presented in Table 8.3.1.14-1. Table 8.3.1.14-1 is organized around column 4, characterization parameters, as the "key" column. The parameter listed in this column "feeds" characterization data to the design and performance parameters listed in column 3. Conversely, the resolution of the performance or design issues and their corresponding parameters listed in column 3 requires data input from the characterization parameter specified in column 4. To reduce duplication in Table 8.3.1.14-1, each characterization parameter is only presented once, in column 4. For each characterization parameter presented in column 4, there can be one or more performance or design parameters, listed in column 3, that require this characterization parameter data. Column 2 indicates which sections in the SCP require the performance or design parameters presented in column 3, and column 1 identifies which issues and programs initiate a need for the performance or design parameters listed in column 3.

The design- and performance-issue parameters in Table 8.3.1.14-1 are determined by the site surface system element (1.1.1) requirements described in Section 8.3.2 (Table 8.3.2.5-1). These design and performance parameters determine what characterization parameters will be needed. The characterization parameters with their expected ranges, confidence levels, and required activities are also presented in Table 8.3.1.14-1.

The issues and site programs related to the surface characteristics program, along with their SCP section number, are as follows (the relationships are discussed in the paragraphs following the list):

Issue or program	Short title
1.8	NRC siting criteria (Section 8.3.5.17)
1.9	Higher level findings--postclosure (Section 8.3.5.18)

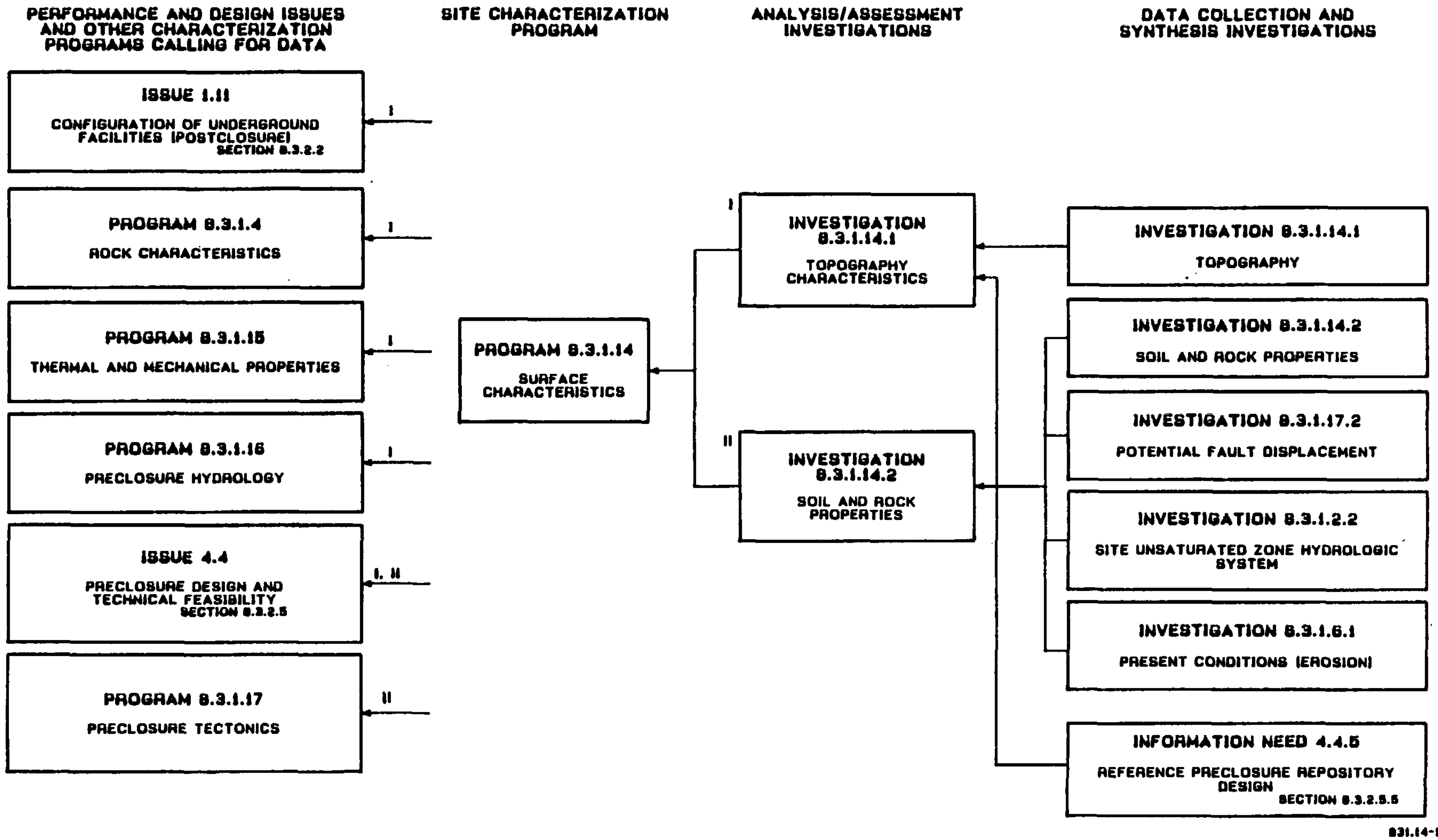


Figure 8.3.1.14-1. Logic diagram for Program 8.3.1.14, surface characteristics. Roman numerals indicate data flow.

Table 8.3.1.14-1. Performance allocation for site surface characterization parameters and the corresponding performance or design parameters and issues they support[a] (page 1 of 12)

Issue or program	SCP section	Performance or design parameters[b]	Characterization parameters (key column)	Current estimate	Current confidence	Needed confidence	Study or activity providing data
			GEOMETRICAL PARAMETERS				
1.11 4.4 8.3.1.4 8.3.1.15 8.3.1.16	8.3.2.2.1 8.3.2.2.3 8.3.2.5.1 8.3.2.5.5 8.3.2.5.7 8.3.1.4.3 8.3.1.15.3 8.3.1.16.1	Surface topography at facility locations (1-m contour interval)	Surface topography at facility locations (1-m contour interval)	20-ft contour interval topographic map (see Figure 4-3 of the SCP-CDR (SNL, 1987))	Medium	Medium	No further studies are planned. Topographical measurements have been made and topographic maps are forthcoming.
4.4	8.3.2.5.1 8.3.2.5.5 8.3.2.5.7	Allowable foundation bearing capacity in soil Allowable foundation bearing capacity in rock Active and passive soil pressures on a wall Active and passive rock pressures on a wall Factor of safety of slope (soil) Factor of safety of slope (rock)					
4.4 8.3.1.16	8.3.2.5.1 8.3.2.5.5 8.3.2.5.7 8.3.1.16.1	Surface topography of access routes (2-m contour intervals)	Surface topography of access routes (2-m contour intervals)	20-ft contour interval topographic map (see Figures 4-2 and 4-3 of the SCP-CDR (SNL, 1987))	Medium	Medium	No further studies are planned. Topographical measurements have been made and topographic maps are forthcoming.

Table 8.3.1.14-1. Performance allocation for site surface characterization parameters and the corresponding performance or design parameters and issues they support[a] (page 2 of 12)

Issue or program	SCP section	Performance or design parameters[b]	Characterization parameters (key column)	Current estimate	Current confidence	Needed confidence	Study or activity providing data
			GEOMETRICAL PARAMETERS (continued)				
4.4	8.3.2.5.1 8.3.2.5.5 8.3.2.5.7	Factor of safety of slope (soil) Factor of safety of slope (rock)					
			SOIL PARAMETERS				
		Allowable foundation bearing capacity in soil Active and passive soil pressure on a wall Factor of safety of slope (soil)	Alluvial stratigraphy Layering Thickness Geometry	General stratigraphic description. Top 0.3 to 0.7 m is loose fine-grained sandy soil overlying approximately 2 m of material that is partly to wholly cemented with calcite (caliche). Below the caliche layer is an 10 to 50 m thick layer of dense sandy gravel alluvial material which overlies the ashflow tuff bedrock (Section 6.1.2.1.2)	Low	Medium	8.3.1.14.2.1.1, 8.3.1.14.2.1.2, 8.3.1.14.2.1.3, 8.3.1.14.3.3
4.4	8.3.2.5.1 8.3.2.5.5 8.3.2.5.7	Soil-structure interaction for foundation[c]					
8.3.1.17	8.3.1.17.3	Soil-structure interaction for retaining wall[c]					
4.4	8.3.2.5.1 8.3.2.5.5 8.3.2.5.7	Magnitude of time dependent settlement in soils below earthfills[d] Magnitude of swell in subgrade soils[d] Magnitude of soil collapse[d] Soil liquefaction potential[d]					
		Identification of any fault within 100 m of facilities important to safety (FITS) with greater than 1 chance in 100 of producing more tha 5 cm of surface displacement in 100 yr	Alluvial faulting (the study for this characterization parameter is developed in Section 8.3.1.17.4.2 (preclosure tectonics) location orientation	See Section 8.3.1.17.4.2 in preclosure tectonics	Low	High	See Study 8.3.1.17.4.2, (location and recency of faulting near prospective surface facilities)

Table 8.3.1.14-1. Performance allocation for site surface characterization parameters and the corresponding performance or design parameters and issues they support[a] (page 3 of 12)

Issue or program	SCP section	Performance or design parameters[b]	Characterization parameters (key column)	Current estimate	Current confidence	Needed confidence	Study or activity providing data
			SOIL PARAMETERS (continued)				
		Allowable foundation bearing capacity in soil	Soil classification vs. depth				
			Soil gradation	GP-GM[e]	Low	Medium	8.3.1.14.2.2.1
		Active and passive soil pressure on a wall	Atterberg limits[d]	From preliminary investigations, no cohesive soils have been found	Low	Medium	
		Factor of safety of slope (soil)					
		Soil-structure interaction for foundation[b]					
		Soil-structure interaction for retaining wall[b]					
		Magnitude of time dependent settlement in soils below earthfills[d]					
		Magnitude of swell in subgrade soils[d]					
		Magnitude of soil collapse[d]					
		Soil liquefaction potential[d]					
		Allowable foundation bearing in soil	Physical properties vs. capacity depth				8.3.1.14.2.2.1, 8.3.1.14.2.3.1
			In situ density	101-112 pcf	Low	Medium	
		Active and passive soil pressure on a wall	Relative density	Not available	Low	Medium	
			Moisture content	7.2%	Low	Medium	
			Percent saturation	47.3%	Low	Medium	
		Factor of safety of slope (soil)	Specific gravity	2.43	Low	Medium	
		Soil-structure interaction for foundation[c]					
		Soil-structure interaction for retaining wall[c]					
		Magnitude of time dependent settlement in soils below earthfills[d]					

Table 8.3.1.14-1. Performance allocation for site surface characterization parameters and the corresponding performance or design parameters and issues they support[a] (page 4 of 12)

Issue or program	SCP section	Performance or design parameters[b]	Characterization parameters (key column)	Current estimate	Current confidence	Needed confidence	Study or activity providing data
			SOIL PARAMETERS (continued)				
		Magnitude of swell in subgrade soils[d]					
		Magnitude of soil collapse[d]					
		Soil liquefaction potential[d]					
		Allowable foundation bearing capacity in soil	Compaction characteristics				
		Active and passive soil pressure on a wall Magnitude of soil collapse[d]	Compaction curves for potential fill material including maximum dry density (γ_d) and optimum water content	γ_d (max) = 108-114 pcf Optimum water content = 12-15%	Low Low	Medium Medium	8.3.1.14.2.2.1
			Mechanical and dynamic properties vs. depth for undisturbed and recompacted soils				
4.4 8.3.1.17	8.3.2.5.1 8.3.2.5.5 8.3.2.5.7 8.3.1.17.3	Allowable foundation bearing capacity in soil Soil structure interaction for foundation[c]	Young's modulus (static and dynamic)	10,000-20,000 psi (static) (Ho et al., (1986) 192,000 psi (dynamic calculated from Vp)	Low	Medium	8.3.1.14.2.2, 8.3.1.14.3.2, 8.3.1.14.2.3.3
		Soil structure interaction for retaining wall[c] Soil liquefaction potential[d]	Poisson's ratio (static and dynamic)	0.3-0.35 (static) (Ho et al., 1986) 0.286 (dynamic) (Neal, 1986)	Low	Medium	8.3.1.14.2.2, 8.3.1.14.2.3.3

Table 8.3.1.14-1. Performance allocation for site surface characterization parameters and the corresponding performance or design parameters and issues they support[a] (page 5 of 12)

Issue or program	SCP section	Performance or design parameters[b]	Characterization parameters (key column)	Current estimate	Current confidence	Needed confidence	Study or activity providing data
			SOIL PARAMETERS (continued)				
		Soil structure interaction for foundation[c] Soil-structure interaction for retaining wall[c] Soil liquefaction potential[d]	Compressive wave velocity (Vp) and shear wave velocity (Vs) (these parameters will be used to calculate the dynamic elastic characterization parameters: Young's modulus, shear modulus, and Poisson's ratio).	Vp = 3,300 ft/sec (Neal, 1986) Vs = 1,800 ft/sec (Neal, 1986)	Medium	High	8.3.1.14.2.3.3
			Shear modulus (static and dynamic)	3,700-7,700 psi (static-calculated) 74,100 psi (dynamic-calculated from Vs)	Low	Medium	8.3.1.14.2.3.3
			Damping	Not available	Low	Medium	8.3.1.14.2.3.3
4.4	8.3.2.5.1 8.3.2.5.5 8.3.2.5.7	Allowable foundation bearing capacity in soil Active and passive soil pressure on a wall Factor of safety of slope (soil) Soil-structure interaction for foundation[c] Soil-structure interaction for retaining wall[c]	Mohr-Coulomb strength parameters in terms of cohesion (c) and angle of friction (ϕ)	c = 500 psf (cemented) ϕ = 33 to 37°	Low	High	8.3.1.14.2.2.2
		Allowable foundation bearing capacity in soil	Plate load bearing pressure vs. settlement	Not available	Low	Medium	

Table 8.3.1.14-1. Performance allocation for site surface characterization parameters and the corresponding performance or design parameters and issues they support[a] (page 6 of 12)

Issue or program	SCP section	Performance or design parameters[b]	Characterization parameters (key column)	Current estimate	Current confidence	Needed confidence	Study or activity providing data
			CONTINGENT SOIL PARAMETERS				
			The following characterization parameters are contingent parameters (see footnote d)				
4.4	8.3.2.5.1 8.3.2.5.5 8.3.2.5.7	Soil-structure interaction for foundation[c]	Other strength parameters such as Drucker-Prager, etc. (if required)[d]	Not available	Low	Medium	8.3.1.14.2.2.2
8.3.1.17	8.3.1.17.3	Soil-structure interaction					
			Bulk modulus and constrained modulus[d]	Not available	Low	Medium	8.3.1.14.2.2.2
		Soil liquefaction potential[d]	Strength and stress-deformation characteristics under dynamic load conditions evaluated as a function of stress rate, confinement stress, initial static stress level, magnitude of pulsating stress, number of stress cycles, and frequency of loading[d]	Not available	Low	Medium	8.3.1.14.2.2.2
			Dynamic shear modulus as a function of strain and confinement stress[d]	Not available	Low	High	8.3.1.14.2.2.2, 8.3.1.14.2.3.3
			Damping as a function of strain[d]	Not available	Low	High	8.3.1.14.2.2.2, 8.3.1.14.2.3.3
			Shear wave velocities as a function of strain[d]	Not available	Low	High	8.3.1.14.2.2.2, 8.3.1.14.2.3.3
			Deformation modulus in terms of stress-strain characteristics and confinement stress conditions[d]	Not available	Low	High	8.3.1.14.2.2.2

Table 8.3.1.14-1. Performance allocation for site surface characterization parameters and the corresponding performance or design parameters and issues they support[a] (page 7 of 12)

Issue or program	SCP section	Performance or design parameters[b]	Characterization parameters (key column)	Current estimate	Current confidence	Needed confidence	Study or activity providing data
		CONTINGENT SOIL PARAMETERS (continued)					
4.4	8.3.2.5.1 8.3.2.5.5 8.3.2.5.7	Soil liquefaction potential[d]	Liquefaction parameters: cyclic shearing stress ratio, cyclic deformation, and pore-pressure response (this information will not be needed if there are no perched water bodies near the ground surface)[d]	Not available	Low	Medium	8.3.1.14.2.2.2
		Allowable foundation bearing capacity in soil Soil-structure interaction for foundation[c] Soil-structure interaction for retaining wall[c]	Modulus of subgrade reaction from plate load test (static and dynamic)[d]	200-300 pci	Low	Medium	8.3.1.14.2.3.2
		Allowable foundation bearing capacity in soil Magnitude and rate of time dependent settlement below earthfills[d] Magnitude of swell in subgrade soils below roads[d]	Compression and swell index (for saturated clayey soils if they are encountered)	Not available	Low	Medium	8.3.1.14.2.2.2
			Coefficient of consolidation (for saturated clayey soils if they are encountered)[d]	Not available	Low	Medium	8.3.1.14.2.2.2
		Allowable foundation bearing capacity in soil Magnitude of soil collapse below surface facilities (foundations, earthfills, and roads) due to saturation and/or loading[d]	Collapse potential (for relative dry low density soils)[d]	Not available	Low	Medium	8.3.1.14.2.2.2

Table 8.3.1.14-1. Performance allocation for site surface characterization parameters and the corresponding performance or design parameters and issues they support[a] (page 8 of 12)

Issue or program	SCP section	Performance or design parameters[b]	Characterization parameters (key column)	Current estimate	Current confidence	Needed confidence	Study or activity providing data
			OTHER SOIL PARAMETERS				
		Favorable hydraulic induced soil erosion characteristics	Erosion potential	<13 m/100 yr of scour around bridge piers <5 m/100 yr of bed erosion <1 m/100 yr of sheet erosion	Low	Medium	8.3.1.6.1.1.2, 8.3.1.6.1.1.3
		Favorable infiltration/runoff ratio	Infiltration/runoff ratio	See Section 8.3.1.12 (meteorology) and 8.3.1.2 (geohydrology)	Low	Medium to high	See Section 8.3.1.12 (meteorology) and 8.3.1.2 (geohydrology)
			ROCK PARAMETERS				
4.4 8.3.1.17	8.3.2.5.1 8.3.2.5.5 8.3.2.5.7 8.3.1.17.3	Allowable foundation bearing capacity in rock Active and passive rock pressure on a wall Factor of safety of slope (rock) Rock-structure interaction for foundation[c] Rock-structure interaction for retaining wall[c]	Rock stratigraphy Rock type Layering Thickness Geometry	See Figure 6-6 in the SCP and Figures 5 and 7 in Neal (1986)	Low	Medium	8.3.1.14.2.1.1, 8.3.1.14.2.1.2, 8.3.1.14.2.1.3, 8.3.1.14.2.3.3
4.4	8.3.2.5.1 8.3.2.5.5 8.3.2.5.7	Allowable foundation bearing capacity in rock Active and passive rock pressure on a wall Factor of safety of slope (rock)	Rock structure Quantitative description of faults Location Orientation Aperture Type of infilling Moisture and/or seepage conditions Waviness and roughness	Not available	Low	High	8.3.1.14.2.1.2, 8.3.1.14.2.1.3, 8.3.1.14.2.3.1

Table 8.3.1.14-1. Performance allocation for site surface characterization parameters and the corresponding performance or design parameters and issues they support[a] (page 9 of 12)

Issue or program	SCP section	Performance or design parameters[b]	Characterization parameters (key column)	Current estimate	Current confidence	Needed confidence	Study or activity providing data
			ROCK PARAMETERS (continued)				
			Quantitative description of joints Number of joint sets Spacing of joints for each set Orientation of each joint set Type of infilling if any Moisture and/or seepage conditions Waviness and roughness Persistence Drill core (total core recovery, discontinuity, frequency, and rock quality designation (RQD))	Not available			
		Allowable foundation bearing capacity in rock Active and passive rock pressure on a wall Rock-structure interaction for foundation[c] Rock-structure interaction for retaining wall[c]	Rock mass classification Rock mass rating (RMR)[f] Tunneling quality index (Q)[f]	Not available	Low	Medium	8.3.1.14.2.3.1
		Allowable foundation bearing capacity in rock Active and passive rock pressure on a wall Factor of safety of slope (rock) Rock-structure interaction for foundation[c] Rock-structure interaction for retaining wall[c]	Physical properties vs. depth				
			Density (dry)	2.23 gm/cc or 139 lb/ft^3	Low	Medium	8.3.1.14.2.2.1
			Percent saturation	67% < 23%	Low	Medium	
			Porosity	11% < 4%	Low	Medium	
			Specific gravity	2.51 < 0.04	Low	Medium	
			Mechanical and dynamic properties				

Table 8.3.1.14-1. Performance allocation for site surface characterization parameters and the corresponding performance or design parameters and issues they support[a] (page 10 of 12)

Issue or program	SCP section	Performance or design parameters[b]	Characterization parameters (key column)	Current estimate	Current confidence	Needed confidence	Study or activity providing data
		ROCK PARAMETERS (continued)					
		Allowable foundation bearing capacity in rock Rock-structure interaction for foundation[c]	Plate load bearing pressure vs. settlement	Not available	Low	Medium	8.3.1.14.2.3.2
		Magnitude of soil collapse below surface facilities[d]					
		Allowable foundation bearing capacity in rock Factor of safety of slope (rock) Rock-structure interaction for foundation[c] Rock-structure interaction for retaining wall[c]	Peak and residual failure envelopes derived from uniaxial and triaxial compression tests	c (peak) = 26.0 ±10.13 MPa (range) ϕ (peak) = 44.7° ±0.20° (range) Tensile strength = 9.3 MPa Unconfined compressive strength = 120 ± 82 MPa (range)	Low	High	8.3.1.14.2.2.2
		Allowable foundation bearing capacity in rock Active and passive rock pressure on a wall Factor of safety of slope (rock)	Discontinuity shear strength in terms of c and ϕ	c = 0.1 MPa < 0.1 (range) ϕ = 28.4 (range: 11.3° - 38.7°	Medium	High	8.3.1.14.2.2.2
4.4 8.3.1.17	8.3.2.5.1 8.3.2.5.5 8.3.2.5.7 8.3.1.17.3	Allowable foundation bearing capacity in rock Rock-structure interaction for foundation[c] Rock-structure interaction for retaining wall[c]	Young's modulus (static and dynamic	20.0 GPa ± 5.55 (range) - static rock mass (SCP, Chapter 6) 2.94 GPa (calculated from in situ Vp)	Low	Medium	8.3.1.14.2.2.2, 8.3.1.14.2.3.2, 8.3.1.14.2.3.3
			Poisson's ratio	0.24 (laboratory-static) (SCP, Chapter 6) 0.319 (in situ calculated from Vp and Vs) (Neal, 1986)	Low	Medium	8.3.1.14.2.2.2, 8.3.1.14.2.3.3
		Rock-structure interaction for foundation[c] Rock-structure interaction for retaining wall[c]	Shear modulus (static and dynamic)	8.1 GPa ± 2.2 (range) - static rock mass 1.1 GPa (calculated from in situ Vs)	Low	Medium	8.3.1.14.2.2.2, 8.3.1.14.2.3.3

Table 8.3.1.14-1. Performance allocation for site surface characterization parameters and the corresponding performance or design parameters and issues they support[a] (page 11 of 12)

Issue or program	SCP section	Performance or design parameters[b]	Characterization parameters (key column)	Current estimate	Current confidence	Needed confidence	Study or activity providing data
			ROCK PARAMETERS (continued)				
		Rock-structure interaction for foundation[c] Rock-structure interaction for retaining wall[c]	Compressive wave velocities vs. depth	Vp = 7,500 - 9,000 ft/sec (laboratory) (Neal, 1986)	Low	High	8.3.1.14.2.2.2, 8.3.1.14.2.3.3
				Vp = 4,500 ft/sec (in situ) (Neal, 1986)	Low	High	
			Shear wave velocities vs. depth (the compressive and shear wave velocities will be used to calculate the dynamic elastic characterization parameters: Young's modulus, shear modulus, and Poisson's ratio)	Vs = 4,390 - 5,790 ft/sec (laboratory-calculated)	Low	High	8.3.1.14.2.2.2, 8.3.1.14.2.3.3
				Vs = 2,320 ft/sec (in situ-calculated)	Low	High	
			Damping vs. depth	Not available	Low	High	8.3.1.14.2.2.2, 8.3.1.14.2.3.3
			CONTINGENT ROCK PARAMETERS				
			The following characterization parameters are contingent parameters (see footnote (d))				
		Rock-structure interaction for foundation[c] Rock-structure interaction for retaining wall[c]	Shear wave velocities as a function of strain[d]	Not available	Low	High	8.3.1.14.2.2.2, 8.3.1.14.2.3.3
			Dynamic shear modulus as a function of strain[d]	Not available	Low	High	8.3.1.14.2.2.2, 8.3.1.14.2.3.3
			Damping as a function of strain[d]	Not available	Low	High	8.3.1.14.2.2.2, 8.3.1.14.2.3.3

Table 8.3.1.14-1. Performance allocation for site surface characterization parameters and the corresponding performance or design parameters and issues they support[a] (page 12 of 12)

Footnotes

[a]This table is organized around column 4, characterization parameters, as the "key" column. The parameter listed in this column "feeds" characterization data to the design and performance parameters listed in column 3, performance or design parameters. Conversely, the resolution of the performance or design issues listed in column 3 requires data input from the characterization parameter specified in column 4 (key column).

[b]See Table 8.3.2.5-1 for complete description of performance and design parameter.

[c]If the alluvium or rock adjacent to the foundation has shear velocities greater than 3,500 ft/sec, then a soil structure interaction analysis will probably not be necessary.

[d]The need for these design and performance parameters or characterization parameters are contingent on the soil and rock conditions encountered, function or design requirements of the surface facilities, types of foundations selected, and the sophistication or type of analyses used in the design or performance studies. However, based on the sites preliminary surface soil and rock data and the type of foundations which are recommended in the SCP-CDR (SNL, 1987), the paramters are currently not needed.

[e]GP = poorly graded gravel; GM = silty gravel.

[f]RMR = rock mass rating from CSIR (South African Council for Scientific and Industrial Research) Geomechanics Classification; Q = NGI (Norwegian Geotechnical Institute) tunneling quality index.

Issue or program	Short title
1.11	Configuration of underground facilities--postclosure (Section 8.3.4.2)
4.4	Preclosure design and technical feasibility (Section 8.3.2.5)
8.3.1.4	Rock characteristics
8.3.1.12	Meteorology program
8.3.1.15	Thermal and mechanical properties program
8.3.1.16	Preclosure hydrology
8.3.1.17	Preclosure tectonics

Surface characteristic information such as topographic contours will be required for locating and designing repository surface facilities (Issue 4.4), establishing repository costs, and determining probable flood levels at potential surface facility locations (Section 8.3.1.16). Topographic contour maps are necessary for locating shaft and ramp entrances above potential flood levels and for locating sensitive structures such as waste handling facilities.

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 (Issues 1.8 and 1.9). The topographic data from Investigation 8.3.1.14.1 will actually be provided to Issue 1.11 to determine if the repository has an adequate amount of overburden to resolve Issues 1.8 and 1.9. Also, in situ stresses will be influenced, in part, by local topography (Sections 8.3.1.4 and 8.3.1.15).

The surface characteristics of the alluvial soil and rock at or near the surface impact the location and design of the surface facilities (Issue 4.4) and their costs. This is especially applicable to sensitive structures, such as the waste-handling facilities, which may experience earthquake loading (Section 8.3.1.17). The soil and rock conditions of the site for static-loading conditions will influence the selection of the surface facility location in addition to its foundation design.

The performance issue under Key Issue 4 specifies that the higher level findings required by 10 CFR Part 960 be supported for (1) the qualifying condition on the preclosure system guideline for ease and cost of construction on the basis of reasonably available technology and (2) the qualifying condition on the technical guideline for surface characteristics. Section 8.3.5.7 (Issue 4.1) discusses the higher level findings.

Approach to satisfy performance and design requirements

Surface-characterization information must be obtained and evaluated to determine whether it will support the preclosure higher level findings for preclosure radiological safety and the ease and cost of siting, construction, operation, and closure of the repository. The approach to determining whether the information about surface characteristics and conditions is adequate to resolve the performance and design issues is an iterative process. Close collaboration between engineering and geotechnical participants is needed to allow timely development of the repository design.

The major elements defining the surface characteristics include topography and soil and bedrock properties. Site surface characteristics data will be used to design surface structures and their foundations for buildings, shaft and ramp portals, roads, drainage systems, and flood control structures. These designs will also consider dynamic loading conditions caused by earthquakes and man-induced explosions.

The information required for any of the surface characteristics investigations will be initiated by the site surface system element 1.1.1 (site surface) requirements described in Section 8.3.2.5. To satisfy these requirements, the appropriate design and performance parameters must be obtained. A listing of these design and performance parameters and their corresponding characterization program parameters was previously presented in Table 8.3.1.14-1. To determine these characterization program parameters, studies and activities have been developed to provide the appropriate data. A list of characterization parameters and their corresponding studies and activities is also presented in Table 8.3.1.14-1.

A summary of the information required for the soil and rock property investigation (8.3.1.14.2) is provided in the logic diagram in Figure 8.3.1.14-2. This figure illustrates the information required by the soil and rock investigation and what studies and activities are needed to provide this information. A similar logic diagram was not developed for the other investigation in Program 8.3.1.14. The topography investigation (8.3.1.14.1) needs no further data acquisition activities since adequate contour maps have already been developed.

The site requirements discussed for this program and its associated investigations will be in conformance with applicable local, State of Nevada, and Federal codes and standards referring to natural hazard and foundation stability, such as those requirements specified in DOE Order 6430.1 (DOE, 1983a).

Interrelationships of surface characteristics investigations

There are no interrelationships between the investigations within the surface characteristics program. The investigations within this program only have interrelationships with issues and programs outside this program. The connections between the surface characteristics program and the performance and design issues or other characterization programs calling for data from this program have already been presented in Figure 8.3.1.14-1. This same figure also shows what investigations or information needs supply data to this program.

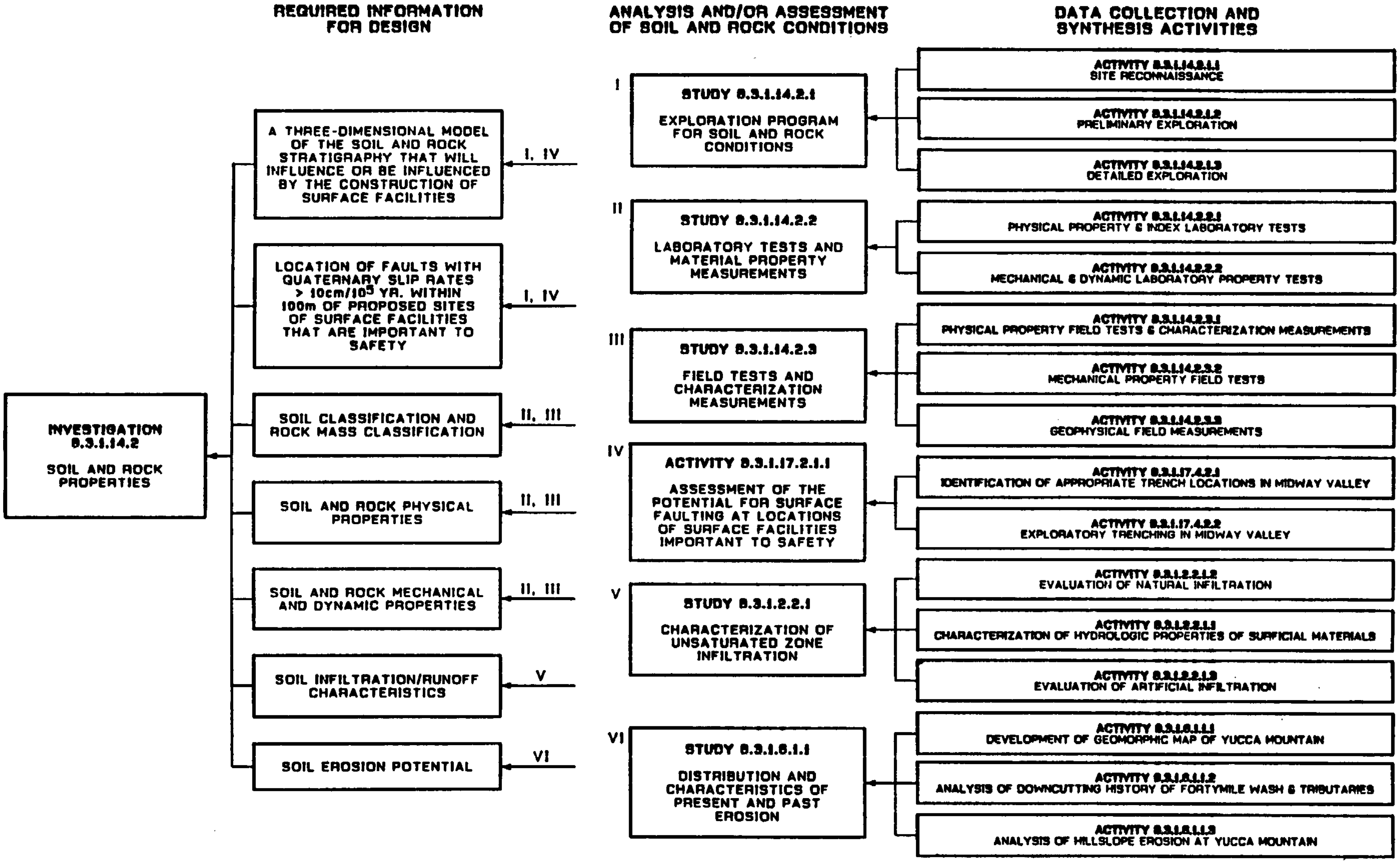


Figure 8.3.1.14-2. Logic diagram for Investigation 8.3.1.14.2, soil and rock properties.

To provide a more detailed description of these interrelationships, two additional tables have been prepared. The investigations and information needs that require parameters from this program are provided in Table 8.3.1.14-2. This table also indicates why the data are needed and recommends general types of studies to obtain the data. Table 8.3.1.14-3 describes the investigations, information needs, and the associated data that will be required by this program.

The schedule information provided for investigations in this section includes the sequencing, interrelationships, and relative durations of the studies in the investigation. Specific durations and start/finish dates for the studies are being developed as part of ongoing planning efforts and will be provided in the SCP at the time of issuance and revised as appropriate in subsequent semiannual progress reports.

Summary of studies

No studies are needed or planned for Investigation 8.3.1.14.1 (topography) because the requirements for this investigation have been satisfied.

The recommended studies to address the requirements of Investigation 8.3.1.14.2 (soil and rock properties) consist of an exploratory program, laboratory testing program, and a field testing and measurement program. The exploratory program will use various methods 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 to 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.

The schedule information for Site Program 8.3.1.14 (surface characteristics) is presented in Section 8.3.1.14.3

8.3.1.14.1 Investigation: Studies to provide the topographic characteristics of potential locations of surface facilities

Technical basis for obtaining the information

Link to the technical data chapters and applicable support documents

The topographic characteristics of the potential surface facility locations can best be illustrated with topographic contour maps. Topographic contour maps of the Yucca Mountain vicinity have been developed for use in the geologic, hydrologic, and climatologic site characterization studies described in this plan; numerous examples are presented as base maps in Chapters 1, 3, 5, and in Section 6.1.2.1.1 (topography and terrain) in Chapter 6. More detailed contour maps of the topography of potential repository surface facilities have been developed; examples are included in Section 6.2.4 (design of surface facilities).

Table 8.3.1.14-2. Investigations and information needs that require parameters from the surface characteristics program (page 1 of 4)

Issue, investigation, or information need calling for data	Parameter	Why data needed	Type of study or analysis needed to develop parameter
		INVESTIGATION 8.3.1.14.1 (TOPOGRAPHY)	
2.3.1 Credible repository accidents (Section 8.3.5.5.1)	Topographic contour maps	Determine if accidents from potential slope instabilities and flooding are credible	Topographic survey of the site
2.7.1 Radiological protection (Section 8.3.2.3.1)	Topographic contour maps	Evaluate the potential for slope instabilities and flooding	Topographic survey of site
4.1 Determine if site meets qualifying conditions of the technical guidelines (Section 8.3.5.7)	Topographic contour maps	Determine ease and cost of siting, construction, operation, and closure	Topographic survey of the site
4.2.1 Site performance information needed for design (Section 8.3.2.4.1)	Topographic contour maps	Evaluate the potential for slope instabilities and flooding that may be a hazard to personnel	Topographic survey of the site
4.4.1 Site and performance assessment information needed for design (Section 8.3.2.5.1)	Topographic contour maps	Evaluate feasibility and cost effective technologies for construction and operation on topography of proposed site	Topographic survey of the site

Table 8.3.1.14-2. Investigations and information needs that require parameters from the surface characteristics program (page 2 of 4)

Issue, investigation, or information need calling for data	Parameter	Why data needed	Type of study or analysis needed to develop parameter
INVESTIGATION 8.3.1.14.1 (TOPOGRAPHY) (continued)			
8.3.1.16.1 Flood recurrence intervals and levels at surface facility locations	Topographic contour maps	Flood magnitudes and levels will be used in performance assessment and surface facility design studies	Topographic survey of the site
1.11 Site characterization information needed for design to determine if the repository configurations satisfy Issues 1.9 (Section 8.3.5.18) and 1.8 (Section 8.3.5.17).	Isopach maps of overburden thickness above repository horizon	Determine if the favorable 300-m overburden depth is satisfied in 10 CFR 60.122(b)(5). Determine if site is disqualified based on minimum 200-m overburden depth in 10 CFR 960.4-2-5(d)	Topographic survey of the site
8.3.1.15.2 and 8.3.1.4.3 Spatial distribution of ambient stress conditions and three-dimensional rock characteristics model	Topographic contour maps and ground surface elevation cross sections	Determine in situ stress at depth considering surface topography variations	Topographic survey of the site
8.3.1.6.1 Present location and rates of erosion	Topographic contour map	Use topographic contours to assist evaluating rates of erosion	Topographic survey of the site

Table 8.3.1.14-2. Investigations and information needs that require parameters from the surface characteristics program (page 3 of 4)

Issue, investigation, or information need calling for data	Parameter	Why data needed	Type of study or analysis needed to develop parameter
INVESTIGATION 8.3.1.14.1 (TOPOGRAPHY) (continued)			
2.3.1 Credible repository accidents (Section 8.3.5.5.1)	Physical and mechanical (static and dynamic) properties of soil and bedrock, alluvium bedrock contact, and layering	Evaluate the potential hazards from earthquakes and slope instabilities to structures and systems important to safety (60.131 (b) (1))	Standard laboratory and field static and dynamic tests
2.7.1 Radiological protection (Section 8.3.2.3.1)	Physical and mechanical (static and dynamic) properties of soil and bedrock, alluvium bedrock contact, and layering	Evaluate the potential hazards from earthquakes and slope instabilities to structures and systems important to safety (60.131 (b) (1))	Standard laboratory and field static and dynamic tests

Table 8.3.1.14-2. Investigations and information needs that require parameters from the surface characteristics program (page 4 of 4)

Issue, investigation, or information need calling for data	Parameter	Why data needed	Type of study or analysis needed to develop parameter
INVESTIGATION 8.3.1.14.2 (SOIL AND ROCK PROPERTIES) (continued)			
4.2.1 Site performance information needed for design (Section 8.3.2.4.1)	Physical and mechanical (static and dynamic) properties of soil and bedrock, alluvium bedrock contact, and layering	To evaluate the potential hazards from earthquakes and slope instabilities to personnel	Evaluate ground-motion response due to earthquakes and conduct a static and dynamic analysis of proposed foundations and slopes
4.4.1. Site and performance information needed for design (Section 8.3.2.5.1)	Physical and mechanical (static and dynamic) properties of soil and bedrock, alluvium bedrock contact, and layering	Do technologies exist for cost effective surface construction on the site's soil and bedrock	Standard laboratory and field static and dynamic tests
8.3.1.17.3 Vibratory ground motion at site from potential man-made or natural seismic-induced events	Alluvium and bedrock stratigraphy and their compressive and shear wave velocities	Evaluate ground motion response due to seismic event for siting and designing surface facilities	Drilling, surface and borehole geophysical testing and laboratory tests to determine stratigraphy and wave velocities

Table 8.3.1.14-3. Investigations or information needs supplying data to the surface characteristics program

Surface characteristics investigation	Information needs and investigations providing data	Data needed by this program
8.3.1.14.1, topography	4.4.5, reference preclosure repository design (Section 8.3.2.5.5)	Location of proposed surface facilities and roads
8.3.1.14.2, soil and rock properties	4.4.5, reference preclosure repository design (Section 8.3.2.5.5)	Location of proposed surface facilities and roads
	8.3.1.17.2, fault displacement	Fault locations
	8.3.1.2.2, site unsaturated zone hydrologic system	Infiltration and run-off characteristics
	8.3.1.6.1, present locations and rates of surface erosion	Soil erosion potential

Parameters

The following parameter has been measured or calculated as a result of site studies performed as part of this investigation: Ground-surface elevation as a function of geographic position at Yucca Mountain and vicinity.

Purpose and objectives of the investigation

The purpose of this investigation was to evaluate the surface topographic elevation and relief at the potential surface facility locations to provide a basis for evaluating (1) the surface drainage, flood levels, and erosion characteristics in the vicinity of Yucca Mountain, (2) the cut-and-fill requirements for the design and engineering of the repository surface facilities, and (3) the stability of natural slopes and cut slopes. Topographic maps will be used in locating surface facilities, roads, and railways.

A knowledge of the surface topographic characteristics of the site will also be required for certain underground design and performance studies. The site's topography will have an influence on the underground design and the site's performance in terms of determining the usable area in the repository horizon while maintaining the required amount of overburden. A favorable site condition will exist if an overburden depth of 300 m is maintained above the repository horizon (10 CFR 60.122(b)(5)). The site will be disqualified if a minimum overburden depth of 200 m is not maintained (10 CFR 960.4-2-5(d)).

Another underground design parameter that is influenced by surface topography is in situ stress. In situ stresses are a result of three stress conditions: gravitational induced stress due to the weight of overburden, residual stress due to energy stored in the rock during the geologic past, and tectonic stress produced by current tectonic forces affecting the region. Bauer et al. (1985) evaluated the effect of Yucca Mountain's topography on gravitational induced horizontal stresses. Their study found that the surface topography will influence the horizontal stress field at the repository horizon.

The surface topographic information resulting from this investigation will contribute to data needs in the following design issues and characterization programs:

Issue or program	Subject
8.3.1.16	Preclosure hydrology. Topographic contours will be used to determine flood level.
4.4	Preclosure design and technical feasibility (Section 8.3.2.5). Topographic contours will be used in the design and therefore influence the technical feasibility of the technologies required for repository construction, operation, closure, and decommissioning.

Issue or program	Subject
1.11	Configuration of underground facilities (postclosure) (Section 8.3.2.2). Topographic contours will be used to determine if the site has less than 200 m of overburden, which would result in disqualification (Section 8.3.5.18). Topographic contours will also be used to determine if the site is favorable with a minimum overburden depth of 300 m (Section 8.3.5.17).
8.3.1.4	Rock characteristics. Topographic contours will be used to determine in situ stress at depth considering surface topography variations.
8.3.1.15	Thermal and mechanical properties. Topographic contours will be used to determine in situ stress at depth considering surface topography variations.

To control map compilation, a total of 623 control points were generated from 50 original ground-targeted points. Field surveys of the targeted points were contracted to a private survey firm. Elevation precision of targeted points is about 0.3 m (1 ft), and the size of the target about 0.6 m (2 ft), producing 80-micrometer images on photographs.

Aerial photographs of the Yucca Mountain region were taken in two phases. Phase 1 photography covered an area 10 by 14 km. Phase 2 photography covered an area 11 by 15 km, from 160°22'30" to 160°30'00" longitude and from 36°48' to 36°56' latitude. Photographs were taken by a 6-in. lens camera at a flight height of 1,140 m above the terrain; the photographic scale is 1:7,500.

Photogrammetric analysis included production of additional control points using analytical photogrammetric methods and map compilation on stereo plots. A total of 623 control points were produced from 179 aerial photographs. Control maps were compiled at a scale of 1:5,000 with a contour interval of 1 to 2 m; each map covers an area 3 by 3 km, and has a precision of 10 cm on the ground.

Digital topographic data were collected from the contour maps. Three-dimensional modeling of the Yucca Mountain geology will be made by combining digital topographic and image data (Section 8.3.1.15.1). Topographic maps of appropriate portions of the Yucca Mountain area were compiled by Wu (1985) at 1 and 2 m contour intervals.

Technical rationale for the investigation

The requirements for this investigation have been satisfied. No further studies, tests, or analyses are planned.

8.3.1.14.1.1 Application of results

The information derived from this investigation will be used to support the following investigations and information needs:

Information need or investigation	Subject
1.11.1	Site characteristics needed for design (determine if the 300-m overburden depth favorable condition in 10 CFR 60.122(b)(5) is satisfied and that the site is not disqualified on the basis of the minimum 200-m overburden requirement in 10 CFR 960.4-2-5(d))
8.3.1.4.3	Three-dimensional rock characteristics model (determine in situ stress at depth considering surface topography variations)
8.3.1.15.2	Spatial distribution of ambient stress conditions (determine in situ stress at depth considering surface topography variations)
8.3.1.6.1	Present locations and rates of erosion (use topographic contours to assist evaluating rates of erosion)
2.3.1	Credible repository accidents (evaluate potential for slope instabilities and flooding) (Section 8.3.5.5.1)
2.7.1	Radiological protection (evaluate potential for slope instabilities and flooding) (Section 8.3.2.3.1)
4.1.2	Site meets qualifying conditions of technical guidelines (evaluate ease and cost of siting, construction, operation, and closure on topography of proposed site) (Section 8.3.5.7.2)
4.2.1	Site performance information needed for design (evaluate potential for slope instabilities and floodings) (Section 8.3.2.4.1)
4.4.1	Site and performance information needed for design (feasibility and cost effective technologies for construction and operation on topography of proposed site) (Section 8.3.2.5.1)
8.3.1.16.1	Flood recurrence intervals and levels at surface facility locations (flood magnitudes and levels will be used in performance assessment and surface facility design studies)

Surface topographic contours will be an integral part of the siting, designing, and cost estimating for the repository's surface facilities.

Thus, the results from this investigation will be part of the data requirements needed to resolve the respective issues for Information Needs 4.1.2 and 4.4.1, and Investigation 8.3.1.16.1. Data on topographic characteristics pertinent to addressing potential natural hazards from earthquakes and slope instabilities will be provided to Information Needs 2.3.1, and 2.7.1. Investigation 8.3.1.6.1 will need topographic data provided by this investigation to assist in the evaluation of erosion rates.

The topographic characteristics of the surface will also influence siting and designing the underground facilities of the repository. Information Need 1.11.1 will require topographic information to assess whether adequate overburden depth exists above the repository to satisfy the disqualifying condition in 10 CFR 960.4-2-5(d) and the favorable condition in 10 CFR 60.122(b)(5) described in Issues 1.9 and 1.8, respectively.

Surface topographic characteristics will also influence other underground design parameters such as in situ stress. The highly variable surface topography must be considered when evaluating the in situ stresses addressed in Investigations 8.3.1.4.3 and 8.3.1.15.2.

8.3.1.14.2 Investigation: Studies to provide soil and rock properties of potential locations of surface facilities

Technical basis for obtaining the information

Link to the technical data chapters and applicable support documents

The following sections of the data chapters provide a technical summary of existing data relevant to this investigation:

SCP section	Subject
2.7.3	Geoengineering properties of surface materials
6.1.2.1.2	Near surface soil and rock
6.2.4	Design of surface facilities

As discussed in Sections 6.1.2.1.2 and 6.2.4, limited preliminary field investigations (boring and test pits) and laboratory tests have been performed to estimate the soil properties and depth-to-rock. The results of these investigations suggest that the foundation soil or rock has adequate physical and mechanical characteristics for supporting the facility buildings and that ground motion amplification is not expected to be a problem. However, these investigations were only preliminary and the engineering properties were conservatively estimated using empirical correlations with soil classification methods. Therefore, further investigations are necessary to confirm these preliminary estimates.

Parameters

The characterization parameters that will be measured or calculated as a result of the site studies planned as part of this investigation were previously presented in Table 8.3.1.14-1. These data requirements are summarized in the following list:

1. Alluvial and rock stratigraphy and structure.

2. Soil and rock classification vs. depth.

3. Physical properties vs. depth.

4. Mechanical and dynamic properties vs. depth.

5. Compaction characteristics of soil.

6. Infiltration-runoff characteristics of soils and rock at surface (Investigations 8.3.1.2.2 and 8.3.1.6.1).

7. Erosion potential of undisturbed soil, cut slopes, and engineered fill slopes (Investigation 8.3.1.6.1).

Data similar to that described in the summarized list of data requirements will be obtained in two other investigations and one study:

Investigation or study	Subject
8.3.1.4.2	Geologic framework of the Yucca Mountain site
8.3.1.17.4	Preclosure tectonics data collection and analysis
8.3.1.5.1.4	Analysis of the paleoenvironmental history of the Yucca Mountain region

Because the objectives of these other investigations and studies are not always the same as that of the soil and rock investigation, differences may exist in the methods or techniques used to obtain the data. These differences may result in an incompatibility between the soil and rock investigation and the data from the previously described investigations and study. However, in the instances where the data are compatible, every effort will be made to coordinate the soil and rock investigation with similar data-gathering activities in the other investigations and studies.

Purpose and objectives of the investigation

The characteristics of the soil and rock at or near the surface will primarily influence the selection of the surface facilities locations and their design. The soil and rock conditions, as well as topographic relief, influence the specific locations selected for surface buildings, shaft and ramp entrances, and road and rail lines. They also provide information on infiltration-runoff characteristics and erosion potential so that the site drainage and erosion control systems can be designed when the facility design has been completed.

The most direct application of the soil and rock characterization activities will be to provide the necessary data to design surface structure foundations and retaining walls, evaluate the soil-structure interaction (response) due to earthquake loading conditions, and evaluate any potential slope instability conditions. Foundation designs will be necessary for various types of structures, including buildings, shaft hoist frames, and ramp portals.

The foundation design will consist of determining what type, size, and configuration of foundation would be most compatible with the soil or rock conditions, expected loads, function of structure, and design requirements. A determination of the allowable bearing load or pressure of the soil or rock will be a key factor in the foundation design analysis.

After the buildings, foundation, and superstructure have been designed for static-loading conditions, the soil or rock-structure interaction must be evaluated for earthquake loading conditions. In this instance, the number of stories and stiffness of the superstructure will affect the soil-structure response, but even more important will be the subsurface soil and rock conditions. Factors such as the thickness and inclination of an alluvial wedge, the seismic impedance contrast between the alluvium and bedrock, and the seismic absorptivity of the alluvium can all significantly contribute to ground motion response and therefore affect the interaction between the soil and structure.

The characterization of the soil and rock conditions will also be needed for evaluating any potential slope instabilities. Slope stability will be evaluated for road or rail line cuts, ramp portal entrances, and any potential unstable cut or natural slope near a surface facility.

The primary design issue that will be influenced by the soil and rock conditions is Issue 4.4 (Section 8.3.2.5). This issue addresses whether available technologies exist to construct, operate, close, and decommission the repository.

Technical rationale for the investigation

The soil and rock properties investigation has been developed into three studies. These studies are further subdivided into activities. The studies and activities for the soil and rock investigation are as follows:

Study	Activity	Subject
8.3.1.14.2.1		Exploration program
	8.3.1.14.2.1.1	Site reconnaissance
	8.3.1.14.2.1.2	Preliminary exploration
	8.3.1.14.2.1.3	Detailed exploration

Study	Activity	Subject
8.3.1.14.2.2		Laboratory test and material property measurements
	8.3.1.14.2.2.1	Physical property and index laboratory tests
	8.3.1.14.2.2.2	Mechanical and dynamic laboratory property tests
8.3.1.14.2.3		Field tests and characterization measurements
	8.3.1.14.2.3.1	Physical property and field tests and characterization measurements
	8.3.1.14.2.3.2	Mechanical property field tests
	8.3.1.14.2.3.3	Geophysical field measurements

The data obtained from this investigation will be primarily used in the resolution of Issue 4.4 (Section 8.3.2.5). As described earlier, and presented in the logic diagram for this program (Figure 8.3.1.14-1), Design Issue 4.4 addresses whether construction, operation, closure, and decommissioning technologies are adequately established to resolve performance issues.

The main objective of the soil and rock investigation is to provide these design issues with the necessary geotechnical information to help locate the surface facilities, conduct foundation design analyses, evaluate soil-structure interactions, and if necessary, evaluate potentially unstable slopes. A secondary objective will be to provide these design issues with hydraulic-related soil information for evaluating erosion potential and infiltration-runoff characteristics. However, this hydraulic-related soil information will be contributed by Studies 8.3.1.2.2.1 and 8.3.1.6.1.1, which are outside this investigation. Other outside information contributing to this investigation will be from Activities 8.3.1.17.2.1.1, 8.3.1.17.4.2.1, and 8.3.1.17.4.2.2. These activities will provide information on surface fault locations that will be used in the surface facility siting process. The contribution from these outside activities to the soil and rock investigation, and ultimately the relevant design issues, is illustrated in Figures 8.3.1.14-1 and 8.3.1.14-2.

A generalized outline of the geotechnical information required for design is also presented in Figure 8.3.1.14-2 with the corresponding studies and activities that will provide this information. A list of the characterization parameters that will be developed from these studies and activities and provide the necessary geotechnical information required for the design process is presented in Table 8.3.1.14-1. Also provided in this table are the studies and activities associated with each of these characterization parameters.

The characterization parameters will be used to develop the design parameters as illustrated in Table 8.3.1.14-1. This is a key interlink since the design process is an iterative process between the surface facility design requirements (functions) and the soil and rock conditions. The surface facility design requirements and soil and rock conditions must both be considered when determining where to locate a surface facility, what type of foundation would be most appropriate, and evaluating the soil-structure interaction and the potential for unstable slope conditions. A preliminary evaluation of the site and a preconceptual design will determine more specifically what design parameters will be needed for further design activities and therefore what characterization parameters will be required to develop these design parameters. The interlink between the design parameters and the surface facility design requirements (functions) is presented in Section 8.3.2.5 (technical feasibility).

The recommended studies and their corresponding activities were listed previously in this section. These studies include (1) exploration program, (2) laboratory tests and material property measurements, and (3) field tests and characterization measurements.

The exploration program will evaluate all existing data (maps, aerial photographs, etc.), obtain representative samples from boreholes or trenches, and conduct geophysical surveys. Laboratory testing will be conducted on representative samples to determine the physical, mechanical, and dynamic properties of the soil and rock. Field tests will also be conducted on the soil and rock to better establish their physical, mechanical, and dynamic properties. Classification and characterization measurements and evaluations will be conducted on the soil and rock in both the laboratory and field.

The geotechnical exploratory program and its associated laboratory and field test programs will focus on the area east of Exile Hill for characterizing the foundation conditions for the central surface facilities area (Figure 8.3.1.14-3). Exploratory characterization activities will also be conducted in the areas of the ramp portals and shafts located west and north of the central surface facilities area. Additional foundation geotechnical exploration activities will be conducted at the bridge site over Fortymile Wash, which is located in the lower right-hand corner of Figure 8.3.1.14-3.

8.3.1.14.2.1 Study: Exploration program

The objectives of this study are to conduct an exploration program for characterization of the soil and rock conditions that will influence or be influenced by the construction of the surface facilities. The exploration program study will consist of three activities: (1) site reconnaissance, (2) preliminary exploration, and (3) detailed exploration. This study will evaluate all existing data and determine what additional and appropriate data will be needed to adequately address all design issues and characterization programs requesting data from this investigation (Figure 8.3.1.14-1). On the basis of these data needs and the expected soil and rock conditions at the site, an optimum exploration program will be developed and implemented to obtain this data using such methods as drilling, trenching, sampling, sounding, and geophysical surveys. The selection of the appropriate methods will

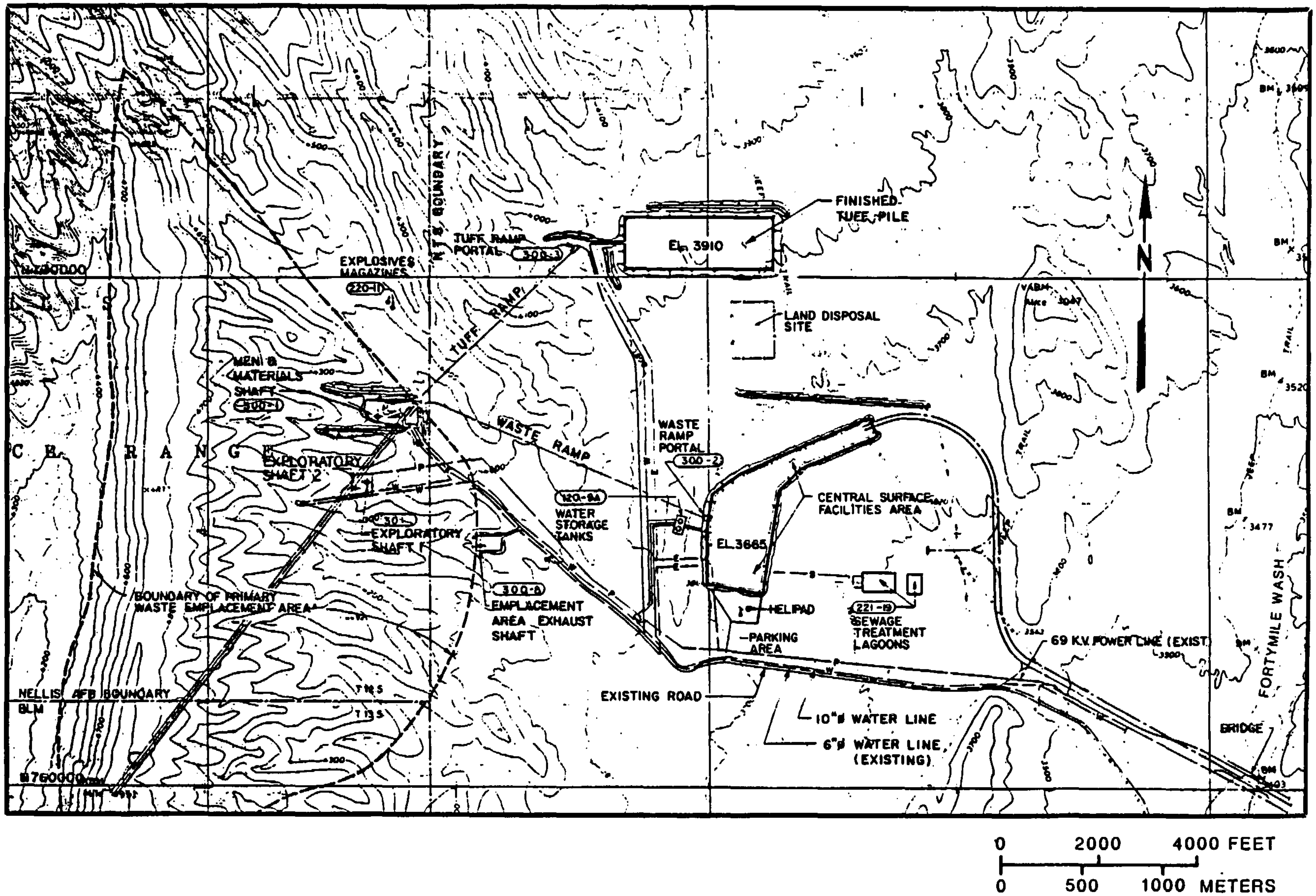


Figure 8.3.1.14-3. Site characterization plan-conceptual design overall site plan.

be dependent on the specific requirements of each data need and the soil or rock conditions that are encountered.

Samples obtained from drilling or trenching will be used in the laboratory testing activities described in Study 8.3.1.14.2.2. Laboratory and field test results and the other geotechnical information developed during this study will contribute to the development of the geotechnical design parameters presented in Table 8.3.1.14-1, which in turn will be used to address Design Issue 4.4 (Section 8.3.2.5).

8.3.1.14.2.1.1 Activity: Site reconnaissance

Objectives

The objectives of this activity are to review existing site information and conduct a field reconnaissance for the purpose of establishing a preliminary exploration program to include subsurface drilling, test pits, trenching, and geophysical methods. Data from this activity will contribute to the development of the geotechnical parameters in Table 8.3.1.14-1 and to the resolution of Design Issue 4.4 (Section 8.3.2.5).

Parameters

The following data are required to fulfill the objectives of this activity:

1. Existing topographic (Investigation 8.3.1.14.1), soil, and geologic maps.

2. Existing subsurface drilling, trenching, and geophysical information.

3. Existing geologic and geotechnical reports.

4. Aerial photographs.

5. Onsite visual reconnaissance.

Some preliminary site reconnaissance and data-gathering activities have already been completed in the Midway Valley-Yucca Mountain area. Four test pits were excavated in the alluvium at potential surface repository facility sites. These sites are located along the western edge of Midway Valley and the eastern edge of Yucca Mountain as illustrated in Figure 8.3.1.14-4. These exploratory activities were conducted to evaluate the conditions of the natural alluvial soils that are expected to support the foundations of the potential surface facility sites. Data collected from these activities include densities, moisture content, specific gravity, gradation analysis, and moisture-dry density compaction relationships (Ho et al., 1986).

Boreholes have also been drilled in the Midway Valley-Exile Hill area as illustrated in Figures 8.3.1.14-4 and 8.3.1.14-5. These boreholes were used to better define the geologic stratigraphy and structure of the preferred

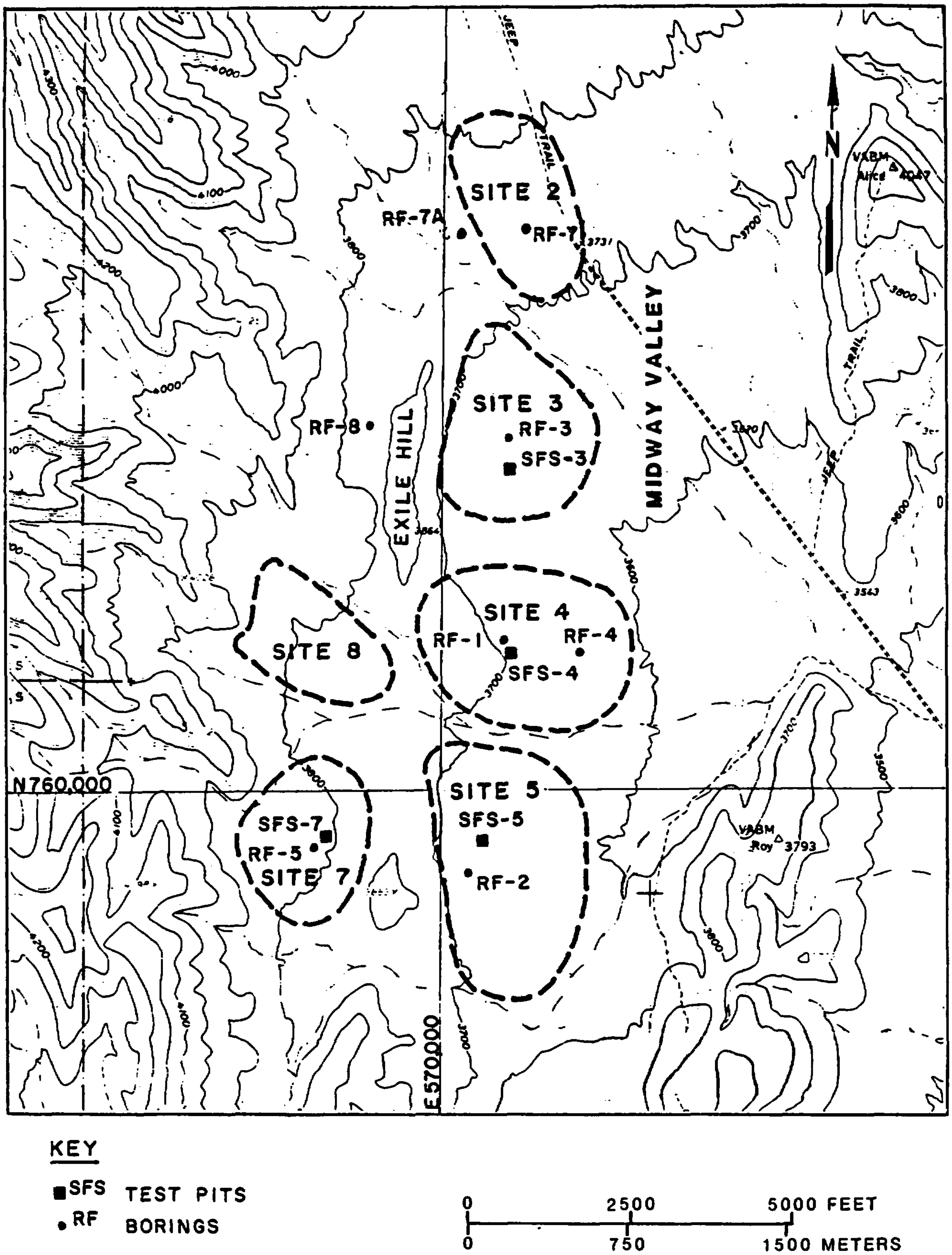


Figure 8.3.1.14-4. Location of surface test pits in alluvium. Modified from Ho et al. (1986).

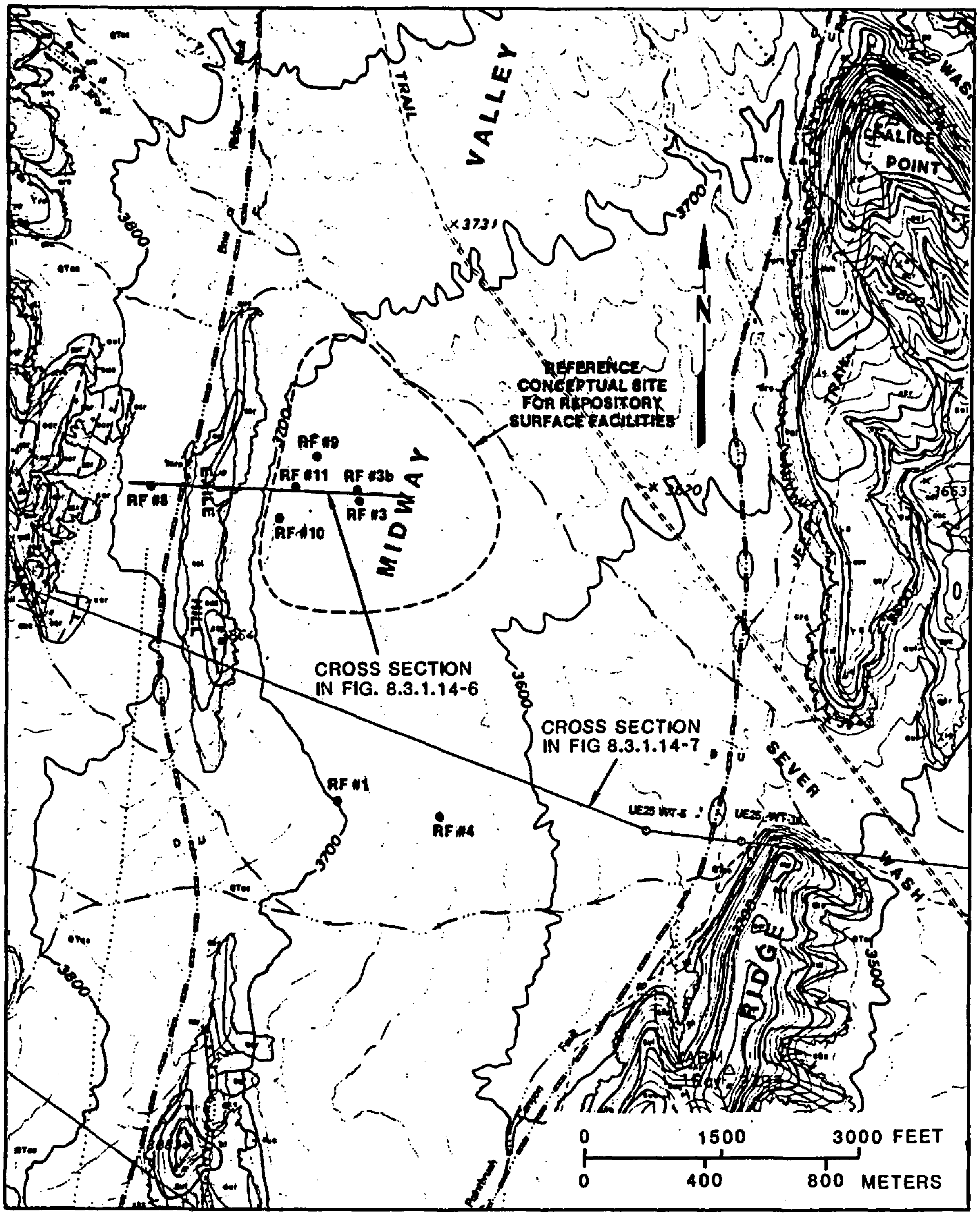


Figure 8.3.1.14-5. Map of the surface geology and faults in the vicinity of Exile Hill. (Unit definitions are given on Figures 8.3.1.14-6 and 8.3.1.14-7.) Modified from Scott and Bonk (1984).

reference conceptual site (Figures 8.3.1.14-5, 8.3.1.14-6, 8.3.1.14-7, and 8.3.1.14-8) and to obtain preliminary physical property and wave velocity data from the alluvium and Tiva Canyon cap rock. These borehole data, plus seismic reflection and refraction surface survey data, were used to determine that the wedge angle between the alluvium and bedrock was low and that the seismic impedance contrast between the alluvium and Tiva Canyon cap rock was small. Both of these characteristics are important from the standpoint of evaluating potential seismic-induced ground motion. It was determined that neither the small wedge angle between the alluvium and bedrock nor the low seismic impedance contrast between the alluvium and bedrock would significantly amplify incoming seismic-induced ground motion (Neal, 1986).

Description

This activity will collect and evaluate all existing geotechnical and air photographic information that exists for the reference conceptual site east of Exile Hill, around shaft and ramp portals, at the tuff pile site, and at other locations associated with surface facilities, such as roads, bridges, and flood protection facilities (e.g., embankments, channels, and culverts). This information will be used in conjunction with an onsite visual reconnaissance to develop an optimum subsurface drilling, trenching, and geophysical survey program.

The previously described site reconnaissance information will be used to develop a preliminary exploration program plan. This plan will identify the type, location, spacing, and depth of subsurface borings, test pits, and trenches. The preliminary exploration program plan will also identify the method and location of recommended geophysical surveys. Recommendations for subsurface boring location, spacing, and depth are given in Hvorslev (1949), and U.S. Army EM 1110-1-1804.

Methods and technical procedures

A preliminary exploration program plan will be developed by analyzing and interpreting existing geotechnical and air photographic information, and the results of the onsite visual reconnaissance. Preliminary exploration specifications describing the type, location, spacing, and depth of subsurface borings, test pits, trenches, and geophysical surveys will be developed considering recommendations provided in the references listed in the following table (as well as similar references not listed).

Method	Technical procedure		
	Number	Title	Date
Site reconnaissance and evaluation of existing data (maps, photos, existing reports)	U.S. Navy NAVFAC DM-7	Design manual - Soil mechanics, foundations, and earth structures	Mar 71

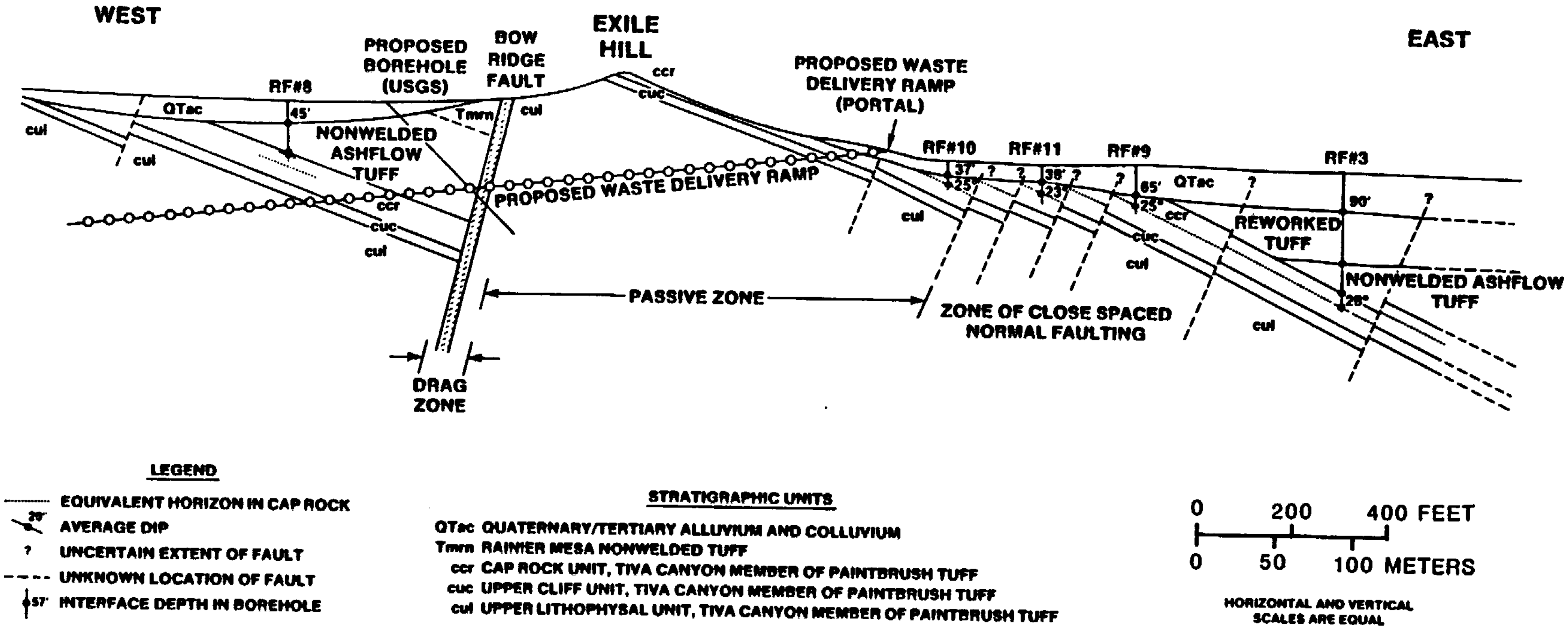
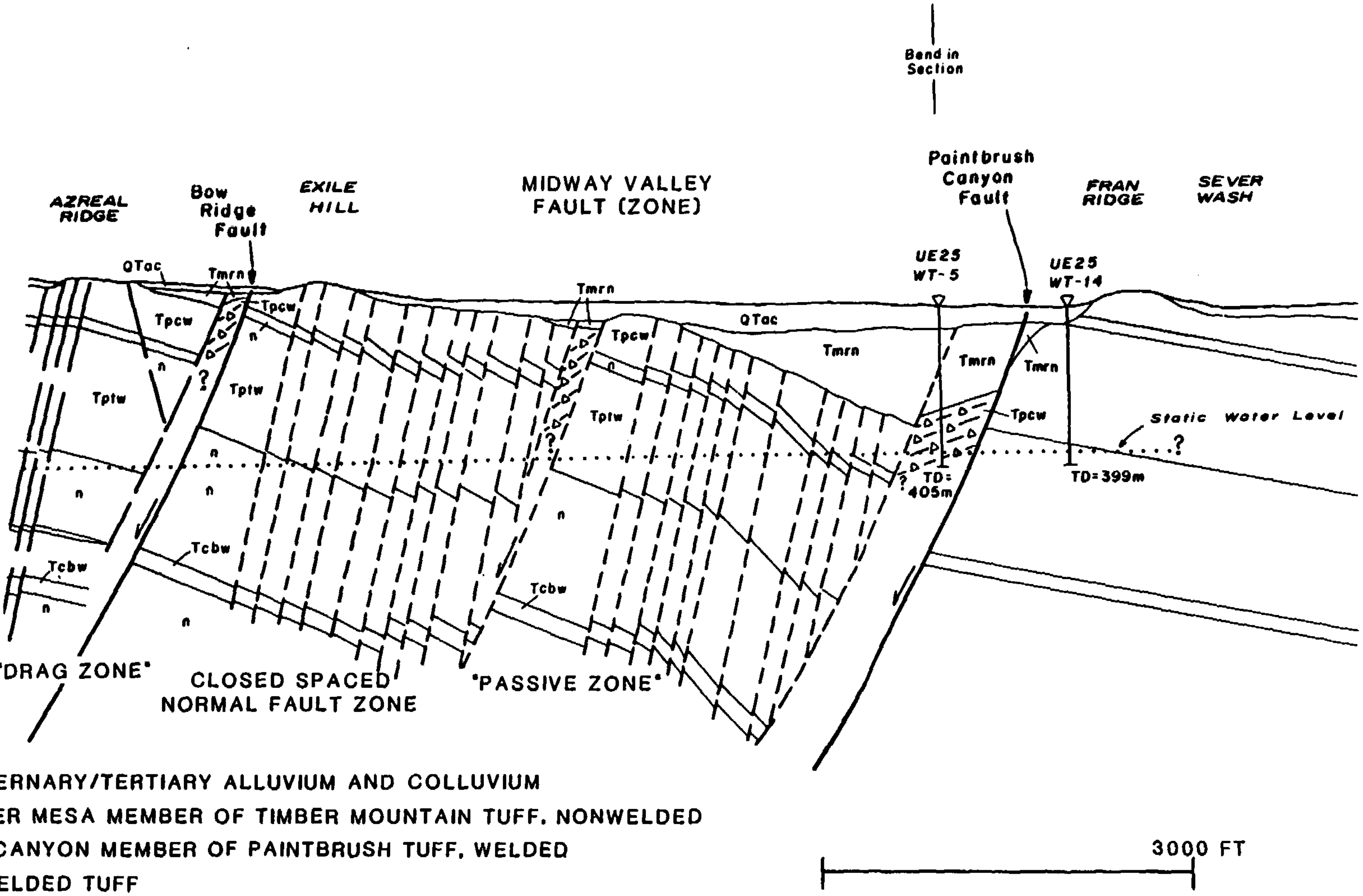


Figure 8.3.1.14-6. Cross section of the geologic structure through Exile Hill and the reference conceptual site based on surface mapping and borehole data. (See Figure 8.3.1.14-5 for the location of the section.) Modified from Scott and Bonk (1984).



QTac	QUATERNARY/TERTIARY ALLUVIUM AND COLLUVIUM
Tmrn	RAINIER MESA MEMBER OF TIMBER MOUNTAIN TUFF, NONWELDED
Tpcw	TIVA CANYON MEMBER OF PAINTBRUSH TUFF, WELDED
n	NONWELDED TUFF
Tptw	TOPOPAH SPRING MEMBER OF PAINTBRUSH TUFF, WELDED
Tcbw	BULLFROG MEMBER OF CRATER FLAT TUFF, WELDED
TD	TOTAL DEPTH

Figure 8.3.1.14-7. Conceptual cross section of the geologic structure south of the reference conceptual site for repository surface facilities. (See Figure 8.3.1.14-5 for the location of the section.) Modified from Scott and Bonk (1984).

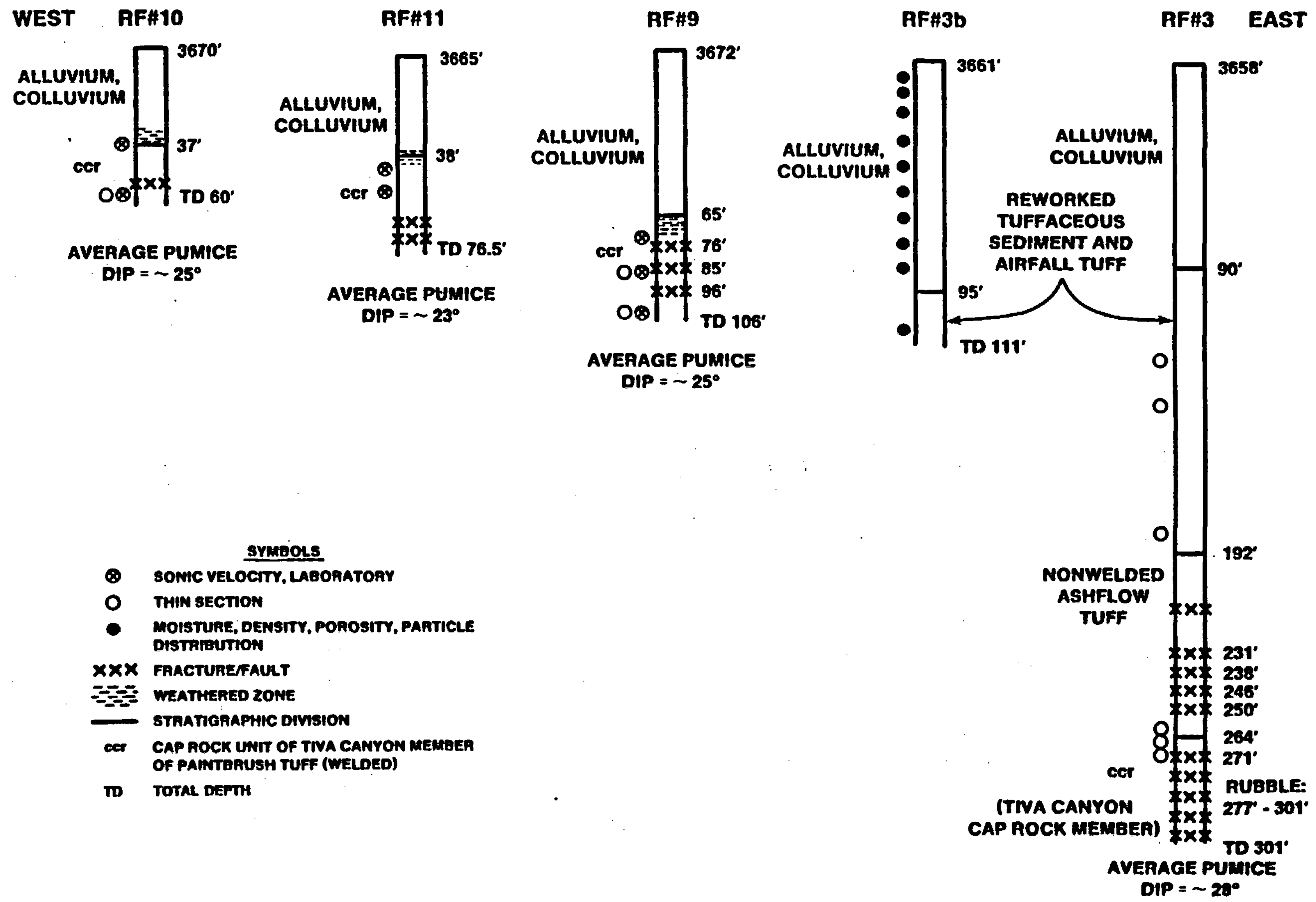


Figure 8.3.1.14-8. Summary of boreholes UE-25 RF#10, 11, 9, 3b. and 3, showing major stratigraphic units and features. (See Figure 8.3.1.14-5 for the locations of the boreholes.) To convert feet to meters, multiply by 0.3048. Modified from Scott and Bonk (1984)

Method	Technical procedure Number	Title	Date
Site reconnaissance and evaluation of existing data (maps, photos, existing reports)	M. J. Hvorslev	Subsurface exploration and sampling of soils for civil engineering purposes	Nov 49
Site reconnaissance and evaluation of existing data (maps, photos, existing reports)	U.S. Army EM 1110-1-1804	Geotechnical investigations	Feb 84

8.3.1.14.2.1.2 Activity: Preliminary exploration

Objectives

The primary objective of the preliminary explorations is to obtain sufficient subsurface data to identify or verify the types, locations, and principal dimensions of all major surface structures comprising the proposed project. Preliminary designs based on these explorations will be suitable for economic and technical feasibility reports and project planning reports. The depth, thickness, and areal extent of all major soil and rock strata that will influence or be influenced by the construction of the surface facilities must be established in reasonable detail. In addition, disturbed and undisturbed samples must be obtained for laboratory testing to provide a basic knowledge of the engineering properties of the various strata.

Parameters

The following data are required to fulfill the objectives of this activity:

1. Depth, thickness, and areal extent of all major soil and rock strata that will be within the zone of stress influence of surface facility loads or that may influence the soil-structure interaction response of the surface facilities under dynamic loading conditions.

2. Identification of existence of significant geologic structures.

3. Representative disturbed and undisturbed samples (undisturbed sampling will be very difficult in a nonsaturated cohesionless soil with cobbles).

4. Identification and classification of soil and rock types encountered.

5. Blow count or penetration resistance with depth in soils (sounding methods).

6. Schmidt impact hammer data for rock.

7. Preliminary determination of physical, mechanical, and dynamic properties developed from empirical methods related to material classifications, blow count or penetration resistance, Schmidt impact hammer data, and geophysical surveys and borehole logging.

Description

Field methods such as sounding, drilling, trenching, and test pits will be used in conjunction with geophysical methods to characterize the depth, thickness, and areal extent of all soil and rock strata that will be within the zone of stress influence of surface facility loads or that may influence the soil-structure interaction response of the surface facilities under dynamic loading conditions. These same methods can also be used to identify significant geologic structures such as faults in the vicinity of critical surface facilities. However, trenching will be the most reliable method for identifying faults in the alluvium at the site. The results of previous preliminary exploration activities (Ho et al., 1986) that were used to develop a conceptual design will be used in conjunction with the results of the exploration program described in this activity to develop an advanced conceptual design and provide the basis for developing a detailed exploration program.

Representative disturbed samples and undisturbed samples (if possible) of the soil and rock will be obtained from the drilling, trenching, and test pit activities for identification, classification, and laboratory testing of physical, mechanical, and dynamic properties. Undisturbed sampling of the unsaturated and cohesionless silty gravels or poorly graded gravels with cobbles at the site (Ho et al., 1986) will be difficult if not impossible.

Preliminary evaluations of the physical, mechanical, and dynamic soil properties of the site will be developed from empirical methods related to material classifications, blow count of penetration resistance, Schmidt impact hammer data, and geophysical surveys and borehole logging. Sounding methods such as the Standard Penetration Test (SPT) (ASTM, 1984b), the Dutch cone penetration resistance (ASTM, 1984a) the Becker penetration resistance (Harder and Seed, 1986) can be used to estimate the physical or mechanical properties of soil. Established empirical relationships can be used to correlate the soil classification and blow count or penetration resistance data to density, Young's modulus, or friction angle (Winterkorn and Fang, 1975). It is recommended that the Becker penetration resistance method be used for coarse gravels that are anticipated at the site. The use of sounding methods such as the SPT blow count or the Dutch cone penetration resistance in coarse gravels may provide unreliable data. If finer grained soil conditions are encountered, then it is recommended to use the SPT blow count method or the Dutch cone penetration resistance method.

Field methods can also be used to provide preliminary estimates of the mechanical rock properties of the site. The point load test (Broch and Franklin, 1972) is commonly used on rock core to estimate its unconfined compressive strength. The Schmidt impact hammer can also be used on rock core or surface outcrops to estimate unconfined compressive strength (ISRM, 1981). These are both very fast, inexpensive, but not necessarily reliable field methods.

Surface and borehole geophysical methods will be used to evaluate the dynamic and physical properties of the subsurface strata. The use of geophysical borehole logging will only be considered below the depth of the trenches or test pits. It will be used to correlate strata between boreholes and provide very approximate values for density, moisture content, porosity, wave velocities, and estimates of the degree of fracturing in rock.

The need for seismic geophysical methods is more apparent. Geophysical methods such as seismic refraction, cross-hole seismic, and up/downhole seismic are recommended for determining the compressive and shear wave velocities of the subsurface strata. The wave velocities will then be used to calculate the dynamic elastic parameters of the subsurface soil and rock. These field parameters are expected to be more reliable than the same parameters measured in the laboratory.

Methods and technical procedures

The following is a list of possible methods that may be used to obtain the data required to fulfill the objectives of this activity. The selection of the most appropriate methods will depend on the soil or rock conditions encountered and the data or parameters required.

1. Subsurface drilling, test pits, and trenching.
2. Sounding (probing) subsurface strata.
3. Geophysical surface surveys.
4. Geophysical borehole logging.
5. Surface and subsurface sampling.

The previously described methods with their corresponding technical procedures are listed in the following table.

Method	Technical procedure		
	Number	Title	Date
Sounding, sampling, classification, drilling, trenching, and geophysical surveys for soils	U.S. Navy NAVFAC DM-7	Design manual - Soil mechanics, foundations, and earth structures	Mar 71
Sounding, drilling, trenching, geophysical surveys and borehole logging and sampling	M.J. Hvorslev	Subsurface exploration and sampling of soils for civil engineering purposes	Nov 49

Method	Technical procedure Number	Title	Date
Sampling for soils	U.S. Army EM 1110-2-1907	Soil sampling	31 Mar 72
Dynamic sounding (blow count) in soils	ASTM D-1586-67	Penetration test and split-barrel sampling of soils	1984
	UCB-EERC-06 Harder & Seed	Determination of penetration resistance for coarse grained soils using tha Becker Hammer Drill	1986
Static sounding-penetration resistance in soils (Dutch cone test)	ASTM D-3441-79	Deep, quasi-static, cone and friction-cone penetration tests of soil	1984
Mechanical properties of rock (indirect)	ISRM Doc. 5, Part 3	Suggested method for determination of the Schmidt Rebound Hardness	Mar 77
Geophysical borehole logging	ISRM Parts 1-11	Suggested methods for geophysical logging of boreholes	1981
Soil classification	ASTM D-2488-69	Description of soils (visual-manual procedure)	1969

8.3.1.14.2.1.3 Activity: Detailed exploration

Objectives

The objective of the detailed exploration activity is to fill in any gaps in the previous preliminary exploration activity and to make such additional explorations that are necessary to define adequately the subsurface conditions. When the subsurface information from the preliminary and detailed exploration activities are combined, the resulting information must be adequate for preparation of bidding plans and specifications for construction.

Parameters

The detailed exploration will conduct activities to improve on the understanding and confidence of the parameters and data identified in the preliminary exploration activity. The soil or rock conditions encountered during the preliminary exploration activities will determine which parameters will require further investigations during the detailed exploration activities or which contingent parameters will require characterization. The results of the preliminary exploration activities may indicate that certain parameters will not require further characterization.

Description

This activity will be an extension of the preliminary exploration program to better define a three-dimensional model or view of subsurface conditions that will influence or be influenced by the construction of surface facilities. Additional boreholes will be drilled or trenches dug at locations planned for critical surface structures or where subsurface conditions are not adequately understood or are highly varied.

In this activity the precise location of each surface facility has been set, and additional borings are made so that an adequate number of borings are located at each surface facility site. During the preliminary exploration, soil or rock conditions may have been encountered that will require different or modified detailed exploration methods. Otherwise, the type of exploration methods used in this activity will be similar to the methods used in the preliminary exploration activity.

Attempts may be made to obtain undisturbed samples; however, the undisturbed sampling of a dry cohesionless soil with cobbles may be difficult if not impossible. The presence of cobbles will require larger samples so that the characteristics of the soil mass will not be overshadowed by the presence of cobbles.

Due to the probable difficulty that will be encountered when attempting to obtain undisturbed samples, it may be necessary to obtain disturbed samples and recompact these samples to the in situ density before testing. The testing of recompacted soil has two disadvantages. The first consideration is that any effects of cementing or fabric will be destroyed by disturbing the sample. The second consideration is that some potential collapse characteristics of the soil sample, if present, may be lost due to the disturbance.

Methods and technical procedures

The same methods and technical procedures described and referenced in the preliminary exploration activity (8.3.1.14.2.1.2) will be used in the detailed exploration activity. However, if unexpected soil or rock conditions are encountered in the preliminary exploration, then different or modified methods and technical procedures may be required for the detailed exploration activity.

8.3.1.14.2.2 Study: Laboratory tests and material property measurements

The objective of this study is to conduct laboratory tests and material property measurements on representative samples of soil and rock. These tests and measurements are intended to determine physical, mechanical, and dynamic properties. Additional tests and measurements will be conducted on soils to determine index properties and moisture-density compaction curves for potential fill material. Geotechnical information from this study will contribute to the development of the geotechnical design parameters presented in Table 8.3.1.14-1, which in turn will be used to address Design Issue 4.4 (Section 8.3.2.5).

8.3.1.14.2.2.1 Activity: Physical property and index laboratory tests

Objectives

The objective of this activity is to measure the soil or rock weight and volume components using physical property tests. Soils can be further characterized by index tests such as gradation analysis and Atterberg limits testing. The physical and index property test results are used to classify soils and rocks, to group soils and rocks in major strata, and to extrapolate results from a restricted number of mechanical and dynamic properties tests to determine properties of other similar materials. Empirical methods can also be used to relate the physical properties and soil or rock classifications to engineering parameters.

Parameters

The following soil and rock parameters will be collected, evaluated, or both to fulfill the objectives of this activity.

1. Soil parameters

   a. Density.

   b. Specific gravity.

   c. Moisture content.

   d. Soil classification.

      i. Gradation analysis.

      ii. Atterberg limits (this parameter will only be determined if cohesive soils are encountered).

   e. Moisture-density compaction curves for potential fill material.

   f. Relative density (cohesionless soils).

2. Rock parameters

   a. Density.
   b. Moisture content.
   c. Porosity.
   d. Specific gravity.

Description

A representative number of samples will be tested so that the variations in physical and index properties throughout the reference conceptual site will be adequately characterized. The laboratory soils tests can be conducted on disturbed samples except for the density and porosity tests. These two soil tests will require undisturbed samples. Because of the difficulty in obtaining an undisturbed sample from a dry cohesionless soil with cobbles, soil densities will have to be determined in situ using either field density test methods, or empirical correlations with sounding methods such as the Standard Penetration Test (SPT) blow count data (Winterhorn and Fong, 1975) or Becker penetration resistance data (Harder and Seed, 1986).

Because of the very coarse nature of the soil, it may not be possible to use the Standard Proctor or Modified Proctor compaction methods to develop the moisture-dry density compaction curve relationships of the soil. For gravelly soils, up to 3-in. maximum size, it is recommended that the U.S. Bureau of Reclamations E-38 procedure be used to develop compaction curves.

Methods and technical procedures

Standard soil testing and classification procedures will be used for Activity 8.3.1.14.2.2.1. A list of possible tests and classification methods follows.

Method	Technical procedure		
	Number	Title	Date
Sample preparation for soils	ASTM D421-58	Dry preparation of soil samples for particle-size analysis and determination of soil constants	1978
Moisture content for soil and rock	ASTM D2216-80	Laboratory determination of water (moisture) content of soil, rock, and soil-aggregate mixtures	1980

Method	Technical procedure Number	Title	Date
Density of soil	ASTM D2937-83	Density of soil in place by the drive-cylinder	1983
Specific gravity for soil			
Materials smaller than number 4 sieve	ASTM D854-83	Specific gravity of soils	1983
Materials larger than number 4 sieve	ASTM C127	Test method for specific and absorption of coarse aggregate	
Atterberg limit[a]			
Liquid and plastic limits	ASTM D4318-83	Liquid limit, plastic limit, and plastic index of soils	1983
Shrinkage limit	ASTM D427-83	Shrinkage factors of soils	1983
Soil Gradation			
Sieve analysis	ASTM D422-63	Particle-size analysis of soils	1972
Hydrometer analysis	ASTM D422-63	Particle-size analysis of soils	1972
Compaction moisture-density relationships			
Standard Proctor	ASTM D698-78	Moisture-density relations of soils and soil-aggregate mixtures using 5.5-lb. hammer and 12-in. drop	1978
Modified Proctor	ASTM D1557-78	Moisture-density relations of soils and soil-aggregate mixtures using 10-lb hammer and 18-in. drop	1978
U.S. Bureau of Reclamation (gravelly soils--3 in. maximum size)	E-38 (Earth Manual)	Compaction test for soil containing gravel	1980

Method	Technical procedure Number	Title	Date
Soil classification	ASTM D2487-83	Classification of soils for engineering purpose	1983
Relative density	ASTM D4254-83	Minimum index density of soils and calculation of relative density	1983
Porosity/density for rock	ISRM Doc. 6 Part 1, No. 2-5	Suggested method for porosity/density determination	Mar 77
Moisture content for rock	ISRM Doc. 6 Part 1, No. 1	Suggested method for determination of water content	Mar 77
Specific gravity for rock	ISRM Doc. 6 Part 1, No. 4	Suggested method for porosity/density determination	Mar 77

[a]Atterberg limits will be required only if cohesive soils are encountered.

8.3.1.14.2.2.2 Activity: Mechanical and dynamic laboratory property tests

Objectives

The objective of this activity is to measure in the laboratory the static and dynamic deformation and strength characteristics of soil and rock samples obtained from the exploratory program. The results of this testing will be used to evaluate bearing capacity, earth pressures, shear strength parameters, slope stability, settlement and swelling potentials, and the dynamic characteristics of the soil and rock. This geotechnical information will be used for locating and designing buildings, foundations, retaining walls, backfills, roads, and slopes. Results from this activity will be the major contributor for developing the geotechnical design parameters presented in Table 8.3.1.14-1.

Parameters

The data and parameters listed in this section will be collected, evaluated, or both, to fulfill the objectives of the activity.

1. Required static load derived parameters.

   a. Mohr-Coulomb strength criteria parameters for soils (cohesion and angle of friction). The type of strength testing will depend on the type of soil, stress history, new stress state, and rate of loading.

b. Peak and residual failure envelopes for rocks.

c. Young's modulus.

d. Poisson's ratio.

e. Shear modulus.

f. Rock discontinuity shear strength parameters in terms of cohesion and angle of friction.

g. Plate load pressure versus settlement.

2. Contingent static load derived parameters.

a. Collapse potential (for relatively dry, low-density soils).

b. Coefficient of consolidation (for saturated, clayey soils).

c. Compression and swell index (for saturated, clayey soils).

d. Other failure criteria parameters such as Drucker-Prager or Hoek and Brown.

e. Deformation modulus of soils in terms of stress-strain characteristics and confinement stress conditions.

f. Bulk modulus and constrained modulus of soils.

3. Required dynamic load derived parameters.

a. Compressive wave velocities versus depth.
b. Shear wave velocities versus depth.
c. Damping versus depth.

4. Contingent dynamic load derived parameters.

a. Strength and stress-deformation characteristics of soil under dynamic load conditions evaluated as a function of stress rates, confinement stress, initial static stress level, magnitude of pulsating stress, number of stress cycles, and frequency of loading.

b. Dynamic shear modulus as a function of strain and confinement stress.

c. Damping as a function of strain.

d. Shear wave velocities as a function of strain.

e. Liquefaction parameters--cyclic shearing stress ratio, cyclic deformation, and pore-pressure response (applicable for soils with perched-water tables near the surface).

The need for any contingent parameters will be determined by the soil or rock conditions encountered, the function or design requirements of the surface facilities, the types of foundations selected, and the type or sophistication of the analyses that are selected for the design or performance studies. On the basis of the known site conditions and the design presented in the SCP-CDR (SNL, 1987), these contingent parameters are not presently required. The contingent parameters will be characterized if unexpected soil and rock conditions are encountered, or if more sophisticated constitutive models are required or used in the soil or rock-structure interaction numerical codes.

Description

Standard laboratory tests for geotechnical engineering practice will be performed. Testing will be conducted on undisturbed or recompacted samples taken from soil and rock strata that will influence or is influenced by surface facility construction. Selection of sample location, depth, and type of test will be influenced by the surface structure function, loads (static or dynamic), and foundation depths and widths. Testing will also be conducted on all soils to be used for engineered fills. These soils must be compacted to the appropriate dry density and moisture content before conducting laboratory tests to determine their mechanical and dynamic properties.

The static strength and deformability of cohesionless soils will be determined in the laboratory from the results of triaxial compression tests and direct shear tests. The results of this testing will be used to confirm or validate the mechanical parameters determined in the field using empirical correlations with soil classification, density, and blow count data. Additionally, plate load bearing tests may be used if spread footings are recommended for the design. Unconfined compressive tests can also be conducted if cohesive soils are encountered.

The type of test or method selected to determine the settlement characteristics of the soil will depend on whether the soil is cohesionless or cohesive. The immediate settlement characteristics of a cohesionless soil will be determined by an analytical method developed by Schmertmann (1970) based on the results of Standard Penetration blow count data or Dutch cone penetration resistance data. The time-dependent settlement characteristics of a saturated cohesive soil will be developed from the results of one-dimensional consolidation tests, however, saturated cohesive soils are not expected to be encountered.

The strength and deformability of rock will be determined in the laboratory from the results of triaxial compression tests, unconfined compression tests, and Brazilian tensile tests. The strength parameters will be in the form of peak and residual strength envelopes. These parameters will be used to evaluate the allowable foundation bearing pressure of the rock (Goodman, 1980).

The direct shear testing method can be used in the laboratory to measure the mechanical properties of the rock discontinuities. The discontinuity strength parameters will be used in the stability evaluation of rock slopes and will contribute to the evaluation of the allowable bearing pressure for a foundation, especially for foundations on sloping topography.

The velocity characteristics of the propagation of elastic waves through soil and rock can be determined in the laboratory using resonant methods. High- and low-frequency ultrasonic pulse techniques can also be used for rock. The resulting velocities from these tests can then be used to determine the elastic deformation parameters of the soil or rock. Elastic deformation parameters derived from laboratory resonant test methods will only be used to confirm or validate the elastic deformation parameters derived from field geophysical seismic methods. However, the material damping characteristics of the soil or rock will be determined in the laboratory using resonant test methods.

Determination of the dynamic compression and shear moduli will depend primarily on field geophysical seismic methods, such as, cross hole and up/downhole measurement techniques. Using these techniques, the maximum dynamic shear modulus (low-strain) can be obtained. The nonlinearity of soil can be considered by reducing the shear modulus with strain based on correlations developed by Seed et al. (1984). It is also recommended that the relationship developed by Seed et al. (1984) be adopted to determine the maximum shear modulus of soil as a function of a density related factor, K_2, obtainable from the field measured shear wave velocities) and the mean effective confining stress. A method for reducing the shear modulus of rock as a function of strain is addressed by Schnabel et al. (1971).

The determination of the strength and stress-deformation characteristics of soils under dynamic load conditions evaluated as a function of stress level, magnitude of pulsating stress, number of stress cycles, and frequency of loading can only be determined in the laboratory using a cyclic loaded triaxial compression test. However, because of the difficulty in obtaining undisturbed samples of the coarse cohesionless soils at the site and the resulting unreliable nature of these samples or recompacted samples, it is recommended that the cyclic loaded triaxial compression test not be conducted if sufficient confidence can be acquired in the previously described field and empirical methods for determining the dynamic mechanical characteristics of the soil. Certain conditions may develop that will either require or produce more of a need for cyclic loaded triaxial test data. These conditions would include a lack of confidence in the previously described field and empirical methods, therefore, requiring the cyclic loaded triaxial test as a means of confirming or validating the parameters developed from the field and empirical methods. In addition, this test would provide the design engineer with more information to better assess the dynamic characteristics of the soil (assuming the data are not totally invalidated due to sample disturbance or questionable testing procedures). The need and validity of the cyclic loaded triaxial test may increase if other soil conditions are encountered such as saturated soils or finer grained soils. Other conditions that may require the implementation of cyclic loaded triaxial test methods are the use of more sophisticated constitutive models in the soil structure interaction numerical codes.

Methods and technical procedures

Standard testing procedures will be used and a list of possible test methods are given in the following table. The selection of the most appropriate method will depend on the soil or rock conditions that are encountered in the exploration activities and the type or sophistication of the analyses that are selected or required for design or performance studies.

Method	Technical procedure Number	Title	Date
Drained triaxial strength of granular soils	Bishop and Henkel	The measurement of soil properties in the triaxial test	1974
Unconfined compression testing for cohesive soils[a]	ASTM 2166-66	Unconfined compressive strength of cohesive soils	1979
Triaxial compression testing for soils[a]	ASTM D2850-82	Unconsolidated, undrained compressive strength of cohesive soils in triaxial compression	1982
Direct-shear strength for soils	ASTM D3080-72	Direct shear test of soils under consolidated drained conditions	1979
Compressibility-swell test for soils[a]	ASTM D2435-80	One-dimensional consolidation properties of soils	1980
Resonant column test for soil	ASTM D4015-81	Modulus and damping of soils by the resonant-column method	1981
High-frequency ultrasonic pulse technique for rock	ISRM, Doc. 4, pp. 108-109	Suggested methods for determining sound velocity	Mar 77
Low-frequency ultrasonic pulse technique for rock	ISRM, Doc. 4, pp. 109-110	Suggested methods for determining sound velocity	Mar 77
Resonant method test for rock	ISRM, Doc. 4, p. 110 velocity	Suggested methods for determining sound	Mar 77

Method	Technical procedure Number	Title	Date
Unconfined compressive strength of rock core	ISRM Part 1	Suggested method for determination of the uniaxial compressive strength of rock materials	Sept 78
Unconfined compressive deformability of rock core	ISRM Part 2	Suggested method for determining deformability of rock materials in uniaxial compression	Sept 78
Triaxial compressive strength of rock core	ISRM, Doc. 7	Suggested methods for determining the strength of rock materials in triaxial compression	Mar 77
Triaxial compressive strength and deformability of rock core	ASTM D2664-80	Triaxial compressive strength of undrained rock core specimens without pore pressure measurements	1980
Indirect tensile strength of rock discontinuities	ISRM, Doc. 8, Part 2	Suggested method for determining indirect tensile strength by the Brazil test	Mar 77
Direct shear strength of rock discontinuities	ISRM, Doc. 1, Part 2	Suggested method for laboratory determination of direct shear strength	Feb 74

[a]The need for these test methods is contingent on encountering cohesive soils. Based on known site conditions, cohesive soils are not expected.

8.3.1.14.2.3 Study: Field tests and characterization measurements

The objective of this study is to conduct field tests and characterization measurements. These field tests are intended to determine the in situ physical, mechanical, and dynamic properties of the soil and rock. Characterization measurements will be conducted on the rock for the purpose of classifying the rock and quantitatively describing the rock structure. Geophysical field measurements will help develop a three-dimensional model of the subsurface soil and rock strata in addition to determining their dynamic properties. Geotechnical information from this study will contribute to the development of the geotechnical design parameters presented in Table 8.3.1.14-1, which in turn will be used to address Design Issue 4.4 (Section 8.3.2.5).

8.3.1.14.2.3.1 Activity: Physical property field tests and characterization measurements

Objectives

The objectives of this activity are to classify and describe the soil and rock conditions in the field and to determine their physical properties. The results of these tests and measurements will be used to develop preliminary estimates of the engineering characteristics of the soils and rocks. In addition, these properties and measurements will aid in the grouping of soils and rocks into stratigraphic units and the extrapolation of results from a restricted number of mechanical and dynamic properties tests to zones of soil and rock with similar material properties.

Parameters

The data and parameters that will be evaluated, collected, or both, to fulfill the objectives of this activity are as follows:

1. Soil
   a. Density.
   b. Relative density (from standard penetration blow count data on cohesionless soils).
2. Rocks
   a. Rock mass classification.
      i. Q-Norwegian Geotechnical Institute (NGI) Tunneling Quality Index.
      ii. RMR--rock mass rating from South African Council for Scientific and Industrial Research (CSIR) Geomechanics Classification.
   b. Rock structure.
      i. Quantitative description of faults.
         (a) Location.
         (b) Orientation.
         (c) Aperture.
         (d) Type of infilling.

(e) Moisture and seepage conditions.
(f) Waviness and roughness.

ii. Quantitative description of joints.

(a) Number of joint sets.

(b) Spacing of joints for each set.

(c) Orientation of each joint set.

(d) Type of infilling if any.

(e) Moisture and seepage conditions.

(f) Waviness and roughness.

(g) Persistence.

(h) Drill core (total core recovery, discontinuity frequency, and rock quality designation (RQD)).

Description

Standard geotechnical engineering field tests and characterization activities will be conducted. A representative number of tests and characterization activities will be conducted throughout the reference conceptual site so that variations in physical properties and characteristics will be adequately understood.

Soils density in the field can be determined by any one of the four different methods described in the following "Methods and technical procedures" section. However, the sand-cone method is the most commonly used method for measuring density in the field. Estimates of relative density in cohesionless soils can be made empirically from Standard Penetration Test (SPT) blow count data. However, SPT blow count data are invalid for the coarse grained gravels found during the previous exploratory activities of the site (Ho et al., 1986). Therefore, the Becker penetration resistance method will be used to obtain blow count data in the coarse gravels and then correlated with equivalent SPT blow count data (Harder and Seed, 1986).

Rock mass classification data will be developed from two commonly used methods. The first method is called the tunneling quality index (Q) method and was developed by the Norwegian Geotechnical Institute, while the second method is referred to as the rock mass rating (RMR) method and was developed by the South African Council for Scientific and Industrial Research. Rock mass classification data can be used to provide preliminary estimates of rock strength and deformation characteristics. However, its primary purpose is to evaluate the stability and required support or reinforcement for subsurface excavations. This characterization data can contribute to locating and designing surface facilities such as ramp portals and shaft collars.

Rock mass discontinuities will be quantitatively described using methods recommended by the International Society for Rock Mechanics Commission on

Standardization of Laboratory and Field Tests. These data will be used in conjunction with the rock mass classification data to evaluate the stability of any potentially hazardous rock slopes and to contribute to a better understanding of the engineering characteristics of the rock mass.

Methods and technical procedures

Standard testing procedures will be used by this activity. A list of possible test methods follows:

Method	Technical procedure Number	Title	Date
Density of soil in place	ASTM D2937-83	Density of soil in place by the drive-cylinder method	1983
	ASTM D1556-82	Density of soil in place by the sand-cone method	1982
	ASTM D2167-66	Density of soil in place by the rubber-balloon method	1977
	ASTM D2922-81	Density of soil and soil-aggregate in place by nuclear methods (shallow depth)	1981
Density of soil in place (U.S. Bureau of Reclamation)	E-24 (Earth Manual)	Field density procedure test	1980
Quantitative description of rock mass discontinuities	ISRM, Part 1 No.1-11	Suggested methods for the quantitative description of discontinuities in rock masses	1978
Rock mass classification, rock mass rating (RMR)	Bieniawski, Z. T.	Rock mass classification in rock engineering	1976
Rock mass classification, tunneling quality (Q)	Barton, Lien, and Lunde	Engineering classification of rock masses for the design of tunnel support	1974

8.3.1.14.2.3.2 Activity: Mechanical property field tests

Objectives

The objective of this activity is to measure the deformation and strength characteristics of in situ soil and rock conditions. The results of this testing will be used to evaluate bearing capacity, earth pressures, settlement and swelling potentials, slope stability, and the dynamic response of soil and rock for the design of foundations, retaining walls, backfills, roads, and slopes.

Parameters

The data and parameters that will be collected, evaluated, or both, to fulfill the objective of this activity are listed in this section.

1. Required parameters for soil (these parameters will be developed from empirical relationships using the following possible data: Dutch cone penetration resistance, Standard Penetration Test (SPT) blow count, Becker penetration resistance, relative density and soil classification or gradation).

    a. Indirect estimates of Mohr-Coulomb shear strength parameters.

    b. Indirect estimates of stiffness or Young's modulus for use in evaluating immediate settlement (compression).

2. Contingent parameters for soil.

    a. Plate load bearing pressure versus settlement (this will be applicable if spread footings are considered in the design).

    b. Modulus of subgrade reaction from plate load test (static or dynamic).

    c. Pile load versus settlement (presently piles are not considered in the SCP-CDR (SNL, 1987)).

3. Required parameters for rock (these parameters will be developed from empirical relationships using rock mass classification data).

    a. Indirect estimates of strength.

    b. Indirect estimates of stiffness or Young's modulus.

4. Contingent parameters for rock.

    a. Plate load bearing pressure vs. settlement (on the surface or down a borehole).

    b. In situ direct shear test to measure the peak and residual shear strength of rock discontinuities.

The need for any contingent parameters will be determined by the soil or rock conditions encountered, the function or design requirements of the surface facilities, the types of foundations selected, and the type or sophistication of the analyses that are selected for the design or performance studies. On the basis of the known site conditions and the design presented in the SCP-CDR (SNL, 1987), these contingent parameters are not presently required. The contingent parameters will be characterized if unexpected soil and rock conditions are encountered, or if more sophisticated constitutive models are required or used in the soil or rock-structure interaction numerical codes.

Description

Standard field tests for geotechnical engineering practice will be conducted. Testing will be conducted only on soil and rock strata that will influence or be influenced by construction at the reference conceptual site. The type of test, location of test, and depth of test are dependent on factors like surface facility function, loads, type and depth of footings, and subsurface soil or rock conditions. If plate bearing or pile loading tests are conducted, they will be located in the immediate vicinity and in the same soil or rock strata as that of the proposed spread footing or pile. In addition, the confinement and moisture conditions of the test and the proposed foundation will also be similar. The results of these in situ loading tests will be extrapolated to estimate the bearing capacity or potential settlement of the larger proposed foundations. However, the in situ loading tests can be extrapolated only if properties of the soil or rock are uniform both laterally and with depth, otherwise potential deep-seated settlement resulting from the entire foundation loading will not be recognized from the results of the in situ loading test.

Indirect in situ methods can be used to estimate strength and stiffness in soils. The two most common methods are the Standard Penetration Test and the Dutch Cone Test. Both of these in situ methods are penetration resistance methods with the Standard Penetration Test applying an impact load and the Dutch Cone applying a continuous load. Another method has recently been developed called the Becker penetration resistance (Harder and Seed, 1986). It is recommended that this method be used in the gravelly soils at the site.

Preliminary estimates of rock mass strength and deformability will be made from empirical relationships with rock mass classification data. Hoek and Brown (1980) have attempted to relate Q and RMR rock mass classification values to failure criteria parameters they developed, which in turn can be related to Mohr-Coulomb failure criteria parameters. Rock mass deformation modulus was also empirically related to rock mass classification values by Bieniawski (1978).

The peak and residual strength of rock discontinuities will be evaluated in the field using in situ direct shear testing methods. This type of test will only be conducted if the site reconnaissance or preliminary exploration activities identify unfavorably oriented discontinuities in a potentially unstable rock slope that could result in a hazard to a critical safety-related structure like the waste handling facility.

Methods and technical procedures

Standard testing procedures will be used for Activity 8.3.1.14.2.3.2. A list of possible test methods are given in the following table.

Method	Technical procedure Number	Title	Date
Plate load settlement in soils or rock (use only if spread footings are considered in the design)	ASTM D194-72	Standard test method for bearing capacity of soil for static load on spread footings	1977
Pile load settlement in soils (pile foundations are presently not considered in the SCP-CDR)[a]	ASTM D1143-81	Standard method of testing piles under static axial compressive load	1981
Plate load settlement in rock (use only if spread footings are considered in the design)	ISRM, Part 2, pp.	Suggested method for field deformability determination using a plate test down a borehole	1978
In situ direct shear strength of rock discontinuity	ISRM, Doc.1, Part 1	Suggested method for in situ determination of direct shear strength	Feb 74

[a]SCP-CDR = Site Characterization Plan-Conceptual Design Report (SNL, 1987).

8.3.1.14.2.3.3 Activity: Geophysical field measurements

Objectives

Geophysical methods will be used to measure in situ soil and rock properties, profile the alluvium-bedrock contact, locate discontinuities or other structural abnormalities, and determine the depth, thickness, and lateral extent of soil and rock stratigraphic units. These geophysical activities will be integrated with other geophysical studies discussed in Section 8.3.1.4.2.1.6. Geophysical methods provide a rapid and economical means of obtaining subsurface information and supplementing other facets of the exploration program. Geophysical measurements can be used to help set up detailed exploration programs (e.g., location, number, and depth of subsurface borings, trenches, and test pits), in addition to providing input for the evaluation of ground motion response and soil-structure interaction caused by earthquakes or underground nuclear events.

Developing an understanding of the seismic response of the ground surface and its interaction with surface facilities is important for siting and designing earthquake-resistant structures. To develop this understanding, it is necessary to first identify the principal parameters that will control the seismic response of the ground surface. These parameters are the depth of the alluvium, the angle between the ground surface and the bedrock-alluvium interface, the seismic impedance contrast between the alluvium and bedrock, and the seismic absorptivity of the alluvium (Harmsen and Harding, 1981; Ohtsuke and Harumi, 1983; King and Tucker, 1984). These parameters will be used in addressing the repository design Issue 4.4 (Section 8.3.2.5) and for the preclosure tectonics investigation (Section 8.3.1.17.3) that evaluates ground motion caused by man-made or natural seismic events.

Parameters

The following data and parameters will be evaluated, collected, or both, to fulfill the objectives of this activity.

The measured or collected data for this activity are

1. Shear-wave velocities (three-dimensional model).
2. Compression-wave velocities (three-dimensional model).
3. Density (three-dimensional model).
4. Porosity.

The evaluated data for this activity are

1. Dynamic Young's modulus.

2. Dynamic shear modulus.

3. Dynamic Poisson's ratio.

4. Damping.

5. Alluvium-bedrock contact depth and angle between the surface and the bedrock-alluvium interface.

6. Seismic impedance contrast between the alluvium and bedrock.

7. Location of changes in physical properties which may indicate a geologic discontinuity.

8. Three-dimensional model of the soil and rock strata.

Description

Sufficient surface and borehole geophysical measurements will be conducted at the reference conceptual site and its vicinity such that three-dimensional models can be developed showing the subsurface geometry of the soil and rock strata and their corresponding dynamic material properties. Dynamic properties such as shear-wave and compression-wave velocities will be determined for alluvial material and bedrock beneath the reference conceptual site for the repository surface facilities and throughout Midway Valley, to a depth of 10 to 20 m below the alluvium-bedrock contract. Information on subsurface seismic-wave transmission properties (velocities, densities, and damping) of the site is required by the preclosure tectonics investigation (Section 8.3.1.17.3) of potential ground motion caused by manmade or natural seismic events. If it is determined that a soil-structure or rock-structure interaction analysis will be required for facilities important to safety (e.g., waste handling building), then the shear-wave and compression-wave velocities will also be needed to determine the dynamic compression and shear moduli, and Poisson's ratio of the subsurface strata beneath the facilities important to safety.

Geophysical measurement methods can be categorized as either surface or borehole methods. Surface methods that will be applicable to this site and provide the required information consist of seismic refraction and possibly electrical resistivity. Borehole methods will consist of seismic and logging techniques. Borehole seismic methods include cross-hole seismic, up-hole seismic, and down-hole seismic techniques. Borehole logging techniques include neutron logging, gamma-gamma density logging, electrical logging, and acoustic or sonic logging.

Shallow seismic refraction methods can be used to determine depth of bedrock or the depth of a stratum with a substantially higher wave velocity. These methods are generally limited to depths of 1,000 ft (300 m) or less. Seismic refraction methods are most useful at sites where wave velocities in successive layers become greater with depth. For depths greater than 1,000 ft (300 m) seismic reflection methods will be used.

Various methods can be used to produce a seismic energy source. These methods can be categorized as impulse or steady-state seismic sources. The most common of these is the impulse method using small charges as the energy source. Mechanically generated energy impulses have also been successfully used to generate seismic waves.

The use of steady-state or continuous vibration provides another seismic energy source technique for characterizing the dynamic properties of the subsurface strata. This technique has certain advantages for characterizing the dynamic properties of soil and rock. All the various energy source techniques can be used to measure wave velocities, but the continuous vibration technique provides another method to better quantify properties such as the natural period of vibration, damping characteristics, and the dynamic modulus of subgrade reaction. The compressive and shear wave velocities can be used to infer the type of subsurface strata, its depth, and its thickness, and will be used in the considerations for siting and designing earthquake-resistant surface structures and foundations. The natural period of vibration is an important factor in the design of foundations subject to induced vibrations. Preliminary estimates of the allowable bearing capacity of soils can be made on the basis of empirical correlations (e.g., Loos, 1937; Terzaghi, 1943; Brennecke and Lohmeyer, 1948) with shear wave velocities or the natural period of vibration. Caution should be taken when using these empirical correlations especially in cases of exploration outside the region for which the correlations have been made.

For shallow geophysical exploration, electrical resistivity methods can be used to help determine the horizontal extents and depths of subsurface strata. These shallow methods are effective within the top 100 ft (30 m) of subsurface strata. The effectiveness of these methods is influenced by the moisture content and salinity of the pore water within the soil and rock. The very low moisture content of the soils at the site may limit its effectiveness. Electrical methods can be used for deeper geophysical exploration, however, they require greater energy sources and greater electrode spacing.

The cross-hole seismic method can be used to measure compressional and shear-wave velocities and damping characteristics of the subsurface strata. This method appears to be the best method for measuring in situ dynamic soil moduli (Woods, 1978). This method also allows for the measurement of velocity as a function of strain. Other advantages include the ability to identify and characterize lower velocity strata located below higher velocity strata. The disadvantage of this method is that it is more costly, requiring two or more boreholes that must be surveyed for vertical deviations. Considering the higher costs, the seismic refraction method may be preferred unless there is a need for strain-dependent velocities or the site is found to have lower velocity strata below higher velocity strata (e.g., a highly cemented layer of soil (caliche) above an uncemented or lightly cemented soil).

Up-hole and down-hole seismic methods can also be used to measure compressional and shear-wave velocities. This method is cheaper than the cross-hole seismic method because it requires only one borehole. The disadvantage is that the properties of individual layers are determined with less certainty with this method because it measures average properties between the source and the recorder.

Geophysical borehole logging will provide estimates of physical properties of the soil and rocks in addition to correlating strata between boreholes and locating strata transitions or contacts. Gamma-gamma logs will provide estimates of the bulk density of the subsurface stratas. If used in combination with neutron and acoustic logs, gamma-gamma logs will indicate the presence and degree of fracturing in crystalline rock. Neutron logs can be used to correlate strata between boreholes and to approximate water content. When used in combination with the gamma-ray log, the neutron log provides a means for identifying lithologies and estimating porosity. Acoustic or sonic logs will be used to measure wave velocities and estimate porosity. The attenuation characteristics of compressional and shear waves may be correlated with the mechanical properties and degree of fracturing and fissuring of the formation.

For correlating strata between boreholes, data from electric logs (electrical resistivity, spontaneous potential, and natural gamma) provide a means for correlation. Data from other geophysical logs will supplement the data from electric logs and will increase the confidence in correlating the strata.

Methods and technical procedures

Standard geophysical measurement methods will be used. A list of possible test methods follows:

1. Surface geophysical methods.

    a. Seismic refraction (Griffiths and King, 1965).

    b. Electrical resistivity (Keller and Frischnecht, 1966).

2. Borehole geophysical methods

    a. Borehole seismic logging.

        i. Cross-hole seismic (Ballard and McLean, 1975).

        ii. Up-hole seismic (Ballard and McLean, 1975).

        iii. Down-hole seismic (Ballard and McLean, 1975).

    b. Other borehole geophysical logging.

        i. Neutron log (ISRM, 1981, Part 6, pp. 63-65).

        ii. Gamma-gamma density log (ISRM, 1981, Part 7, pp. 65-66).

        iii. Acoustic or sonic log (ISRM, 1981, Part 8, pp. 66-67).

        iv. Electrical logs (Pickett, 1977).

It is not suggested that all these geophysical methods will be required. The selection of the appropriate methods will be determined by the site conditions that are encountered and the specific need for parameters such as strain-dependent moduli and damping.

8.3.1.14.2.4 Application of results

The information derived from this investigation will be used to support the following issues, site characterization investigations, and repository design and performance assessment information needs:

Information need, issue, or investigation	Description
2.3.1	Determination of credible accidents applicable to the repository (Section 8.3.5.5.1)
2.7.1	Site information needed for design (Section 8.3.2.3.1)
4.2.1	Site and performance information needed for design (Section 8.3.2.4.1)
4.4.1	Site and performance assessment information needed for design, technical feasibility (Section 8.3.2.5.1)
8.3.1.17.3	Potential vibratory ground motion at the site from natural or manmade seismic sources

Surface soil and rock characteristics will be important considerations in the siting, designing, and cost estimating of the surface facilities at the repository. Investigation 8.3.1.14.2 will provide part of the data required by Information Need 4.4.1 and Investigation 8.3.1.17.3. Soil and rock characteristics data pertinent to addressing potential natural hazards from earthquakes and slope instabilities will also be provided to Information Needs 2.3.1, 2.7.1, and 4.2.1 from Investigation 8.3.1.14.2.

8.3.1.14.3 Schedule for the surface characteristics program

The surface characteristics program includes two investigations, which contain three studies. No further activities are planned for Investigation 8.3.1.14.1. The schedule information for each study of Investigation 8.3.1.14.2 is summarized in Figure 8.3.1.14-9. This figure includes the study number and a brief description, as well as major events associated with each study. A major event, for purposes of these schedules, may represent the initiation or completion of an activity, completion or submittal of a report to the DOE, an important data feed, or a decision point. Solid lines on the schedule represent study durations and dashed lines show interfaces among studies as well as data transferred into or out of the surface characteristics program. The events shown on the schedule and their planned dates of completion are provided in Table 8.3.1.14-4.

The study-level schedules, in combination with information provided in the logic diagrams for this program (Figures 8.4.1.14-1 and -2,) are intended to provide the reader with a basic understanding of the relationships between major elements of the site, performance, and design programs. The information provided in Table 8.3.1.14-4 and Figure 8.3.1.14-9, however, should be viewed as a snapshot in time.

The overall program schedule presented here is consistent with the Draft Mission Plan Amendment (DOE, 1988a). The site characterization program will undergo a series of refinements following issuance of the statutory SCP.

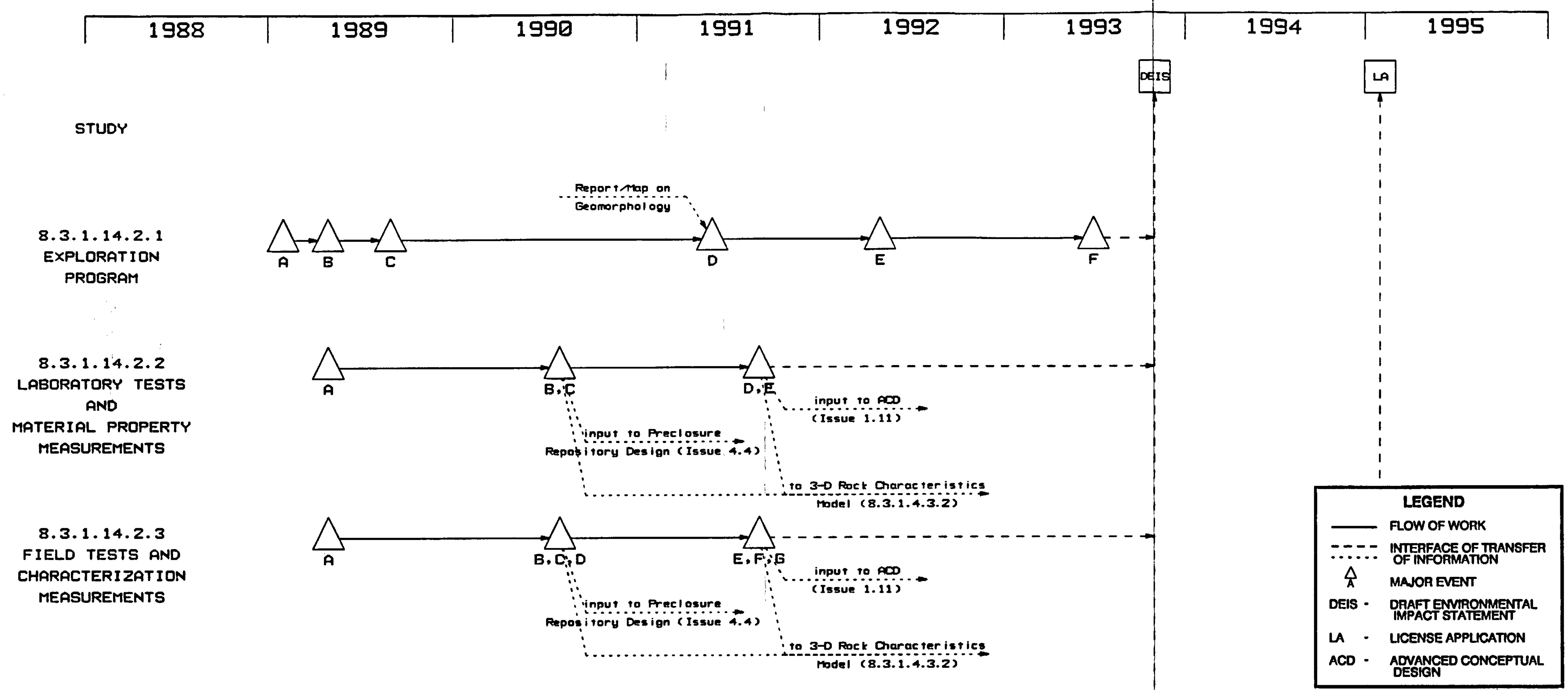


Figure 8.3.1.14-9. Schedule information for studies in Site Program 8.3.1.14 (surface characteristics). See Table 8.3.1.14-4 for description of major events. This network is consistent with the Draft Mission Plan Amendment (DOE, 1988a) schedule. Revisions will be published in semiannual site characterization progress reports as new information becomes available.

Table 8.3.1.14-4. Major events and planned completion dates for studies in the surface characteristics program (page 1 of 3)

Study number	Brief description of study	Major event[a]	Event description	Date
8.3.1.14.2.1	Exploration program	A	Study plan approved	1/89
		B	Begin site reconnaissance	4/89
		C	Complete site reconnaissance	8/89
		D	Draft report available to the U.S. Department of Energy (DOE) on the results of site reconnaissance; begin preliminary exploration	5/91
		E	Draft report available to DOE on the results of preliminary exploration; begin detailed exploration	4/92
		F	Draft report available to DOE on the results of detailed exploration	6/93
8.3.1.14.2.2	Laboratory tests and material property measurements	A	Study plan approved	4/89
		B	Draft report available to DOE on the results of physical properties and index laboratory testing	7/90

Table 8.3.1.14-4. Major events and planned completion dates for studies in the surface characteristics program (page 2 of 3)

Study number	Brief description of study	Major event[a]	Event description	Date
8.3.1.14.2.2	Laboratory tests and material property measurements (continued)	C	Draft report available to DOE on the results of mechanical and dynamic laboratory property testing	7/90
		D	Draft of updated report on physical properties and index laboratory testing available to DOE	8/91
		E	Draft of updated report on mechanical and dynamic laboratory property testing available to DOE	8/91
8.3.1.14.2.3	Field tests and characterization measurements	A	Study plan approved	4/89
		B	Draft report available to DOE on the results of physical property field tests	7/90
		C	Draft report available to DOE on the results of mechanical properties field tests	7/90
		D	Draft report available to DOE on geophysical field measurements	7/90

Table 8.3.1.14-4. Major events and planned completion dates for studies in the surface characteristics program (page 3 of 3)

Study number	Brief description of study	Major event[a]	Event description	Date
8.3.1.14.2.3.	Field tests and characterization measurements (continued)	E	Draft of updated report on the results of physical property field tests available to DOE	8/91
		F	Draft of updated report on the results of mechanical properties field tests available to DOE	8/91
		G	Draft of updated report on geophysical field measurements available to DOE	8/91

[a]The letters in this column key major events shown in Figure 8.3.1.14-9.

Refinements will consider factors both internal and external to the site characterization program, such as changes to the quality assurance program. Such refinements are to be considered in ongoing planning efforts, and changes that are implemented will be reflected in the semiannual progress report. Summary schedule information for the surface characteristics program can be found in Section 8.5.1.1 and 8.5.6.

DOE/RW-0199 DOE/RW-0199

Nuclear Waste Policy Act
(Section 113)

Site Characterization Plan

Yucca Mountain Site, Nevada Research and Development Area, Nevada

Volume V, Part B

Chapter 8, Section 8.3.1.15, Thermal and Mechanical Properties

December 1988

U. S. Department of Energy
Office of Civilian Radioactive Waste Management

8.3.1.15 Overview of thermal and mechanical rock properties program: Description of thermal and mechanical rock properties required by the performance and design issues

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

This program provides all site information needed on thermal and mechanical rock properties and on ambient stress and temperature conditions. The issues specifically requesting information from this characterization program are summarized in the following table. Other issues utilizing this information are indirectly supported by this characterization program (e.g., 1.4, 1.7, 2.4, etc.)

Data required	Issue	Short title	SCP section
Thermal properties of host rock for analyses related to waste package design	1.10	Waste package characteristics (postclosure)	8.3.4.2
Thermal/mechanical properties of the rock for repository design and in situ stress and temperature conditions for initial and boundary conditions for design calculations	1.11	Configuration of underground facilities (postclosure)	8.3.2.2
	1.12	Seal characteristics	8.3.3.2
	4.4	Preclosure design and technical feasibility	8.3.2.5
Thermal properties of rock for disturbed zone analysis	1.6	Ground-water travel time	8.3.5.12
Bulk properties and radon emanation rate for radiologic safety analysis	2.7	Repository design criteria for radiological safety	8.3.2.3
	2.2	Worker radiological safety (normal conditions)	8.3.5.4

Table 8.3.1.15-1 summarizes the required rock characteristics information and outlines the tie to this section's site characterization activities, which describe how the data will be obtained. The parameters to be measured may be different from those requested in the table. The reasons for

Table 8.3.1.15-1. Performance and design parameters, tentative goals, and characterization parameters for thermal and mechanical properties program[a] (page 1 of 12)

Issue requesting parameter (SCP section)	Performance or design parameter	Material type and spatial location[b]	Stratigraphic location[c] (request)	Tentative goal[d,e]	Needed confidence[d]	Current estimate	Current confidence[d]	Parameter to be measured	Material type tested	SCP activity numbers	Spatial location	Stratigraphic location[c]
1.6 (8.3.5.12)	Bulk density	Rock mass; primary area	NS	NS	NS	NS	NS	Grain density, porosity	Intact rock	8.3.1.15.1.1.1	(g)	NS
1.10 (8.3.4.2)	Bulk density	Rock mass; primary area	TSw2	$\bar{x} \pm 0.1\bar{x}$	Medium	2.26 - 2.33 g/cm^3	Low to medium	Grain density, porosity	Intact rock	8.3.1.15.1.1.1	(g)	TSw2
2.2 (8.3.5.4)	Bulk density	Rock mass; primary area	TSw2	NS	High	2.26 - 2.33 g/cm^3	Low to medium	Grain density, porosity	Intact rock	8.3.1.15.1.1.1	(g)	TSw2
2.7 (8.3.2.3)	Bulk density	Rock mass; primary area	TSw2	(f)	Medium to high	2.26 - 2.33 g/cm^3	Low to medium	Grain density, porosity	Intact rock	8.3.1.15.1.1.1	(g)	TSw2
1.6 (8.3.5.12)	Thermal conductivity	Rock mass; primary area	NS	NS	NS	NS	NS	Thermal conductivity of solids, porosity	Intact rock	8.3.1.15.1.1.1	(g)	NS
								Thermal conductivity	Rock mass	8.3.1.15.1.6.2 8.3.1.15.1.6.3 8.3.1.15.1.6.5	ESF	TSw2
1.10 (8.3.4.2)	Thermal conductivity	Intact rock; primary area	TSw2	$\bar{x} \pm 0.1\bar{x}$	Medium	NS	Low to medium	Thermal conductivity of solids, porosity	Intact rock	8.3.1.15.1.1.1 8.3.1.15.1.1.3	(g)	TSw2
	Thermal conductivity	Rock mass; primary area	TSw2	$\bar{x} \pm 0.1\bar{x}$	Medium	NS	Low to medium	Thermal conductivity	Rock mass	8.3.1.15.1.7.2 8.3.1.15.1.6.3 8.3.1.15.1.6.5	ESF	TSw2
1.11 (8.3.2.2)	Thermal conductivity	Rock mass; primary area and extensions	TSw2	$\bar{x} \pm 0.2\bar{x}$	High	See Table 6-16	Low to medium	Thermal conductivity of solids, porosity	Intact rock	8.3.1.15.1.1.1 8.3.1.15.1.1.3	(g)	TSw2
								Thermal conductivity	Rock mass	8.3.1.15.1.6.2 8.3.1.15.1.6.3 8.3.1.15.1.6.5	ESF	TSw2
			TSw1	$\bar{x} \pm 0.2\bar{x}$	Medium	See Table 6-16	Low to medium	Thermal conductivity of solids, porosity	Intact rock	8.3.1.15.1.1.1 8.3.1.15.1.1.3	(g)	TSw1
								Thermal conductivity	Rock mass	8.3.1.15.1.6.1	ESF	TSw1

Table 8.3.1.15-1. Performance and design parameters, tentative goals, and characterization parameters for thermal and mechanical properties program[a] (page 2 of 12)

Issue requesting parameter (SCP section)	Performance or design parameter	Material type and spatial location[b]	Stratigraphic location[c] (request)	Tentative goal[d,e]	Needed confidence[d]	Current estimate	Current confidence[d]	Parameter to be measured	Material type tested	SCP activity numbers	Spatial location	Stratigraphic location[c]
1.11 (8.3.2.2) (continued)			TSw3, CHn1	$\bar{x} \pm 0.2\bar{x}$	Medium	See Table 6-16	Low to medium	Thermal conductivity of solids, porosity	Intact rock	8.3.1.15.1.1.1 8.3.1.15.1.1.3	(g)	TSw3, CHn1
			Units above TSw1, CHn2	$\bar{x} \pm 0.2\bar{x}$	Low	See Table 6-16	Low to medium	Thermal conductivity of solids, porosity	Intact rock	8.3.1.15.1.1.1 8.3.1.15.1.1.3	(g)	(h)
1.12 (8.3.3.2)	Thermal conductivity	Rock mass; primary area	TSw2, CHn1	NS	Medium	NS	Low to medium	Thermal conductivity of solids, porosity	Intact rock	8.3.1.15.1.1.1 8.3.1.15.1.1.3	(g)	TSw2, CHn1
								Thermal conductivity	Rock mass	8.3.1.15.1.6.2 8.3.1.15.1.6.3 8.3.1.15.1.6.5	ESF	TSw2
4.4 (8.3.2.5)	Thermal conductivity	Rock mass; primary area	TSw2	$\bar{x} \pm 0.2\bar{x}$	Medium	$\bar{x}$	Low to medium	Thermal conductivity of solids, porosity	Intact rock	8.3.1.15.1.1.1 8.3.1.15.1.1.3	(g)	TSw2
								Thermal conductivity	Rock mass	8.3.1.15.1.6.2 8.3.1.15.1.6.3 8.3.1.15.1.6.5	ESF	TSw2
			TSw1	$\bar{x} \pm 0.2\bar{x}$	Medium	$\bar{x}$	Low to medium	Thermal conductivity of solids, porosity	Intact rock	8.3.1.15.1.1.1 8.3.1.15.1.1.3	(g)	TSw1
								Thermal conductivity	Rock mass	8.3.1.15.1.6.1	ESF	TSw1
	Thermal conductivity	Rock mass; primary area	Ground surface to base of TSw2	$\bar{x} \pm 0.2\bar{x}$	Low	$\bar{x}$	Low to medium	Thermal conductivity of solids, porosity	Intact rock	8.3.1.15.1.1.1 8.3.1.15.1.1.3	(g)	Alluvium, TCw, PTn, TSw1, TSw2
								Thermal conductivity	Rock mass	8.3.1.15.1.6.1 8.3.1.15.1.6.2 8.3.1.15.1.6.3 8.3.1.15.1.6.5	ESF	TSw1, TSw2

Table 8.3.1.15-1. Performance and design parameters, tentative goals, and characterization parameters for thermal and mechanical properties program[a] (page 3 of 12)

Issue requesting parameter (SCP section)	Performance or design parameter	Material type and spatial location[b]	Stratigraphic location[c] (request)	Tentative goal[d,e]	Needed confidence[d]	Current estimate	Current confidence[d]	Parameter to be measured	Material type tested	SCP activity numbers	Spatial location	Stratigraphic location[c]
1.6 (8.3.5.12)	Heat capacity	Rock mass; primary area	NS	NS	NS	NS	NS	Heat capacity of solids, grain density, porosity	Intact rock	8.3.1.15.1.1.1 8.3.1.15.1.1.2	(g)	NS
								Heat capacity	Rock mass	8.3.1.15.1.6.2 8.3.1.15.1.6.3 8.3.1.15.1.6.5	ESF	TSw2
1.10 (8.3.4.2)	Heat capacity	Intact rock; primary area	TSw2	$\bar{x} \pm 0.2\,\bar{x}$	Medium	$\bar{x}$	Low to Medium	Heat capacity of solids, grain density, porosity	Intact rock	8.3.1.15.1.1.1 8.3.1.15.1.1.2	(g)	TSw2
								Heat capacity	Rock mass	8.3.1.15.1.6.2 8.3.1.15.1.6.3 8.3.1.15.1.6.5	(g)	TSw2
1.11 (8.3.2.2)	Heat capacity	Rock mass; primary area and extensions	TSw2	$\bar{x} \pm 0.1\bar{x}$	High	See Table 6-16	Low to medium	Heat capacity of solids, grain density, porosity	Intact rock	8.3.1.15.1.1.1 8.3.1.15.1.1.2	(g)	TSw2
								Heat capacity	Rock mass	8.3.1.15.1.6.2 8.3.1.15.1.6.3 8.3.1.15.1.6.5	(g)	TSw2
			TSw1	$\bar{x} \pm 0.1\bar{x}$	Medium	See Table 6-16	Low to medium	Heat capacity of solids, grain density, porosity	Intact rock	8.3.1.15.1.1.1 8.3.1.15.1.1.2	(g)	TSw1
								Heat capacity	Rock mass	8.3.1.15.1.6.1	ESF	TSw1
			TSw3, CHn1	$\bar{x} \pm 0.1\bar{x}$	Medium	See Table 6-16	Low to medium	Heat capacity of solids, grain density, porosity	Intact rock	8.3.1.15.1.1.1 8.3.1.15.1.1.2	(g)	TSw3 CHn1
			All units above TSw1, CHn2	$\bar{x} \pm 0.1\bar{x}$	Low	See Table 6-16	Low	Heat capacity of solids, grain density, porosity	Intact Rock	8.3.1.15.1.1.1 8.3.1.15.1.1.2	(g)	(f)
1.12 (8.3.3.2)	Heat capacity	Rock mass; primary area	TSw2, CHn1	NS	Medium	NS	Low to medium	Heat capacity of solids, grain density, porosity	Intact rock	8.3.1.15.1.1.1 8.3.1.15.1.1.2	(g)	TSw2, CHn1
								Heat capacity	Rock mass	8.3.1.15.1.6.2 8.3.1.15.1.6.3 8.3.1.15.1.6.5	ESF	TSw2

Table 8.3.1.15-1. Performance and design parameters, tentative goals, and characterization parameters for thermal and mechanical properties program[a] (page 4 of 12)

Issue requesting parameter (SCP section)	Performance or design parameter	Material type and spatial location[b]	Stratigraphic location[c] (request)	Tentative goal[d,e]	Needed confidence[d]	Current estimate	Current confidence[d]	Parameter to be measured	Material type tested	SCP activity numbers	Spatial location	Stratigraphic location[c]
4.4 (8.3.2.5)	Heat capacity	Rock mass; primary area	TSw2	$\bar{x} \pm 0.1\bar{x}$	Medium	$\bar{x}$	Low to medium	Heat capacity of solids, grain density, porosity	Intact rock	8.3.1.15.1.1.1 8.3.1.15.1.1.2	(g)	TSw2
								Heat capacity	Rock mass	8.3.1.15.1.6.2 8.3.1.15.1.6.3 8.3.1.15.1.6.5	ESF	TSw2
			TSw1	$\bar{x} \pm 0.1\bar{x}$	Medium	$\bar{x}$	Low to medium	Heat capacity of solids, grain density, porosity	Intact rock	8.3.1.15.1.1.1 8.3.1.15.1.1.2	(g)	TSw1
								Heat capacity	Rock mass	8.3.1.15.1.6.1	ESF	TSw1
	Heat capacity	Rock mass; primary area	Ground surface to base of TSw2	$\bar{x} \pm 0.1\bar{x}$	Low	$\bar{x}$	Low to medium	Heat capacity of solids, grain density, porosity	Intact rock	8.3.1.15.1.1.1 8.3.1.15.1.1.2	(g)	Alluvium, TCw, PTn, TSw1, TSw2
								Heat capacity	Rock mass	8.3.1.15.1.6.1 8.3.1.15.1.6.2 8.3.1.15.1.6.3 8.3.1.15.1.6.5		TSw1, TSw2
1.6 (8.3.5.12)	Coefficient of thermal expansion	Rock mass; primary area	NS	NS	NS	NS	NS	Coefficient of thermal expansion	Intact rock	8.3.1.15.1.2.1	(g)	NS
								Coefficient of thermal expansion	Rock mass	8.3.1.15.1.6.2 8.3.1.15.1.6.3 8.3.1.15.1.6.4 8.3.1.15.1.6.5	ESF	TSw2
1.11 (8.3.2.2)	Coefficient of thermal expansion	Rock mass; primary area and extensions	TSw2	$\bar{x} \pm 0.15\bar{x}$	High	See Table 6-16	Medium	Coefficient of thermal expansion	Intact rock	8.3.1.15.1.2.1	(g)	TSw2
								Coefficient of thermal expansion	Rock mass	8.3.1.15.1.6.2 8.3.1.15.1.6.3 8.3.1.15.1.6.4 8.3.1.15.1.6.5	ESF	TSw2
			TSw1	$\bar{x} \pm 0.15\bar{x}$	Medium	See Table 6-16	Low to medium	Coefficient of thermal expansion	Intact rock	8.3.1.15.1.2.1	(g)	TSw1
								Coefficient of thermal expansion	Rock mass	8.3.1.15.1.6.1	ESF	TSw1

Table 8.3.1.15-1. Performance and design parameters, tentative goals, and characterization parameters for thermal and mechanical properties program[a] (page 5 of 12)

Issue requesting parameter (SCP section)	Performance or design parameter	Material type and spatial location[b]	Stratigraphic location[c] (request)	Tentative goal[d,e]	Needed confidence[d]	Current estimate	Current confidence[d]	Parameter to be measured	Material type tested	SCP activity numbers	Spatial location	Stratigraphic location[c]
1.11 (8.3.2.2) (continued)			TSw3, CHn1	$\bar{x} \pm 0.15\bar{x}$	Medium	See Table 6-16	Low to medium	Coefficient of thermal expansion	Intact rock	8.3.1.15.1.2.1	(g)	TSw3, CHn1
			All units above TSw1, CHn2	$\bar{x} \pm 0.15\bar{x}$	Low	See Table 6-16	Low to medium	Coefficient of thermal expansion	Intact rock	8.3.1.15.1.2.1	(g)	(h)
1.12 (8.3.3.2)	Coefficient of thermal expansion	Rock mass; primary area	TSw2, CHn1	NS	Medium	NS	Low to medium	Coefficient of thermal expansion	Intact rock	8.3.1.15.1.2.1	(g)	TSw2, CHn1
								Coefficient of thermal expansion	Rock mass	8.3.1.15.1.6.2 8.3.1.15.1.6.3 8.3.1.15.1.6.4 8.3.1.15.1.6.5	ESF	TSw2
4.4 (8.3.2.5)	Coefficient of thermal expansion	Rock mass; primary area	TSw2	$\bar{x} \pm 0.15\bar{x}$	Medium	$\bar{x}$	Medium	Coefficient of thermal expansion	Intact rock	8.3.1.15.1.2.1	(g)	TSw2
								Coefficient of thermal expansion	Rock mass	8.3.1.15.1.6.2 8.3.1.15.1.6.3 8.3.1.15.1.6.4 8.3.1.15.1.6.5	ESF	TSw2
			TSw1	$\bar{x} \pm 0.15\bar{x}$	Medium	$\bar{x}$	Low to medium	Coefficient of thermal expansion	Intact rock	8.3.1.15.1.2.1	(g)	TSw1
								Coefficient of thermal expansion	Rock mass	8.3.1.15.1.6.1	ESF	TSw1
1.11 (8.3.2.2)	Elastic properties											
	Young's modulus	Intact rock; primary area and extensions	TSw2	$\bar{x} \pm 0.15\bar{x}$	High	See Table 6-12	Medium	Young's modulus	Intact rock	8.3.1.15.1.3.1 8.3.1.15.1.3.2	(g)	TSw2
			TSw1	$\bar{x} \pm 0.15\bar{x}$	Medium	See Table 6-12	Medium	Young's modulus	Intact rock	8.3.1.15.1.3.1 8.3.1.15.1.3.2	(g)	TSw1
			TSw3, CHn1	$\bar{x} \pm 0.15\bar{x}$	Medium	See Table 6-12	Low	Young's modulus	Intact rock	8.3.1.15.1.3.1 8.3.1.15.1.3.2	(g)	TSw3, CHn1
			All units above TSw1, CHn2	$\bar{x} \pm 0.15\bar{x}$	Low	See Table 6-12	Low to medium	Young's modulus	Intact rock	8.3.1.15.1.3.1 8.3.1.15.1.3.2	(g)	(h)

Table 8.3.1.15-1. Performance and design parameters, tentative goals, and characterization parameters for thermal and mechanical properties program[a] (page 6 of 12)

Issue requesting parameter (SCP section)	Performance or design parameter	Material type and spatial location[b]	Stratigraphic location[c] (request)	Tentative goal[d,e]	Needed confidence[d]	Current estimate	Current confidence[d]	Parameter to be measured	Material type tested	SCP activity numbers	Spatial location	Stratigraphic location[c]
1.11 (8.3.2.2) (continued)	Deformation modulus	Rock mass; primary area and extensions	TSw2	$\bar{x} \pm 0.15\bar{x}$	High	See Table 6-14	Low	Young's modulus, fracture stiffness	Intact rock and fractures	8.3.1.15.1.3.1 8.3.1.15.1.3.2 8.3.1.15.1.4.1 8.3.1.15.1.4.2 8.3.1.15.1.3.2	(g)	TSw2
								Deformation modulus	Rock mass	8.3.1.15.1.6.3 8.3.1.15.1.7.1	ESF	TSw2
			TSw1	$\bar{x} \pm 0.15\bar{x}$	Medium	See Table 6-14	Low	Young's modulus fracture stiffnesses	Intact rock and fractures	8.3.1.15.1.3.1 8.3.1.15.1.3.2 8.3.1.15.1.4.1 8.3.1.15.1.4.2	(g)	TSw1
								Deformation modulus	Rock mass	8.3.1.15.1.7.1	ESF	TSw1
			TSw3, CHn1	$\bar{x} \pm 0.15\bar{x}$	Medium	See Table 6-14	Low	Young's modulus, fracture stiffness	Intact rock and fractures	8.3.1.15.1.3.1 8.3.1.15.1.3.2 8.3.1.15.1.4.1 8.3.1.15.1.4.2	(g)	TSw3, CHn1
			All units above TSw1, CHn2	$\bar{x} \pm 0.15\bar{x}$	Low	See Table 6-14	Low	Young's modulus, fracture stiffness	Intact rock and fractures	8.3.1.15.1.3.1 8.3.1.15.1.3.2 8.3.1.15.1.4.1 8.3.1.15.1.4.2	(g)	(h)
	Poisson's ratio	Intact rock; primary area and extensions	TSw2	$\bar{x} \pm 0.2\bar{x}$	Medium	See Table 6-12	Medium	Poisson's ratio	Intact rock	8.3.1.15.1.3.1 8.3.1.15.1.3.2	(g)	TSw2
			All units other than TSw2	$\bar{x} \pm 0.2\bar{x}$	Low	See Table 6-12	Low to medium	Poisson's ratio	Intact rock	8.3.1.15.1.3.1 8.3.1.15.1.3.2	(g)	(h)
4.4 (8.3.2.5)	Elastic properties											
	Young's modulus	Intact rock; primary area	TSw2	29-33 GPa	Medium	31 GPa	Medium	Young's modulus	Intact rock	8.3.1.15.1.3.1 8.3.1.15.1.3.2	(g)	TSw2
			TSw1	Nonlithophysal: 12-54 GPa	Medium	Nonlithophysal: 19-44 GPa	Medium	Young's modulus	Intact rock	8.3.1.15.1.3.1 8.3.1.15.1.3.2	(g)	TSw1

Table 8.3.1.15-1. Performance and design parameters, tentative goals, and characterization parameters for thermal and mechanical properties program[a] (page 7 of 12)

Issue requesting parameter (SCP section)	Performance or design parameter	Material type and spatial location[b]	Stratigraphic location[c] (request)	Tentative goal[d,e]	Needed confidence[d]	Current estimate	Current confidence[d]	Parameter to be measured	Material type tested	SCP activity numbers	Spatial location	Stratigraphic location[c]
4.4 (8.3.2.5) (continued)				Lithophysal: 14-17 GPa	Medium	Lithophysal: 15.5 GPa	Low	Young's modulus				
	Deformation modulus	Rock mass; primary area	TSw2	11-19 GPa	Medium	11-19 GPa	Low	Young's modulus, fracture stiffnesses	Intact rock and fractures	8.3.1.15.1.3.1 8.3.1.15.1.3.2 8.3.1.15.1.4.1 8.3.1.15.1.4.2	(g)	TSw2
								Deformation modulus	Rock mass	8.3.1.15.1.6.3 8.3.1.15.1.7.1 8.3.1.15.2.1.2	ESF	TSw2
			TSw1	Nonlithophysal: 12-20 GPa	Medium	Nonlithophysal: 12-20 GPa	Low	Young's modulus, fracture stiffnesses	Intact rock and fractures	8.3.1.15.1.3.1 8.3.1.15.1.3.2 8.3.1.15.1.4.1 8.3.1.15.1.4.2	(g)	TSw1
				Lithophysal: 4-11 GPa	Medium	Lithophysal: 4-11 GPa	Low					
								Deformation modulus	Rock mass	8.3.1.15.1.3.1	ESF	TSw1
	Poisson's ratio	Intact rock; primary area	TSw2	0.19-0.29	Medium	0.19-0.29	Medium	Poisson's ratio	Intact rock	8.3.1.15.1.3.1 8.3.1.15.1.3.2	(g)	TSw1
			TSw1	Nonlithophysal: 0.20-0.30 GPa	Low	Nonlithophysal: 0.20-0.30 GPa	Low to medium	Poisson's ratio	Intact rock	8.3.1.15.1.3.1 8.3.1.15.1.3.2	(g)	TSw1
				Lithophysal: 0.13-0.19	Low	Lithophysal: 0.13-0.19	Low					
1.11 (8.3.2.2)	Compressive strength	Intact rock; primary area and extensions	TSw2	$\bar{x} \pm 0.2\bar{x}$	High	See Table 6-12	Medium	Compressive strength	Intact rock	8.3.1.15.1.3.1 8.3.1.15.1.3.2	(g)	TSw2
	Compressive strength	Intact rock; primary area and extensions	TSw1	$\bar{x} \pm 0.2\bar{x}$	High	See Table 6-12	Medium	Compressive strength	Intact rock	8.3.1.15.1.3.1 8.3.1.15.1.3.2	(g)	TSw1
	Cohesion and angle of internal friction	Intact rock; primary area and extensions	Units above TSw1 and below TSw2	$\bar{x} \pm 0.2\bar{x}$	Medium	See Table 6-12	Low to medium	Compressive strength	Intact rock	8.3.1.15.1.3.1 8.3.1.15.1.3.2	(g)	(h)

Table 8.3.1.15-1. Performance and design parameters, tentative goals, and characterization parameters for thermal and mechanical properties program[a] (page 8 of 12)

Issue requesting parameter (SCP section)	Performance or design parameter	Material type and spatial location[b]	Stratigraphic location[c] (request)	Tentative goal[d,e]	Needed confidence[d]	Current estimate	Current confidence[d]	Parameter to be measured	Material type tested	SCP activity numbers	Spatial location	Stratigraphic location[c]
1.11 (8.3.2.2) (continued)	Unconfined compressive strength	Intact rock; primary area and extensions	Units above TSw1 and below TSw2	$\bar{x} \pm 0.15\bar{x}$	Low	See Table 6-12	Low to medium	Unconfined compressive strength	Intact rock	8.3.1.15.1.3.1	(g)	(f)
1.12 (8.3.3.2)	Unconfined compressive strength	Rock mass; shaft and ramp locations	TCw	$\bar{x} \pm 0.2\bar{x}$	Medium	See Table 6-12	Low	Compressive strength	Intact rock	8.3.1.15.1.3.1 8.3.1.15.1.3.2	(g)	TCw
	Unconfined compressive strength	Rock mass; primary area	CHn1	$\bar{x} \pm 0.2\bar{x}$	Medium	See Table 6-12	Low	Compressive strength	Intact rock	8.3.1.15.1.3.1 8.3.1.15.1.3.2	(g)	CHn1
	Unconfined compressive strength	Rock mass; primary area	TSw2	$\bar{x} \pm 0.2\bar{x}$	Medium	See Table 6-12	Low	Unconfined compressive strength	Intact rock	8.3.1.15.1.3.1 8.3.1.15.1.3.2	(g)	TSw2
4.4 (8.3.2.5)	Compressive strength	Intact rock; primary area	TSw1, TSw2	TSw1, nonlithophysal: 54-207 MPa	Medium	67-172 MPa	Medium	Unconfined compressive strength	Intact rock	8.3.1.15.1.3.1 8.3.1.15.1.3.2	(g)	TSw1, TSw2
				TSw1, lithophysal: 13-19 MPa	Medium	16 MPa	Medium	Compressive strength				
				TSw2: 121-175 MPa	Medium	148 MPa	Medium	Unconfined compressive strength				
	Unconfined compressive strength	Intact rock; primary area	TCw, PTn	$\bar{x} \pm 0.2\bar{x}$	Medium	$\bar{x}$	Low to medium	Unconfined compressive strength	Intact rock	8.3.1.15.1.3.1 8.3.1.15.1.3.2	(g)	TCw, PTn
	Cohesion and angle of internal friction	Intact rock; primary area	TCw, PTn	$\bar{x} \pm 0.2\bar{x}$	Medium	$\bar{x}$	Low to medium	Compressive strength	Intact rock	8.3.1.15.1.13.1 8.3.1.15.1.3.2	(g)	TCw, PTn, TSw1, TSw2

Table 8.3.1.15-1. Performance and design parameters, tentative goals, and characterization parameters for thermal and mechanical properties program[a] (page 9 of 12)

Issue requesting parameter (SCP section)	Performance or design parameter	Material type and spatial location[b]	Stratigraphic location[c] (request)	Tentative goal[d,e]	Needed confidence[d]	Current estimate	Current confidence[d]	Parameter to be measured	Material type tested	SCP activity numbers	Spatial location	Stratigraphic location[c]
1.11 (8.3.2.2)	Mechanical properties of fractures											
	Cohesion and coefficient of friction	Fractures; primary area and extensions	Units above TSw1 and below TSw2	$\bar{x} \pm 0.15\bar{x}$	Medium	See Table 6-13	Low	Shear stress at onset of slip	Fractures	8.3.1.15.1.4.1 8.3.1.15.1.4.2	(g)	(h)
	Large-scale-joint strength	Fractures; primary area	TSw1, TSw2	$\bar{x} \pm 0.2\bar{x}$	High	NS	Low	Shear stress at onset of slip	Fractures	8.3.1.15.1.4.1 8.3.1.15.1.4.2	(g)	TSw1, TSw2
	Normal and shear stiffnesses	Fractures; primary area and extensions	TSw2	See Table 6-13	Medium	NS	Low	Normal and shear stiffnesses	Fractures	8.3.1.15.1.4.1 8.3.1.15.1.4.2	(g)	TSw2
			TSw1, TSw3, CHn1	See Table 6-13	Low	NS	Low	Normal and shear stiffnesses	Fractures	8.3.1.15.1.4.1 8.3.1.15.1.4.2	(g)	(h)
4.4 (8.3.2.5)	Mechanical properties of fractures											
	Cohesion and coefficient of friction	Fractures; primary area	TSw2	$\bar{x} \pm 0.2\bar{x}$	Medium	$\bar{x}$	Low	Shear stress at onset of slip	Fractures	8.3.1.15.1.4.1 8.3.1.15.1.4.2	(g)	TSw2
	Normal and shear stiffnesses	Fractures; primary area	TSw2	NS	Medium	NS	Low	Normal and shear stiffnesses	Fractures	8.3.1.15.1.4.1 8.3.1.15.1.4.2	(g)	TSw2
2.2 (8.3.5.4)	Radon emanation rate	Rock mass; primary area	TSw2	NS	High	0.48 pCi/m^2s	Low	Radon emanation rate	Rock mass	8.3.1.15.1.6.2	ESF	TSw2
2.7 (8.3.2.3)	Radon emanation rate	Rock mass; primary area	TSw2	(f)	High	0.48 pCi/m^2s	Low	Radon emanation rate	Rock mass	8.3.1.15.1.6.2 8.3.1.15.1.8.4	ESF	TSw2
4.4 (8.3.2.5)	Radon emanation rate	Rock mass; primary area	TSw2	(f)	Medium	NS	Low	Radon emanation rate	Rock mass	8.3.1.15.1.6.2 8.3.1.15.1.8.4	ESF	TSw2
1.11 (8.3.2.2)	Empirical design parameters											
	Joint wall compressive strength	Fracture surfaces; primary area	TSw2	See Table 6-15	Medium	NS	Low	Joint wall compressive strength	Fracture surfaces	8.3.1.15.1.6.3 8.3.1.15.1.7.1	ESF	TSw2

Table 8.3.1.15-1. Performance and design parameters, tentative goals, and characterization parameters for thermal and mechanical properties program[a] (page 10 of 12)

Issue requesting parameter (SCP section)	Performance or design parameter	Material type and spatial location[b]	Stratigraphic location[c] (request)	Tentative goal[d,e]	Needed confidence[d]	Current estimate	Current confidence[d]	Parameter to be measured	Material type tested	SCP activity numbers	Spatial location	Stratigraphic location[c]
1.11 (8.3.2.2) (continued)			TSw1, TSw3, CHn1	See Table 6-15	Low	NS	Low	Joint wall compressive strength	Fracture surfaces	NS	(g)	(h)
	Joint roughness coefficient	Fracture surfaces; primary area	TSw2	See Table 6-15	Medium	NS	Low	Joint roughness coefficient	Fracture surfaces	8.3.1.15.1.6.3 8.3.1.15.1.7.1	ESF	TSw2
			TSw1, TSw3, CHn1	See Table 6-15	Low	NS	Low	Joint wall compressive strength	Fracture surfaces	NS	(g)	(h)
4.4 (8.3.2.5)	Empirical design parameters											
	Joint wall compressive strength	Fracture surfaces; primary area	TSw2	See Table 6-15	Medium	NS	Low	Joint wall compressive strength	Fracture surfaces	8.3.1.15.1.6.3 8.3.1.15.1.7.1	ESF	TSw2
	Joint roughness coefficient	Fracture surfaces; primary area	TSw2	See Table 6-15	Medium	NS	Low	Joint roughness coefficient	Fracture surfaces	8.3.1.15.1.6.3 8.3.1.15.1.7.1	ESF	TSw2
1.11 (8.3.2.2)	In situ stress state[i]											
	σ_v	Rock mass; primary area and extensions	Ground surface to water table	±1 MPa	Medium	(ρgh)[j]	Low to medium	Grain density, porosity	Intact rock	8.3.1.15.1.1.1	(g)	Alluvium, TCw, PTn, TSw1, TSw2, TSw3, CHn1, CHn2
	σ_h, σ_H	Rock mass; primary area and extensions	Ground surface to water table	±2 MPa	Medium	NS	Low	Deformation, elastic properties	Intact rock	8.3.1.15.2.1.1	(g)	TSw2
1.12 (8.3.3.2)	In situ stress state											
	σ_v	Rock mass; primary area	TCw, TSw2, CHn1	±MPa	Low	4-10 MPa	Low to medium	Grain density, porosity	Intact rock	8.3.1.15.1.1.1	(g)	Alluvium, TC2, PTn, TSw1, TSw2, TSw3, CHn1

Table 8.3.1.15-1. Performance and design parameters, tentative goals, and characterization parameters for thermal and mechanical properties program[a] (page 11 of 12)

Issue requesting parameter (SCP section)	Performance or design parameter	Material type and spatial location[b]	Stratigraphic location[c] (request)	Tentative goal[d,e]	Needed confidence[d]	Current estimate	Current confidence[d]	Parameter to be measured	Material type tested	SCP activity numbers	Spatial location	Stratigraphic location[c]
1.12 (8.3.3.2) (continued)	σ_h, σ_H	Rock mass; primary area	TCw, TSw2, CHnl	±2 MPa	Low	σ_h/σ_v, σ_H/σ_v = 0.3-1.0	Low	Deformation, elastic properties	Intact rock	8.3.1.15.2.1.1 8.3.1.15.2.1.2	(g)	TCw, TSw2, CHnl
4.4 (8.3.2.5)	In situ stress state											
	σ_v	Rock mass; primary area	TSw2	300 m depth: 6.3-7.7 MPa	Medium	(6.3-7.7 MPa)	Low to medium	Grain density, porosity	Intact rock	8.3.1.15.1.1.1	(g)	Alluvium, TCw, PTn, TSw1, TSw2,
	σ_h/σ_v	Rock mass; primary area	TSw2	0.3-0.8	Medium	0.3-0.8	Low	Deformation, elastic properties	Intact rock	8.3.1.15.2.1.1 8.3.1.15.2.1.2	(g)	TSw2
	σ_H/σ_v	Rock mass; primary area	TSw2	0.3-1.0	Medium	0.3-1.0	Low	Deformation, elastic properties	Intact rock	8.3.1.15.2.1.1 8.3.1.15.2.1.2	(g)	TSw2
	Bearing of σ_h	Rock mass; primary area	TSw2	N.45°W-N.65°W	Medium	N.45°W-N.65°W	Medium	Deformation, elastic properties	Intact rock	8.3.1.15.2.1.1 8.3.1.15.2.1.2	(g)	TSw2
	Bearing of σ_H	Rock mass; primary area	TSw2	N.25°E-N.40°E	Medium	N.25°E-N.40°E	Medium	Deformation, elastic properties	Intact rock	8.3.1.15.2.1.1 8.3.1.15.2.1.2	(g)	TSw2
1.6 (8.3.5.12)	Initial temperatures	Rock mass; primary area	TSw2	NS	NS	NS	NS	Initial temperatures	Rock mass	8.3.1.15.2.2.1	(g)	TSw2
1.10 (8.3.4.2)	Initial temperatures	Rock mass; primary area	TSw2	±3°C	Medium	23-25°C	Medium	Initial temperatures	Rock mass	8.3.1.15.2.2.1	(g)	TSw2
1.11 (8.3.2.2)	Initial temperatures	Rock mass; primary area and extensions	TSw2	±3°C	Medium	23-26°C	Medium	Initial temperatures	Rock mass	8.3.1.15.2.2.1	(g)	TSw2 and above
4.4 (8.3.2.5)	Initial temperatures	Rock mass; primary area	TSw2	23-25°C	Medium	23-25°C	Medium	Initial temperatures	Rock mass	8.3.1.15.2.2.1	(g)	TSw2

Table 8.3.1.15-1. Performance and design parameters, tentative goals, and characterization parameters for thermal and mechanical properties program[a] (page 12 of 12)

Issue requesting parameter (SCP section)	Performance or design parameter	Material type and spatial location[b]	Stratigraphic location[c] (request)	Tentative goal[d,e]	Needed confidence[d]	Current estimate	Current confidence[d]	Parameter to be measured	Material type tested	SCP activity numbers	Spatial location	Stratigraphic location[c]
4.4 (8.3.2.5) (continued)	Initial temperatures	Rock mass; primary area	TSw2	±2C	Medium	Present values ±2C	Medium	Initial temperatures	Rock mass	8.3.1.15.2.2.1	(g)	TSw2
	Initial temperatures	Rock mass; primary area	Ground surface to base of TSw2	±2C	Medium	Present values ±2C		Initial temperatures	Rock mass	8.3.1.15.2.2.1	(g)	Alluvium TCw, PTn, TSw1, TSw2

[a]This table summarizes requirements of both preclosure and postclosure issues.
[b]Definitions of the primary area and extensions are provided in Chapter 6, Figure 6-87.
[c]The thermal/mechanical stratigraphy at Yucca Mountain is shown in Figure 2-5 of Chapter 2. CHn = Calico Hills nonwelded unit; PTn = Paintbrush nonwelded unit; TCw = Tiva Canyon welded unit; TSw = Topopah Spring welded unit; and NS = not specified.
[d]The manner in which tentative goals and levels of confidence are used in planning the characterization program is discussed in the investigation for Section 8.3.1.15.1.
[e]$\bar{x}$ = mean value of existing sample group.
[f]Tentative goal is that a prescribed percentage (related to the needed confidence) of the data falls within the given interval. Failure to meet the goal will result in a need to reevaluate the existing design.
[g]Spatial locations will be a combination of new boreholes (location to be determined; see Investigation 8.3.1.4.1 for discussion) and the exploratory shaft and associated underground excavations; ESF = exploratory shaft facility.
[h]Stratigraphic locations will be in the units specified as required by pertinent issues if measurements need to be made. For many parameters for which the required confidence level is low, existing data will be sufficient to satisfy the requirements.
[i]σ_v = vertical in situ stress; σ_h = minimum horizontal in situ stress; σ_H = maximum horizontal in situ stress.
[j]ρgh indicates the product of density (ρ), gravitational acceleration (g), and height of overlying column of rock (h).

the differences and the techniques to be used to produce required data from measured data are described in later portions of Section 8.3.1.15. In addition, amplified discussions of the reasons for the selection of testing techniques are provided in a number of study plans to be written in support of the SCP. In some instances, a preferred test technique is to be prototyped before use in site characterization. If prototyping indicates that a preferred technique will not produce satisfactory results, an alternative technique will be selected.

The stratigraphic locations in Table 8.3.1.15-1 are thermal/mechanical units rather than formal stratigraphic units. This approach has been taken because the repository design process uses the thermal/mechanical units as the stratigraphic framework for analysis. The relationship between formal stratigraphic units and thermal/mechanical units is provided in Figure 2-5 in the introduction to Chapter 2.

In addition to the parameter requirements listed in Table 8.3.1.15-1, several additional requirements from design issues affect the characterization program described in this section. Data on the multidimensional deformations that may result from repository-induced stresses will be obtained from the Yucca Mountain heated block experiment (Activity 8.3.1.15.1.6.3). In addition, information on opening stability and ground support systems, required by Issue 4.2 (Section 8.3.2.4) will be obtained as part of Activities 8.3.1.15.1.5.2, 8.3.1.15.1.5.3, and 8.3.1.15.1.6.5, and Study 8.3.1.15.1.8.

Figure 8.3.1.15-1 shows the ties between the investigation for acquisition of data on thermal and mechanical rock properties (Investigation 8.3.1.15.1) and performance assessment and design issues. Detailed logic diagrams are presented in Figure 8.3.1.15-2 (bulk, thermal, and mechanical properties) and Figure 8.3.1.15-3 (ambient stress and temperature conditions) as a supplement to the details in Table 8.3.1.15-1. These detailed diagrams show the studies and activities planned to provide the site data required by the performance and design issues.

Approach to satisfy performance and design requirements

The performance allocation process as described in Section 8.2 requires the definition of performance goals for design and performance assessment issues. These performance goals then are used to define the data necessary to address the issues. The necessary data are specified by the parameters contained in the equations, analyses, relationships, etc. being considered for evaluating whether the performance goals are met. The required thermal and mechanical data are listed in Table 8.3.1.15-1. The characterization goals in the table are 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. The characterization goals and confidence levels reflect the sensitivity of a performance measure to variations in the parameter (Appendix N of SNL, 1987). When more than one issue requires a given parameter at the same location, the requirement that poses the greatest constraint will be used in planning site studies and activities to obtain values for the parameter. As site characterization proceeds, some proportion of the site data values may be found to fall

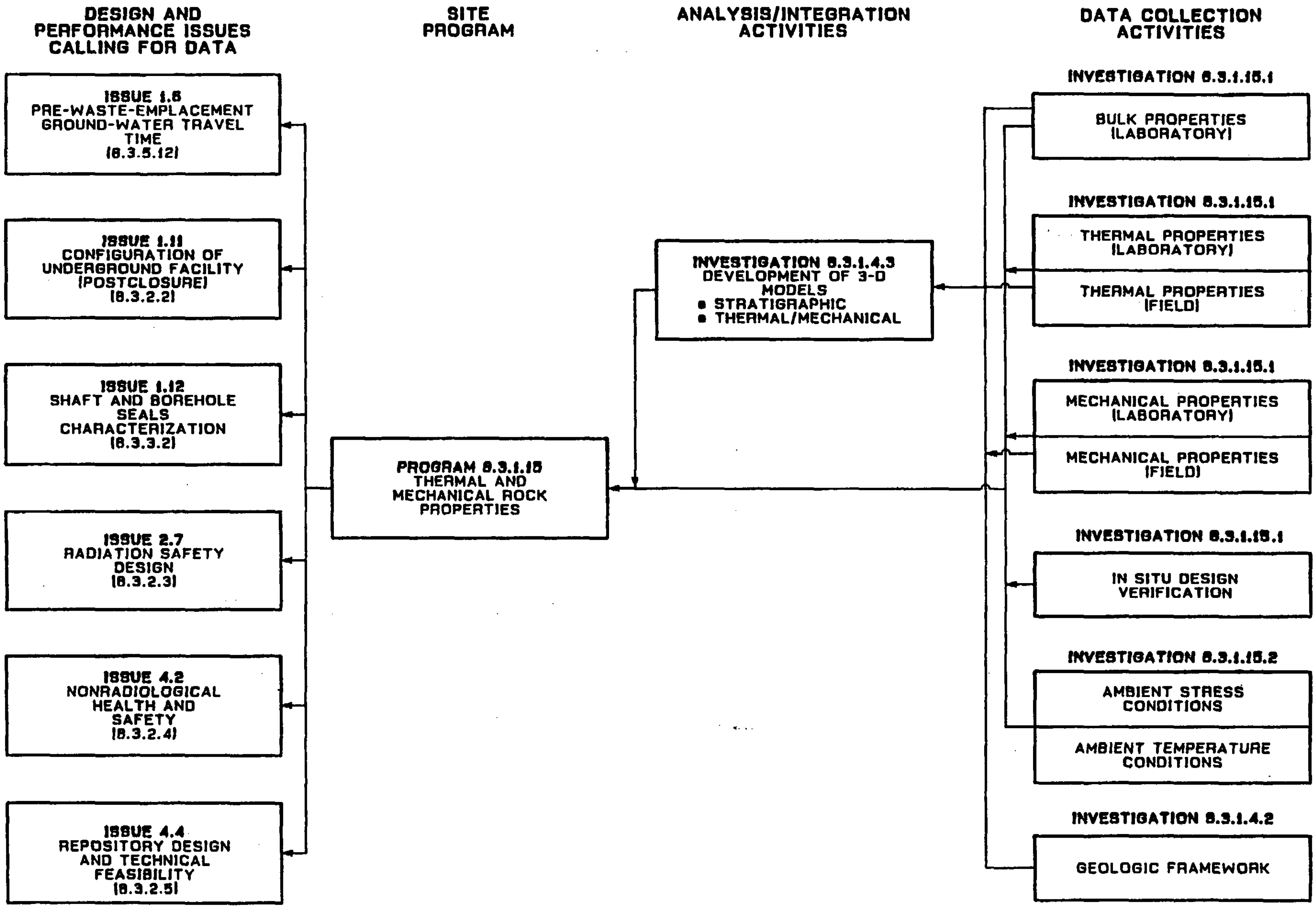


Figure 8.3.1.15-1. Relationship between data acquistion for rock properties and issues requiring the data.

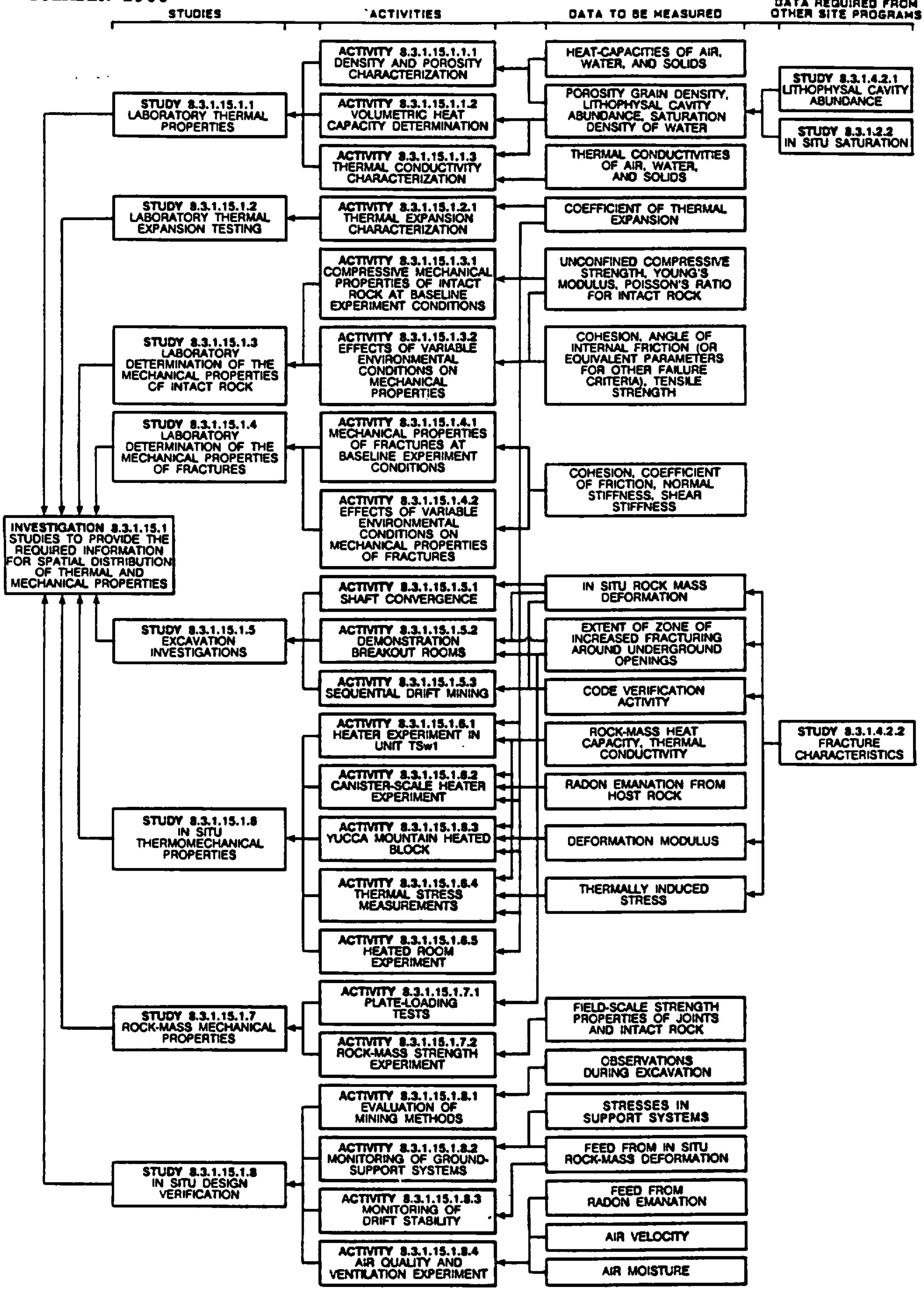


Figure 8.3.1.15-2. Logic diagram for Investigation 8.3.1.15.1, spatial distribution of thermal/mechanical rock properties.

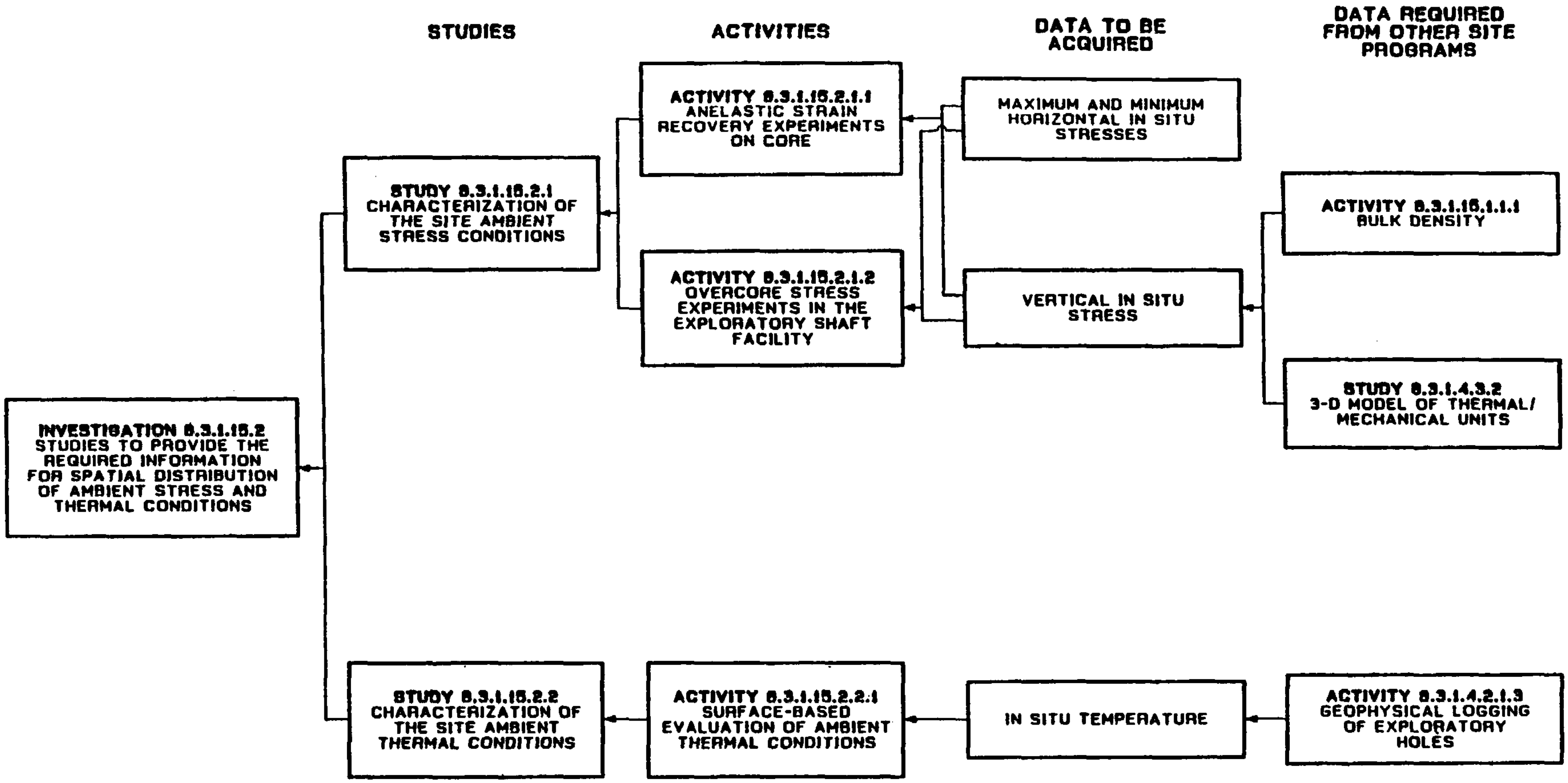


Figure 8.3.1.15-3. Logic diagram for Investigation 8.3.1.15.2, spatial distribution of ambient stress and temperature conditions

outside the specified limits. 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 limits to these data may be specified, and additional data will be collected if necessary.

In addition to the iterative process outlined in the preceding paragraph, the possibility exists that not all necessary data have been identified or that the specified limits are invalid because of the preliminary nature of the supporting sensitivity studies. In these cases, additional data may be requested or the specified limits for a parameter already requested may be changed. Either situation might lead to a modification to the investigations outlined in Sections 8.3.1.15.1 and 8.3.1.15.2.

Alternative conceptual models

As discussed in the overview of the site characterization program (Section 8.3.1.1), hypothesis-testing tables have been constructed that summarize (1) the current hypotheses regarding how the site can be modeled and how modeling parameters can be estimated; (2) the uncertainty associated with this current understanding, including alternative hypotheses which are also consistent with available data and that may compose an alternative conceptual model; (3) the significance of alternative hypotheses; and (4) the activities or studies which are designed to discriminate between alternative hypotheses or to reduce uncertainty. Table 8.3.1.15-2 is the hypothesis-testing table for the site program on thermal and mechanical rock properties. Integration of information from different disciplines is often necessary to comprehensively evaluate alternative hypotheses. Accordingly, the hypothesis-testing tables for each site program call for information from studies and activities in other programs, as appropriate.

Hypotheses for modeling thermal and mechanical properties have been categorized as pertaining to the process of heat transfer or to mechanical constitutive models. These model elements are listed in column one.

The second column of the table lists the current representations for each model element in the form of hypotheses that are based on currently available data.

The third column in Table 8.3.1.15-2 provides a judged level of uncertainty designated "high," "moderate," or "low" associated with the current representation for each element. A brief rationale for the judgment is also given.

The fourth column describes alternative hypotheses to the current representation that are consistent with currently available data. As site characterization proceeds and more information becomes available, alternative hypotheses may be deleted or added or the current hypothesis may be revised and refined.

The fifth column indicates the performance measure or performance parameter that could be affected by the selection of hypotheses related to that element.

Table 8.3.1.15-2. Current representation and alternative hypotheses for modeling for the thermal and mechanical rock properties program (page 1 of 3)

Current representation		Uncertainty and rationale	Alternative hypothesis	Significance of alternative hypothesis				Studies or activities to reduce uncertainty
Model element	Current representation			Performance measure, design or performance parameter	Needed confidence in parameter or performance measure	Sensitivity of parameter or performance measure to hypothesis	Need to reduce uncertainty	
Process of heat transfer	Dominated by conduction	Low--existing thermal conductivity data indicate conduction is dominate heat transfer process	Convection Radiation Convection and radiation Latent heat transfer	Temperature (to limit potential for adverse geochemical, etc. effects on the host rock)	Medium to low	Medium--process of heat transfer impacts repository layout and design	Low--existing data are adequate for planning and conceptual design; additional data will increase confidence for advanced conceptual design and license application	Convection and radiation contributions will be assessed during in situ heater experiments; Study 8.3.1.15.1.6, in situ thermomechanical properties Latent-heat transfer will be assessed during laboratory thermal conductivity experiments; Study 8.3.1.15.1.1 (laboratory thermal properties)
				Temperature in retrieval area	Medium	Same as above	Same as above	
				Potential for significant displacement	Medium	Same as above	Same as above	
				Surface uplift	Low	Same as above	Same as above	
				Rock mass temperature	High	Same as above	Same as above	
				Stress, deformation, factor of safety, and potential rock fall	High	Same as above	Same as above	
				Time container is above boiling temperature of water	High	Same as above	Same as above	

Table 8.3.1.15-2. Current representation and alternative hypotheses for modeling for the thermal and mechanical rock properties program (page 2 of 3)

Current representation		Uncertainty and rationale	Alternative hypothesis	Significance of alternative hypothesis				Studies or activities to reduce uncertainty
Model element	Current representation			Performance measure, design or performance parameter	Needed confidence in parameter or performance measure	Sensitivity of parameter or performance measure to hypothesis	Need to reduce uncertainty	
Mechanical constitutive models	Time-independent deformation Elastic Elastic-plastic Elastic-plastic with compliant joint	Medium-low--existing data and excavation experience in tuffs indicate deformation is time independent	Time-dependent deformation Linear creep Nonlinear creep	Access closure Drift closure Rock movement Access sizes and grades compatible with requirements for personnel, material transport and utility routing	Medium Medium Medium High to medium	High--deformation type could affect long-term opening stability, retrievability, and nonradiological worker health and safety	Medium--existing data are adequate for planning and conceptual design; additional data are required to increase confidence for advanced conceptual design and license application	Creep experiments are planned on intact rock samples and fractured samples; Study 8.3.1.15.1.3, Laboratory determination of mechanical properties of intact rock; Study 8.3.1.15.1.4, Laboratory determination of mechanical properties of fractures
				Accesses (shafts and ramps) usable for 100 yr with reasonable maintenance	High	Same as above	Same as above	Same as above
				Rockfall quantity and retention	Medium	Same as above	Same as above	Same as above
	Material can be modeled as a continuum, with discrete slip surfaces	Medium--there is reasonable agreement between preliminary continuum model results and excavation experience in tuffs	Material is a collection of individual blocks (Cundall-type block model)	Same as above	Same as above	Low--small magnitudes of anticipated rock mass displacements are insensitive to constitutive model type	Low--existing model representation is appropriate for advanced conceptual design and licensed application design	Evaluations of the constitutive model types are planned under activities discussed in Section 8.3.2.1.4

Table 8.3.1.15-2. Current representation and alternative hypotheses for modeling for the thermal and mechanical rock properties program (page 3 of 3)

Current representation		Uncertainty in current understanding	Alternative hypothesis and significance					Tests to distinguish hypothesis and reduce uncertainty
Model element	Current representation	Uncertainty and rationale	Alternative hypothesis	Performance measure, design or performance parameter	Needed confidence in parameter or performance measure	Sensitivity of parameter or performance measure to hypothesis	Need to reduce uncertainty	Studies or activities to reduce uncertainty
Mechanical constitutive models (continued)	Matrix failure considered through post-processing of analyses	Medium--excavation experience to date indicates that matrix failure does not control rock mass failure	Matrix damage is feasible mechanism that must be modeled and and included as part of analysis	Same as above	Same as above	Low--preliminary model results indicate that post-processing of analyses is appropriate to address matrix failure because model stresses generally do not exceed matrix failure criterion	Low--existing model representation is appropriate for advanced conceptual design and license application design	Evaluations of the constitutive model types are planned under activities discussed in Section 8.3.2.1.4

Column six gives the needed confidence in the indicated performance measure or performance parameters, as defined in the performance allocation tables.

The seventh column presents a judgment of the sensitivity of performance parameters in column five to the selection of hypotheses in columns two and four for that element. The sensitivity is rated high if significant changes in the values of the performance parameter might occur if an alternate hypothesis were found to be the valid hypothesis for the system.

The eighth column presents a judgment on the need to reduce uncertainty in the selection of hypotheses. This judgment is based on the uncertainty in the current representation, the sensitivity of the performance parameters to alternative hypotheses, the significance and needed confidence of affected performance parameters, and the likelihood that feasible data-gathering activities could significantly reduce uncertainty.

The final column identifies the characterization studies or activities that will discriminate among alternative hypotheses or that will reduce uncertainties associated with the current representation for each model element.

Interrelationships of thermal and mechanical rock properties investigations

As shown on Figures 8.3.1.15-2 and 8.3.1.15-3, two investigations and ten 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. Studies related to laboratory testing are grouped by parameter(s). In contrast, in situ experiments are divided into four categories by type of experiment: (1) experiments related to evaluation of the effects of excavation, (2) mechanical property experiments, (3) thermomechanical property experiments, and (4) in situ design verification experiments. Characterization of ambient stress and thermal conditions will include measurements of stress and temperature in exploratory holes and in the exploratory shaft.

Data on thermal and mechanical rock properties will be needed for and/or obtained from many of the coupled-interaction tests listed in Table 8.3.2.1-1 (Studies or activities for coupled interaction tests). This includes the effects of thermal perturbations on near-field repository rocks in Study 1.10.4.2 (hydrologic properties of waste package environment).

The schedule information for the thermal and mechanical rock properties program is presented in Section 8.3.1.15.3.

8.3.1.15.1 Investigation: Studies to provide the required information for spatial distribution of thermal and mechanical properties

Technical basis for obtaining the information

Link to the technical data chapters and applicable support documents

Chapter 2 summarizes the available data relevant to thermal and mechanical properties of the tuff units at Yucca Mountain.

Parameters

Table 8.3.1.15-1 presented in the previous section summarizes the thermal/mechanical properties required for resolution of performance assessment and design issues. Table 8.3.1.15-3 summarizes the thermal and mechanical properties listed in Table 8.3.1.15-1. These properties will be used with the other data on rock characteristics to develop the three-dimensional thermal, mechanical, and thermomechanical models in Section 8.3.1.4.3. Several additional parameters also are required to enable estimates to be made for some of the parameters listed in Table 8.3.1.15-3. These additional parameters include grain density, heat capacity and thermal conductivity of zero-porosity material, lithophysal cavity abundance, and in situ saturation state. The relevance of each of these parameters is discussed later. All are to be obtained in the studies contained in Investigation 8.3.1.15.1 with the exception of lithophysal cavity abundance and saturation state. Acquisition of data on cavity abundance is discussed in Investigation 8.3.1.4.2 (geologic framework), whereas data acquisition for saturation state is discussed in Investigations 8.3.1.2.2 and 8.3.1.2.3 (site unsaturated and saturated zone hydrologic system). Information obtained from mineralogic and petrologic studies discussed in Investigation 8.3.1.3.2 (mineralogy, petrology, and rock chemistry) will be used to help determine the spatial distribution of thermal and mechanical properties.

Purpose and objectives of the investigation

The purpose of this investigation is to provide the information on spatial distribution of thermal and mechanical properties requested by performance and design issues. The performance allocation process identified performance measures and goals. To determine whether the performance goals can be met, data must be available on various site parameters, and the data must have associated levels of confidence. The parameters and associated confidence levels are identified in the performance assessment and design issues, and serve as the basis for planning of a site characterization program. The information required by performance assessment and design issues on bulk, thermal, and mechanical properties is shown in Table 8.3.1.15-1 together with the activities planned to acquire site characterization data on these properties. The general link between the site characterization program and the issues requiring data was shown in Figure 8.3.1.15-1, and Figure 8.3.1.15-2 depicts the detailed logic for completion of this investigation.

Table 8.3.1.15-3. Thermal and mechanical properties required by other issues

Property	Matrix	Fractures	Rock mass
<u>Thermal</u>			
Thermal conductivity			x
Heat capacity			x
<u>Thermomechanical</u>			
Coefficient of thermal expansion	x		
<u>Mechanical</u>			
Poisson's ratio	x		
Young's modulus	x		
Deformation modulus			x
Compressive strength	x		
Cohesion	x		
Angle of internal friction	x		
Fracture properties			
Cohesion		x	
Coefficient of friction		x	
Normal stiffness		x	
Shear stiffness		x	
Joint wall compressive strength		x	
Roughness coefficient		x	
<u>Miscellaneous</u>			
Bulk density			x
Radon emanation			x
Excavation observations		x	x

Technical rationale for the investigation

Completion of this investigation requires the acquisition of data for each parameter listed in Table 8.3.1.15-3 as well as evaluation of the spatial variation of each parameter. Preliminary data are available for most of these parameters, as summarized in Chapter 2. However, additional data are required to analyze spatial variability of properties and, for some parameters, to obtain the required number of data. In addition, existing data may be biased because of drillhole orientation or other sampling limitations; the potential bias needs to be evaluated and recognized during future work.

Of the parameters listed in Table 8.3.1.15-3, thermal expansion coefficients, Poisson's ratios, Young's moduli, and compressive strength (laboratory), will be obtained directly from laboratory measurements. Joint properties (normal and shear stiffnesses, cohesion, and friction coefficient) will also be measured in the laboratory, but with the realization that it will be necessary to scale the results to achieve relevance to in situ conditions.

Several of the parameters identified in Table 8.3.1.15-3 are intended to be representative of the rock mass; they are included in the table in recognition of the fact that the rock-mass behavior cannot be adequately characterized by laboratory-determined parameter values alone. The approach taken in this section is to consider two categories of parameters in addressing the question of whether the laboratory and field-obtained data are representative of the rock mass.

In the first category, which includes parameters such as in situ bulk density, heat capacity, and thermal conductivity, data applicable to the rock mass will be calculated or estimated from other parameters not specifically required by performance assessment or design issues, such as grain density, mineral constituents, and porosity. Knowledge of laboratory-measured values of these non-required parameters, and their variability in the laboratory or in situ, will support the determination of rock-mass data for required parameters in the first category. Calculated data for the rock mass, together with related laboratory data, can be compared with the corresponding parameter values obtained from field experiments. Historical evidence suggests that there is likely to be good correlation between laboratory and field results for this category of in situ parameters. Any discrepancies that may arise between predicted in situ parameter values and the measured in situ values will be assessed to ascertain the adequacy of the predictive algorithm and of the measurement techniques used in field tests. If necessary, the basis of any predictive algorithm used will be reevaluated and additional laboratory or field tests may be performed. These additional tests could be required because of a need to measure different parameters, a need to repeat measurements under different test conditions, or a need to revise in situ measurement techniques.

The second category of parameters that can be obtained from in situ tests, including such parameters as rock-mass deformability and rock-mass strength, will be treated differently. The parameters in this category are not expected to be calculable using simple predictive equations and laboratory-obtained parameter values. Rather, parameters in this category are sensitive to the scale of the test (volume of rock material involved in the test). It is expected that field measurements of parameters other than the parameter of interest will be required to estimate the in situ value of the parameter. For the rock-mass deformation properties identified in this section, fracture geometry, characteristics, and properties are the most likely additional required information. Differences between laboratory and in situ measured values for parameters such as deformation modulus are expected to be caused by the presence of fractures in the rock mass on a scale that cannot be included in laboratory samples. Values for deformation properties can be calculated by combining intact-rock properties and fracture characteristics and properties in finite-element computations. Alternatively, the rock-mass properties can be estimated by applying corrections deduced from in situ fracture characteristics to intact-rock properties.

Historically, such corrections in the form of reduction factors have been deduced from fracture frequency, or such indices as rock quality designation.

It would be imprudent to plan numerous large-scale tests to measure rock-mass deformation properties considering the time and expense required for such tests. Furthermore, the data from these tests is potentially difficult to interpret. In the planned program, information about rock-mass deformation properties will be obtained through a combination of empirical approaches to rock-mass opening design, sequential instrument emplacement and excavation, and analytical modeling of excavation behavior. The analytical modeling described in Sections 6.4.8 and 8.3.2.8 will make use of both equivalent modulus and compliant joint approaches. The equivalent modulus approach will use the reduced modulus values derived from laboratory modulus tests, observed fracture characteristics, and measured in situ deformation moduli. The compliant joint approach will use laboratory-measured moduli and joint deformation properties such as stiffness, as well as joint characteristics such as location, orientation, and spacing. The results of both modeling approaches will be used to confirm the reduction factor used to estimate in situ deformation moduli.

There are two additional considerations relevant to rock-mass deformation and strength properties. Rock-mass strength can be considered in terms of allowable movement on joints, of the strength of the intact rock, or of a combination of the two. Modeling performed to date does not provide confidence in predicting the rock-mass response because of the preliminary nature of the physical models studied and of the data used. Some of the different situations modeled should be examined further using refined codes and a more complete and representative data set. Data to be obtained from the rock-mass response experiment(s) (Section 8.3.1.15.1.7.2) will aid in this modeling effort and in the characterization of rock-mass strength.

The second additional consideration relevant to rock-mass deformability involves the estimation of in situ modulus of deformation. Estimation of in situ modulus of deformation will involve a combined examination of spatial variability in Young's modulus as determined through statistical analysis of laboratory data, of limited field measurements, demonstration excavations, modeling, and spatial variability of other in situ properties such as fracture characteristics. This approach could be sensitive to significant changes in rock-mass conditions such as fracture characteristics. The planned program should be sufficiently flexible to provide a methodology for confirming estimated values of rock-mass modulus should significant changes in fracture characteristics be encountered within the exploratory shaft facility (ESF) or within the boundaries of the repository excavation. It will not be known in advance of ESF excavation whether lateral variability in fracture characteristics would be significant to the point of requiring additional confirmatory testing of deformation modulus within the ESF beyond the testing already planned.

Parameters that vary as a function of saturation (i.e., bulk density, heat capacity, thermal conductivity, and the strength of intact rock) are difficult to characterize for all possible saturation states. Estimates of these parameters will be obtained from known parameters by following the steps described below (bulk density will be used as an example):

1. Calculate the mean value of the parameter to be estimated using the mean values of the known parameters:

$$\rho_b = \rho_g(1-\phi) + \rho_w \phi S \tag{8.3.1.15-1}$$

where

ρ_b = bulk density
ρ_g = grain density
ϕ = porosity (matrix porosity and lithophysal cavities)
ρ_w = density of water
S = saturation.

2. Obtain the partial derivatives of Equation 8.3.1.15-1 (or the appropriate equation for another parameter; such equations need not be linear functions of saturation) with respect to the known parameters $\left(\text{e.g., } \frac{\partial \rho_b}{\partial \rho_g}, \frac{\partial \rho_b}{\partial \phi}, \frac{\partial \rho_b}{\partial S}, \frac{\partial \rho_b}{\partial \rho_w}\right)$

3. Calculate the standard deviation of the parameter to be estimated (e.g., ρ_{db}) using the partial derivatives from step 2 and the standard deviations of the known parameters:

$$\sigma_{\rho_b} \approx \left[\sigma^2_{\rho_g}\left(\frac{\partial \rho_b}{\partial \rho_g}\right)^2 + \sigma^2_{\phi}\left(\frac{\partial \rho_b}{\partial \phi}\right)^2 + \sigma^2_{S}\left(\frac{\partial \rho_b}{\partial S}\right)^2 + \sigma^2_{\rho_w}\left(\frac{\partial \rho_b}{\partial \rho_w}\right)^2\right]^{1/2} \tag{8.3.1.15-2}$$

where the partial derivatives are evaluated at the mean values of the known parameters. Note that the implicit assumption is made in the use of Equation 8.3.1.15-2 that all variables on the right-hand side for which standard deviations are given are independent random variables.

The assumption is often made that rock properties are monotonic functions of saturation. This may not be true for thermal conductivity. The thermal conductivity of partially saturated materials may be higher than that of dry or fully saturated samples because of latent heat transfer (e.g., Pratt, 1969). Measurements are planned to evaluate the nature of this saturation dependence (Section 8.3.1.15.1.1.3).

Use of statistics in design of characterization program. For most of the parameters listed in Table 8.3.1.15-3, preliminary data are available that can be used to estimate future testing requirements for satisfaction of the information need. These preliminary data are the result either of measurements in the laboratory or of the estimating procedure outlined above. The parameters for which such preliminary data are not available are fracture properties (cohesion, coefficient of friction, normal stiffness, and shear stiffness). The logic for determining the fracture properties with the required confidence is presented at the end of the following discussion.

The preliminary data comprise observations from a number of sample locations (boreholes). The data were statistically analyzed to evaluate whether they represented a single unit, several units, or varied according to some spatial trend. For each parameter, a sample mean ($\bar{x}$) and standard deviation (s) were calculated. These quantities are estimates of the population mean (μ) and standard deviation (σ). If the samples are from the same unit, the population mean for each sample will be equal:

$$\mu_1 = \mu_2 = \mu_3 = \ldots = \mu_i$$

This hypothesis was tested by comparing the sample means statistically by an analysis-of-variance technique. On the basis of these analyses, it was concluded that the samples were from the same unit (i.e., spatial variability over large distances is not present) and the statistics for the unit ($\bar{x}$, s) were calculated from all the observations.

The parameters discussed in this section are assumed to be normally distributed. The validity of this assumption will be checked for each parameter during site characterization activities. The requirements imposed by performance and design issues are that some proportion γ of the interval $\bar{x} \pm$ ks will include $100(1 - \alpha)$ percent or more of the true distribution, where α is the level of significance (Bowker and Lieberman, 1972) and k is related to α, γ, and n, the number of samples. In this analysis, γ is a preassigned probability that the interval between $\bar{x}$ - ks and $\bar{x}$ + ks includes at least a specified proportion $(1 - \alpha)$ of the true distribution. The goals listed for the parameters in Table 8.3.1.15-1 usually take the form of $\bar{x} \pm F\bar{x}$ where F is a function of $\bar{x}$. Comparison of $F\bar{x}$ with ks, where $\bar{x}$ and s are calculated using existing data, allows estimates of a value for k.

One of three qualitative levels of confidence has been associated with each data request listed in Table 8.3.1.15-1 -- high, medium, or low. To obtain initial estimates of sampling requirements, the following numerical values of α are associated with each qualitative confidence level:

Specified confidence	α
High	0.05
Medium	0.10
Low	0.25

The qualitative levels of confidence were assigned by different individuals, all of whom have different problems to address. Thus, the values of α given above may be more restrictive than is necessary for some applications. However, the values have been selected in an attempt to satisfy even the most stringent of the qualitative requirements. For convenience, $(1 - \alpha)$ is assumed to be the same as γ. Given values of α, γ, k, and an assumed statistical distribution, statistical tables can be used to estimate n, the number of samples to be tested in order to satisfy the specified requirements. Depending on the structure of observed data, it may be appropriate to use types of distribution functions other than the normal distribution for revising the estimates of the required number of samples.

For example, to calculate the vertical in situ stress in unit TSw2 with medium confidence, the in situ bulk density of unit TSw2 must be known with medium confidence. Thus, from the preceding discussion, $\gamma = (1 - \alpha) = 0.90$. If the range were required to be $\bar{x} \pm 0.1\bar{x}$, then equating ks and $0.1\bar{x}$ (using existing data to estimate $\bar{x}$ and s for in situ bulk density) would give $k = 0.1\bar{x}/s \approx 2.13$. Entering the appropriate table in Bowker and Lieberman (1972), the number of samples is found to be 22.

Two comments on this technique are necessary. First, the values of n obtained are estimates based on the preliminary data currently available. These values of n may need to be revised as site characterization data become available because the possibility exists that statistical analysis of the site characterization data may indicate spatial trends of μ and σ within a unit.

Secondly, the values of n are for a specified set of conditions at which preliminary data were obtained. No a priori assumptions have been made about the variability in a parameter resulting from changes in the experiment environment. If a parameter should vary as a function of sample size or experiment conditions, then n measurements should be obtained at each set of relevant experiment conditions. Because of the relatively large value of n for unit TSw2 (discussed in subsequent text), fewer experiments will be performed in the initial evaluation of the effects of experiment conditions. More experiments will be performed if these initial experiments indicate the need.

For the fracture properties, values of $\bar{x}$ and s are not available, so that n cannot be estimated by the procedure discussed above. Instead, the number of samples to be tested initially will be selected arbitrarily. The data from these initial experiments then will be used to estimate n, and additional experiments will be conducted if necessary.

Some parameters have preliminary data for which the variability is quite large. Variability can result from a number of sources: natural, sampling, preparation, and analytical. Present data are insufficient to determine the magnitude of the contribution from each source. For parameters where the existing value of s is too large to allow calculation of n using the tolerance limits requested by other issues, the initial value of n is arbitrarily assumed as follows:

Specified confidence	Number of samples
High	35
Medium	10
Low	5

Data obtained from these experiments then will be used to reassess whether the requested tolerance limits can be met using the normal distribution function or other distribution functions, as applicable. If not, either new tolerance limits will be set, and the impact on repository design or performance will be evaluated, or additional experiments will be performed to determine whether an increased sample size will reduce the observed variability.

Evaluation of data sufficiency after initial sampling and testing will be used with other information to help decide if additional testing is necessary.

The preceding discussion is based in part on the assumption that the sample used to obtain $\bar{x}$ and s is a random sample of the total population. Each thermal/mechanical unit is a three-dimensional body; the five existing core holes comprise only a partially random sample of the units, as will the exploratory shaft (ES) excavations. In fact, a site characterization program in which core holes and underground excavations are designed to investigate specific areas or features of interest can be considered to provide approximations rather than statistically representative sampling.

In view of the limitations on the randomness of sampling, the next best situation is one in which coverage of the repository area is maximized. The existing core holes within and close to the area are situated near the northern and southern limits. The ES facilities will expand coverage of the northern area within the repository unit (thermal/mechanical unit TSw2). However, the central and southern portions of the repository area will not be sampled as part of the ES facility; even sampling of the northern portion will be relatively sparse for thermal/mechanical units other than those mentioned previously. This situation suggests that coring of several new core holes is necessary for the determination of the spatial variability of thermal and mechanical properties.

Preliminary data suggest that spatial variability of these properties is small within TSw1 and TSw2 (Nimick and Schwartz, 1987). However, additional data are required for these and other units in the central and southern portions of the repository area. Also, data for units lying below the top of CHn1z must be obtained from at least one additional core hole in the northern part of the area, because the ES will not be sufficiently deep to provide samples of these units. As stated earlier, the estimated values of n for individual parameters in individual thermal/mechanical units will apply for each core hole and for the ES.

As discussed previously, acquisition of thermal and mechanical properties with the confidences requested by performance and design issues requires minimum numbers of experiments that vary with each property. The relatively large number of laboratory tests will augment the data available from a necessarily limited number of in situ tests. Values of rock-mass properties that will be obtained from in situ thermal and mechanical tests will serve as guideline properties and will be used to examine the validity of estimating rock-mass properties using laboratory data combined with information about in situ fracture characteristics.

In addition to providing estimates of rock-mass properties, in situ experiments will serve other purposes. Some tests will be used to monitor the behavior of underground excavations in units TSw1 and TSw2. Both qualitative and quantitative information will be obtained from these observations. Quantitative information for one experiment (sequential drift mining, Activity 8.3.1.15.1.5.3) will be used for code validation work on codes used to calculate mechanical response to imposed stresses. Validation work also will be performed for codes that calculate thermal, mechanical, or coupled thermal and mechanical responses to imposed temperatures and stresses using data from the canister-scale heater and heated-block experiments. In general, the codes to be validated will be used to contribute to the resolution of Issues 1.11 and 4.4 (Sections 8.3.2.2 and 8.3.2.5). Additional discussion of code-validation work is presented in Section 8.3.2.1.4.

8.3.1.15.1.1 Study: Laboratory thermal properties

The objective of this study is to provide laboratory characterization of thermal conductivity and heat capacity and the spatial variability thereof. In order to do so, porosity, grain density, and the heat capacity and thermal conductivity of zero-porosity material also must be characterized. The discussion for Activities 8.3.1.15.1.1.1, 8.3.1.15.1.1.2, and 8.3.1.15.1.1.3 applies for each new core hole selected for characterization and for the exploratory shaft (ES).

The validity of extrapolation of laboratory-determined thermal properties to in situ conditions will be examined by comparison of the properties with data obtained from in situ heater tests in the ES. Temperature fields induced during the heater tests will be modeled using numerical techniques, with values for thermal properties being varied until an optimum match of predicted and actual temperatures is obtained. Additional discussion of the heater tests is presented for Activities 8.3.1.15.1.6.1, 8.3.1.15.1.6.2, 8.3.1.15.1.6.3, and 8.3.1.15.1.6.5 under Study 8.3.1.15.1.6.

8.3.1.15.1.1.1 Activity: Density and porosity characterization

Objectives

The objective of this activity is to obtain data on density and porosity and to evaluate the spatial variability thereof. Data will contribute to determination of in situ thermal properties (porosity and grain density), to vertical in situ stress (bulk density), and radiation-shielding properties (bulk density).

Parameters

The parameters for this activity are matrix porosity, grain density, and in situ bulk density. (Matrix porosity refers to the total void space, as distinguished from the effective porosity that is available for hydrologic flow.) Parameters required that are to be supplied by other investigations are in situ saturation and lithophysal cavity abundance.

Description

The number of experiments necessary to characterize the density and porosity of each thermal/mechanical unit in Activity 8.3.1.15.1.1.1 are given in Table 8.3.1.15-4. These numbers have been obtained using available data

Table 8.3.1.15-4. Experiments required for each location selected for characterization of spatial variability of rock properties

Unit[a]	Bulk density[b] (8.3.1.15.1.1.1)	Density and porosity[c] (8.3.1.15.1.1.1)	Heat capacity (8.3.1.15.1.1.2)	Thermal conductivity (8.3.1.15.1.1.3)	Thermal expansion (8.3.1.15.1.2.1)	Compressive mechanical properties (8.3.1.15.1.3)
	Rock property and activity					
TCw	10	10	5	5	5	10
PTn	10	10	5	5	5	10
TSw1	10	10	10	10	10	35[d]
TSw2	35	35	35	35	35	35
TSw3	10	10	4	10	10	10
CHn1v	10	10	10	10	10	10
CHn1	10	10	10	10	10	10
CHn2v	5	6	5	6	5	5
CHn2z	5	6	5	6	5	5

[a]The relationship between thermal/mechanical units and formal stratigraphic units is provided in the introduction to Chapter 2.

[b]Numbers of experiments for bulk density are calculated based on requirements for vertical in situ stress or on requirements for TSw2 related to radon emanation rate.

[c]Number of experiments for density and porosity are related to the experiments required for bulk density, characterization of heat capacity, and thermal conductivity indicated in this table.

[d]Lithophysae-poor TSw1.

as discussed under the technical rationale for this investigation. The numbers are based on the number of experiments estimated as necessary for bulk density, volumetric heat capacity, and thermal conductivity (as needed for this activity and for Activities 8.3.1.15.1.1.2 and 8.3.1.15.1.1.3). The number of experiments applies to each new core hole selected for characterization and to the exploratory shaft. Each experiment will require approximately 65 cm^3 of material.

In addition to the experiments listed in Table 8.3.1.15-4, grain density and porosity data will be gathered from other samples. Values will be obtained for 5 to 10 samples of material taken from instrumentation holes in the vicinity of in situ experiments in the exploratory shaft facility. These site-specific values will aid in the interpretation of in situ experiment results and will add to the data base for units TSw1 and TSw2.

Also, density and porosity data will be obtained on samples tested for thermal and mechanical properties by measurement of dry and saturated bulk densities of the samples. These data will be somewhat less accurate than those gathered by the more standardized techniques listed below but will be specific to the individual test samples. This specificity will enhance the ability to interpret mechanical and thermal test results.

Grain densities (ρ_g) and dry bulk densities (ρ_{db}) will be measured. Matrix porosities then will be calculated by

$$\phi = 1 - \frac{\rho_{db}}{\rho_g} \qquad (8.3.1.15\text{-}3)$$

Data for grain density and matrix porosity will be combined with data on lithophysal cavity abundance and in situ saturation state to calculate in situ bulk densities. These bulk densities then will be used to calculate the vertical component of in situ stress.

Methods and technical procedures

The methods and technical procedures for Activity 8.3.1.15.1.1.1 are given in the following table.

Method	Technical procedure[a] Number	Title	Date
Measurement of dry bulk density	TP-057	Procedure for laboratory bulk density (saturated, natural state, dry) measurements	TBD[b]

Method	Technical procedure[a] Number	Title	Date
Measurement of grain density	TP-058	Procedure for laboratory grain density/water pycnometer measurements	TBD

[a]Nationally recognized procedures will be modified to conform to requirements of the Yucca Mountain Project quality assurance program when producing the procedures listed in the table.
[b]TBD = to be determined.

8.3.1.15.1.1.2 Activity: Volumetric heat capacity characterization

Objectives

The objectives of this activity are to obtain data for volumetric heat capacity and to evaluate the spatial variability thereof. The data will be used in calculations of the thermal response to the presence of heat-producing waste in unit TSw2.

Parameters

The parameters for this activity are the estimated in situ values of volumetric heat capacity. Parameters required from other investigations include in situ saturation and lithophysal cavity abundance. Parameters required from other activities within this investigation are matrix porosity and grain density.

Description

To estimate in situ values of volumetric heat capacity, data are required for grain density, matrix porosity, lithophysal cavity abundance, in situ saturation, and the heat capacities (C_p) of air, water, and solids. All of these, with the exception of the heat capacity of solids, will be available either in handbooks or as the result of other site characterization activities.

The number of experiments or calculations from chemistry or mineralogy to be performed in each new core hole selected for characterization to determine the heat capacity of solids for each thermal/mechanical unit in Activity 8.3.1.15.1.1.2 are given in Table 8.3.1.15-4. These numbers are the number of experiments estimated as necessary for volumetric heat capacity. Each experiment will require approximately 65 cm^3 of material. Each experiment on material from units TSw1, TSw2, TSw3, CHn1v, and CHn1z will include measurements (or calculations) over the temperature range from 25 to 275°C. For other units, the temperature range will be from 25 to 100°C. For some units that will be outside the temperature field produced by a repository, data from other units are assumed to be representative based on lithologic similarity. The impact of this assumption is expected to be negligible.

In addition to the experiments listed in Table 8.3.1.15-4, heat capacity data will be gathered from other samples. Values will be obtained for two to three samples of material taken from instrumentation holes in the vicinity of in situ experiments in the exploratory shaft facility. These site-specific values will aid in the interpretation of in situ experiment results and will add to the data base for units TSw1 and TSw2. If heat capacities of solids are calculated from chemical or mineralogic data, additional heat capacity information can be obtained using the chemical and mineralogic information to be gathered for the activities described in Section 8.3.1.3.2.1.

The data obtained from the measurements will be used to calculate volumetric heat capacity [$(\rho C_p)_{\text{in situ}}$] using the following equation (Nimick and Schwartz, 1987):

$$(\rho C_p)_{\text{in situ}} = \rho_g(1 - \phi_m - \phi_L)C_p^s + \phi_m S \rho_w C_p^{H_2O} + [\phi_m(1 - S) + \phi_L] C_p^{air} \rho_{air} \qquad (8.3.1.15\text{-}4)$$

where

ρ_g = grain density,

C_p^s = heat capacity of solid material,

S = saturation,

ϕ_m = matrix porosity,

ϕ_L = volume fraction of lithophysal cavities,

ρ_w = density of water,

ρ_{air} = density of air,

C_p^{air} = heat capacity of air,

$C_p^{H_2O}$ = heat capacity of water.

Because the density of air is so low, the last term is usually dropped from Equation 8.3.1.15-4. C_p^s and $C_p^{H_2O}$ and ρ_w are functions of temperature, so that ρC_p also is a function of temperature. The temperature ranges for which ρC_p will be obtained are the same as those specified earlier for C_p^s.

Methods and technical procedures

The methods and technical procedures for Activity 8.3.1.15.1.1.2 are given in the following table.

Method	Technical procedure[a]		
	Number	Title	Date
Heat capacity determination	TP-049	Procedure for laboratory heat capacity measurements	TBD[b]
Thermogravimetric analysis	TP-050	Procedure for thermogravimetric analysis	TBD

[a]Nationally recognized procedures will be modified to conform to requirements of the Yucca Mountain Project quality assurance program when producing the procedures listed in the table.
[b]TBD = to be determined.

8.3.1.15.1.1.3 Activity: Thermal conductivity characterization

Objectives

The objectives of this activity are to obtain data for thermal conductivity and to evaluate the spatial variability thereof. The data will be used in calculations of the thermal response to the presence of heat-producing waste in unit TSw2.

Parameters

The parameters for this activity are estimates of in situ thermal conductivity. Parameters required from other investigations are in situ saturation and lithophysal cavity abundance. A parameter required from another activity in this investigation is matrix porosity. These parameters will be combined in an appropriate model with the thermal conductivities of air, water, and solids to estimate in situ thermal conductivity.

Description

To estimate in situ values of thermal conductivity, data are required for the thermal conductivity of the solid material, air, and water and for matrix porosity, lithophysal cavity abundance, and in situ saturation. All of these, with the exception of the thermal conductivity of solids, will be available either in handbooks or as the result of other site characterization activities.

The number of experiments to be performed to determine the thermal conductivity of solids for each thermal/mechanical unit included in this activity are given in Table 8.3.1.15-4. These numbers are those estimated as necessary for thermal conductivity of the bulk material, using available data and the procedures outlined earlier in the technical rationale discussion for this investigation. For some units that will be outside the temperature field produced by a repository, data from other units are assumed to be representative based on lithologic similarity. Each experiment on material from units TSw1, TSw2, TSw3, CHn1v, and CHn1z will include measurements over the temperature range from 25 to 275°C. For other units, the temperature interval will be 25 to 100°C. Each experiment will use a sample that is equal to or smaller than 13 cm of NX (approximately 50 mm diameter) core; actual size will depend on the final experimental technique.

In addition to the experiments listed in Table 8.3.1.15-4, thermal-conductivity data will be gathered from other samples. The effects of fractures, saturation state, lithophysae, and potential anisotropy on thermal conductivity will be examined using measurements on appropriate samples from units TSw1 and TSw2 taken from the ESF. Values will be obtained for two to three samples of material taken from instrumentation holes in the vicinity of in situ experiments in the exploratory shaft facility. These site-specific values will aid in the interpretation of in situ experiment results and will add to the data base for units TSw1 and TSw2.

Thermal conductivity of several samples of Yucca Mountain tuffs will be measured in support of the activity related to determination of in situ temperatures (Activity 8.3.1.15.2.2.1). Data from these measurements also will contribute to the total data base on thermal properties.

The equation that has been used to date in analysis of the Yucca Mountain Project thermal-conductivity data has been a geometric-mean equation (Nimick and Lappin, 1985):

$$K = K_o^{(1-\phi_T)} K_w^{S\phi_m} K_a^{[(1-S)\phi_m+\phi_L]} \qquad (8.3.1.15\text{-}5)$$

where

K = bulk thermal conductivity
K_o = thermal conductivity of solids,
K_w = thermal conductivity of water,
K_a = thermal conductivity of air,
S = saturation,
ϕ_L = volume fraction of lithophysal cavities,
ϕ_m = matrix porosity,
ϕ_T = total porosity $(\phi_m + \phi_L)$.

This formulation will be reevaluated against other possible representations (including the possibility that the thermal conductivity is not a monotonic function of saturation); the actual equation that will be used to analyze data for site characterization has not been selected. K_o, K_w, and K_a are functions of temperature, so that K is also a function of temperature. The temperature ranges for which K will be obtained are the same as those specified earlier for K_o.

Methods and technical procedures

The methods and technical procedures for Activity 8.3.1.15.1.1.3 are given in the following table.

Method	Technical procedure[a] Number	Title	Date
Thermal conductivity determination	TP-046	Procedure for laboratory thermal conductivity measurements (unconfined)	TBD[b]

[a]Nationally recognized procedures will be modified to conform to requirements of the Yucca Mountain Project quality assurance program when producing the procedure shown in the table.
[b]TBD = to be determined.

8.3.1.15.1.2 Study: Laboratory thermal expansion testing

The objective of this study is to provide laboratory characterization of thermal-expansion behavior and the spatial variability thereof. The discussion that follows applies for each new core hole and for the exploratory shaft (ES). Testing frequency at the main test level in the ES will depend on spatial variability.

8.3.1.15.1.2.1 Activity: Thermal expansion characterization

Objectives

The objective of this activity is to obtain data for thermal-expansion behavior and to evaluate the spatial variability thereof. The data will be used in calculations of thermal stress and deformation associated with the temperature field produced by the presence of heat-producing waste in unit TSw2.

Parameters

The parameter for this activity is the coefficient of thermal expansion.

Description

The number of experiments necessary to obtain the coefficient of thermal expansion for each thermal/mechanical unit in Activity 8.3.1.15.1.2.1 is given in Table 8.3.1.15-4. The numbers have been obtained using available data and the procedure outlined in the technical rationale discussion for this investigation. For some units that will be outside the temperature field produced by a repository, data from other units are assumed to be representative on the basis of lithologic similarity. The impact of this assumption is expected to be negligible. Each experiment for units TSw1, TSw2, TSw3, CHn1v, and CHn1z will include measurements over the temperature range from 25 to 275°C. For other units, the temperature range will be 25 to

100°C. Sample size will be similar to that used in previous experiments (Chapter 2), ranging from 25.4 by 25.4 by 3 mm up to cylinders 50.8 mm in diameter and 101.6 mm in length.

Thermal-expansion experiments will be performed on initially saturated samples under conditions that minimize dehydration at temperatures below 100°C. Samples will be allowed to dehydrate at approximately 100°C until a stable length is achieved, then heating will continue if the experiment includes heating to 275°C. Heating rates will be selected to minimize any kinetic effects of dehydration or mineral transformations on the rates of thermal expansion (or contraction).

For thermal/mechanical unit TSw1, data are necessary for both lithophysae-rich and lithophysae-poor portions of the unit. Both portions of unit TSw1 will be characterized by the same method used for the units discussed in the previous paragraph, although samples from the lithophysae-rich portions will be significantly larger than the sizes mentioned earlier. For unit TSw2, scoping experiments will be performed to assess the significance, if any, of anisotropy, fracturing, or sample size on the thermal expansion behavior of unit TSw2.

In addition to the thermal-expansion experiments performed to examine spatial variability of this property, experiments will be done on samples collected from the vicinity of in situ experiments that involve elevated temperatures. These thermal-expansion data will be used in the interpretation of in situ experiment results as well as to augment the data base on the thermal expansion of units TSw1 and TSw2.

Methods and technical procedures

The methods and technical procedures for Activity 8.3.1.15.1.2.1 are given in the following table.

Method	Technical procedure[a]		
	Number	Title	Date
Measurement of thermal expansion	TP-043	Procedure for laboratory thermal expansion measurements (confined)	TBD[b]
	TP-044	Procedure for laboratory thermal expansion measurements (unconfined)	TBD

[a]To the extent possible, nationally recognized procedures will be modified to conform to requirements of the Yucca Mountain Project quality assurance program when producing the procedures listed in the table.
[b]TBD = to be determined.

8.3.1.15.1.3 Study: Laboratory determination of mechanical properties of intact rock

The objective of this study is to provide laboratory characterization of the mechanical properties of intact rock and the spatial variability thereof. The discussion for Activity 8.3.1.15.1.3.1 applies for each new core hole and for the ES. Testing frequency at the main test level in the ES will depend on spatial variability.

8.3.1.15.1.3.1 Activity: Compressive mechanical properties of intact rock at baseline experiment conditions

Objectives

The objective of this activity is to obtain data for the compressive mechanical properties of intact rock, and the spatial variability thereof, for baseline experiment conditions. These data will be used in mechanical and thermomechanical calculations of stresses and deformations induced by the presence of underground openings in unit TSw2 and overlying units and by the presence of heat-producing waste in unit TSw2.

Parameters

The parameters for this activity include uniaxial compressive strength, Young's modulus, and Poisson's ratio.

Description

As discussed in Chapter 2, the compressive strength of Yucca Mountain tuffs is a function of various conditions, including strain rate, confining pressure, temperature, sample size, and saturation state. To evaluate the effects of these parameters, a set of baseline experiment conditions must be defined for which compressive mechanical data will be obtained. These conditions will be as follows:

Sample diameter: 50.8 mm
Sample length to diameter ratio: 2.0
Saturation state: Saturated
Temperature: Room temperature (22°C)
Confining pressure: Atmospheric (0.1 MPa)
Strain rate: 10^{-5} s^{-1}

The number of experiments to be performed at these conditions for each thermal/mechanical unit in Activity 8.3.1.15.1.3.1 are summarized in Table 8.3.1.15-4. The numbers have been obtained from available data using the procedure outlined in the technical rationale discussion for this investigation. For some far-field units, data from characterized units are assumed to be representative based on lithologic similarity. Because the far-field units are outside the regions of significantly altered stress and temperature, the impact of this assumption is assumed to be negligible.

In addition to the experiments listed for this activity (8.3.1.15.1.3.1) in Table 8.3.1.15-4, compressive experiments at the baseline conditions will be performed on samples obtained in the vicinity of in situ experiments. The data from these laboratory experiments will aid in the interpretation of in situ experiment results as well as contributing to the data base for the compressive mechanical properties of units TSw1 and TSw2.

Methods and technical procedures

The methods and technical procedures for Activity 8.3.1.15.1.3.1 are given in the following table.

Method	Technical procedure[a]		
	Number	Title	Date
Compression testing	TP-053	Procedure for determination of compressive mechanical properties	TBD[b]

[a]To the extent possible, nationally recognized procedures will be modified to conform to requirements of the Yucca Mountain Project quality assurance program when producing the procedure shown in the table.
[b]TBD = to be determined.

8.3.1.15.1.3.2 Activity: Effects of variable environmental conditions on mechanical properties

Objectives

The objective of this activity is to evaluate the effects of varying sample size, strain rate, temperature, confining pressure, lithophysal content, saturation state, and anisotropy on compressive mechanical properties. In addition, the tensile strength of unit TSw2 will be measured. Data will be used in mechanical and thermomechanical calculations of stresses and deformations induced by the presence of underground openings in unit TSw2 and overlying units and by the presence of heat-producing waste in unit TSw2.

Parameters

The parameters for this activity are unconfined compressive strength, Young's modulus, Poisson's ratio, cohesion, and angle of internal friction.

Description

As discussed in Chapter 2, compressive mechanical properties are a function of the sample characteristics and experimental conditions at which the properties are measured. This activity will determine the effects of sample size, strain rate, temperature, confining pressure, lithophysal content, saturation state, and anisotropy on the compressive mechanical properties of unit TSw2, the proposed repository horizon. In addition, the effects of confining pressure on the mechanical properties of units TCw, PTn, and lithophysae-poor portions of unit TSw1 will be determined, as well as the tensile strength of unit TSw2. Material for testing of unit TSw2 will be obtained from the walls of the excavations at the main test level in the exploratory shaft (ES) facility, whereas samples of other units will be collected from the ES itself.

In addition to the testing just summarized, scoping experiments are ongoing to determine whether creep deformation or deformation at very low strain rates are of concern for unit TSw2. Samples taken from outcrop at Busted Butte are being tested in compression at low strain rates (10^{-8} to 10^{-9} s^{-1}), elevated temperature (250°C), and in creep experiments. Results will be used to assess whether the experiment program mentioned in the preceding paragraph should include additional experiments at these extreme conditions.

Methods and technical procedures

The methods and technical procedures for Activity 8.3.1.15.1.3.2 are given in the following table.

Method	Technical procedure[a]		
	Number	Title	Date
Compression testing	TP-053	Procedure for determination of compressive mechanical properties	TBD[b]
Tensile strength testing	TP-054	Procedure for determination of tensile mechanical properties	TBD

[a]To the extent possible, nationally recognized procedures will be modified to conform to the requirements of the Yucca Mountain Project quality assurance program when producing the procedure shown in the table.
[b]TBD = to be determined.

8.3.1.15.1.4 Study: Laboratory determination of the mechanical properties of fractures

The objective of this study is to provide laboratory characterization of the mechanical properties of fractures and the spatial variability thereof. The discussion applies for each new core hole and for the exploratory shaft (ES).

8.3.1.15.1.4.1 Activity: Mechanical properties of fractures at baseline experiment conditions

Objectives

The objective of this activity is to obtain data for the mechanical properties of fractures, and the spatial variability thereof, for baseline experiment conditions. The data will be used in mechanical and thermo-mechanical calculations of the stresses and deformations induced by the presence of underground openings in unit TSw2 and overlying units and by the presence of heat-producing waste in unit TSw2.

Parameters

The parameters for this activity are cohesion, coefficient of friction, shear stiffness, normal stiffness.

Description

As discussed in Chapter 2, the mechanical behavior of fractures may be a function of various conditions, including normal stress, displacement rate, temperature, mineralogy, sample size, fracture roughness, and saturation state. To evaluate the effects of these parameters, a set of baseline experimental conditions must be defined for which the parameters listed in this section will be obtained. These conditions will be as follows:

Sample (fracture) area: 2.0×10^{-3} to 4.0×10^{-3} m^2
Saturation state: Dry
Temperature: Room temperature (22°C)
Displacement rate (shear loading): 10 µm/s
Loading rate (normal loading): 0.03 MPa/s
Fracture: Artificial (ground sawcut)

No data are presently available with which to estimate the number of fractures that must be tested. Scoping experiments are under way on samples from unit TSw2 collected from Busted Butte. These experiments will provide preliminary data that will be used to design the initial phase of fracture testing in terms of sampling frequency.

Methods and technical procedures

The methods and technical procedures for Activity 8.3.1.15.1.4.1 are given in the following table.

Method	Technical procedure Number	Title	Date
Fracture testing	TP-052	Procedure for determination of fracture mechanical properties	TBD[a]

8.3.1.15.1.4.2 Activity: Effects of variable environmental conditions on mechanical properties of fractures

Objectives

The objective of this activity is to evaluate the effects of varying normal stress, displacement rate, temperature, sample size, fracture roughness, and saturation state on the mechanical properties of artificial and natural fractures. The data will be used in mechanical and thermomechanical calculations of stresses and deformations induced by the presence of underground openings in unit TSw2 and overlying units and by the presence of heat-producing waste in unit TSw2.

Parameters

The parameters of this activity are cohesion, coefficient of friction, shear stiffness, and normal stiffness.

Description

Fracture properties are a function of the fracture surface characteristics and the experimental conditions. This activity will determine the effects of normal stress, displacement rate, temperature, sample size, fracture roughness, and saturation state on the fracture properties. Approximately 20 experiments will be performed at each set of experiment conditions for samples of unit TSw2, with fewer experiments on samples of adjacent units if such experiments appear to be necessary. Tentative ranges in experiment conditions are as follows:

Saturation state: Dry and saturated
Temperature: 22 to 200°C
Normal stress: 0.1 to 30 MPa
Displacement rate: 10^{-1} to 10^{2} µm/s
sample area: 2×10^{-3} to 100×10^{-3} m^2

In addition, several scoping experiments will be performed to examine whether creep is a realistic deformation mechanism for fractures in unit TSw2.

The range in sample size (surface area) will depend on material availability. The range probably will extend from NX-core to fracture surfaces up to 0.1 m^2 in area. Sampling plans for this activity will take into account the importance of scaling effects when extrapolating from laboratory results to in situ fractures.

The range in roughness of fracture surfaces will depend on the results of characterization of fracture sets and sensitivity calculations. All types of fractures estimated to be of potential importance to the mechanical behavior of the rock mass will be tested.

Methods and technical procedures

The methods and technical procedures for Activity 8.3.1.15.1.4.2 are given in the following table.

Method	Technical procedure		
	Number	Title	Date
Fracture testing	TP-052	Procedure for determination of fracture mechanical properties	TBD[a]
Fracture sampling	TP-165	Procedure for obtaining representative samples of in situ fractures	TBD

[a]TBD = to be determined.

8.3.1.15.1.5 Study: Excavation investigations

The objective of this study is to obtain site-specific information concerning the behavior of underground excavations in the proposed repository horizon and overlying units. Most of the data will be used for testing of computer codes that will be used to predict mechanical behavior of the rock mass (Section 8.3.2.1.4). In addition, some of the information will serve as direct demonstration of constructability with reasonably available technology (relevant to resolution of Issue 4.4). All of the in situ experiments will be conducted in the exploratory shaft (ES) facility. Interpretation of the data to be obtained from the activities for this study (8.3.1.15.1.5) will utilize information gathered for 8.3.1.4.2.2 (characterization of structural features within the site area).

8.3.1.15.1.5.1 Activity: Shaft convergence

Objectives

The objectives of this activity are to monitor rock-mass deformation around a vertical shaft (the ES) and to measure horizontal in situ stresses. In situ stress data will contribute to definition of boundary and initial conditions for mechanical and thermomechanical analyses, whereas observations of rock-mass deformation also will contribute to empirical evaluations of nonradiological health and safety (Issue 4.2).

Parameters

Information will be obtained concerning rock-mass deformation and horizontal in situ stress. Both will be obtained in more than one location (vertically), so that some information regarding spatial variability of rock-mass deformation and horizontal stresses will be obtained.

Description

The following description covers the monitoring of rock-mass deformation.

Rock-mass deformation around the ES will be monitored at three measurement stations consisting of two levels separated by several meters, using multiple-point borehole extensometers (MPBXs) placed at 120° intervals around the shaft circumference. The MPBXs will be installed as soon as practicable after excavation of the relevant level in the ES. Deformations will be measured across the shaft diameter and as a function of distance from the shaft at multiple locations in the walls. The MPBX heads will not be covered by the shaft liner, so that the deformations can be monitored as a function of time. In addition to MPBX measurements, deformations will be measured with rod extensometers at each of the three measurement stations. Extensometer measurements will be made along diameters in the same plane as the MPBXs at 60° from the MPBX heads.

Methods and technical procedures

The methods and technical procedures for Activity 8.3.1.15.1.5.1 are given in the following table.

Method	Technical procedure Number	Technical procedure Title	Technical procedure Date
Preparation of instrumentation holes	TP-001	Procedure for diamond-drilling holes for instrumentation	TBD[a]

Method	Technical procedure		
	Number	Title	Date
Preparation of instrumentation holes (continued)	TP-002	Procedure for percussion-drilling holes for instrumentation	TBD
Overcoring stress measurements	TP-003	Procedure for overcoring for stress measurements	TBD
Biaxial stress measurements	TP-004	Procedure for biaxial stress measurements for overcoring testing	TBD
Rod extensometer measurements	TP-005	Procedure for installation and operation of rod extensometers	TBD
MPBX[b] measurements	TP-006	Procedure for installation and operation of MPBXs	TBD
Borescope observation	TP-014	Procedure for inspection of borehole, using a borescope	TBD
Use of borehole deformation gages	TP-017	Procedure for installation and operation of borehole deformation gages (BDG)	TBD
Definition of joint properties	TP-023	Procedure for characterization of fracture properties and geometries in thin slots	TBD
Monitoring of pressure control systems	TP-033	Procedure for monitored pressure control systems	TBD
Data acquisition	TP-034	Procedure for monitoring of data acquisition system	TBD

[a]TBD = to be determined.
[b]MPBX = multiple-point borehole extensometers.

8.3.1.15.1.5.2 Activity: Demonstration breakout rooms

Objectives

The major objective of this activity is to demonstrate constructability and stability of underground rooms with cross-sectional dimensions equivalent to those of a repository in both lithophysae-rich and lithophysae-poor material. This demonstration will include an evaluation of the deformations that occur around the openings. A secondary objective is to provide facilities for other testing (e.g., heater tests and overcoring). Demonstration of constructability and stability will contribute to empirical evaluations of nonradiological health and safety (Issue 4.2).

Parameters

Data will be obtained concerning deformations caused by repository-sized excavations in welded tuff. Information also will be obtained about the extent of the zone of increased fracturing adjacent to the excavations, about rock-bolt loading, and observations about excavation efficiency.

Description

Two rooms with cross-sectional dimensions equivalent to those of a repository will be excavated, one in lithophysae-rich tuff (unit TSw1) and the second in lithophysae-poor material (unit TSw2). The rooms will be stabilized using rock bolts and wire mesh. Deformations will be monitored using multiple-point borehole extensometers (MPBXs) at five stations in each room, with six MPBXs at each station. The MPBXs will be installed as soon as practicable after excavation of the relevant interval of the rooms. Rod extensometer measurements will be made between drift convergence anchors located in the room floor and back at eleven stations. In addition, rock bolt load cells will be used to monitor changes in the stress-altered region.

Methods and technical procedures

The methods and technical procedures for Activity 8.3.1.15.1.5.2 are given in the following table.

Method	Technical procedure Number	Title	Date
Preparation of instrumentation holes	TP-001	Procedure for diamond-drilling holes for instrumentation	TBD[a]
	TP-002	Procedure for percussion-drilling holes for instrumentation	TBD

Method	Technical procedure		
	Number	Title	Date
Rod extensometer measurements	TP-005	Procedure for installation and operation of rod extensometers	TBD
MPBX[b] measurements	TP-006	Procedure for installation and operation of MPBXs	TBD
Use of rock bolt load cells	TP-008	Procedure for installation and operation of rock bolt load cells (RBLC)	TBD
Borescope observation	TP-014	Procedure for inspection of boreholes using borescope	TBD
Definition of joint properties	TP-023	Procedure for characterization of fracture properties and geometries in thin slots	TBD
Data acquisition	TP-034	Procedure for monitoring of data acquisition system	TBD
Rock bolt installation	TP-037	Procedure for installation of rock bolts	TBD
Blasted rock characterization	TP-038	Procedure for blasted rock sorting and size evaluation	TBD
Excavation activities	TP-041	Procedure for drilling and blasting	TBD
	TP-042	Procedure for loading and blasting	TBD

[a]TBD = to be determined.
[b]MPBX = multiple-point borehole extensometers.

8.3.1.15.1.5.3 Activity: Sequential drift mining

Objectives

The objectives of this activity are to obtain data on the deformation response of drifts with cross-sectional dimensions equivalent to those of a repository in welded tuff, to use the data in code evaluation activities, and to demonstrate constructability and stability of repository-sized drifts in lithophysae-poor material. Data will contribute to validation of computer codes to be used to calculate mechanical responses, as well as contributing to empirical evaluations related to nonradiological health and safety (Issue 4.2).

Parameters

Data will be obtained concerning deformations caused by the presence of multiple underground excavations in welded tuff (unit TSw2). Stress changes also will be monitored.

Description

Although a final design for this experiment is not available, the concept includes the following sequence:

1. Excavate observation drift with cross-sectional dimensions smaller than or equivalent to those of a repository.

2. Instrument and characterize the rock mass between the observation drifts using MPBXs, borehole stress meters, permeability and cross-hole geophysical techniques before excavating the main experiment drift.

3. Excavate the experiment drift and install MPBXs to monitor rock mass deformation as excavation proceeds.

Deformations caused by the excavation of the main experiment drift in step 3 will be measured from the observation drift using borehole deflectometers and multiple-point borehole extensometers (MPBXs), and within the experiment drifts using rod extensometers and MPBXs. Instrumentation will be installed for step 2 and also will be placed in the secondary excavation(s) in step 3 as mining progresses. Changes in near-field stresses around the drifts will be monitored with borehole stressmeters.

Quantitative information from the measurements will be used to aid in evaluation of computer codes to be used in calculation of the mechanical response of the rock-mass. Before this site characterization experiment begins, some prototype experiments will be performed in G-tunnel. These initial experiments are designed to aid in development of appropriate instrumentation. Emphasis will be placed on the development of appropriate instruments to monitor ground motion (acceleration, velocity, and stress) associated with blasting activities in welded tuff, with application to the possible survivability of the full range of instrumentation to be used in site characterization activities in the ESF.

Methods and technical procedures

The methods and technical procedures for Activity 8.3.1.15.1.5.3 are given in the following table.

Method	Technical procedure		
	Number	Title	Date
Preparation of instrumentation holes	TP-001	Procedure for diamond-drilling holes for instrumentation	TBD[a]
	TP-002	Procedure for percussion-drilling holes for instrumentation	TBD
Rod extensometer measurements	TP-005	Procedure for installation and operation of rod extensometers	TBD
MPBX[b] measurements	TP-006	Procedure for installation and operation of MPBXs	TBD
Use of rock bolt load cells	TP-008	Procedure for installation and operation of rock bolt load cells (RBLC)	TBD
Borehole deflectometer measurements	TP-010	Procedure for installation and operation of borehole deflectometer	TBD
Borehole stress meter measurements	TP-011	Procedure for installation and operation of borehole stress meters	TBD
Use of water permeability equipment	TP-013	Procedure for installation and operation of water permeability equipment	TBD
Borescope observation	TP-014	Procedure for inspection of boreholes using a borescope	TBD
Definition of joint properties	TP-023	Procedure for characterization of fracture properties and geometries in thin slots	TBD
Data acquisition	TP-034	Procedure for monitoring of data acquisition system	TBD
Rock bolt installation	TP-037	Procedure for installation of rock bolts	TBD

Method	Technical procedure Number	Title	Date
Evaluation of blasted rock	TP-038	Procedure for blasted rock sorting and size evaluation	TBD
Excavation activities	TP-041	Procedure for drilling and blasting	TBD
	TP-042	Procedure for loading and blasting	TBD

[a]TBD = to be determined.
[b]MPBX = multiple-point borehole extensometers.

8.3.1.15.1.6 Study: In situ thermomechanical properties

The objective of this study is to obtain data on in situ thermal and thermomechanical properties for units TSw1 and TSw2. Properties to be obtained include heat capacity, thermal conductivity, and thermal expansion. Deformation modulus, strain ratio, and radon emanation rates also will be determined during some of the testing activities. In addition, the effects of heating on in situ water content, deformation modulus, changes in thermally induced stress, radon emanation, and the deformation response of the rock around a heated room will be observed. Some of the data will be used for testing computer codes used in heat transfer and thermomechanical calculations. Additional heater experiments will be conducted to characterize the waste container environment, as discussed in Section 8.3.4.2.4.

Interpretation of the data to be obtained from the activities for this study will utilize information gathered for Study 8.3.1.4.2.2 (characterization of the structural features within the site area).

8.3.1.15.1.6.1 Activity: Heater experiment in unit TSw1

Objectives

The objectives of this activity are to estimate the in situ thermomechanical properties of lithophysae-rich tuff (unit TSw1) and to evaluate the thermal and mechanical response of this tuff unit to elevated temperatures. The data will be used to evaluate models during this and other experiments.

Parameters

The parameters obtained for this activity are thermal conductivity, heat capacity, and thermal expansion coefficient.

Description

The design of this experiment, in terms of heater dimensions and power output, has not been finalized. However, data to be measured will include temperatures, deformations, and changes in moisture content regardless of the heater used. Use of heater-induced temperature changes to estimate in situ values of thermal conductivity and heat capacity is discussed for Study 8.3.1.15.1.1 (laboratory thermal properties). A neutron probe will be used to evaluate changes in bulk moisture content near the heater; this information will be used in calculation of in situ thermal properties and in qualitative evaluation of hydrothermal mechanisms. Estimates of thermal expansion coefficients will be obtained through a combination of the measured temperatures and thermally induced deformations as measured with multiple-point borehole extensometers.

Methods and technical procedures

The methods and technical procedures for Activity 8.3.1.15.1.6.1 are given in the following table.

Method	Technical procedure		
	Number	Title	Date
Preparation of instrumentation hole	TP-001	Procedure for diamond-drilling holes for instrumentation	TBD[a]
	TP-002	Procedure for percussion-drilling holes for instrumentation	TBD
MPBX[b] measurements	TP-006	Procedure for installation and operation of MPBXs	TBD
Borescope observation	TP-014	Procedure for inspection of boreholes using a borescope	TBD
Temperature measurements	TP-024	Procedure for installation and operation of thermocouples	TBD

Method	Technical procedure Number	Title	Date
Heater operation	TP-026	Procedure for installation and operation of small-scale heater	TBD
	TP-027	Procedure for installation and operation of canister-scale heater	TBD
Data acquisition	TP-034	Procedure for monitoring of data acquisition system	TBD
Heater control	TP-035	Procedure for monitoring temperature or heater control systems	TBD
Moisture measurements	TP-039	Procedure for installation and operation of neutron probe for determination of moisture content	TBD

[a]TBD = to be determined.
[b]MPBX = multiple-point borehole extensometers.

8.3.1.15.1.6.2 Activity: Canister-scale heater experiment

Objectives

The objective of this activity is to obtain thermal and thermomechanical rock-mass measurements of the effects of thermal inputs on a representative (canister-scale) waste-emplacement borehole in lithophysae-poor tuff (unit TSw2). The data will be used to evaluate the thermal and thermomechanical models. Early testing will simulate heat fluxes expected during repository operations to evaluate geomechanical models. The heat fluxes will be increased subsequently during a thermal overdrive to determine the upper heat limit for waste-emplacement borehole stability.

Parameters

The parameters to be obtained for this activity are thermal expansion coefficient, thermal conductivity, and heat capacity.

Description

A canister-scale heater will be emplaced in unit TSw2, and temperatures, deformations, and changes in moisture content and changes in stresses will be monitored. Instruments will include thermocouples, multiple-point borehole extensometers (MPBXs), borehole deformation gauges, and a neutron probe. The use of heater-induced temperature changes to estimate in situ values of thermal conductivity and heat capacity is discussed for Study 8.3.1.15.1.1 (laboratory thermal properties). Estimates of thermal expansion coefficients will be obtained through a combination of the measured temperatures and thermally induced deformations as measured with the thermocouples and MPBXs. Data will be used to test computer codes intended to estimate the thermal and thermomechanical behavior of the rock mass. Values for rock-mass thermal properties will be obtained from evaluation of the response of the rock mass and from estimates based on laboratory measurements of samples obtained from the vicinity of the canister-scale heater. Additional discussion of code evaluation activities is presented in Section 8.3.2.1.4. Qualitative information concerning stability of the heater hole under conditions of elevated temperature will be made during a thermal overdrive and will contribute to an evaluation of retrievability.

An additional activity associated with the canister-scale experiment is the measurement of radon emissions in unit TSw2 as a function of temperature. A borehole near the heater will be monitored for radon concentrations throughout the duration of the canister-scale experiment. Results will be used to help satisfy Issue 2.7 (Section 8.3.2.3).

Methods and technical procedures

The methods and technical procedures for Activity 8.3.1.15.1.6.2 are given in the following table.

Method	Technical procedure: Number	Technical procedure: Title	Technical procedure: Date
Preparation of instrumentation	TP-001	Procedure for diamond-drilling holes for instrumentation	TBD[a]
	TP-002	Procedure for percussion-drilling holes for instrumentation	TBD
MPBX[b] measurements	TP-006	Procedure for installation and operation of MPBXs	TBD

Method	Technical procedure		
	Number	Title	Date
Borescope observations	TP-014	Procedure for inspection of boreholes using a borescope	TBD
Borehole deformation gage measurements	TP-017	Procedure for installation and operation of borehole deformation gages (BDG)	TBD
Temperature measurements	TP-024	Procedure for installation and operation of thermocouples	TBD
Heater operation	TP-027	Procedure for installation and operation of canister-scale heater	TBD
Radon measurements	TP-028	Procedure for installation and operation of instrumentation for monitoring radon emanations	TBD
Data acquisition	TP-034	Procedure for monitoring of data acquisition system	TBD
Heater control	TP-035	Procedure for monitoring temperature or heater control systems	TBD
Moisture measurements	TP-039	Procedure for installation and operation of neutron probe for determination of moisture content	TBD

[a]TBD = to be determined.
[b]MPBX = multiple-point borehole extensometers.

8.3.1.15.1.6.3 Activity: Yucca Mountain heated block

Objectives

The objectives of this activity are to estimate in situ mechanical and thermomechanical properties of unit TSw2 and to test thermomechanical computer models. Data on the properties will be used in mechanical and thermomechanical calculations of stresses and deformations induced by the presence of underground openings in unit TSw2 and overlying units and by the presence of heat-producing waste in unit TSw2.

Parameters

The parameters of this activity are deformation modulus, thermal expansion coefficient, thermal conductivity, heat capacity, joint wall compressive strength, and joint roughness coefficient.

Description

Slots isolating a 2-m by 2-m block will be cut in an alcove at the main test level in the exploratory shaft (ES). Flatjacks will be set in the slots adjacent to the block, enabling application of uniaxial or biaxial stresses. Two rows of heaters outside opposite sides of the block will be used to heat the block. Before and during the heated phases, stresses will be applied and deformation will be monitored to obtain values for the deformation modulus and the ratio of lateral strain to axial strain (principal strain ratio), and the variation of these two properties with temperature. Thermally induced deformation will be used to obtain estimates of the thermal expansion coefficient. Use of heater-induced temperature changes to estimate in situ values of thermal conductivity and heat capacity is discussed for Study 8.3.1.15.1.1 (laboratory thermal properties). A thermal probe also will be used as a transient-line heat source to measure in situ thermal conductivity directly. In addition to the parameters mentioned previously, changes in moisture content as a function of temperature and position will be monitored with a neutron probe. Experience gained from the G-tunnel heated block experiment (Zimmerman et al., 1986) will guide the experiment at Yucca Mountain.

After some portion of the experiment has been completed for this activity, the feasibility of cutting slots for a second block will be assessed. If feasible, this block would be oriented in a manner allowing for measuring shear and normal mechanical properties of in situ fractures.

Instruments for measuring deformation for this activity may include set pins, strain gage rosettes, horizontal extensometers, tiltmeters, and multiple-point borehole extensometers. Stress changes during the experiment will be monitored with borehole deformation gages. As mentioned earlier, thermal and neutron probes also will be used.

To help interpret the data from this experiment, laboratory measurements will be made using core from instrumentation holes in or near the block. Thermal conductivity, heat capacity, and mechanical properties will be measured. In addition, measurements of joint wall compressive strength and joint roughness coefficient (Barton and Choubey, 1977) will be made on joints within or near the location of the block.

Methods and technical procedures

The methods and technical procedures for Activity 8.3.1.15.1.6.3 are given in the following table.

Method	Technical procedure		
	Number	Title	Date
Preparation of instrumentation holes	TP-001	Procedure for diamond-drilling holes for instrumentation	TBD[a]
	TP-002	Procedure for percussion-drilling holes for instrumentation	TBD
MPBX[b] measurements	TP-006	Procedure for installation and operation of MPBXs	TBD
Slot cutting	TP-015	Procedure for slot cutting with 2-m chain saw in the floor	TBD
	TP-016	Procedure for slot cutting with 2-m chain saw in the rib	TBD
Borehole deformation gage measurements	TP-017	Procedure for installation and operation of borehole deformation gages (BDG)	TBD
Whittemore pin measurements	TP-019	Procedure for installation and operation of pins and operation of Whittemore gage	TBD
Strain gage measurements	TP-020	Procedure for installation and operation of surface strain gages	TBD

Method	Technical procedure		
	Number	Title	Date
Tiltmeter measurements	TP-021	Procedure for installation and operation of tiltmeters	TBD
Flatjack operation	TP-022	Procedure for installation and operation of flatjacks in thin slots	TBD
Fracture characterization	TP-023	Procedure for characterization of fracture properties and geometry in thin slots	TBD
Temperature measurements	TP-024	Procedure for installation and operation of thermocouples	TBD
Thermal probe measurements	TP-025	Procedure for installation and operation of thermal probe	TBD
Heater operation	TP-026	Procedure for installation and operation of small-scale heater	TBD
Data acquisition	TP-034	Procedure for monitoring of data acquisition system	TBD
Heater control	TP-035	Procedure for monitoring temperature or heater control systems	TBD
Moisture measurements	TP-039	Procedure for installation and operation of neutron probe for determination of moisture content	TBD

[a]TBD = to be determined.
[b]MPBX = multiple-point borehole extensometer.

8.3.1.15.1.6.4 Activity: Thermal stress measurements

Objectives

The objective of this activity is to monitor changes in thermally induced stress in jointed welded tuffs in an accelerated test. The data will be used to evaluate thermally induced stresses calculated with thermomechanical computer codes. The focus of this experiment is directed toward evaluating drift stability as it might affect retrievability.

Parameters

Parameters for this activity are temperature, thermally induced stresses, and displacement.

Description

A slot will be cut in the roof or a rib of a drift and a flatjack will be inserted in the slot. Two rows of heaters parallel to and on either side of the slot will be energized, and a new method for stress cancellation will be used to measure the stresses induced by the temperature field. In addition, deformation in the surrounding heated volume (>36 m^3) will be monitored using MPBXs and long-gage surface extensometers. The combinations of measured deformation with measured temperatures will allow confirmation of in situ thermal expansion coefficients measured in other in situ tests (Activities 8.3.1.15.1.6.1, 8.3.1.15.1.6.2, and 8.3.1.15.1.6.3).

The specific number and location of these experiments has not yet been defined. At a minimum, experiments in the roof and rib are envisioned. Evaluation of the experiment design and prototype experiments are ongoing. The prototype experiments include development of equipment (e.g., high-pressure flatjacks) as well as the methodology.

Methods and technical procedures

The methods and technical procedures for Activity 8.3.1.15.1.6.4 are given in the following table.

Method	Technical procedure		
	Number	Title	Date
Preparation of instrumentation holes	TP-001	Procedure for diamond-drilling holes for instrumentation	TBD[a]
	TP-002	Procedure for percussion-drilling holes for instrumentation	TBD

Method	Technical procedure Number	Title	Date
MPBX[b] measurements	TP-006	Procedure for installation and operation of MPBXs	TBD
Slot cutting	TP-015	Procedure for slot cutting with 2-m chain saw in the floor	TBD
	TP-016	Procedure for slot cutting with 2-m chain saw in the rib	TBD
Long-gage extensometer measurements	TP-018	Procedure for installation and operation of long-gage surface extensometers	TBD
Whittemore pin measurements	TP-019	Procedure for installation and operation of pins and operation of Whittemore gage	TBD
Flatjack operation	TP-022	Procedure for installation and operation of flatjacks	TBD
Temperature measurements	TP-024	Procedure for installation and operation of thermocouples	TBD
Heater operation	TP-026	Procedure for installation and operation of small-scale heater	TBD
Data acquisition	TP-034	Procedure for monitoring of data acquisition system	TBD
Heater control	TP-035	Procedure for monitoring temperature or heater control systems	TBD

Method	Technical procedure Number	Title	Date
Stress cancellation testing	TP-079	Procedure for measurement of in situ slot normal stress in the field	TBD

[a]TBD = to be determined.
[b]MPBX = multiple-point borehole extensometer.

8.3.1.15.1.6.5 Activity: Heated room experiment

Objectives

The objectives of this activity are (1) to evaluate the thermomechanical response of welded tuff around repository openings to expected repository conditions during both construction and operation, (2) to develop a data base for evaluating thermal and thermomechanical design analyses and methods applicable for repository considerations, and (3) to use actual site data in predicting drift response and support/rock interactions during construction, operation, retrievability, and postclosure.

Parameters

The following parameters and information will be obtained during this experiment: rock-mass deformation; estimate of the region in which the stress state is changed by elevation of temperature; stress changes; thermal conductivity and heat capacity; ground-support loading and deformation; and the temperature dependence of measured parameters.

Description

The design of this experiment is in the preliminary stage. The experiment will be conducted in unit TSw2. The experiment will consist of developing a representative room in a drift and heating the rock around it to expected repository operating temperatures. The length of the heated room and geometrical placement of the heat sources will be determined by evaluating the length and heat source placement with a reasonable number of heaters required to generate repository-like conditions. Preliminary plans call for the heated room to be paralleled by two drifts, which will serve as unheated access drifts where the heaters originate. The three drifts would be in the same horizontal plane. Distances between the drifts would be established to facilitate the model testing process and an accelerated testing schedule. A goal in the test planning is to develop sufficient heat for initial thermomechanical evaluations during the site characterization phase and that thermal stresses representative of repository operating conditions would be generated as early as three years after starting the heating.

The heated room experiment serves as a demonstration of the capabilities of welded tuff to sustain thermal stresses at a scale representing repository conditions. The accelerated heating is designed to reach stress conditions representative of 100 yr of emplacement. The measurements are to be used to test empirical and opening-support design models. Additional discussion of model validation activities is presented in Section 8.3.5.20.

Instrumentation will include thermocouples, multiple-point borehole extensometers, long-gage surface extensometers, borehole deformation gages, and possibly a neutron probe. If possible, flatjack-control system components of the thermal stress measurements system (Section 8.3.1.15.1.6.4) will be incorporated. Considerations will be made regarding the use of acoustic emission techniques to monitor rock-mass emissions in a spatial arrangement.

Methods and technical procedures

The methods and technical procedures for Activity 8.3.1.15.1.6.5 are given in the following table.

Method	Technical procedure		
	Number	Title	Date
Preparation of instrumentation holes	TP-001	Procedure for diamond-drilling holes for instrumentation	TBD[a]
Preparation of instrumentation holes	TP-002	Procedure for percussion-drilling holes for instrumentation	TBD
Rod extensometer measurements	TP-005	Procedure for installation and operation of rod extensometer	TBD
MPBX[b] measurements	TP-006	Procedure for installation and operation of MPBXs	TBD
Borescope observation	TP-014	Procedure for inspection of boreholes using a borescope	TBD
Use of borehole deformation gages	TP-017	Procedure for installation and operation of borehole deformation gages (BDGs)	TBD

Method	Technical procedure Number	Title	Date
Long-gage surface extensometer measurements	TP-018	Procedure for installation and operation of long-gage surface extensometers	TBD
Use of tiltmeters	TP-021	Procedure for installation and operation of tiltmeter	TBD
Definition of joint properties	TP-023	Procedure for characterization of fracture properties and geometries in thin slots	TBD
Use of thermocouples	TP-024	Procedure for thermocouple installation and operation	TBD
Heater operation	TP-026	Procedure for installation and operation of small-scale heater	TBD
	TP-027	Procedure for installation and operation of canister-scale heater	TBD
Acoustic emission observation	TP-029	Procedure for acoustic emission instrumentation installation and operation	TBD
Monitoring of pressure control systems	TP-033	Procedure for monitoring pressure control systems	TBD
Data acquisition	TP-034	Procedure for monitoring of data acquisition system	TBD
Monitoring of temperature control systems	TP-035	Procedure for monitoring temperature or heater control systems	TBD
Rockbolt installation	TP-037	Procedure for installation of rockbolt	TBD

Method	Technical procedure Number	Title	Date
Use of neutron probe	TP-039	Procedure for installation and operation of neutron probe for determination of moisture content	TBD
	TP-040	Procedure for installation and operation of neutron probe for density measurements	TBD

[a]TBD = to be determined.
[b]MPBX = multiple-point borehole extensometer.

8.3.1.15.1.7 Study: In situ mechanical properties

The objectives of this study are to obtain in situ measurements of the mechanical properties of the rock mass for unit TSw2. Mechanical properties include rock-mass deformability and evaluations of responses of single and multiple joints to controlled loadings. The numbers of experiments to obtain such properties will not fulfill requirements for confidence as expressed by performance and design issues. Therefore, the data will be used as preliminary indicators of rock-mass values and as checks of the validity of extrapolation of laboratory-determined data to in situ conditions. In addition, measurements of rock-mass deformation modulus in different locations will provide an estimate of spatial variability of rock-mass mechanical properties. Necessary information about fractures that is relevant to individual test locations (as well as to Yucca Mountain as a whole) will be gathered as part of Study 8.3.1.4.2.2.

8.3.1.15.1.7.1 Activity: Plate loading tests

Objectives

The objectives of this activity are to measure the deformation modulus of the rock mass and to evaluate the zone of increased fracturing adjacent to underground openings. Modulus data are to be used in thermomechanical calculations of the stresses and deformations induced by the presence of underground openings in unit TSw2 and overlying units and by the presence of heat-producing waste in unit TSw2. Characterization of the zone of increased fracturing will contribute to the definition of initial conditions, boundary conditions, and properties to be used in the calculations.

Parameters

The parameters for this activity are rock-mass deformation modulus, joint wall compressive strength, joint roughness coefficient, and spatial variability thereof.

Description

Plate-loading experiments will be performed at numerous (10 to 20) locations in the exploratory shaft facility and associated excavations both in unit TSw1 (upper demonstration breakout room) and in unit TSw2 at the main test level. Individual experiments will be performed with vertical and horizontal orientations at each location. Rock deformations will be measured using a multiple-point borehole extensometer (MPBX) oriented parallel to the load axis in the center of the plate area. Deformation of the loading column will be monitored using rod extensometers. Values of the rock deformation modulus will be calculated using the rock deformation and the applied stresses. Moduli from different stations will be compared to evaluate spatial variability within unit TSw2. These data primarily will be applicable to the material around an opening that has been affected by the presence of the opening and by the excavation process. As such, the moduli will represent lower bounds on the modulus of the undisturbed rock mass.

Borehole dilatometer measurements performed in association with overcoring experiments (Activity 8.3.1.15.2.1.2) will be used to obtain data on the borehole deformation modulus. These data will provide another measure of the spatial variability of in situ moduli.

Acoustic emission techniques will be used to detect rock-mass responses to the loadings with the goal of detecting spatial distributions of nonuniform emissions. Emission data will be helpful in interpreting any irregular mechanical responses of the rock mass to the loadings. If possible, rock bolt load cells will be attached to bolts in the nearby rock to serve the same purpose.

To aid in the interpretation of data obtained from these experiments, mechanical properties of the intact rock will be measured in the laboratory using core from instrumentation holes at each experiment location. In addition, joint wall compressive strength and joint roughness coefficient (Barton and Choubey, 1977) and joint geometry will be measured on joints near each experiment location. Frictional and stiffness properties of the joints may be used in the analysis of the plate-loading experiments. Such properties will be measured on site-specific samples if samples can be obtained. If no site-specific samples are available, data will be taken from the results of Activities 8.3.1.15.1.4.1 and 8.3.1.15.1.4.2.

Methods and technical procedures

The methods and technical procedures for Activity 8.3.1.15.1.7.1 are given in the following table.

Method	Technical procedure Number	Title	Date
Preparation of instrumentation holes	TP-001	Procedure for diamond-drilling holes for instrumentation	TBD[a]
	TP-002	Procedure for percussion-drilling holes for instrumentation	TBD
MPBX[b] measurements	TP-006	Procedure for installation and operation of MPBXs	TBD
Rock bolt load cell	TP-008	Procedure for installation and operation of rock bolt load cell	TBD
Borescope observation	TP-014	Procedure for inspection of boreholes using borescope	TBD
Flatjack operation	TP-022	Procedure for installation and operation of flatjacks	TBD
Definition of joint properties	TP-023	Procedure for definition of joint properties and geometries	TBD
Acoustic emission	TP-029	Procedure for installation and operation of acoustic emission instruments	TBD
Monitoring pressure control systems	TP-033	Procedure for monitoring pressure control systems	TBD
Data acquisition	TP-034	Procedure for monitoring of data acquisition system	TBD
Borehole dilatometer	TP-166	Borehole dilatometer testing	TBD

[a]TBD = to be determined.
[b]MPBX = multiple-point borehole extensometer.

8.3.1.15.1.7.2 Activity: Rock-mass strength experiment

Objectives

The objective of this activity is to evaluate the mechanical behavior of the rock mass or its components. Experiments will be performed to obtain information with regards to the mechanical strength of single joints and multiply jointed volumes of rock. It is envisaged that this experiment will be conducted in several areas that are representative of the range of conditions encountered in the exploratory shaft facility (ESF). The information will be used to evaluate potential scale effects between laboratory and in situ conditions, to provide data to evaluate empirical design criteria, and to provide data to evaluate and validate jointed-rock models.

Parameters

The following parameters will be obtained during this experiment: joint characteristics (including joint shear strength, joint wall compressive strength, and joint roughness coefficient), joint normal and joint shear deformation response, and rock mass deformation modulus.

Description

Rock-mass strength experiments will be conducted in several areas of the ESF. These areas have not yet been determined, but they will be chosen to be representative of the range of geologic conditions expected in the repository. Joint shear response will be measured on individual joints of a size of 70 by 70 cm as suggested in the International Society of Rock Mechanics Suggested Methods (ISRM, 1981). The shear strength experiments will provide data on the in situ joint shear strength as well as the normal and shear displacement response on in situ joints. This information will be used to evaluate jointed-rock models. The rock-mass strength portion of this experiment will measure the uniaxial load-bearing capacity of large blocks (up to 1 by 1 by 2 m) of rock that include multiple joints. This will provide data on the behavior of multiple joints to compressive loads and will be used to evaluate jointed-rock models and to evaluate empirical rock-mass strength relationships such as those developed by Hoek and Brown (1980). The rock-mass strength portion of this experiment will be similar to other large-scale in situ compression tests (Jahns, 1966; Bieniawski, 1968; Pratt et al., 1972; Wagner, 1975). The block of rock will be cut using hydraulic chain saws (Zimmerman et al., 1987) and the compressive loads will be applied through high-pressure flatjacks being developed at Sandia National Laboratories.

Methods and technical procedures

The methods and technical procedures for Activity 8.3.1.15.1.7.2 are given in the following table.

Method	Technical procedure Number	Title	Date
Preparation of instrumentation holes	TP-001	Procedure for diamond-drilling holes for instrumentation	TBD[a]
Preparation of instrumentation holes	TP-002	Procedure for percussion-drilling holes for instrumentation	TBD
MPBX[b] measurements	TP-006	Procedure for installation and operation of MPBXs	TBD
Borescope observations	TP-014	Procedure for inspecting boreholes using a borescope	TBD
Slot cutting	TP-015	Procedure for slot cutting with 2-m chain saw in the floor	TBD
	TP-016	Procedure for slot cutting with 2-m chain saw in the rib	TBD
	TP-030	Procedure for slot cutting with 1-m chain saw in the floor	TBD
	TP-031	Procedure for slot cutting with 1-m chain saw in the rib	TBD
	TP-032	Procedure for slot cutting with 1-m chain saw in the back (roof)	TBD
Use of long-gage surface extensometer	TP-018	Procedure for installation and operation of long-gage surface extensometers	TBD
Use of surface strain gages	TP-020	Procedure for installation and operation of surface strain gages	TBD

Method	Technical procedure Number	Title	Date
Use of flatjacks	TP-022	Procedure for installation and operation of flatjacks in thin slots	TBD
Definition of joint properties	TP-023	Procedure for characterization of fracture properties and geometries in thin slots	TBD
Acoustic emission measurements	TP-029	Procedure for installation and operation of acoustic emission instruments	TBD
Monitoring of pressure control systems	TP-033	Procedure for monitoring pressure control systems	TBD
Data acquisition	TP-034	Procedure for monitoring of data acquisition system	TBD
Sampling methods	TP-045	Procedure for sampling methods	TBD

[a]TBD = to be determined.
[b]MPBX = multiple-point borehole extensometer.

8.3.1.15.1.8 Study: In situ design verification

The objectives of this study are to (1) investigate the effects of the spatial variability of the rock on drift stability, mining activities, and ground supports; (2) evaluate techniques for underground excavation and ground support, for selecting ground supports to be used in different rock types, and for monitoring drift stability; (3) quantify the emanation of radon into repository drifts and observe its dispersion with airflow, and (4) measure parameters needed to design repository ventilation systems.

8.3.1.15.1.8.1 Activity: Evaluation of mining methods

Objectives

The objective of this experiment is to develop recommendations for mining in the repository by monitoring and evaluating mining activities in the exploratory shaft facility, and by conducting mining investigations.

Parameters

This activity does not include measurement of any geomechanical parameters.

Description

Mining methods in ES-1 and in the long exploratory drifts will be monitored. Particular attention will be given to the effects of the spatial variability of the rock. Items to be monitored during mining include equipment performance, blast patterns, explosives and detonators used, cycle times, and quantities of water used. Results of mining to be evaluated include characteristics of the excavated spaces (including geologic mapping), rubble size distributions, and effects of blasting on the surrounding rock. Mining investigations will be concentrated in the repository-scale portions of the long drifts and will include particle velocity measurements, segmented blasting of rounds, and examination of blast-induced damage in boreholes.

Methods and technical procedures

The methods and technical procedures for this experiment are listed in the following table.

Method	Technical procedure		
	Number	Title	Date
Ground motion monitoring	TP-009	Procedure for installation and operation of accelerometers	TBD[a]
Evaluating depth of fracturing	TP-014	Procedure for inspection of boreholes using a borescope	TBD
Blasted rock characterization	TP-038	Procedure for blasted rock sorting and size evaluation	TBD

[a]TBD = to be determined.

8.3.1.15.1.8.2 Activity: Monitoring of ground-support systems

Objectives

The objective of this experiment is to develop recommendations for a ground-support methodology to be used in drifts in the repository, based on evaluations of the ground-support methodology used in the exploratory shaft facility (ESF), and on experimentation with other ground-support configurations. Recommendations will be made for support systems to be used, as well as for methods of selection of supports that are appropriate for the ground conditions encountered.

Parameters

This activity includes compiling parameters used to classify the rock mass in order to select supports. These parameters might include rock quality designation, joint orientation, spacing, and characteristics, intact rock strength, and in situ stresses.

Description

Evaluation of ground-support systems will be carried out in the long drifts to enhance the measurements made in the main test area (Activity 8.3.1.15.1.5.2 and 8.3.1.15.1.5.3). The selection, installation, and performance of the support systems used will be monitored. Monitoring of the selection of ground-support systems will involve cataloging the parameters that are evaluated to classify the rock mass in order to select supports. Monitoring of the installation process will include documenting materials and equipment used, installation procedures and schedules, and support configurations. The performance of the supports will be measured in terms of rock-mass convergence, block movement and rock falls, required maintenance (all measured as part of Activity 8.3.1.15.1.8.3), loads on rock bolts and steel sets, and observed behavior of shotcrete or concrete. Results of other tests describing the performance of ground supports in the upper breakout room and around the main test area also will be considered in these evaluations.

Further experimentation with ground-supports in the long drifts will include rock-bolt pull tests, observation of unsupported rock, strength measurements on shotcrete cores, and trial deviations from the ESF-prescribed ground-support systems.

Complete assessments of ground-support systems for use in the repository must incorporate the results of this experiment with those of other experiments and analyses (Activity 8.3.1.15.1.6.5), because the drifts to be monitored will not be heated, and behavior must be predicted through the 100-yr operational life of the underground facility.

Methods and Technical Procedures

The methods and technical procedures for this experiment are listed in the following table.

Method	Technical procedure Number	Title	Date
Data acquisition	TP-034	Procedure for monitoring of data acquisition system	TBD[a]
Rock mass classification	TP-072	Procedure for determination of rock quality designation (RQD)	TBD
Ground-support monitoring	TP-184	Procedure for the instrumentation of rock bolts for strain	TBD
Strength testing of supports	TP-186	Procedure for pull-testing rock bolts	TBD
	TP-187	Procedure for strength-testing shotcrete	TBD

[a]TBD = to be determined

8.3.1.15.1.8.3 Activity: Monitoring drift stability

Objectives

The objectives of this experiment are to (1) provide confidence in predictions of usability of the repository underground facilities over their 100-yr operational life, (2) contribute to evaluations of the effectiveness of mining methods and ground-supports (Activities 8.3.1.15.1.8.1 and 8.3.1.15.1.8.2), (3) calibrate and refine criteria for determining stability of the openings, and (4) develop techniques for monitoring stability of the repository drifts.

Parameters

Representative amounts and rates of closure around drifts in the repository horizon will be established.

Description

This activity involves monitoring drift convergence and drift maintenance activities at the main test level. Instrumentation will be concentrated in the long drifts, although a limited number of convergence points may be set up in the main test area, and similar measurements that will be taken in other tests will be included in final evaluations.

Convergence measurements will be taken throughout the long drifts, in a continuous manner, if practical. Rock-mass relaxation will be investigated in the repository-scale portions of the long drifts using multiple-point borehole extensometers. Rock-mass performance will be considered in light of results from geologic mapping activities (Activity 8.3.1.4.2.2.4). Rock falls and maintenance activities will be documented through observations and with photographs.

Methods and technical procedures

The methods and technical procedures for this experiment are listed in the following table.

Method	Technical procedure Number	Technical procedure Title	Technical procedure Date
Preparation of instrumentation holes	TP-001	Procedure for diamond-drilling holes for instrumentation	TBD[a]
Borehole extensometer measurements	TP-006	Procedure for the installation and operation of MPBXs[b]	TBD
Data acquisition	TP-034	Procedure for monitoring of data acquisition system	TBD
Tape extensometer measurements	TP-193	Procedure for the installation and operation of tape extensometers	TBD

[a]TBD = to be determined.
[b]MPBX = multiple-point borehole extensometer.

8.3.1.15.1.8.4 Activity: Air quality and ventilation experiment

Objectives

The objectives of this experiment are to (1) measure the rate of radon emanation from the repository host rock and (2) evaluate parameters and variables needed as input to or for testing of the models to be used for design of the ventilation systems in the repository underground facility.

Parameters

The rate of radon emanation from the repository host rock will be evaluated. Air flow velocity, air pressures, air temperature, humidity, air resistance factors, dust concentrations and dust characteristics will be evaluated.

Description

This activity consists of five separate items: (1) radon emanation measurements, (2) surveys of airflow velocity and pressure and of temperature and humidity, (3) determination of the heat transfer coefficient for the rock to the air, (4) determination of air resistance factors, and (5) dust characterization.

The radon emanation measurements will be made in a dead-end drift that has been sealed with a bulkhead, allowing the radon gas to come into equilibrium with its short-lived daughter products. Measurements possibly will be made in a borehole as well. The sealed drift will be repeatedly ventilated and then allowed to return to equilibrium in order to establish relationships between airflow and concentrations of radon and radon daughters.

Items 2, 4 and 5 in this activity will be performed with portable instruments over periods of a few days each. They are not expected to interfere significantly with other underground activities. Item 3 will be performed either by estimating a value for the heat transfer coefficient using information from literature sources or inferring a value based on the data gathered from item 2.

Methods and technical procedures

The methods and technical procedures for this activity are listed in the following table.

Method	Technical procedure Number	Technical procedure Title	Technical procedure Date
Radon measurements	TP-028	Procedure for installation and operation of instrumentation for monitoring radon emanations	TBD[a]
	TP-188	Procedure for conducting radon measurements using the Lucas flask method	TBD
	TP-189	Procedure for operation of instant working level meter	TBD

Method	Technical procedure Number	Title	Date
Environmental measurements	TP-172	Procedure for measuring ventilation air velocity	TBD
	TP-190	Procedure for measuring barometric pressure	TBD
	TP-191	Procedure for measuring differential air pressures	TBD
	TP-192	Procedure for measuring air temperatures and relative humidity	TBD
	TP-194	Procedure for determining heat transfer coefficient	TBD
Dust measurements	TP-170	Procedure for monitoring dust generated during mining	TBD
Data acquisition	TP-034	Procedure for monitoring of data acquisition system	TBD

[a]TBD = to be determined

8.3.1.15.1.9 Application of results

The information obtained from the studies and activities described in the preceding sections will be used in the resolution of the issues listed in Table 8.3.1.15-1. As discussed earlier, the process may be an interactive one, so that interaction between testing, performance assessment, and design functions may be necessary before the investigation is complete. Data will be used in computer analyses of thermal and mechanical responses of the rock mass to a repository, as well as in more empirical evaluations of such topics as required ground support and stand-up time of underground openings. Results from this study will be used to periodically update the thermal and mechanical property data contained in the Reference Information Base (RIB) for the Yucca Mountain Project. A brief description of the RIB is provided in Section 6.1.2.

8.3.1.15.2 Investigation: Studies to provide the required information for spatial distribution of ambient stress and thermal conditions

Technical basis for obtaining the information

Link to the technical data chapters and applicable support documents

The following sections of the SCP provide a summary of available data relevant to ambient stress and thermal conditions and identify areas of insufficient or inconclusive information:

SCP section	Subject
1.3.2.3	Existing stress regime
1.3.2.5	Geothermal regime
1.8.1	Summary of significant results (geology)
1.8.2	Relation to design (geology)
2.4.2	Thermal and thermomechanical properties of rock at the site (intact rock)
2.5.2	Thermal and thermomechanical properties of rock at the site (large scale)
2.6.1	Stress regime in region of the site
2.6.2	Stress regime at the site

Parameters

Table 8.3.1.15-1 summarizes the information and parameters required for resolution of design and performance assessment issues.

Purpose and objectives of the investigation

The performance allocation process as implemented by performance assessment and design has identified performance measures and goals. To determine whether the performance goals can be met, data must be available on various site parameters, and the data must have associated levels of confidence. The parameters and associated confidence levels are identified in the performance assessment and design issues and serve as the basis for planning of a site characterization program.

Table 8.3.1.15-1 provides a detailed comparison of the information required by performance assessment and design issues on ambient in situ stress and temperature conditions with the activities planned to acquire site characterization data on these conditions. Figure 8.3.1.15-1 shows the general link between site characterization and the issues requiring data, and Figure 8.3.1.15-3 depicts the detailed logic for completion of Investigation 8.3.1.15.2. Completion of the activities shown in Figure 8.3.1.15-3 and discussed in the following pages will provide all required information on ambient in situ stress and temperature conditions required by performance assessment and design.

Technical rationale for the investigation

The data requirements summarized in Table 8.3.1.15-1 are straightforward. For ambient stress conditions, determination of the principal stresses and the spatial variability thereof will provide the required information. For ambient thermal conditions, measurement of the in situ temperatures and the spatial variability thereof will satisfy the requirements. In addition, heat flow data may be used as a check on the internal consistency of models of heat and water flow at Yucca Mountain.

8.3.1.15.2.1 Study: Characterization of the site ambient stress conditions

The objective of this study is to characterize the ambient (prerepository) state of stress of the Yucca Mountain host rock and surrounding units for use as initial conditions for geomechanical models used in the design and performance assessment of the repository underground facilities.

8.3.1.15.2.1.1 Activity: Anelastic strain recovery experiments in core holes

Objectives

The objective of these experiments using samples from core holes is to determine the horizontal stresses at Yucca Mountain and especially the spatial variability thereof. In situ stress data will contribute to definition of initial and boundary conditions for mechanical and thermomechanical analyses.

Parameters

The parameters to be determined during these experiments are the magnitude and orientation of the minimum and maximum horizontal stresses. In addition, values of Young's modulus and Poisson's ratio will be obtained on the samples to enable stresses to be calculated from measured strains.

Description

The anelastic strain recovery method of obtaining in situ stress data involves measurement of biaxial strains on core immediately after the core is removed from the core hole. Oriented core is used for the measurements. A viscoelastic model is used with the magnitude and orientation of the measured strains to calculate in situ stresses. The technique assumes that partial recoverable strain is proportional to the total recoverable strain, that the recovery behavior is linearly viscoelastic, and that the material is either isotropic or transversely isotropic. A comparison of the technique with hydraulic fracturing is presented in Teufel and Warpinski (1984).

This technique may be used in several of the new core holes at Yucca Mountain. Suitable core (i.e., unfractured and with limited lithophysae) will be measured, with the following experiment distribution in each hole:

Thermal/mechanical unit	Number of experiments
TCw	1 (if feasible)
PTn	1 (if feasible)
TSw1	2-3
TSw2	2-3
TSw3	0
CHn1v	1
CHn1z	1

The number and distribution of experiments are designed to examine both vertical and horizontal variability of in situ stress while minimizing the total number of experiments. After strains are measured on a specific interval, the core will be deformed in the laboratory to obtain Young's modulus and Poisson's ratio data with which to calculate the stresses from the measured strains.

The applicability of the technique to welded tuffs removed from relatively shallow depths (<500 m) will be evaluated by prototype testing in the Grouse Canyon Member in existing excavations in Rainier Mesa at the Nevada Test Site. The experimental program just outlined will be conducted only if the experiment results in the Grouse Canyon Member indicate that useful data are likely to be obtainable at Yucca Mountain.

Methods and technical procedures

The methods and technical procedures for Activity 8.3.1.15.2.1.1 are given in the following table.

Method	Technical procedure		
	Number	Title	Date
Anelastic strain recovery	TP-073	Procedure for determining in situ stress using anelastic strain recovery method	TBD[a]

Method	Technical procedure Number	Title	Date
Laboratory deformation measurements	TP-074	Procedure for laboratory measurements in support of anelastic strain recovery method	TBD

[a]TBD = to be determined.

8.3.1.15.2.1.2 Activity: Overcore stress experiments in the exploratory shaft facility

Objectives

The primary objectives of these experiments are (1) to determine the in situ state of stress above, within, and below the repository host rock in that portion of the repository block penetrated by the exploratory shaft (ES) and (2) to evaluate the extent to which the ambient stress conditions are redistributed adjacent to excavations. In situ stress data will contribute to definition of initial and boundary conditions for mechanical and thermomechanical analyses.

Parameters

The parameters of this activity are in situ stresses and spatial variability thereof.

Description

Overcoring tests to measure stresses in two dimensions will be done at three levels in the ES in connection with the shaft convergence experiment (Activity 8.3.1.15.1.5.1). At each level, a 10-m-long EX-size pilot hole will be drilled downward from the center of the shaft. At least three overcore stress experiments using borehole deformation gages (BDG) will be conducted in each pilot hole; overcoring will produce 14.6-cm diameter hollow core. Strain measurements will be completed on the recovered core before it is tested in a biaxial pressure chamber. This testing will be conducted to obtain a deformation modulus with which to calculate stresses from the strain data observed in situ.

A separate set of overcoring experiments, to measure stresses in three dimensions, will be performed in lateral excavations from the ES. Holes will be drilled laterally both at the upper breakout level and at the main test level. Drillholes also will be located in a drilling alcove excavated laterally from the ES at the Calico Hills test level in the nonwelded and zeolitized tuffaceous beds of the Calico Hills (unit CHn1z). Three types of core holes will be included in these experiments. First, 76-mm-diameter

(NX-size) holes will be cored to a depth of 15 m to examine fracture characteristics in the vicinity of the overcoring experiments. Then, 38-mm-diameter (EX-size) pilot holes will be cored beginning at or near the excavation boundary, and 15.2-cm-diameter core barrels will be used to overcore the pilot holes. Actual drillhole configurations and orientations may change, depending on local geologic conditions (fracturing, lithophysal content). At each location, overcoring will extend up to 15 m radially into the rock mass from the edge of the excavation.

Each core hole involved in the overcoring work will be surveyed for fractures by a borehole video camera. The fracture surveys are intended to provide data on the location, distribution, orientation, spacing, apertures, and infilling of the fractures at each location and to assist in placement of BDGs in the pilot holes. Borehole dilatometer experiments will be conducted in the 76-mm (NX) core holes to obtain estimates of the rock-mass deformation modulus and its variability along the length of each hole.

The number of locations at which overcoring will be performed at the main test level will depend on spatial variability of in situ stress.

Methods and technical procedures

The methods and technical procedures for Activity 8.3.1.15.2.1.2 are given in the following table.

Method	Technical procedure		
	Number	Title	Date
Borehole drilling and coring	TP-001	Procedure for diamond-drilling holes for instrumentation	TBD[a]
Borehole video surveys	TP-014	Procedure for inspection of boreholes using a borescope	TBD
Borehole dilatometer measurements	TBD	Borehole dilatometer measurements	TBD
Overcoring	TP-003	Procedure for overcoring for stress measurement	TBD
Installation and use of borehole deformation gauges	TP-017	Procedure for installation and operation of borehole deformation gauge	TBD
Field biaxial stress testing	TP-004	Procedure for biaxial stress measurement	TBD

Method	Technical procedure Number	Title	Date
Rock fabric analysis	TBD	Procedure for characterization of fracture properties and geometries in thin slots	TBD
Low-volume hydrofracturing stress measurements	TBD	Low-volume hydrofracturing stress measurements	TBD

[a]TBD = to be determined.

8.3.1.15.2.2 Study: Characterization of the site ambient thermal conditions

The objective of this study is to characterize the ambient (pre-repository) temperature of the Yucca Mountain host rock and surrounding units for use as initial conditions for thermomechanical models used in the design and performance assessment of the repository underground facilities.

8.3.1.15.2.2.1 Activity: Surface-based evaluation of ambient thermal conditions

Objectives

The objectives of this activity are (1) to measure in existing wells the spatial variation of temperature with depth and to provide baseline temperatures within the repository host rock and surrounding units, (2) to measure thermal conductivity (near 25°C) of core samples as a check on independent thermal property determinations at various temperatures, and (3) to determine heat flow at Yucca Mountain.

Parameters

The parameters of this activity are ambient temperature and spatial variability thereof and thermal conductivity.

Description

Temperature logs will be obtained in all available wells at Yucca Mountain and in the surrounding area. Temperatures will be logged at 0.3-m depth intervals below the water table and in water-filled casing above the water table. In air-filled casing above the water table, temperatures will be measured at 30-m intervals because of long-time constants. In all instances, calibrated thermistor probes will be used. Temperature profiles and cross sections will be prepared.

Thermal conductivities will be measured on cores (in conjunction with Activity 8.3.1.15.1.1.3) or drill cuttings. In addition, least-squares analyses will be performed on nearly linear segments of temperature profiles and combined with the thermal conductivities to determine the near-surface heat flow and its variation, both vertically and laterally, within and around the proposed repository location.

Methods and technical procedures

The methods and technical procedures for Activity 8.3.1.15.2.2.1 are given in the following table.

Method	Technical procedure		
	Number	Title	Date
Borehole drilling and coring	TBD[a]	Borehole drilling and coring procedures	TBD
Drill-cutting and core sampling	TBD	Drill-cutting and core sampling	TBD
Borehole ambient temperature measurement	GPP-02, R0	Heat-flow studies related to nuclear waste storage investigations	11 Jan 82
Laboratory thermal conductivity measurement	GPP-02, R0	Heat-flow studies related to nuclear waste storage investigations	11 Jan 82
	GPP-10, R0	Rock property analysis of Yucca Mountain core samples	6 Jul 88

[a]TBD = to be determined.

8.3.1.15.2.3 Application of results

The parameters evaluated by the studies and activities of this investigation will be used for the following issues in the areas of performance assessment and repository design:

Issue	Subject
1.6	Ground-water travel time (Section 8.3.5.12)
1.11	Configuration of underground facilities (Postclosure) (Section 8.3.2.2)
1.12	Seal characteristics (Section 8.3.3.2)
4.4	Preclosure design and technical feasibility (Section 8.3.2.5)

8.3.1.15.3 Schedule for the thermal and rock properties program

The thermal and mechanical rock properties program includes two investigations, which contain ten studies. The schedule information for each study is summarized in Figure 8.3.1.15-4. This figure includes the study number and a brief description, as well as major events associated with each study. A major event, for purposes of these schedules, may represent the initiation or completion of an activity, completion or submittal of a report to the DOE, an important data feed, or a decision point. Solid lines on the schedule represent study durations and dashed lines show interfaces among studies as well as data transferred into or out of the thermal and mechanical rock properties program. The events shown on the schedule and their planned dates of completion are provided in Table 8.3.1.15-5.

The study-level schedules, in combination with information provided in the logic diagrams for this program (Figures 8.3.1.15-1, -2, and -3), are intended to provide the reader with a basic understanding of the relationships between major elements of the site, performance, and design programs. The information provided in Table 8.3.1.15-5 and Figure 8.3.1.15-4, however, should be viewed as a snapshot in time.

The overall program schedule presented here is consistent with the Draft Mission Plan Amendment (DOE, 1988a). The site characterization program will undergo a series of refinements following issuance of the statutory SCP. Refinements will consider factors both internal and external to the site characterization program, such as changes to the quality assurance program. Such refinements are to be considered in ongoing planning efforts, and changes that are implemented will be reflected in the semiannual progress reports. Summary schedule information for the thermal and mechanical rock properties program can be found in Sections 8.5.1.1 and 8.5.6.

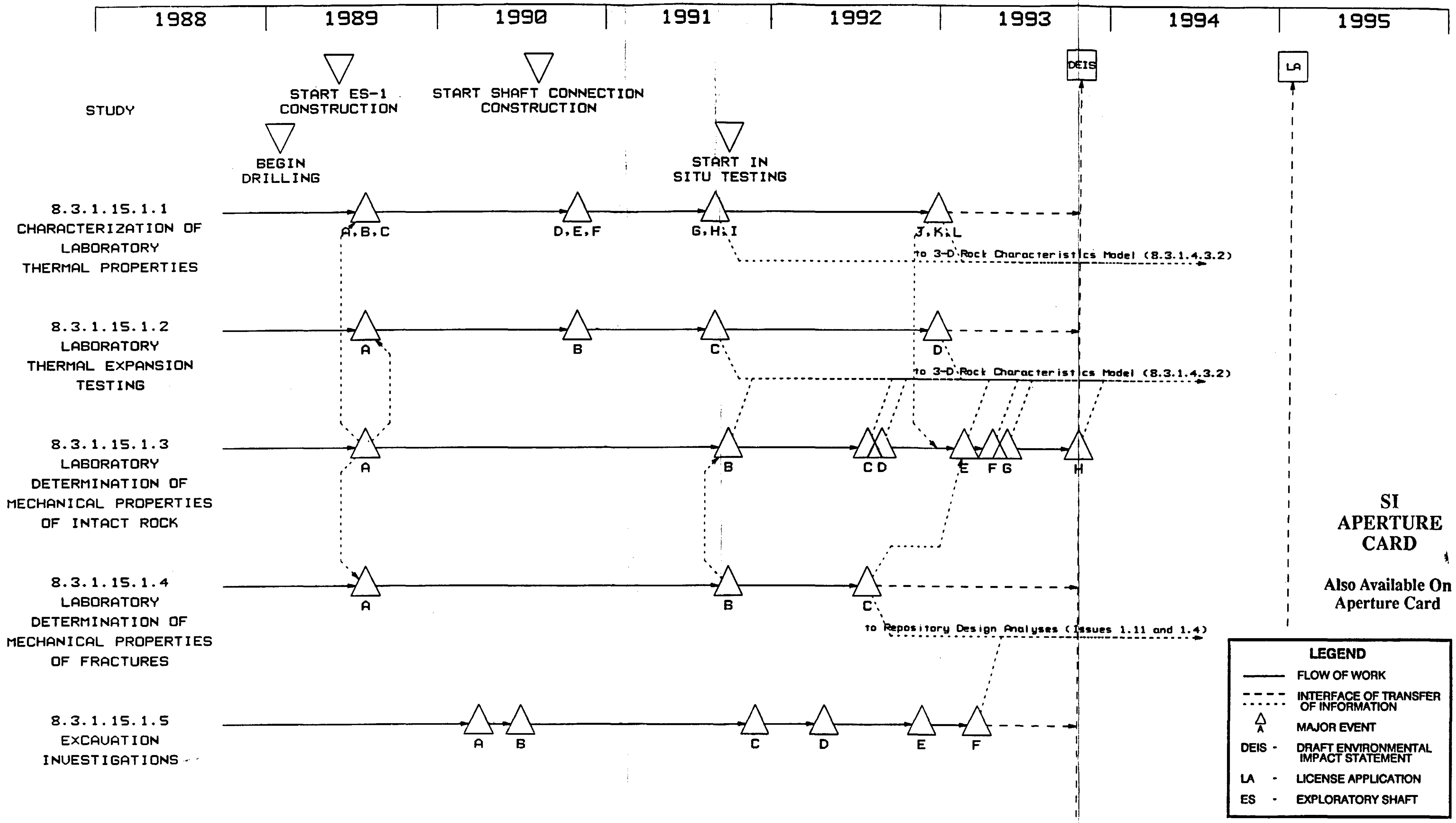


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Figure 8.3.1.15-4. Schedule information for studies in Site Program 8.3.1.15 (thermal and mechanical rock properties). See Table 8.3.1.15-5 for descriptions of major events. This network is consistent with the Draft Mission Plan Amendment (DOE, 1988a) schedule. Revisions will be published in semiannual site characterization progress reports as new information becomes available. (page 1 of 2)

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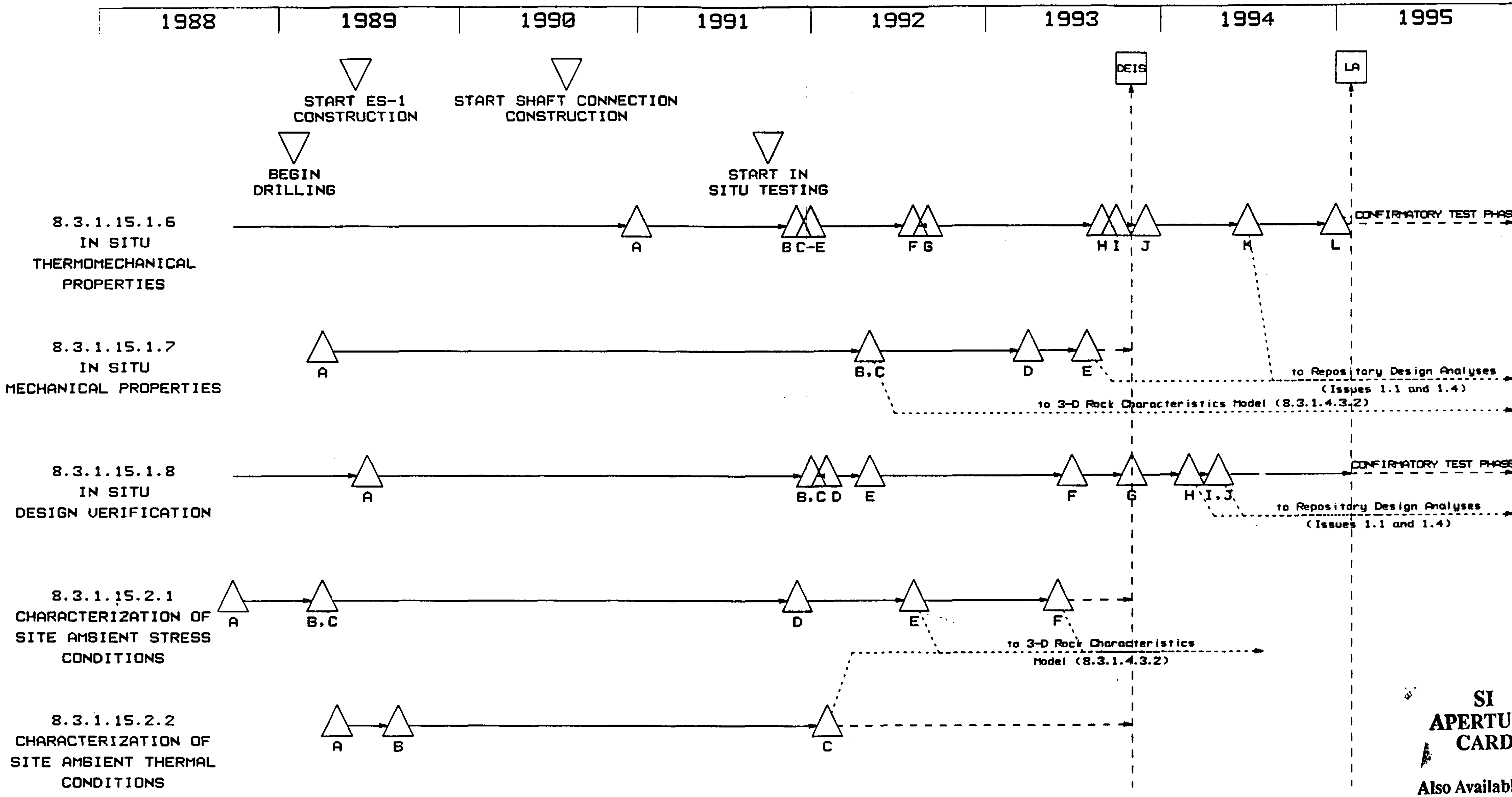

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Figure 8.3.1.15-4. Schedule information for studies in Site Program 8.3.1.15 (thermal and mechanical rock properties). See Table 8.3.1.15-5 for descriptions of major events. This network is consistent with the Draft Mission Plan Amendment (DOE, 1988a) schedule. Revisions will be published in semiannual site characterization progress reports as new information becomes available. (page 2 of 2)

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Table 8.3.1.15-5. Schedule information for studies in the thermal and mechanical rock properties program (page 1 of 10)

Study number	Brief description of study	Major event[a]	Event description	Date
8.3.1.15.1.1	Characterization of laboratory thermal properties	A	Begin density and porosity characterization as part of shaft construction phase testing	7/89
		B	Begin volumetric heat capacity determination as part of shaft construction phase testing	7/89
		C	Begin thermal conductivity characterization as part of shaft construction phase testing	7/89
		D	Begin density and porosity characterization as part of systematic drilling phase testing	10/90
		E	Begin volumetric heat capacity determination as part of systematic drilling phase testing	10/90
		F	Begin thermal conductivity characterization as part of systematic drilling phase testing	10/90
		G	Draft report available to the U.S. Department of Energy (DOE) on density and porosity characterization as part of shaft construction phase testing	8/91

Table 8.3.1.15-5. Schedule information for studies in the thermal and mechanical rock properties program (page 2 of 10)

Study number	Brief description of study	Major event[a]	Event description	Date
8.3.1.15.1.1	Characterization of laboratory thermal properties (continued)	H	Draft report available to DOE on volumetric heat capacity determination as part of shaft construction phase testing	8/91
		I	Draft report available to DOE on thermal conductivity characerization as part of shaft construction phase testing	8/91
		J	Draft report available to DOE on density and porosity characterization as part of systematic drilling phase testing	12/92
		K	Draft report available to DOE on volumetric heat capacity determination as part of systematic drilling phase testing	12/92
		L	Draft report available to DOE on thermal conductivity characterization as part of systematic drilling phase testing	12/92

Table 8.3.1.15-5. Schedule information for studies in the thermal and mechanical rock properties program (page 3 of 10)

Study number	Brief description of study	Major event[a]	Event description	Date
8.3.1.15.1.2	Laboratory thermal expansion testing	A	Begin thermal expansion characterization as part of shaft construction phase testing	7/89
		B	Begin thermal expansion characterization as part of systematic drilling phase testing	10/90
		C	Draft report available to DOE on thermal expansion characterization as part of shaft construction phase testing	8/91
		D	Draft report available to DOE on thermal expansion characterization as part of systematic drilling phase testing	12/92
8.3.1.15.1.3 (ongoing)	Laboratory determination of mechanical properties of intact rock	A	Begin laboratory testing of geoengineering properties	7/89
8.3.1.15.1.3 (ongoing)	Laboratory determination of mechanical properties of intact rock	B	Draft of final report on thermal, thermomechanical, and mechanical properties available to DOE	9/91

Table 8.3.1.15-5. Schedule information for studies in the thermal and mechanical rock properties program (page 4 of 10)

Study number	Brief description of study	Major event[a]	Event description	Date
8.3.1.15.1.3 (ongoing)	Laboratory determination of mechanical properties of intact rock	C	Draft of final report on parametric sensitivity of laboratory mechanical properties available to DOE	7/92
		D	Draft of final report on mechanical properties of lithophysal tuff available to DOE	8/92
		E	Interim report available to DOE on the results of rock mechanics testing	2/93
		F	Draft of final report on laboratory properties of material from lateral drifts available to DOE	4/93
		G	Draft of final report on the analysis of spatial variation of thermal and mechanical properties of intact rock available to DOE	5/93
		H	Complete rock mechanics data summary	10/93

Table 8.3.1.15-5. Schedule information for studies in the thermal and mechanical rock properties program (page 5 of 10)

Study number	Brief description of study	Major event[a]	Event description	Date
8.3.1.15.1.4	Laboratory determination of the mechanical properties of fractures	A	Begin determination of mechanical properties of fractures at baseline conditions	7/89
		B	Draft report available to DOE on mechanical properties of fractures at baseline conditions	9/91
		C	Draft report available to DOE on the effects of variable environmental conditions on the mechanical properties of fractures	7/92
8.3.1.15.1.5	Excavation investigations	A	Begin shaft convergence test	3/90
		B	Begin demonstration breakout room testing	6/90
		C	Begin sequential drift mining evaluations	11/91
		D	Draft report available to DOE on the results of shaft convergence tests	4/92

Table 8.3.1.15-5. Schedule information for studies in the thermal and mechanical rock properties program (page 6 of 10)

Study number	Brief description of study	Major event[a]	Event description	Date
8.3.1.15.1.5	Excavation investigations (continued)	E	Draft report available to DOE on the results of demonstration breakout room testing	11/92
		F	Draft report available to DOE on the results of sequential drift mining evaluations	3/93
8.3.1.15.1.6	In situ thermomechanical properties	A	Begin thermal stress test	12/90
		B	Begin heater experiment in TSw1	11/91
		C	Begin canister scale heater experiment	12/91
		D	Begin Yucca Mountain heated block experiment	12/91
		E	Begin heated room test	12/91
		F	Draft report available to DOE on thermal stress	7/92
		G	Draft of final report on results of the heater experiment available to DOE	8/92

Table 8.3.1.15-5. Schedule information for studies in the thermal and mechanical rock properties program (page 7 of 10)

Study number	Brief description of study	Major event[a]	Event description	Date
8.3.1.15.1.6	In situ thermomechanical properties (continued)	H	Draft report available to DOE on results of the heated block experiment	8/93
		I	Draft report available to DOE on model evaluation for the canister scale heater experiment	9/93
		J	Draft of preliminary report on results of the heated room experiment available to DOE	11/93
		K	Draft report available to DOE on results of the canister scale heater experiment	6/94
		L	Annual report on results of the heated room experiment available to DOE; the heated room experiment will continue as performance confirmation	1/95
8.3.1.15.1.7	In situ mechanical properties	A	Study plan approved	3/89
		B	Begin plate loading test	4/92
		C	Begin rock mass response experiment	4/92

Table 8.3.1.15-5. Schedule information for studies in the thermal and mechanical rock properties program (page 8 of 10)

Study number	Brief description of study	Major event[a]	Event description	Date
8.3.1.15.1.7	In situ mechanical properties (continued)	D	Draft of final report on the results of rock mass response experiment available to DOE	3/93
		E	Draft of final report on the results of plate loading testing available to DOE	7/93
8.3.1.15.1.8	In situ design verification	A	Begin evaluation of mining methods in ES-1	6/89
		B	Begin monitoring of drift stability	12/91
		C	Begin monitoring of ground support service systems	12/91
		D	Begin air quality monitoring	1/92
		E	Data report available to DOE on preliminary evaluations of shaft mining methods	4/92
		F	Data report available to DOE on the preliminary results from the air quality and ventilation experiment	6/93

Table 8.3.1.15-5. Schedule information for studies in the thermal and mechanical rock properties program (page 9 of 10)

Study number	Brief description of study	Major event[a]	Event description	Date
8.3.1.15.1.8	In situ design verification (continued)	G	Data report available to DOE on preliminary evaluations of mining methods in long lateral drifts	10/93
		H	Complete air quality and and ventilation experiment	2/94
		I	Report available to DOE on preliminary results from monitoring ground support systems	4/94
		J	Report available to DOE on preliminary results from monitoring drift stability; drift stability monitoring will continue as performance confirmation	4/94
8.3.1.15.2.1	Characterization of the site ambient stress conditions	A	Study plan approved	10/88
		B	Begin anelastic testing on surface core	3/89
		C	Data report available to DOE on preliminary anelastic strain recovery experiment results	3/89

Table 8.3.1.15-5. Schedule information for studies in the thermal and mechanical rock properties program (page 10 of 10)

Study number	Brief description of study	Major event[a]	Event description	Date
8.3.1.15.2.1	Characterization of the site ambient stress conditions (continued)	D	Begin overcore test	11/91
		E	Draft of final report on anelastic strain recovery testing available to DOE	7/92
		F	Draft report available to DOE on the results of in situ stress testing	5/93
8.3.1.15.2.2	Characterization of the site ambient thermal conditions	A	Study plan approved	4/89
		B	Begin ambient thermal test	8/89
		C	Draft report available to DOE on site ambient thermal conditions	1/92

[a]The letters in this column key major events shown in Figure 8.3.1.15-4.

DOE/RW-0199

Nuclear Waste Policy Act
(Section 113)

Site Characterization Plan

Yucca Mountain Site, Nevada Research and Development Area, Nevada

Volume V, Part B

Chapter 8, Section 8.3.1.16, Preclosure Hydrology

December 1988

U. S. Department of Energy
Office of Civilian Radioactive Waste Management

8.3.1.16 Overview of preclosure hydrology program: Description of preclosure hydrologic characteristics and conditions required by the performance and design issues

Summary of performance and design requirements for hydrology information

The preclosure hydrology test program addresses the requirements of performance and design issues. The hydrologic conditions, which include the potential for flooding, the availability of water for repository construction and operation, and the subsurface hydrologic conditions both within and above the repository horizon, must be examined to determine if engineering measures that require excessive cost, or technology beyond that which is reasonably available, will be needed.

The preclosure hydrology program (this section) and the geohydrology program (Section 8.3.1.2) will obtain specific data required for the design of the systems and components that are important to safety. The descriptions and analyses will consider the margins of safety under conditions that may result from expected operational occurrences, including those of natural origin such as flooding. These analyses must also consider the adequacy of structures provided for the prevention of accidents and mitigation of their consequences, including natural phenomena. Thus, information on the flash flood potential of the site is needed to aid in the design of the flood control measures, should they be required.

Four issues (Issues 1.11, 1.12, 4.2, and 4.4) request data from the preclosure hydrology program. The requests for hydrologic data can be summarized as follows:

1. Information required for Issue 4.4 (technical feasibility, Section 8.3.2.5) and Issue 4.2 (nonradiological health and safety, Section 8.3.2.4) relates to the potential for surface flooding. Flood frequency and magnitude data are needed for analyses being performed to determine the impacts of potential flooding on the design of the surface facilities.

2. The second type of data requested by Issue 4.4 are the parameters required to locate adequate and alternative sources of water for the repository. Current plans are to develop two new wells for repository water supply. In the event of well failures, an alternative source of water also must be available. Existing wells J-12 and J-13 could be adequate for repository-related water needs and will be considered in the evaluation for suitable alternative sources. Characteristics of aquifers proximal to the site will be evaluated to identify potentially suitable sources. Modeling studies in support of Activity 8.3.1.2.3.3.3 will determine the possible changes to the flow system that might result from withdrawals made from the wells supplying water for the repository and from the proposed alternative sources.

3. Issues 4.4 (technical feasibility, Section 8.3.2.5), 1.11 (configuration of underground facilities, Section 8.3.2.2), and 1.12 (seal characteristics, Section 8.3.3.2) require a description of the hydrologic conditions within and above the repository horizon. This

information is needed to estimate moisture content, flux, and potential moisture influx above and within the host horizon, as well as the potential for perched water zones, which will be used as input for the design of the repository, shaft liners, and seals.

Approach to satisfy performance and design requirements

The strategy of the preclosure hydrology program is to satisfy the requirements of design and performance issues. Three different types of preclosure hydrologic data have been identified by the design and performance issues: (1) flood frequency and magnitude, (2) water supply for repository-related water needs, and (3) subsurface hydrologic conditions at the site. These data requirements form the basis for the three investigations. Tables 8.3.1.16-1 and 8.3.1.16-2 list the parameters to be collected by this program, identify the issues that will use each parameter, and define the activities under which each parameter is to be collected. Figure 8.3.1.16-1 illustrates how the investigations of the preclosure hydrology program and the geohydrology program will obtain the data needed to satisfy the parameter requests of the design and performance issues.

The different types of data required will be obtained from three different investigations. Each investigation focuses on the specific type of data to be collected. Investigation 8.3.1.16.1 addresses the aspects of surface hydrology related to flood and debris hazards; Investigation 8.3.1.16.2 addresses the hydrologic and economic requirements of water supply; and Investigation 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, shafts, shaft liners 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) the ability to construct the repository using available technology and at reasonable cost.

Interrelationships of preclosure hydrology investigations

Three investigations have been developed to provide the necessary information for the preclosure hydrology program. Investigation 8.3.1.16.1 (flood recurrence intervals) will obtain data that will be used to define flood recurrence intervals, flood levels, and the probable maximum flood at potential locations for the surface facilities.

Study 8.3.1.16.1.1 (flood potential of the Yucca Mountain site) will evaluate flood potential by collecting peak streamflow data, assessing the debris movement in drainages at or near the Yucca Mountain site, and investigating geologic evidence of paleofloods. The character of selected channel and floodplain deposits will be examined to determine the nature of the fluvial processes involved in deposition. Field judgments of the nature and severity of debris transport by floods will be made to evaluate the characteristics of debris hazards posed by the floods. Pertinent engineering analytical techniques, including standard flood-frequency analysis techniques, will be applied to the data collected in the appropriate drainages. This will yield an estimate of the magnitude and frequency of future flood events. These standard flood-frequency analysis techniques will be used to determine

Table 8.3.1.16-1. Data requirements of the design and performance issues satisfied by the preclosure hydrology program for System Element 1.1.1 (surface)

SCP Issue requesting parameters	Design parameters	Goal	Confidence	Characterization parameters	Testing basis: Current estimate	Testing basis: Present confidence[a]	Testing basis: Confidence needed[b]	Studies/activities
4.4 Technical feasibility (Section 8.3.2.5) 4.2 Nonradiological health and safety (Section 8.3.2.4)	Surface hydrology at all surface facility locations Magnitude of 5, 25, 50, 100, 500 yr, and probable maximum floods Area and depth of inundation for facilities and access portals	Determine parameter values using ANSI and other standard applicable methods Define elevation of flood levels to ±2 m	High	Precipiation quantities and rates (from regional data)	Refer to Section 5.1	Low to moderate	High	8.3.1.16.1.1 (flood potential of Yucca Mountain)
				Streamflow rates, quantities, and durations (clear water	Refer to Bullard (1986)	Low	High	8.3.1.2.1.1 (regional meteorology) and 8.3.1.2.1.2 (runoff streamflow)
				Peak flow discharge for 5, 25, 50, 100, 500 yr, and probable maximum floods	Refer to Bullard (1986) and Squires and Young (1984)	Low to moderate	High	
				Channel morphology and surface topography	Refer to Squires and Young (1984) and Waddell et al. (1984)	Low to moderate	Moderate	
	Flow velocities Debris load of flows	Calculate maximum tractive force of channel flow and sheet flow in area of inundation	High	Quantity and character of debris moved during flooding	Refer to Costa (1983)	Very low	High	8.3.1.16.1.1 (flood potential of Yucca Mountain)
				Define water to sediment ratio	Refer to Costa (1983)	Very low	High	8.3.1.2.1.2 (runoff and streamflow)
				Characterize sediments within watershed	Refer to Costa (1983)	Very low	High	8.3.1.2.2 (unsaturated-zone hydrologic system)

[a]Present confidence ratings of high, moderate, and low are based on the quality of data and the number of site-specific measurements currently available.
[b]Confidence needed is an indication of the level of certainty that will be necessary to demonstrate that a goal is met.

Table 8.3.1.16-2. Data requirements of the design and performance issues satisfied by the preclosure hydrology program for System Element 1.1.2 (subsurface)

SCP Issue requesting parameters	Design parameters	Goal	Confidence	Characterization parameters	Testing basis: Current estimate	Testing basis: Present confidence[a]	Testing basis: Confidence needed[b]	Studies/activities
4.4 Technical feasibility (Section 8.3.2.5)	Sustained yield of wells	864,000 m^3/yr	Moderate	Aquifer transmissivity and storage coefficient	To be determined from well testing.	Medium	Moderate	8.3.1.16.2.1 (location of adequate water supply) and 8.3.1.2.3 (regional ground-water flow system)
1.11 Configuration of underground facilities (Section 8.3.2.2) 1.12 Seal characteristics (Section 8.3.3.2)	Water inflow to underground facility (including seasonal variation)	Quantify potential inflow rate (total into mine). Expected 0-20 gpm accuracy ±10	Moderate	Fracture flow into exploratory shaft facility	≤100 gpd	Low	Moderate	8.3.1.2.2.3 (surface based exploratory shaft testing), 8.3.1.2.2.4 (unsaturated-zone percolation), and 8.3.1.16.1.1 (flood potential of Yucca Mountain)

[a]Present confidence ratings of high, moderate, and low are based on the quality of data and the number of site-specific measurements currently available.
[b]Confidence needed is an indication of the level of certainty that will be necessary to demonstrate that a goal has been met.

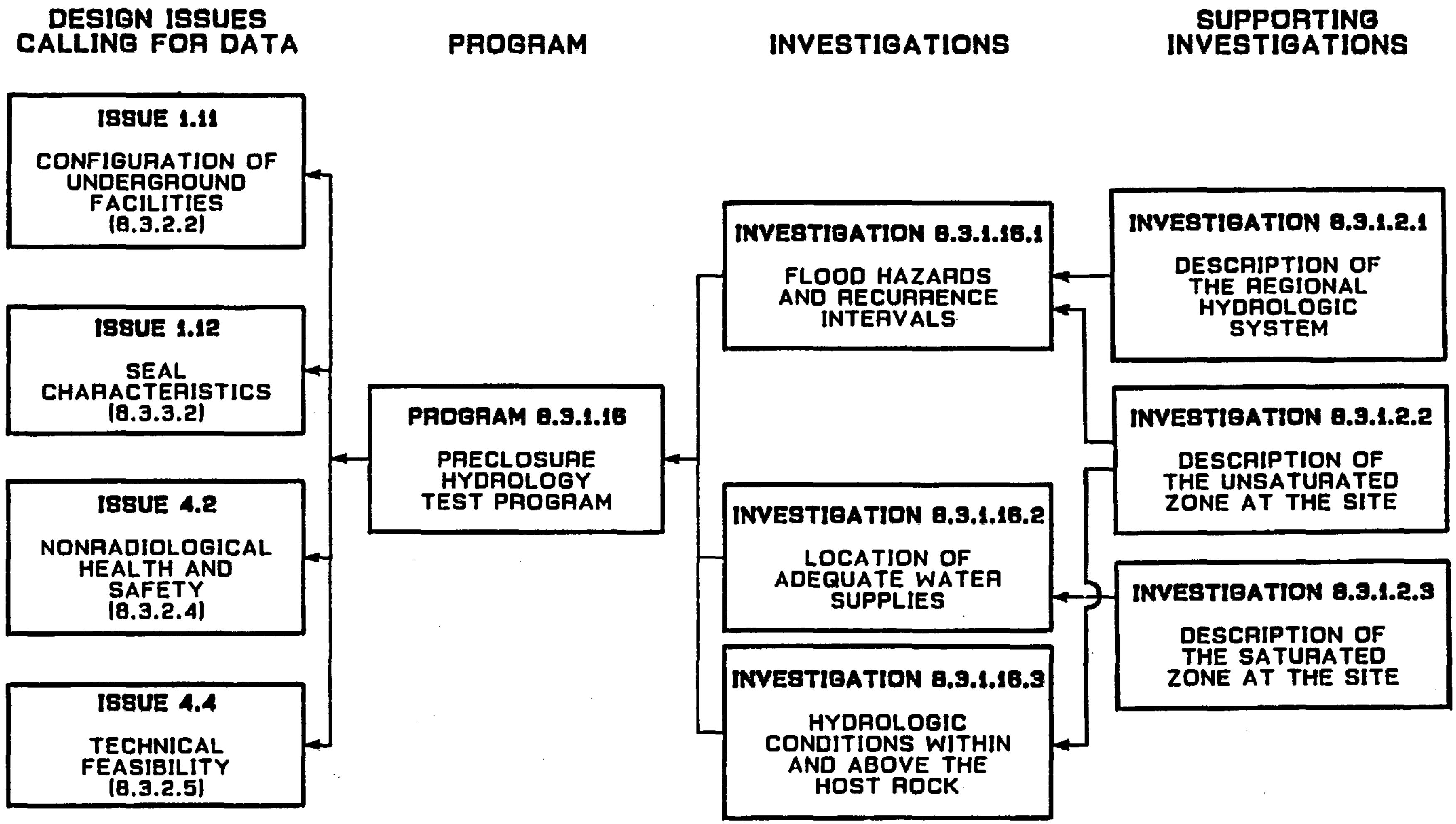

Figure 8.3.1.16-1. Relationship between the preclosure hydrology test program and its investigations.

design requirements for nonsensitive structures while more conservative flood-hazard design requirements will be used for sensitive structures such as shafts and waste-handling structures.

The specific parameters that have been defined for Study 8.3.1.16.1.1 are the maximum rates and quantities of precipitation, streamflow characteristics, flood flow and debris transport conditions, and the recurrence for runoff and flood events. By calculating flood recurrence intervals, and quantifying the probable maximum flood level, adequate design measures can be implemented to avoid and mitigate the hazards associated with flood events.

Investigation 8.3.1.16.2 (adequate water supplies) addresses the location of adequate water supply for repository construction, operation, and closure. Two subordinate concerns to this investigation are the location of an alternative water supply and the possibility of using wells J-12 and J-13 as the alternative wells.

The second study, Study 8.3.1.16.2.1 (adequate water supply for the mined geologic disposal system) consists of three activities. The parameters that will be evaluated include the hydraulic characteristics of aquifers located proximal to the site, the cost and feasibility of constructing new water wells and a distribution system, and the identification of the possible effects on the flow system that might result from water withdrawals made from the proposed primary wells or from the proposed alternative wells.

Investigation 8.3.1.16.3 (ground-water conditions) involves characterizing the unsaturated zone above and within the repository horizon to define the moisture conditions between the repository and the land surface.

Study 8.3.1.16.3.1 is primarily a synthesis activity. The characterization of the hydrologic conditions within and above the repository horizon will be accomplished by studies being performed in support of Investigation 8.3.1.2.2. Although the bases for addressing the investigations are different (repository design versus long-term performance assessment), the parameters that must be obtained to satisfy both of these investigations are the same. Information on flux, moisture content, and potential influx will be obtained from the geohydrology program (Section 8.3.1.2). The data collected under the geohydrology program will be compiled, analyzed, and evaluated under Activity 8.3.1.16.3.1.1, and will be used to define the moisture conditions at the site that are needed for design.

The schedule information for Site Program 8.3.1.16 (preclosure hydrology) is presented in Section 8.3.1.16.4.

8.3.1.16.1 Investigation: Flood recurrence intervals and levels at potential locations of surface facilities

Technical basis for obtaining the information

Link to the technical data chapters and applicable support documents

Section 3.2 summarizes the current information regarding flood history, the potential for future flooding, current and future studies of flood and debris hazards, and flood protection. Local convective storms coupled with the rugged terrain at Yucca Mountain can cause intense flash flooding to occur sporadically in dry washes that drain the mountain. The meteorology and climatology of the Yucca Mountain site and the region are discussed further in Section 5.1. Further evaluation of the flood potential of these washes is necessary to ensure adequate design of the surface facilities. Flood protection design considerations are discussed in Sections 6.2.4 and 3.10.2.

Parameters

The following parameters will be measured or calculated as a result of the site studies planned to satisfy this investigation:

1. Precipitation quantities and rates.

2. Streamflow rates, quantities, and durations.

3. Peak flood discharges.

4. Quantity and character of debris moved during floods.

5. Character of fluids moved during flooding (relative proportions of water and sediment).

6. Recurrence intervals for runoff and flooding.

Most of the data for these parameters are being, or will be, collected through the following studies:

Study	Subject
8.3.1.2.1.2	Characterization of regional surface water (surface-water runoff and fluvial transport of debris by floods)
8.3.1.5.2.1	Characterization of the Quaternary regional hydrology (regional paleofloods)
8.3.1.12.2.1	Meteorological data collection at the Yucca Mountain site

Purpose and objectives of the investigation

To meet the purpose of identifying the potential hazards associated with floods and debris movement, three objectives must be met: (1) to determine the magnitudes and frequencies of major flood events that can potentially occur during the period of repository operation, (2) to identify all potential areas of inundation, and (3) to determine the quantities and size characteristics of debris transported by flooding. Figure 8.3.1.16-2 illustrates how the activities of Study 8.3.1.16.1.1, in conjunction with activities of the geohydrology program, will obtain the required parameters.

Technical rationale for the investigation

Surface facilities such as roadways, building pads, and buildings to serve as workshops, offices, laboratories, and living spaces, must be located and designed for minimum natural disturbance during their intended life (approximately 100 yr) largely for safety and economic reasons. It is also critical that all surface sites for handling the waste packages, including buildings, storage areas, and repository access facilities such as shaft collar and hoisting structures, be located in an area where flood or debris-flow events would not have serious effects on their stability during the preclosure period. To accomplish this, flood and debris-hazard studies have been designed to document flooding and severe sediment erosion, transport, and deposition to aid in predicting the maximum flood intensities and recurrence intervals, which are necessary for the design of safe facilities.

In these studies, floods will be characterized by measuring the peak streamflows and generally assessing associated debris movement in drainages that are at or near the Yucca Mountain site. The surficial character of selected channel and floodplain deposits in the numerous ephemeral drainages will also be examined in an attempt to determine the nature of the fluvial processes involved in the emplacement of the deposits. Field judgments of the nature and severity of debris transport by floods will be made to evaluate properly the characteristics of debris hazards posed by the floods. Pertinent engineering-analytical techniques, including standard-flood-frequency-analysis techniques (e.g., the log-Pearson type III distribution), will be applied to the data collected in the drainages in question to estimate the magnitude and frequency of future floods. Using this approach, non-sensitive structures can then be designed by standard engineering methods of flood analysis, while the shaft and restricted-area facilities will use more conservative flood hazard design procedures.

Peak streamflow data at and around Yucca Mountain will be collected as part of Activity 8.3.1.2.1.2.1 (surface-water runoff monitoring). The analyses of these data will also incorporate data from nearby crest-stage gages that have been operative since the 1960s as part of the U.S. Geological Survey, Nevada Department of Transportation flood-study program. The field judgments of the nature and severity of debris transport by flood flows will be made as part of Activity 8.3.1.2.1.2.2 (transport of debris by severe runoff). Pertinent information from Activity 8.3.1.5.2.1.1 (regional paleoflood evaluation) will also be transferred to this activity for use in characterizing the flood and debris hazards.

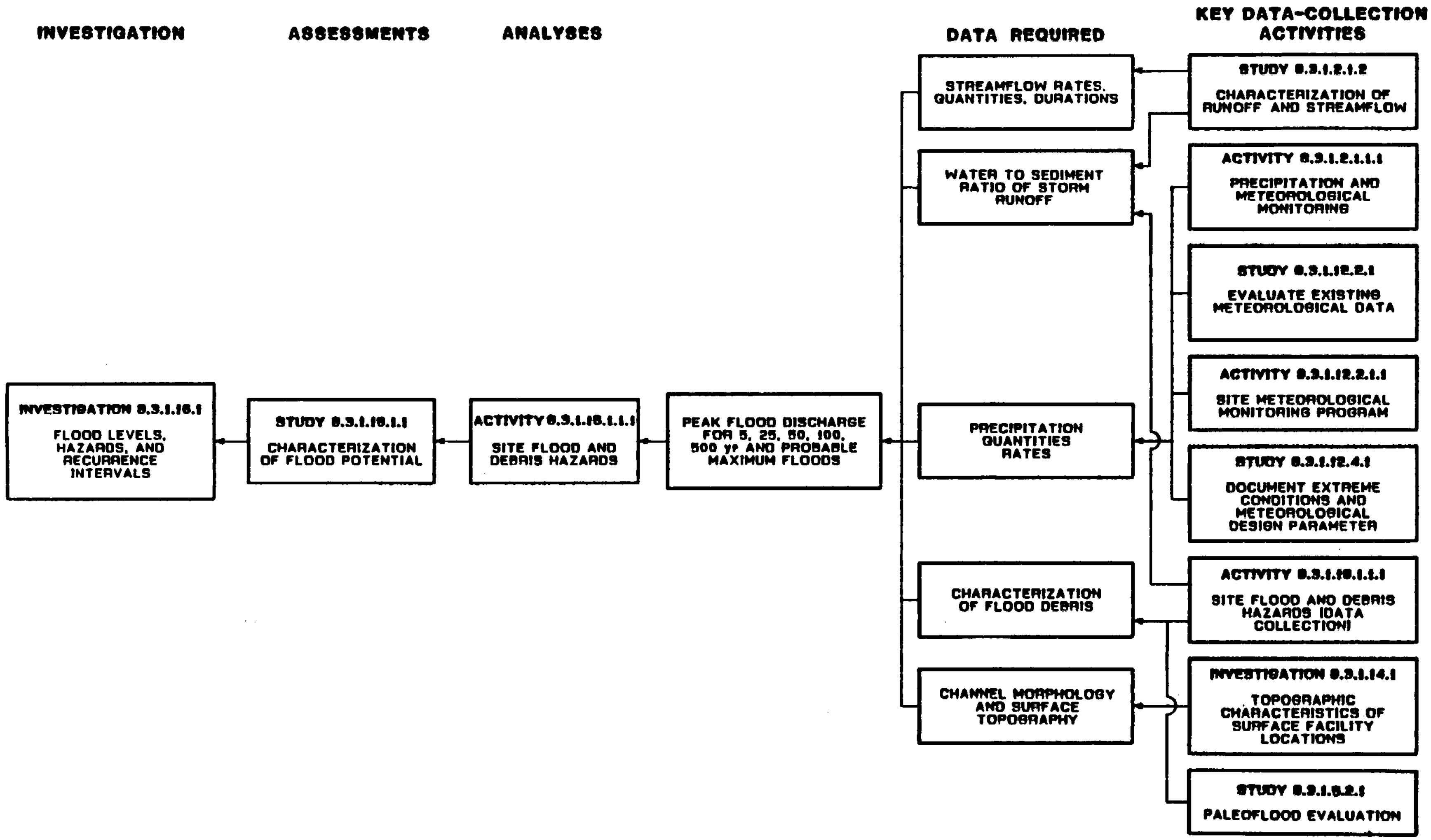

Figure 8.3.1.16-2. Logic diagram for Investigation 8.3.1.16.1 (flood recurrence intervals).

The techniques used to obtain this information will complement each other and also will allow a comparison of data to decrease data uncertainty. It is recognized that the short period of record for direct flow measurements will be inadequate to derive confident estimates of flood recurrence intervals larger than a few years. Therefore, this study will rely upon a combination of direct and indirect techniques. In areas where the flood recurrence and intensity analyses will have to be translated to surface facility sites where actual data may not have been collected, the geologic record of paleofloods will be used to temper the probability analyses for sensitive surface facilities. Trench studies of ancient deposits and morphologic studies of the area will be used to complement the peak streamflow measurements for determining the characteristic depths of flooding, depths of scour, characteristics of sediment load, and thickness of deposits formed in the past.

Section 8.3.1.5.2 describes paleoflood studies that will be used to augment this investigation. Initial trench studies suggest that paleoflood techniques may not be adequate to fully assess flood and debris hazards because of the lack of datable materials (e.g., organics, tephra, and soil formation). Thus, a dual strategy will be maintained to determine flood and debris hazards. Crest-stage data collection will continue indefinitely, and flood events will be documented if and when they occur. Data from these modern flood studies will be supplemented by information from paleoflood reconstruction activities to be performed as part of the geohydrology program (Section 8.3.1.2).

8.3.1.16.1.1 Study: Characterization of flood potential of the Yucca Mountain site

This study contains one activity and evaluates the potential for flooding in the many small, dry, desert washes that drain Yucca Mountain. This evaluation will be used for designing the surface facilities for the proposed repository. Proper design for flood potential is necessary to ensure the safety of the workers and the surface facilities.

8.3.1.16.1.1.1 Activity: Site flood and debris hazards studies

Objectives

The objective of this activity is to assess the flood and debris hazards at and near the potential repository surface facilities locations to allow adequate design of facilities to prevent or reduce hazards to an acceptable level.

Parameters

The parameters of this activity are

1. Precipitation quantities and rates.

2. Streamflow rates, quantities, and durations.

3. Peak flood discharge.

4. Quantity and character of debris moved during severe floods.

5. Character of fluids moved during flooding (relative proportions of water and sediment).

6. Recurrence intervals for runoff and flooding.

7. Channel morphology definition.

8. Surface topography.

Description

Floods will be characterized by measuring the peak streamflows and assessing the debris movement in drainages that are at or near the Yucca Mountain site. Streamflow measurements will be made as part of Activity 8.3.1.2.1.2.1 (surface-water runoff monitoring), which includes two stream gage networks: one at the regional scale and one specific to Yucca Mountain. Surface runoff monitoring at Yucca Mountain is needed to provide detailed data for the study of natural infiltration (Activity 8.3.1.2.2.1.2 of Investigation 8.3.1.2.2, the unsaturated zone hydrologic system at the site). Many stream gages, rain gages, and some automated fluvial-sediment samplers situated at strategic locations will be used. Streamflow documented by the stream gage networks will be incorporated into the pertinent flood-prediction analyses. Twenty-five to fifty small drainages may be included in this study effort. Pertinent flood data and precipitation data from drainages throughout the southern Nevada region will be incorporated into analyses of flooding at and around Yucca Mountain.

The surface character of selected channel and floodplain deposits in the numerous ephemeral drainages in and around the proposed storage site will be examined to determine the fluvial processes involved in the emplacement of the deposits. If this reconnaissance discloses a variety of processes or significant variations within any process, an attempt will be made to differentiate the processes and degrees of differences. The results of this effort may then determine whether the variations in the characteristics of the deposits can or should be shown on surficial deposit maps of the drainages.

As part of Activity 8.3.1.2.1.2.2 (transport of debris by severe runoff), field judgments of the nature and severity of debris transport by flood flows will be evaluated to determine the characteristics of debris hazards from flood flows. No standard techniques are available to sample moving coarse-grained debris, which constitutes the major debris hazard, but flood investigators will describe both qualitatively and somewhat quantitatively (by careful field observations) the character of debris that has moved within and through the drainage during severe runoff events. Also, some debris movement characteristics will be deduced through analysis of the debris deposits. Fresh erosion that has resulted from recent flooding will be noted on maps to allow an assessment of potential slope instability. Assembling this type of semiquantitative information will, with time and experience, form the bases for designating the degrees of debris hazards on different types of slopes. Much of the debris hazard assessment is experimental at this time, and more precise investigative plans cannot be formalized until experience with debris movement during flooding increases.

After a reasonable amount of experiences and data are gained through field investigations, laboratory experiments would seem to be the next logical step in the study process. However, laboratory efforts are not planned at this time. Scaling problems associated with laboratory models may be insurmountable, and the technology of physical modeling of debris movement is not sufficiently advanced to be a reliable alternative or supplement to the planned activities.

Pertinent engineering analytical techniques, including standard-flood-frequency-analysis techniques, will be applied to the data collected in the drainages in question to estimate future flood flows. Several computational or graphic techniques are available to estimate probable peak flood flows.

In one graphic technique, a maximum envelope curve defines the largest floods measured for variously sized drainage basins (Crippen and Bue, 1977). Thus, for a given size of drainage, the curve predicts the largest flood that would be expected on the basis of historical evidence of the largest observed floods for drainages of comparable size within the same geographic region.

Another widely used technique in the nuclear industry is the computational determination of the probable maximum flood (PMF) (ANSI/ANS 2.8-1981). This computational procedure is based on the U.S. National Weather Service estimates of probable maximum precipitation that can be expected throughout a specific geographical area. Neither of these techniques takes into account debris transport that may pose a serious hazard associated with a flood.

A computational technique based on field evidence has been proposed (Costa, 1983). In this technique, the average size of the five largest boulders deposited in the channel by fluid flows is determined. A velocity capable of moving particles of that size is computed, and physical surveys of the stream channel in the reach of the deposits are used to help assess the area of the flow section. Then the product of the velocity and the flow-sectional area determines the discharge necessary to move the largest particles. Application of the technique thus yields an estimate of the peak flood discharge that emplaced the largest debris fragments.

Flood frequencies and recurrence intervals may be evaluated with the log-Pearson type III curve, The log-Pearson type III is a theoretical, flexible frequency distribution computed by calculating the mean, standard deviation, and skewness coefficient of the logs of peak annual discharge data. A frequency factor is obtained from tables of skewness coefficients and exceedance probabilities. Regional values of the skewness coefficients are available.

Other similar techniques, if available, will also be applied to the drainages of concern. Flow predictions resulting from these applied techniques can then be compared, and a prediction of peak flood flows can result from the comparisons.

Methods and technical procedures

The methods and technical procedures for Activity 8.3.1.16.1.1.1 are given in the following table.

Method	Technical procedure Number	Title	Date
Flood characterization	TBD[a]	No technical procedures identified	TBD
Debris transport characterization	TBD	Techniques for mapping surficially exposed fluvial deposits	TBD
Assessment of potential future flooding	TBD	Method for carbon-13 determination	TBD
Assessment of debris hazards associated with potential future flooding	TBD	No technical procedures identified	TBD

[a]TBD = to be determined.

8.3.1.16.1.2 Application of results

The information derived from the studies and activities of the plans described previously will be used in the following areas of site characterization, repository design, and performance assessment:

Investigation or information need	Subject
8.3.1.2.1	Regional hydrologic system
8.3.1.6.1	Present locations and rates of surface erosion
8.3.1.9.1	Degradation of markers
4.4.1	Site and performance assessment information needed for design (Section 8.3.2.5.1)

Investigation or information need	Subject
4.4.7	Design analyses including potential impacts of hydrologic characteristics on design (Section 8.3.2.5.7)
4.4.8	Technology for surface facilities (Section 8.3.2.5.8)

8.3.1.16.2 Investigation: Location of adequate water supplies

Technical basis for obtaining the information

Link to the technical data chapters and applicable support documents

Section 3.8 summarizes current information on the estimated quantity of water needed to support a mined geologic disposal system at Yucca Mountain.

Parameters

Three sets of parameters will be measured or calculated as a result of the site studies planned to obtain the information needed as follows:

1. Cost and feasibility of using wells J-12 and J-13 for repository-related water use as an alternative source.
2. Identification of a primary source of water for repository-related water needs.
3. Identification of an alternative source of water for repository-related water needs.
4. Identification and evaluation of potential effects of repository-related water withdrawals on the local flow system and water supply.

Purpose and objectives of the investigation

To meet the purpose of identifying the most suitable water supply and alternative, the following objectives must be met: (1) determine the adequacy of existing wells J-12 and J-13 in terms of available resource potential, total cost, and technologic feasibility as an alternative water supply for a repository at Yucca Mountain (water rights are discussed in Section 8.3.1.11), (2) identify and locate a primary source of water for a repository at Yucca Mountain, (3) identify and locate potential alternative sources of water, and (4) determine the potential effects of repository-related water withdrawals on the local flow system at Yucca Mountain. Figure 8.3.1.16-3 illustrates how the activities of Study 8.3.1.16.2.1 will obtain the parameters needed to satisfy the design requirements.

Technical rationale for the investigation

Current plans are to develop a primary source closer to the proposed site than wells J-12 or J-13 to supply repository-related water needs. In

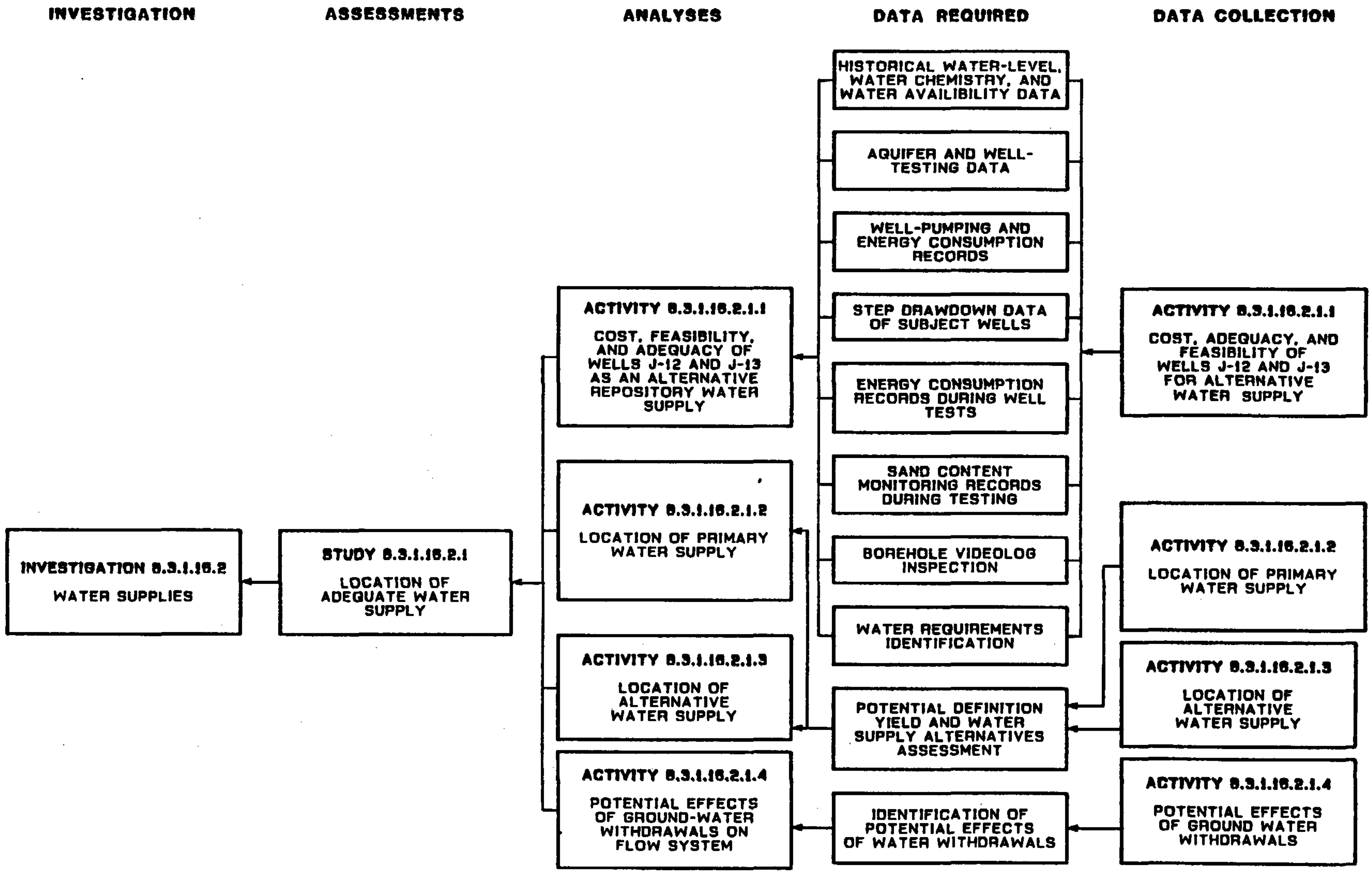

Figure 8.3.1.16-3. Logic diagram for Investigation 8.3.1.16.2 (water supplies).

the event that a primary source cannot serve repository-related water needs through decommissioning, an alternative source of water must be readily available. Wells J-12 and J-13 (Figure 8.3.1.16-4) are under consideration as sources to provide water during repository site preparation and the early phases of construction if Yucca Mountain is selected. They are also being considered as possible alternative sources. The hydrostratigraphic unit source for wells J-12 and J-13, the Topopah Spring Member of the Paintbrush Tuff, is presently considered capable of yielding water at a sufficient rate to supply repository-related water needs through closure and decommissioning. An assessment of the expected future performance, estimated total cost, and the feasibility of using these wells as alternative sources is needed to demonstrate that the wells are adequate and can be used at a reasonable cost with available technology.

The water that will be used to support repository construction, operation, and closure will cause an increase in local water use, which could affect the local flow system at Yucca Mountain. Potential effects from repository-related water withdrawals will be identified and assessed to determine if any mitigating measures might be required.

The data required to satisfy the performance and design requirements will be collected by the four activities of Investigation 8.3.1.16.2 and other studies performed in support of Investigations 8.3.1.2.1, 8.3.1.2.3, and 8.3.1.9.2.

8.3.1.16.2.1 Study: Location of adequate water supply for construction, operation, closure, and decommissioning of a mined geologic disposal system at Yucca Mountain, Nevada

This study includes four activities.

8.3.1.16.2.1.1 Activity: Assessment of the cost, feasibility, and adequacy of wells J-12 and J-13 for use as the alternative water supply for a mined geologic disposal system at Yucca Mountain, Nevada

Objectives

The objective of this activity is to determine (1) the adequacy of wells J-12 and J-13 in terms of available resource potential and (2) the total cost and technical feasibility of supplying the water needed to support a repository at Yucca Mountain. These wells will be evaluated for use as alternative sources.

Parameters

The parameters required for this activity are the total time-phased water demand through decommissioning, estimated peak annual water demand, the maximum water resources available from wells J-12 and J-13 based on historical production capabilities and existing well and pumping-test data, the

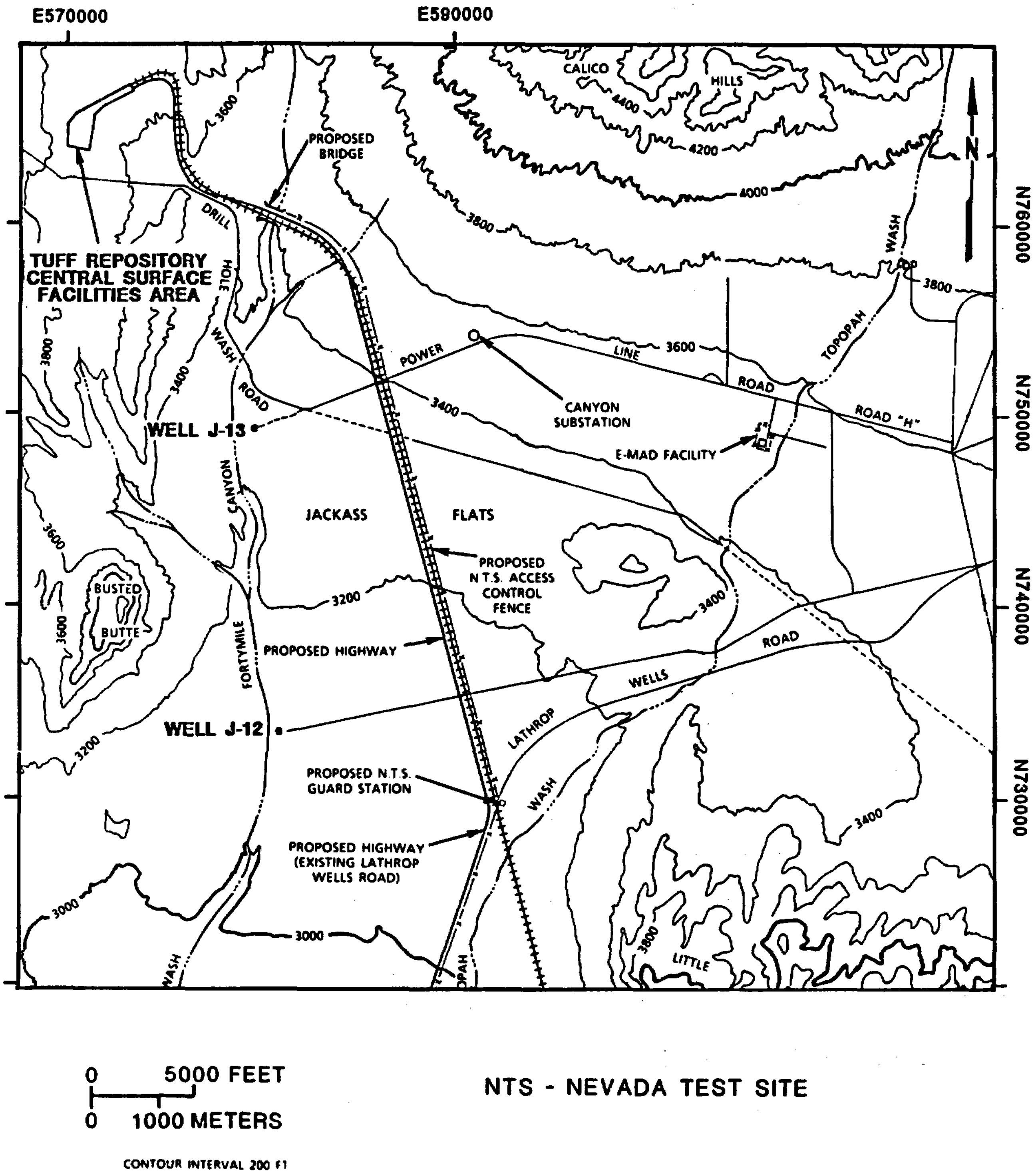

Figure 8.3.1.16-4. Locations of wells J-12 and J-13 relative to the surface facility location.

estimated cost of water withdrawals (pumping, treatment, and distribution), and the quantity of water appropriated by local water users through permits and certifications.

Description

Several steps may be necessary to complete this activity. The actual field work performed will depend on the type, quality, and amount of data available. Thus, the first step will be to compile all data pertinent to the construction, operation, and performance of wells J-12 and J-13. These data will be analyzed to determine their adequacy for predicting long-term well performance. The data to be compiled include historical water levels, water chemistries, aquifer test results, well test results, energy consumption records, and well construction records.

After all existing data have been compiled, the following methods will be applied. Hydrographs of water levels, ionic constituents, and pumping rates will be prepared to evaluate the past performance of the subject wells. Aquifer and other test results will be reanalyzed as necessary to meet the quality assurance requirements of the Yucca Mountain Project. If the existing data are found inadequate for use in assessing long-term well performance, a well test plan will be developed.

The well test plan will identify any additional tests and analyses that may be necessary to assess long-term well performance. Specific tests could include step drawdown testing of both wells, sediment-content monitoring during testing (if applicable), borehole videolog inspection of the casing and open hole, and water chemistry analyses. Step drawdown test results will be analyzed to determine well- and formation-loss coefficients, optimal and maximum well yields, and operating efficiencies. Energy consumption will be monitored during testing to aid in developing unit costs for ground-water withdrawals. Pumping of sediment will be measured and the physical condition of the wells will be described to ascertain whether the wells will require excessive maintenance during long-term operation.

The final calculated repository water requirement will be obtained from the Advanced Conceptual Design report and will be used as the baseline to assess the adequacy and viability of wells J-12 and J-13 for use as an alternative water supply. All results will be compiled and evaluated to determine the cost and technical feasibility of meeting the repository water demand.

Methods and technical procedures

The methods and technical procedures for Activity 8.3.1.16.2.1.1 are given in the following table.

Method	Technical procedure		
	Number	Title	Date
Data compilation	GP-02, R0	Subsurface investigations	1 Mar 83

Method	Technical procedure Number	Title	Date
Step drawdown test	HP-06, R0	Hydrologic pumping test	1 Jan 82
	HP-53, R0	Method for calibrating digital and analog watches	11 Nov 84
Sand content test	TBD[a]	Sand content monitoring	TBD
Videolog inspection	TBD	Inspecting well casings with videologs	TBD
Water level measurement	HP-01, R0	Methods for determining water level	1 Jan 82
Sampling of J-13	033-NNWSI-P 13.1, R0	Collection, storage, and distribution of J-13 water	21 Apr 87
	TWS-INC-DP-62, R1	Bulk Nevada Test Site well water samples	13 Oct 87
	HP-23, R1	Collection and field analysis of saturated-zone ground-water samples	4 Nov 83
Energy consumption	TBD	Monitoring energy consumption of pumping wells	TBD
Unit cost development	TBD	Determining the unit cost of pumping ground water	TBD
Chemical analysis	HP-08, R0	Methods for determination of inorganic substances in water	6 Aug 82
	TWS-INC-OP 26, R0	Preparation of aqueous standards for analysis of water samples	1 Jun 83

[a]TBD = to be determined.

8.3.1.16.2.1.2 Activity: Location of a primary water supply for a mined geologic disposal system at Yucca Mountain, Nevada

Objectives

The objective of this activity is to identify and locate a primary source of water for a repository at Yucca Mountain. Ideally, the primary sources would be located nearer to the surface facilities than wells J-12 and J-13, and at an elevation above the surface facilities, thereby reducing distribution costs and total pumping lifts.

Parameters

This activity will rely heavily on input from Investigations 8.3.1.2.1 and 8.3.1.2.3. Values of aquifer storativity, transmissivity, thickness, and depth to water will be provided by the hydrologic drilling and modeling activities. Remote sensing information (i.e., satellite imagery) will be used in performing lineament analyses to help identify potentially suitable well locations. The parameters that will be measured or calculated as a result of this activity are the locations of, distances to, and relative elevations of all potentially suitable aquifers.

Other parameters that will be obtained from this activity and Study 8.3.1.9.2.2 (ground-water resource assessment) include a compilation of local water users, water uses, amounts of existing local appropriations, points of diversion, and points of use.

Description

The first part of this activity will focus on identifying the amount of unappropriated water available from sources other than wells J-12 and J-13. Other sources may include other water wells located on the NTS, or other unappropriated ground water in basins adjacent to the site. These data, in conjunction with imagery analysis techniques described by Taranik and Trautwein (1977), will be used to define the ground-water yield potential of areas located proximal to the Yucca Mountain site. Subsequent to defining the ground-water yield potential, options for a primary water source will be identified. Once the location of the potential primary source has been identified, a test well will be developed and tested. The hydraulic characteristics of the well will be determined to ensure that the source is capable of producing adequate water to meet the repository-related water demand.

Methods and technical procedures

The methods and technical procedures for Activity 8.3.1.16.2.1.2 are given in the following table.

Method	Technical procedure Number	Title	Date
Data compilation	GP-02, R0	Subsurface investigations	1 Mar 83
Imagery analysis	TBD[a]	Methods for ground-water exploration using remote sensing	TBD
Step drawdown test constant discharge test	HP-06, R0	Hydrologic pumping test	1 Jan 82
	HP-53, R0	Method for calibrating digital and analog watches	11 Nov 84
Sand content test	TBD	Sand content monitoring	TBD
Videolog inspection	TBD	Inspecting well casings with videologs	TBD
Water level measurement	HP-01, R0	Methods for determining water level	1 Jan 82
Well sampling	TWS-INC-DP-62, R1	Bulk Nevada Test Site well water samples	13 Oct 87
Ground-water analysis	HP-23, R1	Collection and field analysis of saturated-zone ground-water samples	4 Nov 83
Energy consumption	TBD	Monitoring energy consumption of pumping wells	TBD
Unit cost development	TBD	Determining the unit cost of pumping ground water	TBD
Chemical analysis	HP-08, R0	Methods for determination of inorganic substances in water	6 Aug 82
	TWS-INC-OP-26, R0	Preparation of aqueous standards for analysis of water samples	1 Jun 83

[a]TBD = to be determined.

8.3.1.16.2.1.3 Activity: Location of alternative water supplies for a mined geologic disposal system at Yucca Mountain Nevada.

Objectives

The objective of this activity is to identify and locate an alternative source of water for a repository at Yucca Mountain in the event that the primary source cannot meet the water demand.

Parameters

As with Activity 8.3.1.16.2.1.2, this activity will rely heavily on input from Investigations 8.3.1.2.1, 8.3.1.2.3, and 8.3.1.9.2. Values of aquifer storativity, transmissivity, thickness, and depth to water will be provided by the hydrologic drilling and modeling activities. Remote sensing information will be used in performing lineament analyses to help identify potentially suitable well locations. The parameters that will be measured or calculated as a result of this activity are the locations of, distances to, and relative elevations of all potentially suitable aquifers.

Other parameters that will be obtained from this activity and Study 8.3.1.9.2.2 (water resource assessment) include a compilation of local water users, water uses, amounts of existing local appropriations, points of diversion, and points of use.

Description

The first part of this activity will focus on identifying the amount of unappropriated water available from potential alternative sources. These sources may include other water wells located on the Nevada Test Site or other unappropriated ground water in basins adjacent to the site. These data, in conjunction with imagery analysis techniques described by Taranik and Trautwein (1977) will be used to define the ground-water yield potential of areas located proximal to the Yucca Mountain site. Subsequent to defining the ground-water yield potential, options for alternative water sources will be identified. A potential well location will be identified, and a test well will be drilled and tested.

Methods and technical procedures

The methods and technical procedures for Activity 8.3.1.16.2.1.3 are given in the following table.

Method	Technical procedure Number	Technical procedure Title	Technical procedure Date
Data compilation	GP-02, R0	Subsurface investitions	1 Mar 83

Method	Technical procedure Number	Title	Date
Imagery analysis	TBD[a]	Methods for ground water exploration using remote sensing	TBD
Step drawdown test constant discharge test	HP-06, R0	Hydrologic pumping test	1 Jan 82
	HP-53, R0	Method for calibrating digital and analog watches	11 Nov 84
Sand content test	TBD	Sand content monitoring	TBD
Videolog inspection	TBD	Inspecting well casings with videologs	TBD
Water level measurement	HP-01, R0	Methods for determining water level	1 Jan 82
Well sampling	TWS-INC-DP-62, R1	Bulk Nevada Test Site well water samples	13 Oct 87
Ground-water analysis	HP-23, R1	Collection and field analysis of saturated-zone ground-water samples	4 Nov 83
Energy consumption	TBD	Monitoring energy consumption of pumping wells	TBD
Unit cost development	TBD	Determining the unit cost of pumping ground water	TBD
Chemical analysis	HP-08, R0	Methods for determination of inorganic substances in water	6 Aug 82
	TWS-INC-OP-26, R0	Preparation of aqueous standards for analysis of water samples	1 Jun 83

[a]TBD = to be determined.

8.3.1.16.2.1.4 Activity: Identification and evaluation of potential effects of repository related withdrawals on the local flow system at Yucca Mountain, Nevada

Objectives

The objective of this activity is to determine the potential effects of repository-related water withdrawals on the local flow system at Yucca Mountain. The potential effects from water withdrawal include modifications to the preclosure ground-water travel path and the lowering of the potentiometric surface. Such effects will be identified and quantified to establish any mitigating measures that might be required.

Parameters

The parameters that will be collected from this activity are the effects of the time-phased water withdrawals from the primary and alternative water supply wells on the local flow system.

Description

Using the parameters and computer codes from Investigations 8.3.1.2.1 and 8.3.1.2.3, the effects of the time-phased water withdrawals on the local flow system will be modeled. The results of these computer simulations will be evaluated, and any effects on the flow system will be identified. If any adverse effects on the flow path or potentiometric surface are identified, plans to mitigate the effects will be developed. It is quite likely that any effect on the potentiometric surface may be beneficial to waste isolation, as the thickness of the unsaturated zone will increase in areas where drawdown is induced due to pumping. This will be assessed and documented for further evaluation of repository performance.

Methods and technical procedures

The methods and technical procedures for Activity 8.3.1.16.2.1.4 are given in the following table.

Method	Technical procedure		
	Number	Title	Date
Data compilation	GP-02, R0	Subsurface investigations	1 Mar 83

8.3.1.16.2.2 Application of results

The information obtained from Study 8.3.1.16.2.1 will be used to assess the suitability of candidate wells for repository water supply through decommissioning. This information will be used as an input parameter to Information Need 1.11.4 (Section 8.3.2.2.4), which examines the design constraints to limit water usage for the repository. The results of this study will also be used as input to Information Need 4.4.3 (Section 8.3.2.5.3), which is the plan for repository construction, operation, closure, and decommissioning.

8.3.1.16.3 Investigation: Ground-water conditions within and above the potential host rock

Technical basis for obtaining the information

Link to the technical data chapters and applicable support documents

The following sections of Chapter 3 provide a technical summary of existing data relevant to this investigation:

Section	Title
3.9.1.3	Hydrochemistry
3.9.2.1	Hydraulic characteristics of the unsaturated zone
3.9.3.2	Potentiometric levels and head relationships in the unsaturated zone

Parameters

The following parameters will be measured or calculated as a result of the planned site studies:

1. Subsurface moisture content above the repository horizon.
2. Flux above and within the repository horizon.
3. Moisture content of the repository horizon.
4. Locations and descriptions of perched water zones.
5. Potential influx to the repository and access shafts.

Purpose and objectives of the investigation

To meet the purpose of describing the baseline characteristics of the unsaturated zone within and above the repository horizon, the following objectives must be met: (1) determine the amount of water inflow to the repository horizon including seasonal variations in inflow rate, (2) determine the existence of perched water, and (3) define the locations, depths, thickness, lateral extent, seasonal variation, and degree of saturation of perched water zones if any are identified. These data will be obtained from the geohydrology program (8.3.1.2); the preclosure hydrology program will synthesize the data to help resolve the design issues. Figure 8.3.1.16-5 illustrates the strategy that will be used to obtain and compile the required parameters for the design issues.

Technical rationale for the investigation

Measurements of the subsurface hydrologic conditions both above and within the repository horizon are required for design of the repository shafts, and seals. Preliminary data presented in Chapter 3 indicate that no special technology will be needed to construct and operate a repository at Yucca Mountain as a result of existing hydrologic conditions. Data obtained from this investigation will provide the design bases required to construct and operate a repository.

8.3.1.16.3.1 Study: Determination of the preclosure hydrologic conditions of the unsaturated zone at Yucca Mountain, Nevada

This study includes one activity.

8.3.1.16.3.1.1 Activity: Synthesis of data from site program 8.3.1.2 to determine the preclosure hydrologic characteristics of the unsaturated zone at Yucca Mountain, Nevada

Objectives

The objectives of this activity are to compile the data collected under geohydrology Investigation 8.3.1.2.2, in Study 8.3.1.2.2.4 (exploratory shaft facilities investigations) for input to design Issue 4.4 (Section 8.3.2.5).

Parameters

Among the parameters that will be collected from Investigation 8.3.1.2.2 are flux, moisture content above and within the repository horizon, and locations and descriptions of perched water zones.

Description

The parameters obtained from Study 8.3.1.2.2.4 will be compiled and evaluated to ensure that data collected from the exploratory shaft is sufficient to satisfy the objectives set by the design issues. The information will then be passed to the design issues to be used as input.

Methods and technical procedures

No methods or technical procedures have been identified for Activity 8.3.1.16.3.1.1.

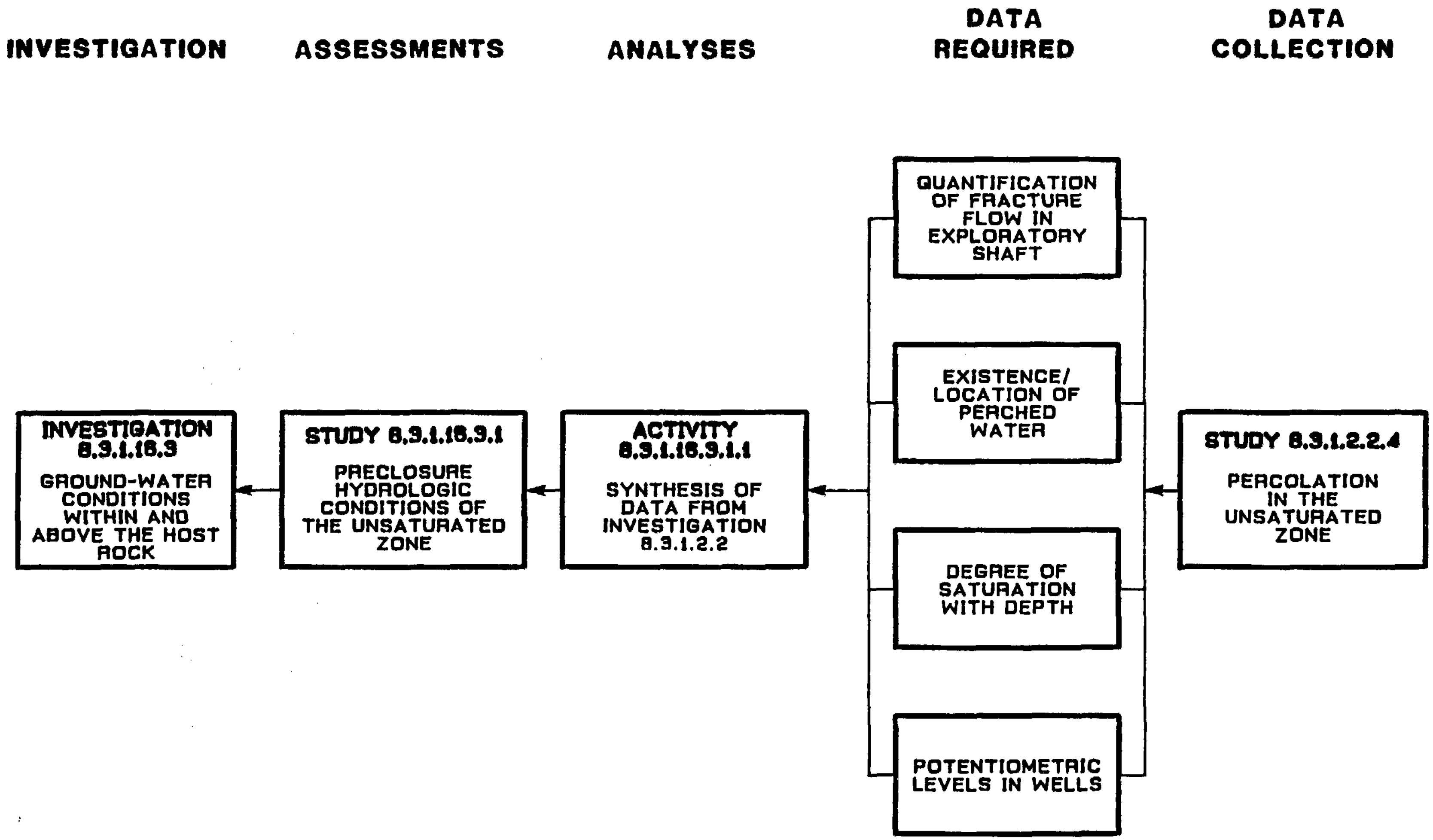

Figure 8.3.1.16-5. Logic diagram for Investigation 8.3.1.16.3 (ground water conditions).

8.3.1.16.3.2 Application of results

The data collected by this investigation will serve as input parameters for design of the repository, access shafts, and seals. The following information needs call for data from this investigation:

Information need	Short title	SCP section
4.4.4	Repository design requirements	8.3.2.5.4
4.4.7	Design analyses (hydrologic impacts)	8.3.2.5.7
4.4.9	Technology for underground facilities	8.3.2.5.9

8.3.1.16.4 Schedule for the preclosure hydrology program

The preclosure hydrology program includes three investigations, which contain three studies. The schedule information for each study is summarized in Figure 8.3.1.16-6. This figure includes the study number and a brief description, as well as major events associated with each study. A major event, for purposes of these schedules, may represent the initiation or completion of an activity, completion or submittal of a report to the DOE, an important data feed, or a decision point. Solid lines on the schedule represent study durations and dashed lines show interfaces among studies as well as data transferred into or out of the preclosure hydrology program. The events shown on the schedule and their planned dates of completion are provided in Table 8.3.1.16-3.

The study-level schedules, in combination with information provided in the logic diagrams for this program (Figures 8.3.1.16-1 through 8.3.1.16-3 and 8.3.1.16-5), are intended to provide the reader with a basic understanding of the relationships between major elements of the site, performance, and design programs. The information provided in Table 8.3.1.16-3 and Figure 8.3.1.16-6, however, should be viewed as a snapshot in time.

The overall program schedule presented here is consistent with the Draft Mission Plan Amendment (DOE, 1988a). The site characterization program will undergo a series of refinements following issuance of the statutory SCP. Refinements will consider factors both internal and external to the site characterization program, such as changes to the quality assurance program. Such refinements are to be considered in ongoing planning efforts, and changes that are implemented will be reflected in the semiannual progress reports. Summary schedule information for the preclosure hydrology program can be found in Sections 8.5.1.1 and 8.5.6.

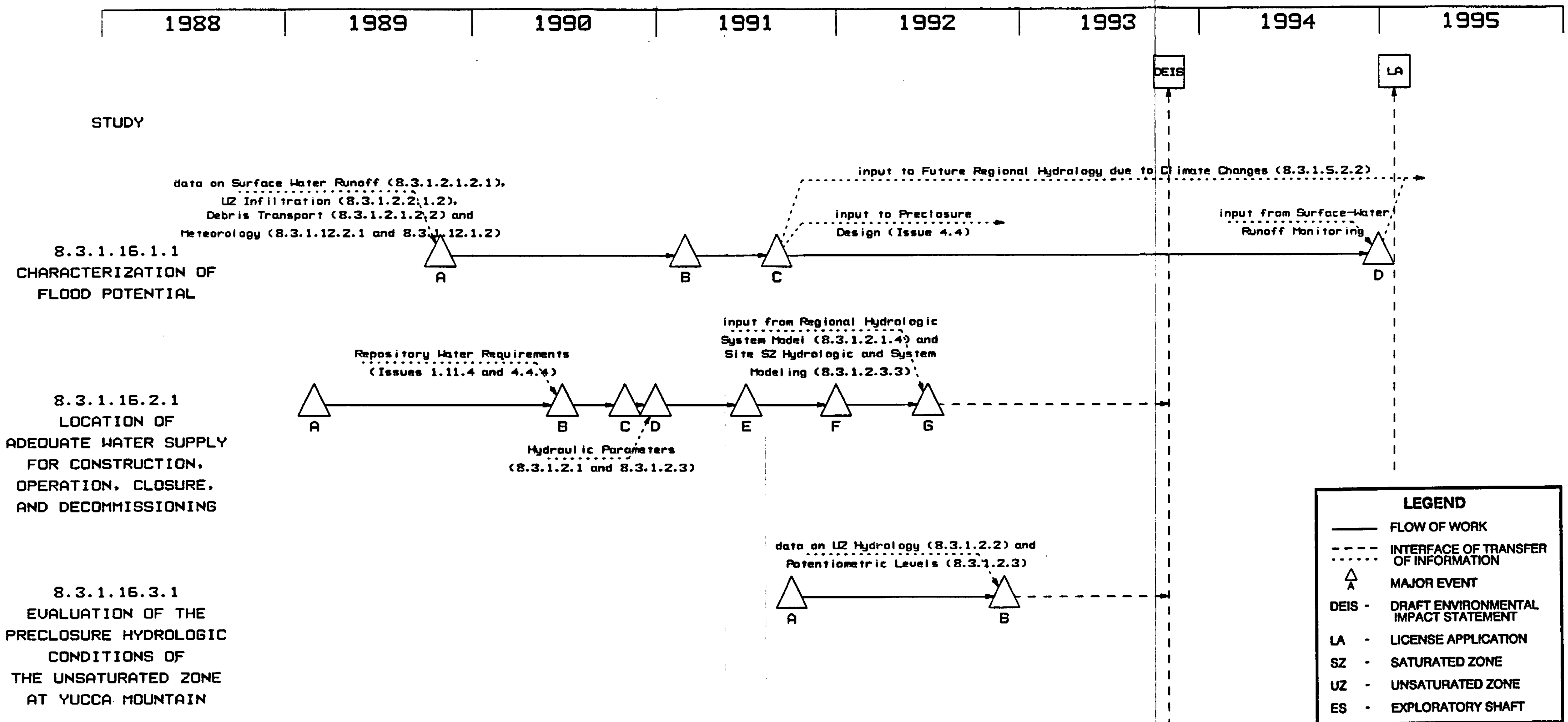

Figure 8.3.1.16-6. Schedule information for studies in Site Program 8.3.1.16 (preclosure hydrology). See Table 8.3.1.16-3 for description of major events. This network is consistent with the Draft Mission Plan Amendment (DOE, 1988a) schedule. Revisions will be published in semiannual site characterization progress reports as new information becomes available.

Table 8.3.1.16-3. Major events and planned completion dates for studies in the preclosure hydrology program (page 1 of 2)

Study number	Brief description of study	Major event[a]	Event description	Date
8.3.1.16.1.1	Characterization of flood potential	A	Study plan approved	10/89
		B	Draft of summary report on prehistoric flooding available to DOE (report primarily associated with Study 8.3.1.5.2.1.1)	2/91
		C	Input to report on modern flooding events (Study 8.3.1.5.2.2)	8/91
		D	Compile current information on future flooding and debris transport and begin preparation of report	12/94
8.3.1.16.2.1	Location of adequate water supply for construction, operation, closure, and decommissioning	A	Study plan approved	2/89
		B	Draft report available to DOE on the assessment of Wells J-12 and J-13 for repository water supply	6/90
		C	Draft of preliminary report on water use and constraints available to DOE; Begin modeling water supplies	10/90

Table 8.3.1.16-3. Major events and planned completion dates for studies in the preclosure hydrology program (page 2 of 2)

Study number	Brief description of study	Major event	Event description	Date
8.3.1.16.2.1	Location of adequate water supply for construction, operation, closure, and decommissioning (continued)	D	Identify possible well sites for aquifer tests	12/90
		E	Complete drilling and testing primary and alternative test wells	6/91
		F	Draft report available to DOE on repository-related water supply alternatives	12/91
		G	Draft report available to DOE on the effects of water withdrawals on local flow system	6/92
8.3.1.16.3.1	Evaluation of the preclosure hydrologic conditions of the unsaturated zone at Yucca Mountain	A	Study plan approved	9/91
		B	Draft report available to DOE on ground-water conditions within and above potential host rock	11/92

[a]The letters in this column key major events shown in Figure 8.3.1.17-6.

DOE/RW-0199

DOE/RW-0199

Nuclear Waste Policy Act
(Section 113)

Site Characterization Plan

Yucca Mountain Site, Nevada Research and Development Area, Nevada

Volume V, Part B

Chapter 8, Section 8.3.1.17, Preclosure Tectonics

December 1988

U. S. Department of Energy
Office of Civilian Radioactive Waste Management

8.3.1.17 Overview of preclosure tectonics: Description of tectonic and igneous events required by performance and design requirements

Summary of performance and design requirements for preclosure tectonics information

The preclosure tectonics program (Program 8.3.1.17) is designed to develop an understanding of and to characterize the tectonic events and processes that could impact proposed repository structures, systems, or components considered to be important to safety through the operational phase; i.e, until permanent closure is achieved. In addition, characterizations 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. Tectonic processes and events that are relevant to waste isolation following permanent closure will be investigated within the postclosure tectonics program (Program 8.3.1.8).

Performance and design issues that require data from the preclosure tectonics program are indicated in the left half of Figure 8.3.1.17-1; the right half of the figure indicates investigations that provide the requested data. Data requirements come from Issue 4.4 (Section 8.3.2.5), which evaluates the technical feasibility of repository construction, operation, closure, and decommissioning, and from postclosure Issue 1.12 (Section 8.3.3.2), which considers the design of seals for shafts, drifts, and boreholes. Investigations of technical feasibility include data requirements from three additional performance and design issues, also noted in Figure 8.3.1.17-1. These three issues are preclosure radiological safety (Issue 2.7, Section 8.3.2.3), potential radiologic exposure to the public due to credible accidents (Issue 2.3, Section 8.3.5.5), and preservation of the waste retrieval option (Issue 2.4, Section 8.3.5.2). In addition, data developed by the preclosure tectonics program will be used by the postclosure tectonics program (Program 8.3.1.8) and the preclosure and postclosure rock characteristics programs (Programs 8.3.1.15 and 8.3.1.4).

The evaluation of technical feasibility (Issue 4.4, Section 8.3.2.5) establishes the major requirement for characterizing potentially disruptive tectonic events.

The required characterization data are summarized in part a of Tables 8.3.1.17-1 through 8.3.1.17-6; part b of these tables provides summary information on the characterization program designed to provide the required data. The technical content of these tables is discussed in detail below. The data requirements are organized by the type of potential tectonic event: volcanic, including eruption and ashfall; faulting; and vibratory ground motion from natural earthquakes and underground nuclear explosions. Two tables are presented for each type of event, one for considerations of surface facilities and one for underground facilities.

The following information is used to specify each data requirement: design and performance parameters, to specify the type of data that is required; goal, to establish the precision or level of conservatism that is required; and needed confidence, to indicate the degree of certainty that the goal will be met. The needed confidences are specified using the terms high,

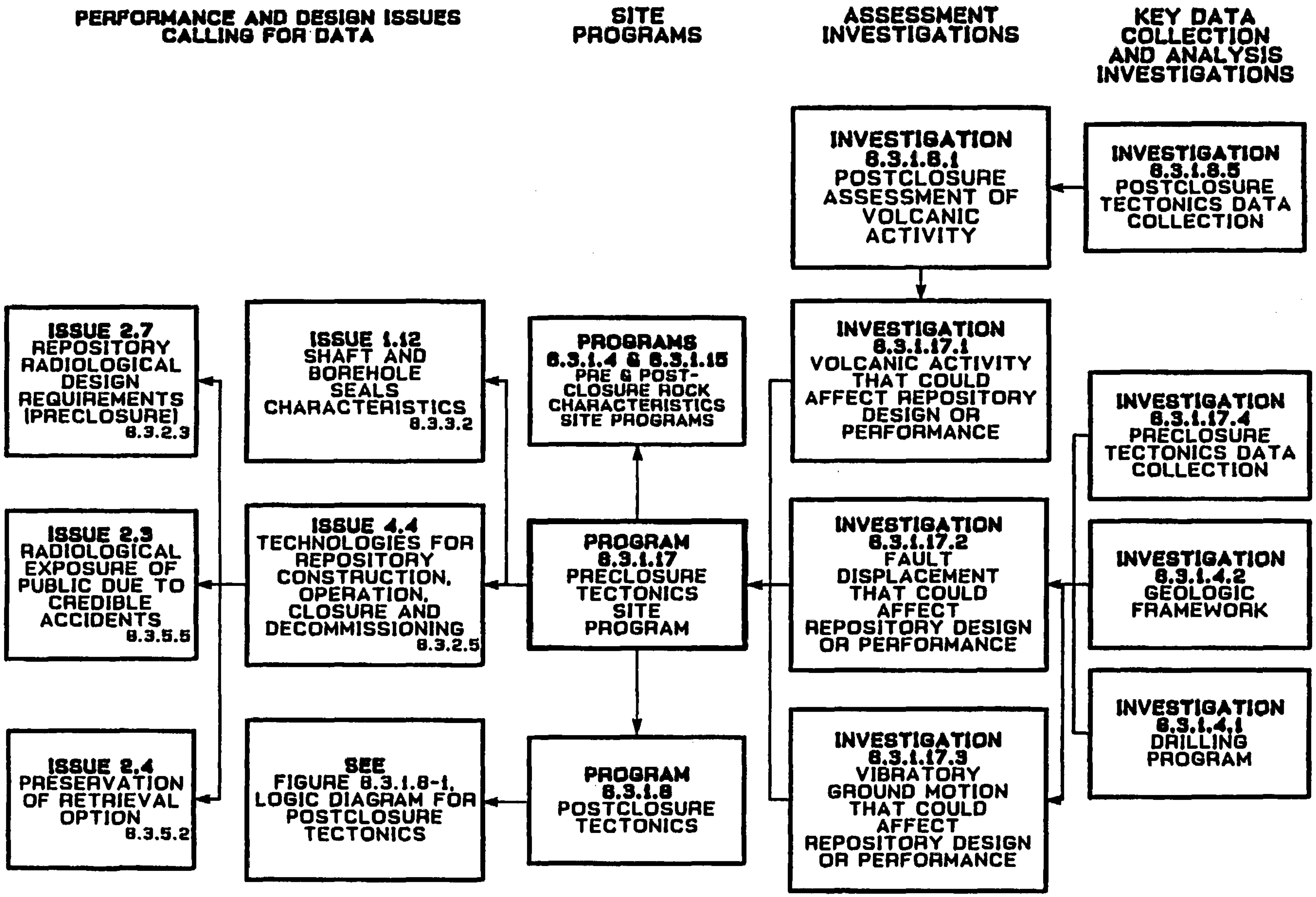

Figure 8.3.1.17-1. Logic diagram for the preclosure tectonics site program.

8.3.1.17-1a. Design and performance parameters related to surface facilities and preclosure volcanic activity

Design or performance parameter[a]	Goal	Needed confidence	Characterization parameters
Probability of volcanic eruption that would disrupt surface facilities	Less than 1 chance in 10,000 in 100 yr	High	Annual probability of volcanic disruption at the site
Design-basis ash-fall thickness for facilities important to safety (FITS) ventilation systems	Less than 1 chance in 10 of exceeding design-basis ash-fall thickness in 100 yr	Low to medium	Probability of ash fall at the site as a function of ash-fall thickness
			1,000-yr(+) ash-fall thickness at the site
Ash-fall particle density and size distribution	TBD[b]	Low to medium	Potential density and distribution of ash-fall particles

[a]These parameters are from Issue 4.4 (technical feasibility, Section 8.3.2.5), and corresponding performance measures are given in that issue.
[b]TBD = to be determined.

Table 8.3.1.17-1b. Characterization parameters related to surface facilities and preclosure volcanic activity

Characterization parameters	Testing basis: Current estimate (range)	Testing basis: Confidence in current estimate	Testing basis: Needed confidence in final values	Key studies/activities supplying parameters
Annual probability of volcanic disruption at the site	10^{-7} to 10^{-9} per yr	Moderate	Medium to high	8.3.1.8.1.1.4--Probability calculations (of volcanic disruption) and assessment
Probability of ash fall at the site as a function of ash-fall thickness	TBD[a]	TBD	Low to medium	8.3.1.17.1.1.2--Assess potential ash-fall thickness at the site
1,000-yr(+) ash-fall thickness at the site	0.1-2.0 cm	Low	Low to medium	8.3.1.17.1.1.2--Assess potential ash-fall thickness at the site
Potential density and distribution of ash-fall particles	TBD	TBD	Low to medium	8.3.1.17.1.1.3--Assess potential density and size distribution of ash fall at the site

[a]TBD = to be determined.

Table 8.3.1.17-2a. Design and performance parameters related to underground facilities and preclosure volcanic activity

Design or performance parameter[a]	Goal	Needed confidence	Characterization parameters
Probability of volcanic eruption through the underground facilities	Less than 1 chance in 10,000 in 100 yr	High	Annual probability of volcanic disruption of the underground facilities
Design-basis ash-fall thickness (at ventilation shaft locations)	Less than 1 chance in 10 of exceeding design-basis ash-fall thickness in 100 yr	Low to medium	Probability of ash fall at the site as a function of ash-fall thickness
			1,000-yr(+) ash-fall thickness at the site
Ash-fall particle density and size distribution	TBD[b]	Low to medium	Potential density and size distribution of ash-fall particles

[a]These parameters are from Issue 4.4 (technical feasibility, Section 8.3.2.5), and corresponding performance measures are given in that issue.

[b]TBD = to be determined.

Table 8.3.1.17-2b. Characterization parameters related to underground facilities and preclosure volcanic activity

Characterization parameters	Testing basis: Current estimate (range)	Testing basis: Confidence in current estimate	Testing basis: Needed confidence in final values	Key studies/activities supplying parameters
Annual probability of volcanic disruption of the underground facilities	4.7×10^{-8} to 3.3×10^{-10} per yr	Medium	Medium to high	8.3.1.8.1.1.4--Probability calculations (of volcanic disruption) and assessment
Probability of ash fall at the site as a function of ash-fall thickness	TBD[a]	TBD	Low to medium	8.3.1.17.1.1.2--Assess potential ash-fall thickness at the site
1,000-yr(+) ash-fall thickness	0.1-2.0 cm	Low	Low to medium	8.3.1.17.1.1.2--Assess potential ash-fall thickness at the site
Potential density and size distribution of ash-fall particles	TBD	TBD	Low to medium	8.3.1.8.1.1.3--Assess potential particulate size distribution of ash fall at the site

[a]TBD = to be determined.

Table 8.3.1.17-3a. Design and performance parameters related to surface facilities and preclosure fault displacement (page 1 of 2)

Design or performance parameter[a]	Goal	Needed confidence	Characterization parameters
Identification of any fault within 100 m of facilities important to safety (FITS) with greater than 1 chance in 100 of producing more than 5 cm of surface offset during the preclosure period (approximately 100 yr)	Determine existence	High	Identification and characterization of potentially significant Quaternary faults within 5 km of FITS
If existence is determined, establish			
Classification	Standard practice	High	Identification and characterization of faults within 100 m of FITS that have apparent Quaternary slip rates >0.001 mm/yr or that measurably offset materials less than 100,000 yr old
Location at surface	±5 m	High	
Orientation at surface	±10°	High	

Table 8.3.1.17-3a. Design and performance parameters related to surface facilities and preclosure fault displacement (page 2 of 2)

Design or performance parameter[a]	Goal	Needed confidence	Characterization parameters
Total probability of exceeding 5 cm fault displacement at locations proposed for FITS	Less than 1 chance in 100 of exceeding 5 cm displacement beneath surface FITS in 100 yr	High	Estimate of total probability for >5 cm displacement beneath FITS, considering known and possibly concealed faults and tectonic interrelationships among local faults

[a]These parameters are from Issue 4.4 (technical feasibility, Section 8.3.2.5), and corresponding performance measures are given in that issue.

Table 8.3.1.17-3b. Characterization parameters related to surface facilities and preclosure fault displacement

Characterization parameters	Testing basis: Current estimate (range)	Testing basis: Confidence in current estimate	Testing basis: Needed confidence in final values	Key studies/activities supplying parameters
Identification and characterization of potentially significant Quaternary faults within 5 km of facilities important to safety (FITS)	4 such faults	Low	Medium to high	8.3.1.17.4.6.1--Evaluate Quaternary geology and potential Quaternary faults at Yucca Mountain
Identification and characterization of faults within 100 m of FITS that have apparent Quaternary slip rates > 0.001 mm/yr or that measurably offset materials less than 100,000 yr old	No such faults	Low	High	8.3.1.17.4.2.2--Conduct exploratory trenching in in Midway Valley
Estimate of total probability for >5 cm displacement beneath FITS, considering known and possibly concealed faults and tectonic interrelationships among local faults	Less than 1 chance in 100 of exceeding 5 cm displacement beneath FITS in 100 yr	Low	High	8.3.1.17.2.1.1--Assess the potential for surface faulting at prospective sites of surface FITS

Table 8.3.1.17-4a. Design and performance parameters related to underground facilities and preclosure fault displacement (page 1 of 2)

Design or performance parameter[a]	Goal	Needed confidence	Characterization parameters
Identification and characterization of significant Quaternary faults in the repository block:			Surface locations of faults in the repository with > 1 m offset of Quaternary materials or with > 100 m offset of Tertiary rocks
Classification	Standard practice	High	
Location at surface	±5 m	High	
Orientation at surface	±10°	High	
Identification and characterization of any fault within the waste emplacement area with greater than 1 chance in 100 of producing more than 7 cm (waste-package air-gap distance) of subsurface offset during the preclosure period (approximately 100 yr)	Determine existence; for any such faults (none are now known to exist), determine location within the waste emplacement area	High	Surface and subsurface locations of faults with Quaternary slip rates > 0.005 mm/yr that intersect underground facilities

Table 8.3.1.17-4a. Design and performance parameters related to underground facilities and preclosure fault displacement (page 2 of 2)

Design or performance parameter[a]	Goal	Needed confidence	Characterization parameters
Total probability of exceeding 7 cm fault displacement on any fault that intersects areas of waste emplacement	Less than 1 chance in 10 in 100 yr of exceeding 7 cm displacement on any fault that intersects areas of waste emplacement	Medium	Estimated total probability of fault displacement exceeding 7 cm in areas of emplaced waste, considering known and possibly concealed faults and tectonic interrelationships among local faults

[a]These parameters are from Issue 4.4 (technical feasibility, Section 8.3.2.5), and corresponding performance measures are given in that issue.

Table 8.3.1.17-4b. Characterization parameters related to the underground facilities and preclosure fault displacement

Characterization parameters	Testing basis: Current estimate (range)	Testing basis: Confidence in current estimate	Testing basis: Needed confidence in final values	Key studies/activities supplying parameters
Surface locations of faults in the repository block with >1 m offset of Quaternary materials or with >100 m offset of Tertiary rocks	2 such faults exist	Low to medium	Medium	8.3.1.17.4.6.1--Evaluate Quaternary geology and potential Quaternary faults at Yucca Mountain
Surface and subsurface locations of faults with Quaternary slip rates >0.005 mm/yr that intersect underground facilities	No such faults exist	Medium	Medium to high	8.3.1.17.4.6.1--Evaluate Quaternary geology and potential Quaternary faults at Yucca Mountain 8.3.1.17.4.6.2--Evaluate age and recurrence of movement on suspected and known Quaternary faults within the site area 8.3.1.17.4.7--Subsurface geometry and concealed extensions of Quaternary faults at Yucca Mountain
Estimated total probability of fault displacement exceeding 7 cm in areas of emplaced waste, considering known and possibly concealed faults and tectonic interrelationships among local faults	Less than 1 chance in 100 in 100 yr of exceeding 7 cm displacement in areas of emplaced waste	Medium	Medium	8.3.1.17.2.1.2--Assess the potential for rupture on faults that intersect underground facilities

Table 8.3.1.17-5a. Design and performance parameters related to surface facilities and preclosure vibratory ground motion (page 1 of 3)

Design or performance parameter[a]	Goal	Needed confidence	Characterization parameters
Design-basis ground motion time histories (minimum band width = 0.5 to 33 Hz) and corresponding response spectra (at 1 Hz intervals) for surface facilities important to safety (FITS)	Representative of 10,000-yr cumulative slip earthquakes on nearby faults, or maximum potential underground nuclear explosions (UNEs) that would control site ground motion at any frequency between 0.5 and 33 Hz (including any effect of local geology or building embedment)	Medium to high	Identification of potential earthquake sources in the controlled area Potentially relevant earthquake sources in the region (≤100 km) Magnitude of 10,000-yr cumulative slip earthquakes on local sources Magnitude of 10,000-yr cumulative slip earthquakes on regional sources Maximum future underground nuclear explosion Closest distance of future UNEs Ground motion attenuation with distance Spectral modification due to local geology Controlling ground motion event(s) Time histories and reponse spectra representative of controlling event(s)

Table 8.3.1.17-5a. Design and performance parameters related to surface facilities and preclosure vibratory ground motion (page 2 of 3)

Design or performance parameter[a]	Goal	Needed confidence	Characterization parameters
Combined potential for vibratory ground motion at FITS, considering all faults	Less than 1 chance in 10 of exceeding design-basis ground motion in 100 yr	Medium to high	Identification of potential earthquake sources in the controlled area Potentially relevant earthquake sources in the region (≤100 km) Earthquake recurrence relationships for local and regional sources Ground motion attenuation with distance Spectral modification due to local geology Ground motion exceedance probabilities
Probability versus peak acceleration, peak velocity, and peak velocity response at selected frequencies, at surface locations of FITS	Values estimated for annual probabilities ranging from 10^{-2} to 10^{-6} per yr	Medium	Identification of potential earthquake sources in the controlled area Potentially relevant earthquake sources in the region (≤100 km) Earthquake recurrence relationships for local and regional sources

Table 8.3.1.17-5a. Design and performance parameters related to surface facilities and preclosure vibratory ground motion (page 3 of 3)

Design or performance parameter[a]	Goal	Needed confidence	Characterization parameters
Probability versus peak acceleration, peak velocity, and peak velocity response at selected frequencies, at surface locations of FITS (continued)			Ground motion attenuation with distance Spectral modification due to local geology Ground motion exceedance probabilities

[a]These parameters come from Issues 4.4 (technical feasibility, Section 8.3.2.5) and 1.12 (seal characteristics, Section 8.3.3.2), and corresponding performance measures are given in those issues.

Table 8.3.1.17-5b. Characterization parameters related to surface facilities and preclosure vibratory ground motion (page 1 of 3)

Characterization parameters	Testing basis: Current estimate (range)	Testing basis: Confidence in current estimate	Testing basis: Needed confidence in final values	Key studies/activities supplying parameters
Identification of potential earthquake sources in the controlled area	See Chapter 1	Medium	Medium to high	8.3.1.17.3.1.1--Identify relevant earthquake sources
Potentially relevant earthquake sources in the region (≤100 km)	See Chapter 1	Low to medium	Medium	8.3.1.17.3.1.1--Identify relevant earthquake sources
Magnitude of 10,000-year cumulative slip earthquakes on local sources	≈6 1/2	Low to medium	Medium to high	8.3.1.17.3.1.2--Characterize 10,000-year cumulative slip earthquakes for relevant seismogenic sources
Magnitude of 10,000-year cumulative slip earthquakes on regional sources	6 1/2 to 8 1/2	Low	Medium	8.3.1.17.3.1.2--Characterize 10,000-year cumulative slip earthquakes for relevant seismogenic sources
Maximum future underground nuclear explosion (UNE)	150-750 kt	Medium	Medium	8.3.1.17.3.2.2--Determine maximum UNE source(s)
Closest distance of future future UNEs	23 km (Buckboard Mesa area)	Medium	Medium	8.3.1.17.3.2.2--Determine maximum UNE source(s)

Table 8.3.1.17-5b. Characterization parameters related to surface facilities and preclosure vibratory ground motion (page 2 of 3)

Characterization parameters	Testing basis: Current estimate (range)	Testing basis: Confidence in current estimate	Testing basis: Needed confidence in final values	Key studies/activities supplying parameters
Ground motion attenuation with distance	Published models for California and western U.S.	Low to medium	Medium	8.3.1.17.3.3--Ground motion from earthquakes and UNEs
Spectral modification at facilities important to safety due to local geology	1/2 to 4	Low	Medium	8.3.1.17.3.4--Effects of local site geology on surface and subsurface motions
Controlling ground motion event(s)	≈6 1/2 M earthquake on Paintbrush Canyon	Low to medium	Medium to high	8.3.1.17.3.5.1--Identify controlling seismic events
Time histories and response spectra representative of controlling event(s)	TBD[a] (0.4-0.6g peak acceleration)	Low to medium	Medium to high	8.3.1.17.3.5.2--Characterize ground motion from controlling seismic events
Earthquake recurrence relationships for local and regional sources	See section 1.4.2	Low to medium	Medium	8.3.1.17.3.6.1--Evaluate earthquake sources

Table 8.3.1.17-5b. Characterization parameters related to surface facilities and preclosure vibratory ground motion (page 3 of 3)

Characterization parameters	Testing basis: Current estimate (range)	Testing basis: Confidence in current estimate	Testing basis: Needed confidence in final values	Key studies/activities supplying parameters
Ground motion exceedance probabilities	1-5 x 10^{-4}/yr for 0.5g	Low to medium	Medium	8.3.1.17.3.6.2--Evaluate ground motion probabilities

[a]TBD = to be determined.

Table 8.3.1.17-6a. Design and performance parameters related to underground facilities and preclosure vibratory ground motion (page 1 of 4)

Design or performance parameter[a]	Goal	Needed confidence	Characterization parameters
Design-basis ground motion time histories and corresponding response spectra for underground facilities (at various depths) (minimum band width = 0.5 to 33 Hz; 1 Hz interval for response spectra)	Representative of 10,000-year cumulative slip earthquakes or nearby faults, or maximum potential underground nuclear explosions (UNEs) that would control site ground motion at any frequency between 0.5 and 33 Hz (including any effects of local geology or depth of burial)	Medium	Identification of potential earthquake sources in the controlled area Potentially relevant earthquake sources in the region (≤100 km) Magnitude of 10,000-year cumulative slip earthquakes on local sources Magnitude of 10,000-year cumulative slip earthquakes on regional sources Future maximum UNE Closest distance of future UNEs Ground motion attenuation with distance

Table 8.3.1.17-6a. Design and performance parameters related to underground facilities and preclosure vibratory ground motion (page 2 of 4)

Design or performance parameter[a]	Goal	Needed confidence	Characterization parameters
Design-basis ground motion time histories and corresponding response spectra for underground facilities (at various depths) (minimum band width = 0.5 to 33 Hz; 1 Hz interval for response spectra) (continued)			Spectral modification due to local geology and depth of burial Controlling ground motion event(s) Time histories and response spectra representative of of controlling event(s)
Combined potential for vibratory ground motion at underground facility locations, considering all faults	Less than 1 chance in 10 of exceeding design-basis ground motion in 100 yr	Medium	Identification of potential earthquake sources in the controlled area Potentially relevant earthquake sources in the region (≤100 km) Earthquake recurrence relationships for local and regional sources

Table 8.3.1.17-6a. Design and performance parameters related to underground facilities and preclosure vibratory ground motion (page 3 of 4)

Design or performance parameter[a]	Goal	Needed confidence	Characterization parameters
Combined potential for vibratory ground motion at underground facility locations, considering all faults (continued)			Ground motion attenuation with distance Spectral modification due to local geology and depth of burial Ground motion exceedance probabilities
Probability versus peak acceleration, peak velocity, and peak velocity response at selected frequencies at underground facility locations	Values estimated for annual probabilities ranging from 10^{-2} to 10^{-6} per yr	Low to medium	Identification of potential earthquake sources in the controlled area Potentially relevant earthquake sources in the region (≤100 km) Earthquake recurrence relationships for local and regional sources

Table 8.3.1.17-6a. Design and performance parameters related to underground facilities and preclosure vibratory ground motion (page 4 of 4)

Design or performance parameter[a]	Goal	Needed confidence	Characterization parameters
Probability versus peak acceleration, peak velocity, and peak velocity response at selected frequencies at underground facility locations (continued)			Ground motion attenuation with distance Spectral modification due to local geology and depth of burial Ground motion exceedance probabilities

[a]These parameters are from Issues 4.4 (technical feasibility, Section 8.3.2.5) and 1.12 (seal characteristics, Section 8.3.3.2), and corresponding performance measures are given in those issues.

Table 8.3.1.17-6b. Characterization parameters related to underground facilities and preclosure vibratory ground motion (page 1 of 3)

Characterization parameters	Testing basis: Current estimate (range)	Testing basis: Confidence in current estimate	Testing basis: Needed confidence in final values	Key studies/activities supplying parameters
Identification of potential earthquake sources in the controlled area	See Chapter 1	Medium	Medium	8.3.1.17.3.1.1--Identify relevant earthquake sources
Potentially relevant earthquake sources in the region (≤100 km)	See Chapter 1	Low to medium	Medium	8.3.1.17.3.1.1--Identify relevant earthquake sources
Magnitude of 10,000-yr cumulative slip earthquakes on local sources	≈6.5	Low to medium	Medium to high	8.3.1.17.3.1.2--Characterize 10,000-yr cumulative slip earthquakes for relevant seismogenic sources
Magnitude of 10,000-yr cumulative slip earthquakes on regional sources	6.5-8.5	Low	Medium	8.3.1.17.3.1.2--Characterize 10,000-yr cumulative slip earthquakes for relevant seismogenic sources
Maximum future underground nuclear explosion (UNE)	150-750 kt	Medium	Medium	8.3.1.17.3.2.2--Determine maximum UNE source(s)
Closest distance of future future UNEs	23 km (Buckboard Mesa area)	Medium	Medium	8.3.1.17.3.2.2--Determine maximum UNE source(s)

Table 8.3.1.17-6b. Characterization parameters related to underground facilities and preclosure vibratory ground motion (page 2 of 3)

Characterization parameters	Testing basis: Current estimate (range)	Testing basis: Confidence in current estimate	Testing basis: Needed confidence in final values	Key studies/activities supplying parameters
Ground motion attenuation with distance	Published models for California and western U.S.	Low to medium	Medium	8.3.1.17.3.3--Ground motion from regional earthquakes and UNEs
Spectral modification due to local geology and depth of burial	.25-1	Low	Medium	8.3.1.17.3.4--Effects of local site geology on surface and subsurface motions
Controlling ground motion event(s)	≈6.5 M earthquake on Paintbrush Canyon fault	Low to medium	Medium	8.3.1.17.3.5.1--Identify controlling seismic events
Time-histories and response spectra representative of controlling event(s)	TBD[a]	Low to medium	Medium	8.3.1.17.3.5.2--Characterize ground motion from controlling seismic events
Earthquake recurrence relationships for local and regional sources	See Section 1.4.2	Low to medium	Medium	8.3.1.17.3.6.1--Evaluate earthquake sources

Table 8.3.1.17-6b. Characterization parameters related to underground facilities and preclosure vibratory ground motion (page 3 of 3)

Characterization parameters	Testing basis: Current estimate (range)	Testing basis: Confidence in current estimate	Testing basis: Needed confidence in final values	Key studies/activities supplying parameters
Ground motion exceedance probabilities	10^{-4}/yr for 0.5g	Low	Low to medium	8.3.1.17.3.6.2--Evaluate ground motion probabilities

[a]TBD = to be determined.

medium, and low to denote the relative importance of each parameter-goal pair for contributing to the resolution of design and performance issues. High confidence indicates that the parameter is of primary importance, and, consequently, that the goal should be met by a characterization of the parameter that conservatively accounts for residual uncertainties. Low confidence indicates that resolution of design and performance issues is not strongly influenced by the parameter and that the goal should be met by a best estimate of the parameter, based on limited data. Medium confidence is used for parameters of intermediate importance.

Investigations performed to satisfy the data requirements will produce information that will also be used by the postclosure tectonics program (Section 8.3.1.8), and conversely, investigations performed by that program will provide information that will be used in the preclosure tectonics program. The postclosure tectonics program requires information on (1) current seismicity, to help evaluate tectonic processes, including the presence of magma bodies; (2) the potential for earthquake ground motions, to support evaluations of the stability of underground facilities; (3) the potential for fault displacement, to support evaluations of possible disruption of waste packages and to support evaluations of possible changes in the hydrologic environment; and (4) tectonic stress and rate of tectonic deformations, to support evaluations of possible changes in the hydrologic environment. The postclosure tectonics program will supply information on the potential for local volcanic eruptions to support the preclosure tectonics program in the characterization of such events. Technical considerations of the information contained in Tables 8.3.1.17-1 through 8.3.1.17-6 are discussed in the next section, on the approach to satisfying the performance and design requirements.

Approach to satisfying performance and design requirements

General methodology

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 design and characterization parameters that will be used to satisfy performance and design requirements are listed in Tables 8.3.1.17-1b through 8.3.1.17-6b.

For each data requirement presented in the tables, one or more characterization parameters have been identified to serve as the technical basis for satisfying the requirement. The tables also present current estimates for the characterization parameters (where available and quantifiable) along with assessments of the current confidence in these estimates and the confidences needed to satisfy the data requirement. Differences between the current and needed confidence for each characterization parameter provide a measure of the remaining amount of work that is required to finalize the result. The last column of Tables 8.3.1.17-1b through 8.3.1.17-6b lists the key studies or activities that will be providing results for each characterization parameter, and the corresponding section numbers where descriptions of these studies and activities are provided. The technical considerations summarized in these tables are discussed below.

The tectonic characteristics of the site will be investigated in sufficient scope and detail to provide reasonable assurance that the processes are understood and that the characterization parameters are determined with the confidences specified in Tables 8.3.1.17-1 through 8.3.1.17-6. The investigations will use data from a variety of sources, including scientific literature, current and historical seismicity, geologic maps, logs from boreholes and surface trenches, gravity surveys, aeromagnetic and paleomagnetic observations, seismic reflection and refraction profiles, and magnetotelluric soundings.

The planned approach is to use both deterministic and probabilistic methods 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 (1) to ensure that adequate consideration is given to the full range of potential tectonic processes and to their associated uncertainties, and (2) to help identify those processes that are key to characterizing the geologic hazards at the site.

Using the deterministic approach, results (e.g., ground motions) will be determined for specific events that are postulated to occur (e.g., an earthquake or an underground nuclear explosion). Judgment is required for postulating the specific source events to ensure adequate conservatism. The deterministic approach will be used to establish ground-motion conditions to be considered in the next phase of design (advanced conceptual design) and, if appropriate, in the final design. This approach is suited to the determination of detailed ground-motion conditions that would likely be produced by postulated earthquakes and underground nuclear explosions (UNEs) including the amplitude and duration of shaking over the frequency band relevant to design. Because source events that will be postulated are not likely to change as more refined fault data become available, the resulting motions are expected to provide a stable basis for use in design.

The probabilistic approach will be used to characterize the range of possible seismic-source interpretations as constrained by contemporary knowledge about the local tectonic framework, including uncertainties. In addition to the cause-and-effect relationships basic to the deterministic approach, the probabilistic approach facilitates consideration of the full range of potential source events (e.g., earthquakes of varying magnitude and distance) in conjunction with probability estimates that the various source events will occur (e.g., spatially varying recurrence relationships for earthquakes of varying magnitude) and probability estimates that a particular outcome will result from the various source events, assuming they do occur. The probabilistic approach will explicitly quantify the effect of including uncertainty in interpretations on the estimated seismic hazard.

The current plan is to apply probabilistic methods for evaluating adequacy of deterministic final results. These methods will also be useful for constraining the technical judgments required for postulating deterministic source events and to help focus field investigations on the resolution of those conditions most relevant to satisfying the performance and design requirements. Probabilistic methods will also be used to provide input for the assessment of risk of accidental release of radionuclides.

Review of the local tectonic environment

Consideration of local faults with evidence of movement during the Quaternary period (about the last 2 million years) is essential to the characterization of the potential for fault displacement and vibratory ground motions at the site of repository facilities. Fault data that are particularly relevant to the characterization approach are reviewed here; more detailed information is presented in Section 1.3.2.2.2.

Figure 8.3.1.17-2 shows north-trending faults with evidence of Quaternary movement on both the east and west side of Yucca Mountain. Midway Valley, the proposed location of the waste handling facilities on the east side of Yucca Mountain, is bounded to the east and west, respectively, by the Paintbrush Canyon and Bow Ridge faults. The Solitario Canyon fault passes just west of the proposed underground facilities, and the Windy Wash fault lies a few kilometers farther to the west. The Ghost Dance fault, on the east side of the repository block, may not have moved in the Quaternary, but evidence confirming this has not yet been obtained.

It is possible that other faults in the site area have experienced movement during the Quaternary period. (The site area is defined for this section as the rectangular area 237 km^2 (91 mi^2) encompassing the central Yucca Mountain block and its structural and physiographic boundaries (Fortymile Wash, Yucca Wash, Solitario Canyon, and the Stagecoach Road fault.) These faults include the northeast-trending Stagecoach Road and Rock Valley faults and postulated detachment faults (the Rock Valley fault, outside the area shown in Figure 8.3.1.17-2, is discussed in Section 8.3.1.17.4.4). The approach discussed here for evaluating faulting and ground motion potential is intended to include conservative characterizations of such faults. As yet unidentified Quaternary faulting is particularly likely at the southern extent of the site area, as discussed subsequently.

The Paintbrush Canyon, Bow Ridge, Solitario, and Windy Wash faults show evidence of normal dip-slip movement along surfaces that dip steeply to the west (see Figure 1-32 of Section 1.3.2.2.2). The lengths of these faults have not been precisely determined, either because their projected trace is obscured by late Quaternary deposits without recognized geomorphic expression of the faults, or because potential linkages between discrete faults segments have not been unambiguously established. However, on the basis of published mapping, the length of the Paintbrush Canyon fault is inferred to be 17 to 31 km, the Bow Ridge fault 10 to 19 km, the Solitario Canyon fault 15 to 17 km, and the Windy Wash fault 6 to 19 km (Table 1-8, Section 1.3.2.2.2). The Paintbrush Canyon fault could be longer than the estimate given above if it links at its southern end to the Stagecoach Road fault (Figure 8.3.1.17-2).

Quaternary deposits are demonstrably offset by the faults at scattered localities along their trace. Preliminary study of the faults at a few of

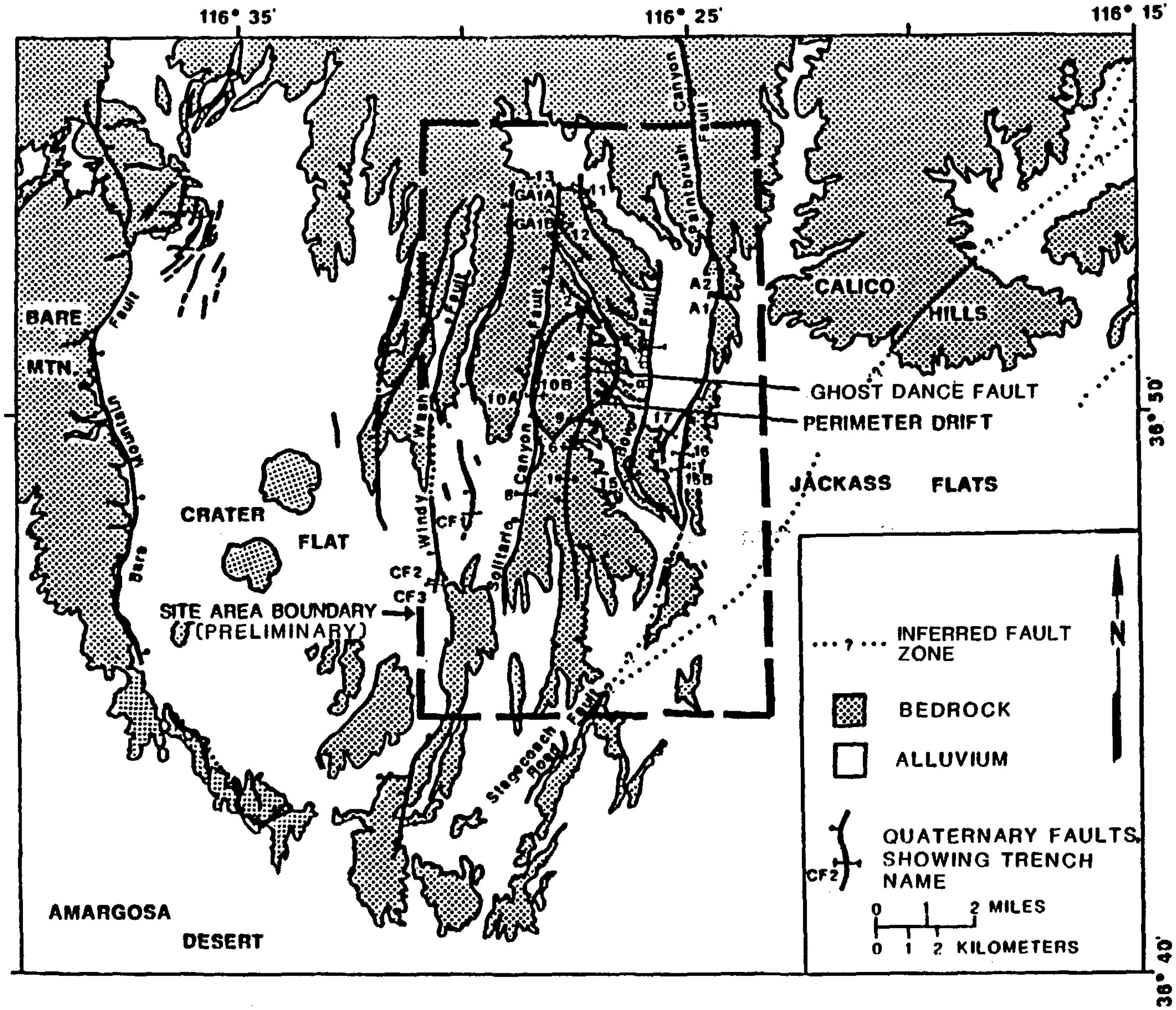

Figure 8.3.1.17-2. Quaternary normal faults and postulated detachment faults on or near Yucca Mountain. Modified from Swadley et al. (1984), USGS (1984), and Reheis (1986).

these localities, using trenching and dating of offset Quaternary deposits, indicates that reliably dated middle-to-late Quaternary soils have been offset by dip-slip movement on the faults at rates up to approximately 0.01 mm/yr. Uncertainty in slip-rate values exists due to uncertainty in the age of soil layers, particularly ash layers. Slip-rate values will have to be revised if new age dates become available. Lateral offset of Quaternary deposits that indicate a strike-slip component of fault movement have not been recognized but cannot be ruled out on the basis of available data.

The Paintbrush Canyon fault, which dips under Midway Valley, is particularly important for evaluating the potential for future vibratory ground motion at the proposed site of the waste-handling facilities. Considering the length and nature of this fault, it could have been the source of moderate earthquakes (M 6.5) in the past, although such events would appear to be rare based on the low rate of movement. Assuming the Quaternary rate of displacement for the Paintbrush Canyon fault is about 0.01 mm/yr, the recurrence time between magnitude 6.5 earthquakes on this fault should be about 50,000 yr (Slemmons and Depolo, 1986). If larger-magnitude earthquakes were postulated for this feature, their recurrence times would be longer. Long recurrence intervals appear to be typical of the local faults (Sections 1.3 and 1.5). Whitney et al. (1986) have estimated the recurrence interval between faulting events on the Windy Wash fault to be about 70,000 yr. Further investigations will be performed to test this conclusion.

The Bare Mountain fault, about 18 km west of Midway Valley, appears to be a more likely source of a moderate earthquake than the local faults (Section 1.4.2). Dated displacements presented in Table 1-8 indicate that this fault appears to be over ten times as active as the local faults. Thus, the Bare Mountain fault may be a significant contributor to probabilistic assessments of future ground motions at the site. Also, this fault, which dips eastward and southeastward (along its northern extent), may be tectonically linked at depth to the local faults (which dip to the west) via a detachment fault or graben structure.

The east-west spacing between adjacent local faults, illustrated in Figure 8.3.1.17-2, is less than their mapped lengths, and less than the 10 to 15 km thickness of the seismogenic zone found in this area (Section 1.4). The close proximity of the local faults suggests the possibility of interconnections at depth, most notably between the Paintbrush Canyon and the Bow Ridge faults, which appear to converge near their southern extent. One important hypothesis is that the local north-trending faults flatten with depth and merge into a detachment fault that dips gently to the west (Section 1.3.2). Another possibility that must also be considered is that the local faults continue downward at a steep dip through the seismogenic zone with possible interconnections at intermediate depths. Until such uncertainties are resolved, the evaluation and characterization of potential ground motion and faulting at the site must allow for alternate interpretations of the local tectonics.

Considerations of volcanic activity

A volcanic eruption within close proximity to the repository facilities could be highly disruptive. Current estimates described in Section 1.5.1.2.3 indicate that the probability of such an event is well below that considered to be significant for the preclosure time period. Additional work will be conducted under the postclosure tectonics program (Investigation 8.3.1.8.1) to develop increased confidence in the probability estimates for a local eruption.

Significant deposition of volcanic ash on the surface of the repository could temporarily disrupt operations. However, the nearest silicic volcanism during the Quaternary is at the margins of the Great Basin (Crowe et al., 1983b). A thousand-year ash-fall event will be characterized, but because of the considerable distances and infrequent occurrences, the event is not expected to be a significant design factor.

Tables 8.3.1.17-1a and 8.3.1.17-2a show information on ash fall thickness and particle size distribution for the design of ventilation systems for the surface and underground facilities, respectively. Analyses will be conducted using data already available in the literature (Investigation 8.3.1.17.1). Probabilistic methods will be used to characterize the results.

Consideration of fault displacement

As noted previously, faults with evidence of Quaternary displacement are present in the site area, and the possibility exists that additional, undetected faults may also be present. Significant displacement on a fault or along a distributed zone of faulting immediately adjacent to repository facilities could disrupt operations and damage facilities. Performance and design issues require characterization of the potential for fault displacement at the proposed site for surface facilities that are considered important to safety (Table 8.3.1.17-3a) and at the location of the underground facilities (Table 8.3.1.17-4a). Currently, the waste handling facilities are the only surface facilities considered to be important to safety (Section 6.2).

Faulting considerations are particularly important for establishing a suitably stable site for the waste handling facilities, currently planned for Midway Valley. The concern is for avoiding relative displacement at the base of the structural foundation in excess of a few inches; smaller displacement is not expected to cause serious damage. The primary goal expressed in Table 8.3.1.17-3a is to demonstrate, with a high degree of confidence, that there is less than a one-percent chance of exceeding 5 cm of net (combined dip-slip and strike-slip) fault displacement at the site of the waste handling facility in 100 yr. Displacements less than 5 cm are not expected to cause serious damage to waste-handling facilities, based on preliminary, conservative engineering judgment.

This goal, which establishes the maximum allowable annual probability for exceeding 5 cm of fault displacement at 10^{-4}/yr, appears to be consistent with safety considerations for this and other types of facilities. For example, comparable and higher annual probabilities have been found to be acceptably conservative for the seismic designs of nuclear power plants to withstand vibratory motions (Reiter and Jackson, 1983). While this comparison is not analogous in several respects, the risk resulting from fault displacements in excess of 5 cm at the site of the waste handling facilities is probably less than the risk resulting from vibratory ground motions that exceed the design basis for a nuclear power plant, and, therefore, the comparison does provide a useful check on the acceptance goal for faulting.

Another useful comparison can be made with criteria used to identify repository structures, systems, and components considered important to safety. Importance to safety is established if the probability of failure is greater than 10^{-5}/yr and if the failure would lead to radiation exposures of 0.5 rem or greater at or beyond the restricted area (Laub and Jardine, 1987). The annual probability that failure of this magnitude would result from faulting is expected to be less than 10^{-5}/yr for a site in which the annual probability for 5 cm of displacement is less than 10^{-4}/yr. This line of reasoning indicates that the goal for siting the waste handling facilities provides adequate safeguards to avoid areas of potentially significant faulting.

Additional field data are needed to achieve the required high degree of confidence in the determination of faulting probabilities. This need is indicated in Table 8.3.1.17-3b in which the current confidence in the values of the characterization parameters is considered to be low and the needed confidence is generally high.

Significant faulting is sometimes accompanied by sympathetic displacement at other locations. The first consideration then is to identify and characterize those faults within 5 km that could have significant impact on faulting at the proposed site. Geomorphic and other evidence that a Quaternary fault might trend toward Midway Valley in the vicinity of the site will be evaluated and characterized. Additional information will be obtained on the properties of the Paintbrush Canyon fault, which dips under the east side of Midway Valley, to evaluate the possibility of it becoming listric at shallow depth. Midway Valley will be carefully examined for geomorphic evidence of faulting, and trenching may be required to confirm the existence of suspected faults at distances up to one kilometer or more from the proposed site.

The most important data for constraining the possibilities for faulting at facilities important to safety are expected to come from extensive field investigations in the immediate site vicinity. Geologists will work with engineers in siting the waste-handling facilities to ensure that adequate stability is provided with respect to the possibility of faulting. The design parameter gives preliminary guidance on the distance (100 m) detailed studies (continuous trenching) should extend from the location of facilities important to safety and the accuracy that these studies should have in recognizing faulting. The parameters were selected so that any significant displacement resulting from faulting or deformation associated with main, branch, or secondary faulting in the vicinity of the surface facilities important to safety would be recognized and evaluated. Preliminary surveys may include small test pits or trenches to evaluate the stratigraphy and the possibility of previous local faulting. One or more trenches will be excavated across the site (or adjacent to the site) and extended to the east and the west beyond the proposed boundaries of the waste handling building. While the exact length of these trenches is yet to be determined, it is anticipated that at least one trench will be hundreds of meters long. It is anticipated that these exploratory trenches will intersect surficial units that were deposited at least 100,000 yr ago (based on the results of mapping by Swadley et al., 1984). Cross section B-B′ in Scott and Bonk (1984) indicates that the alluvium of Midway Valley varies in thickness from zero meters at Exile Hill on the west side of the valley, to an undetermined amount in the valley center, to about 50 m in borehole UE-25 WT#5 near the Paintbrush Canyon fault on the east side of the valley.

The assessment of the total probability of faulting beneath facilities important to safety will consider the preliminary probability of significant faulting, before the results of the detailed site (trenching) studies are available, the probability that a normal or strike-slip fault capable of producing significant offset could go undetected by the trenching program, and the probability of new faulting. The preliminary probability of faulting will be assessed considering such factors as the regional density and nature of Quaternary faulting, concealed extensions of nearby Quaternary faults, secondary faulting associated with rupture on nearby faults, tectonic interrelationships between local faults, and rates of regional seismic moment release and regional crustal deformation. The exact methodology for integrating the information discussed above and estimating the total probability of faulting beneath facilities important to safety will be developed as part of site characterization. Very likely a number of different approaches using different types of information will be used and the results compared.

A final assessment of surface faulting probabilities at locations of facilities important to safety (FITS) will be prepared when detailed site studies are completed. Displacement amplitudes will be estimated for annual probabilities ranging from 10^{-2} to 10^{-6} or less per year for use in risk assessments.

Faulting conditions for underground facilities will also be evaluated. The primary issue here is that significant fault displacement could disrupt normal operations or impede execution of the option for waste retrieval.

The first requirement presented in Table 8.3.1.17-4a is to identify and characterize late Quaternary faults within close proximity of the proposed underground facilities. This requirement is to aid in developing the layout and design of underground facilities. The second part of the table notes that current data provide low to moderate confidence that two such faults exist; namely, the Bow Ridge fault and the Solitario Canyon fault. Further work is required to provide added confidence that there are no additional late Quaternary faults in this area.

A further requirement is presented in Table 8.3.1.17-4a to identify, characterize, and locate at the repository horizon any fault with greater than a one-percent chance of displacing more than 7 cm in the area of waste emplacement during the preclosure period. This requirement is to ensure viability of the waste-retrieval option. Less than 7 cm of fault displacement is not expected to significantly impact normal retrieval operations because the diameter of the waste package will be about 7.6 cm smaller than the diameter of the emplacement hole (See Section 8.3.2.5). Larger displacements might bind or shear the waste packages thereby creating off-normal conditions for waste retrieval.

Assuming a preclosure period of 100 yr, the requirement just discussed is to identify, characterize, and locate at depth any fault passing through the area of waste emplacement that has an annual probability greater than 10^{-4}/yr for displacing more than 7 cm. Assuming event recurrences are random in time, the average rate of slip for such a fault would need to be considerably larger than 7 cm per 10^4 yr (i.e., 0.007 mm/yr) to account for excess displacement from events that produce less than and more than 7 cm. Accordingly, the screening criterion presented in Table 8.3.1.17-4b for locating faults in the underground, an average Quaternary slip rate greater than 0.005 mm/yr, provides considerable margin with respect to requirements presented in part a of this table.

As noted above, the Bow Ridge fault and the Solitario Canyon fault are late Quaternary faults within close proximity to the proposed underground facilities. The Bow Ridge fault crosses the planned access ramp that enters the repository block from the east. The rate of Quaternary displacement for the Bow Ridge fault is not well constrained. However, assuming the rate of activity is similar to other faults in the area, long recurrence intervals between faulting events would be expected. For example, Whitney et al. (1986) have identified four faulting sequences within about 270,000 yr on the Windy Wash fault, giving an average recurrence interval of about 70,000 yr between faulting events (Section 1.3.3.3.3). Preliminary estimates, assuming the local Quaternary faults have a similar rate of activity, indicate that the annual probability for exceeding 10 cm of displacement on faults such as the Bow Ridge fault is about 1 x 10^{-5}/yr (URS/Blume, 1987). Additional field investigations will be conducted to develop more information about the characteristics of this fault, particularly with respect to its Quaternary rate of activity. Design measures are being implemented to minimize possible fault-induced damage and to facilitate rapid repair in the unlikely event that movement should occur on this fault during the preclosure period.

The western boundary of the underground facilities will extend to the proximity of the Solitario Canyon fault, which is known to have Quaternary displacement. As with other local faults, the probability for experiencing significant displacement during the preclosure period appears to be well below that required by considerations for waste retrieval. Additional investigations will be conducted to further constrain fault characteristics, particularly the possibility of extension of the Solitario Canyon fault into the repository block.

Analyses will be performed to estimate the total probability for experiencing significant fault movement anywhere in the underground facilities during the preclosure period. These estimates will consider possible effects from known and unknown faults in the area.

Consideration of vibratory ground motion

Repository facilities will be designed and constructed to withstand the effects of vibratory ground motions. Conventional standards will be used for most facilities; however, more conservative design measures will be used for those facilities considered important to safety, specifically the waste handling facilities. Thus, the requirement is to determine ground-motion characteristics for consideration in the design of facilities important to safety.

Performance and design requirements for characterizing the potential for vibratory ground motion are presented in Table 8.3.1.17-5a. The design-basis ground motions are to be characterized for frequencies significant to facilities important to safety such that there is less than a 10-percent chance for being exceeded during 100 yr. Accordingly, the design-basis motions are to have an annual excedance probability less than 10^{-3}/yr, which translates to an average recurrence period greater than 1,000 yr. This goal appears to be consistent with the level of conservatism used for other facilities with important considerations for safety.

An important precedent is provided by nuclear power plants where annual probabilities for exceeding the design-basis motions have been found to be on the order of 10^{-3}/yr to 10^{-4}/yr for several operating plants (Reiter and Jackson, 1983).

Based on current understanding of design needs, the approach that has been developed here uses both deterministic and probabilistic methods to their best advantage. The role of the deterministic approach is primary. It provides the level of detail needed by design engineers in the characterization of ground motions. The probabilistic approach provides a logical, structured procedure for integrating the range of possible earthquakes that contribute to the ground-motion hazard at the site. This capability will be used to guide, test, and substantiate the deterministic analyses. Sensitivity analyses will be performed using probabilistic methods to evaluate the effect of uncertainties on the ground motion potential. Results from these analyses will be used to help focus field investigations toward refinement of those seismic parameters that most strongly influence ground-motion potential at the site. In addition, probabilistic methods will be used as needed to provide input for the assessment of risk of accidental release of radionuclides.

Vibratory ground motions at the site can result from natural earthquakes on local and regional faults, and from underground nuclear explosions (UNEs) detonated at the Nevada Test Site. Much of the discussion to follow on the current approach for developing design-basis ground motions focuses on issues of natural earthquakes. The deterministic methods that will be applied for analyzing ground motions from UNEs parallel, in most respects, those described for dealing with natural earthquakes.

The ground-motion potential near Yucca Mountain differs considerably from that in much of California where a major portion of the relative plate motions are being accommodated, and also from that in the true plate interior regions of the midwestern and eastern U.S. There is an abundance of faults local to the site, but their rate of movement appears to be low. On the basis of fault data and historical seismicity, severe earthquakes are probably not as common in the vicinity of Yucca Mountain as in the more active regions surrounding much of the Great Basin.

To adequately characterize the local earthquake hazards, some of the terminology and procedures used in characterizing potential ground motions elsewhere are being refined to meet the needs of a waste repository. For example, in the determination of design ground motions for some types of critical facilities, professional practice has been to define maximum earthquake magnitudes with the understanding that a larger earthquake magnitude may be possible, although very unlikely. This practice is being made more explicit for characterizing this site. In particular, 10,000-yr cumulative slip earthquakes will be identified for consideration in repository design. A 10,000-yr cumulative slip earthquake is defined here to be an earthquake that, occurring every 10,000 yr, would produce the observed or estimated average Quaternary slip rate on a fault. A detailed discussion of the concept is provided in the description of Activity 8.3.1.17.3.1.2.

An important advantage of this refinement is that a 10,000-yr cumulative slip earthquake magnitude, being associated with a particular recurrence interval, can be determined with greater confidence than a true maximum magnitude. Because large earthquakes occur infrequently, few observational data are available for calibrating the maximum seismogenic potential of individual faults. This is particularly true for faults of the type found in the southern Great Basin, where recurrence intervals for large earthquakes appear to range from about 10,000 to 100,000 yr (Section 1.4.2). Therefore, conventional methods for determining maximum earthquake magnitudes from the physical characteristics of local faults appear to be subject to larger uncertainties than for the more active faults associated with plate motions. Use of slip-rate data (to constrain recurrence times) in conjunction with more conventional fault data provides added assurance that adequately conservative assessments of the local seismogenic potential will be accomplished.

The planned procedure for characterizing potential ground motions at the site is as follows: First, the active surface faults and potentially active fracture zones at depth that could produce locally severe ground motions will be identified. Second, 10,000-yr cumulative slip earthquakes, as defined previously, will be determined. Third, controlling earthquakes will be identified as those 10,000-yr cumulative slip earthquakes that produce the most severe motions at the site. The resulting vibratory ground motions will then be characterized by a suite of representative time histories and response spectra that have been scaled to the magnitudes and distances of the controlling earthquakes and modified, as needed, to account for the effects of local site geology. A suite of representative strong-motion records may be needed for more than one controlling earthquake, to cover the possibility that different source regions could control ground motions at the site in different frequency bands.

To characterize potential ground motions from UNEs, a similar procedure will be followed. First, the possible locations and upper limits on the yields of future UNEs at the Nevada Test Site will be identified. With this information, the maximum UNEs with respect to generating ground motions at the site will be determined. If the resulting site ground-motion estimates are comparable to those for the controlling earthquake sources, the UNE ground motions will be further characterized by a suite of representative time histories and spectra.

Preliminary evaluations of potential earthquake sources in the vicinity of Yucca Mountain have identified several local faults as long as 20 km or more. If, as is currently planned, the waste handling facilities were located on Midway Valley, the controlling source would appear to be the north-south trending Paintbrush Canyon fault, which bounds Midway Valley on the east. The closest approach of the Paintbrush Canyon fault to the proposed site of the waste handling facilities is about one kilometer. This fault may be capable of producing a moderate earthquake (M about 6.5) with a recurrence interval greater than ten thousand years. Site characterization will determine which fault or faults control the ground motion at frequencies within the range of engineering interest.

Because the annual probability for the controlling earthquake is expected to be low (less than about 10^{-4}, assuming the Paintbrush Canyon fault is controlling), and because the components required to contain radioactive materials within the waste-handling building can be expected to survive ground motions more severe than those used for design, ample conservatism can be achieved by using the most probable motions from the 10,000-yr cumulative slip earthquake(s) on the controlling earthquake source(s) as the basis for seismic design. Probabilistic calculations will be performed to test and verify that the resulting ground motions exceed the thousand-year estimate from the combined hazard from natural earthquakes and underground nuclear explosions.

Alternative conceptual models

As discussed in the overview of the site characterization program (Section 8.3.1.1), hypothesis-testing tables have been constructed that summarize (1) the current hypotheses regarding how the site can be modeled and how modeling parameters can be estimated; (2) the uncertainty associated with this current understanding, including alternative hypotheses which are also consistent with available data and that may compose an alternative conceptual model; (3) the significance of alternative hypotheses; and (4) activities or studies which are designed to discriminate between alternative hypotheses or to reduce uncertainty. Tables 8.3.1.17-7 and 8.3.1.17-8 summarize current understanding in the modeling of local and regional tectonics, respectively, that is being performed as part of the preclosure tectonics site program. Integration of information from different disciplines is often necessary to comprehensively evaluate alternative hypotheses. Accordingly, the hypothesis-testing tables for each site program call for information from studies and activities in other programs, as appropriate.

To help ensure comprehensiveness of the hypotheses considered in Tables 8.3.1.17-7 and 8.3.1.17-8, hypotheses for preclosure tectonics modeling have been divided into elements or components that describe the physical domain defined by the model, the driving forces/processes that influence the behavior of the model, the boundary conditions that affect the model, the system geometry of the physical components of the model, and a series of elements that describe the system response/dynamics of the model in response to its driving forces, boundary conditions, and system geometry. These elements are listed in column one.

The second column of the tables lists the current representations for each model element in the form of hypotheses that are based on currently available data.

The third column in Tables 8.3.1.17-7 and 8.3.1.17-8 provides a judged level of uncertainty designated "high," "moderate," or "low" associated with the current representation for each element. A brief rationale for the judgment is also given.

Table 8.3.1.17-7. Current representation and alternative hypotheses for local model for the preclosure tectonics program (page 1 of 7)

Current representation		Uncertainty and rationale	Alternative hypothesis	Significance of alternative hypothesis				Studies or activities to reduce uncertainty
Model element	Current representation			Performance measure, design or performance parameter	Needed confidence in parameter or performance measure	Sensitivity of parameter or performance measure to hypothesis	Need to reduce uncertainty	
Physical domain	Area extending 25 km from boundary of controlled area	Low-medium--events or processes outside preferred domain unlikely to affect facility design or waste isolation in the controlled area[a]	Area extending >25 km from boundary of controlled area	Design-basis ground motion time histories and corresponding response spectra for facilities important to safety (FITS)	Medium to high	Medium--potential events that control ground-motion design are probably in or near the controlled area	Medium--need to determine distance that tectonic events could influence performance in controlled area	8.3.1.17.4.12.2, 8.3.1.8.1.1.4, 8.3.1.17.3.5.1
				Probability of faulting with displacements over 5 cm in repository and at location of faciltities important to safety	Medium to high	Low--only faulting or deformation at repository and facilities impor- to safety significant	Low--size of domain does not significantly affect	8.3.1.17.2.1.1, 8.3.1.17.2.1.2
Driving forces/ processes	Mechanically driven through plate interaction of local and regional structures	Low--geophysical, geochemical, and heat flow data support preferred hypothesis	Thermally driven through mantle convection cell Combination of thermal and mechanical driving forces	Combined potential for vibratory ground motion at facilities important to safety considering all faults	Medium to high	Low-medium--mantle convection (incipient rift) hypothesis could affect faulting rate	Low--existing data generally sufficient to differentiate	8.3.1.17.4.12.2

Table 8.3.1.17-7. Current representation and alternative hypotheses for local model for the preclosure tectonics program (page 2 of 7)

Current representation: Model element	Current representation: Current representation	Uncertainty and rationale	Alternative hypothesis	Significance of alternative hypothesis: Performance measure, design or performance parameter	Significance of alternative hypothesis: Needed confidence in parameter or performance measure	Significance of alternative hypothesis: Sensitivity of parameter or performance measure to hypothesis	Significance of alternative hypothesis: Need to reduce uncertainty	Studies or activities to reduce uncertainty
Boundary conditions	Horizontal strains must be consistent with Quaternary Pacific-North American plate movement history and regional controls that affect the distribution of strain in the region surrounding the domain Vertical strains--no boundary condition specified	Low--no alternatives available	(No alternative, but need to reduce uncertainty)	Combined potential for vibratory ground motion at facilities important to safety considering all faults	Medium to high	High--local strain rates will affect faulting probabilities, size of events	Medium--strain rates in the local domain will affect faulting rates and probabilities	8.3.1.17.4.12.2
				Probability of faulting with displacement over 5 cm in repository and at location of facilities important to safety	Medium to high	Same as above	Same as above	8.3.1.17.4.12.2
System geometry	Brittle crust--15 km thick, underlain by ductile lithosphere Brittle crust is cut by inactive and active faults of various orientations Ductile crust and underlying mantle are relatively passive elements	Low--geophysical and heat flow data provide some support for preferred hypotheses	Convection cell in mantle introduces heat and strain into brittle crust and results in crustal thinning (Death Valley-Pancake Range zone is incipient rift)	Combined potential for vibratory ground motion at facilities important to safety considering all faults	Medium to high	Low-medium--mantle convection hypotheses could affect faulting rate	Medium--existing data nearly sufficient to differentiate	8.3.1.17.4.12.2, 8.3.1.17.4.3.1

Table 8.3.1.17-7. Current representation and alternative hypotheses for local model for the preclosure tectonics program (page 3 of 7)

Current representation: Model element	Current representation: Current representation	Uncertainty and rationale	Alternative hypothesis	Significance of alternative hypothesis: Performance measure design or performance parameter	Needed confidence in parameter or performance measure	Sensitivity of parameter or performance measure to hypothesis	Need to reduce uncertainty	Studies or activities to reduce uncertainty
			SYSTEM RESPONSE/DYNAMICS					
Faulting geometry and mechanisms	No hypothesis selected (one or more alternative hypotheses may apply to domain)	High--no data on on subsurface geometry of local faults, no measurements of strike-slip component of movement	Faults in the domain are Planar-rotational faults (north-trending faults in domain are planar normal and extend to base of brittle crust) Detachment faults (north-trending faults in domain are listric, merging with west-dipping low-angle extensional fault at or below base of Tertiary), NE trending strike-slip are shallow features that mark the boundaries of detached faults	Design-basis ground-motion time histories and corresponding response spectra for facilities important to safety	Medium to high	High--local fault geometries could significantly affect ground-motion and fault slip estimates	High	8.3.1.17.4.7.1, 8.3.1.17.4.6.2, 8.3.1.17.4.4, 8.3.1.17.4.5, 8.3.1.17.4.2.2, 8.3.1.17.4.1.2, 8.3.1.4.2.3.1
				Combined potential for vibratory ground motion at facilities important to safety	Medium to high	Same as above	High	Same as above
				Probability of faulting with displacements over 5 cm in repository and at location of facilities important to safety	Medium to high	Same as above	High	Same as above

Table 8.3.1.17-7. Current representation and alternative hypotheses for local model for the preclosure tectonics program (page 4 of 7)

Current representation: Model element	Current representation: Current representation	Uncertainty and rationale	Alternative hypothesis	Significance of alternative hypothesis: Performance measure, design or performance parameter	Needed confidence in parameter or performance measure	Sensitivity of parameter or performance measure to hypothesis	Need to reduce uncertainty	Studies or activities to reduce uncertainty
SYSTEM RESPONSE DYNAMICS (continued)								
Faulting geometry and mechanisms (continued)			Part of Walker Lane system (faults in domain are part of or related to an en echelon system of NW and NE-trending right- and left-lateral fault strands that have a significant strike-slip component of movement; faults are high angle and extend to base of brittle crust)					
			Related to a strike-slip fault concealed beneath a detached upper fault plate					
			Normal faults resulting from incipient rifting along the Death Valley-Pancake Range zone due to thermally driven processes					

Table 8.3.1.17-7. Current representation and alternative hypotheses for local model for the preclosure tectonics program (page 5 of 7)

Current representation		Uncertainty and rationale	Alternative hypothesis	Significance of alternative hypothesis				Studies or activities to reduce uncertainty
Model element	Current representation			Performance measure, design or performance parameter	Needed confidence in parameter or performance measure	Sensitivity of parameter or performance measure to hypothesis	Need to reduce uncertainty	
				SYSTEM RESPONSE DYNAMICS (continued)				
Fault activity	Some faults in and near the controlled area have been active in Quaternary time	Low--trenching data show Quaternary activity	None identified	Design-basis ground-motion time histories and corresponding response spectra for facilities important to safety	Medium to high	High--presence of Quaternary faulting increases design and performance assessment concerns related to faulting	None	None
				Probability of faulting with displacements over 5 cm in repository and at location of facilities important to safety	Medium to high	Same as above	None	None
Faulting rates	Slip rates on faults near the controlled area are low (<0.01 mm/yr) with long recurrence intervals (>10,000 yr	Medium--no direct measurements of strike-slip component	Slip rates are higher because of an unrecognized component of strike-slip faulting	Design-basis ground-motion time histories and corresponding response spectra for facilities important to safety	Medium to high	High--slip rates important in estimating probability of various sized faulting	High	8.3.1.17.4.6.2, 8.3.1.17.4.4, 8.3.1.17.4.5, and 8.3.1.17.4.3.2
				Probability of faulting with displacements over 5 cm in repository and at location of facilities important to safety	Medium to high	Same as above	High	Same as above

Table 8.3.1.17-7. Current representation and alternative hypotheses for local model for the preclosure tectonics program (page 6 of 7)

Current representation		Uncertainty and rationale	Alternative hypothesis	Significance of alternative hypothesis				Studies or activities to reduce uncertainty
Model element	Current representation			Performance measure, design or performance parameter	Needed confidence in parameter or performance measure	Sensitivity of parameter or performance measure to hypothesis	Need to reduce uncertainty	
				SYSTEM RESPONSE/DYNAMICS (continued)				
Fault rupture pattern	No hypothesis selected	High--current data insufficient to choose among possible alternatives	Individual faulting events are confined to single fault strands on the north-trending faults around the site	Design-basis ground motion time histories and corresponding response spectra for facilities important to safety	Medium to high	High--nature of single event displacements significant in estimating earthquake magnitude and probability of faulting	High	8.3.1.17.4.6.2, 8.3.1.17.4.4, 8.3.1.17.4.5, 8.3.1.17.4.3.2
			Movement occurs on several parallel north-trending faults during a single faulting event	Probability of faulting with displacements over 5 cm in repository and at location of facilities important to safety	Medium to high	Same as above	High	Same as above
			The north-trending faults are secondary faults or splays off a larger fault (major strike-slip or detachment feature) and move at the same time movement occurs on the larger fault	Same as above	Medium to high	Same as above	High	Same as above

Table 8.3.1.17-7. Current representation and alternative hypotheses for local model for the preclosure tectonics program (page 7 of 7)

Current representation		Uncertainty and rationale	Alternative hypothesis	Significance of alternative hypothesis				Studies or activities to reduce uncertainty
Model element	Current representation			Performance measure, design or performance parameter	Needed confidence in parameter or performance measure	Sensitivity of parameter or performance measure to hypothesis	Need to reduce uncertainty	
			SYSTEM RESPONSE/DYNAMICS (continued)					
Distribution of seismic potential	Ground-motion hazard is controlled by moderate earthquakes on faults in and near the the controlled area	Low--presence of surface fault rupture on local faults shows events are large enough to overshadow underground nuclear explosions and large distant sources	Underground nuclear explosions and large distant earthquakes are significant factors that also control facility ground-motion design	Design-basis ground-motion time histories and corresponding response spectra for facilities important to safety	Medium to high	Medium--alternatives to preferred hypothesis would probably produce lower ground motion design values	Low	8.3.1.17.3.3, 8.3.1.17.3.5.1, 8.3.1.17.3.2, 8.3.1.17.3.1.1, 8.3.1.17.4.5
			Local faults are detachments on which movement is aseismic resulting in a different basis for assessing ground-motion hazard	Combined potential for vibratory ground motion at facilities important to safety considering all faults	Medium to high	Same as above	Low	Same as above
Adequate seismic design basis	A deterministic model based on a 10,000-yr cumulative-slip earthquake provides an adequate basis for design of surfacilities important to safety	Low--10,000-yr design events adequately conservative for facilities important to safety with a <100-yr design life; recurrence of safe shutdown earthquake for reactor design generally about 1,000 to 5,000 yr; facilities important to safety pose lower hazard than reactor	A probabilistic 1,000 a probabilistic model provides a reasonable basis for design A deterministic model based on a "maximum" credible earthquake provides a reasonable basis for design	Design-basis ground-motion time histories and corresponding response spectra for facilities important to safety	Medium to high	High--would change basis for estimating ground-motion hazard for facility design	High--requires consensus on relative hazard posed by facility and acceptable design approach	8.3.1.17.3.6, 8.3.1.17.3.5.2

[a]Controlled area is the actual area chosen according to the 10 CFR 60.2 definition.

Table 8.3.1.17-8. Current representation and alternative hypotheses for the regional model for the preclosure tectonics program (page 1 of 5)

Current representation: Model element	Current representation: Current representation	Uncertainty and rationale	Alternative hypothesis	Significance of alternative hypothesis: Performance measure, design or performance parameter	Significance of alternative hypothesis: Needed confidence in parameter or performance measure	Significance of alternative hypothesis: Sensitivity of parameter or performance measure to hypothesis	Significance of alternative hypothesis: Need to reduce uncertainty	Studies or activities to reduce uncertainty
Physical domain	Brittle crust, southern Great Basin	Low--regional processes outside model domain unlikely to affect site design or performance	NA[a]	Combined potential for vibratory ground motion at facilities important to safety considering all faults	Medium to high	Low--events outside of model domain unlikely to affect potential ground motion	Low--processes outside domain unlikely to affect design or performance	8.3.1.17.4.12.2
				Design basis ash-fall thickness for facilties important to safety ventilation systems	Low to medium	Medium--volcanic events outside model domain may affect ash-fall probability	Same as above	8.3.1.17.4.12.2
Driving forces/ processes	Mechanical plate interaction	Low--geophysical, geochemical, and heat flow data support current representation	Mantle convection cell	Combined potential for vibratory ground motion at facilities important to safety considering all faults	Medium to high	Low-medium--mantle convection hypothesis could affect faulting rate	Low--existing data generally sufficient to differentiate	8.3.1.17.4.12.2

Table 8.3.1.17-8. Current representation and alternative hypotheses for the regional model for the preclosure tectonics program (page 2 of 5)

Current representation: Model element	Current representation: Current representation	Uncertainty and rationale	Alternative hypothesis	Significance of alternative hypothesis: Performance measure, design or performance parameter	Significance of alternative hypothesis: Needed confidence in parameter or performance measure	Significance of alternative hypothesis: Sensitivity of parameter or performance measure to hypothesis	Significance of alternative hypothesis: Need to reduce uncertainty	Studies or activities to reduce uncertainty
Boundary conditions	Horizontal strains must be consistent with Quaternary Pacific-North American plate movement history Vertical strains-no boundary condition specified	Low--no alternatives available	None identified	Combined potential for vibratory ground motion at facilities important to safety considering all faults	Medium to high	Low-medium--regional strain rates influence faulting probabilities but local variations more significant	Low-existing data sufficient and increased accuracy probably not reasonably achievable	8.3.1.17.4.12.2
				Probability of faulting with displacement over 5 cm in repository and at location of facilities important to safety	Medium to high	Same as above	Same as above	8.3.1.17.4.12.2
System geometry	Brittle crust--15 km thick, underlain by ductile lithosphere Brittle crust is cut by inactive and active faults of various orientations Ductile crust and underlying mantle are relatively passive elements	Low--geophysical and heat flow data provide support for current representation	Convection cell in mantle introduces heat and strain into brittle crust and results in crustal thinning (Death Valley-Pancake Range zone is incipient rift)	Combined potential for vibratory ground motion at facilities important to safety considering all faults	Medium to high	Low-medium--mantle convection hypotheses could affect faulting rate	Medium--existing data nearly sufficient to differentiate	8.3.1.17.4.12.2 and 8.3.1.17.4.3.1

Table 8.3.1.17-8. Current representation and alternative hypotheses for the regional model for the preclosure tectonics program (page 3 of 5)

Current representation		Uncertainty and rationale	Alternative hypothesis	Significance of alternative hypothesis				Studies or activities to reduce uncertainty
Model element	Current representation			Performance measure, design or performance parameter	Needed confidence in parameter or performance measure	Sensitivity of parameter or performance measure to hypothesis	Need to reduce uncertainty	
			SYSTEM RESPONSE/DYNAMICS					
Regional faulting mechanisms	None selected	High--data do not support a single hypothesis; geologic and seismic reflection data indicate extensional model with detachments; data from historical earthquakes indicate planar normal faults with a strike-slip component and high-angle, deep-focus strike-slip faults	Regional extension dominates; any strike-slip motion is the result of extensional processes (e.g., detachment faulting with bounding shallow strike-slip faults) Strike-slip faulting is a primary feature that controls the Quaternary tectonics of at least part of the domain; a part of Pacific-North American right-lateral transform movement is communicated inland to Death Valley-Furnace Creek faults and Walker Lane; faulting results from right-lateral movement on en echelon strands of the Walker Lane, and dip-slip movement on N-to-NE trending normal faults connecting these strands	Design-basis ground motion time histories and corresponding response spectra for facilities important to safety	Medium to high	Medium--regional dynamics affect ground-motion estimates, but local faulting relationships more significant; regional models may allow a variety of local fault geometries	Medium--more important to reduce uncertainties about nature of local faulting for design and performance than to resolve faulting mechanisms throughout the domain	8.3.1.17.4.12.2, 8.3.1.17.4.3.1, and 8.3.1.17.4.3.2
				Combined potential for vibratory ground motion at facilities important to safety considering all faults	Medium to high	Same as above	Same as above	Same as above
				Probability of faulting with displacement over 5 cm in repository and at location of facilities important to safety	Medium to high	Same as above	Same as above	Same as above

Table 8.3.1.17-8. Current representation and alternative hypotheses for the regional model for the preclosure tectonics program (page 4 of 5)

Current representation		Uncertainty and rationale	Alternative hypothesis	Significance of alternative hypothesis				Studies or activities to reduce uncertainty
Model element	Current representation			Performance measure, design or performance parameter	Needed confidence in parameter or performance measure	Sensitivity of parameter or performance measure to hypothesis	Need to reduce uncertainty	
				SYSTEM RESPONSE/DYNAMICS (continued)				
Frequency and distribution of events	None selected	High--frequency and distribution of significant events across domain not well known	Volcanism and faulting in the domain are episodic; probability of events may be modeled as Poissonian Volcanism and faulting in the domain are cyclic; zones in the domain may be active for a period and then quiescent as activity migrates to another zone	Design-basis ground time histories and corresponding response spectra for facilities important to safety	Medium to high	Low-medium--variability of event occurrence probably great enough that Poissonian assumptions are sufficient even if processes are cyclic; cyclic hypotheses most significant if assumed site is in quiescent zone	Low-medium--hazard analyses will generally assume site is in active part of a cycle, and use the highest measured rate for a definable part of the Quaternary	8.3.1.17.4.12.2, 8.3.1.17.4.3.2, 8.3.1.8.5.1.5, 8.3.1.8.5.1.2
				Combined potential for vibratory ground motion at facilities important to safety considering all faults	Medium to high	Same as above	Same as above	Same as above
				Probability of faulting with displacements over 5 cm in repository and at location of facilities important to safey	Medium to high	Same as above	Same as above	Same as above

8.3.1.17.1 Investigation: Studies to provide required information on volcanic activity that could affect repository design or performance

Technical basis for obtaining the information

Link to technical data chapters and applicable support documents

The following sections provide a technical summary of existing data relevant to this investigation:

SCP section	Subject
1.3.2.1	Volcanic history
1.5.1	Volcanism
1.8.1.3.1	Significant results
1.8.1.3.2	Discussion of significant results
1.8.1.5.1	Significant results

Parameters

This investigation will provide the following characterization parameters related to potential ash fall at the site from distal silicic volcanic centers (Tables 8.3.1.17-1a, -1b, -2a, and -2b):

1. Probability of ash fall at the site as a function of ash-fall thickness.

2. Expected ash-fall thickness at the site in a 1,000-yr period.

3. Potential ash-fall particle densities and size distributions.

Investigation 8.3.1.8.1 (direct releases resulting from volcanic activity--postclosure) will provide the following characterization parameters related to the potential for a basaltic volcanic eruption at the site (Table 8.3.1.8-1):

1. Location and timing of volcanic events near the site.

2. Evaluation of structural controls on the occurrence of basaltic eruptions.

3. Presence of magma bodies in the vicinity of the site.

4. Effects of Strombolian eruptions.

5. Effects of hydrovolcanic eruptions.

Purpose and objectives of the investigation

Two types of volcanic hazards that could credibly affect preclosure repository performance will be characterized: (1) ash fall from distal silicic volcanic centers in the western Great Basin and (2) a basaltic volcanic eruption at the site. Ash fall is being addressed under preclosure tectonics because of its potential impact on surface and subsurface ventilation systems (dust filters). However, the study of basaltic volcanism in the site region will be conducted under the postclosure tectonics program (Section 8.3.1.8), because the probability of basaltic volcanism at the site is greater over the longer postclosure time frame. The probability of a basaltic volcanic eruption at the site during the preclosure period will be estimated there. No studies are planned of potential silicic volcanism in the site region because a silicic volcanic eruption at the site is not considered a credible event (Section 1.5.1).

The characterization parameters related to ash fall are being provided so that the filtration systems of the surface-facility and mining ventilation systems can be designed to accommodate potential ash falls at the site. The characterization parameters related to basaltic volcanism are intended to provide assurance that the probability of a volcanic eruption at the site is acceptably low (i.e., as interpreted here, less than one chance in 10,000 in 100 yr).

Technical rationale for the investigation

A logic diagram for the investigation of preclosure volcanic activity is presented in Figure 8.3.1.17-3. The potential for ash falls at the site from distal silicic volcanic centers will be addressed in Study 8.3.1.17.1.1. Since much work has already been published on silicic volcanism in the region, data will be compiled primarily through a literature survey in Activity 8.3.1.17.1.1.1. For the western Great Basin, locations of silicic volcanic center, rates and volumes of past eruptions, tephra dispersal patterns for past eruptions, and tephra particle-size, distributions in past eruptions will be compiled. The ash-fall potential at the site will be assessed by assuming that silicic volcanic eruptions are a stationary random process and, hence, that observed Quaternary rates and distributions can be projected into the future.

The potential ash-fall thickness at the site will be assessed in Activity 8.3.1.17.1.1.2 and expressed in terms of the characterization parameters listed in Tables 8.3.1.17-1a, -1b, -2a, and -2b. A probability-versus-thickness function will be estimated, and a particular ash-fall thickness that has less than one chance in 10 of occurring in 100 yr (i.e., a greater-than-1,000-yr ash fall) will be estimated for consideration in the design of mining and surface ventilation systems. The potential particle density and particle-size distribution of an ash fall at the site will be assessed in Activity 8.3.1.17.1.1.3.

The potential for a basaltic volcanic eruption to directly disrupt the repository is being addressed in Investigation 8.3.1.8.1, under postclosure tectonics. The probability of a basaltic eruption penetrating the repository will be estimated in Study 8.3.1.8.1.1, and the potential geologic effects of such an eruption on the site will be assessed in Study 8.3.1.8.1.2. The supporting activities and data requirements for these two studies are indicated in the logic diagram for Investigation 8.3.1.8.1 (Figure 8.3.1.8-3).

Table 8.3.1.17-8. Current representation and alternative hypotheses for the regional model for the preclosure tectonics program (page 5 of 5)

Current representation		Uncertainty and rationale	Alternative hypothesis	Significance of alternative hypothesis				Studies or activities to reduce uncertainty
Model element	Current representation			Performance measure, design or performance parameter	Needed confidence in parameter or performance measure	Sensitivity of parameter or performance measure to hypothesis	Need to reduce uncertainty	
				SYSTEM RESPONSE/DYNAMICS (continued)				
Extension rate and distribution	Average east-west extension rate across domain is about 1 cm per year in the Quaternary, but extension is concentrated in local zone	Medium--degree of localization of extension not well known	Average east-west extension rate across domain is about 1 cm per year in the Quaternary, and extension is evenly distributed across Great Basin	Combined potential for vibratory ground motion at facilities important to safety considering all faults	Medium to high	Low-medium--regional strain rates influence faulting probabilities but local variations more significant	Low--existing data on regional rates sufficient and increased accuracy probably not reasonably achievable; local model will assess local rates	8.3.1.17.4.12.2
				Probability of faulting with displacement over 5 cm in repository and at location of facilities important to safety	Medium to high	Same as above	Same as above	8.3.1.17.4.12.2

*NA = not applicable.

The fourth column describes alternative hypotheses to the current representation that are consistent with currently available data. As site characterization proceeds and more information becomes available, alternative hypotheses may be deleted or added or the current hypothesis may be revised and refined.

The fifth column indicates the performance measure or performance parameter that could be affected by the selection of hypotheses related to that element.

Column six gives the needed confidence in the indicated performance measure or performance parameter, as defined in the performance allocation tables.

The seventh column presents a judgment of the sensitivity of the performance parameters in column five to the selection of hypotheses in columns two and four of that element. The sensitivity is rated high if significant changes in the values of the performance parameter might occur if an alternate hypothesis were found to be the valid hypothesis for the system.

The eighth column presents a judgment on the need to reduce uncertainty in the selection of hypotheses. This judgment is based on the uncertainty in the current representation, the sensitivity of the performance parameters to alternative hypotheses, the significance and needed confidence of affected performance parameters, and the likelihood that feasible data-gathering activities could significantly reduce uncertainty.

The final column identifies the characterization studies or activities that will discriminate between alternative hypotheses or that will reduce uncertainties associated with the current representation for each model element.

Interrelationships of preclosure tectonics investigations

The interrelationships of the investigations in the preclosure tectonics site characterization program are shown in Figure 8.3.1.17-1. There are three analysis and assessment investigations that correspond to potentially disruptive volcanic activity, fault displacements, and vibratory ground motion, respectively. These three investigations are designed to provide the required characterization parameters. A fourth investigation comprises a number of data collection and synthesis activities that support one or more of the three analysis and assessment investigations.

Schedule information for Site Program 8.3.1.17 (preclosure tectonics) is presented in Section 8.3.1.17.5.

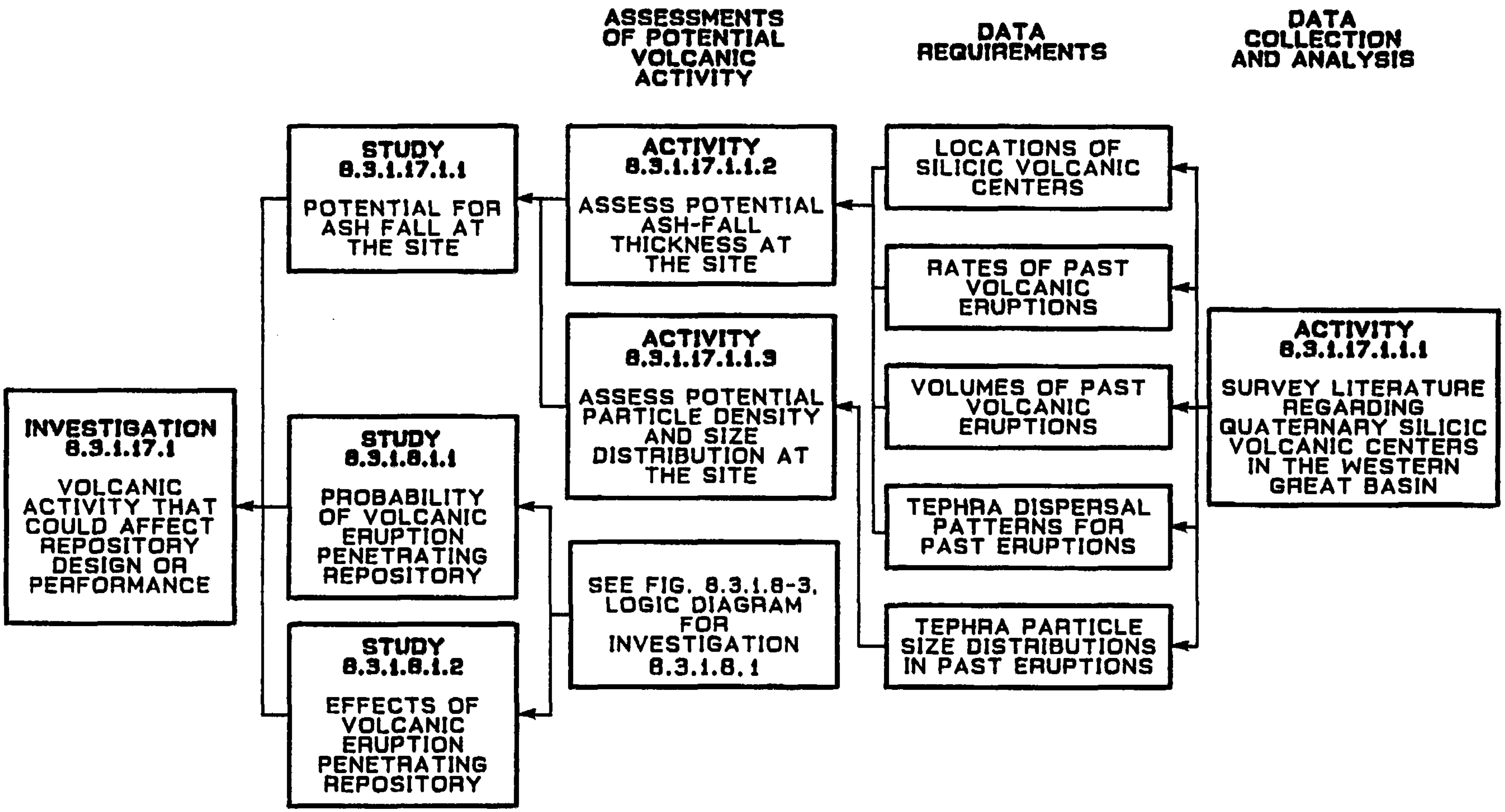

Figure 8.3.1.17-3. Logic diagram for Investigation 8.3.1.17.1 (preclosure volcanic activity).

8.3.1.17.1.1 Study: Potential for ash fall at the site

Three activities are included in this study.

8.3.1.17.1.1.1 Activity: Survey literature regarding Quaternary silicic volcanic centers in the western Great Basin

Objectives

The objective of this activity is to compile information on Quaternary silicic volcanism in the western Great Basin, the reoccurrence of which might produce an ash fall at the site.

Parameters

Information to be compiled includes locations of silicic volcanic centers, rates of past eruptions, volumes of past eruptions, tephra dispersal patterns in past eruptions, and tephra particle size distributions in past eruptions.

Description

Required data will be gathered from the geological literature. Volcanic fields of interest include the Coso field, the Big Pine field, Long Valley caldera, and the Mono-Inyo Dome chain.

Methods and technical procedures

No original work will be required to address this activity. Published geologic literature will be used based on Project SOP-03-03 (Acceptance of data or data interpretation not developed under the Project quality assurance plan).

8.3.1.17.1.1.2 Activity: Assess potential ash-fall thickness at the site

Objectives

The objective of this activity is to produce an approximate probability-versus-thickness function for potential ash falls at the site and to estimate a particular ash-fall thickness that has less than one chance in ten of occurring in 100 yr. These hazard estimates will be considered in the design of filters in the mining and surface-facility ventilation systems.

Parameters

The parameters required for this assessment activity include the following:

1. Locations of Quaternary silicic volcanic centers in the western Great Basin.

2. Rates, volumes, and tephra dispersal patterns of Quaternary silicic volcanic eruptions in the western Great Basin.

Description

The ash-fall hazard estimates will be produced by extrapolating the observed Quaternary rates, volumes, and tephra dispersal patterns of silicic volcanic eruptions in the western Great Basin into the future and by calculating the probabilities of experiencing different ash-fall thicknesses at the site, considering the site location relative to the silicic volcanic centers. These estimates will be based on the information compiled in Activity 8.3.1.17.1.1.1.

Methods and technical procedures

This activity will only synthesize and compile data collected by other activities. Therefore, no specific technical procedures are anticipated at this time. All evaluations and calculations will be documented or verified in conformance with the U.S. Department of Energy (DOE) quality assurance program (Section 8.6).

8.3.1.17.1.1.3 Activity: Assess potential particle density and size distribution of ash fall at the site

Objectives

The objective of this activity is to estimate the potential particle densities and particle-size distributions of ash falls at the site for consideration in the design of filters in the mining- and surface-facility ventilation systems.

Parameters

The parameters required for this assessment activity are historical ash-fall particle densities from silicic volcanic eruptions and particle-size distributions in ash beds corresponding to Quaternary silicic volcanic eruptions in the western Great Basin.

Description

Potential ash-fall particle densities at the site will be assumed to be comparable to particle densities that have been observed historically in ash falls from silicic volcanic eruptions, at distances similar to those between the site and the silicic volcanic centers in the western Great Basin. Potential particle size distributions at the site will be estimated on the basis of observed size distributions in ash beds that correspond to Quaternary silicic volcanic eruptions in the western Great Basin and that are at distances comparable to that of the site from the volcanic centers. The analyses will be based on information compiled in Activity 8.3.1.17.1.1.1.

Methods and technical procedures

This activity will only synthesize and compile data collected by other activities. All evaluations and calculations will be documented or verified in conformance with the DOE quality assurance program (Section 8.6).

8.3.1.17.1.2 Application of results

The information to be obtained in Study 8.3.1.17.1.1 is required for consideration in the design of filters in both the mining- and the surface-facility ventilation systems. As such, it is called for by Information Needs 4.4.8 and 4.4.9 (identification of technologies for surface-facility and underground-facility construction, operation, closure, and decommissioning, respectively).

8.3.1.17.2 Investigation: Studies to provide required information on fault displacement that could affect repository design or performance

Technical basis for obtaining the information

Link to the technical data chapters and applicable support documents

The sections of the SCP data chapters that summarize existing data relevant to this investigation are as follows:

SCP section	Subject
6.1.4	Surface structures, systems, and components considered important to safety
1.3	Structural geology and tectonics
1.5	Long-term stability with respect to tectonics and geologic processes

Parameters

This investigation will compile or develop the following characterization parameters related to the potential for fault displacement beneath surface facilities considered important to safety (Tables 8.3.1.17-3a and -3b):

1. Identification and characterization of potentially significant Quaternary faults within 5 km of facilities important to safety (FITS).

2. Identification and characterization of faults within 100 m of FITS that have apparent Quaternary slip rates greater than 0.001 mm/yr or that measurably offset materials that are less than 100,000 yr old.

3. Estimated total probability of exceeding 5 cm displacement beneath FITS, considering known faults, possibly concealed faults, and tectonic interrelationships among local faults.

The following characterization parameters related to the potential for underground fault displacement in areas of emplaced waste will also be compiled or developed in this investigation (Tables 8.3.1.17-4a and -4b):

1. Surface locations of faults in the repository block that offset Quaternary materials by more than 1 m or Tertiary rocks by more than 100 m.

2. Surface and subsurface locations of any faults that intersect prospective underground facilities and that have average Quaternary slip rates greater than 0.005 mm/yr.

3. Estimated total probability of exceeding 7 cm displacement on any fault in the the area of emplaced waste, considering known and possibly concealed faults and the tectonic interrelationships among local faults.

Purpose and objectives of investigation

The siting objective vis-a-vis potential surface faulting is to avoid fault displacement in excess of a few inches beneath the structural foundations of surface facilities considered important to safety. The corresponding goal of this investigation, expressed in Table 8.3.1.17-3a, is to demonstrate, with a high degree of confidence, that there is less than a one percent chance of exceeding 5 cm of fault displacement beneath surface facilities important to safety during the preclosure period (approximately 100 yr). (A discussion of the reasonableness of this goal is provided in the overview of this section.)

The primary concern regarding faulting in the underground facilities during preclosure is that waste packages might be sheared or become jammed in their waste-emplacement boreholes, making retrieval more difficult and time consuming than it otherwise would be. The corresponding goal (Tables 8.3.1.17-4a and -4b) is to demonstrate with a moderate degree of confidence that there is less than a ten percent chance of exceeding 7 cm of fault displacement in areas of emplaced waste in 100 yr, considering all faults that may intersect these areas. (A displacement of 7 cm is the minimum value at which the sides of a faulted waste-emplacement borehole would be expected to contact a waste package.) No single fault with the potential to exceed this goal is currently thought to exist, but if such a fault is identified, an attempt will be made to determine its location underground for consideration in the positioning of waste-emplacement boreholes.

Technical rationale for investigation

A logic diagram for the investigation of preclosure fault displacement is presented in Figure 8.3.1.17-4.

The potential for surface faulting at locations of surface facilities important to safety (FITS) will be assessed in Activity 8.3.1.17.2.1.1 and expressed in terms of the characterization parameters listed in Table 8.3.1.17-3b. The most important information pertaining to potential fault displacement beneath FITS is expected to come from detailed geologic mapping of alluvial deposits in Midway Valley and from exploratory trenching in the immediate vicinity of prospective surface FITS. Exploratory trenches are expected to intersect surficial units that are at least 100,000 yr old. Any faults that measurably displace units less than 100,000 yr old and any faults found to have Quaternary slip rates exceeding 0.001 mm/yr (10 cm/100,000 yr) will be identified.

Because significant faulting is sometimes accompanied by sympathetic displacements in adjacent areas, information on fault-zone widths and recurrence of movement on Quaternary faults within 5 km of surface FITS will also be analyzed. Of particular interest for any such fault will be any evidence of concealed extensions that may trend toward Midway Valley and the sites of prospective FITS.

The probability of exceeding 5 cm displacement on any fault beneath prospective surface FITS will be estimated in Activity 8.3.1.17.2.1.2, considering, in addition to the information cited previously, the tectonic interrelationships between local faults, the possible existence of concealed faults, and the potential for the surface trace of a fault to change locations from event to event. The goal is to locate the surface FITS in an area where there is less than a one percent chance of exceeding 5 cm of net (combined dip-slip and strike-slip) displacement in 100 yr, with high confidence.

Any site without faults having apparent Quaternary slip rates greater than 0.001 mm/yr and faults that measurably offset materials less than 100,000 yr old is expected to meet the above goal conservatively, even if an undetected component of strike-slip motion exists that is as large as the measured dip-slip components. This expectation is based in part on the observation that main, branch, and secondary faulting generally recurs at the same location. An example is the 1983 Borah Peak earthquake, where new ruptures were found to coincide with older scarps that defined both the main trace and graben-bounding antithetic faults (Crone et al., 1985; Schwartz and Crone, 1985). The 1932 Cedar Mountain earthquake is another example where trenches across the 1932 ruptures revealed many previous events (Bell, 1988). The prior Cedar Mountain events coincide with the 1932 breaks even though the general pattern of faulting was distributed. Data from these earthquakes and others indicate that a trenching program of the type proposed here, if conducted before the recent faulting, would have detected these faults and accurately identified the locations of future ruptures.

The potential for displacement on faults that intersect underground facilities will be assessed in Activity 8.3.1.17.2.1.2; the corresponding

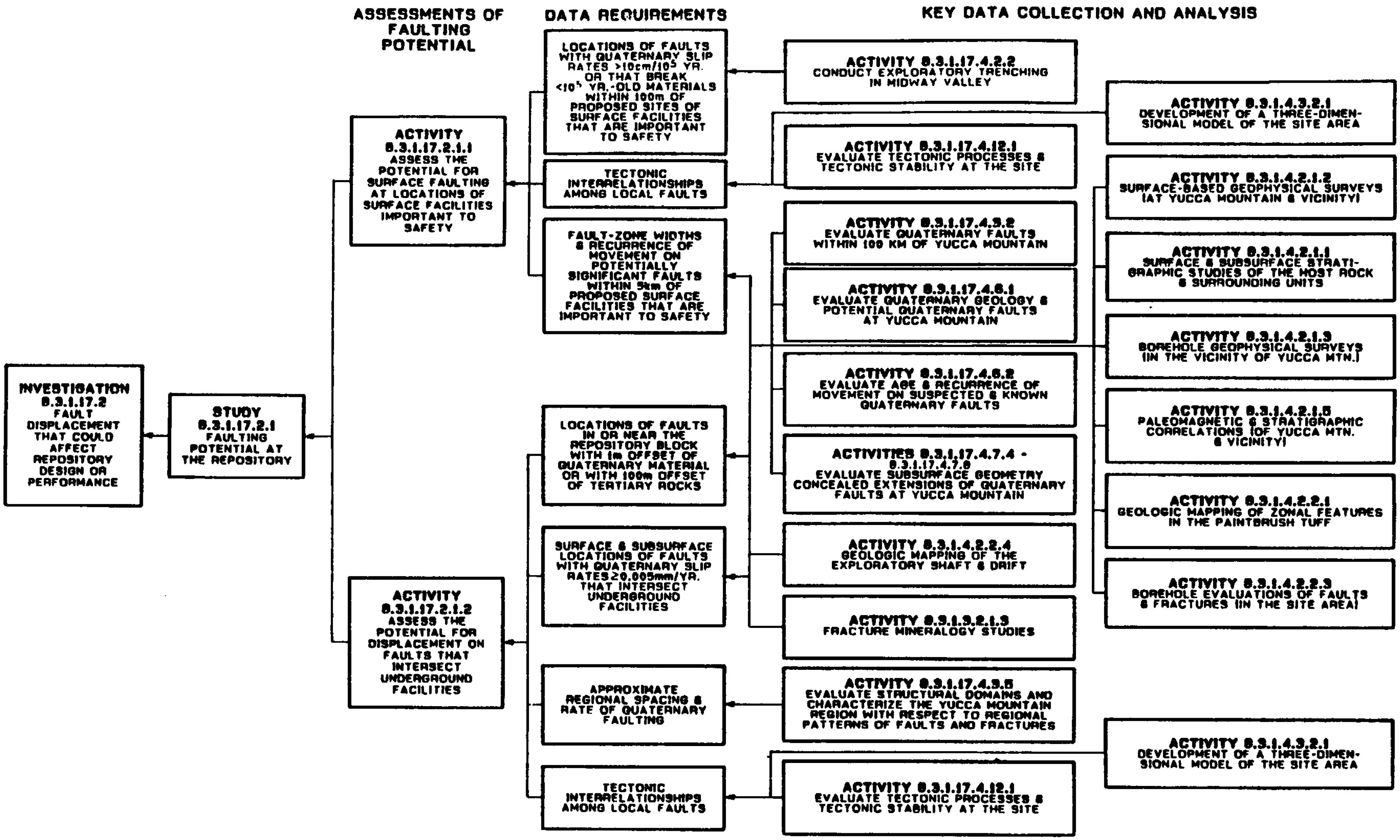

Figure 8.3.1.17-4. Logic diagram for the Investigation 8.3.1.17.2 (preclosure fault displacement)

design parameters and characterization parameters are listed in Tables 8.3.1.17-4a and -4b.

To meet the design-parameter goal of identifying and characterizing significant late Quaternary faults in the repository block, the locations of faults with more than 1-m offset of Quaternary materials, or with more than 100-m offset of Tertiary rocks, will be determined. Current data provide low-to-moderate confidence that only two such faults exist, namely the Bow Ridge and Solitario Canyon faults. Further work will be performed in Study 8.3.1.17.4.6 (Quaternary faulting within the site area) to provide added confidence that there are no additional significant late-Quaternary faults in the repository block.

A second design-parameter goal is to identify, characterize, and locate within the waste-emplacement area any fault with more than a one percent chance of producing displacement greater than 7 cm during the preclosure period. Faults with slip rates less than 0.005 mm/yr would be very unlikely to exceed this threshold (see overview discussion of the preclosure tectonics site program in this section), and current data indicate that, with moderate confidence, no faults with Quaternary slip rates greater than 0.005 mm/yr exist in the repository block. Further work will be performed in Study 8.3.1.17.4.7 to achieve a moderate-to-high level of confidence in this finding.

Information on particular Quaternary faults in the repository block, data on the regional spacing and rate of movement of Quaternary faults, and interpretations of tectonic interrelationships among local faults will be synthesized in Activity 8.3.1.17.2.1.2 to estimate a total probability of exceeding 7 cm displacement on faults that intersect areas of emplaced waste. This work is expected to corroborate the current assessment that, with moderate confidence, the total probability of exceeding 7 cm displacement in 100 yr on any fault in the area proposed for waste emplacement is less than one percent.

8.3.1.17.2.1 Study: Faulting potential at the repository

This study includes two activities.

8.3.1.17.2.1.1 Activity: Assess the potential for surface faulting at prospective sites of surface facilities important to safety

Objectives

The objective of this activity is to assess the stability of the site surface with respect to fault displacement, at locations proposed for facilities important to safety (FITS). Particular objectives are to develop the characterization parameters listed in Table 8.3.1.17-3b and discussed previously with the indicated levels of confidence.

Parameters

The data required for this synthesis activity include the following:

1. Locations of faults within 100 m of locations proposed for FITS that have apparent Quaternary slip rates greater than 0.001 mm/yr or that measurably offset materials less than 100,000 yr old.

2. Fault-zone widths and recurrence of movement on potentially significant faults within 5 km of locations proposed for FITS.

3. Tectonic interrelationships among local faults.

The key parameter to be produced by this activity is an estimate of the total probability of exceeding 5 cm fault displacement at locations proposed for FITS.

Description

This is a synthesis and assessment activity that draws on data collected elsewhere, mostly from the Quaternary faulting studies in Investigation 8.3.1.17.4 and the studies of stratigraphy and structure in Investigation 8.3.1.4.2. The data sets that will be synthesized, the general approach to the synthesis, and the required assessments are described previously in the discussion of the technical rationale for this investigation and in the overview of the preclosure tectonics site program. A few more details on the synthesis of the faulting potential are provided here.

The assessment of the probability of fault displacement beneath FITS may benefit from a consideration of the fractal characteristics of local fault systems and of the mechanical interactions between local faults.

Surface FITS will be sited where there is no evidence of substantial Quaternary faulting, but concealed faults and the possibility of the surface trace of a fault appearing at a new location cannot be ruled out and will be evaluated. Since fault systems tend to have self-similar geometries (i.e., to have similar degrees of branching and complexity over a wide range of map scales) an analysis of the fractal characteristics of local fault systems may be useful for estimating the spatial density and lengths of subsidiary faults that may lie concealed in the vicinity of FITS.

The reasonableness of postulated tectonic interrelationships among local faults can be checked to some extent by analyzing the stresses generated by the displacements that are assumed to be occurring; the local stress field generated by assumed slip on one fault should not act to oppose the slip that is assumed for other faults. If slip directions and magnitudes are constrained by geologic data, stress analyses may indicate areas of stress concentration that may be accommodated by concealed faults.

Methods and technical procedures

This activity will only synthesize and compile data collected by other activities. All evaluations and calculations will be documented or verified in conformance with the DOE quality assurance program (Section 8.6).

8.3.1.17.2.1.2 Activity: Assess the potential for displacement on faults that intersect underground facilities

Objectives

The objective of this activity is to assess the potential for displacement on faults that intersect underground facilities. Particular objectives are to develop the characterization parameters listed in Table 8.3.1.17-4b with the indicated levels of confidence.

Parameters

Data required for this synthesis activity include the following:

1. Locations of faults in the repository block that offset Quaternary materials by more than 1 m or Tertiary rocks by more than 100 m.

2. Surface and subsurface locations of faults with Quaternary slip rates greater than 0.005 mm/yr that intersect areas proposed for waste emplacement.

3. Approximate regional spacing and rate of Quaternary faults.

4. Tectonic interrelationships among local faults.

The key parameter to be provided by this activity is an estimate of the total probability of exceeding 7 cm displacement in 100 yr on any fault that intersects areas proposed for waste emplacement.

Description

This is a synthesis and assessment activity that draws on data collected by other activities, as indicated in Figure 8.3.1.17-4. The data sets that will be synthesized, the general approach to the synthesis, and the required assessments are described previously in the discussion of the technical rationale for this investigation and in the overview of the preclosure tectonics site program. A few observations on the general approach are presented here.

The assessment of faulting potential at depth will be predominantly inferential, because the recency and amount of movement on a fault encountered at depth while mining is nearly impossible to determine from the limited exposure in the mine. Also, the subsurface projections of faults that are expressed at the surface are often poorly constrained by surface geophysical evidence. In the unexpected instance that a fault is found that may project through proposed areas of emplaced waste and that has surface evidence of a slip rate exceeding 0.005 mm/yr, the fault will be located (perhaps by drilling and coring) in the underground.

The inference of faulting potential will be based in part on the average spacing of Quaternary faults that is estimated for the structural domain that encompasses the site. (A structural domain is a crustal block within which faulting of a given genetic type generally occurs with uniform characteristics.) Key information for defining the structural domain of the site will come from Activity 8.3.1.17.4.3.5. The assessment of faulting potential will also consider estimates of slip rates on Quaternary faults in the site area (from Activity 8.3.1.17.4.6.2), the fractal geometry of local fault systems (see description of Activity 8.3.1.17.2.1.1), interpreted tectonic (mechanistic) interrelationships among local faults, and models for the accommodation of regional strain by local faults.

Methods and technical procedures

This activity will only synthesize and compile data collected by other activities. All evaluations and calculations will be documented or verified in conformance with the DOE quality assurance program (Section 8.6).

8.3.1.17.2.2 Application of results

Information on potential fault displacement will be used as follows:

1. In the development and analyses of the repository design (Issue 4.4, preclosure design and technical feasibility, Section 8.3.2.5).

2. In the determination of credible accidents that are applicable to the repository (Issue 2.3, accidental radiological releases, Section 8.3.5.5).

3. In the determination that waste can be accessed and removed from the emplacement boreholes throughout the retrievability period for normal and off-normal conditions (Issue 2.4, waste retrievability, Section 8.3.5.2).

4. In the identification of normal and accident conditions, including disruptive events (Issue 2.7, preclosure radiological design requirements, Section 8.3.2.3).

8.3.1.17.3 Investigation: Studies to provide required information on vibratory ground motion that could affect repository design or performance

Technical basis for obtaining the information need

Link to the technical data chapters and applicable support documents

Sections 1.3, 1.4, and 1.5 of the SCP data chapters provide a technical summary of existing data relevant to this investigation.

Parameters

This investigation will provide the following characterization parameters related to potential vibratory ground motion at the site from natural and man-made seismic sources (Tables 8.3.1.17-5a -5b, -6a, and -6b):

1. Identification of potential earthquake sources in the controlled area.

2. Identification of earthquake sources within 100 km of the site that could be relevant to the site (i.e., that could conceivably control the design-basis ground motions at the site in any frequency band of engineering significance).

3. Magnitudes of 10,000-yr cumulative slip* earthquakes on local earthquake sources.

4. Magnitudes of 10,000-yr cumulative slip* earthquakes on regional earthquake sources.

5. Maximum potential yields of future underground nuclear explosions (UNEs) at the Nevada Test Site (NTS).

6. Closest distance between the site and potential future UNEs at NTS.

7. Ground-motion models/attenuation relationships for the site region (i.e., mathematical models for predicting the values of ground-motion parameters as a function of the distance from and the strength of the earthquake or UNE source).

8. Spectral amplification functions that represent the effects of local site geology on surface seismic motions and the effects of depth on underground seismic motions.

9. Identification of controlling seismic events--those 10,000-yr cumulative slip earthquakes and/or potential largest and closest UNEs that would generate the most severe ground motions at the site in any frequency band of engineering significance, taking into account an local-geologic or depth effects on the ground motion.

10. Time histories and response spectra that are representative of potential ground motion at the site from the controlling seismic event(s).

11. Magnitude-recurrence relationships for all regional earthquake sources that could contribute to the earthquake hazard at the site.

12. Probabilities of exceeding selected ground-motion parameters at the site, developed through probabilistic seismic hazard analysis.

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*10,000-yr cumulative earthquakes are defined here to be earthquakes that, occurring every 10,000 yr, would produce the observed or estimated average Quaternary slip rate on a fault; see discussion in description of Activity 8.3.1.17.3.1.2.

Purpose and objectives of the investigation

The purposes of this investigation are to (1) develop a seismic-design basis for repository facilities that are important to safety and (2) provide other information that will facilitate the assessment of the adequacy of the seismic-design basis and the identification of credible accidents that might be initiated by seismic events and lead to release of radioactive materials. The seismic-design basis will account for both the potential occurrence of earthquakes on nearby faults and potential future underground nuclear explosions at the Nevada Test Site.

The planned methodology for developing the seismic-design basis is, as is discussed in detail below, intended to result in design levels such that the probability of the design level being exceeded is comparable to typical exceedance probabilities for the seismic-design bases of operating nuclear power plants in the United States (i.e., annual probabilities of exceedance on the order of 1×10^{-3} to 1×10^{-4}).

Although this investigation is motivated by the need to develop a seismic-design basis and other information related to the design of facilities important to safety (FITS), the resulting design-basis ground-motion descriptions also may be considered in the design of other repository facilities. (Presently, only the shipping cask and certain components of the waste-handling facilities are considered potentially important to safety (Laub and Jardine, 1987). Current plans call for the FITS seismic-design basis to be considered also in the design of underground facilities (Information Need 4.4.1, site and performance assessment information needed for design, Section 8.3.2.5.1).

The approach that is currently considered appropriate for developing a seismic design basis is deterministic, meaning that the design-basis ground-motion description will correspond to the postulated occurrence of a discrete seismic event or events (e.g., the occurrence of an earthquake of specified magnitude on a particular fault). This type of approach parallels that used to develop the seismic design bases of all nuclear power plants in the United States. In addition, probabilistic estimates of the seismic hazard at the site will be developed that integrate individual contributions to the site's ground-motion potential from earthquake sources at different distances and with different earthquake recurrence characteristics. The probabilistic seismic hazard estimates will be used to evaluate and constrain required technical judgments in the deterministic approach, evaluate the adequacy of the deterministic results, and help identify and focus efforts to refine those parameters that are most important for the deterministic calculations. The probabilistic hazard estimates will also provide input needed to determine credible accidents that are applicable to the repository (Information Need 2.3.1, Section 8.3.5.5.1).

In summary, probabilistic seismic hazard estimates will be an important adjunct to the deterministic estimates that will be developed for consideration in the seismic design of FITS. A discussion of the reasons for using deterministic and probabilistic methodologies in this fashion is given in the Overview section for this investigation.

Technical rationale for investigation

Ten-thousand year cumulative slip earthquakes are defined here to be earthquakes that, occurring every ten-thousand years, would produce the observed or estimated average Quaternary slip rate on a fault (see detailed discussion in description of Activity 8.3.1.17.3.1.2). Controlling seismic events are those exceptional earthquakes and/or potential largest and closest UNEs that would generate the most severe ground motions at the site in any frequency band of engineering significance. The seismic design basis for FITS will be suites of ground-motion time histories and corresponding response spectra that are representative of the controlling seismic events.

A logic diagram for this investigation is presented in Figure 8.3.1.17-5.

Study 8.3.1.17.3.1 will identify and characterize earthquake sources that could potentially be relevant to a deterministic seismic hazard analysis of the site, i.e., sources that could conceivably produce exceptional earthquakes that would control the seismic-design basis in any frequency band of engineering significance. Characterization of earthquake sources for the deterministic hazard assessment will include a determination of each source's location, orientation, depth, likely style of faulting, and an evaluation of the 10,000-yr cumulative slip earthquake magnitude. Here, and elsewhere, uncertainty in the determination of input parameters will be estimated so that the sensitivity of the final results to key assumptions can be estimated.

The identification and characterization of relevant earthquake sources will consider the historical record of regional seismicity; the potential for seismicity to be induced at the site by human activities; the location, nature, and rate of Quaternary faulting in the site area; crustal stresses at seismogenic depths; evidence of neotectonic deformation in the Yucca Mountain area; and the overall tectonic framework of the region.

Study 8.3.1.17.3.2 will determine the potential locations and maximum yields of future UNEs at the NTS, considering constraints such as damage thresholds in Las Vegas. The UNE(s) that would cause the most severe ground motions at the site will then be identified using a predictive model for UNE ground motions.

Models for predicting UNE ground motions and models for predicting earthquake ground motions will be selected or developed in Study 8.3.1.17.3.3. Published ground-motion models for UNEs at NTS will be used where appropriate. If published models are not available for all ground-motion parameters needed, available data will be compiled and the needed models will be developed through regression analyses. Earthquake ground-motion data from the Great Basin and tectonically analogous areas will be tested for statistically significant deviations from published earthquake ground-motion models that have been developed for California and western North America. If the deviations are not statistically significant, a published model will be selected. If needed, new models will be developed through regression analyses.

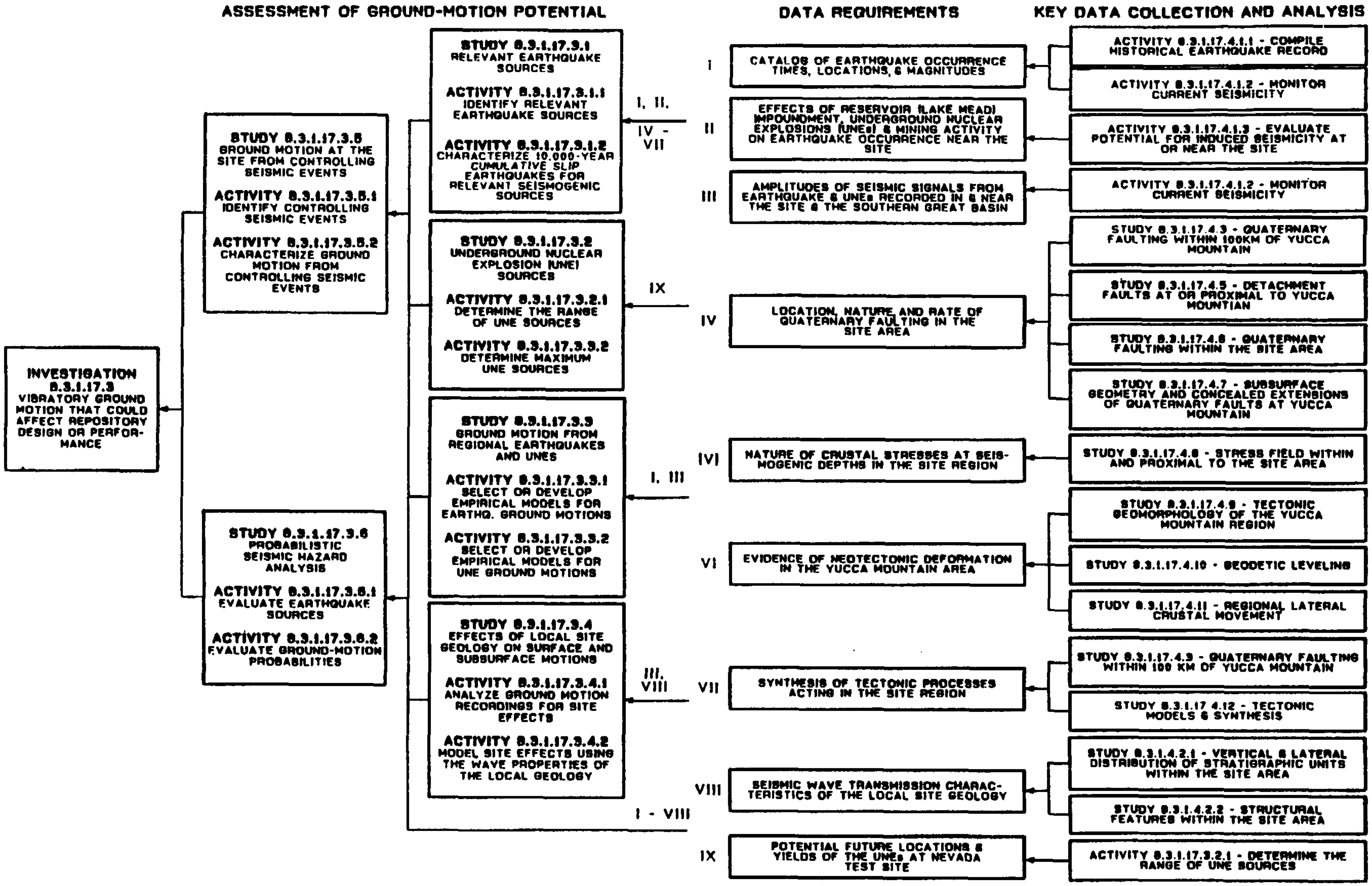

Figure 8.3.1.17-5. Logic diagram for the Investigation 8.3.1.17.3 (preclosure vibratory ground motion). (Roman numerals indicate data flow.)

Systematic effects on surface and subsurface ground motions resulting from the local site geology will be identified and used to correct predictions of the regional ground-motion models developed in Study 8.3.1.17.3.3. These correction factors will be based, to the extent possible, on actual ground-motion recordings obtained in Study 8.3.1.17.4.1. Theoretical models based on the wave properties of the local geology will be developed to the degree necessary to explain the observations to first order and then used to extrapolate the observations to locations and depths where ground motions must be predicted but where recordings are not available.

Identification of controlling seismic events and characterization of the resulting ground motion at the site will be accomplished in Study 8.3.1.17.3.5. Identification of the controlling seismic events will follow directly from the identification of 10,000-year cumulative slip earthquakes on relevant sources in Study 8.3.1.17.3.1, the determination of potential maximum future UNEs in Study 8.3.1.17.3.2, the earthquake and UNE ground-motion models developed in Study 8.3.1.17.3.3, and the local site correction factors developed in Study 8.3.1.17.3.4.

Controlling-event ground motions will be characterized by suites of strong-motion time histories that are representative in terms of expected amplitudes, frequency content, and duration. Methodologies for constructing these time histories will be evaluated. Two different methodologies may be implemented and the results compared to help assess the uncertainty in the final results.

The probabilistic seismic hazard analysis of the site constitutes Study 8.3.1.17.3.6. The first step in the analysis is to identify and characterize earthquake sources that contribute to the hazard (the probability of exceeding different ground-motion levels) at the site. Sources that are more distant and sources with smaller earthquake potential than the "relevant" sources addressed in Study 8.3.1.17.3.1 will be characterized so that exceedance probabilities for ground-motion levels below the design-basis levels can be estimated. (Exceedance probabilities for motions beyond the design-basis will also be estimated.) Each seismic source will be characterized as to location, depth, shape, and magnitude-recurrence characteristics, including maximum-magnitude potential. The considerations in characterizing the contributing earthquake sources in the probabilistic analysis are essentially the same as those in characterizing relevant sources in the deterministic analysis, and so the same types of data are required.

There are different methodologies available for encoding uncertainty in seismic-source-zone interpretations and for aggregating the results of multiple interpretations in a probabilistic seismic hazard analysis. The advantages and disadvantages of available methodologies will be assessed before an approach is chosen.

A probabilistic seismic hazard analysis of the site is expected to be performed concurrently with the deterministic analysis and repeated one or more times, with detail increasing as more data become available. The sensitivity of estimated hazard to various input parameters is easy to assess within the probabilistic framework, and the preliminary analyses will help to identify the parameters of greatest importance to both the probabilistic and deterministic analyses; this information will be used to redirect and focus the characterization activities. The calculated probabilistic hazard levels will also be used to help assess the adequacy of the deterministically derived design-basis ground motions. As was stated earlier, a measure of adequacy that is adopted here is that the annual probability of the design-basis ground motions being exceeded is between 10^{-3} and 10^{-4} per yr, which is the range of probabilities that appears to correspond to seismic-design bases that have been accepted for nuclear power plants in the United States.

8.3.1.17.3.1 Study: Relevant earthquake sources

The objectives of this study are to identify and characterize those earthquake sources that are relevant to a deterministic seismic hazard analysis of the site (i.e., those sources that could be active) and, if active, could cause severe ground shaking at the site. Potential earthquake sources include faults with surface geologic expression as well as concealed faults. Each seismic source will be characterized by its location, depth, orientation, likely style of faulting, and 10,000-yr cumulative slip earthquake magnitude.

8.3.1.17.3.1.1 Activity: Identify relevant earthquake sources

Objectives

The objective of this activity is to identify earthquake sources that could generate severe ground motions at the site.

Parameters

The following types of information will be synthesized in this activity:

1. Maps and cross sections of historical earthquake locations.
2. Maps showing Quaternary faults with lengths greater than about 20 km within 100 km of the site and Quaternary faults with lengths greater than about 1 km within 10 km of the site.
3. Data on the style and rate of Quaternary faulting in the site region.
4. Evidence of neotectonic deformation or stability in the site region.
5. Regional heat-flow anomaly maps and regional and local magnetic-anomaly and gravity-anomaly maps.
6. Regional and local crustal seismic data.
7. Information on local and regional crustal stresses.
8. Local and regional tectonic models.

These information items will be supplied mostly by the data-collection-and-analysis activities in Investigation 8.3.1.17.4 (Figure 8.3.1.17-5).

Description

Relevant earthquake sources will be identified through a synthesis of information of the types listed in the parameter section. Surface evidence of Quaternary faulting and patterns of historical seismicity will be paramount considerations. Magnetic and gravity anomalies, crustal seismic data, and heat-flow will be analyzed for indications of faulting at depth. The assessment of whether a geophysical anomaly corresponds to a fault will consider information on the local structural geology and surface geomorphology. The likelihood of a buried fault being active will be evaluated considering the spatial correlation of the fault with historical seismicity, the orientation of the feature with respect to measured or inferred crustal stress orientations, potential tectonic interrelationships with other local faults, and conceptual models of the regional tectonics.

The assessment of relevance of an identified seismic source requires an assessment of the magnitude capability of the source. Hence, this activity will be performed concurrently and iteratively with the effort to define 10,000-yr cumulative slip earthquakes for relevant earthquake sources in Activity 8.3.1.17.3.1.2.

Relevance to a deterministic seismic hazard analysis of the site of identified earthquake sources will be judged according to a preliminary estimation of the 10,000-yr cumulative slip earthquake magnitude of the source and the distance of the source from the site, using criteria similar to the following:

Source distance (R)	10,000-year cumulative slip earthquake magnitude (M)
$0 \leq R < 3$ km	$M > 5$
$3 \leq R < 100$ km	$M > 4 + 2 \log_{10}R$

Relevance to a deterministic seismic hazard analysis of identified earthquake sources is determined by the potential for such sources to possibly control the severity of ground shaking at any frequency of engineering significance. The determination of relevance involves the determination of the 10,000-yr cumulative slip earthquake for each source and the prediction of potential ground motion in different frequency bands. Attenuation relationships for frequency-specific measures of ground-motion severity (e.g., spectral ordinates of pseudo-relative velocity response) are thus required for the relevancy determination.

The conceptual approach for identifying potentially relevant earthquake sources is illustrated graphically in Figure 8.3.1.17-6. The curve in this figure is based on preliminary professional judgment. No numerical calculations were performed to construct the curve; it is intended to be illustrative only.

The curve drawn in Figure 8.3.1.17-6 reflects the expectation that local faults will control potential high-frequency ground motion and that larger, more distant faults could control lower frequency ground motions. The curve

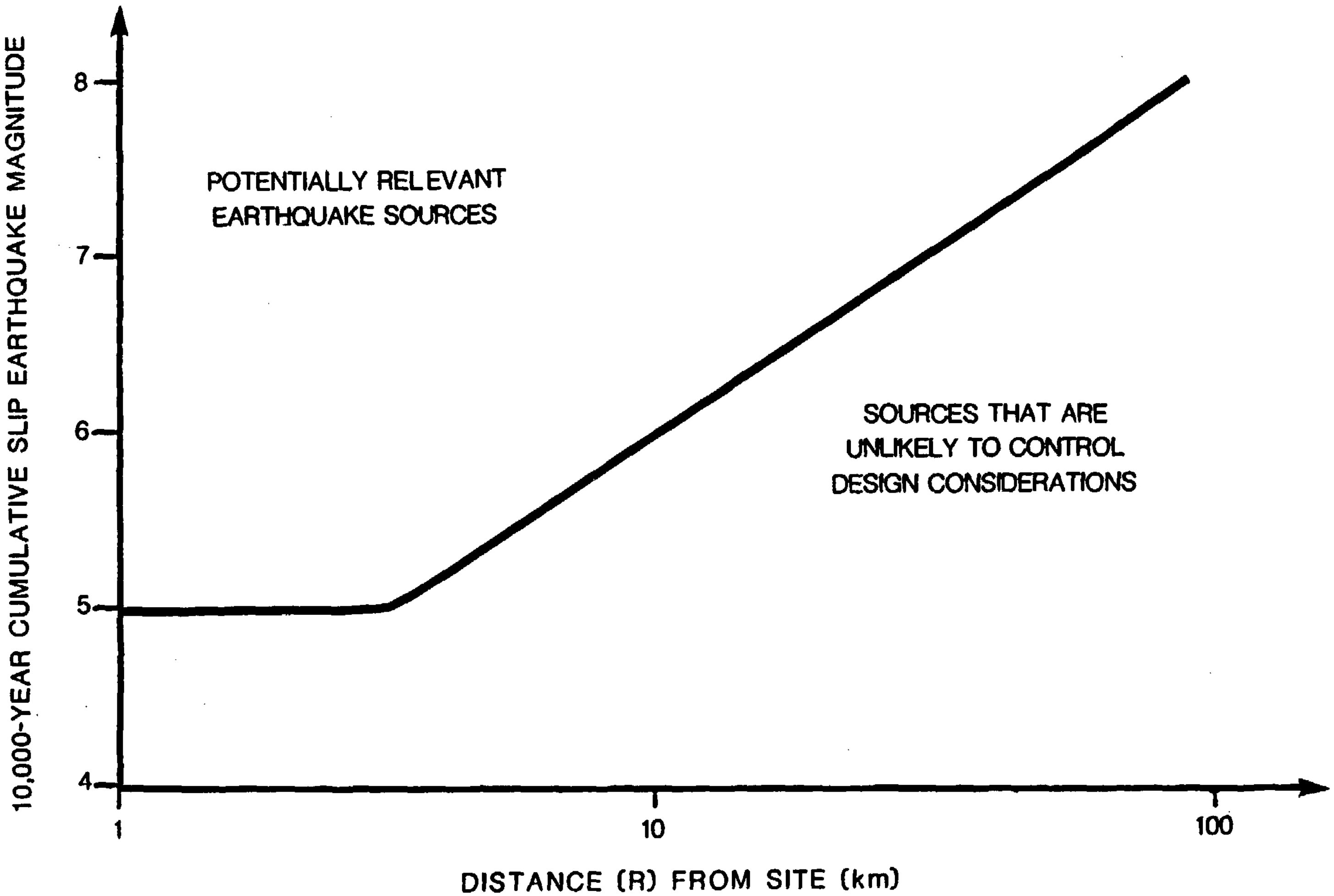

Figure 8.3.1.17-6. Conceptual approach for identifying potentially relevant earthquake sources.

is not permitted to go below magnitude 5 because faults with cumulative-slip earthquake magnitudes less than this value are probably too small to detect with any confidence. (If it is determined that earthquakes smaller than magnitude 5 could impact repository design or performance, their occurrence will be considered to be spatially and temporally random and the associated hazard will be modeled probablistically as part of Study 8.3.1.17.3.6.)

The relevancy criteria will be refined through analysis of the earthquake ground-motion (attenuation) relationships that will be selected or developed in Study 8.3.1.17.3.3 and considering any revisions to the parameters needed for seismic design (Section 8.3.2.5.1) and design analysis (Section 8.3.2.5.7). Given the uncertainty in estimating magnitudes and ground motions, any criteria developed will be applied conservatively to avoid the premature screening of potentially relevant sources.

Methods and technical procedures

This activity will only synthesize and compile data collected by other activities. All evaluations and calculations will be documented or verified in conformance with the DOE quality assurance program (Section 8.6).

8.3.1.17.3.1.2 Activity: Characterize 10,000-yr cumulative slip earthquakes for relevant seismogenic sources

Objectives

The objective of this activity is to characterize 10,000-yr cumulative slip earthquakes for each of the relevant seismogenic sources identified in the previous activity. The nature, size, and location of 10,000-yr cumulative slip earthquakes are to be established based on the seismogenic properties of the potential sources.

Description

The concept of 10,000-yr cumulative slip earthquakes is being established to develop deterministic characterizations of potential severe vibratory ground motion for consideration in the design of repository facilities important to safety. Available data (Section 1.3) for faults in the site region that have moved during the Quaternary suggest that recurrences intervals may be on the order of 1×10^4 to 1×10^5 yr. Such low rates suggest that the use of fault length or displacement to develop deterministic estimates of magnitude for a given fault may be misleading in terms of the hazard posed by the fault. The concept of the 10,000-yr cumulative slip earthquake takes recurrence rates into account, in addition to the fault characteristics, for determining a maximum magnitude for the purpose of estimating potential severe vibratory ground motion at the site. 10,000-yr cumulative slip earthquakes for Quaternary faults are defined as those earthquakes that, occurring every 10,000 yr, would produce the observed or estimated average Quaternary slip rate on a fault. The magnitude of a 10,000-yr cumulative slip earthquake is a best estimate based on the equivalent 10,000-yr displacement and available information on fault dimensions and geometry and possible interactions with other faults. To ensure applicability of the concept in cases where slip rates are such that major strain-releasing earthquakes are expected more often than every 10,000 yr (e.g., the San Andreas fault), the 10,000-yr cumulative slip earthquake magnitude is constrained to not exceed the best-estimate maximum magnitude. Finally, to ensure adequate conservatism of the design vibratory ground motion, an additional constraint on the magnitude is that the resulting design-basis ground motion for facilities important to safety have an annual probability of exceedance between 10^{-3} and 10^{-4} per yr.

Various types of data will be used to evaluate 10,000-yr cumulative slip earthquakes, including estimated slip rates, mapped fault lengths, fault displacement (per event if available), fault type, and other pertinent geologic data. The following hypothetical calculation is presented to illustrate how data collected during site characterization studies will be used to estimate the 10,000-yr cumulative slip earthquake for the ground motion design of surface facilities.

Sample Calculation: A fault in the vicinity of the site is identified by the procedures in Activity 8.3.1.17.3.1.1 as a potentially relevant earthquake source. Mapping and trenching studies find that the fault is 30 km long and that it displaces a 740,000-yr-old layer 7.5 m vertically and 1.5 m horizontally. Trenching at other localities along the fault indicate that the above values are representative of the behavior of the fault through the Quaternary. The above data are used to calculate a net slip of 7.65 m over 740,000 yr and a Quaternary slip rate of 0.01 mm/yr. The average cumulative slip over 10,000 yr can then be calculated as 0.1 m. The 10,000-yr cumulative slip earthquake assumption is that all this displacement is released as a single event. The magnitude of this event can be estimated using empirical regression curves such as Bonilla et al. (1984) and Slemmons (1982). The published regression curves use maximum displacement rather than average displacement to estimate magnitude, so a maximum displacement must be estimated for the 10,000-yr event. Bonilla (1982) found that the maximum displacement is about 3 times the average displacement for most events. Using this value, the maximum displacement for the 10,000-yr event is about 0.3 m. When these calculations are conducted for the final evaluations, all published methods will be evaluated and compared. New regression analyses may also be prepared for the Basin and Range province comparing displacement with magnitude or moment. For the purposes of this example, the results of Bonilla et al. (1984) will be used. Using the wna.dm (western North American; displacement-magnitude) relation of Bonilla et al. (1984), a 0.3 m displacement would indicate an earthquake of M_s 6.6. The rupture length of this event can be estimated using the wna.dl (western North American; displacement-length) relation of Bonilla et al. (1984) as 18.8 km. The reasonableness of these estimates can be checked by calculating the percentage of the total fault length hypothesized to rupture (63 percent) and comparing the results with historical events in the province or with data on measured scarp lengths along the subject fault. Any data on single event displacements and recurrence intervals can also be compared with the design event to evaluate the results.

Uncertainty in the estimation of the magnitude of the 10,000-yr event can come from the statistical uncertainty associated with the use of regression curves and the uncertainty in the estimate of average displacement rates. The statistical uncertainty in the magnitude estimates can be quantified using the techniques discussed in Bonilla et al. (1984). The uncertainty in the slip rate estimates will be evaluated by reviewing the results from multiple locations along the subject fault and the data on the accuracy of displacement and age-dating measurements.

Earthquake magnitude-frequency relationships will be estimated (using available data) considering characteristic-earthquake models or other relationships such as exponentially decaying models or maximum likelihood models. A probability distribution for true maximum magnitude, M_{max}, will be estimated for the probabilistic seismic hazard analysis of the site--Activity 8.3.1.17.3.6.1. The magnitude-frequency relationship will be used to evaluate the recurrence interval associated with M_{max} and will assist in determining whether the 10,000-yr cumulative slip earthquake magnitude should differ from M_{max}.

The 10,000-yr cumulative slip earthquakes for each relevant earthquake source will be characterized by an expected depth or depth-range and earthquake magnitude.

The 10,000-yr cumulative slip earthquake methodology and the planned adjunct probabilistic seismic hazard analysis provide a useful and sufficient framework for scoping, organizing, and prioritizing seismic-hazard-related site-characterization activities. Together the cumulative slip earthquake methodology and the probabilistic analysis require, and the planned site-characterization activities are designed to provide, all types of information that are material to the characterization of seismic hazard, including data on fault lengths and displacements, slip rates, faulting styles, maximum-magnitude estimates, recurrence-rate estimates, attenuation relationships, local and regional tectonic models, historical seismicity, and the uncertainties associated with all these items. The cumulative slip earthquake methodology may be revised or a different methodology may be used to actually develop a design basis for the advanced conceptual design and the license application design. In any instance, the data gathered will be comprehensive and sufficient for application to any methodology.

Methods and technical procedures

This activity will only synthesize and compile data collected by other activities. All evaluations and calculations will be documented or verified in conformance with the DOE quality assurance program (Section 8.6).

8.3.1.17.3.2 Study: Underground nuclear explosion sources

The objective of this study is to characterize the potential future underground nuclear explosions (UNEs) at the Nevada Test Site (NTS) that region would result in the most severe motions at the repository site.

8.3.1.17.3.2.1 Activity: Determine the range of UNE sources

Objectives

The objective of this activity is to determine potential locations and upper limits on the yield of future UNE tests within the NTS.

Description

Previous work on potential UNE ground motions at the site has assumed that a 700-kiloton explosion is detonated in the Buckboard Mesa area of the NTS, at a distance of 23 km from the repository shaft (Vortman, 1986). This activity will review the basis for these assumptions, in particular, the constraints on maximum UNE yields, such as damage thresholds in Las Vegas. (The current test-ban treaty threshold is 150 kiloton.) Factors that could influence the locations of future UNEs, such as terrain and rock types at the NTS, will be reviewed. Information on depth of burial as a function of yield will be compiled. Information available in the open literature is expected to adequately constrain the potential locations, depths, and maximum yields of future UNEs at the NTS.

Methods and technical procedures

This activity will only synthesize and compile data collected by other activities. All evaluations and calculations will be documented or verified in conformance with the DOE quality assurance program (Section 8.6).

8.3.1.17.3.2.2 Activity: Determine maximum underground nuclear explosion source(s)

Objectives

The objective of this activity is to identify the potential future UNE(s) that would generate the most severe ground motions at the site.

Description

UNE ground-motion (attenuation) models (which will be developed or selected in Activity 8.3.1.17.3.3.2) will be used to estimate site ground motions that would result from the largest and/or closest potential future UNEs, as identified in Activity 8.3.1.17.3.2.1. The UNE or UNEs that would generate the most severe ground motions at the site, in any frequency band of engineering significance, will be identified.

Methods and technical procedures

This activity will only synthesize and compile data collected by other activities. All evaluations and calculations will be documented or verified in conformance with the Project quality assurance program (Section 8.6).

8.3.1.17.3.3 Study: Ground motion from regional earthquakes and underground nuclear explosions

Objectives

The objective of this study is to select or develop ground-motion models that are appropriate for estimating ground motion at the site from earthquakes and UNEs. These models will be used to determine the relevancy of seismic sources to a deterministic seismic hazard analysis (Activity 8.3.1.17.3.1.1), identify controlling seismic events (Activity 8.3.1.17.3.5.1), constrain simulated ground motions from controlling seismic events (Activity 8.3.1.17.3.5.2) and estimate the probabilities of exceeding given ground-motion levels at the site (Activity 8.3.1.17.3.6.2).

8.3.1.17.3.3.1 Activity: Select or develop empirical models for earthquake ground motions

Objectives

The objective of this activity is to select or develop empirical ground-motion models that are appropriate for estimating earthquake ground motion at the site. The models will predict ground motion as a function of earthquake magnitude and distance between the earthquake source and the site.

Parameters

Models will be determined for a number of ground-motion parameters, including peak ground acceleration and velocity, duration, and spectral amplitudes at frequencies sampled over the range of engineering significance.

Description

The approach here will be to test available ground-motion data from the Great Basin and areas elsewhere that are tectonically analogous for statistically significant deviations from published models that have been developed for California and western North America. If the deviations are not statistically significant, a published model will be selected. If the deviations are statistically significant or if published models are not available for any of the ground-motion parameters to be modeled, then new models will be developed through regression analyses. Each model selected or developed will include an explicit description of the uncertainty in the model predictions.

Methods and technical procedures

This activity will only synthesize and compile data collected by other activities. All evaluations and calculations will be documented or verified in conformance with the DOE quality assurance program (Section 8.6).

8.3.1.17.3.3.2 Activity: Select or develop empirical models for ground motion from underground nuclear explosions

Objectives

The objective of this activity is to select or develop empirical ground-motion models that are appropriate for estimating ground motion at the site from UNEs at the NTS. The models will predict ground motion as a function of the yield and distance of the UNE.

Parameters

As for earthquakes, models will be determined for a number of ground-motion parameters, including peak ground acceleration and velocity, duration, and spectral amplitudes sampled over the range of engineering significance.

Description

If possible, published ground-motion models for NTS explosions (Vortman, 1986) will be used. If appropriate published models are not available for all ground-motion parameters needed, available data will be compiled and the needed models will be developed through regression analyses.

Methods and technical procedures

This activity will only synthesize and compile data collected by other activities. All evaluations and calculations will be documented or verified in conformance with the DOE quality assurance program (Section 8.6).

8.3.1.17.3.4 Study: Effects of local site geology on surface and subsurface motions

Objectives

The objective of this study is to document systematic effects on surface and subsurface ground motions resulting from the local site geology. Local correction factors will be developed for application to predictions of the regional ground-motion models developed in Study 8.3.1.17.3.3. These correction factors will be based, to the extent possible, on instrumental recordings of ground motion obtained in Study 8.3.1.17.4.1. Theoretical models for the observed site effects will be developed to the extent necessary to explain the observations to first order and then used to extrapolate the observations to locations and depths where ground motions must be predicted but where recordings are not available.

8.3.1.17.3.4.1 Activity: Determine site effects from ground-motion recordings

Objectives

The objectives of this study are to determine, from ground-motion recordings, systematic effects of the local site geology on surface and subsurface motions, and to identify any significant site-wide bias in ground-motion levels, as compared with average levels for the southern Great Basin. These empirical determinations will be used to calibrate theoretical site-effects models in Activity 8.3.1.17.3.4.2.

Parameters

Ground-motion biases in the proximity of proposed locations of surface facilities important to safety, as compared with area averages obtained on rock sites, will be characterized using ratios of Fourier spectra and ratios of peak ground-motion parameters (peak accelerations and peak velocities). Corresponding ratios will be used to characterize reductions in ground motions recorded at the approximate depth of underground facilities as compared to area averages of surface recordings on rock sites.

Description

Recordings of teleseisms, regional earthquakes, local microearthquakes (if any), and UNEs will be obtained at several (3 to 6) surface and two or more borehole sites in Midway Valley, and at the proposed location of surface facilities, as described in Activity 8.3.1.17.4.1.2. The recorded motions will be examined for variation with position to identify any systematic biases, particularly with respect to the depth of the valley sediments. These recorded motions and the spatial variability will be used to help calibrate theoretical models developed in Activity 8.3.1.17.3.4.2 and to determine motion averages representative of proposed locations of surface facilities important to safety.

Spectral amplification functions will be estimated by forming ratios of recorded earthquake spectra at individual locations on Midway Valley to local-array-averaged spectra obtained on nearby rock stations. Amplification factors for peak ground-motion parameters will be similarly determined. The possibility of a site-wide bias in ground-motion levels will be checked by comparing amplitudes recorded at site locations to amplitudes recorded at sites elsewhere in the southern Great Basin, for earthquakes of similar size and at comparable distances.

The spectral amplitudes of subsurface motions will be compared with the spectral amplitudes for the corresponding surface motions and with the area averages for surface motions at rock stations. Previously recorded relevant NTS data will also be considered. These data will be used to quantify spectral reductions in motion with depth as a function of frequency. Instruments will be installed at two or more surface sites on Yucca Mountain, above proposed underground facilities, and at several sites within the exploratory shafts and drifts. The local array stations will be installed during the first phase of a planned upgrade of the current regional seismic network. These stations will digitally record and buffer incoming signals and then telemeter them via a satellite link to Golden, Colorado. In addition, a dense array of portable seismic event recorders will be temporarily deployed at some point for the study of local site effects. This temporary array will likely be deployed to take advantage of announced nuclear tests at the NTS.

Methods and technical procedures

This activity will only synthesize and compile data collected by other activities. All evaluations and calculations will be documented or verified in conformance with the DOE quality assurance program (Section 8.6).

8.3.1.17.3.4.2 Activity: Model site effects using the wave properties of the local geology

Objectives

The objective of this activity is to develop a calibrated theoretical site-effects model for use in extrapolating the observations documented in Activity 8.3.1.17.3.4.1 to locations and depths where ground-motion predictions are needed, but where instrumental recordings are not available.

Parameters

The product of this activity will be theoretical spectral amplification functions. Corresponding amplification factors for peak-ground-motion parameters will be estimated from the spectral amplification functions, if needed.

Description

Theoretical site-effects models will be developed, based on measurements of the wave properties (shear- and compressional-wave velocities, material damping, and densities) as determined in the investigation of soil and bedrock properties (Section 8.3.1.14.2). As part of that investigation, the seismic velocity structure of the site will be determined to a depth of at least 1 km, particularly under Midway Valley.

The approach to modeling will be to construct the simplest model that predicts the first-order features of the observed site-response functions. The initial model will assume a one-dimensional velocity structure, linear soil response, and vertically incident body waves. More complexity (e.g., nonvertically incident body waves, surface waves, equivalent-linear soil response, or two-dimensional velocity structure) will be introduced as necessary.

Methods and technical procedures

This activity will only synthesize and compile data collected by other activities. All evaluations and calculations will be documented or verified in conformance with the DOE quality assurance program (Section 8.6).

8.3.1.17.3.5 Study: Ground motion at the site from controlling seismic events

The objectives of this study are to identify the controlling seismic events and to characterize the resulting controlling ground motions. Controlling seismic events are those UNEs or 10,000-yr cumulative slip earthquakes that would generate the most severe ground motions at the site, at frequencies of engineering significance.

Two activities are included in this study.

8.3.1.17.3.5.1 Activity: Identify controlling seismic events

Objectives

The objective of this activity is to identify those UNEs or 10,000-yr cumulative slip earthquakes that would produce the most severe ground motions at the site at frequencies of engineering significance. There may be more than one controlling seismic event because different events may generate the most severe ground motions in different frequency bands.

Parameters

The controlling earthquake(s) will be characterized by earthquake magnitude and hypocentral location. Controlling earthquakes will be additionally characterized by the fault strike and dip and expected slip direction. The controlling UNE(s), if any, will be characterized by distance, azimuth, depth, and yield.

Description

Identification of the controlling seismic events will follow directly from the identification of 10,000-yr cumulative slip earthquakes on relevant sources in Study 8.3.1.17.3.1, the identification of potential future UNEs in Study 8.3.1.17.3.2, the earthquake and UNE ground-motion models developed in Study 8.3.1.17.3.3, and the local site correction factors developed in Study 8.3.1.17.3.4. Site ground-motion parameters, including peak ground acceleration and velocity, duration, and spectral ordinates at several frequencies, will be calculated for the 10,000-yr cumulative slip earthquakes and for the closest, largest potential UNEs. The seismic sources that produce the most severe ground motions as indicated by the calculated ground-motion parameters will be designated as controlling.

Methods and technical procedures

This activity will only synthesize and compile data collected by other activities. All evaluations and calculations will be documented or verified in conformance with the DOE quality assurance program (Section 8.6).

8.3.1.17.3.5.2 Activity: Characterize ground motion from the controlling seismic events

Objectives

The objective of this activity is to generate suites of strong-motion time histories and corresponding response spectra that are representative in amplitude, frequency content, and duration of site ground motions that could be generated by the controlling seismic events.

Parameters

The parameters for this activity are identified in the previous section on objectives.

Description

A number of methodologies are available for simulating strong ground motions, and the first task in this activity will be to determine which method or methods will be used. At present, two general approaches appear promising.

The first approach is to scale selected instrumental strong-motion records to the sizes (earthquake magnitudes or UNE yields) and distances of the controlling seismic events. The advantage of this approach is that the instrumental records can be chosen to minimize the necessary size and distance scaling. The disadvantage of this approach is that the available strong-motion records come from locations other than Yucca Mountain and therefore reflect different site conditions and, for earthquakes, perhaps different source characteristics.

The second approach is to model motion from a controlling seismic event by a summation of motions recorded at the site for smaller events (i.e., to use the small-event records as Green's functions in the simulation of the larger, controlling event (Hartzell, 1985; Spudich, 1985)). The advantage of the Green's function summation method is that propagation-path and local-geologic effects on site ground motions are inherently accounted for. The disadvantage (for earthquakes) is the uncertainty associated with scaling source characteristics of small events to those of large events.

The feasibility of both approaches described above, and possibly others, will be evaluated for application to Yucca Mountain. It may be appropriate to implement more than one approach and compare the results to help assess the uncertainty in the final results.

The peak ground-motion parameters, durations, and spectral ordinates of the resulting time histories will be checked for consistency with the regional ground-motion models developed in Study 8.3.1.17.3.3 and any necessary corrections will be made. The spectral content of the time histories will be corrected for local site effects, as necessary, using the spectral amplification functions developed in Study 8.3.1.17.3.4.

Methods and technical procedures

This activity will only synthesize and compile data collected by other activities. All evaluations and calculations will be documented or verified in conformance with the DOE quality assurance program (Section 8.6).

8.3.1.17.3.6 Study: Probabilistic seismic hazards analyses

The primary objective of this study is to quantify the probability for experiencing ground motions of varying degrees of severity that might result from earthquakes of varying magnitude and distance from the site. Results from this study will be used to evaluate and constrain required technical judgments in the deterministic evaluation of design-basis ground motions (such as the determination of exceptional earthquake magnitudes), evaluate the adequacy of the deterministic results, and help identify and focus efforts to refine those parameters that are most important for the deterministic calculations. The probabilistic hazard estimates will also provide information needed to assess the credibility of postulated accidents at the repository that might lead to releases of radioactive materials (Information Need 2.3.1, Section 8.3.5.5.1).

8.3.1.17.3.6.1 Activity: Evaluate earthquake sources

Objectives

The objective of this activity is to determine average rates for earthquake recurrence as a function of magnitude for the southern Great Basin to a distance of about 100 km from the site, and then to apportion these rates onto active faults and subregional seismic source zones.

Parameters

Earthquake sources will be characterized by location, shape, depth, and earthquake-recurrence rates as a function of magnitude, including the specification of a maximum magnitude or probability distribution for maximum magnitude.

The following types of information will be synthesized in this activity:

1. Maps and cross sections of historical earthquake locations.

2. Maps showing Quaternary faults with lengths greater than about 20 km within 100 km of the site and Quaternary faults with lengths greater than about 1 km within 10 km of the site.

3. Data on the style and rate of Quaternary faulting in the site region.

4. Evidence of neotectonic deformation or stability in the site region.

5. Regional and local magnetic-anomaly and gravity-anomaly maps.

6. Regional and local crustal seismic data.

7. Information on local and regional crustal stresses.

8. Local and regional tectonic models.

Description

The earthquake catalog developed in Study 8.3.1.17.4.1 will be used to determine the rate that earthquakes have occurred in the region surrounding the site during historical time as a function of magnitude. The completeness of the historical earthquake record in different areas and time intervals will be evaluated considering the number of events reported in the catalog as a function of magnitude and time, past human population distributions, and past distributions of recording instruments. Different types of magnitudes reported in the catalog will be converted to a uniform magnitude measure, possibly M_L, moment-magnitude, or both. (Statistical uncertainty in the conversions will be carried through the hazard analysis.) Additional checks will be made to reconcile the gross rates of crustal deformation for the southern Great Basin with deformation rates implied from observations of seismic-moment release rates. Estimates of the upper-magnitude limits for earthquakes in this area will be required to translate rates of earthquake occurrences to rates of crustal deformations. From these investigations, best estimates, accompanied by estimates of uncertainty, will be developed for characterizing the regional rate of earthquake occurrences.

This regional rate of earthquake occurrences will then be apportioned onto active faults and subregional source zones according to models of the local and regional tectonics. More than one model will likely be required for apportioning the earthquake activity in order to express the uncertainty in current scientific interpretations and to focus efforts to refine those source representations that have the greatest impact on the site.

In this activity, seismologic and geologic data will be used to interpret earthquake sources that contribute to the probability of exceeding given ground-motion levels at the site in essentially the same manner as they will be used in Study 8.3.1.17.3.1 to interpret earthquake sources that might control site ground motions in a deterministic hazard analysis. See the description sections of Activities 8.3.1.17.3.1.1 and 8.3.1.17.3.1.2. The scope of this activity is more comprehensive in that more seismic sources will be characterized, multiple interpretations of seismic sources will most likely be retained and their relative likelihoods judged, any dependencies in the interpreted existence of source zones (e.g., perfect dependence or mutual exclusiveness of some sources) must be specified, and maximum magnitudes must be estimated explicitly.

Source-zone maps will be produced by this activity to indicate the earthquake probability as a function of magnitude and location within the southern Great Basin.

Methods and technical procedures

The methods and technical procedures for Activity 8.3.1.17.3.6.1 are given in the following table.

Method	Technical procedure		
	Number	Title	Date
	(NWM-USGS-)		
Integration of regional seismic and geologic data	SP-02,R0	Procedure for calculating frequency of recurrence curves	14 Sept 81
	SP-03,R0	Seismic zoning procedure	14 Sept 81
	SP-08,R0	Seismic study of the tectonic environment	06 June 83

[a]TBD = to be determined.

8.3.1.17.3.6.2 Activity: Evaluate ground motion probabilities

Objectives

The objectives of this activity are (1) to estimate the probability of exceeding given ground-motion levels at the site and (2) to integrate the contributions to that probability from all identified earthquake sources that could generate potentially damaging ground motion at the site.

Parameters

The basic information items needed for a probabilistic seismic hazard analysis are as follows:

1. Boundaries of seismic source zones, including, if warranted, alternative interpretations and corresponding judgments of the relative likelihood that each interpretation is correct.

2. Earthquake-magnitude recurrence rates for each source zone, including estimates of maximum magnitudes and assessments of uncertainty.

3. Specification of any dependencies in the interpreted existence or activity of source zones (e.g., perfect dependence or mutual exclusiveness of some sources).

4. Ground-motion (attenuation) models for predicting expected values and variances of required ground-motion parameters (e.g., peak velocity) as a function of distance and source size.

Description

There are a number of software packages available for computing probabilistic seismic hazard estimates given the information listed in the parameters section (e.g., codes developed by the Electric Power Research Institute (EPRI, 1986) and Lawrence Livermore National Laboratory (Bernreuter et al., 1986)). Some codes embody different means of propagating uncertainties through the analysis to the final results, and the alternative approaches will be evaluated. It may be appropriate to calculate hazard levels using different codes for comparison.

As stated previously, the probabilistic seismic hazard analysis will be performed iteratively, in parallel with the deterministic hazard analysis. The sensitivity of calculated hazard to different input parameters will be tested to identify what interpretations impact the site the most and may, therefore, warrant refinement. The final hazard estimates will be compared with the deterministically derived design-basis ground motions to verify that they correspond to annual exceedance probabilities of 10^{-3} to 10^{-4} per year.

Methods and technical procedures

The methods and technical procedures for Activity 8.3.1.17.3.6.2 are given in the following table.

Method	Technical procedure		
	Number	Title	Date
Probabilistic hazard calculations	TBD[a]	Probabilistic ground-motion calculations	TBD

[a]TBD = to be determined.

8.3.1.17.3.7 Application of results

Information on vibratory ground motion will be used as follows:

1. In the development and analysis of the repository design (Issue 4.4, technical feasibility, Section 8.3.2.5).

2. In the determination of credible accidents that are applicable to the repository (Issue 2.3, accidental radiological releases, Section 8.3.5.5).

3. In the determination that waste can be accessed and removed from the emplacement boreholes throughout the retrievability period for normal and off-normal conditions (Issue 2.4, waste retrievability, Section 8.3.5.2).

4. In the identification of normal and accident conditions, including disruptive events (Issue 2.7, repository design criteria on radiological safety, Section 8.3.2.3).

8.3.1.17.4 Investigation: Preclosure tectonics data collection and analysis

Technical basis for obtaining the information

Link to technical data chapters and applicable support documents

The following sections provide a summary of existing data relevant to this investigation:

SCP section	Subject
1.3.1	Tectonic framework
1.3.2	Tectonic history
1.4.1	Seismology of the southern Great Basin
1.4.2	Seismology of Yucca Mountain
1.5.1	Volcanism
1.5.2	Faulting
1.5.3	Vertical and lateral crustal movement
1.8.1	Summary of significant results

Parameters

Information to be provided by the studies under this investigation include the following:

1. Catalog of historical earthquake occurrence times, locations, and magnitudes.

2. Analysis of potential for UNEs, mining activity, or reservoir (Lake Mead) impoundment to induce seismicity near the site.

3. Recordings obtained at the site and at other locations in the southern Great Basin of ground motions from earthquakes and UNEs.

4. Geological and geophysical evidence of large-scale Quaternary faulting within 100 km of the site and of smaller-scale Quaternary faulting in the site area.

5. Analysis of the seismogenic potential of detachment faults in the site area.

6. Evaluation of crustal stresses at seismogenic depths in the site region.

7. Morphologic and morphometric analysis of neotectonic deformation in the site region.

8. Geodetic and survey evidence of recent crustal movements in the site region.

9. Synthesis of tectonic processes acting in the site region (development of tectonic models).

Purpose and objectives of the investigation

The primary purpose of this investigation is to provide data and analyses that are required by Investigation 8.3.1.17.2, assessment of fault displacement that could affect repository design or performance, and Investigation 8.3.1.17.3, assessment of vibratory ground motion that could affect repository design or performance (refer to logic diagrams for these two investigations, Figures 8.3.1.17-4 and 8.3.1.17-5). The limited data collection and analysis that is required by Investigation 8.3.1.17.1, volcanic activity that could impact the repository, will be performed within that investigation (Figure 8.3.1.17-3).

Technical rationale for the investigation

The data-collection-and-analysis studies have been aggregated under this fourth investigation for two reasons. Much of the information that will be provided by the data-collection-and-analysis studies is needed for more than one assessment. For example, information on Quaternary faulting near the site is germane to both the faulting and the ground-motion potential at the site. Also, most of the studies are most naturally organized around a geological problem, the solution of which may require a broader focus than the repository site itself. All studies are intended to contribute to the resolution of design or performance issues, even though the linkage may sometimes be indirect for studies that have a broad focus, such as the evaluation of tectonic models (Study 8.3.1.17.4.12).

8.3.1.17.4.1 Study: Historical and current seismicity

The objective of this study is to compile information on reported and instrumentally recorded earthquakes that characterize the earthquake potential near Yucca Mountain. This information will be used (1) to help identify and characterize potentially relevant earthquake sources for the deterministic hazard analysis (Study 8.3.1.17.3.1) and potentially contributing earthquake sources for the probabilistic hazard analysis (Study 8.3.1.17.3.6), (2) to develop regional earthquake ground-motion models (Activity 8.3.1.17.3.3.1), and (3) to determine local-geologic and depth-of-burial effects on ground motion at the site (Activity 8.3.1.17.3.4.1).

8.3.1.17.4.1.1 Activity: Compile historical earthquake record

Objectives

The objective of this activity is to compile a record of historical seismic events in the southern Great Basin or within 100 km of Yucca Mountain. The record will be as complete and accurate as is reasonably achievable, and will indicate whether each cataloged seismic event is thought to be a natural earthquake, induced earthquake, underground nuclear explosion (UNE), cavity collapse, or blast. For potentially damaging earthquakes ($M \geq 5.5$) in the study region, available information will be compiled on ground-motion intensity, availability of strong-motion records, and extent and style of faulting.

Parameters

Parameters to be compiled for recorded seismic events include the following:

1. Date.

2. Origin time.

3. Hypocentral location.

4. Hypocenter uncertainty estimate.

5. Magnitude (and magnitude type).

6. Magnitude uncertainty estimate.

7. Annotation of whether the event is an earthquake, UNE, cavity collapse, etc.

Additional parameters to be compiled as available for the larger ($M \geq 5.5$) earthquakes include the following:

1. Focal mechanism (dip, strike, and rake).
2. Seismic moment.
3. Stress drop.
4. Extent of surface rupture.
5. Epicentral intensity.
6. Epicentral intensity uncertainty estimate.
7. Total felt area.
8. Falloff of intensity with distance.
9. Peak ground accelerations.
10. Peak ground velocities.
11. Durations.
12. Selected spectral amplitudes.

Description

The required parameters will be obtained primarily through a literature survey. Meremonte and Rogers (1987) have compiled a catalog of historical earthquakes in the southern Great Basin that provides most of the needed information. The catalog will be updated periodically to add new information, and the geographic coverage of the catalog may need to be extended somewhat to cover all areas of interest. Also, uncertainty estimates for magnitudes and epicentral intensities need to be added to the catalog. Most of the additional parameters for the larger earthquakes will also be obtained from the literature. If source parameters (focal mechanism, seismic moment, and stress drop) have not been published for any of the larger earthquakes in the record and sufficient data are available to determine them, these data will be obtained and the source parameters will be determined.

Methods and technical procedures

This activity will only synthesize and compile data collected by other activities. All evaluations and calculations will be documented or verified in conformance with the DOE quality assurance program (Section 8.6).

8.3.1.17.4.1.2 Activity: Monitor current seismicity

Objectives

The objective of this activity is to provide empirical information on how often earthquakes are currently occurring in the southern Great Basin; what the orientation, depth, and style of faulting are; how seismic wave amplitudes scale with magnitude and attenuate with distance in the region; and how ground motions vary with depth and with surface geology in the site area. The information on faulting and earthquake location and recurrence will be used to identify potentially relevant earthquake sources for the deterministic hazard analysis (Study 8.3.1.17.3.1) and potentially contributing earthquake sources for the probabilistic hazard analysis (Study 8.3.1.17.3.6). The information on magnitude and distance scaling will be used to develop regional ground-motion models (Study 8.3.1.17.3.3). The data on ground-motion variations at the site will be used to develop site correction factors and response functions (Study 8.3.1.17.3.4). Recordings obtained at Yucca Mountain of small earthquakes may be used as Green's functions in the simulation of controlling earthquake motions (Activity 8.3.1.17.3.5.2).

Parameters

Parameters to be compiled for recorded seismic events include the following:

1. Date.

2. Origin time.

3. Hypocentral location.

4. Hypocenter uncertainty estimate.

5. Magnitude (and magnitude type).

6. Magnitude uncertainty estimate.

7. Annotation of whether the event is a earthquake, UNE, cavity collapse, etc.

For the larger ($M \geq 5.5$) earthquakes, available information will be compiled as follows:

1. Focal mechanism (strike, dip, and rake).
2. Seismic moment.
3. Stress drop.
4. Extent of surface rupture.
5. Epicentral intensity.
6. Epicentral intensity uncertainty estimate.
7. Total felt area.
8. Falloff of intensity with distance.
9. Peak ground accelerations.
10. Peak ground velocities.
11. Durations.
12. Spectral amplitudes.

Description

Current seismicity will be monitored by a regional seismograph network, a local accelerograph array, and a portable array of digital seismic event recorders that can be deployed with seismometers, accelerometers, or both. The southern Great Basin (SGB) regional seismograph network has been in operation since 1978 (Rogers et al., 1981; 1983) and will continue to be operated and maintained. The SGB network consists of 49 high-gain seismograph stations within a 150-km radius of Yucca Mountain and an additional subnet of six seismometers on Yucca Mountain, providing a local detection threshold of about local magnitude (M_L) 0.0, and a regional detection threshold of about M_L 1.0.

The output of each seismometer in the SGB network is converted to an FM radio signal and telemetered via microwave links and telephone lines to Golden, Colorado. The bandwidth and dynamic range of the current seismometer-telemetry system is somewhat limited. For example, the usable dynamic range (of about 40 dB) is such that a local earthquake that is recorded with good fidelity in one area of the network will likely be in the noise or off-scale in another area of the network because of the attenuation of earthquake ground motion with distance. It may, therefore, be appropriate to upgrade the network recording capability. A subtask of this activity is to assess what enhancements of recording capability are needed, if any, to provide the required data parameters. If warranted, available options for enhancing network performance will be evaluated and an appropriate option will be implemented.

A local accelerograph array will be installed at the site as described in Activity 8.3.1.17.4.1.2, with about a half-dozen three-component transducers located on Yucca Mountain and in Midway Valley. The primary purpose of this array will be to record, on scale, strong ground motions from a nearby moderate-to-large earthquake should one occur.

A portable array of digital seismic event recorders with about a 30-channel capacity will be used for special studies, such as obtaining high-dynamic-range data that are suitable for calculating earthquake source parameters (e.g., stress drop and moment), obtaining accurate aftershock locations, monitoring microseismicity in the vicinity of suspect tectonic features, or measuring local site effects on ground motion.

It will be useful to record with good fidelity a number of UNEs from the Nevada Test Site at surface and subsurface locations on Yucca Mountain and near the sites of prospective surface facilities in Midway Valley. Such records will enable regression relations for UNE ground motions to be calibrated against actual observations at the site and will provide important information on the local variability of surface ground motion and on the variation of ground motion with depth. These data could be obtained by adding seismometers and higher- gain channels to the local accelerograph array (in which case digital recording for the array would be indicated) or by a several-year deployment of portable digital event recorders. The costs and benefits of each approach will be evaluated and the most cost-effective approach will be implemented.

Methods and technical procedures

This activity will only synthesize and compile data collected by other activities. All evaluations and calculations will be documented or verified in conformance with the DOE quality assurance program (Section 8.6).

8.3.1.17.4.1.3 Activity: Evaluate potential for induced seismicity at the site

Objectives

The objective of this activity is to evaluate the potential for human activities to significantly perturb the natural seismic hazard at the site by inducing seismicity at or near the site. To date, the human activities that have been identified as having a potential to induce seismicity in the site region are the impoundment of Lake Mead, the testing of nuclear devices at Nevada Test Site (NTS), and the mining of the repository itself. The information developed in this activity will be used in estimating of magnitude-recurrence relationships for earthquake sources that are relevant to the deterministic hazard analysis (Activity 8.3.1.17.3.1.1) and for earthquake sources that contribute to the probabilistic seismic hazard at the site (Activity 8.3.1.17.3.6.1).

Parameters

Data needed for this activity include

1. Historical catalog of southern Great Basin earthquakes.

2. Locations, times, and yields of UNEs at the NTS.

3. Survey of literature on seismicity induced by the impoundment of Lake Mead.

4. Survey of literature on mining-induced seismicity (rock bursts).

Information to be provided by this activity includes

1. Correlation between earthquake occurrences and UNE occurrences.

2. Correlation between earthquake occurrences and the impoundment of Lake Mead.

3. Identification of induced earthquakes in the historical catalog.

4. Assessment of likelihood of mining induced seismicity.

Description

The catalog of southern Great Basin earthquakes will be examined to determine if significant changes in rates of occurrence of earthquakes are detectable following nuclear tests at the NTS. An estimate of background levels of seismicity in various annuli surrounding Pahute Mesa and Yucca Flats will be compared with seismicity levels in those annuli for short time spans (on the order of several hours to several weeks) following nuclear tests. A search for significant differences in rates will be conducted. If a statistically significant increase in earthquake activity (after-shocks) following nuclear tests is found, the correlation between earthquake rates and UNEs will be evaluated as a function of distance form the test, time after the test, and yield of the test. The feasibility of correcting historical earthquake-recurrence rates for bias from nuclear-event after shocks will be explored, as will the means of identifying individual induced events in the historical catalog.

Because Lake Mead is about 120 mi from the site, it is not expected that reservoir-induced seismicity will impact the site. A survey of the literature on Lake Mead-induced earthquakes will be performed to confirm this expectation. Should the literature survey prove inconclusive, a statistical analysis will be performed of the correlation between earthquake occurrences, distance from the lake, time since impoundment, and fluctuations in water level.

Mining-induced earthquakes (rock bursts) are believed to occur when relatively small local cavity stresses trigger failure in a much larger volume of highly prestressed rock. This type of failure has occurred mostly in deep mines (McGarr, 1984) under conditions where rock sample testing shows the rock to be both very strong and very brittle (McGarr et al., 1975). Sudden exfoliation has accompanied excavation at shallow depths in granite quarries (Suppe, 1985). The failure is apparently associated with a "buckling beam" instability as slabs of rock flex upward as the load is removed. This is associated with large horizontal compressive stresses.

Of particular relevance to the planned excavations in Yucca Mountain is experience from coal mines in the eastern Wasatch Plateau. Earthquake-like activity, clearly related to mining, extends from near the base of the mine to some depth (Williams, 1987). However, the activity is associated with the removal of massive amounts of material (several million tons per year) that is then transported far from the site.

Considerable mining experience exists at the NTS (e.g., Zimmerman and Finley, 1987), and no reports of mine-induced catastrophic failure are known. The prospective Yucca Mountain mine excavation will not be much greater in size and no deeper than other cavities on the test site and will be tiny when compared with the Utah coal workings. Also, the material mined will be left on the surface to minimize the change of loading.

No examples of explosive catastrophe associated with conditions of extensional tectonics similar to those found in Yucca Mountain have been found in a limited survey of the literature. A more comprehensive review of the literature will be performed to increase the confidence in this finding. In the improbable event that seismic activity does appear when excavation starts, its study will, at least in the first instance, be covered by the standard needs of the seismology program.

Procedures to invert for earthquake parameters, such as origin time and hypocentral location, will take into account, when appropriate, the structural velocity models developed in Activity 8.3.1.17.4.1.2. In addition, a variety of algorithms will be used to model P- and S-wave propagation through homogenous plane layers, and layers with velocity gradients.

Methods and technical procedures

This activity will only synthesize and compile data collected by other activities. All evaluations and calculations will be documented or verified in conformance with the DOE quality assurance program (Section 8.6).

8.3.1.17.4.2 Study: Location and recency of faulting near prospective surface facilities

Two activities are included in this study.

8.3.1.17.4.2.1 Activity: Identify appropriate trench locations in Midway Valley

Objectives

The objective of this activity is to identify appropriate trench locations at proposed locations for repository surface facilities that are important to safety through detailed geologic mapping and remote sensing studies. The recommended locations will be used in trenching investigations in Activity 8.3.1.17.4.2.2.

Parameters

The parameters for this activity include

1. Displacement history on mappable faults in bedrock and alluvium.

2. Distribution of mappable surficial deposits (1:5000 scale) based on regional geomorphic categorization.

3. Ages of units in item 2; absolute where possible and relative otherwise.

4. Topographic features or lineaments that may be expressions of previous fault rupture.

5. Potential for surface rupture from underlying structural features.

Description

The alluvial area in Midway Valley and adjacent bedrock on Exile Hill will be mapped geologically at a scale of 1:5000. The bedrock units are to be identified according to attitude, distribution, age, and salient features, e.g., weathering, fracturing, composition, and texture (size of particles and mineral components). The surficial deposits will be mapped using geomorphic expression, degree of carbonate cementation, and lithology. The mapping will be supplemented by small test pits, coupled with subsurface data obtained from existing boreholes and geophysical profiles. The mapping will be carried out using existing color aerial photography and observations from field traversing.

Tiva Canyon units of the Paintbrush Tuff are the only bedrock expected; preliminary mapping has identified caprock, upper cliff, and upper lithophysal units. Only minor faults have been observed on the east side of Exile Hill, and a geologic map and accompanying geologic cross sections (Scott and Bonk, 1984) are inconclusive regarding extent of faulting. Neal (1986) indicates that closely spaced faults (<50 m) occur beneath the surficial deposits, but not necessarily on the exposed part of the east flank of Exile Hill. Q1, Q2, and QTa deposits are known to occur, based on preliminary mapping by Swadley et al. (1984). Faults are not believed to penetrate alluvial units; surface expression is not evident.

The mapping will use commonly recognized chronology for Quaternary units, i.e., Holocene (Q1), intermediate (Q2), and older (QTa). Age assignments will be based on chronostratigraphic correlation (e.g., relative to known, dated units such as the Bishop ash (738,000 yr)), on dating of deposits using applicable soil techniques where possible, and on correlations based on geomorphic expression and lithology.

The dating of stratigraphic or soil horizons frequently depends on extrapolation of mapped units and generally must be grouped within broad age categories. Dating by almost any method is subject to limitations inherent in the methods (Szabo et al., 1981; Rosholt, 1985). Several appropriate dating methods are possible for use at Yucca Mountain and more than one method of dating may be required to establish confidence at a given location.

The siting approach for the waste handling building is to position it where there is no evidence of faults with Quaternary slip rates exceeding 0.001 mm/yr or faults that measurably offset materials less than 100,000 yr old (refer to discussion of purpose and objectives of Investigation 8.3.1.17.2, studies to provide information on fault displacement that could affect repository design or performance). Possible areas of Quaternary faulting will be identified by interpreting aerial photography of various scales and sun-angles in addition to the geologic mapping. Remote sensing studies will identify linear topographic breaks, alignment of drainages, or vegetation changes that could be related to Quaternary faulting. Any lineaments that are found will be investigated on the ground during the geologic mapping. Areas of suspected Quaternary faulting may also be investigated using topographic profiling or shallow geophysical techniques (e.g., seismic refraction and reflection).

Methods and technical procedures

The methods and technical procedures for Activity 8.3.1.17.4.2.1 are given in the following table.

Method	Technical procedure		
	Number	Title	Date
Evaluation of surface geologic features	SNL TP-0068	Surface geologic mapping	31 July 87

8.3.1.17.4.2.2 Activity: Conduct exploratory trenching in Midway Valley

Objectives

The objective of this activity is to investigate the possible occurrence of late Quaternary surface fault rupture in the vicinity of planned surface facility locations important to safety and to identify sites without evidence of significant late Quaternary faulting. This activity will provide input into the location and design of surface facilities important to safety, particularly those associated with waste handling.

Parameters

The characterization parameters for this activity are the identification and characterization of faults that have apparent Quaternary slip rates greater than 0.001 mm/yr or that measurably offset materials less than 100,000 yr old, within 100 m of proposed locations of facilities important to safety (FITS).

Note that the 100 m distance is not intended to represent an appropriate standoff distance for FITS from faults that have a potential for displacement. Should the faulting investigations identify a fault within 100 m of proposed FITS locations, the appropriate standoff distance and/or mitigative engineering measures will be assessed.

Description

The potential for Quaternary faulting in the immediate vicinity of proposed sites for waste-handling facilities will be evaluated by excavating a trench across the site, in the surficial deposits of Midway Valley. The proposed sites of any other surface facilities identified as being important to safety will be explored by excavating similar trenches.

The trenching pattern to be used will either be a cross centered on the proposed site with arms extending in a north-south and east-west direction or a perimeter trench around the waste-handling facility. The trenches will extend at least 100 m from the proposed facility site and will be excavated to a depth that exposes material at least 100,000 yr old and preferably substantially older (including QTa deposits). Older deposits are preferred because of the added potential for detecting cumulative displacements on minor faults. The trenches will also be excavated deep enough to expose bedded material that can be reliably used to detect displacements.

One wall of the trenches will be logged in sufficient detail to demonstrate the continuity of bedding and the absence of displacement. More detailed investigations will be conducted in areas where faulting is suspected or cannot be disproved. The deposits exposed by the trenches will be dated using applicable techniques or by correlation with nearby dated deposits. Credible demonstration of the absence of faulting during the late Quaternary and the estimation of slip rates on observed faults will rely on the accuracy of measured or extrapolated ages of deposits.

Additional trenching across Midway Valley will be considered, pending the results of the above trenching.

Methods and technical procedures

The methods and technical procedures for Activity 8.3.1.17.4.2.2 are given in the following table.

Method	Technical procedure		
	Number	Title	Date
Surface geologic mapping	SNL TP-0068	Surface Geologic Mapping	30 July 87
Logging trench wall	SNL TP-0069	Trench-wall Mapping	30 July 87

Method	Technical procedure Number	Title	Date
Dating of Quaternary deposits	SNL TP-0071	Geologic Age Dating	30 July 87

8.3.1.17.4.3 Study: Quaternary faulting within 100 km of Yucca Mountain, including the Walker Lane

The objectives of this study are (1) to identify Quaternary faults within 100 km of Yucca Mountain and (2) to characterize those faults capable of future earthquakes with magnitude such that associated ground shaking could impact design or affect performance of the waste facility. This study is complemented by more specialized studies of faults at and proximal to the site. These studies are 8.3.1.17.4.2 (faulting potential near prospective surface facilities); 8.3.1.17.4.6 (Quaternary faulting within the site area); 8.3.1.17.4.4 (Quaternary faulting proximal to the site within northeast-trending fault zones); 8.3.1.17.4.5 (detachment faults at or proximal to Yucca Mountain).

The existing geologic and geophysical data base for Yucca Mountain and areas to the north and east is substantial. That area (Figure 8.3.1.17-7) is covered in its entirety by modern geologic maps of bedrock at a scale of 1:24,000 or larger, and the information contained therein is supplemented by numerous specialized geologic and geophysical studies. Figure 8.3.1.17-8 shows areas to the south (Amargosa Desert) and west (Crater Flat, Bare Mountain, Beatty area) that are less well known. Mapping of Quaternary geology, including distribution of Quaternary geologic materials, and analysis of Quaternary geomorphic evolution is not yet complete.

Yucca Mountain lies within a northwest-trending zone of structural transition between parts of south-central Nevada characterized by north-trending basins and ranges, and the Inyo-Mono area of eastern California, characterized by northwest-trending basins and ranges. This zone of transition was referred to as the Walker Belt by Stewart (1980). The northeastern boundary of the zone is diffuse; the southwestern boundary is formed by the Death Valley-Furnace Creek fault zone (Carr, 1984), a right-lateral wrench fault that cuts Holocene deposits over much of its extent. The Walker Belt contains within it zones of wrench faulting, including the Las Vegas Valley shear zone on the southeast and the shear zone near Cedar Mountain on the northwest (Gianella and Callaghan, 1934b). These shear zones were thought to be elements of a continuous zone of right-lateral shearing that was named the Walker Lane by Locke et al. (1940) (Figure 8.3.1.17-9).

The Walker Belt, then, is the zone of structural transition between adjacent structural provinces, and the Walker Lane is the postulated through-going zone of right-lateral faulting located within the Walker Belt. The Walker Lane is not a continuous linear fault, at least at the surface.

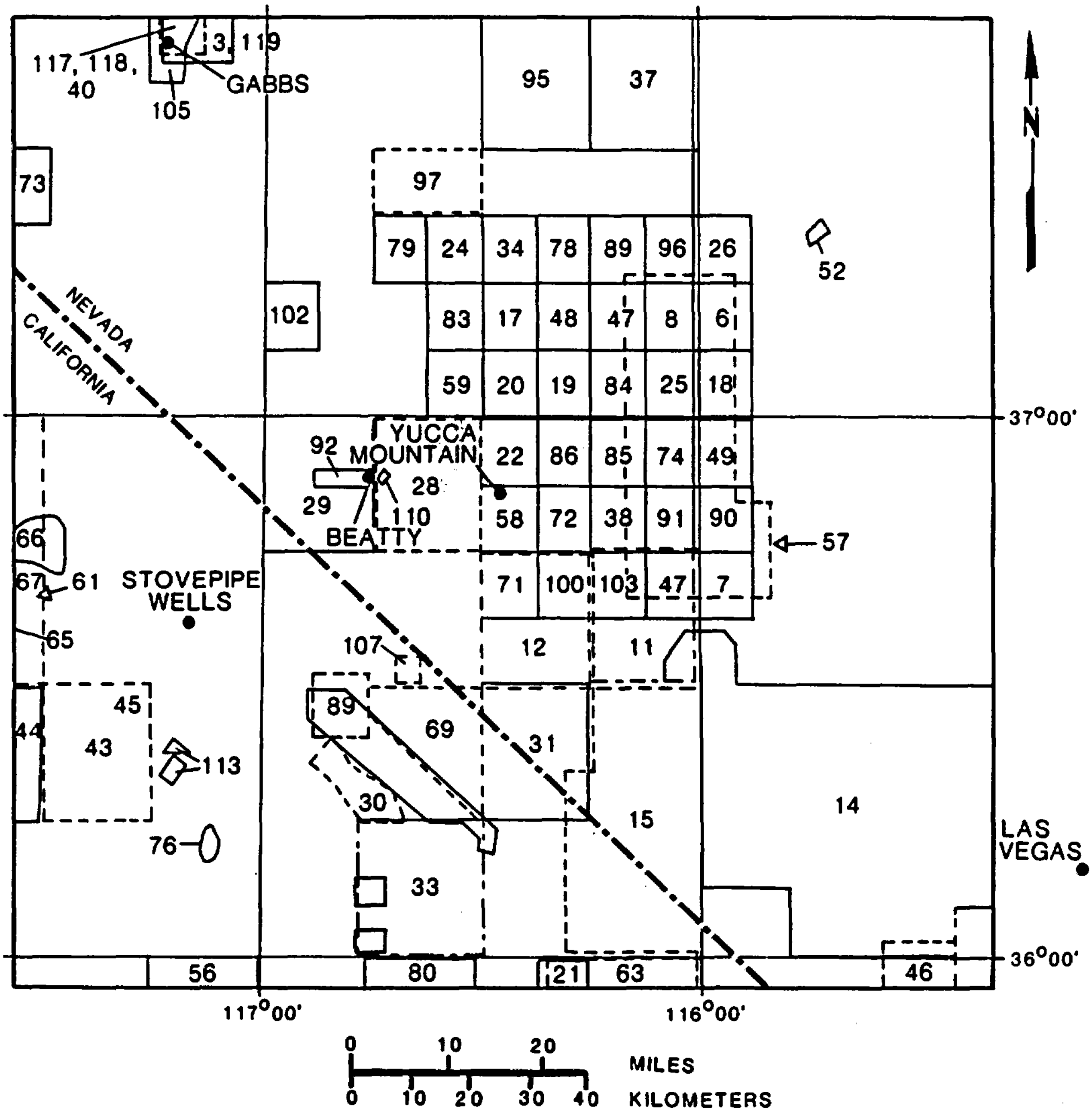

Figure 8.3.1.17-7. Index map showing published geologic map coverage at scales of 1:63,630 and larger. Map areas (numbered) referenced in Fouty (1984).

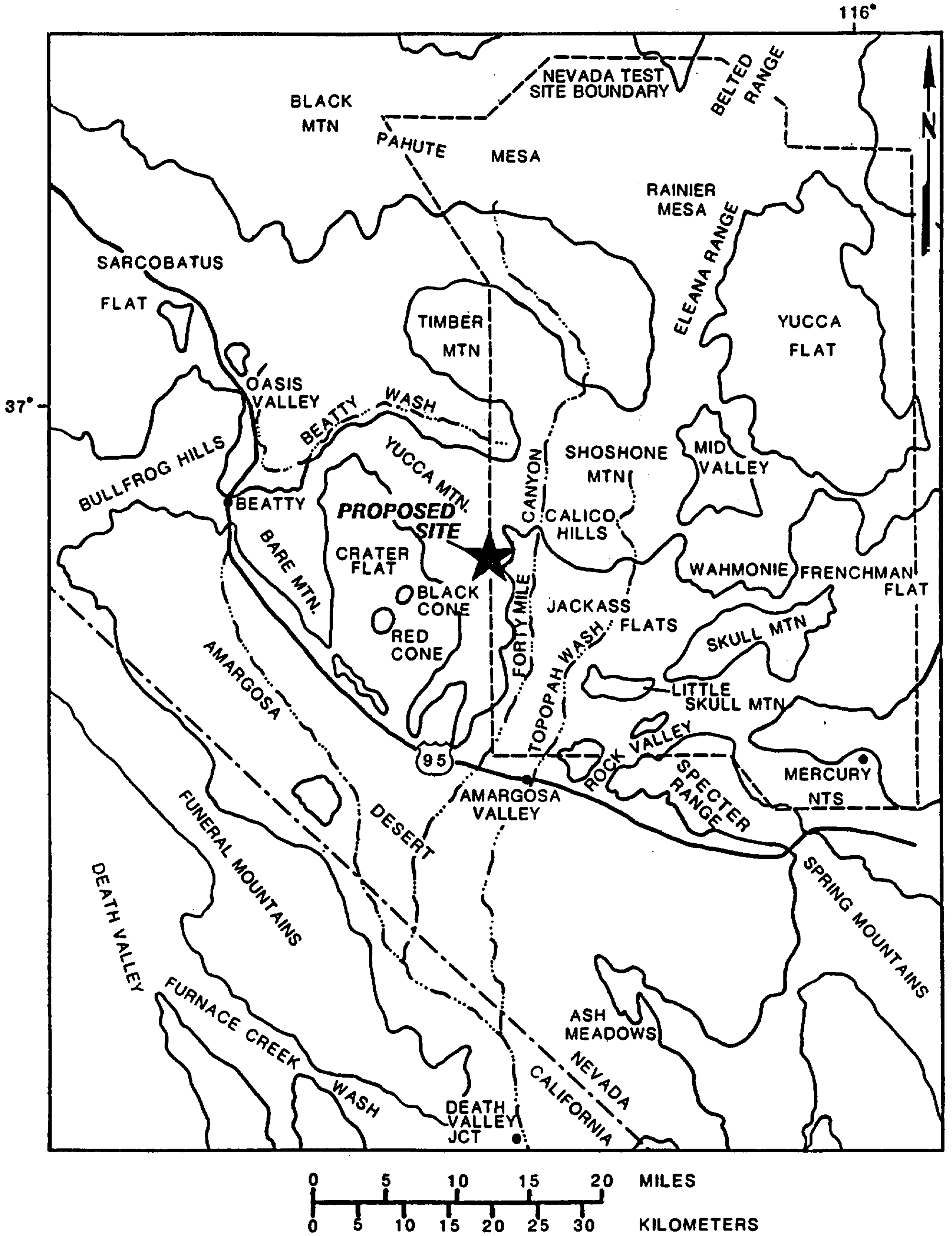

Figure 8.3.1.17-8. General localities map showing areas of exposed bedrock.

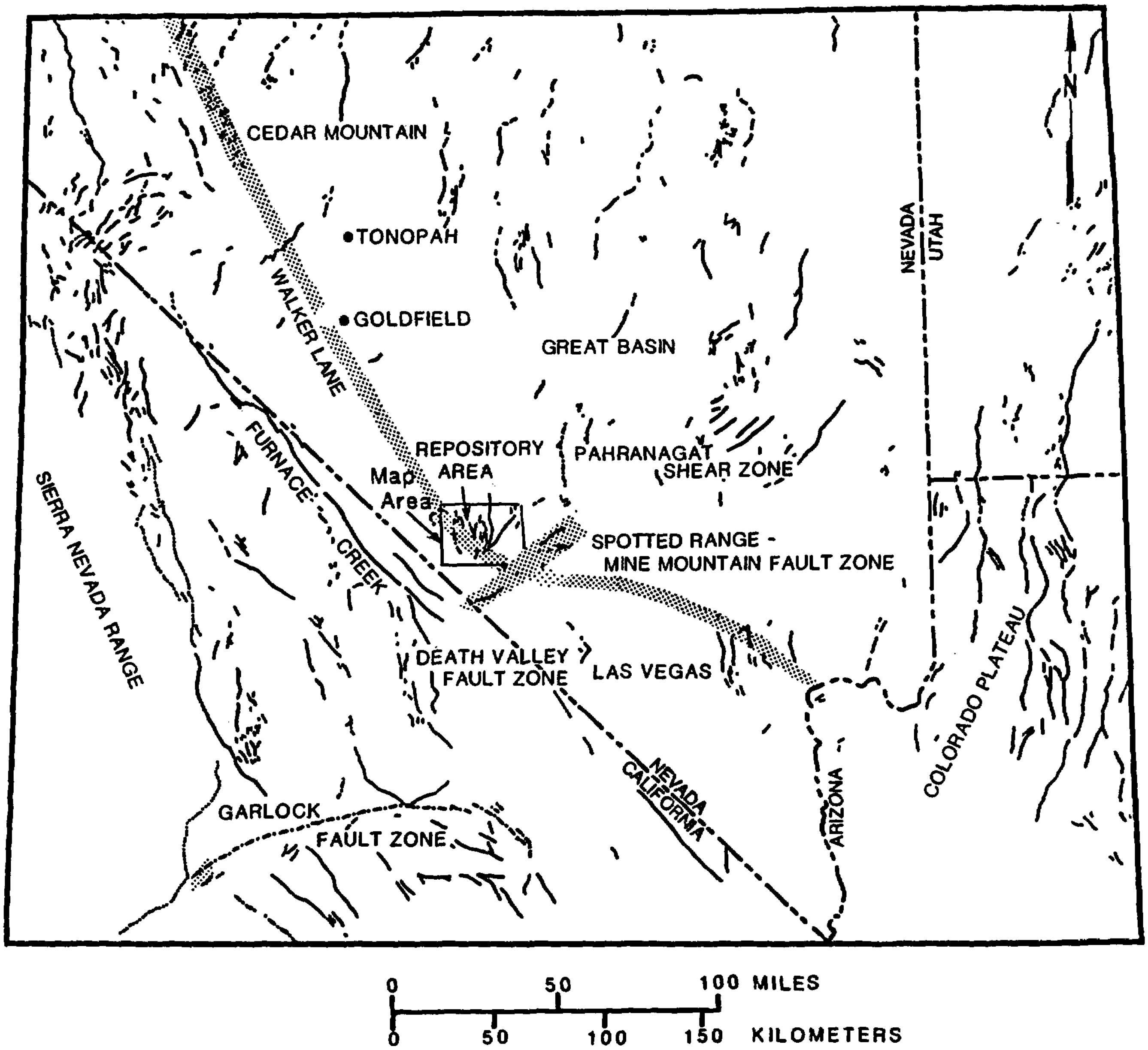

Figure 8.3.1.17-9. Regional structure map, showing location of the repository area, map areas of Figure 8.3.1.17-2 and 8.3.1.17-11, and major Quaternary structural features.

Near Cedar Mountain, site of the M = 7.2 to 7.3 earthquake of 1932, the shear zone is interpreted to be structurally overlain by a detached upper plate of Tertiary volcanic and sedimentary rocks (Molinari, 1984). According to Molinari (1984), right-lateral movement on the subsurface shear zone during the 1932 earthquake was expressed by movement of small, en echelon faults in the overlying upper plate.

At the Nevada Test Site, the Las Vegas Valley shear zone, which forms the southeastern element of the Walker Lane, as defined by Gianella and Callaghan (1934b) and Locke et al. (1940), cuts Paleozoic rocks and is overlain by Oligocene-Miocene sedimentary deposits and Miocene ash flows (Ekren, 1968). The Oligocene-Miocene rocks are thought to be part of an upper plate (Figure 8.3.1.17-10) that is structurally detached from subjacent basement blocks bounding either side of the subsurface extension of the Las Vegas Valley shear zone (Burchfiel, 1965). An alternative interpretation is that the Las Vegas Valley shear zone curves westward and, concealed below the upper plate, connects with the Furnace Creek fault, rather than with other elements of the Walker Lane to the northwest (Burchfiel, 1965).

Northwest-trending lineaments and right-lateral strike-slip faults exposed at Yucca Mountain and vicinity could be surface expressions of the Walker Lane. These include faults at Yucca Wash (Carr, 1984), Drill Hole Wash (Spengler and Rosenbaum, 1980), and the Yucca-Frenchman shear zone (Carr, 1974). Quaternary movement on these faults has not been recognized. As shown in Section 1.4, current seismicity is not identified with these faults, and focal mechanisms of earthquakes within and proximal to the site do not show northwest-trending fault planes. This may suggest that this part of the Walker Lane has not been seismically active since records have been kept.

In addition to the change in orientation of basins and ranges that occurs within the Walker Belt, the structural grain of certain structural blocks within the belt is sharply deflected from the regional trend. These blocks appear to have been rotated about a vertical axis forming an oroflex (Albers, 1967). Recent paleomagnetic and structural studies of Miocene ash flows suggest that Yucca Mountain has been bent into an oroflex since middle Miocene time, with the southern part of the mountain apparently rotated clockwise up to 30 degrees relative to the northern part (Scott and Rosenbaum, 1986); thus, it appears to have been deformed within a right-lateral couple, as have other parts of the Walker Belt.

In summary, two potential seismic source zones within a 100-km radius of the site are the Walker Lane, whose postulated subsurface continuation passes below the Miocene volcanic and volcaniclastic rocks of the NTS (Ekren, 1968; Burchfiel, 1965), and the Death Valley-Furnace Creek fault zone, which at its closest approach lies 52 km southwest of the site. Both of these structures are right-lateral wrench zones. The Death Valley-Furnace Creek fault zone offsets Holocene deposits in its central and southern segments and is long enough to generate a great earthquake; hence the zone is thought to be the most significant potential source of ground shaking outside a 50-km radius of the site.

The Walker Lane is approximately 600 km long, shows substantial (25 to 30 km) post-Miocene right-lateral displacement, and is seismically active in its northern and central parts. The Cedar Mountain earthquake of 1932

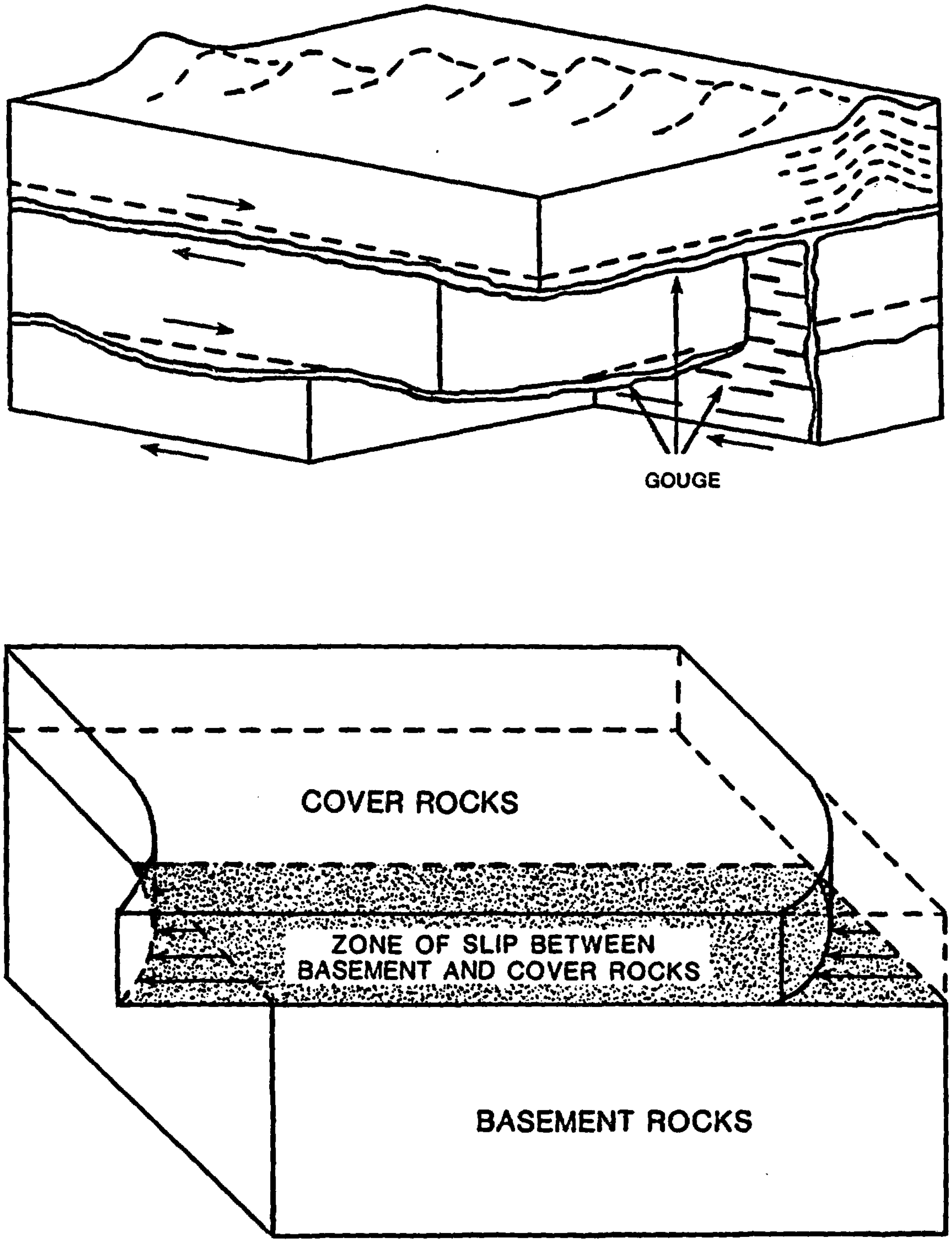

Figure 8.3.1.17-10. Idealized models of upper crustal deformation involving right-lateral shear on through-going wrench fault and displacement on overlying detachment fault, as postulated for Cedar Mountain area by Molinari (1984) and southern Nevada Test Site by Burchfiel (1965).

(M = 7.2 to 7.3) was located on the central part of the Walker Lane, approximately 175 km northwest of the site. Post-Miocene right-lateral displacement is not obvious on the part of the Walker Lane within 100 km of the site. Thus, either the southern part of the Walker Lane is pre-Quaternary in age, Quaternary movement has not been translated through the overlying Miocene volcanic rocks of Yucca Mountain and the Nevada Test Site, or Quaternary movement has occurred but has not yet been recognized.

Although the principal focus of this study is on the Walker Lane and the Death Valley-Furnace Creek fault zone, other potentially significant Quaternary faults within a 100-km radius of the site will be identified through a search of the existing data, supplemented by examination of air photos and ground reconnaissance. Features that could be significant sources of ground motion include the Beatty scarp (if it is a fault) and the Bare Mountain fault zone.

Because of the geologic investigations at and near the site area, the density of known Quaternary faults in that area (Figure 8.3.1.17-11) now substantially exceeds that of much of the surrounding region. (The site area is defined here as the rectangular 237 km^2 (91 mi^2) area encompassing the central Yucca Mountain block and its structural and physiographic boundaries (Fortymile Wash, Yucca Wash, Solitario Canyon, and the Stagecoach Road fault.) Mapping of Quaternary faults and surficial deposits within the Beatty 1:100,000 quadrangle should clarify whether this concentration is real or is simply an artifact of the focusing of effort on the Yucca Mountain area. In any instance, to evaluate the likelihood of future faulting within the site area (an objective of Study 8.3.1.17.4.6--Quaternary faulting within the site area) the boundaries of the structural domain, including Yucca Mountain, within which Quaternary faults have a uniform density and common genesis will be defined. Structural domains within 100 km of Yucca Mountain will be delineated on the basis of regional variation in fracture density and fracture pattern as observed on Landsat V Thematic Mapper imagery. The Landsat V imagery will also provide information on distribution of desert varnish, which is related to the presence of stable geomorphic surfaces (whose definition is an objective of Study 8.3.1.17.4.9--tectonic geomorphology of the Yucca Mountain region).

Activities planned for this study are (1) an evaluation of crustal structure and subsurface expression of Quaternary faults in an east-west transect crossing the Furnace Creek fault zone, Yucca Mountain, and the Walker Lane; (2) an evaluation of surface expression of Quaternary faults within a 100-km radius of the site (Yucca Mountain); (3) an evaluation of the Cedar Mountain earthquake of 1932 and its bearing on wrench tectonics of the Walker Lane; (4) an evaluation of the Bare Mountain fault; and (5) an evaluation of structural domains and characterization of the Yucca Mountain region with respect to regional patterns of faults and fractures.

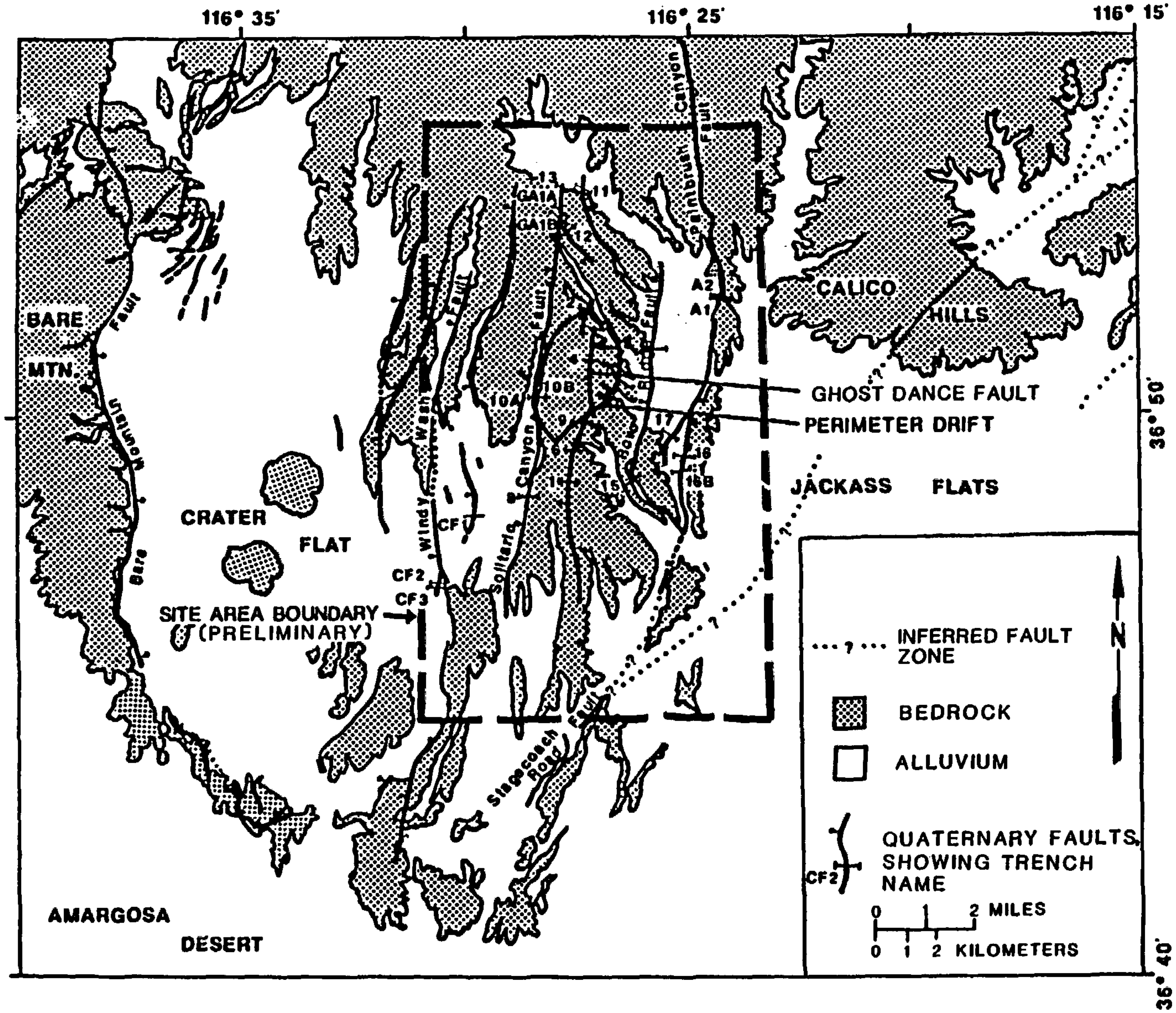

Figure 8.3.1.17-11. Generalized Quaternary fault map of Yucca Mountain and vicinity, showing trench locations (CF1, 1, GA1A, etc.) and site area.

8.3.1.17.4.3.1 Activity: Conduct and evaluate deep geophysical surveys in an east-west transect crossing the Furnace Creek fault zone, Yucca Mountain, and the Walker Lane

Objectives

The objectives of this activity are

1. To help identify and locate potentially significant seismic source zones, including possible through-going extensions of the Walker Lane, beneath the Oligocene-Miocene cover of the Yucca Mountain area; to determine the width and subsurface geometry of such extensions and of the Furnace Creek fault zone and the relation of these features to detachment faults and to Quaternary faults; and to evaluate the postulated incipient rift zone at Crater Flat.

2. To characterize the crustal velocity structure and define lateral inhomogeneities in that structure in the Yucca Mountain area.

3. To trace the 5- and 10-s events found on Death Valley Consortium for Continental Reflection Profiling (COCORP) profiles through the Yucca Mountain region and, if possible, to trace reflections from the upper and lower carbonate aquifers, the Precambrian-Cambrian Pahrump Group and Noonday Dolomite, and the Proterozoic basement across the Furnace Creek fault and through the area of the projected northwest continuation in the subsurface of the Las Vegas Valley shear zone.

4. To identify differences in mass caused by variation in source lithology in the upper few kilometers of the crust, and correlate those sources with reflections obtained in the seismic reflection survey, or with conductivity features obtained in the magneto-telluric survey.

5. To identify differences in magnetic field caused by sources in the upper few kilometers of the crust and correlate those sources with reflections obtained in the seismic reflection survey, or with conductivity features obtained in the magnetotelluric survey.

6. To characterize the conductivity structure of the crust in the Yucca Mountain region, focusing in particular on the conductivity signature of the Walker Lane and Walker Belt, and if possible, tracing the signature into the subsurface of conductive units such as the Eleana Formation or nonconductive units such as the lineated and mylonitized gneisses (lower plate?) of the northern Amargosa Desert, and to correlate these features or their offsets with Quaternary faults.

7. To provide data for analysis to determine if buried magma bodies are present in the vicinity of Yucca Mountain. These data and analyses will be used to address the objective of Activity 8.3.1.8.1.1.3, (presence of magma bodies in the vicinity of the site).

Parameters

The parameters for this activity are

1. Lateral discontinuities in seismic refraction profiles.

2. Lateral discontinuities in seismic reflection profiles.

3. Gravity anomalies.

4. Magnetic anomalies.

5. Lateral and vertical discontinuities in crustal conductivity structure.

Description

Geophysical methods may be useful for locating possible subsurface extensions of surface or near-surface geologic structures of interest. At Yucca Mountain, this includes the subsurface geometry of postulated detachment faults, interconnections between northeast-trending and north-trending faults, and possible through going extensions of the Walker Lane beneath the Oligocene-Miocene cover.

Proposed geophysical studies are summarized in Tables 8.3.1.17-9 and -10. As indicated in the tables, a variety of geophysical studies are planned at different locations and scales, to address a number of questions. Planned studies include deep and shallow seismic refraction; deep, intermediate, and shallow seismic reflection; gravity and magnetic surveys of the region and the site; gravity surveys coincident with the deep-seismic reflection surveys; magnetic surveys coincident with the deep and shallow reflection surveys; electrical conductivity surveys; radiometric and remote-sensing investigations; and paleomagnetic investigations.

In general, the shallow studies will focus on individual geologic structures, such as a specific Quaternary fault, and the deep studies will examine regional structures that may play a part in Quaternary tectonic processes in the southern Great Basin.

The geophysical studies will be conducted under Activity 8.3.1.17.4.3.1, described in this section, and in Study 8.3.1.17.4.7. The studies in Activity 8.3.1.17.4.3.1 are directed at deep, regional geologic features, whereas Study 8.3.1.17.4.7 addresses the subsurface geometry and possible concealed extensions of specific Quaternary faults at and near Yucca Mountain through intermediate- and shallow-depth geophysical surveys.

The geophysics program is designed to obtain different types of data that, when analyzed as a whole, will aid in the interpretation of recorded seismicity and surface geologic data. The simultaneous interpretation of geophysical, seismological and geologic data may help resolve such issues as the width, dip, and geometry of north-trending Quaternary normal faults at and near the site and whether there are subsurface structures that are related to known Quaternary structures.

Table 8.3.1.17-9. Summary of geophysical studies in preclosure and postclosure tectonics (Sections 8.3.1.17 and 8.3.1.8) (page 1 of 4)

Method	Activity	Location	Scope	Decision points	Comments
			SEISMOLOGY		
Deep refraction	8.3.1.17.4.3.1	E-W Transect Indian Springs-Stovepipe Wells (Figure 8.3.1.17-12)	Reversed profiles and cross-profiles, shot-points 8 to 20 km spacing	None	Existing surveys shown in Figure 8.3.1.17-12. See Pankratz (1982), Mooney et al., (1982), Hoffman and Mooney (1983), Hoover et al. (1982), Monfort and Evans (1982), and Sutton (1984).
Shallow (bison) refraction and shear wave refraction and reflection	8.3.1.17.4.4.1 and others	Quaternary faults, Yucca Mountain and vicinity	250 to 500 m traverses, portable instruments sledgehammer energy source. Shear wave method uses 12 (or more) geophones, 3 m spacing	Number and location to be decided on the basis of geological and geophysical mapping	Maximum depth of penetration 100 m. Used to detect offset in surficial deposits. Shear wave method capable of detecting 30 cm offset.
Evaluation of proposed deep reflection survey	8.3.1.17.4.3.1	Proposed survey crosses Yucca Mountain and Crater Flat; 15 km test line to be located south of Amargosa Valley or southwest of Beatty	To be determined	Decision to proceed (DTP) after evaluation of preliminary tests (15 km reconnaissance line) and peer review	COCORP[a] survey extending northward into southern Death Valley produced marginal quality data, although data in the upper one second are locally good. Six second reflections were imaged with local continuity. See de Voogd et al. (1986).
Intermediate reflection and intermediate refraction	8.3.1.17.4.7.1	Site-controlled area, Yucca Mountain (Figure 8.3.1.17-11)	Evaluate previous results, assess potential for application of this method to Yucca Mountain, plan new application if appropriate	None	This is a planning activity only. Previous reflection survey using Vibroseis at Yucca Mountain failed (McGovern, 1983). More recent surveys using air gun at Mid Valley produced useful results (McArthur and Burkhard, 1986). See also Hoover et al. (1982).
Shallow (mini-sosie) reflection	8.3.1.17.4.7.8 and others	Yucca Mountain, Crater Flat, Jackass Flats (Figure 8.3.1.4-8)	7 to 15 profiles, 1 to 5 km in long, hand carried instruments. Energy from battery of hand-operated tampers	DTP after evaluation of two preliminary profiles	Maximum depth of penetration 1 km. Used to map shallow structural and stratigraphic features.
			GRAVITY INVESTIGATIONS		
Regional maps	8.3.1.17.4.12.1	Yucca Mountain and vicinity	Beatty 1:100,000 quadrangle, Pahute Mesa 1:100,000 quadrangle, Nevada Test Site 1:100,000 map area, Yucca Mountain 1:48,000 map area	None	Field work complete, compilation complete, preliminary drafts available. See Snyder and Oliver (1981), Kane et al. (1981), Ponce (1981), Ponce and Oliver (1981), Hoover et al. (1982), Ponce and Hanna (1982), Jansma et al. (1982), Ponce (1984), and Snyder and Carr (1984).

Table 8.3.1.17-9. Summary of geophysical studies in preclosure and postclosure tectonics (Sections 8.3.1.17 and 8.3.1.8) (page 2 of 4)

Method	Activity	Location	Scope	Decision points	Comments
			GRAVITY INVESTIGATIONS (continued)		
Site area map	8.3.1.17.4.7.2	Yucca Mountain (Figure 8.3.1.17-11)	1:24,000 map of site and vicinity, 200 ft spacing of stations along E-W lines spaced 500 ft apart (where topography permits)	None	Will require additional 7,500 stations. Useful for establishing stratigraphic variability of repository host rock and fault location and offset. See Snyder (1981), Snyder and Carr (1982), Jansma et al. (1982), Kane et al. (1982), Ponce et al. (1985)
Detailed surveys, deep reflection profiles	8.3.1.17.4.3.1	Stovepipe Wells, Yucca Mountain, Indian Springs. Precise location to be determined.	Gravity determinations along profiles at 500 ft spacing	DTP only if seismic surveys run	Assists interpretation of seismic results.
			MAGNETIC METHODS		
Regional aeromagnetic maps	8.3.1.17.4.12.1	Yucca Mountain and vicinity	Beatty-, Pahute Mesa-, Indian Springs-, and Pahrangat 1:100,000 quadrangles to be compiled from existing surveys	None	Field investigations complete, compilation 80% (?) complete. See Kane et al. (1981), Hoover et al (1982), Ponce and Hanna (1982), Kane and Bracken (1983), U.S. Geological Survey (1984), Ponce (1984).
Site area aeromagnetic map	8.3.1.17.4.7.3	Yucca Mountain (Figure 8.3.1.17-11)	1:12,000 scale map of site and vicinity, continuous aeromagnetic survey along E-W flight lines spaced 1/16 mile apart.	None	1:62,500 scale map complete (U.S. Geological Survey, 1984), See also Jansma et al. (1982), Bath et al. (1982), Kane et al. (1982), Kane and Bracken (1983), and Bath and Jahren (1984).
Ground magnetic survey, deep reflection profiles and shallow reflection profiles	8.3.1.17.4.3.1	Stovepipe Wells, Yucca Mountain, Indian Springs. Precise location to be determined	Magnetic determinations along profiles at 10- to 20-ft spacing where accessible by truck, 50 to 100 ft spacing elsewhere	DTP only if seismic surveys run	Assists interpretation of seismic results.

Table 8.3.1.17-9. Summary of geophysical studies in preclosure and postclosure tectonics (Sections 8.3.1.17 and 8.3.1.8) (page 3 of 4)

Method	Activity	Location	Scope	Decision points	Comments
			MAGNETIC METHODS (continued)		
Site ground magnetic surveys	8.3.1.17.4.7.4	Yucca Mountain (Figure 8.3.1.4-11)	Ground magnetic surveys at (1) known and inferred structures, (2) vicinity of drill-holes (3) vicinity of shaft and surface facilities, (4) anomalies detected in site aeromagnetic map (described previously). Surveys to be semicontinuous (10 to 20 ft spacing)	Number and location to be determined through evaluation of geologic and geophysical mapping	Primary purpose is to locate concealed extensions of faults. See Bath and Jahren (1984; 1985), Scott et al. (1984).
Curie isotherm	8.3.1.8.5.2.1	Yucca Mountain Region	Analysis of existing regional aeromagnetic data	None	Purpose is to map configuration of Curie isothermal surface, and to compare areas of shallow isotherms with areas of high heat flow and recent volcanism. See Connard et al. (1983).
			ELECTRICAL METHODS		
Regional magnetotelluric (MT)	8.3.1.17.4.3.1	Yucca Mountain, Crater Flat, Jackass Flats, Amargosa Desert, Death Valley (Figure 8.3.1.17-8)	Detailed survey with stations at 3 to 5 km spacing of Yucca Mountain, Crater Flat, and northern Amargosa Desert, reconnaissance survey with stations at 10-km spacing in remainder of area	None	Previous survey by Furgerson (1982) shows mappable conductivity contrasts in 1-15 km depth range. See also Kauahikaua (1981), Hoover et al. (1982).
Surface geoelectric investigations (airbourne electromagnetic slinggram, very low frequency, dc resistivity, electromagnetic soundings, tensor audio magnetotellurics, and telluric profiling)	8.3.1.17.4.7.5	Yucca Mountain	Assess potential for application of these methods, evaluate previous results, plan new applications if appropriate, conduct prototype tests	DTP with full scale application of selected methods only if warranted by results of prototype testing	Applied to structural and stratigraphic problems at the site by Flanigan (1981), Smith and Ross (1982), Fitterman (1982), Hoover et al. (1982), Senterfit et al. (1982), Scott et al. (1984), Frischknecht and Raab (1984). Other studies in region include Zablocki (1979), Anderson (1982), Smith et al. (1981), Greenhaus and Zablocki (1982).

Table 8.3.1.17-9. Summary of geophysical studies in preclosure and postclosure tectonics (Sections 8.3.1.17 and 8.3.1.8) (page 4 of 4)

Method	Activity	Location	Scope	Decision points	Comments
			RADIOMETRIC AND REMOTE SENSING METHODS		
Surface and airbourne gamma ray investigations	8.3.1.17.4.7.6	Yucca Mountain	Assess potential for application of these methods with preliminary survey over known faults using static ground measurements	DTP with full-scale application of airbourne methods only if warranted by results of preliminary survey	Could detect percolation of radon through fault zones.
Thermal infrared investigations	8.3.1.17.4.7.7	Yucca Mountain	Assess potential for application of aircraft and satellite thermal infrared imagery in mapping of fracture network	DTP based on evaluation of cost and expected results	Method depends on detection of surface temperature variation, which is largely dependent on soil moisture content, which in turn is in part related to infiltration along fractures.
Thematic Mapper Satellite Imagery	8.3.1.17.4.3.5	Yucca Mountain and vicinity	Tapes of the four Thematic Mapper V scenes encompassing the Yucca Mountain Region (Beatty, Indian Springs, Pahute Mesa, and Pahrangat Range 1:100,000 quadrangles) to be used to produce spectral and spectral ratio maps, from which areas containing distinctive patterns of lineations will be delineated	None	Used to define structural domains, areas of well-developed desert varnish, and areas of hydrothermal alteration.
			PALEOMAGNETISM		
Region	8.3.1.17.4.3.2	Yucca Mountain, Little Skull Mountain, Crater Flat, Skull Mountain, southern Yucca Mountain, eastern Yucca Flat	5 to 6 sites at Yucca Mountain will be sampled. If useful results are obtained, other sites as listed may be sampled	DTP only if useful results obtained at Yucca Mountain, and if suitable strata are present	Prelimiary results at Yucca Mountain suggest 30° rotation (Scott and Rosenbaum, 1986).

[a]COCORP = Consortium for Continental Reflection Profiling.

Table 8.3.1.17-10. Summary of other geophysical studies contributing to preclosure and postclosure tectonics (Sections 8.3.1.17 and 8.3.1.8) (page 1 of 4)

Method	Activity	Location	Scope	Decision points	Comments
			SEISMOLOGY		
Vertical seismic profiling/ tomography	8.3.1.4.2.2.5	Repository block and vicinity	15-25 geotomographic profiles, 0.2 to 2 km in length, cross-hole and surface down-hole surveys. Directional shear- and compression-energy sources	Decision to proceed (DTP) after prototype of feasibility DTP after calibration in shaft and drifts	Used to map 3-dimensional network of rock mass fractures. 20 m pixel geometry.
Shallow seismic refraction	8.3.1.14.2.3.3	Vicinity of surface facilities	TBD[a]	None	Will provide data for modeling soil-structure interaction and local site effects on vibratory ground motion.
Intermediate depth seismic refraction	8.3.1.4.2.1.2	E-W line across Yucca Mountain, N of block	Explosive sources; shotholes	None	See Sutton (1985).
			PALEOMAGNETISM		
Site	8.3.1.4.2.1.5	Yucca Mountain	Orient drill core as it becomes available. Establish reference orientation through study of outcrop samples. Determine magnetic character of outcrop samples to aid in interpretation of aeromagnetic data.	None	See Rosenbaum (1983), Rosenbaum and Rivers (1984), Rosenbaum and Snyder (1985), Rosenbaum (1985)
			BOREHOLE GEOPHYSICAL METHODS		
Geophysical logging					
Borehole gravimetry	8.3.1.4.2.1.3	Yucca Mountain	15 water-table drillholes, existing deep holes that can be made available, and all new holes that reach the base of the Topopah Spring Member	None	Already have data in drillholes H-1, P-1, G-1, G-3, and G-4. Data will be used to model structure in the immediate vicinity of each borehole, to study lithophysal zones, and to model the Paleozoic surface beneath Yucca Mountain. See Robbins et al. (1982), Healey et al. (1984), and Healey et al. (1986).

Table 8.3.1.17-10. Summary of other geophysical studies contributing to preclosure and postclosure tectonics (Sections 8.3.1.17 and 8.3.1.8) (page 2 of 4)

Method	Activity	Location	Scope	Decision points	Comments
			BOREHOLE GEOPHYSICAL METHODS (continued)		
Borehole magnetic logs	8.3.1.4.2.1.3	Yucca Mountain	15 water-table drill-holes, and new drill-holes prior to casing operations	None	Used to determine mappable magnetic events for studying structural integrity of Yucca Mountain, and to supplement paleomagnetic and litho-physal studies. See Hagstrum et al. (1980).
Induced potential logs	8.3.1.4.2.1.3	Yucca Mountain	Test in one or two drillholes	Evaluate for effec-tiveness after 1 or 2 drillholes	Feasibility study to determine if the method can be used to map zeolitized rock.
Commercially available logs	8.3.1.4.2.1.1	Yucca Mountain	All existing unlogged drillholes, all new holes, and relog selected holes	None	To obtain parameters for hydrologic, geologic, and geophysical models, and to determine uniformity and lateral distribution of rock prop-erties within the stratigraphic units. Refer to Spengler et al. (1979), Maldanado et al. (1979), Daniels and Scott (1981), Hagstrum et al. (1980), Daniels et al. (1981), Muller (1982), Muller and Kibler (1984), Spengler and Chornack (1984), Muller (1985), and Muller and Kibler (1985).
Borehole radar logs	8.3.1.4.2.1.3	Yucca Mountain	Drillholes that pene-trate the base of the Topopah Spring Member	Evaluate for effec-tiveness after 1 or 2 drillholes	Primarily used for fracture detection or to demonstrate the absence of fractures in the unsaturated zone.
Acoustic televiewer logs and TV camera logs	8.3.1.4.2.2.3	Yucca Mountain	All Yucca Mountain drillholes	None	For fracture and fault zone detection, and stratigraphic and lithologic correlation. See Healy et al. (1984), Stock et al. (1984), Stock and Healy (1984), Stock et al. (1985).
Large spacing electro-magnetic and resisti-vity logs	8.3.1.4.2.1.3	Yucca Mountain	Selected drillholes	After evaluation of surface and borehole data	To determine accurate large volume in situ values for studying fracture and lithophysal zones, and for interpretating anomalies detected with surface and borehole data.

Table 8.3.1.17-10. Summary of other geophysical studies contributing to preclosure and postclosure tectonics (Sections 8.3.1.17 and 8.3.1.8) (page 3 of 4)

Method	Activity	Location	Scope	Decision points	Comments
			BOREHOLE TO SURFACE METHODS		
Resistivity and electromagnetic methods	8.3.1.4.2.1.3	Yucca Mountain	Selected drillholes	After evaluation of surface and borehole data	For fracture studies in the unsaturated zone, to obtain detailed structure in areas of anomalous surface geophysical data and in critical locations such as the shaft site and surface facilities locations, and to verify projected faults at critical locations. See Daniels and Scott (1981).
High resolution P and S wave seismic	8.3.1.4.2.1.3	Yucca Mountain	Selected drillholes	After evaluation of surface and borehole surveys	Same as previously, and to obtain parameters for designing effective deeper-penetrating seismic surveys.
Surface-to-hole seismic refraction	8.3.1.4.2.1.3	Yucca Mountain	Selected drillholes	After evaluation of surface and borehole surveys	Same as two previous, and for critical fault location and bed tracing.
Up-hole and down-hole seismic	8.3.1.14.2.3.3	Vicinity of surface facilities	TBD	After evaluation of shallow seismic refraction survey	Will provide data for modeling soil-structure interaction and local site effects on vibratory ground motion
			BOREHOLE TO BOREHOLE METHODS		
Borehole to borehole methods	8.3.1.4.2.2.5	Yucca Mountain close-spaced holes for hydrologic testing and for surface facilities studies	Selected drillholes	None	Geotomography to map fractures and demonstrate mappability of features that intersect the drillholes using resistivity, electromagnetic radar, and high resolution P and S seismic (Yo Yo) methods.
Cross-hole seismic	8.3.1.14.2.3.3	Vicinity of surface facilities	TBD	After evaluation of shallow seismic refraction survey	Will provide data for modeling soil-structure interaction and local site effects on vibratory ground motion

Table 8.3.1.17-10. Summary of other geophysical studies contributing to preclosure and postclosure tectonics (Sections 8.3.1.17 and 8.3.1.8) (page 4 of 4)

Method	Activity	Location	Scope	Decision points	Comments
			PETROPHYSICS		
Petrophysics	8.3.1.4.2.1.4	Yucca Mountain	Selected core from cored drillholes	None	To verify geophysical log accuracy, calibrate computed logs, determine properties that are not or cannot be measured in situ, and to model and interpret surface geophysical studies.

*TBD = to be determined.

Planned locations of geophysical surveys, as described below, may change. Activity 8.3.1.4.2.1.6 will be responsible for reviewing and integrating the planned geophysical data-gathering activities for all studies and programs. Several surveys involve feasibility tests and decision points before implementation. Before any planned geophysical surveys are conducted, Activity 8.3.1.4.2.1.6 will review the results of any feasibility tests or past surveys to estimate the likelihood that useful data will be generated by the planned effort. Activity 8.3.1.4.2.1.6 will also review the location, scheduling, techniques, and objectives of the planned survey to determine if the objectives of this activity and activities in other programs (such as 8.3.1.8.1.1.3) that also require this data are being met. Locations of surveys and data collection techniques will not be finalized until the review by Activity 8.3.1.4.2.1.6 is complete. Final plans and changes will be reported in SCP progress reports and study plans.

The seismic reflection studies will be preceded by a preliminary test to determine if the results of the technique will be useful for evaluating subsurface structure in the Yucca Mountain region. A peer-review panel conducted as part of Activity 8.3.1.4.2.1.6 will review the initial results and will determine if further work is warranted.

A detailed description of the planned geophysical studies follows.

Seismic refraction methods have been used to characterize the general velocity structure of the upper crust in the Yucca Mountain area (Figure 8.3.1.17-12), and to establish the location and nature of major discontinuities in that velocity structure (Hoffman and Mooney, 1983). When used in conjunction with gravity and magnetic surveys, the method is useful in limiting applicable structural models (Snyder and Carr, 1984), although resolving power is low. The refraction survey will include an east-west profile spanning the transect, and three shorter cross-profiles (Figure 8.3.1.17-12).

Seismic reflection methods are used where clear resolution of upper crustal stratigraphy and structure is required. A seismic reflection survey across the northern Walker Lane successfully imaged strands of northwest-trending faults within the zone (Knuepfer et al., 1987). The Walker Lane in that area appears to be the surface expression of a southwest dipping (45°) fault that soles into a midcrustal detachment (Knuepfer al., 1987). Analogous features in the Yucca Mountain region include major structures such as a 6-s (two-way sonic travel time) reflection in Death Valley that may be interpreted as a mid-crustal brittle-ductile transition zone (de Voogd et al., 1986), the Furnace Creek fault zone and the Walker Lane, and the mylonitic detachment-bounded upper surface of the Precambrian, exposed in the northern Amargosa Desert. Other potential reflectors in the Yucca Mountain region include the upper and lower carbonate aquifers within the Paleozoic sequence (Winograd and Thordarson, 1975), and the Miocene-Paleozoic contact.

If good quality reflections can be obtained in this area, then high-resolution reflection seismology, supplemented by gravity and magnetic surveys, could define the width, continuity, and depth of these features, thus constraining the location and character of potential sources of ground motion and rupture within 100 km of the site. This possibility will be evaluated through testing of a preliminary seismic reflection survey.

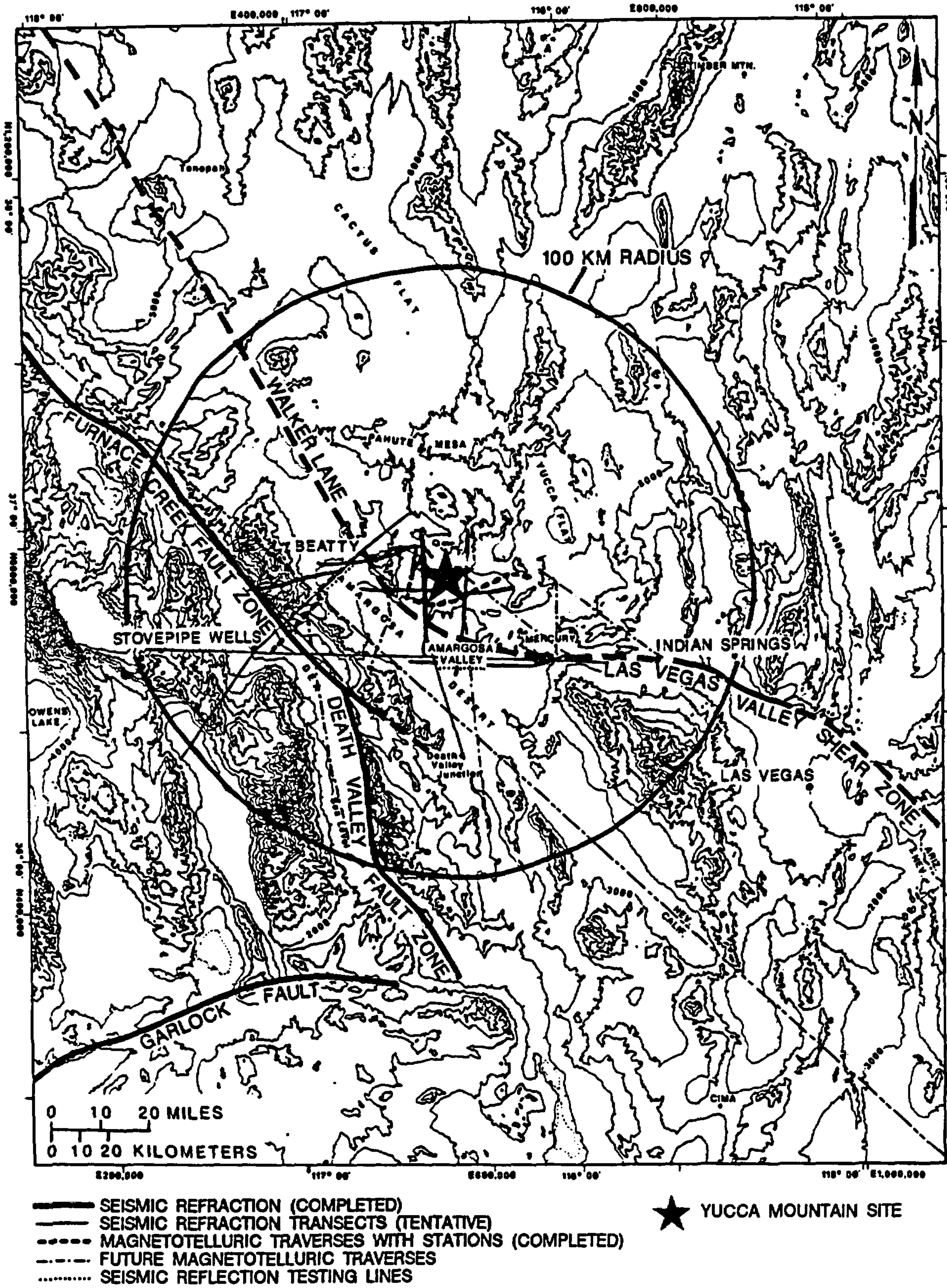

Figure 8.3.1.17-12. Location of seismic refraction and magnetotelluric sounding traverses.

Magnetotelluric (MT) soundings (Furguson, 1982) in the Yucca Mountain region indicate the presence of substantial conductivity contrast between Precambrian crystalline rocks, Paleozoic aquifers and aquitards, argillaceous units of the Paleozoic such as the Eleana Formation, Miocene volcanic rocks, and Quaternary basin fill deposits. Furguson's (1982) soundings are too widely spaced to permit reliable interpretation of structure. Additional soundings, planned as part of this study, should help constrain the location of fault zones, the identity of deep reflectors observed on the high-precision seismic reflection profiles, and in addition will help distinguish deep-seated bodies of molten rock.

The MT survey will include a detailed net with stations spaced at 3 to 5 km, and a reconnaissance net with stations spaced at 8 to 10 km. The detailed net will extend from Stovepipe Wells eastward to Mercury, Nevada, with additional offline stations in the northern Amargosa Desert and in Crater Flat. The reconnaissance net will include north-south lines designed to tie the Yucca Mountain area to the Consortium for Continental Reflection Profiling (COCORP) reflection surveys to the south. The MT survey and refraction survey will provide a gross characterization of crustal structure at low cost.

Seismic refraction survey (Death Valley-Beatty Junction-Sheep Range). Four seismic refraction profiles are tentatively planned. As presently conceived, a 160-km long east-west profile centered on Yucca Mountain will consist of two 80-km deployments, each using 120 instruments spaced at 0.7 to 1.0 km and recording seven 900- to 1,800-kg shots spaced at 8 to 20 km. Three cross-profiles, potentially including an 80-km profile extending southward from the northern end of Crater Flat, a 110-km profile extending southwestward from the northern end of Crater Flat, and a 70-km northwest-southeast profile centered on Stovepipe Wells, will consist of one to two deployments of 120 instruments recording two to three 900- to 1800-kg shots per deployment. Field work for the central and eastern part of the survey is currently under way, and completion is planned in 1987 or early 1988. The full extent of the survey will be determined after further consideration of the applicability of the expected results to Project needs.

Evaluation of proposed deep seismic reflection survey. A proposal to conduct a seismic reflection survey crossing Yucca Mountain and possibly extending across the Furnace Creek fault and the Walker Lane will be evaluated through preliminary testing and peer review.

The preliminary test will consist of a field survey of one line at a location to be determined, 15 km long, plus noise tests. The preliminary survey will use 10-km spreads, 24 geophones per group, 50-m group interval, 240 groups per spread, Vibroseis energy source, 100-m vibrator interval, 54,000-kg minimum peak vibrator force, and 240 channel floating-point digital recording. This configuration will be varied to optimize shallow and midcrustal reflections. Results of the preliminary tests and the design, scope, and potential application of the proposed survey to Yucca Mountain Project needs will be evaluated by a panel convened for that purpose. Two alternative locations for the test line have been proposed, including (1) an east-west line located in the Amargosa Valley, approximately 5 km south of the town of Amargosa Valley and (2) a northeast-trending line located about 10 km southwest of Beatty (Figure 8.3.1.17-12). Desired features of the proposed location include good access, low noise levels, and presence of alluvial cover.

Gravity survey (Stovepipe Wells-Death Valley-Beatty-Mercury-Indian Springs). If the proposed deep seismic reflection survey is implemented, a detailed gravity survey (using the La Costa Romberg gravimeter) will be conducted along a traverse coincident with the seismic reflection survey, possibly from Stovepipe Wells northeastward to Beatty, thence eastward to the northern Specter Range, thence northward to the northeast corner of the Nevada Test Site (NTS) through Yucca Flat. Gravity measurements will be made using portable devices, and surveying will use standard field methods.

Low-level magnetic survey (Stovepipe Wells-Death Valley-Beatty-Amargosa Valley-Indian Springs). If the proposed deep seismic reflection survey is implemented, a detailed low-level magnetic survey will be conducted along a traverse coincident with the seismic reflection survey, possibly from Stovepipe Wells northeastward to Beatty, thence eastward to the northern Specter Range, thence northward to the northeast corner of the NTS through Yucca Flat. Magnetometer measurements will be made using portable devices and surveying will use standard field methods.

Magnetotelluric survey (Stovepipe Wells-Death Valley-Beatty-Crater Flat-Mercury). Natural ambient magnetic fields and their induced electric fields at oscillations between 0.003 and 10 Hz will be measured using: high-precision voltage measurements across 150-m long electrode spreads; high-sensitivity induction coils; four-matched-channel, band-passed filtering with amplification; and real-time, floating-point, digital processing, and recording.

A 100-km long east-west line crossing the southern part of the NTS and the suspected subsurface extension of the Walker Lane (Las Vegas Valley shear zone) was surveyed in 1986 using close-spaced (3 to 6 km) field stations. The line included a 25-km traverse from Beatty, northeastward to northern Crater Flat, thence southwestward between Big Cone and Red Cone and across Bare Mountain to Highway 95, and thence eastward through the southern part of Yucca Mountain. The location and scope of additional traverse lines to be surveyed in 1988 and beyond will be based on application of expected results to Project needs.

Methods and technical procedures

The methods and technical procedures for Activity 8.3.1.17.4.3.1 are given in the following table.

Method	Technical procedure Number	Title	Date
Seismic refraction survey (Death Valley-Beatty Junction-Sheep Range)	SP-08,R0	Seismic study of the tectonic environment	6 June 83
Seismic reflection survey (Stovepipe Wells-Beatty-Crater Flat-Yucca Mountain-Mercury-Indian Springs)	TBD[a]	Seismic reflection survey	TBD
Gravity survey (Stovepipe Wells-Death Valley-Beatty-Mercury-Indian Springs)	GPP-01,R1	Gravity measurement and data reduction	14 Jan 85
Low-level magnetic survey (Stovepipe Wells-Death Valley-Beatty-Amargosa Valley-Indian Springs)	TBD	Ground-based magnetic survey	TBD
Magnetotelluric survey (Stovepipe Wells-Death Valley-Beatty-Crater Flat-Mercury)	GPP-18,R0	Magnetotelluric survey	27 May 86

[a]TBD = to be determined.

8.3.1.17.4.3.2 Activity: Evaluate Quaternary faults within 100 km of Yucca Mountain

Objectives

The objectives of this activity are

1. To establish the abundance, distribution, and geographic orientation of known and suspected Quaternary faults within 100 km of the site.

2. To characterize the Quaternary and Holocene fault and fracture pattern within 100 km of the site and, if feasible, to relate that pattern to regionally important wrench fault systems, including the Walker Lane, the Death Valley-Furnace Creek fault zone, and the Mine Mountain-Pahranagat shear zone.

3. To characterize those Quaternary faults within 100 km of the site whose apparent length or recurrence rate indicate potential for

future earthquakes of magnitude sufficient to affect design or performance of the waste facility.

4. To evaluate the recurrence history of that part of the Death Valley-Furnace Creek fault zone within 100 km of the site.

5. To identify fault scarps within 100 km of the site that may have been overlooked during conventional geologic field surveys and that may not have been apparent on conventional vertical aerial photography.

6. To verify the existence and age of scarps in the NTS area that were detected by low-sun-angle photogeologic interpretation.

7. To determine whether the Beatty scarp originated through tectonic or fluvial processes, or both; the nature of movement along the scarp, if tectonic; and the age of the scarp.

8. To ascertain the amount of post-middle Miocene horizontal rotation of bedrock alongside wrench faults and of bedrock suspected to be part of upper plate above subsurface wrench faults.

Parameters

The parameters of this activity are

1. Location, orientation, patterns, displacement, age and nature of Quaternary faults.

2. Fault scarp morphology and offset of Quaternary deposits.

3. Relative and absolute ages of Quaternary faults.

4. Abundance, dimensions, and orientations of Quaternary ruptures in the path of suspected subsurface wrench fault.

5. Rotation of upper-plate rock in Yucca Mountain region as defined by deflections of paleomagnetic pole declinations.

6. Quaternary rate of fault movement.

Description

This activity will supply information on the nature and rate of faulting during the Quaternary within 100 km of the site, and identify and characterize any faults whose length or recurrence rate indicate potential for earthquakes of magnitude sufficient to affect design or performances of the waste facility. The abundance of mapped Quaternary faults within the NTS and vicinity is substantially greater than that elsewhere within any part of the Walker Lane southeast of Monte Cristo Valley. This contrast is at least in part an artifact of the lack of detailed mapping outside of the Nevada Test Site (NTS) (Figure 8.3.1.17-7).

As an initial step, a map of Quaternary faults within 100 km of the site will be compiled from published and unpublished sources. Vertical aerial photographs of the same area will then be examined and a photogeologic map prepared to illustrate suspected Quaternary scarps and faults. A selected proportion of the suspected faults will be verified and examined in the field, and the age and amount of movement estimated. The relation of the fault pattern to major regional structures, including the Walker Lane, will also be evaluated.

This map will define the source regions of major earthquakes that have produced surface faulting during late Quaternary time and, thus, provide an estimate of regional variations in the long-term rates of occurrence of large magnitude earthquakes.

Conventional vertical photography has been carried out for the Yucca Mountain area. To minimize the number of scarps that have been overlooked, low-sun-angle vertical photographs covering selected areas will be procured and photogeologic maps of suspected Quaternary scarps will be prepared and verified in the field.

As originally conceived by Gianella and Callaghan (1934b), the Walker Lane includes a curvilinear fault near Beatty, Nevada, defined by a prominent Quaternary scarp. If real, the fault could be a potential source of future ground motion at the site. However, the origin of the scarp is somewhat uncertain. It could have originated through fluvial processes (as postulated by Swadley et al., 1988), tectonic processes, or some combination of the two. To address this problem and the potential significance to design or performance issues, the scarp will be dated by a variety of methods, mapped, and its relation to faults at depth investigated.

The Walker Lane is commonly believed to be a zone of oroclinal or oroflexural bending because the structural grain of bedrock terranes curve abruptly as it intersects the zone forming a reverse S-shaped pattern indicating right-lateral wrenching. The structural grain in the vicinity of Yucca Mountain is obscured by the intersection of the Walker Lane with the left-lateral faults of the Mine Mountain-Spotted Range belt. To ascertain the degree to which oroflexural bending affects the Miocene volcanic cover at Yucca Mountain, paleomagnetic poles of selected ash flows will be measured at various locations from one side of the zone to the other. Comparison of the declination of these poles should provide a measure of the oroflexural bending since middle Miocene time.

Development of map of Quaternary faults within 100 km of the site (Las Vegas to Cedar Mountain). Known and suspected Quaternary faults within 100 km of the site will be identified from published and unpublished literature. A map showing the distribution of these faults will be compiled at a scale of 1:500,000. This subactivity is 50 percent complete. The duration of future work is three months.

Development of photogeologic map of Quaternary scarps within 100 km of the site. Quaternary scarps will be identified within 100 km of the site through photogeologic interpretation of existing 1:20,000- to 1:80,000-scale black-and-white, vertical aerial photographs. Photographs have been or will be obtained from Federal, State, and County archives. Study of potentially significant Quaternary faults will be augmented through analysis of low-sun-angle photographs. Scarps are to be compiled on 1:100,000- to 1:200,000-scale base maps. This effort is estimated to be 25 percent complete. The duration of future work is eighteen months.

Field verification of Quaternary scarps within 100 km of the site. Scarps identified through photogeologic interpretation will be selectively examined in the field. The age of these scarps will be estimated from scarp morphology and bracketed by ages of units judged to be offset by or overlapping the scarps. Trenching will be done at scarps whose age would significantly constrain age of the Walker Lane or other large faults with potential for significant future ground motion. As yet, no scarps of this character have been identified.

Development of low-sun-angle photogeologic Quaternary scarp map (Yucca Mountain area). Medium-scale vertical aerial photographs taken during periods of low-sun-angle will be procured for that part of the Walker Lane, proximal to Yucca Mountain, focusing on Jackass Flats, Crater Flat, and northern Amargosa Desert. Photographs will be interpreted using conventional procedures and scarps compiled on 1:100,000 scale base maps of the Yucca Mountain area. Estimated duration of this subactivity is one year.

Field verification of low-sun-angle photogeologic Quaternary scarps (Yucca Mountain area). Scarps that are identified through low-sun-angle photogeology will be examined in the field, their age estimated from scarp morphology and bracketed by ages of units judged to be offset by or overlapping the scarp. Trenching will be done at scarps whose age would significantly constrain age of faults with potential for significant future ground motion. The estimated duration of this subactivity is six months.

Mapping of Quaternary faults and deposits of the Beatty 1:100,000 quadrangle. Quaternary deposits and faults displacing those deposits will be mapped, using standard field methods, including annotating contacts on 1:20,000-scale aerial photographs, and compiling at 1:24,000 and 1:100,000 scales. Local stratigraphic type localities and sections will be established. Deposits will be dated using soil development, cation ratio (desert varnish), uranium-trend, and uranium-series, ash fingerprinting, as appropriate. Approximately 50 percent of the quadrangle has been completed. The estimated duration of future work is three years.

Evaluation of nature of Beatty scarp and relation to geologic boundary. The Beatty scarp and its southeastern extension was considered a segment of the Walker Lane by Gianella and Callahan (1934b). The apparent length of the scarp, including its poorly defined southeastern extension, is 15 to 25 km. Detailed mapping of Quaternary deposits of the Beatty scarp will be supplemented by mapping of Quaternary datums in trenches crossing the scarp. Ages of the datums will be determined by analysis of soil development, uranium-series and uranium-trend analyses, radiocarbon dating, and cation-ratio (desert varnish) dating. Shallow seismic reflection (mini-sosie) and seismic refraction (Bison-type) surveys along traverses crossing the scarp and extending for 1 to 2 km (0.6 to 1.2 mi) to either side of the scarp will be performed to investigate the relation of the scarp to faults at depth. The duration of future work is three to six months.

<u>Quaternary recurrence rate of the Death Valley-Furnace Creek fault zone</u>. The Quaternary recurrence rate of this fault zone will be evaluated, using published and unpublished data, supplemented by limited field reconnaissance. The field investigation will focus on scarp morphology and age of surficial deposits intersected by or overlapping the fault. No excavations are planned. The estimated duration of this subactivity is 6 to 12 months.

<u>Analysis of rotation (drag) of bedrock alongside or over suspected wrench faults based on rotation of paleomagnetic poles</u>. Paleomagnetic orientations of samples collected from localities within the Tiva Canyon Member of the Paintbrush Tuff suggest that the Yucca Mountain area has been oroflexurally bent. Bending is clockwise and preliminary data suggest that the amount of bending relative to the north end of the mountain progressively increases through the central part and then increases sharply across the Stagecoach Road fault, reaching approximately 30 degrees at the south end (Scott and Rosenbaum, 1986). Bending could be related to right-lateral wrench faulting along the Walker Lane or, more speculatively, to detachment faulting in which a horizontal rotation of the detached plate is combined with dip-slip motion. The rotation occurred after 12.5 million years ago, the age of the Tiva Canyon Member.

This subactivity is designed to evaluate the preliminary results of paleomagnetic sampling at Yucca Mountain cited above through sampling of five to six additional localities to be selected from within the Tiva Canyon Member. If the rotation at Yucca Mountain is confirmed, then (1) the eastward extent of rotation and the possible influence of left-lateral faulting within the Mine Mountain-Spotted Range belt will be evaluated through sampling of two to five sites to be selected from within the Tiva Canyon Member at Little Skull Mountain or Skull Mountain, provided suitable localities are present, and (2) the age of rotation will be evaluated through sampling of late Miocene and Pliocene basalt flows in Jackass Flats and southeastern Crater Flat, provided suitable volcanic units are present.

Individual Miocene ash flows will be cored using hand-held drills at localities to be selected. Eight to ten oriented specimens will be obtained per site. After thermal demagnetization (Activity 8.3.1.4.2.1.5) the orientation of the magnetic pole for each specimen will be measured and corrected for inclination of the strata at the sample site. Comparison of declination from site-to-site will provide a measure of relative horizontal tectonic rotation. The estimated duration of future work is one to two years.

<u>Methods and technical procedures</u>

The methods and technical procedures for Activity 8.3.1.17.4.3.2 are given in the following table.

Method	Technical procedure Number	Title	Date
Development of map of Quaternary faults within 100 km of the site	GP-01,R0	Geologic mapping	1 Mar 83
Development of photogeologic map and field verification of Quaternary scarps within 100 km of the site	GP-01,R0	Geologic mapping	1 Mar 83
	GP-03,R0	Stratigraphic studies	1 Mar 83
	GP-04,R0	Structural studies	1 Mar 83
	TBD[a]	Photogeologic evaluation of faults using vertical aerial photographs	TBD
Development of low-sun-angle photogeologic Quaternary scarp map and field verification (Yucca Mountain area)	GP-01,R0	Geologic mapping	1 Mar 83
	GP-03,R0	Stratigraphic studies	1 Mar 83
	GP-03,R0	Structural studies	1 Mar 83
	TBD	Photogeologic evaluation of faults using low-sun-angle photographs	TBD
Mapping of Quaternary geology of the eastern one-fourth of the Beatty 1:100,000 quadrangle	GCP-01,R0	Radiometric-age data bank	15 Jun 81
	GCP-02,R1	Labeling, identification, and control of samples for geochemistry and isotope	20 Jun 87
	GCP-03,R1	Uranium-series dating	9 Mar 88
	GP-01,R0	Geologic mapping	1 Mar 83
	GP-03,R0	Stratigraphic studies	1 Mar 83
	GP-04,R0	Structural studies	1 Mar 83

Method	Technical procedure Number	Title	Date
Mapping of Quaternary geology of the eastern one-fourth of the Beatty 1:100,000 quadrangle (continued)	GP-17,R0	Describing and sampling soils in the field	19 Feb 86
	GCP-04,R1	Uranium-trend dating	27 May 88
	TBD	Ash fingerprinting	TBD
	TBD	Cation ratio (desert varnish) dating	TBD
	GCP-01,R0	Radiometric-age data bank	15 Jun 81
	GCP-02,R1	Labeling, identification, and control of samples for geochemistry and isotope geology	20 Jun 87
	GCP-03,R1	Uranium-series dating	9 Mar 88
	GCP-01,R0	Geologic mapping	1 Mar 83
	GP-03,R0	Stratigraphic studies	1 Mar 83
	GP-04,R0	Structural studies	1 Mar 83
	GP-17,R0	Describing and sampling soils in the field	19 Feb 86
	GCP-04,R1	Uranium-trend dating	27 May 88
	TBD	Ash fingerprinting	TBD
	TBD	Cation ratio (desert varnish) dating	TBD
Evaluation of nature of Beatty scarp and relation to geologic boundary	GCP-01,R0	Radiometric-age data bank	15 Jun 81

Method	Technical procedure Number	Title	Date
Evaluation of nature of Beatty scarp and relation to geologic boundary (continued)	GCP-02,R1	Labeling, identification, and control of samples for geochemistry and isotope geology	20 Jan 87
	GCP-03,R1	Uranium-series dating	9 Mar 88
	GP-01,R0	Geologic mapping	1 Mar 83
	GP-03,R0	Stratigraphic studies	1 Mar 83
	GP-04,R0	Structural studies	1 Mar 83
	GP-07,R0	Geologic trenching studies	14 Aug 84
	GCP-04,R1	Uranium-trend dating	27 May 88
	TBD	Cation ratio (desert varnish) dating	TBD
	TBD	Radiocarbon dating, conventional and tandem accelerator methods	TBD
	TBD	Shallow seismic reflection and refraction surveys	TBD
Quaternary recurrence rate of the Death Valley-Furnace Creek fault zone	GP-01,R0	Geologic mapping	1 Mar 83
	GP-02,R0	Subsurface investigation	1 Mar 83
	GP-03,R0	Stratigraphic studies	1 Mar 83
Analysis of rotation (drag) of bedrock alongside or over suspected wrench faults based on rotation of paleomagnetic poles	GPP-06,R0	Rock and paleomagnetic investigations	1 Nov 84

Method	Technical procedure Number	Title	Date
Analysis of rotation (drag) of bedrock alongside or over suspected wrench faults based on rotation of paleo-magnetic poles (continued)	TBD	Hand-held drilling and oriented-core sampling for paleo-magnetic	TBD

[a]TBD = to be determined.

8.3.1.17.4.3.3 Activity: Evaluate the Cedar Mountain earthquake of 1932 and its bearing on wrench tectonics of the Walker Lane within 100 km of the site

Objectives

The objective of this activity is to evaluate the relevance of the Cedar Mountain earthquake of 1932 to potential sources of ground shaking and rupture in that part of the Walker Lane within 100 km of Yucca Mountain.

Parameters

The parameters for this activity are

1. Geologic structure and stratigraphy of Stewart and Monte Cristo valleys.

2. Stewart and Monte Cristo Valley faults and their relation to the Walker Lane.

3. Surface ruptures formed during 1932 Cedar Mountain earthquake.

4. Focal mechanism of the 1932 Cedar Mountain earthquake.

Description

This activity will entail a review of the published geologic literature concerning the Cedar Mountain earthquake, photogeologic interpretation, limited fieldwork, and evaluation of concurrent research by investigators not affiliated with the Project. Emphasis will be on the tectonic setting (is it part of Walker Lane, Churchill Arc, or both?), continuity with Quaternary faults of Stewart Valley and with through-going shears mapped by Ekren and Byers (1985), distribution and character of surface breaks, and recurrence history.

Ruptures will be classified according to style and length measured by scaling from maps by Molinari (1984), and Gianella and Callaghan (1934a,b). Selected ruptures will be examined in the field. The width of the rupture zone, the width of individual ruptures, and other attributes (length, offset, aperture, fissure-fillings, brecciation) will be noted. The rupture zone has been trenched by investigators not affiliated with the Yucca Mountain Project. Additional trenching is not anticipated. This activity is estimated to be 50 percent complete. The estimated duration of future work is 6 to 12 months.

Methods and technical procedures

The methods and technical procedures for Activity 8.3.1.17.4.3.3 are given in the following table.

Method	Technical procedure Number	Title	Date
	(NWM-USGS-)		
Analysis of tectonic setting and ruptures (1932 Cedar Mountain earthquake)	GP-01,R0	Geologic mapping	1 Mar 83
	GP-07,R0	Geologic trenching studies	14 Aug 84
	TBD[a]	Photogeologic evaluation of faults using vertical aerial photographs	TBD
Determination of focal mechanism, Cedar Mountain earthquake	SP-06,R1	Determination of earthquake focal mechanism	19 May 88

[a]TBD = to be determined.

8.3.1.17.4.3.4 Activity: Evaluate the Bare Mountain fault zone

Objectives

The objectives of this activity are to

1. Evaluate the potential for ground shaking associated with future movement along the Bare Mountain fault zone.

2. Estimate the age of the most recent faulting on the Bare Mountain frontal fault.

3. Estimate the recurrence intervals of faulting.

4. Determine the nature and age of faulting within the fault complex east of the frontal zone, and to determine nature of tectonic control of the location and orientation of the main wash in Crater Flat.

5. Determine the subsurface configuration of fault zones.

Parameters

The parameters for this activity are

1. Age of datums.
2. Amount and direction of offset of datums.
3. Geologic structure and stratigraphy, seismic reflections.

Description

Bare Mountain has a steep, curvilinear eastern range front, the configuration of which is controlled by a complex of steeply eastward and moderately southeastward-dipping faults having Quaternary displacement. This complex is referred to as the Bare Mountain fault zone.

This activity consists of (1) geologic mapping of the fault zone and (2) trenching and dating of deposits cut by the fault zone.

Alluvial fans and stream deposits within Crater Flat along the eastern flank of Bare Mountain (Bare Mountain 15-min quadrangle (USGS, 1954)) will be mapped and deposits dated through soil development, uranium-series, and uranium-trend analysis, thermoluminescence, and cation ratios (desert varnish). Trenches intersecting the trace of the frontal fault will be excavated and mapped. Deposits offset by and overlapping the rupture zones exposed in the trenches will be dated.

Two new trenches are planned, and two existing prospect pits are to be enlarged, as follows:

1. Bulldozer trench, south side Tarantula Canyon, existing road. SW/4, NE/4, sec. 29, T.12S., R.48E. Estimated depth 3 to 4 m, width 5 m, length 15 to 20 m.

2. Backhoe trench, no existing road. SE/4, NW/4, sec. 24, T.13S., R47-1/2E. Estimated depth 2 to 3 m, width 2 to 3 m, length 5 m.

3. Enlargement of two existing adjacent prospect pits using backhoe, existing road. SW/4, SW/4, sec. 25, T.13S., R.47-1/2E. Estimate increase depth from 3 to 5 m, enlarge slightly.

This activity is 75 percent complete, and one report has been published (Reheis, 1986). Information derived from this activity will be integrated with information on bedrock geology (Activity 8.3.1.17.4.5.2), geomorphology (Activity 8.3.1.17.4.9.3), and geophysics in an integrating and synthesis activity (Activity 8.3.1.17.4.12.1, evaluate tectonic processes and tectonic stability at the site). The duration of the future work is 6 to 12 months.

Methods and technical procedures

The methods and technical procedures for Activity 8.3.1.17.4.3.4 are given in the following table.

Method	Technical procedure Number	Title	Date
Evaluation of age of Bare Mountain frontal zone faulting based on offset of Quaternary datums	GCP-01,R0	Radiometric-age data bank	15 Jun 84
	GCP-02,R1	Labeling, identification, and control of samples for geochemistry and isotope geology	20 Jan 87
	GCP-03,R1	Uranium-series dating	9 Mar 88
	GP-01,R0	Geologic mapping	1 Mar 83
	GP-01,R0	Subsurface investigations	1 Mar 83
	GP-07,R0	Geologic trenching studies	14 Aug 84
	GP-17,R0	Describing and sampling soils in the field	19 Feb 86
	GCP-04,R1	Uranium-trend dating	27 Mar 88
	TBD[a]	Cation ratio (desert varnish) dating	TBD
	TBD	Thermoluminescence dating	TBD

[a]TBD = to be determined.

8.3.1.17.4.3.5 Activity: Evaluate structural domains and characterize the Yucca Mountain region with respect to regional patterns of faults and fractures

Objectives

The objectives of this activity are to

1. Map faults and lineaments within a 100 km radius of the site and to identify those with geomorphic expression indicative of Quaternary faulting.

2. Classify the area into subareas (domains) containing relatively homogeneous fault and lineament populations (prominent geomorphic expression, density, and orientation) suggestive of Quaternary faulting. This information will be used in Activity 8.3.1.17.2.1.2 to help assess the faulting potential in areas of emplaced waste.

3. Map the areal extent of desert varnish coatings. This information will be used in Activity 8.3.1.17.4.9.1 to help establish the areal extent of tectonically stable areas near Yucca Mountain.

4. Identify areas of suspected hydrothermal alteration. This information will be used in Study 8.3.1.9.2.1 (natural resource assessment) to evaluate the relationship of the suspected hydrothermal alteration to potential mineralization in Activity 8.3.1.5.2.1.5 (calcite- and opaline-vein deposits) to aid in evaluating the possible origin of calcite-silica deposits and in Study 8.3.1.8.5.2 to aid in evaluating local heat flow anomalies.

Parameters

The parameters for this activity are

1. Fracture orientation, length, distribution.
2. Optical reflectance and absorption for selected wavelengths.
3. Age and distribution of desert varnish.
4. Distribution of hydrothermal alteration.

Description

High-quality Landsat V Thematic Mapper (TM) data provide a uniform set of data for the region and can be applied to numerous geologic problems. In this activity, a variety of remote sensing techniques will be applied to geologic problems being investigated in the region, including (1) analysis of linear features detectable with the high-resolution TM data, and characterization of regional fracture patterns, (2) mapping of the distribution of hydrothermal alteration related to near-surface igneous processes based on the spectral reflectance characteristics of alteration-associated minerals by using computer-enhanced TM data supplemented by field evaluations, and (3) mapping of surfaces with a substantial coating of desert varnish to aid in defining areas of tectonic stability.

The area under study comprises most of four 1:100,000-scale quadrangles --Beatty, Indian Springs, Pahute Mesa, and Pahranagat Range. Tapes of the four Thematic Mapper V scenes encompassing this area will be purchased, and spectral and spectral ratio maps will be prepared including bands sensitive to hydroxyl-containing minerals in the ultraviolet part of the spectrum. Computer-enhanced images will be interpreted, linear features identified, and their length and orientation measured. Domains containing distinctive patterns of fractures and lineaments will be delineated.

Color-ratio composite TM images will be used to identify areas of alteration. These areas will be reconnoitered in the field to determine the type of alteration and the nature of the causal volcanic or igneous processes. The estimated duration of the future work is two years.

Methods and technical procedures

The methods and technical procedures for Activity 8.3.1.17.4.3.5 are given in the following table.

Method	Technical procedure		
	Number	Title	Date
Analysis of Landsat V thematic mapper imagery of the Nevada Test Site region	TBD[a]	Analysis of linear features	TBD
	TBD	Analysis of hydrothermal alteration	TBD
	TBD	Analysis of desert varnish coating	TBD

[a]TBD = to be determined.

8.3.1.17.4.4 Study: Quaternary faulting proximal to the site within northeast-trending fault zones

Objectives

The primary objective of this study is to evaluate the potential for ground motion resulting from future movement on Quaternary left-lateral(?) strike-slip faults east and south of the site-area.

The left-lateral(?) strike-slip faults in that area strike to the north-east or east-northeast, and form an en echelon pattern within the Mine Mountain-Spotted Range structural zone (Carr, 1974), cutting across the northwestern extension of the Las Vegas Valley shear zone. The belt is aligned with the Pahranagat shear zone to the east-northeast, and the Garlock fault to the west-southwest (Figure 8.3.1.17-9). Four of the left-lateral(?) faults show evidence of significant Quaternary displacement. From northwest to southeast, they are the Stagecoach Road fault, the Mine Mountain fault, the Cane Spring fault zone, and the Rock Valley fault zone (Figure 8.3.1.17-13).

The Stagecoach Road fault cuts across the southern end of Yucca Mountain. It could connect to the northeast with the Paintbrush Canyon fault (to be studied as part of Activity 8.3.1.17.4.6.2 (evaluate age and recurrence of movement on suspected and known Quaternary faults) or alternatively, continue northeastward across western Jackass Flats into the Calico Hills, as shown by Maldanado (1985a). The Mine Mountain fault zone (not to be confused with the Mine Mountain thrust fault) trends northeast, with mapped extent of approximately 27 km (scaled from Figure 7 of Carr, 1984), and extends from Jackass Flat through Mid Valley to Yucca Flat. The Rock Valley fault zone trends east-northeast, with mapped extent of approximately 68 km (scaled from Figure 7 of Carr, 1984), if discontinuous segments are included, and extends from Amargosa Desert through Rock Valley to Frenchman Flat. The Cane Spring fault zone trends northeast, with mapped extent of 23 km (scaled from Figure 7 of Carr, 1984).

The part of the Mine Mountain-Spotted Range structural zone in the area between and adjacent to the Mine Mountain and Rock Valley fault zones is marked by above average seismic activity. However, focal mechanism solutions generally indicate right-lateral movement on north-trending faults, rather than left-lateral movement parallel to the northeast to east-northeast-trending faults.

Activities planned for this study are (1) an evaluation of the Rock Valley fault system, (2) an evaluation of the Mine Mountain fault system, (3) an evaluation of the Stagecoach Road fault zone, and (4) an evaluation of the Cane Spring fault zone.

8.3.1.17.4.4.1 Activity: Evaluate the Rock Valley fault system

Objectives

The objective of this activity is to determine the location, spatial orientation, length, width, Quaternary recurrence rate, and the location, amount, and nature of Quaternary movement of the Rock Valley fault system. An objective of the trenching is to estimate the total displacement, including strike-slip and dip-slip components, of Quaternary datums. Accordingly, trenching will use methods designed to facilitate measurement of these components, as described in Section 8.3.1.17.4.6.2.

Parameters

The parameters for the activity are

1. Length, location, and spatial orientation of the fault system.

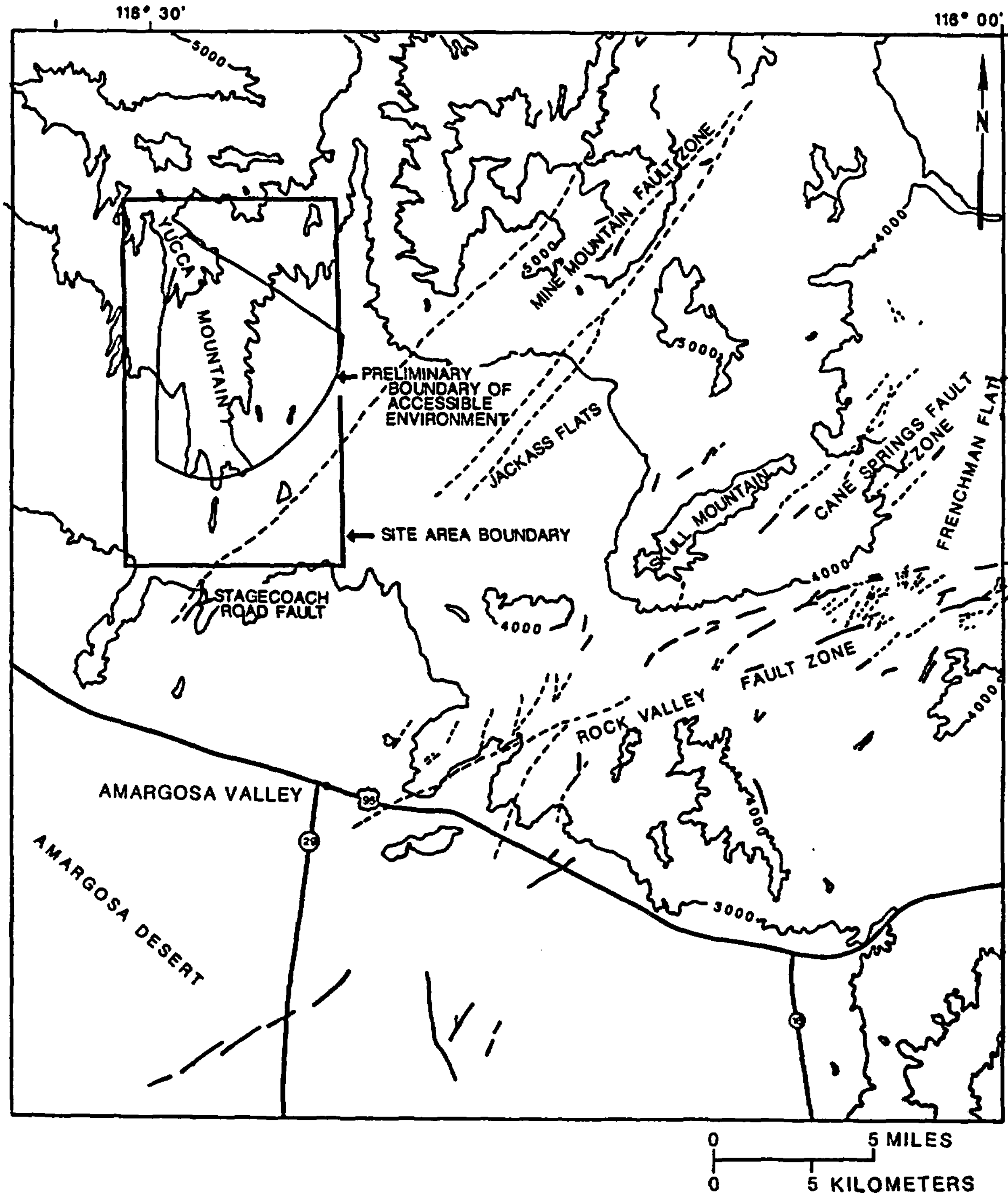

Figure 8.3.1.17-13. Map showing relation of proposed repository area to Mine Mountain, Cane Spring, Rock Valley, and Stagecoach Road fault zones.

2. Segmentation within the fault system.

3. Width of the fault system.

4. Age and nature of Quaternary deposits and Quaternary surfaces displaced by or covering Quaternary strands within the fault system.

5. Location, amount, and direction of displacement of Quaternary deposits and Quaternary surfaces.

6. Age, lateral extent, and height of fault scarps.

Description

This activity focuses on estimating the Quaternary rate of activity on the Rock Valley fault through trenching and mapping and dating of strata cut by the fault. Traces of the main strands of the fault will be examined and mapped, and the subsurface expression of the fault zone will be investigated through shallow seismic refraction and reflection surveys.

Evaluation of Quaternary displacement along main trace of the Rock Valley fault system as established by trenching and very shallow seismic refraction (Bison-type) and seismic reflection (mini-sosie). Two to four trenches will be excavated across fault scarps and fault lines, and the Quaternary stratigraphy exposed in trench walls and floor mapped. Areas of lateral disruption and discontinuity of Quaternary datums will be identified, and the age of disrupted Quaternary datums and overlying undisrupted Quaternary datums established, if present. The age of datums will be established through stratigraphic correlation, chemical fingerprinting, soil development analysis, radiocarbon dating, uranium-trend and uranium-series analysis, cation ratio dating, and other methods, as appropriate. The orientation of clast fabric in zones of rupture will be measured. Fracture-filling minerals will be identified and dated. The orientation of all fractures cutting the Quaternary deposits will be measured. By using portable seismic refraction apparatus (Bison-type), velocity profiles within very shallow (to depth of 100 m) deposits along selected traverses crossing known and suspected fault traces will be established. The subsurface configuration of the fault zone will be examined using shallow seismic reflection (mini-sosie) along a 1.5-km (0.9 mi) long traverse orthogonal to the fault. This subactivity is 95 percent complete.

Evaluation of Quaternary displacement along the southern extension of the Rock Valley fault system, south of Amargosa Valley. Faults cutting fine-grained sands and muds approximately 12 km (7 mi) south of Amargosa Valley appear to represent an extension of the Rock Valley fault system. Mapping, trenching, and shallow (Bison) seismic refraction will be undertaken to determine fault width, the horizontal and vertical components of slip along these faults, and the age of the deposits cut by the faults. Where applicable, all techniques described in the evaluation of the main trace of the Rock Valley fault will be used. One or two trenches at locations to be determined are planned. The estimated duration of this work is one year.

Methods and technical procedures

The methods and procedures for Activity 8.3.1.17.4.4.1 are given in the following table.

Method	Technical procedure Number	Technical procedure Title	Technical procedure Date
	(NWM-USGS-)		
Evaluation of Quaternary displacement along main trace of the Rock Valley fault system as established by trenching and very shallow seismic refraction and reflection	GCP-01,R0	Radiometric-age data bank	15 Jun 84
	GCP-02,R1	Labeling, identification, and control of samples for geochemistry and isotope geology	20 Jan 87
	GCP-03,R1	Uranium-series dating	9 Mar 88
	GP-01,R0	Geologic mapping	1 Mar 83
	GP-03,R0	Stratigraphic studies	1 Mar 83
	GP-07,R0	Geologic trenching studies	14 Aug 84
	GCP-04,R1	Uranium-trend dating	27 May 88
	TBD[a]	Cation ratio (desert varnish) dating	TBD
	TBD	Chemical fingerprinting	TBD
	TBD	Dating by soil development analysis	TBD
	TBD	Radiocarbon dating, conventional and tandem accelerator methods	TBD
	TBD	Shallow seismic reflection and refraction surveys	TBD

Method	Technical procedure Number	Title	Date
	(NWM-USGS-)		
Evaluation of Quaternary displacement along the southern extension of the Rock Valley fault system, south of Amargosa Valley (formally known as Lathrop Wells)	GCP-01,R0	Radiometric-age data bank	15 Jun 81
	GCP-02,R1	Labeling, identification, and control of samples for geochemistry and iostope geology	20 Jan 87
	GCP-03,R1	Uranium-series dating	9 Mar 88
	GCP-08,R1	Fission-track dating	26 May 88
	GP-01,R0	Geologic mapping	1 Mar 83
	GP-03,R0	Stratigraphic studies	1 Mar 83
	GP-07,R0	Geologic trenching studies	14 Aug 84
	GCP-04,R1	Uranium-trend dating	27 May 88
	TBD	Cation ratio (desert varnish) dating	TBD
	TBD	Dating by soil development analysis	TBD
	TBD	Radiocarbon dating, conventional and tandem accelerator methods	TBD
	TBD	Shallow seismic reflection and refraction surveys	TBD

[a]TBD = to be determined.

8.3.1.17.4.4.2 Activity: Evaluate the Mine Mountain fault system

Objectives

The objective of this activity is to determine the location, spatial orientation, length, width, Quaternary recurrence rate, and the location, amount, and nature of Quaternary movement of the Mine Mountain fault system.

Parameters

The parameters for this activity are

1. Length, location, and spatial orientation of the fault system.

2. Segmentation within the fault system.

3. Width of the fault system.

4. Age and nature of Quaternary deposits and Quaternary surfaces displaced by or covering Quaternary strands within the fault system.

5. Location, amount and direction of displacement of Quaternary deposits and Quaternary surfaces.

6. Age, lateral extent, and height of fault scarps.

Description

A substantial body of data on the Mine Mountain fault system at Mid Valley, 25 to 30 km east-northeast of Yucca Mountain, has been collected, indicating that the fault is a wide zone with substantial dip-slip displacement, possibly merging with or terminating at a low-angle extensional fault at depth (McArthur and Birkhard, 1986). McArthur and Birkhard (1986) citing Orkild (personal communication), state that older alluvium is disturbed along the trace of the fault and conclude on this basis that some movement occurred within the last one million years.

The fault zone projects below alluvial cover southwestward from Mid Valley into jackass Flats (Maldonado, 1985), thus possibly approaching to within 15 km of Yucca Mountain (Figure 8.3.1.17-13). However, no displacement of Quaternary deposits along the trace of the fault within Jackass Flats has been recognized.

In this activity, published data (cited above) will be reviewed and interpreted. The reported disturbance of older alluvium in Mid Valley will be verified and evaluated. In addition, Quaternary deposits in Jackass Flats along the projected trace of the fault will be examined for evidence of faulting. Any scarps and lineaments indicative of Quaternary faulting will be evaluated and, if necessary, trenched to determine slip rate and style of faulting. Supporting data on subsurface geometry of the possible projection of the fault into Jackass Flats will be provided by Activity 8.3.1.17.4.7.8 (evaluate shallow seismic reflection (mini-sosie) methods and, if appropriate, conduct surveys of selected structures at and proximal to the site area). Additional data on Quaternary expression of faults in Jackass Flats will be gathered by Activity 8.3.1.17.4.3.2 (evaluate Quaternary faults within 100 km of Yucca Mountain).

Methods and technical procedures

The method and technical procedure for this activity are given in the following table.

Method	Technical procedure		
	Number	Title	Date
Mine Mountain fault system synthesis	TBD[a]	Geologic synthesis	TBD

[a]TBD = to be determined.

8.3.1.17.4.4.3 Activity: Evaluate the Stagecoach Road fault zone

Objectives

The objectives of this activity are to

1. Determine the location, spatial orientation, length, width, Quaternary recurrence rate, and the location, amount, and nature of Quaternary movement of the Stagecoach Road fault system.

2. Evaluate the possibility that the Stagecoach Road fault zone is a continuation of the Paintbrush Canyon fault.

3. Evaluate the geometry of the intersection in the subsurface of the Paintbrush Canyon fault and hypothesized shallow detachment faults.

Parameters

The parameters for this activity are

1. Length, location, and spatial orientation of the fault system.

2. Segmentation within the fault system.

3. Width of the fault system.

4. Age and nature of Quaternary deposits and Quaternary surfaces displaced by or younger than Quaternary strands within the fault system.

5. Location, amount and direction of displacement of Quaternary deposits and Quaternary surfaces.

6. Age, lateral extent, and height of fault scarps.

7. Subsurface geometry of the fault zone.

8. Geometry of intersection with Paintbrush Canyon fault.

9. Continuity in subsurface between southern Yucca Mountain and Calico Hills.

Description

This activity focuses on (1) estimating the Quaternary rate of activity on the Stagecoach fault through trenching, mapping, and dating of strata and geomorphic features cut by the fault and (2) determining the chronologic and tectonic relationship between the Stagecoach fault and the Paintbrush Canyon-Busted Butte fault system. In addition, the subsurface expression of the fault zone will be investigated through shallow seismic refraction surveys and possibly reflection surveys. An objective of the trenching is to estimate the total displacement, including strike-slip and dip-slip components, of Quaternary datums. Accordingly, trenching will use methods designed to facilitate measurement of these components, as described in Section 8.3.1.17.4.6.2.

Surficial deposits and geomorphic features will be mapped in detail to determine the apparent strike-slip component of fault movement. Two to four trenches will be excavated across fault scarps and fault lines at locations to be determined, and the Quaternary stratigraphy exposed in trench walls and floor mapped. Areas of lateral disruption and discontinuity of Quaternary datums will be identified, and the age of disrupted datums and overlying undisrupted Quaternary datums established, if present. The age of the datums will be established through stratigraphic correlation, chemical fingerprinting, soil development analysis, radiocarbon dating, uranium-trend and uranium-series analysis, cation-ratio dating, and other methods, as appropriate. The orientation of clast fabric in zones of rupture will be measured. Fracture-filling minerals will be identified and dated. The orientation of all fractures cutting the Quaternary deposits will be measured. Scarps and lineaments will be mapped, and the subsurface geometry investigated using shallow seismic refraction methods. A shallow seismic reflection profile (mini-sosie) will be surveyed as part of Activity 8.3.1.17.4.7.8 (evaluate shallow seismic reflection (mini-sosie) methods) provided that method proves to be effective. Information on the subsurface geometry will also be provided through application of other geophysical methods, as described in Activity 8.3.1.17.4.3.1 (evaluate crustal structure and subsurface expression of Quaternary faults in an east-west transect crossing the Furnace Creek fault zone, Yucca Mountain, and the Walker Lane). Expected duration of this activity is two years.

Methods and technical procedures

The methods and technical procedures for Activity 8.3.1.17.4.4.3 are given in the following table.

Method	Technical procedure Number	Title	Date
	(NWM-USGS-)		
Evaluation of Quaternary displacement along main trace of the Stagecoach Road fault zone as established by trenching and mapping	GCP-01,R0	Radiometric-age data bank	15 Jun 81
	GCP-02,R1	Labeling, identification, and control of samples for geochemistry and iostope geology	20 Jan 87
	GCP-03,R1	Uranium-series dating	9 Mar 88
	GP-01,R0	Geologic mapping	1 Mar 83
	GP-03,R0	Stratigraphic studies	1 Mar 83
	GP-07,R0	Geologic trenching studies	14 Aug 84
	GP-17,R0	Describing and sampling soils in the field	19 Feb 86
	GCP-04,R1	Uranium-trend dating	27 May 88
	TBD[a]	Cation ratio (desert varnish) dating	TBD
	TBD	Chemical fingerprinting	TBD
	TBD	Dating by soil development analysis	TBD
	TBD	Radiocarbon dating, conventional and tandem accelerator methods	TBD
	TBD	Shallow seismic reflection and refraction surveys	TBD

[a]TBD = to be determined.

8.3.1.17.4.4.4 Activity: Evaluate the Cane Spring fault system

Objectives

The objective of this activity is to determine the location, spatial orientation, length, width, Quaternary recurrence rate, and the location, amount, and nature of Quaternary movement of the Cane Spring fault system.

Parameters

The parameters for this activity are

1. Length, location, and spatial orientation of the fault system.

2. Segmentation within the fault system.

3. Width of the fault system.

4. Age and nature of Quaternary deposits and Quaternary surfaces displaced by or covering Quaternary strands within the fault system.

5. Location, amount, and direction of displacement of Quaternary deposits and Quaternary surfaces.

6. Age, lateral extent, and height of fault scarps.

Description

This activity focuses on evaluation of the potential of the Cane Springs fault system to produce moderate to large earthquakes. The Cane Spring fault system trends northeast between Skull Mountain and Frenchman Flat, bisecting the region lying between the Rock Valley fault zone and the Mine Mountain fault zone. Offset of bedrock by the fault indicates significant left-lateral movement in later Tertiary. Distinct alinements of brush and physiographic features in Quaternary material along the fault trace suggests that movement has continued into the Quaternary, particularly at the northeast end of the fault system. Detailed mapping of surficial deposits along the fault trace, including soil description and shallow seismic (Bison) refraction is planned to evaluate the possibility that the lineaments are caused by faulting of Quaternary deposits. If strong indications of faulting are found, then selected fault traces will be trenched, and the age of faulted and unfaulted units intersected by the fault will be determined. The expected duration of this activity is six months.

Methods and technical procedures

The methods and technical procedures for Activity 8.3.1.17.4.4.4 are given in the following table.

Method	Technical procedure Number	Title	Date
Evaluation of the Cane Spring fault system	GCP-01,R0	Radiometric-age data bank	15 Jun 81
	GCP-02,R1	Labeling, identification, and control of samples for geochemistry and isotope geology	20 Jan 87
	GCP-03,R1	Uranium-series dating	9 Mar 88
	GP-01,R0	Geologic mapping	1 Mar 83
	GP-03,R0	Stratigraphic studies	1 Mar 83
	GP-07,R0	Geologic trenching studies	14 Aug 84
	GCP-04,R1	Uranium-trend dating	27 May 88
	TBD[a]	Cation ratio (desert varnish) dating	TBD
	TBD	Chemical fingerprinting	TBD
	TBD	Dating by soil development analysis	TBD
	TBD	Radiocarbon dating, conventional and tandem accelerator methods	TBD
	TBD	Shallow seismic reflection and refraction surveys	TBD

[a]TBD = to be determined.

8.3.1.17.4.5 Study: Detachment faults at or proximal to Yucca Mountain

Objectives

The objective of this study is to supply information pertaining to the distribution, displacement rate, and age of detachment faults proximal to Yucca Mountain. The key questions regarding detachment faults are

(1) whether they represent a significant earthquake source and (2) whether they conceal a significant earthquake source at depth. To resolve both questions, activities are focused on resolving the Quaternary behavior of postulated detachment faults.

Review of detailed (1:24,000 to 1:62,500 scale) maps of the Nevada Test Site and adjacent areas to the west (Bare Mountain and Beatty areas), using current concepts of structural geology, suggests that some features mapped as depositional contacts or thrust faults are in fact detachment faults. In particular, the basal contact of Oligocene-Miocene sedimentary rocks or Miocene volcanic rocks on Paleozoic rocks in the Mercury, Calico Hills, and Bare Mountain areas appears at several localities to be a detachment fault of moderate (perhaps one to several kilometers) displacement. Recent mapping south and west of Beatty shows that the basal contact of the Miocene volcanic rocks is a detachment fault with substantial displacement (Maldanado, 1985b).

Structural analysis of deformed and faulted Miocene ash-flows suggests that the entire area of Yucca Mountain, including the area of the proposed repository, is underlain at unknown depth by one or more detachment faults (Scott, 1986; Scott and Whitney, 1987). This possibility has not been confirmed, nor has the depth, attitude, and total extent of the postulated detachment(s) been determined. Conjecturing that the uppermost detachment fault corresponds to the contact between Miocene volcanic rocks and subjacent Paleozoic rocks, preliminary reinterpretation of published gravity data (Synder and Carr, 1984), suggests that this detachment(?) surface slopes moderately in a N.60°W. direction, which is the direction of least horizontal stress (Stock et al., 1985). That surface, or a high-angle fault offsetting it (M. D. Carr et al., 1986) was intersected in drillhole UE-25p#1 at a depth of about 1,200 m.

If detachment faults exist at depth below the site, their relevance to repository design and performance as potential sources of ground motion, rupture, or hydrologic conduits or barriers hinges on their age, depth, and nature of the intersection of the detachment faults with the steeply dipping Quaternary normal faults within the site area. This study focuses on examination of suspected detachment faults where they are exposed in areas adjacent to Yucca Mountain. Information on the potential subsurface extent and geometry of detachment faults and their possible connection to listric Quaternary faults at Yucca Mountain is derived through geophysical studies described in Activity 8.3.1.17.4.3.1 (evaluate crustal structure and subsurface expression of Quaternary faults in an East-West transect crossing the Furnace Creek fault zone, Yucca Mountain, and the Walker Lane) and Study 8.3.1.17.4.7 (subsurface geometry and concealed extensions of Quaternary faults at Yucca Mountain).

Yucca Mountain Project strategy for investigating the age and displacement rate of detachment faults includes five elements:

1. Observation of contact relations of detachment faults and Quaternary deposits at the outcrop and measurements of the radiometric age of detachment surfaces, to be undertaken as part of this study.

2. Evaluation of the subsurface geometric relationship of detachment faults (as deduced from geophysical studies described above and

hydrologic and site-geology drillhole data) to Quaternary high-angle faults, such as the Bare Mountain fault, the Windy Wash fault, and the Paintbrush Canyon fault.

3. Evaluation of the recurrence rate and displacement history of Quaternary high-angle faults that could merge with detachment faults in the subsurface, to be undertaken as part of Study 8.3.1.17.4.6 (Quaternary faulting within the site area) and other studies of faulting.

4. Evaluation of in situ stress data developed within Study 8.3.1.17.4.8 (stress field within and proximal to the site area).

5. Evaluation of focal mechanism solutions developed in Study 8.3.1.17.4.1 (historical and current seismicity).

This information is to be synthesized in Study 8.3.1.17.4.12 (tectonic models and synthesis), which will (1) evaluate the possibility that one or more detachment faults are present in the subsurface below or in the vicinity of the proposed repository site, and (2) if considered to be present, evaluate the direction and rate of movement of the upper plate, the depth and configuration of the fault surfaces, and the nature of the association, if any, between the detachment fault(s) and the normal faults in the upper plate.

Activities planned for this study are to evaluate (1) the significance of the Miocene-Paleozoic contact in the Calico Hills area to detachment faulting within the site area, (2) postulated detachment faults in the Beatty-Bare Mountain area, (3) the potential relationship of megabreccia within and south of Crater Flat to detachment faulting, (4) postulated detachment faults in the Specter Range and Camp Desert Rock areas, and (5) the age of detachment faults by using radiometric ages.

8.3.1.17.4.5.1 Activity: Evaluate the significance of the Miocene-Paleozoic contact in the Calico Hills area to detachment faulting within the site area

Objectives

The objectives of this activity are (1) to determine whether the contact of Miocene volcanic rocks on Paleozoic strata is tectonic or depositional, (2) if tectonic, to determine the Quaternary activity, if any, of the possible detachment fault, and (3) if Quaternary, the direction and age of movement, attitude of fault plane, and nature of deformation of the Miocene (upper plate?) sequence.

Parameters

The parameters for this activity are geologic structure and stratigraphy.

Description

The contact between Miocene volcanic (and volcaniclastic) rocks and subjacent Paleozoic strata, which lies a kilometer or more below the surface at the site of the proposed repository at Yucca Mountain, surfaces a few kilometers to the northeast in the Calico Hills. The volcanic rocks are broken by faults, some with displacement in excess of 200 m, and locally are moderately to steeply tilted. This activity is designed to establish whether the contact with Paleozoic strata is tectonic or depositional, and if tectonic, whether the Miocene volcanic rocks are part of a detachment-bounded upper plate or not. The activity calls for conventional geologic mapping.

The suspected tectonic contact between Miocene rocks and Paleozoic rocks in the Calico Hills area will be mapped in detail with particular attention to evidence bearing on age of movement and displacement rate, including apparent offset of the Miocene-Paleozoic contact by pre-Quaternary faults. The Calico Hills area and vicinity will be mapped using conventional field methods, including annotation of field observations on large-scale (1:12,000) aerial photographs (color or false color, where available), and compiled at 1:24,000 scale. This activity is estimated to be 75 percent complete. The expected duration of the future work is six months.

Methods and technical procedures

The method and technical procedure for Activity 8.3.1.17.4.5.1 are given in the following table.

Method	Technical procedure		
	Number	Title	Date
	(NWM-USGS)		
Detailed mapping and analysis of suspected tectonic contact between Miocene rocks and Paleozoic rocks in Calico Hills area	GP-01,R0	Geologic mapping	1 Mar 83

8.3.1.17.4.5.2 Activity: Evaluate postulated detachment faults in the Beatty-Bare Mountain area

Objectives

The objectives of this activity are

1. To determine if postulated detachment faults in the Beatty-Bare Mountain have been active in the Quaternary.

2. If Quaternary, to

   a. Establish the displacement rate, location, and nature of the low-angle imbricate fault zones between lineated and mylonitized and variably recrystallized gneiss of the northern Amargosa Desert and the Paleozoic and Miocene rocks of the Beatty area, and to ascertain the nature of deformation of the Miocene (upper plate?) rocks.

   b. Establish the displacement rate, location, and nature of the low-angle fault zone between Paleozoic rocks of Bare Mountain and the Miocene volcanic rocks north of Bare Mountain, and to ascertain the nature of deformation of the Miocene (upper plate?) rocks.

   c. Ascertain the nature of internal deformation of Paleozoic rocks, their degree of metamorphism, the nature of suspected low-angle tectonic contact with the lineated and mylonitized gneiss of the northern Amargosa Desert, and the nature of the suspected low-angle tectonic contact with Miocene rocks at the northern end of Bare Mountain.

Parameters

The parameters for this activity are geologic structure and stratigraphy, age of datums, and amount and direction of offset of datums.

Description

The Beatty-Bare Mountain area, centered about 27 km west of the proposed repository at Yucca Mountain, is interpreted as an eroded and beveled stack of imbricated detachment-fault-bounded plates. The lowest exposed plate, cropping out in the northern Amargosa Desert southwest of Beatty, consists of lineated and mylonitized crystalline rocks, schist, and semischist. It is structurally overlain by one or more intermediate plates, consisting of moderately to weakly metamorphosed Precambrian and Paleozoic strata that form the Bare Mountain massif. The Bare Mountain massif is in turn structurally overlain by an upper plate, which west of Beatty, consists of Miocene volcanic and volcaniclastic strata. Older geologic maps have been reinterpreted and this reinterpretation suggests that the detachment between the intermediate (Bare Mountain) plates and the upper plate extends east of Beatty, curving around the north side of Bare Mountain, and is cut off by the Bare Mountain frontal fault.

This activity is designed to work out the structural geology of this detachment complex through conventional geologic mapping.

Detailed mapping and analysis of Beatty-Bare Mountain area--Bullfrog N.E. 7.5-min quadrangle. The Miocene rocks and their contact with subjacent units will be mapped using conventional field methods, including annotation of field observations on medium-scale (1:20,000) black-and-white and color-aerial photographs, and compilation at 1:24,000 scale. This subactivity is 95 percent complete. A map-report describing results of this mapping is in review.

Detailed mapping and analysis of Beatty-Bare Mountain area--Bare Mountain N.W. 7.5-min quadrangle. The Miocene rocks and their contact with subjacent units will be mapped using conventional field methods, including annotating field observations on medium-scale (1:20,000) black-and-white and color aerial photographs, and compiling at 1:24,000 scale. Estimated duration of work is one year.

Detailed mapping and analysis of Bare Mountain area--Bare Mountain S.W. 7.5-min quadrangle, plus parts of adjoining quadrangles. The Paleozoic rocks and their contact with overlying Miocene units and with subjacent units will be mapped using conventional field methods, including annotating field observations on medium-scale (1:20,000) black-and-white and color aerial photographs, and compiling at 1:24,000 scale. This subactivity is estimated to be 75 percent complete. The duration of the future work is six months.

Methods and technical procedures

The methods and technical procedures for Activity 8.3.1.17.4.5.2 are given in the following table.

Method	Technical procedure Number	Technical procedure Title	Technical procedure Date
	(NWM-USGS-)		
Detailed mapping and analysis of Beatty-Bare Mountain area - Bullfrog N.E. 7.5-min quadrangle	GP-01,R0	Geologic mapping	1 Mar 83
Detailed mapping and analysis of Beatty-Bare Mountain area - Bare Mountain N.W. 7.5-min quadrangle	GP-01,R0	Geologic mapping	1 Mar 83

Method	Technical procedure Number	Title	Date
	(NWM-USGS-)		
Detailed mapping and analysis of Bare Mountain area - Bare Mountain S.W. 7.5-min quadrangle, plus parts of adjoining quadrangles	GP-01,R0	Geologic mapping	1 Mar 83

8.3.1.17.4.5.3 Activity: Evaluate the potential relationship of breccia within and south of Crater Flat to detachment faulting

Objectives

The objective of this activity is to determine whether breccias tectonically emplaced on low-angle surfaces beveled across Paleozoic and younger strata are slide masses or near-surface parts of a detached upper plate; and if either, how they relate to postulated Quaternary detachment faulting.

Parameters

The parameters for this activity are

1. Distribution of breccia in the subsurface below Crater Flat.

2. Nature of fragmentation of the breccia.

3. Nature of basal contact of the breccia, including indicators of direction of relative movement.

Description

Breccias intersected in VH-2 (Carr and Parrish, 1985), located in the central part of Crater Flat between Red Cone and Black Cone, could be the lateral extension of similar material cropping out above Miocene volcanic rocks along the southern rim of Crater Flat. The breccias appear to be monolithologic, composed chiefly of Paleozoic carbonate rock, possibly derived from Bare Mountain, or from now-concealed outcrops of correlative strata east or south of Crater Flat. In this activity, recently completed detailed maps of the area within which the breccia crops out will be reviewed, as will cores from USW VH-1 and USW VH-2. Field work, limited to examination of outcrops along the southern rim of Crater Flat, will focus on evaluation of the internal character and nature of the basal contact of the breccia, and evaluation of potential sources of the breccia. The expected duration of this work is six months.

Methods and technical procedures

The methods and technical procedures for Activity 8.3.1.17.4.5.3 are given in the following table.

Method	Technical procedure Number	Title	Date
Evaluation of megabreccia in and south of Crater Flat	GP-02,R0	Subsurface investigations	1 Mar 83
	GP-04,R0	Structural studies	1 Mar 83

8.3.1.17.4.5.4 Activity: Evaluate postulated detachment faults in the Specter Range and Camp Desert Rock areas

Objectives

The objective of this activity is to determine whether the basal contact of the Horse Spring Formation is depositional or tectonic; and if tectonic, to determine whether movement was Quaternary or older and, if Quaternary, to determine the direction and amount of offset, the amount of extension, and the style of internal deformation of the upper plate.

Parameters

The parameters of this activity are geologic structure and stratigraphy.

Description

The contact between Miocene strata and Paleozoic strata crops out in the Specter Range and Camp Desert Rock areas. Preliminary reconnaissance indicates that in places the contact is tectonic and that the Miocene rocks locally form a detachment-fault-bounded upper plate. In this area, the basal Miocene (possible partly Oligocene) strata are dominantly lacustrine and fluvial deposits that become progressively more volcanogenic up-section. This activity includes conventional geologic mapping, with emphasis on structure of the Paleozoic-Miocene contact and on stratigraphy and basin analysis of the Miocene sedimentary deposits. Ashes intercalated in the section will be dated using potassium-argon dating methods. Although the primary area of interest is the Specter Range and Camp Desert Rock area, Miocene (Oligocene?) stratigraphy in other areas, including the Funeral Mountains and the Sheep Mountains, will be studied for purposes of comparison.

The stratigraphy and structure of the Horse Springs-Pavits Spring sequence in the Specter Range and Camp Desert Rock areas will be evaluated. The basal contact of the Horse Springs will be mapped in detail using conventional field methods, with field mapping annotated on 1:20,000 scale vertical black-and-white or color aerial photographs, and then compiled at 1:24,000 scale. Internal structure, stratigraphy, provenance, and age of the Horse Springs-Pavits Spring sequence will be investigated using conventional procedures. This activity is approximately 50 percent complete. The estimated duration of the remaining work is two years.

Methods and technical procedures

The methods and technical procedures for Activity 8.3.1.17.4.5.4 are given in the following table.

Method	Technical procedure		
	Number	Title	Date
	(NWM-USGS-)		
Evaluation of the stratigraphy and structure of the Horse Springs-Pavits Spring sequence in the Specter Range and Camp Desert Rock areas	GP-01,R0	Geologic mapping	1 Mar 83
	GP-03,R0	Stratigraphic studies	1 Mar 83
	GP-04,R0	Structural studies	1 Mar 83
	GP-06,R0	Geodetic, leveling and trilateration surveys	6 June 83

8.3.1.17.4.5.5 Activity: Evaluate the age of detachment faults using radiometric ages

Objectives

The objectives of this activity are to

1. Determine if the subdetachment basement and the Bare Mountain massif cooled through the blocking temperatures of zircon and appetite during the Quaternary period.

2. Determine if the Northern Amargosa core complex cooled through the blocking temperatures of muscovite and biotite during the Quaternary period.

Parameters

The parameters of this activity are

1. Fission-track ages of zircon and apatite.
2. Location of dated samples with respect to detachment surfaces.
3. Potassium-argon dating method ages of muscovite and biotite.

Description

Rocks forming the Northern Amargosa core complex include lineated and mylonitized crystalline rocks, schist, and semi-schist. These rocks were probably deformed at or below the ductile-brittle transition zone (i.e., at crustal depths in excess of 5 km). Exposure of these rocks requires substantial tectonic denudation. The rate and timing of this denudation is not known. Structurally higher detachment faults cut volcanic rocks as young as 7.5 million years; possibly all the denudation took place since that time. The detachment faults are also possibly in part rejuvenated Mesozoic features; if so, much of the denudation is pre-Neogene. This activity is designed to determine if the mid-crustal rocks of the core complex cooled through the blocking temperatures of zircon or apatite during the Quaternary. The Precambrian and Paleozoic rocks of the Bare Mountain massif may form a detached plate structurally overlying the Northern Amargosa rocks. Fission-track dating of zircon and apatite from these rocks should constrain the age of denudation and cooling.

Fission-track dating of the northern Amargosa Desert core complex (area of high-grade lineated and mylonitized gneiss, schist, and semi-schist constituting the subdetachment basement) and the Bare Mountain massif (deformed Precambrian and Paleozoic strata). Samples will be collected from the central part of the northern Amargosa Desert core complex, from the shear zones marking the detachment surfaces between the core complex and the overlying plate of Paleozoic rocks, and from between that plate and the uppermost plate of Miocene volcanic rocks. At Bare Mountain, samples will be collected at low elevation from the deeply disected central part of the massif, from the shear zone marking the detachment at the northern end of the massif, and from the shear zone exposed at low elevation along the eastern front of the range. Zircon and apatite separated from these samples will be dated using standard fission-track dating procedures. This subactivity is approximately 25 percent complete. The estimated duration of this work is two years.

Potassium-argon dating of the northern Amargosa core complex (area of high-grade lineated and mylonitized gneiss, schist, and semi-schist constituting the subdetachment basement). Samples will be collected from the central part of the core complex, from suitable targets nearest the shear zone marking the detachment surface separating the core complex from structurally overlying plate of Paleozoic rocks, and from dike rocks within the uppermost plate that are truncated by the basal detachment of that plate. Suitable minerals (muscovite and biotite) will be separated from these samples and their age determined using standard potassium-argon dating techniques. This subactivity is currently under way and approximately 25 percent complete. The estimated duration of this work is two years.

Methods and technical procedures

The methods and technical procedures for Activity 8.3.1.17.4.5.5 are given in the following table.

Method	Technical procedure Number	Title	Date
	(NWM-USGS-)		
Fission-track dating of the Northern Amargosa Desert core complex	GCP-01,R0	Radiometric-age data bank	15 Jun 81
	GCP-02,R1	Labeling, identification, and control of samples for geochemistry and isotope geology	20 Jan 87
	GCP-08,R1	Fission-track dating	26 May 88
Potassium-argon dating of the Northern Amargosa core complex	GCP-01,R0	Radiometric-age data bank	15 Jun 81
	GCP-02,R1	Labeling, identification, and control of samples for geochemistry and isotope geology	20 Jan 87
	GCP-06,R0	Potassium-argon dating	15 Jun 81
Fission-track and potassium-argon dating of miscellaneous samples supplied by other activities in support of program objectives	TBD[a]	Fission-track and potassium-argon dating of miscellaneous samples supplied by other activities in support of program objectives	TBD

[a]TBD = to be determined.

8.3.1.17.4.6 Study: Quaternary faulting within the site area

Objectives

The objectives of this study are (1) to identify and characterize Quaternary faults that intersect or project toward the surface facility, the repository, or the controlled area and (2) to identify and characterize Quaternary faults at the site whose length or recurrence rate suggest a potential for future earthquakes with magnitude such that associated ground shaking could impact design or affect performance of the waste facility.

The site area is defined here as the rectangular 237 km^2 (91 mi^2) area encompassing the central Yucca Mountain block and its structural and physiographic boundaries (Fortymile Wash, Yucca Wash, Solitario Canyon, and the Stagecoach Road fault) (Figure 8.3.1.17-11). Except for the southwest-striking, possibly left-lateral Stagecoach Road fault at the south boundary of the site, Quaternary faults within the site are predominantly north-trending, west-dipping normal- or oblique-slip faults. Potentially significant representatives of this group include the Paintbrush Canyon, the Bow Ridge, the Windy Wash, and the Solitario Canyon faults. Northwest-trending lineaments and faults are also present, but no Quaternary movement on them has been recognized.

Activities planned for this study are to (1) evaluate Quaternary geology and potential Quaternary faults at Yucca Mountain and (2) evaluate age and recurrence of movement on suspected and known Quaternary faults.

Knowledge of the age, length, width, displacement rate, and recurrence interval of the Quaternary faults is required to establish the rate of faulting within the site area during the Quaternary, and the potential for ground shaking and rupture. Included in this study are investigations of known faults, relying primarily on mapping and trenching of Quaternary materials intersected by the faults to establish which datums are cut, and the direction and amount of offset. Also included are investigations of the precise age of Quaternary datums using direct dating methods and mapping to establish relative ages.

Information from this study will be useful in estimating the probability of future rupture or ground shaking. Knowledge of the age, recurrence interval, and length of faults are required for this estimate; this information will be provided through parallel investigations described previously, and other studies of faulting.

Faulting at the surface facility is the subject of a separate study (Study 8.3.1.17.4.2, location and recency of faulting near prospective surface facilities). The Stagecoach Road fault, which intersects the southeastern boundary of the site area, is to be evaluated as part of Study 8.3.1.17.4.4 (Quaternary faulting proximal to the site within northeast-trending fault zones). Other geologic studies contributing to the evaluation of faults at the site include Study 8.3.1.17.4.3 (Quaternary faulting within 100 km of Yucca Mountain) and Study 8.3.1.17.4.5 (detachment faults at or proximal to Yucca Mountain).

Geophysical methods, including gravity surveys, magnetic surveys, and shallow reflection seismic surveys, will be used to establish continuity in the subsurface of fault segments observed at the surface at Yucca Mountain and vicinity and to evaluate the geometric relation of high-angle faults exposed at the surface to postulated detachment faults at depth. The geophysical work will be done as part of Study 8.3.1.17.4.7 (subsurface geometry and concealed extension of Quaternary faults at Yucca Mountain) and Activity 8.3.1.17.4.3.1 (evaluate crustal structure and subsurface expression of Quaternary faults in an east-west transect crossing the Furnace Creek fault zone, Yucca Mountain, and the Walker Lane).

The characteristics to be evaluated include (1) fault length, (2) scarp height, (3) scarp morphology, (4) datums cut by fault and datums overlapping fault, (5) age of datums, (6) width of fault zone (including subsidiary fractures), (7) width and character of rupture zones, (8) fabric of sheared material within rupture zones, (9) age and character of mineral coatings and fracture fillings, (10) character of fracture surfaces, (11) gravity and magnetic expression of fault zones, (12) fault orientation at surface and at depth, (13) areal fault pattern, and (14) seismic expression of faults.

8.3.1.17.4.6.1 Activity: Evaluate Quaternary geology and potential Quaternary faults at Yucca Mountain

Objectives

The objectives of this activity are to

1. Synthesize and evaluate data pertaining to the location, spatial orientation, length, width, Quaternary recurrence rate, and the location, amount, and nature of Quaternary movement of faults within the site area.

2. Identify hitherto unrecognized Quaternary faults within the site area.

Parameters

The parameters for this activity are

1. Length, location, and spatial orientation of faults.

2. Segmentation within individual faults.

3. Width of faults.

4. Age and nature of Quaternary deposits and Quaternary surfaces displaced by or covering Quaternary faults within the site area.

5. Location, amount, and direction of displacement of Quaternary deposits and Quaternary surfaces.

6. Age, lateral extent, and height of fault scarps.

7. Lineaments with expression in surficial deposits.

Description

This activity focuses on the (1) synthesis and evaluation of data pertaining to the length, age, recurrence rate, and displacement rate of faults within the site area; (2) search of the site area for hitherto unrecognized Quaternary faults; and (3) determination of the distribution of surficial deposits within the site area. The principal vehicle for accomplishing these objectives is through the preparation of 1:24,000-scale maps of the site area, one with emphasis on Quaternary faults (to be compiled in this activity), and the other with emphasis on surficial deposits (to be compiled in Activity 8.3.1.5.1.4.2). The fault map will depict the location and extent of faults, as well as the amount and timing of displacement of Quaternary datums.

Calculation of rates of faulting requires delineation of areas within which recognition of pre-Holocene faulting would not be possible because of cover by Holocene deposits. To satisfy this requirement, Holocene deposits of Yucca Mountain will be mapped in detail at 1:24,000 scale.

Surficial deposits mapping of Yucca Mountain. In Activity 8.3.1.5.1.4.2, existing unpublished maps of surficial deposits at Yucca Mountain will be reviewed and upgraded, then compiled at a scale of 1:24,000. Surficial deposits along known Quaternary faults extending outside the site area will be mapped in conjunction with investigations of those specific faults. This subactivity is 25 percent complete. Duration of future work is estimated to be two years.

Quaternary fault map of Yucca Mountain. In this activity, Quaternary faults will be mapped at a scale of 1:24,000. Information will be compiled from existing geologic mapping (Scott and Bonk, 1984) and all Quaternary faults will be examined in the field to determine the age of youngest offset Quaternary deposits. Information on the age and recurrence intervals of individual faults will be added to the map from detailed trench studies described in Activity 8.3.1.17.4.6.2 (evaluate age and recurrence of movement on suspected and known Quaternary faults). The map will be periodically updated as other studies of faults are completed and released in final form when site characterization is completed.

Methods and technical procedures

The methods and technical procedures for Activity 8.3.1.17.4.6.1 are given in the following table.

Method	Technical procedure Number	Title	Date
	(NWM-USGS-)		
Quaternary fault map of Yucca Mountain	GP-01,R0	Geologic mapping	1 Mar 83
	GP-03,R0	Stratigraphic studies	1 Mar 83
	GP-04,R0	Structural studies	1 Mar 83

8.3.1.17.4.6.2 Activity: Evaluate age and recurrence of movement on suspected and known Quaternary faults

Objectives

The objectives of this activity are to

1. Determine, through trenching and mapping, the location, spatial orientation, length, width, Quaternary recurrence rate, interconnections at the surface, and the location, amount, and nature of Quaternary movement of the Paintbrush Canyon, Solitario Canyon, Windy Wash, and Ghost Dance faults, and other suspected or possible Quaternary faults within the site area.

2. Determine through trenching and dating, the age, amount and nature of offset, and the recurrence history of the Bow Ridge fault system and to evaluate that information in context with data contributed by other studies on the age, nature, and origin of fracture coatings and fissure fillings deposited within that zone.

Parameters

The parameters for this activity are

1. Length, location, and spatial orientation of faults.

2. Segmentation within individual faults.

3. Width of faults.

4. Age and nature of Quaternary deposits and Quaternary surfaces displaced by or covering Quaternary faults within the site area.

5. Location, amount, and direction of displacement of Quaternary deposits and Quaternary surfaces.

6. Age, lateral extent, and height of fault scarps.

7. Age of soils overlapping or displaced by faults.

8. Age of volcanic ashes intercalated in surficial deposits that overlap or are displaced by faults, or that have filled fissures within the fault zones.

Description

This activity is designed (1) to characterize, through geologic mapping and trenching, potentially significant Quaternary faults in the Yucca Mountain area and (2) to define interconnections between these faults at the surface. The Paintbrush Canyon, Bow Ridge, Windy Wash, and Solitario Canyon fault zones are zones where multiple episodes of Quaternary movement are suspected, hence have been singled out for special attention. Other suspected or possible Quaternary faults will be examined and their potential significance to design or performance issues will be evaluated. Trenching at locations to be determined may be required to assess the significance of these faults.

Large-scale (approximately 1:6000 scale), low-sun aerial photographs of suspected or known fault traces will be examined for evidence of ponded alluvium, shutterridges, brushlines, scarps, lineaments, and offset drainages. Recognition of these and other geomorphic features commonly associated with Quaternary faults will assist in focusing field studies on likely locations of faults and in locating trenches intended to intersect faults.

Determination of direction and amount of fault slip depends on identification of Quaternary datums and measurement of the displacement or offset of those datums by faults. Suitable datums include depositional contacts between distinctive soils, paleosols, debris flows, and alluvial deposits. These units are typically thin (0.1 to 2 m thick), subplanar and subhorizontal, thus the vertical component of displacement is in general easily recognized and measured in trenches excavated through these deposits where they are intersected by faults. Because the lateral extent of these deposits is commonly large, direct measurement of the strike-slip component of displacement is more difficult. Direct measurement is feasible, however, if intersections of faults with lateral boundaries or with clearly identifiable linear features (i.e., channels) within the surficial deposits can be found.

An objective of trench mapping planned as part of this and other studies of Quaternary faults is to determine the direction, amount, and age of slip on faults. Accordingly, at each trench locality, one or more trenches 20 to 50 m in length and 2 to 5 m in depth will be excavated across the fault zone. The location of fault(s) will be pinpointed, and the age and amount of the dip-slip component of displacement determined.

Where feasible, the direction and amount of the strike-slip component of slip will be established through mapping of Quaternary datums exposed in walls and floors of smaller subsidiary trenches excavated along the fault trace. These trenches will be progressively deepened and mapped, thus enabling development of a detailed three-dimensional representation of Quaternary structure and stratigraphy within the dimensions of each trench.

If suitable markers are found, the direction and amount of fault slip can then be calculated.

Alternative procedures will also be used where circumstances dictate. These procedures allow calculation of total displacement, including the strike-slip component, provided that both the dip-slip component and the direction of fault slip are known. The direction can in rare cases be inferred from orientation of slickensides or, less precisely, from orientation of elongate pebbles and cobbles that have been rotated by shear within the fault zone. Slickensides are commonly present on bedrock fault surfaces, but their age can seldom be determined. Slickensides are rarely present on fault surfaces within the surficial deposits. These approaches to determination of total displacement are thus of limited utility. Offset of small stream channels and other geomorphic features intersected by Quaternary faults may also provide a measure of strike-slip displacement.

Determination of total fault displacement depends on exposing concealed intersections of faults with Quaternary datums. Because these features are irregularly distributed, their discovery is to a degree fortuitous. Thus, it is not expected that all trenches will reveal Quaternary datums or stratigraphic features that would permit calculation or measurement of total fault displacement. It thus may be necessary to excavate additional trenches at certain localities.

Dating of fault movement depends on accurate determination of the age of soils and other deposits cut by the fault and the age of vein materials deposited in fissures along the fault surface. These materials are to be dated by uranium-trend, uranium-series, and varnish cation ratio methods, and the methods themselves will be calibrated by dating deposits of known age elsewhere within the immediate region. The ages of soils are to be established through quantitative chemical and physical comparison with soil development indexes established within Activity 8.3.1.5.1.4.1 (modeling of soil properties in the Yucca Mountain region).

Where exact ages are difficult to measure, relative ages can commonly be determined through stratigraphic correlation of deposits involved in the faulting. Stratigraphic correlation is planned at two scales; large-scale, detailed stratigraphic mapping of surficial deposits of Yucca Mountain (to be contributed by Activity 8.3.1.17.4.6.1--evaluate Quaternary geology and potential Quaternary faults at Yucca Mountain), and medium-scale regional stratigraphic mapping of surficial deposits of the Beatty 1:100,000 quadrangle (to be contributed by Activity 8.3.1.17.4.3.2--evaluate Quaternary faults within 100 km of Yucca Mountain).

Volcanic ashes are commonly intercalated within the Quaternary deposits, as at Busted Butte. Their identification, correlation, and dating depends on chemical fingerprinting and recognition of the source eruptions of the ash, which typically are volcanic centers in the eastern Sierra Nevada, Yellowstone, or Cascades. Volcanic ashes from the Yucca Mountain area will be collected and chemically analyzed, and the analyses compared with analyses of reference samples from the western United States.

<u>Mapping and analysis of offset of Quaternary datums in trenches and outcrop (Paintbrush Canyon fault zone)</u>. Quaternary deposits and faults

within and proximal to the Paintbrush Canyon fault zone, including the Busted Butte area will be mapped using conventional field methods. Existing trenches (see Figure 8.3.1.17-11 for location) across fault traces and scarps will be supplemented with two to four additional trenches in the Busted Butte area. The distribution of Quaternary datums, rupture zones, fracture zones, and fracture fillings in trenches will be mapped. Datums will be sampled and their age determined through appropriate procedures, including uranium-trend, uranium-series, soil development, and ash correlation. The work is 25 percent completed, and the duration of the future work is estimated to be two years.

Analysis of offset of Quaternary datums in trenches (Bow Ridge fault system, Yucca Mountain area). The distribution of Quaternary datums, rupture zones, fracture zones, and fracture and fissure fillings will be mapped at large scale in trenches excavated across the fault zone. The orientation of fractures and slickensides for paleostress determination will be recorded. Age of datums, fracture coatings and fissure fillings will be determined through appropriate procedures, including uranium-trend, uranium-series, and soil development. Vein material and fracture coatings will be identified using standard petrographic techniques, x-ray diffraction, x-ray fluorescence, and wet-chemical analyses. Information on the carbon and oxygen isotopes in the carbonate in these materials will be provided by Activity 8.3.1.5.2.1.5 (studies of calcite and opaline-silica vein deposits). The fault has been trenched at two locations (Figure 8.3.1.17-11), and logging of these trenches is 50 percent completed. Provided suitable locations can be found, one or two additional trenches may be excavated. The duration of the future work is estimated to be one year.

Mapping and analysis of offset of Quaternary datums in trenches and outcrop (Windy Wash fault zone). Quaternary deposits and faults within and proximal to the Windy Wash fault zone will be mapped using conventional field methods. Fault traces and scarps will be trenched. The distribution of Quaternary datums, rupture zones, fracture zones, and fracture fillings in trenches will be mapped. Datums will be sampled and their age determined through appropriate procedures, including uranium-trend, uranium-series, thermoluminescence, soil development, and ash correlation. Two trenches have been excavated and logged (Figure 8.3.1.17-11). Additional trenching at these same locations is planned to define the strike-slip component of offset. The duration of the future work is estimated to be one year.

Mapping and analysis of offset of Quaternary datums in trenches and outcrop (Ghost Dance fault zone). Quaternary deposits and faults within and proximal to the Ghost Dance fault zone will be mapped using conventional field methods.

The distribution of Quaternary datums, rupture zones, fracture zones, and fracture and fissure fillings will be mapped at large scale in trenches excavated across the fault zone. The orientation of fractures and slickensides for paleostress determination will be recorded. Age of datums, fracture coatings, and fissure fillings will be determined through appropriate procedures, including uranium-trend, uranium-series, soil development, and thermoluminescence. Five trenches have been excavated along or near the fault zone without revealing definitive data on Quaternary movement. Provided suitable locations can be found, two additional trenches are planned. The duration of the future work is estimated to be one year.

Mapping and analysis of offset of Quaternary datums in trenches and outcrop (Solitario Canyon fault zone). Quaternary deposits and faults within and proximal to the Solitario Canyon fault zone will be mapped using conventional field methods.

The distribution of Quaternary datums, rupture zones, fracture zones, and fracture and fissure fillings will be mapped at large scale in trenches excavated across the fault zone. The orientation of fractures and slickensides for paleostress determination will be recorded. Age of datums, fracture coatings, and fissure fillings will be determined through appropriate procedures, including uranium-trend, uranium-series, soil development, and thermoluminescence. Six trenches have been excavated across the trace of the fault (Figure 8.3.1.17-11). Provided suitable locations can be found, one to two additional trenches will be excavated. The duration of the future work is estimated to be six months.

Uranium-trend, uranium-series, and varnish cation ratio dating of Quaternary datums and fracture fillings. Samples of alluvium, colluvium, eolian deposits, and fracture fillings will be collected. Uranium-trend (open-system) methods will be used to date sediments. Carbonate-rich fracture fillings will be dated by uranium-series (closed-system) methods. Rock varnish will be dated by the cation-ratio method.

The dating effort will be focused on (1) collecting and analyzing samples of units of unknown age at Yucca Mountain and vicinity that are cut by or overlap faults and also are key marker beds within the Beatty 1:100,000 quadrangle and (2) collecting and analyzing samples of units of known age within the region to calibrate the method. This subactivity will be conducted on an as-needed basis to support the analyses in this activity.

Quaternary volcanic ash correlation and dating. Glass shards from bulk samples of ash intercalated in Quaternary deposits cut by or overlapping Quaternary faults will be separated. The glass will be chemically analyzed using microprobe neutron activation and x-ray fluorescence procedures. Analytical data will be compared with that of known and well-dated ashes within the region. Biotite, muscovite, and zircon from bulk samples of ashes intercalated in Quaternary and older deposits will be dated with potassium-argon dating method or fission-track techniques, as appropriate, where these minerals are present in the sample. This subactivity will be conducted on an as-needed basis to support the analyses in this activity.

Methods and technical procedures

The methods and technical procedures for Activity 8.3.1.17.4.6.2 are given in the following table.

Method	Technical procedure Number	Title	Date
Mapping and evaluation of offset of Quaternary datums in trenches and outcrop (Paintbrush Canyon fault zone)	GCP-01,R0	Radiometric-age data bank	15 Jun 81
	GCP-02,R1	Labeling, identification, and control of samples for geochemistry and isotope geology	20 Jan 87
	GCP-03,R1	Uranium-series dating	9 Mar 88
	GCP-09,R0	Spike calibration	15 Jun 81
	GP-01,R0	Geologic mapping	1 Mar 83
	GP-03,R0	Stratigraphic studies	1 Mar 83
	GP-04,R0	Structural studies	1 Mar 83
	GP-07,R0	Geologic trenching studies	14 Aug 84
	GP-17,R0	Describing and sampling soils in the field	19 Feb 86
	GCP-04,R1	Uranium-trend dating	27 May 88
	GCP-07,R1	Mineral separation for geochemistry and isotopic analysis	27 May 88
	TBD[a]	Cation ratio (desert varnish) dating	TBD
	TBD	Photography of trench walls	TBD
	DP-114,R0	Sampling of rock varnish	TBD

Method	Technical procedure Number	Title	Date
Evaluation of offset of Quaternary datums in trenches (Bow Ridge fault system, Yucca Mountain area)	GCP-01,R0	Radiometric-age data bank	15 Jun 81
	GCP-02,R1	Labeling, identification, and control of samples for geochemistry and isotope geology	20 Jun 87
	GCP-03,R1	Uranium-series dating	9 Mar 88
	GCP-09,R0	Spike calibration	15 Jun 81
	GP-01,R0	Geologic mapping	1 Mar 83
	GP-03,R0	Stratigraphic studies	1 Mar 83
	GP-04,R0	Structural studies	1 Mar 83
	GP-07,R0	Geologic trenching studies	14 Aug 84
	GP-08,R0	Correlation of tephra by means of chemical analyses	19 Feb 86
	GP-17,R0	Describing and sampling soils in the field	19 Feb 86
	DP-07,R2	Microprobe operating procedure	8 Jul 86
	DP-16,R2	Siemens X-ray diffractometer procedure	2 Feb 86
	GCP-04,R1	Uranium-trend dating	27 May 88
	GCP-07,R1	Mineral separation for geochemistry and isotopic analysis	27 May 88
	TBD	Cation ratio (desert varnish) dating	TBD
	TBD	Wet-chemical analysis	TBD

Method	Technical procedure Number	Title	Date
Evaluation of offset of Quaternary datums in trenches (Bow Ridge fault system, Yucca Mountain area) (continued)	TBD	X-ray fluorescence analysis	TBD
	TBD	Instrumental neutron activation	TBD
	TBD	Photography of trench walls	TBD
	DP-114,R0	Sampling of rock varnish	TBD
Mapping and evaluation of offset of Quaternary datums in trenches and outcrop (Windy Wash fault zone)	GCP-01,R0	Radiometric-age data bank	15 Jun 81
	GCP-02,R1	Labeling, identification, and control of samples for geochemistry and isotope geology	20 Jan 87
	GCP-03,R1	Uranium-series dating	9 Mar 88
	GCP-09,R0	Spike calibration	15 Jun 81
	GP-01,R0	Geologic mapping	1 Mar 83
	GP-03,R0	Stratigraphic studies	1 Mar 83
	GP-04,R0	Structural studies	1 Mar 83
	GP-07,R0	Geologic trenching studies	14 Aug 84
	GP-08,R0	Correlation of tephra by means of chemical analyses	19 Feb 86
	GP-17,R0	Describing and sampling soils in the field	19 Feb 86
	DP-07,R2	Microprobe operating procedure	8 Jul 86

Method	Technical procedure Number	Title	Date
Mapping and evaluation of offset of Quaternary datums in trenches and outcrop (Windy Wash fault zone) (continued)	GCP-04,R1	Uranium-trend dating	27 Mar 88
	GCP-07,R1	Mineral separation for geochemistry and isotopic analysis	27 May 88
	TBD	Cation ratio (desert varnish) dating	TBD
	TBD	X-ray fluorescence analysis	TBD
	TBD	Instrumental neutron activation	TBD
	TBD	Photography of trench walls	TBD
	DP-114,R0	Sampling of rock varnish	TBD
Mapping and evaluation of offset of Quaternary datums in trenches and outcrop (Ghost Dance fault zone)	GCP-01,R0	Radiometric-age data bank	15 Jun 81
	GCP-02,R1	Labeling, identification, and control of samples for geochemistry and isotope geology	20 Jan 87
	GCP-03,R1	Uranium-series dating	9 Mar 88
	GCP-09,R0	Spike calibration	15 Jun 81
	GP-01,R0	Geologic mapping	1 Mar 83
	GP-03,R0	Stratigraphic studies	1 Mar 83
	GP-04,R0	Structural studies	1 Mar 83
	GP-07,R0	Geologic trenching studies	14 Aug 84
	GP-17,R0	Describing and sampling soils in the field	19 Feb 86
	GCP-04,R1	Uranium-trend dating	27 May 88

Method	Technical procedure Number	Title	Date
Mapping and evaluation of offset of Quaternary datums in trenches and outcrop (Ghost Dance fault zone) (continued)	GCP-07,R1	Mineral separation for geochemistry and isotopic analysis	27 May 88
	TBD	Cation ratio (desert varnish) dating	TBD
	TBD	Photography of trench walls	TBD
	DP-114,R0	Sampling of rock varnish	TBD
Mapping and evaluation of offset of Quaternary datums in trenches and outcrop (Solitario Canyon fault zone)	GCP-01,R0	Radiometric-age data bank	15 Jun 81
	GCP-02,R1	Labeling, identification, and control of samples for geochemistry and isotope geology	20 Jan 87
	GCP-03,R1	Uranium-series dating	9 Mar 88
	GCP-09,R0	Spike calibration	15 Jun 81
	GP-01,R0	Geologic mapping	1 Mar 83
	GP-03,R0	Stratigraphic studies	1 Mar 83
	GP-04,R0	Structural studies	1 Mar 83
	GP-07,R0	Geologic trenching studies	14 Aug 84
	GP-08,R0	Correlation of tephra by means of chemical analyses	19 Feb 86
	GP-17,R0	Describing and sampling soils in the field	19 Feb 86
	DP-07,R2	Microprobe operating procedure	8 Jul 86
	GCP-04,R1	Uranium-trend dating	27 May 88

Method	Technical procedure Number	Title	Date
Mapping and evaluation of offset of Quaternary datums in trenches and outcrop (Solitario Canyon fault zone) (continued)	GCP-07,R1	Mineral separation for geochemistry and isotopic analysis	27 May 88
	TBD	Cation ratio (desert varnish) dating	TBD
	TBD	X-ray fluorescence analysis	TBD
	TBD	Instrumental neutron activation	TBD
	TBD	Photography of trench walls	TBD
	DP-114,R0	Sampling of rock varnish	TBD
Mapping and evaluation of offset of Quaternary datums in trenches and outcrop (other suspected and possible fault zones)	TBD	Some or all of the technical procedures for the five known Quaternary faults	TBD
Numerical dating	GCP-01,R0	Radiometric-age data bank	15 Jun 81
	GCP-02,R1	Labeling, indentification, and control of samples for geochemistry and iostope geology	20 Jan 87
	GCP-03,R1	Uranium-series dating	9 Mar 88
	GCP-09,R0	Spike calibration	15 Jun 81
	GCP-04,R1	Uranium-trend dating	27 May 88
	GCP-07,R1	Mineral separation for geochemistry and isotopic analysis	27 May 88
	TBD	Cation ratio (desert varnish) dating	TBD

Method	Technical procedure		
	Number	Title	Date
Numerical dating (continued)	DP-114,R0	Sampling of rock varnish	TBD
Volcanic ash correlation and dating	GCP-01,R0	Radiometric-age data bank	TBD
	GCP-02,R1	Labeling, identification, and control of samples for geochemistry and isotope geology	20 Jan 87
	GCP-06,R0	Potassium-argon dating	15 Jun 81
	GCP-08,R1	Fission-track dating	26 May 88
	GCP-09,R0	Spike calibration	15 Jun 81
	GP-08,R0	Correlation of tephra by means of chemical analysis	19 Feb 86
	DP-07,R2	Microprobe operating procedure	8 Jul 86
	GCP-07,R1	Mineral separation for geochemistry and isotopic analysis	27 May 88
	TBD	X-ray fluorescence analysis	TBD
	TBD	Instrumental neutron activation	TBD

[a]TBD = to be determined.

8.3.1.17.4.7 Study: Subsurface geometry and concealed extensions of Quaternary faults at Yucca Mountain

The objectives of this study are to (1) provide data on distribution of mass, magnetic gradients, geoelectric features, and seismic velocities and reflections that will aid in evaluating the continuity of Quaternary faults where concealed by Holocene and late Pleistocene surficial deposits; (2) evaluate that data and its limitations; and (3) evaluate the possibility that Quaternary faults exposed as high-angle faults at the site continue to depth as planar, high-angle faults, or alternatively, flatten at depth and merge with one or more low-angle faults. The geophysical methods used in this study measure rock properties (mass, magnetism, electrical resistivity, gamma radiation), sensing faults as discontinuities in those properties. The same methods are therefore useful in solving the converse problem, determination of continuity of rock units at the site. A third objective, then, is to provide information on continuity of rock units within the repository and controlled area to assist the investigation of site geology (Section 8.3.1.4).

Activities planned for this study include (1) evaluation of intermediate depth (2 to 3 km) reflection and refraction methods and planning of potential application of these methods at the site; (2) detailed gravity survey of the site; (3) detailed aeromagnetic survey of the site; (4) detailed ground magnetic surveys of specific features at the site; (5) evaluation of surface geoelectric methods and planning of potential applications of these methods at the site; (6) evaluation of methods to detect buried faults using gamma ray measurements, and conduct an airborne gamma-ray survey of the site; (7) evaluation of thermal infrared methods and planning for potential applications of these methods at the site; and (8) shallow seismic reflection (mini-sosie) survey of selected structures at and proximal to the site. These and other geophysical methods being applied in other studies that contribute to site and regional tectonic and geologic problems are listed in Tables 8.3.1.17-7 and -8. Synthesis of the geophysical data is to be done in Study 8.3.1.17.4.12 (tectonic models and synthesis).

The activities planned as part of this study will be reviewed by Activity 8.3.1.4.2.1.6 before any surveys are started. Activity 8.3.1.4.2.1.6 will be responsible for reviewing and integrating the planned geophysical data gathering activities for all studies and programs. Some surveys involve feasibility tests and decision points before implementation. Before planned geophysical surveys are conducted, Activity 8.3.1.4.2.1.6 will review the results of any feasibility tests or past surveys to estimate the likelihood that useful data will be generated by the planned effort. Activity 8.3.1.4.2.1.6 will also review the location, scheduling, techniques, and objectives of the planned survey to determine if the objectives of this activity and activities in other programs that also require this data are being met. Locations of surveys and data collection techniques will not be finalized until the review by Activity 8.3.1.4.2.1.6 is complete. Final plans and changes will be reported in SCP progress reports and study plans.

8.3.1.17.4.7.1 Activity: Evaluate intermediate depth (2 to 3 km) reflection and refraction methods and plan potential application of these methods within the site area

Objectives

The objectives of this activity are to (1) evaluate previous attempts to use seismic refraction and reflection methods at the site, (2) evaluate technology currently available, (3) evaluate potential contribution to information on velocity structure and on subsurface geometry of faults, (4) review potential applications of these methods to Yucca Mountain Project needs, and (5) if appropriate, plan applications of these methods at the site.

Parameters

Parameters for this activity are

1. Seismologic reflections and discontinuities.
2. Seismic velocity structure.

Description

A previous attempt to apply reflection seismology using Vibroseis energy source at Yucca Mountain failed to produce useful results (McGovern, 1983). More recent surveys at Mid Valley using an air gun energy source produced excellent reflections to 1.5 s (two-way travel time), resulting in satisfactory resolution of faults and thickness and inclination of subsurface units. These results will be reviewed and their potential application to the site evaluated. If appropriate, a reflection and refraction survey of the site will be planned. The expected duration of this activity is three months.

This is a planning activity only. Decision to proceed with actual application of these methods is contingent on results of the evaluation, technical peer review and review of potential applications to Yucca Mountain Project needs.

Methods and technical procedures

The methods and procedures for Activity 8.3.1.17.4.7.1 are given in the following table.

Method	Technical procedure Number	Title	Date
Feasibility test	TBD[a]	Feasibility tests	TBD
Evaluation of intermediate depth (2 to 3 km) reflection and refraction methods and planning of potential application of these methods at the site	TBD	Evaluation of intermediate depth (2 to 3 km) reflection and refraction methods and planning of potential application of these methods and planning of potential applications of these methods	TBD

Method	Technical procedure Number	Title	Date
Reflection surveys	TBD	Reflection surveys	TBD

[a]TBD = to be determined.

8.3.1.17.4.7.2 Activity: Detailed gravity survey of the site area

Objectives

The objectives of this activity are to measure variations in mass of near-surface strata and surficial deposits, and to infer from this information the location of faults and continuity of rock units within the site.

Parameters

The parameters for this activity are gravity gradients and anomalies at the site.

Description

The gravity maps of the site currently available are based on gravity observations that are too widely spaced to be useful in discrimination of faults or demonstration of continuity of rock units. In this activity, a 1:24,000-scale map of the site will be constructed from gravity observation at stations spaced 200 ft apart along east-west lines spaced 500 ft apart (where topography permits). The expected duration of this activity is one year.

Methods and technical procedures

The method and technical procedure for Activity 8.3.1.17.4.7.2 is given in the following table.

Method	Technical procedure Number	Title	Date
Detailed gravity survey of the site area	GPP-01,R1	Gravity measurement and data reduction	14 Jan 85

8.3.1.17.4.7.3 Activity: Detailed aeromagnetic survey of the site area

Objectives

The objectives of this activity are to measure variations in rock magnetism of surface strata and surficial deposits and to infer from this information the location of faults and continuity of rock units within the site.

Parameters

The parameters for this activity are magnetic gradients and anomalies at the site.

Description

The aeromagnetic maps of the site currently available are based on measurement of magnetic field along flight lines at one-fourth-mile spacing. These observations are too widely spaced to resolve ambiguities in fault continuity or to demonstrate the continuity of rock units. In this activity, a 1:12,000-scale map of the site will be constructed from measurement of the magnetic field along east-west flight lines spaced one-sixteenth mile apart. The survey will be draped over topography, maintaining a nominal terrain clearance of 400 ft. The expected duration of this activity is one year.

Methods and technical procedures

The methods and technical procedures for Activity 8.3.1.17.4.7.3 are given in the following table.

Method	Technical procedure		
	Number	Title	Date
Detailed aeromagnetic survey of the site	TBD[a]	Airborne magnetic surveying	TBD

[a]TBD = to be determined.

8.3.1.17.4.7.4 Activity: Detailed ground magnetic survey of specific features within the site area

Objectives

The objectives of this activity are (1) to measure variations in rock magnetism of surface strata and surficial deposits in the vicinity of specific faults, the shaft and surface facilities, drillholes, and aeromagnetic anomalies and (2) to infer from this information the location of faults and continuity of rock units at these locations.

Parameters

The parameters for this activity are magnetic gradients and anomalies at specified locations.

Description

In this activity, the magnetic field in the vicinity of specific features (Figure 8.3.1.4-9) will be measured from truck-mounted or hand-carried magnetometers. Observations will be semicontinuous (10- to 20-ft intervals). The classes of features at which these measurements will be made include (1) known and inferred structures, (2) vicinity of drillholes, (3) vicinity of shaft and surface facilities, and (4) vicinity of anomalies detected through aeromagnetic surveying (Activity 8.3.1.17.4.7.3). Not all such features will be surveyed. The number and location of those selected for investigation using this method will be determined by principal investigators as the need arises through evaluation of geologic and geophysical mapping.

Methods and technical procedures

The method and technical procedure for Activity 8.3.1.17.4.7.4 is given in the following table.

Method	Technical procedure Number	Technical procedure Title	Technical procedure Date
	(NWM-USGS-)		
Detailed ground magnetic surveys	GP-05,R0	Geologic support activities	1 Mar 83

8.3.1.17.4.7.5 Activity: Evaluate surface geoelectric methods and plan potential applications of these methods within the site area

Objectives

The objectives of this activity are to (1)evaluate previous attempts to use surface geoelectric methods at the site, (2) evaluate technology currently available, (3) evaluate the potential contribution of these methods to definition of subsurface geometry of faults, (4) review potential applications of these methods to Yucca Mountain Project needs, and (5) if appropriate, plan future applications of these methods at the site.

Parameters

The parameters for this activity are

1. Sensitivity and resolution of geoelectric field measurements.

2. Correlation of geoelectric measurements with faults and rock properties.

Description

Surface-based geoelectric investigations, including airborne electromagetic slingram, VLF, DC resistivity, electromagnetic soundings, tensor audio magnetotellurics, and telluric profiling have been applied to site and regional geologic problems (refer to the references in Table 8.3.1.17-7 and -8). Results of these investigations and the status of current technology will be reviewed and their potential application to structural and stratigraphic problems at the site evaluated. If appropriate, surface-based geoelectric investigations at site will be planned. Expected duration of this activity is three months.

This is a planning activity only. The decision to proceed with actual application of these methods is contingent on the results of the evaluation and a review of potential applications to Yucca Mountain Project needs.

Methods and technical procedures

The methods and technical procedure for Activity 8.3.1.17.4.7.5 are given in the following table.

Method	Technical procedure		
	Number	Title	Date
Evaluation of surface geoelectric methods and planning of potential applications of these methods within the site area	TBD[a]	Evaluating surface geoelectric methods and planning potential applications of these methods within the site area	TBD

[a]TBD = to be determined.

8.3.1.17.4.7.6 Activity: Evaluate methods to detect buried faults using gamma-ray measurements, and plan potential application of these methods within the site area

Objectives

The objectives of this activity are (1)to evaluate the feasibility of using surface and airborne gamma-ray measurements to detect and discriminate faults at the site, (2) to review potential applications of these methods to Project needs, and (3) if appropriate, conduct an airborne radiometric survey for that purpose as an adjunct to the aeromagnetic survey of the site.

Parameters

The parameters for this activity are

1. Sensitivity and resolution of surface and airborne gamma-ray measurements.

2. Correlation of gamma-ray gradients and anomalies with faults and rock properties.

Description

The principal natural sources of gamma radiation are uranium, thorium, potassium, and radon gas. Because gamma-ray measurements (aerial or ground) detect gamma rays from the uppermost 50 cm of rock and soil, to be detectable buried faults must have a near-surface expression that is reflected in the near-surface distribution of the natural radioelements. In the site area, the Tiva Canyon and Topopah Spring members are potassium- and thorium-rich volcanic rocks. Gamma-ray spectral logs show typically 4 percent potassium, 6 ppm uranium and 30 ppm thorium for these rock units. Reconnaissance airborne gamma-ray surveys show that colluvium derived from these volcanic rocks, as along Fortymile Wash, has essentially the same signature as the rocks themselves.

To be detectable, buried faults must be reflected by near-surface radioelement distributions, perhaps arising through migration of uranium or potassium along the fault zone through percolation of meteoric water, or through percolation of radon from the fault to the surface in sufficient quantities to be detected by gamma-ray measurements.

In this activity, the possibility that buried faults can be detected will be evaluated through measurement of gamma rays using portable quantitatively calibrated gamma-ray spectrometers along several short (100 m long) traverses crossing buried extensions of the Paintbrush Canyon, Bow Ridge, Windy Wash, and Stagecoach Road faults. If results of these tests so warrant, an airborne radiometric survey will be conducted as an adjunct to the detailed aeromagnetic survey. Expected duration of this activity is three months.

This is a planning activity only. The decision to proceed with actual application of these methods is contingent on the results of the evaluation and a review of potential applications to Yucca Mountain Project needs.

Methods and technical procedures

The methods and technical procedures for Activity 8.3.1.17.4.7.6 are given in the following table.

Method	Technical procedure Number	Title	Date
Evaluation of methods to detect buried faults using gamma-ray measurement	TBD[a]	Evaluation of methods to detect buried faults using gamma-ray measurement	TBD
Feasibility traverses (100 m length)	TBD	Feasibility traverses	TBD

[a]TBD = to be determined.

8.3.1.17.4.7.7 Activity: Evaluate thermal infrared methods and plan potential applications of these methods within the site area

Objectives

The objectives of this activity are to evaluate current thermal infrared survey technology, evaluate its potential application to remote mapping of fractures and faults at Yucca Mountain, review potential applications of these methods to Project needs, and if appropriate, plan future applications of these methods at the site.

Parameters

The parameters for this activity are

1. Sensitivity and resolution of remote thermal infrared survey methods.

2. Correlation of thermal infrared signature with faults and fractures.

Description

Fractures and faults at Yucca Mountain are potential conduits for percolation of meteoric waters. Surface temperature variation associated with differing moisture content of near-surface material is detectable through thermal imaging from aircraft or satellites, and hence it may be possible to map the fault and fracture network at Yucca Mountain using remote thermal infrared sensing methods. In this activity, existing technology and its application to detection of faults and fractures, and water percolation pattern at the site will be evaluated. If appropriate, application of remote thermal infrared techniques to these problems will be planned. The expected duration of this activity is three months.

This is a planning activity only. The decision to proceed with the actual application of these methods is contingent on results of the evaluation and review of potential applications to Yucca Mountain Project needs.

Methods and technical procedures

The methods and technical procedures for Activity 8.3.1.17.4.7.7 are given in the following table.

Method	Technical procedure		
	Number	Title	Date
Evaluation of thermal infrared methods and planning of potential applications of these methods at the site	TBD[a]	Evaluating of thermal infrared methods and planning applications of these methods at the site	TBD

[a]TBD = to be determined.

8.3.1.17.4.7.8 Activity: Evaluate shallow seismic reflection (mini-sosie) methods and, if appropriate, conduct surveys of selected structures at and proximal to the site area

Objectives

The objectives of this activity are to evaluate the subsurface configuration of selected Quaternary faults and the lateral continuity and inclination of key beds within the Miocene volcanic sequence at the northeastern, eastern, and southwestern parts of the site area.

Parameters

The parameters for this activity are

1. Seismic reflections in the vicinity of selected faults.

2. Seismic reflections in the northeastern, eastern, and southwestern parts of the site.

3. Seismic velocity structure at and proximal to the site.

Description

Shallow seismic reflection (mini-sosie) has proved to be a rapid and economical method of defining subsurface geometry within the uppermost 1 km of the crust in some areas. However, previous attempts to use the method in the vicinity of the site have produced somewhat ambiguous results. The method has previously been used in defining the subsurface extent of the Beatty scarp and the Rock Valley fault, and field work has been completed on traverses crossing the Bare Mountain range front fault, and the central part of Crater Flat (Figure 8.3.1.4-8).

Nine additional profiles have been proposed (Figure 8.3.1.4-8), all but one of which are within the site area. Two of these (Jackass Flats and Fran Ridge traverses) are designated as preliminary traverses. Each begins and ends at drillholes, providing opportunity to tie the reflections to known beds. If acceptable results are achieved in the preliminary tests, the remaining profiles will be run.

The method uses portable instruments, 9.1-m source point (data stacked at common midpoints every 4.6 m at 12-fold, or every 9.1 m at 24-fold) with 12 geophones per group. The energy source is a battery of hand-held construction tampers.

This is an activity to evaluate the suitability of the technique. The expected duration of this activity is three months. The decision to proceed with full-scale application of the method is contingent on results of the evaluation.

Methods and technical procedures

The methods and procedures for Activity 8.3.1.17.4.7.8 are given in the following table.

Method	Technical procedure		
	Number	Title	Date
Shallow seismic reflection (mini-sosie) survey of selected structures at and proximal to the site	TBD[a]	Shallow seismic reflection (mini-sosie) survey of selected structures at and proximal to the site	TBD
Additional profiles	TBD	Additional profiles	TBD

[a]TBD = to be determined.

8.3.1.17.4.8 Study: Stress field within and proximal to the site area

Objectives

The primary objective of this study is to provide data on the ambient stress at the site and its immediate vicinity that will aid in evaluating (1) the most favored orientation and nature of future movement on faults within the site area, (2) the stability of potential pathways for radionuclide travel controlled by or related to fracture aperture, (3) the stability of mined excavations, (4) the response of the rock mass to thermal loading, and (5) the applicability of tectonic models. A secondary objective is to evaluate the potential relevance of paleostress data to prediction of future stress orientations.

For convenience, the larger and smaller components of the principal stresses in the horizontal plane are referred to as S_H and S_h, respectively, and the component of the principal stresses in the vertical plane as S_v. At Yucca Mountain, the average direction S_h is approximately N.60°W., on the basis of in situ stress determinations (Stock et al., 1985). This direction is in reasonable agreement with the average orientation of the stress field in the Yucca Mountain region based on focal plane solutions of recent earthquakes and on in situ stress determinations at Rainier Mesa. However, to the west, in the Coso Volcanic Field, the average direction of S_h is approximately east-west (Walter and Weaver, 1980). The exact location and nature of the transition from N.60°W. at Yucca Mountain to east-west in the area west of Death Valley is unknown.

The in situ measurements at Yucca Mountain indicate the $S_h < S_H < S_v$, with the magnitude of S_h near the failure criterion for dip-slip failure on N.30°E.-trending faults and so low that the aperture of favorably oriented fractures is sensitive to hydrostatic pressure of the fluid column in boreholes (Ellis and Swolfs, 1983). However, most of the focal-plane solutions of recent earthquakes within the immediate region of Yucca Mountain indicate predominantly strike-slip movement on north-trending faults, suggesting that $S_h < S_v < S_H$. Additional study is required to verify the compatibility or lack of it for these two data sets and to evaluate their potentially conflicting implications pertaining to rupture, ground motion, and tectonic effects on hydrology.

Possibly the in situ measurements are only characteristic of a shallow part of the lithospheric crust, a part that is decoupled from deeper parts by one or more detachment faults. Such a zone of decoupling may distinguish active from inactive detachment faults. It follows that subsurface extensions of detachment faults forming the contact between Miocene and Paleozoic rocks north of Mercury, and at the northern flank of Bare Mountain, and at the southern edge of the Bullfrog Hills may be zones of mechanical decoupling between upper plate and lower plates. If so, stress regimes above and below such zones may be quite distinct; this possibility will be evaluated in Activity 8.3.1.17.4.8.4

In addition to the possible complications of the regional stress pattern arising from the potential presence of detached plates, other complications may result from the apparent organization of the upper crust as a mosaic of structurally distinct blocks. The Yucca Mountain region appears to be an aggregation of such blocks, including for example, the blocks corresponding to the northern Amargosa Desert, the Bare Mountain, the Yucca Mountain, and the Little Skull Mountain areas. The orientation and degree of development of Neogene and Quaternary structures appear to vary from block to block.

The structural grain of some blocks, such as Little Skull Mountain, appears to be rotated 30 degrees clockwise from the regional trend, a feature known to be characteristic of bedrock terranes adjacent to the Walker Lane. The appearance of rotation probably reflects both a physical rotation about a vertical axis (the oroflexural bending of Albers, 1967) and, during the time the blocks were actively rotating, sharp curvature of stress trajectories crossing or curving into the Walker Lane. Investigation of ambient stress and paleostress at Yucca Mountain and vicinity should help evaluate the applicability of these and other tectonic models to the neotectonics of the site.

Activities planned for this study include (1) an evaluation of the effectiveness of shallow borehole hydrofrac and triaxial strain recovery methods for the determination of in situ stress and their potential application to determination of the stress field proximal to the site, (2) an evaluation of the present stress field at the site, (3) an evaluation of the published and unpublished data on paleostress orientation at and proximal to the site and an assessment of the relevance of this data to future stress orientations, and (4) an evaluation of theoretical stress distributions associated with potential tectonic settings (e.g., wrench fault, normal fault, and detachment fault setting) of the site.

Rationalization of the stress and stain at the site in relation to the plate-tectonic setting and applicable tectonic models will be performed in Study 8.3.1.17.4.12 (regional tectonic models and synthesis). In situ stress determinations will also be made in the exploratory shaft facility. Refer to Activity 8.3.1.4.3.1.1 for a description of these tests. Paleostress indicators in the form of fractures and slickenside lineations will also be evaluated in the exploratory shaft facility. Refer to Activity 8.3.1.4.2.2.4 for a description of this activity.

8.3.1.17.4.8.1 Activity: Evaluate present stress field within the site area

Objectives

The objective of this activity is to measure the vertical and lateral variation of in situ stress at the site. These measurements will include the variation of in situ stress within the vicinity of the steep hydrologic gradient in the northwestern section of the site area, and in one borehole that is expected to intersect a postulated detachment fault and subjacent Paleozoic rocks below Yucca Mountain.

Parameters

The parameters for this procedure are

1. The magnitude of in situ stress.
2. The orientation of induced fractures and borehole breakouts.

Description

In situ stress measurements at the site have previously been made in drillholes USW G-1, USW G-2, USW G-3, and UE-25p#1 (Figure 8.3.1.4-5). These measurements suggest that the least principal horizontal stress (S_h) is oriented about N.60°W., and that at depths up to one kilometer $S_h < S_H < S_v$, indicating a normal faulting stress regime. On the basis of focal plane solutions for recent earthquakes, however, the deep (greater than 1-km depth) stress field in the region encompassing the site is believed to be characterized by strike-slip faulting. This is contrary to the general observation, reported in Chapter 1, that the stress field in the Great Basin province is characterized by a strike-slip regime near the surface and a normal faulting regime at depth (Vetter and Ryall, 1983).

This activity is designed to contribute to the characterization of in situ stress at the site through hydrofrac measurements and analysis of borehole breakouts in three boreholes (USW G-5, USW G-6 and USW G-7, Figure 8.3.1.4-5) to be drilled for other purposes. It is expected that borehole G-7 will pass through a postulated detachment and terminate in subjacent Paleozoic rocks. The in situ stress will also be measured in a fourth borehole, to be drilled for other purposes within the area of the steep hydrologic gradient in the northwestern sector of the site area, provided that these measurements will not compromise proposed hydrologic tests within this borehole. The duration is contingent on drilling schedule for these holes, but is estimated to be one to two years. Vertical variation of in situ stress will be evaluated through collection of hydrofrac measurements at 6 to 10 depth intervals within each well including, if feasible, one or more intervals within Paleozoic rocks.

Methods and technical procedures

The method and procedure for Activity 8.3.1.17.4.8.1 is given in the following table.

Method	Technical procedure Number	Technical procedure Title	Technical procedure Date
	(NWM-USGS)		
Deep borehole in situ stress tests	GPP-04,R0	In situ stress investigations	27 June 83

8.3.1.17.4.8.2 Activity: Evaluate 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

Objectives

The objectives of this activity are to

1. Evaluate the usefulness of shallow borehole hydrofrac and triaxial strain recovery methods for the determination of in situ stress.

2. Measure the lateral variation of in situ stress in areas proximal to the site.

3. Measure vertical variation in stress above and below the possible detachment between Miocene and Paleozoic rocks east of Yucca Mountain in the Little Skull Mountain or Striped Hills area.

Parameters

The parameters of this activity are

1. Magnitude of in situ stress.
2. Orientation of induced fractures and borehole breakouts.
3. Triaxial strain in oriented samples of drill core.

Description

The orientation and magnitude of the principal stresses at any particular place are apt to vary from the regional average as a result of location with respect to boundaries of structural blocks, zones of active dislocation, and possible differences in end loads and tractive forces at the base of the crustal blocks. For this reason, it is possible that in situ stress determinations could contain considerable information about the manner in which the upper crust in the vicinity of the site is deforming. However, the in situ stress at any point is also influenced by local elastic properties, topographic effects, local discontinuities, and previous history of deformation. The hydrofrac measurements must therefore be interpreted with caution, and several measurements at varying depth must be made to be confident of the result.

This activity is designed to examine the vertical variation in stress at two drillholes, one within the site area, the other east of the site in the Little Skull Mountain or Striped Hills area. Measurements at the site, using a shallow borehole (drilled for other purposes) will help evaluate existing hydrofrac measurements of in situ stress. Measurements at a location in the Little Skull Mountain or Striped Hills areas, using a shallow borehole (to be drilled for this purpose) will help evaluate vertical variation in stress near a possible detachment fault that projects toward Yucca Mountain in the subsurface. Locations of the two drillholes will be determined considering the structural and Quaternary tectonic setting of Yucca Mountain.

The two drillholes, 500 to 800 ft (165 to 260 m) deep, are to be continuously cored. Hydrofrac measurements will use standard procedures. The cores will be sampled at regular intervals, and elastic constants of the samples measured. In addition, the in situ stress in the cored intervals will be evaluated using the three-axis strain recovery technique. These measurements are intended to test the utility of the technique in the Yucca Mountain environment and evaluate whether additional in situ stress measurements are necessary to meet programmatic needs.

If the evaluation is favorable, a program to use these techniques to evaluate in situ stress in the structural blocks adjacent to the site will be planned.

This is an evaluation and planning activity only. Expected duration is six months. Larger scale application of the methods will depend on the results of the evaluation.

Methods and technical procedures

The methods and procedures for Activity 8.3.1.17.4.8.2 are given in the following table.

Method	Technical procedure		
	Number	Title	Date
	(NWM-USGS-)		
Shallow borehole in situ hydrofrac tests	GPP-04,R0	In situ stress investigations	27 June 83
Triaxial strain recovery stress measurement	TBD[a]	Triaxial strain recovery stress measurement	TBD

[a]TBD = To be determined.

8.3.1.17.4.8.3 Activity: Evaluate published and unpublished data on paleostress orientation at and proximal to the site and assess the relevance of these data to Quaternary tectonics

Objectives

The objective of this activity is to establish successive orientations of principal horizontal components of stress in the vicinity of Yucca Mountain to evaluate the stability of stress through time and to provide a partial basis for determining the duration of the contemporary tectonic framework.

Parameters

The parameters of this activity are the orientation and age of paleostress indicators.

Description

Statistical summaries of movement directions of conjugate fault sets may be uniquely related to orientation and relative magnitude of principal stresses at the time of faulting. By noting relative ages of different fault sets, a sequential picture of changing stress orientation with time may be developed for a given area. The method has utility where ages of fault sets may be established within narrow limits, as is generally possible for faults cutting the Miocene and younger rocks at Yucca Mountain and vicinity. This activity seeks to relate these faults to the stress regime in which they were formed and to compare that stress regime with the present in situ stress field.

The orientation of fractures and associated slickensides in Miocene or younger rock has been studied in the south-central and southeastern parts of the Nevada Test Site by Frizzell and Zoback (1987) and by Dockery Ander (1984). These data will be merged with data being produced as a byproduct of shaft and mapping activities and the orientation of paleostress deduced using computer analysis.

Surface expressions of fracture displacements will be integrated with similar determinations obtained in subsurface core and exploratory shaft facility evaluations (Activity 8.3.1.4.2.2.4). Duration of this activity is expected to be three to six months.

Methods and technical procedures

The methods and procedures for Activity 8.3.1.17.4.8.3 are given in the following table.

Method	Technical procedure		
	Number	Title	Date
	(NWM-USGS-)		
Evaluation of paleostress indicators	GP-01,R0	Geologic mapping	1 Mar 83
	GP-04,R0	Structural studies	1 Mar 83

8.3.1.17.4.8.4 Activity: Evaluate theoretical stress distributions associated with potential tectonic settings (wrench fault, normal fault, detachment fault setting, etc.) of the site

Objectives

The objectives of this activity are (1) to evaluate possible three-dimensional orientations of stress trajectories associated with potential tectonic settings of Yucca Mountain, including wrench fault, normal fault, and detachment fault tectonic models; (2) to evaluate the degree to which in situ stress data from Yucca Mountain and vicinity constrains applicability of these tectonic models to neotectonics of the site; and (3) to evaluate the potential relation between fracture aperture and in situ stress at Yucca Mountain.

Parameters

The parameters for this activity are

1. Measured magnitudes of principal stresses.
2. Measured orientation of stress trajectories.
3. Measured orientation and aperture of fractures at Yucca Mountain.

Description

Crustal stress measurements at Yucca Mountain will be compared with theoretical patterns, such as stress trajectory maps, unique to wrench-fault, detachment-fault, and normal-fault tectonic models to help assess the applicability of these models or their various permutations to the site. This activity will evaluate possible theoretical stress patterns associated with these and other tectonic models. The theoretical patterns will be chiefly drawn from published sources (e.g., Berger and Johnson, 1980; 1982; Savage and Smith, 1986) but modified where feasible to parallel potential geologic settings of the site. For example, stress distribution within the upper plate of a detachment fault is somewhat analogous to stress distribution within a glacier or a landslide. Mathematical solutions worked out for the case of landslide by Savage and Smith (1986) will be modified to fit a detachment analogue.

This activity will also evaluate the degree to which the data on stress distribution at Yucca Mountain and vicinity can be rationalized with one or more of the theoretical stress patterns. As part of this evaluation, consideration will be given to the inherent uncertainties in the degree to which the in situ measurements and focal plane solutions represent actual in situ stress at the point of measurement, and the degree to which that point represents some larger volume of rock. Consideration will also be given to potential effects of nontectonic factors, including topography and anisotropic elastic constants. The relation between fracture aperture, orientation, and in situ stress at Yucca Mountain will also be evaluated using either theoretical or empirical methods, as appropriate. Data on fracture aperture and orientation will be supplied by other activities (e.g., Activity 8.3.1.4.2.2.2). Results of this evaluation will be used by Activity 8.3.1.8.3.3.3 (assessment of the effects of stress or strain on hyrologic properties of the rock mass). The estimated duration of this activity is six months.

Methods and technical procedures

The methods and technical procedures for Activity 8.3.1.17.4.8.4 are given in the following table.

Method	Technical procedure Number	Title	Date
Mathematical modeling of stress trajectory modeling three-dimensional stress trajectories	TBD[a]	Mathematical modeling of stress trajectories (three-dimensional)	TBD

[a]TBD = to be determined.

8.3.1.17.4.9 Study: Tectonic geomorphology of the Yucca Mountain region

Objectives

The objectives of this study are (1) to document the magnitude of Quaternary uplift and subsidence within the Yucca Mountain region and (2) to evaluate regional variation in the nature and intensity of Quaternary faulting.

The major premise of this study is that certain tectonic processes operating during the Quaternary have influenced the development of contemporary geomorphic features; hence, those features record information on the nature, rate, and localization of those processes. Those processes include faulting, uplift, and subsidence. Consideration of regional topography indicates that some areas within the Yucca Mountain region appear to be in the youthful stage of geomorphic development, with deeply incised drainages, V-shaped canyons, and steep mountain fronts. Other areas, in contrast, are characterized by worn-down remnants of old mountains, that are laced with alluviated washes reaching nearly to their summits. This could imply that some areas were, and perhaps still are, actively rising and others subsiding during late Pliocene and Quaternary time.

Planned investigations focus on evaluation of relative rates and location of uplift and subsidence (1) through definition of surfaces of long-lived stability, as gauged by age and degree of development of desert varnish; (2) through identification of subregional variation in range sinuosity and fan development; and (3) through evaluation of the development of the

Amargosa drainage system. Variation in the nature and intensity of Quaternary faulting in the area within 100 km of Yucca Mountain will be evaluated through morphometric and morphologic analysis.

The data derived through this study will assist in evaluating the degree to which certain potentially adverse conditions are or are not present at the site and its immediate vicinity, including structural deformation such as uplift, subsidence, folding, or faulting during the Quaternary Period. The data will also be used to assist in formulation and validation of tectonic models (Study 8.3.1.17.4.12). Validation includes reconciling structural deformation within the site area with that outside the area, but within 100 km of the site.

The activities of this study are to (1) evaluate age and extent of tectonically stable areas at and near Yucca Mountain, (2) evaluate extent of areas of late Pleistocene and Holocene uplift and subsidence at and near Yucca Mountain, and (3) evaluate variation in the nature and intensity of Quaternary faulting in the area within 100 km of Yucca Mountain through morphometric and morphologic analysis.

8.3.1.17.4.9.1 Activity: Evaluate age and extent of tectonically stable areas at and near Yucca Mountain

Objectives

The objective of this activity is to evaluate the age and areal distribution of surfaces that appear to have been tectonically stable at and near Yucca Mountain through determination of the distribution and age of surfaces with substantial coatings of desert varnish.

Parameters

The parameters for this activity are the age and distribution of desert varnish.

Description

The age and thickness of coatings of desert varnish are a measure of prolonged exposure, which in itself is a measure of stability. The rock-varnish dating technique has recently been applied to dating of Late Cenozoic rocks, surficial deposits, and geologic surfaces in the Yucca Mountain region. Research at Los Alamos National Laboratory has shown that energy dispersive analysis by the scanning electron microscope is a very effective technique to determine the relative abundances of minor elements in rock varnish.

The age of rock varnish has been shown to influence strongly the ratio between soluble and insoluble cations (Dorn, 1983). The rock-varnish dating curve for the Nevada Test Site (NTS) has been extended to include older deposits and calibrated to several independently dated deposits. Yet to be completed are direct comparisons with the Dorn technique, study of chemical variations in varnish, and variation of cation ratios with varnish depth, and study of significance of varnish color (red versus black) on cation ratio.

The technique will be used to date surficial deposits and materials at Yucca Mountain and vicinity that are not datable by conventional isotopic techniques, including faulted surfaces, alluvial fans, stream terraces, pediment surfaces, bedrock surfaces, and hillslope deposits.

The application planned in this activity uses the cation-ratio dating technique to date "old" surfaces coated with desert varnish. Such surfaces are thought to be tectonically more stable than other areas where accumulation of desert varnish is precluded or interrupted because of rapid dissection or alluviation. Desert varnish has been shown to be highly reflective, producing bright spots in Thematic Mapper V satellite imagery. Hence, it is feasible to map such surfaces using the satellite imagery produced as a by-product of another activity (Activity 8.3.1.17.4.3.5).

Calibration of the cation-ratio dating technique (diffused-beam scanning electron microscope procedure) will be achieved by measuring cation ratios of rock varnish at well-dated localities in the NTS region. Cation ratios of samples from within the NTS will be compared with curves showing regional correlation of age with cation ratio. Surfaces with substantial coatings of desert varnish, as shown by maps produced from Thematic Mapper V satellite imagery, will be dated. Desert varnish dates on geomorphic surfaces will be compared with the geomorphic development of each surface as determined through morphometric analysis (Dohrenwand, 1987). This activity is estimated to be 10 percent complete. The estimated future duration is two years.

Methods and technical procedures

The methods and procedures for Activity 8.3.1.17.4.9.1 are given in the following table.

Method	Technical procedure		
	Number	Title	Date
Definition and dating of desert-varnish coated surfaces	TBD[a]	Cation-ratio (desert varnish) dating	TBD
	TBD	Analyses of desert varnish coating using remote imagery	TBD
	TBD	Morphometric analyses of geomorphic surfaces	TBD

[a]TBD = to be determined.

8.3.1.17.4.9.2 Activity: Evaluate extent of areas of Quaternary uplift and subsidence at and near Yucca Mountain

Objectives

The objectives of this activity are to

1. Identify areas of rapid uplift by comparing volume of fan with the area of the associated drainage basin.

2. Identify areas of Quaternary subsidence and uplift, including Amargosa Desert, Crater Flat, Fortymile Wash, Rock Valley, and Ash Meadows, through an analysis of fluvial history of the Amargosa drainage system.

3. Complete a study of average or general rates of erosion and dissection in the southern Great Basin province.

Parameters

The parameters for this activity are the area of drainage basins, the volume of fans, the drainage pattern, the stream profiles, and the rates of degradation of constructional (volcanic) landforms.

Description

In this activity, areas of Quaternary uplift or subsidence will be defined through identification of basins and ranges within the Yucca Mountain region that show anomalously high rates of erosion or sedimentation, compared with adjoining areas and with province-wide averages. Regional rates of erosion will be documented through completion of a study of degradation and erosion of well-dated Quaternary constructional landforms. Local erosional or depositional anomalies will be determined through comparison of fan volume and drainage basin area, and through analysis of the fluvial history of the Amargosa River and its tributaries.

Alluvial fans and drainage basins will be correlated and delineated on maps. Area of fans and drainage basins in the area will be defined and measured using medium-scale (1:20,000) aerial photographs and topographic maps. Age of material in the fans will be established using Quaternary geologic maps and by field examination, supplemented by dating of fan deposits where required.

The Quaternary history of the Amargosa drainage system will be evaluated. Newly active areas of ponding or incision will be mapped as a means of identifying areas of Quaternary subsidence or uplift. Terraces, shorelines, stream captures, and stream diversions within the Amargosa River drainage basin will be identified, mapped, and interpreted in terms of Quaternary tectonics.

The regional rate of erosion and dissection will be measured through analysis of erosion and degradation of well-dated constructional landforms and volcanic deposits at volcanic centers in the southern Great Basin. This activity is estimated to be 90 percent complete; the remaining work is primarily report publication.

Methods and technical procedures

The methods and procedures for Activity 8.3.1.17.4.9.2 are given in the following table.

Method	Technical procedure Number	Title	Date
Mapping, analysis, and correlation of bank alluvial fans and drainage basins	GCP-01,R0	Radiometric-age data	15 Jun 81
	GCP-02,R1	Labeling, identification, and control of samples for geochemistry and isotope geology	20 Jan 87
	GCP-03,R1	Uranium-series dating	9 Mar 88
	GP-01,R0	Geologic mapping	1 Mar 83
	GP-03,R0	Stratigraphic studies	1 Mar 83
	GP-17,R0	Describing and sampling soils in the field	19 Feb 88
	GCP-04,R1	Uranium-trend dating	27 May 88
	TBD[a]	Cation ratio (desert varnish) dating	TBD
	TBD	Radiocarbon dating, conventional and tandem accelerator methods	TBD
Evaluation of Quaternary history of Amargosa drainage system uplift and subsidence	GP-01,R0	Geologic mapping	1 Mar 83

Method	Technical procedure Number	Title	Date
Analysis of regional rate of erosion and dissection	GP-01,R0	Geologic mapping	1 Mar 83
	GP-17,R0	Describing and sampling soils in the field	19 Feb 86

[a]TBD = to be determined.

8.3.1.17.4.9.3 Activity: Evaluate variations in the nature and intensity of Quaternary faulting within 100 km of Yucca Mountain through morphometric and morphologic analysis

Objectives

The objectives of this activity are to

1. Define morphotectonic domains in the area within 100 km of Yucca Mountain and relate them to areal variation in intensity or nature of faulting.

2. Improve the definition of morphologic indicators of shallow detachment faulting, wrench faulting, and basin-range type normal faulting, and to use those indicators to characterize the nature of faulting in morphotectonic domains within 100 km of Yucca Mountain.

3. Constrain tectonic models applicable to the site through evaluation of regional patterns of Quaternary deformation as expressed by distribution of morphotectonic domains.

Parameters

The parameters for this activity are

1. Structural and stratigraphic indicators, location, and timing of detachment faulting, basin-range faulting, and strike-slip faulting.

2. Regional morphometry of that part of the southwest Basin and Range within 100 km of the site; range spacing relief; total relief; range lengths, widths, and areas; basin lengths, widths, and areas; pediment widths and slopes; range-to-basin width ratios; depths of basin closure range front sinuosity.

Description

The planned activity will be divided into two phases: data gathering and comparative analysis, and interpretation. Data gathering and preliminary analyses will require about one half man-year. Interpretative work will begin late in the first year and progressively expand during succeeding years. Because the activity will provide a useful regional context for geologic and geophysical investigations, it is likely that much of the interpretative work would be carried out in coordination with other investigations (perhaps as a predictive reconnaissance tool). This activity compliments Activity 8.3.1.17.4.3.2 (evaluate Quaternary faults within 100 km of Yucca Mountain) and Activity 8.3.1.17.4.6.1 (evaluate Quaternary geology and potential Quaternary faults at Yucca Mountain).

At present, the relationships between geomorphology and tectonic activity are, at best, imperfectly understood. The most successful work to date has involved the use of range front morphometry and morphology to interpret general vertical tectonic activity (Bull and McFadden, 1977; Wallace, 1978; Bull, 1984). These approaches, however, do not clearly resolve differences between the timing and rate of differential vertical movement, and they are of relatively little use in assessing horizontal tectonic activity (e.g., strike-slip faulting, detachment faulting). Moreover, the timing, distribution, and relations between late Cenozoic shallow detachment faulting and basin-range faulting in the Basin and Range are also imperfectly understood. Analysis of the tectonic geomorphology of the area within 100 km of the site, therefore, will require improvement of existing indicators of vertical tectonic activity, identification and definition of new indicators of horizontal tectonic activity (particularly detachment faulting), and at least a general synthesis of what is presently known about the Quaternary tectonics of the region. To evaluate the relation between nature and intensity of Quaternary faulting and morphologic features this activity will

1. Compile available Quaternary structural, stratigraphic, and tectonic data for the southwest Basin and Range using existing summaries and reviews.

2. Describe the regional morphometry of the area within 100 km of the site.

3. Develop reconnaissance maps of piedmonts and Quaternary piedmont deposits for the area within 100 km of the site.

4. Develop and refine a suite of geomorphic indicators of shallow detachment faulting, wrench faulting, and normal faulting.

5. Synthesize and relate morphometric and morphologic characteristics to Quaternary tectonic development of the area within 100 km of the site.

This activity is estimated to be 30 percent complete. The expected duration of the remaining work is two years.

Methods and technical procedures

The methods and procedures for Activity 8.3.1.17.4.9.3 are given in the following table.

Method	Technical procedure Number	Title	Date
	(NWM-USGS-)		
Compilation of available Quaternary structural, stratigraphic and tectonic data for the southwest Basin and Range	GP-01,R0	Geologic mapping	1 Mar 83
Description of the regional morphometry of the southwest Basin and Range	GP-01,R0	Geologic mapping	1 Mar 83
Development of reconnaissance maps of piedmonts and Quaternary piedmont deposits for the southwest Basin and Range	GP-01,R0	Geologic mapping	1 Mar 83
Development and refinement of a suite of geomorphic indicators of shallow detachment faulting	GP-01,R0	Geologic mapping	1 Mar 83
Synthesis and identification of morphometric and morphologic characteristics related to tectonic activity and history of the region	GP-01,R0	Geologic mapping	1 Mar 83
	GP-03,R0	Stratigraphic studies	1 Mar 83

8.3.1.17.4.10 Study: Geodetic leveling

The primary objective of this study is to evaluate possible historical and contemporary vertical displacements across potentially significant Quaternary faults within 100 km of Yucca Mountain. A secondary objective is to characterize the historical rate of uplift and subsidence in the Yucca Mountain region, and evaluate the possible existence of tectonic boundaries, coinciding perhaps with the Walker Lane or with the Furnace Creek fault zone, that separate domains with differing rates of uplift and subsidence. Geologic evidence suggests that a boundary of such a domain, however diffuse, lies somewhere toward the western edge of the region.

For the purposes of this study, the region is defined as the area bounded by Death Valley on the west, Crystal Springs Valley on the east, Warm Springs on the north, and Las Vegas on the south.

Three activities are planned: (1) releveling of base station network, Yucca Mountain and vicinity; (2) global positioning satellite survey of selected base stations, Yucca Mountain and vicinity; and (3) analysis of existing releveling data, Yucca Mountain and vicinity.

In evaluating the potential effectiveness of these activities, some consideration should be given to uncertainties in the measurements and the ability of the measuring techniques to resolve contemporary deformation. The magnitudes of potential displacements are likely to be proportional to the length of time between surveys. For periods of several years the displacements are likely to be difficult to detect with confidence. For example, repeated levelings across the Furnace Creek fault between 1970 and 1985 show no detectable offset, although levelings over this same time period across probable strands of the Death Valley fault indicate possibly 2 mm of vertical displacement across one strand (Artists Drive fault), and possibly 7 mm across another (Sylvester and Bie, 1986). Suitable baselines must be established, however, for possible periodic resurveying during the preclosure time period or for measurement of displacements after large earthquakes, should they occur.

Data developed in this study will be used in Study 8.3.1.17.4.12 (tectonic models and synthesis) to limit estimates of strain rates and contemporary fault displacements within 100 km of Yucca Mountain.

8.3.1.17.4.10.1 Activity: Relevel base-station network, Yucca Mountain and vicinity

Objectives

The objectives of this activity are (1) to evaluate the historic vertical displacement across potentially significant Quaternary faults and (2) to establish the locations and rates of uplift during historical times through measurement of the change in altitude of benchmarks since the last survey.

Parameters

The parameters for this activity are to determine the altitude of benchmarks.

Description

This activity includes biennial resurvey of existing first-order level lines across Yucca Mountain. The existing lines extend westward from Mercury, Nevada, crossing the Paintbrush Canyon, Bow Ridge, Solitario Canyon, and Windy Wash faults at Yucca Mountain, thence through Crater Flat to the western terminus approximately 25 km west of Amargosa Valley. This line, plus quadrilateral nets across each of the faults listed above, was established in 1982-83.

The desirability of adding two additional surveys is to be evaluated with respect to potential contributions to site characterization and with respect to land access matters. The first of these includes two relatively short lines, one extending from Stovepipe Wells southeast to Death Valley Junction, the other from Death Valley southward along the Amargosa River and thence eastward through Jubilee Pass to Shoshone. This survey provides releveling across the Furnace Creek and southern Death Valley fault zones. The second survey includes the releveling of several earlier first and second-order lines north and east of the Nevada Test Site (NTS), forming a small circuit that immediately surrounds the NTS. The proposed route extends along an older first-order survey from Warm Springs southeastward along Nevada Highway 375 to Crystal Springs, southward along several older second-order lines along U.S. Highway 93 to about 15 km south of Alamo, and southwestward along a dirt road to Corn Creek Springs. This route crosses several Quaternary features of regional importance, including the northern part of the Death Valley-Pancake Range volcanic belt, the Pahranagat Range shear zone, and the Las Vegas Valley shear zone, and the Walker Lane belt. Decision to proceed with the two additional surveys is contingent on the results of the evaluation, and review of potential application to Project needs. Baseline surveys are to be completed within one year.

Methods and technical procedures

Methods and technical procedures for Activity 8.3.1.17.4.10.1 are given in the following table.

Method	Technical procedure Number	Technical procedure Title	Technical procedure Date
Resurvey of quadrilaterals (5)	TBD[a]	Resurvey of quadrilaterals	TBD

Method	Technical procedure Number	Title	Date
Evaluate desirability of adding two levels lines	TBD	No tests identified	TBD

[a]TBD = to be determined.

8.3.1.17.4.10.2 Activity: Survey selected base stations, Yucca Mountain and vicinity, using global positioning satellite

Objectives

The objective of this activity is to evaluate contemporary vertical displacement across potentially significant Quaternary faults and the contemporary rate of uplift and subsidence within 100 km of the site on the basis of altitude and position of selected base stations.

Parameters

The parameters for this activity are elevation and location of base stations.

Description

To more fully benefit from the relevelings undertaken as part of Activity 8.3.1.17.4.10.1, junction points and selected benchmarks will be observed periodically (annually and biannually) using the global positioning satellite (GPS). The observations will either be made as part of the National Geodetic Survey GPS program, or alternatively, using recently acquired USGS receivers. GPS vertical measurement precision (replication capability) scales linearly as a function of distance, and is currently on the order of 80 mm over a 50-km line. Comparisons with terrestrial measurements are indirect in the sense that GPS measures a geometrically defined quantity, whereas leveling measures a geopotential difference between points. Accordingly, a gravity dependent correction will be made to bring terrestrial-based height differences into conformity with the GPS-based height differences. Baseline surveys are to be completed within one year.

Methods and technical procedures

Methods and technical procedures for Activity 8.3.1.17.4.10.2 are given in the following table.

Method	Technical procedure Number	Title	Date
Resurvey base station net	TBD[a]	No tests identified	TBD

[a]TBD = to be determined.

8.3.1.17.4.10.3 Activity: Analyze existing releveling data, Yucca Mountain and vicinity

Objectives

The objective of this activity is to evaluate historical vertical displacement across potentially significant Quaternary faults, and possible historic uplift and subsidence within 100 km of Yucca Mountain through detection of changes in altitude as recorded by existing leveling data.

Parameters

The parameter for this activity is the altitude of base stations.

Description

This activity will review the results of releveling of the network of benchmarks in the Yucca Mountain region. The activity involves search of archives, and the collection, collation, and analysis of leveling data. No field work is planned. This activity is estimated to be 50 percent complete. The duration of the remaining work is six months.

Methods and technical procedures

The methods and procedures for Study 8.3.1.17.4.10.3 are given in the following table.

Method	Technical procedure Number	Title	Date
	(NWM-USGS-)		
Resurvey of geodetic leveling network	GP-06,R0	Geodetic, leveling and trilateration surveys	6 June 83

Method	Technical procedure		
	Number	Title	Date
	(NWM-USGS-)		
Analysis of rates of uplift during historical times	GP-06,R0	Geodetic, leveling and trilateration surveys	6 June 83

8.3.1.17.4.11 Study: Characterization of regional lateral crustal movement

The objective of this study is to evaluate rates and orientations of historical and current lateral crustal movement based on analysis of existing data on seismicity, historical fault offset, and creep in the Basin and Range province.

Results of the evaluation will be used in Study 8.3.1.17.4.12 (tectonic models and synthesis) to constrain tectonic models applicable to Quaternary tectonics of the site, and in Study 8.3.1.17.4.1 (historical and current seismicity) to constrain probabilistic models of seismicity within 100 km of Yucca Mountain.

The characteristics to be evaluated include historical fault displacements, creep, historical seismicity, focal plane solutions, and seismic energy release.

8.3.1.17.4.11.1 Activity: Analyze lateral component of crustal movement based on historical faulting, seismicity, and trilateration surveys

Objectives

The objective of this activity is to evaluate rates and orientation of historical and current crustal strain in the Basin and Range province and the Yucca Mountain region.

Parameters

The parameters for this activity are historical fault displacements, creep, historical seismicity, focal mechanisms, seismic energy release, historical crustal strain, and changes in distances between benchmarks in the Yucca Mountain region.

Description

Data pertaining to historical seismicity, focal mechanisms, and seismic energy release will be supplied by Study 8.3.1.17.4.1 (historical and current seismicity). Data pertaining to fault displacements, creep, and crustal strain as measured by strain gauges and land surveys will be compiled. Surveys of the trilateration network at Yucca Mountain and vicinity will be repeated.

Methods and technical procedures

The methods and procedures for Activity 8.3.1.17.4.11.1 are given in the following table.

Method	Technical procedure Number	Technical procedure Title	Technical procedure Date
	(NWM-USGS-)		
Synthesis of published information (Basin and Range province)	TBD[a]	Strain rate analysis	TBD
Trilateration surveys (Yucca Mountain region)	GP-06,R0	Geodetic, leveling and trilateration surveys	6 June 83

[a]TBD = to be determined.

8.3.1.17.4.12 Study: Tectonic models and synthesis

The objectives of this study are (1) to synthesize data relevant to tectonics, (2) to develop a model or range of models that establishes the causal relation between application of tectonic forces and formation of structures observed at Yucca Mountain and vicinity, (3) to link observed rates of formation of those structures with regional rates of crustal strain, (4) to forecast changes in tectonic setting and the manner in which those changes will affect both the regional crustal strain rate and tectonic stability in the Yucca Mountain region, (5) to estimate the effect of those changes on rate and nature of crustal strain at Yucca Mountain and vicinity, and (6) to estimate the future rate of tectonic processes at Yucca Mountain.

A tectonic model or range of models will be developed or compiled to satisfy this investigation. Tectonic model is used here to mean a system of postulates, data, and inferences that explains the deformation of the earth's crust in the vicinity of the site, the forces involved in or producing such deformation, and the resulting geologic structures. Data relevant to faulting, magmatic activity, folding, and uplift and subsidence will be synthesized, including data on gravity residuals, magnetic residuals, seismic velocities, in situ stress, geologic structure and stratigraphy, and tectonic geomorphology.

The compilation or development of regional tectonic models will serve two purposes. The first purpose is to ensure that assumptions that are made about the local manifestation of tectonic processes are consistent with current scientific understanding of tectonic processes acting in the region. For example, the determination of slip rate on the Paintbrush Canyon fault, from age dating of offset strata, will be checked for consistency with interpretive tectonic models that account for the style and rate of faulting throughout the site region. The second purpose of regional tectonic models is to document scientific uncertainty in the characterization of tectonic hazards so that it can be accounted for in evaluations of repository design and performance. This will be accomplished by developing or compiling a range of alternative models that represent the range of current scientific thinking about the tectonic processes that might affect the site.

Regional tectonic models are expected to be most germane to the characterization of the site's ground-motion potential (Investigation 8.3.1.17.3) because earthquake sources at regional distances can contribute to the ground-motion hazard at the site. Alternative tectonic models will be interpreted in terms of alternative, judgmentally weighted seismic source zones in a probabilistic seismic hazard analysis of the site (Study 8.3.1.17.3.6). In addition, tectonic models will provide context for interpretations of the local, preclosure surface faulting potential (Investigation 8.3.1.17.2) and the potential for faulting, folding, uplift, or subsidence to affect postclosure repository performance (Investigation 8.3.1.8.2).

The activities planned for this study are to (1) evaluate tectonic processes and tectonic stability at the site, (2) evaluate tectonic models, and (3) evaluate tectonic disruption sequences.

8.3.1.17.4.12.1 Activity: Evaluate tectonic processes and tectonic stability at the site

Objectives

The objectives of this activity are to

1. Synthesize gravity studies at Yucca Mountain and vicinity, and define regional variations in mass, and attribute them, as appropriate, to variations in crustal thickness, degree of melting, shallow intrusions, distribution of specific stratigraphic units, and faults.

2. Synthesize magnetic studies at Yucca Mountain and vicinity, and define areal variations in magnetic field, and relate them as

appropriate to distribution of specific stratigraphic units, shallow intrusions, and subsurface configuration of faults.

3. Evaluate the regional extent of detachment faults, wrench faults, volcanic rocks belonging to the Death Valley-Pancake Range belt, evaluate the regional pattern of oroclinal bending (oroflexing), evaluate the regional extent of Miocene ash-flow tuffs and associated pyroclastic and epiclastic rocks, and evaluate regional extent of Paleozoic rocks known to be aquifers, aquitards, or to provide favored surfaces of detachment or thrusting.

4. Synthesize and evaluate information pertaining to Quaternary wrench faulting in the Walker Lane (Las Vegas to Cedar Mountain), constrain, if possible, the rate of offset and recurrence interval of potentially significant faults (including the Bare Mountain fault and faults analogous to those near Cedar Mountain), and evaluate the applicability of this information to geologic hazards at the site.

5. Synthesize and evaluate information pertaining to detachment faults at Yucca Mountain and vicinity, and constrain, if possible, the rate of displacement, subsurface configuration, and character of risk posed by this class of faults.

6. Synthesize and evaluate information pertaining to normal (and north-trending oblique and strike-slip faults) at the site and vicinity, and constrain, if possible, aggregate strain rate, subsurface configuration, recurrence interval, and character of risk posed by this class of faults.

7. Synthesize and evaluate information pertaining to the northeast-trending left-lateral strike-slip faults at the Nevada Test Site and vicinity, and constrain, if possible, slip rate, recurrence interval, and character of risk posed by this class of fault.

Parameters

The parameters for this activity are gravitational force, geomagnetic field, geologic structure, and stratigraphy.

Description

This activity includes compilation and interpretation of geologic, gravity, and magnetic maps of the Beatty 1:100,000 quadrangle, synthesis of geologic and geophysical studies, and preparation of topical reports on Quaternary wrench faulting, detachment faulting, normal faulting, and left-lateral strike-slip faulting. Information and interpretations supplied by these syntheses will form the basis for formulation of a tectonic model or models describing the way in which forces and bodies in the Yucca Mountain region interact to produce the geologic and tectonic framework of the proposed repository.

Maps (1:100,000 scale) of Bouguer gravity, residual gravity, and isostatic gravity will be compiled and amplified where necessary with additional gravity surveys. Data on density of geologic units will be collected and compiled. Filtered gravity maps (nominal passing wavelengths of 240 km) will be produced. Maxi spot or a comparable computer program will be used to identify and quantify gradient changes. Crustal models based on gravity and seismic velocity will be produced.

Maps (1:100,000 scale) of aeromagnetic data of the Nevada Test Site and vicinity will be compiled. Source models combining gravity data with magnetic signature of relevant anomalies will be calculated and compared.

Geologic maps (1:100,000 scale) of the Beatty 1 by 1/2° quadrangle will be compiled from published sources. Geologic cross sections showing inferred subsurface structural and stratigraphic geometry will be prepared. This activity is estimated to be 50 percent complete. The duration of the future work is estimated to be four years.

Methods and technical procedures

The methods and procedures for Activity 8.3.1.17.4.12.1 are given in the following table.

Method	Technical procedure Number	Technical procedure Title	Technical procedure Date
	(NWM-USGS-)		
Regional gravity synthesis	GPP-01,R0	Gravity measurement and data reduction	14 Jan 85
Regional magnetic synthesis	GP-01,R0	Geologic mapping	1 Mar 83
	TBD[a]	Magnetic measurements and data interpretation	TBD
Beatty 1:100,000 geologic synthesis	GP-01,R0	Geologic mapping	1 Mar 83
	GP-03,R0	Stratigraphic studies	1 Mar 83
	GP-04,R0	Structural studies	1 Mar 83
NTS 1:100,000 geologic synthesis	TBD	NTS 1:100,000 geologic synthesis	TBD
Synthesis - Quaternary wrench faulting in Walker Lane	GP-01,R0	Geologic mapping	1 Mar 83
	GP-04,R0	Structural studies	1 Mar 83

Method	Technical procedure Number	Title	Date
	(NWM-USGS-)		
Synthesis - detachment faults at NTS and vicinity	GP-01,R0	Geologic mapping	1 Mar 83
	GP-04,R0	Structural studies	1 Mar 83
Synthesis - Quaternary faulting at NTS and vicinity	GP-01,R0	Geologic mapping	1 Mar 83
	GP-04,R0	Structural studies	1 Mar 83
Synthesis - left-lateral strike-slip faults	GP-01,R0	Geologic mapping	1 Mar 83
	GP-04,R0	Structural studies	1 Mar 83

[a]TBD = to be determined.

8.3.1.17.4.12.2 Activity: Evaluate tectonic models

Objectives

The objectives of this activity are to

1. Formulate a range of tectonic models that relate the nature and estimated rates (including bounding values of those estimated rates) of Quaternary processes (volcanism, faulting, uplift and subsidence, lateral strain, and possibly folding) of potential significance to design and performance of the repository at Yucca Mountain.

2. Evaluate temporal changes in tectonic activity and resulting changes in fractures and other structural features of potential hydrologic significance at and in the vicinity of Yucca Mountain. Relate tectonic cycle, if it exists, to tectonic model(s).

3. Ensure that assumptions, inferences, and conclusions concerning tectonic processes that are important to design and performance of the repository are consistent with tectonic models applicable to the site.

4. Ensure that uncertainty in the data, assumptions, and inferences concerning rates and nature of those tectonic processes that are important to design or performance of the repository is adequately reflected in conclusions about those processes.

Parameters

The parameters for this activity are recurrence rates, strain rates, ambient stress, boundary conditions, structural geology of the site area, structural geology of the area within 100 km of Yucca Mountain, location and geometry of Quaternary faults, fracture distributions and age of fracture-filling minerals in the site area, and age and location of basaltic volcanism within 25 km of Yucca Mountain.

Description

The various tectonic hypotheses that are potentially applicable to the neotectonics of Yucca Mountain include as end members the following: (1) the wrench fault hypothesis, which explains deformation at Yucca Mountain as resulting from right-lateral transform movement on an intracontinental shear zone (the Walker Lane) passing through or near the site area; (2) the detachment fault hypothesis, which explains deformation at Yucca Mountain as resulting from extension on subsurface detachment faults and the set of listric normal faults which merge with the detachment faults; and (3) the basin-range normal fault hypothesis, which explains the Quaternary normal faults at Yucca Mountain as planar rotational faults extending to great depth. Quaternary volcanism in and south of Crater Flat could be attributed to (1) volcanism along a north-northeast-trending incipient rift zone (Death Valley-Pancake Range zone) or (2) volcanism at zones of extension developed between en echelon segments of northwest-trending wrench faults (leaky transform hypothesis). These and other potentially applicable tectonic hypotheses are listed in Tables 8.3.1.17-7 and -8. Each of these hypotheses, as stated, is consistent with some data and inconsistent with other data. There probably are, however, a set of models that include various elements of these hypotheses and that satisfactorily explain all or most of the data.

In this activity, data pertaining to tectonic cycles, including timing and localization of faulting, fracturing, and basaltic volcanism will be synthesized. Alternative conceptual tectonic models will be formulated, and the degree to which those models qualitatively and quantitatively incorporate and reconcile information on the parameters just listed will be evaluated. That information includes that gathered by other studies in tectonics and site geology. The tectonic models are expected to evolve as additional data are gathered, and hence this activity is expected to continue for the duration of the site characterization process. Preliminary models will be produced for use during site characterization.

Methods and technical procedures

The methods and procedures for Activity 8.3.1.17.4.12.2 are given in the following table.

Method	Technical procedure Number	Title	Date
	(NWM-USGS-)		
Tectonic model evaluation	TBD[a]	Tectonic model evaluation	TBD

[a]TBD = to be determined.

8.3.1.17.4.12.3 Activity: Evaluate tectonic disruption sequences

Objectives

The objective of this activity is to evaluate disruption sequences involving faulting, folding, uplift and subsidence, and volcanism that are of potential significance to design or performance of the repository.

Parameters

The parameters for this activity are tectonic models, processes, and rates; probabilities of tectonic events; and physical consequences at the proposed repository site.

Description

The purpose of this activity is to evaluate disruption sequences involving faulting, folding, uplift and subsidence, and volcanism, acting either individually or in concert. Where possible, the probability of each sequence actually occurring in the future will be estimated and the range of geologic consequences described.

Methods and technical procedures

The methods and procedures for Activity 8.3.1.17.4.12.3 are given in the following table.

Method	Technical procedure		
	Number	Title	Date
Tectonic process scenario analysis, Nevada Test Site, and vicinity	TBD[a]	Synthesis	TBD

[a]TBD = to be determined.

8.3.1.17.4.13 Application of results

The information derived from the studies and activities of the plans described previously will be used in the following issues, information needs, and investigations of site characterization, repository design, and performance assessment:

Number	Subject
1.1.1	Site information needed to calculate the releases of radionuclides to the accessible environment (Section 8.3.5.13.1)
1.1.3	Representative release scenarios that address both anticipated and unanticipated conditions (Section 8.3.5.13.3)
1.5.1	Site information and design concepts needed to calculate the release rates from the engineered barrier system (Section 8.3.5.10.1)
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 (Section 8.3.5.12.1)
1.8	Site information needed to identify favorable and potentially adverse conditions at the site that may influence postclosure repository performance (Section 8.3.5.17)
1.11.1	Site characteristics needed for design (Section 8.3.2.2.1)
8.3.1.2.1	Regional hydrologic system
8.3.1.4.2	Geologic framework

Number	Subject
8.3.1.4.3	Three-dimensional rock characteristics model
8.3.1.6.3	Tectonic effects on erosion
8.3.1.8.1	Volcanic activity
8.3.1.8.2	Information required on rupture of waste packages due to tectonic events
8.3.1.8.3	Information required on changes in saturated and unsaturated zone hydrology due to tectonic events
8.3.1.8.4	Information required on changes in rock geochemical properties resulting from tectonic processes
4.4.1	Site and performance information needed for design (Section 8.3.2.5.1)
4.4.7	Potential impacts of tectonic activity on design (Section 8.3.2.5.7)
8.3.1.15.1	Stratigraphy and structure necessary to locate the underground facility
8.3.1.15.2	Spatial distribution of ambient stress and thermal conditions
8.3.1.17.1	Potential volcanic activity that could have an impact at the site
8.3.1.17.2	Potential fault movements at the site
8.3.1.17.3	Ground motion at the site from potential man-made or natural seismic events

8.3.1.17.5 Schedule for postclosure tectonics program

The preclosure tectonics program includes 4 investigations, which contain 20 studies. The schedule information for each study is summarized in Figure 8.3.1.17-14. This figure includes the study number and a brief description, as well as major events associated with each study. A major event, for purposes of these schedules, may represent the initiation or completion of an activity, completion or submittal of a report to the DOE, an important data feed, or a decision point. Solid lines on the schedule represent study durations and dashed lines show interfaces among studies as well as data transferred into or out of the preclosure tectonics program. The events shown on the schedule and their planned dates of completion are provided in Table 8.3.1.17-11.

Number	Subject
8.3.1.4.3	Three-dimensional rock characteristics model
8.3.1.6.3	Tectonic effects on erosion
8.3.1.8.1	Volcanic activity
8.3.1.8.2	Information required on rupture of waste packages due to tectonic events
8.3.1.8.3	Information required on changes in saturated and unsaturated zone hydrology due to tectonic events
8.3.1.8.4	Information required on changes in rock geochemical properties resulting from tectonic processes
4.4.1	Site and performance information needed for design (Section 8.3.2.5.1)
4.4.7	Potential impacts of tectonic activity on design (Section 8.3.2.5.7)
8.3.1.15.1	Stratigraphy and structure necessary to locate the underground facility
8.3.1.15.2	Spatial distribution of ambient stress and thermal conditions
8.3.1.17.1	Potential volcanic activity that could have an impact at the site
8.3.1.17.2	Potential fault movements at the site
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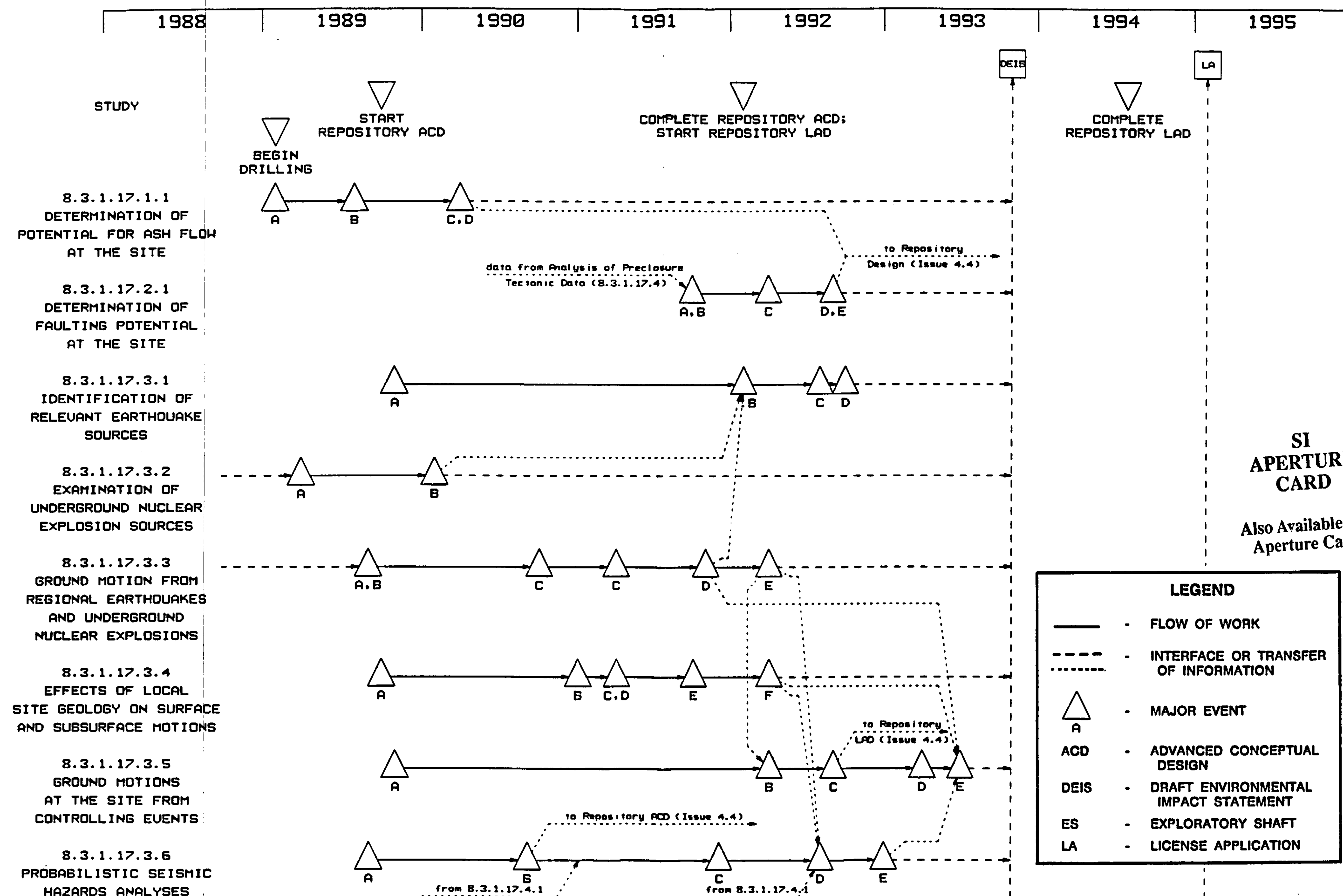

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Also Available On Aperture Card

Figure 8.3.1.17-14. Schedule information for studies in Site Program 8.3.1.17 (preclosure tectonics). See Table 8.3.1.17-9 for description of major events. This network is consistent with the Draft Mission Plan Amendment (DOE, 1988a) schedule. Revisions will be published in semiannual site characterization progress reports as new information becomes available. (page 1 of 3)

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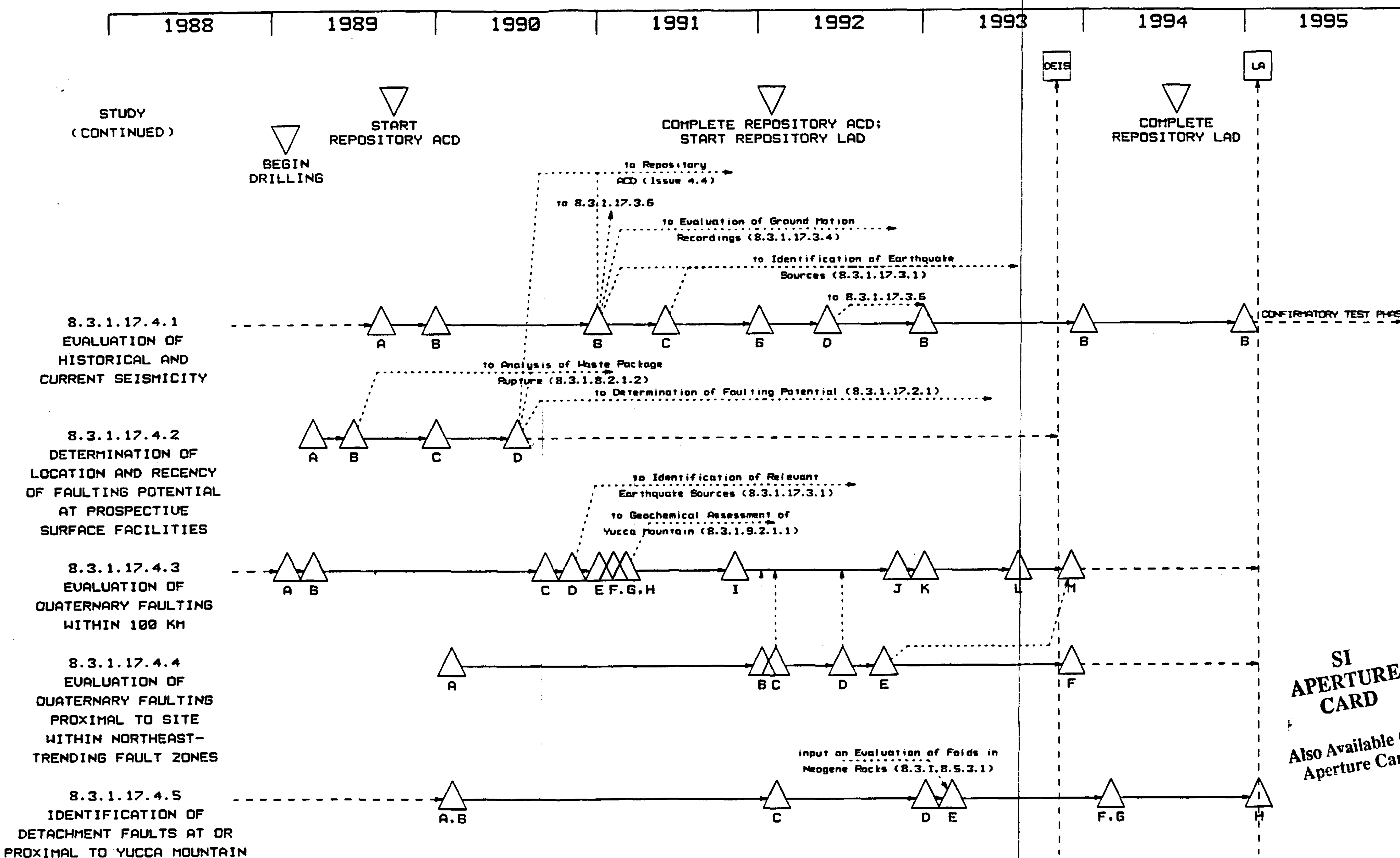

Figure 8.3.1.17-14. Schedule information for studies in Site Program 8.3.1.17 (preclosure tectonics). See Table 8.3.1.17-9 for description of major events. This network is consistent with the Draft Mission Plan Amendment (DOE, 1988a) schedule. Revisions will be published in semiannual site characterization progress reports as new information becomes available. (page 2 of 3)

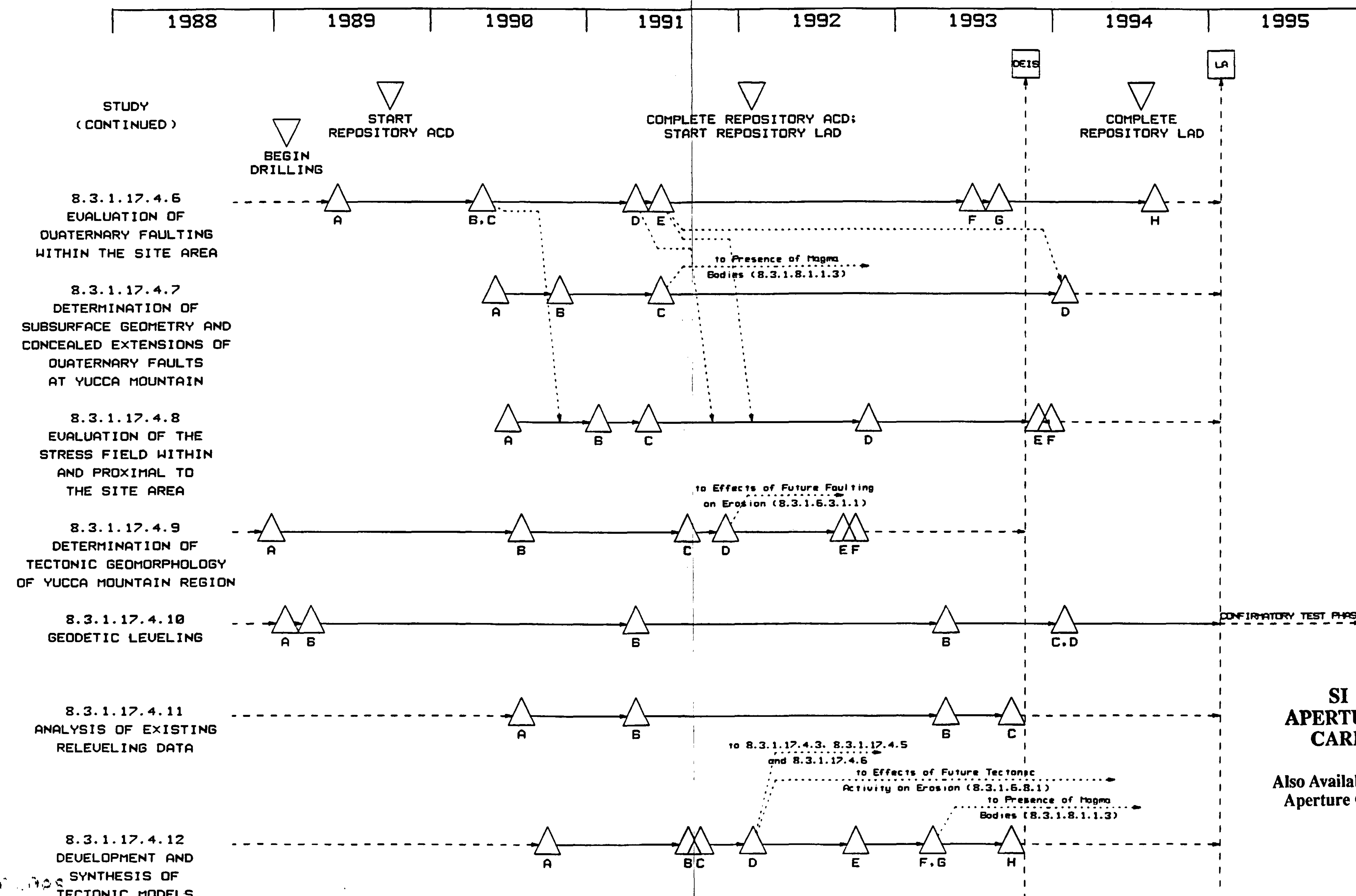

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Figure 8.3.1.17-14. Schedule information for studies in Site Program 8.3.1.17 (preclosure tectonics). See Table 8.3.1.17-9 for description of major events. This network is consistent with the Draft Mission Plan Amendment (DOE, 1988a) schedule. Revisions will be published in semiannual site characterization progress reports as new information becomes available. (page 3 of 3)

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Table 8.3.1.17-11. Major events and planned completion dates for studies in the preclosure tectonics program (page 1 of 15)

Study number	Brief description of study	Major event[a]	Event description	Date
8.3.1.17.1.1	Determination of the potential for ash flow at the site	A	Study plan approved	1/89
		B	Complete literature survey of Quaternary volcanic centers	7/89
		C	Draft report available to the U.S. Department of Energy (DOE) on potential ash-fall thickness at the site	3/90
		D	Draft report available to DOE on preclosure hazards of volcanism	3/90
8.3.1.17.2.1	Determination of the faulting potential at the site	A	Begin evaluation of faulting potential at surface facilities	9/91
		B	Begin evaluation of potential displacement on faults that intersect underground facilities	9/91
		C	Draft of preliminary report on the potential for faulting at surface facilities available to DOE	3/92

Study number	Brief description of study	Major event[a]	Event description	Date
8.3.1.17.2.1	Determination of the faulting potential at the site (continued)	D	Draft of final report on the potential for faulting at the surface facilities available to DOE	8/92
		E	Draft report available to DOE on the potential for displacement on faults that intersect underground facilities	8/92
8.3.1.17.3.1	Identification of relevant earthquake sources	A	Study plan approved	10/89
		B	Begin final identification of relevant earthquake sources	1/92
		C	Relevant earthquake sources identified	7/92
		D	Complete earthquake magnitude estimates	9/92
8.3.1.17.3.2 (ongoing)	Examination of underground nuclear explosion sources	A	Study plan approved	3/89
		B	Draft report available to DOE on the potential maximum yields and locations of underground nuclear explosions (UNEs)	1/90

Table 8.3.1.17-11. Major events and planned completion dates for studies in the preclosure tectonics program (page 3 of 15)

Study number	Brief description of study	Major event[a]	Event description	Date
8.3.1.17.3.3 (ongoing)	Evaluation of ground motion from regional earthquakes and underground nuclear explosions	A	Study plan approved	8/89
		B	Start empirical model selection	8/89
		C	Interim reports on preparation of final UNE ground motion models available to DOE	9/90 3/91
		D	Draft of final report on UNE ground-motion models available to DOE	10/91
		E	Select final ground motion model	3/92
8.3.1.17.3.4	Evaluation of the effects of local site geology on surface and subsurface motions	A	Study plan approved	9/89
		B	Begin evaluation of ground-motion recordings	12/90
		C	Draft of preliminary report on the effects of local site geology on surface and subsurface ground motion available to DOE	3/91
		D	Begin preparation of calibrated site effects model	3/91

Table 8.3.1.17-11. Major events and planned completion dates for studies in the preclosure tectonics program (page 4 of 15)

Study number	Brief description of study	Major event[a]	Event description	Date
8.3.1.17.3.4	Evaluation of the effects of local site geology on surface and subsurface motions (continued)	E	Draft report available to DOE on the effects of local geology on ground motion	9/91
		F	Complete calibrated site effects model	3/92
8.3.1.17.3.5	Evaluation of ground motions at the site from controlling events	A	Study plan approved	10/89
		B	Begin evaluation of preliminary design values	3/92
		C	Preliminary design values available	8/92
		D	Identify controlling seismic events	3/93
		E	Draft report available to DOE on ground motion design basis and time histories	6/93
8.3.1.17.3.6	Probabilistic seismic hazards analyses	A	Study plan approved	8/89
		B	Draft of preliminary report on the probabilistic seismic hazards assessment available to DOE	8/90

Table 8.3.1.17-11. Major events and planned completion dates for studies in the preclosure tectonics program (page 5 of 15)

Study number	Brief description of study	Major event[a]	Event description	Date
8.3.1.17.3.6	Probabilistic seismic hazards analyses (continued)	C	Complete earthquake source evaluation	11/91
		D	Complete methodology for probabilistic ground motion assessment	7/92
		E	Draft report available to DOE on the probabilistic ground motion assessment	12/92
8.3.1.17.4.1 (ongoing)	Evaluation of historical and current seismicity	A	Study plan approved	8/89
		B	Yearly reports on current seismicity data available to DOE; seismic network monitoring will continue as performance confirmation	12/89 12/90 12/91 12/92 12/93 12/94
		C	Complete compilation of historical earthquake record	5/91
		D	Draft report available to DOE on evaluation of the potential for induced seismicity at and near the site	5/92

Table 8.3.1.17-11. Major events and planned completion dates for studies in the preclosure tectonics program (page 6 of 15)

Study number	Brief description of study	Major event[a]	Event description	Date
8.3.1.17.4.2	Determination of the location and recency of faulting potential at prospective surface facilities	A	Study plan approved	3/89
		B	Select trench location	6/89
		C	Trench logging completed	12/89
		D	Draft report available to DOE on the location and recency of faulting near prospective surface facilities	6/90
8.3.1.17.4.3 (ongoing)	Evaluation of Quaternary faulting within 100 km of Yucca Mountain	A	Interim report on seismic reflection field studies available to DOE	1/89
		B	Study plan approved	3/89
		C	Interim report available to DOE on seismic refraction	8/90
		D	Draft report available to DOE on the Bare Mountain fault zone	10/90
		E	Draft map/report available to DOE on photogeologic Quaternary scarps	12/90

Table 8.3.1.17-11. Major events and planned completion dates for studies in the preclosure tectonics program (page 7 of 15)

Study number	Brief description of study	Major event[a]	Event description	Date
8.3.1.17.4.3 (ongoing)	Evaluation of Quaternary faulting within 100 km of Yucca Mountain (continued)	F	Draft of final report on completion of seismic refraction field studies available to DOE	1/91
		G	Draft report available to DOE on the evaluation of the Cedar Mountain earthquake of 1932 and its bearing on wrench tectonics of the Walker Lane within 100 km of the site	2/91
		H	Draft report available to DOE on structural domains, NTS and vicinity, from Thematic Mapper-V	2/91
		I	Draft map/report available to DOE on conductivity structure, NTS and vicinity	10/91
		J	Begin synthesizing data on deformation in the Walker Lane fault zone	10/92
		K	Draft report available to DOE on trenched scarps within 100 km of Yucca Mountain	12/92

Table 8.3.1.17-11. Major events and planned completion dates for studies in the preclosure tectonics program (page 8 of 15)

Study number	Brief description of study	Major event[a]	Event description	Date
8.3.1.17.4.3	Evaluation of Quaternary faulting within 100 km of Yucca Mountain (continued)	L	Draft report available to DOE on Quaternary faulting within 100 km of Yucca Mountain	7/93
		M	Draft report synthesizing Quaternary deformation in the Walker Lane fault zone available to DOE	11/93
8.3.1.17.4.4	Evaluation of Quaternary faulting proximal to the site within northeast-trending fault zones	A	Study plan approved	1/90
		B	Draft report available to DOE on the evaluation of the Mine Mountain fault system	12/91
		C	Draft report available to DOE on faulting at Rock Valley	1/92
		D	Draft report available to DOE on the evaluation of the Stage Coach Road fault zone	6/92
		E	Draft report available to DOE on the evaluation of the Cane Springs fault	9/92
		F	Draft report available to DOE on left lateral faulting in the site vicinity	11/93

Table 8.3.1.17-11. Major events and planned completion dates for studies in the preclosure tectonics program (page 9 of 15)

Study number	Brief description of study	Major event[a]	Event description	Date
8.3.1.17.4.5 (ongoing)	Identification of detachment faults at or proximal to Yucca Mountain	A	Draft report/map available to DOE on the Calico Hills area	1/90
		B	Study plan approved	1/90
		C	Draft report available to DOE on the evaluation of megabreccia related to detachment faulting	1/92
		D	Map of Bare Mountain NW available to DOE	12/92
		E	Draft of interpretive report on Miocene folding available to DOE	2/93
		F	Draft report available to DOE on the stratigraphic and structural analysis of the Specter Range and Camp Desert Rock areas	2/94
		G	Report available to DOE on K-Ar dating of the North Amargosa complex	2/94
		H	Report available to DOE on detachment faults at or proximal to Yucca Mountain	1/95

Table 8.3.1.17-11. Major events and planned completion dates for studies in the preclosure tectonics program (page 10 of 15)

Study number	Brief description of study	Major event[a]	Event description	Date
8.3.1.17.4.6 (ongoing)	Evaluation of Quaternary faulting within the site area	A	Study plan approved	5/89
		B	Draft interpretive report available to DOE on the Bow Ridge fault	4/90
		C	Draft report available to DOE on the Windy Wash-Fatigue Wash fault	4/90
		D	Draft report available to DOE on the Paintbrush Canyon fault zone	4/91
		E	Complete Ghost Dance and Solitario Canyon fault studies	6/91
		F	Draft of final report on Quaternary faulting within the site area available to DOE	6/93
		G	Begin synthesis of data on Quaternary north-trending faults	8/93
		H	Report available to DOE on the synthesis of data on Quaternary north-trending faults	8/94

Table 8.3.1.17-11. Major events and planned completion dates for studies in the preclosure tectonics program (page 11 of 15)

Study number	Brief description of study	Major event[a]	Event description	Date
8.3.1.17.4.7	Determination of subsurface geometry and concealed extensions of Quaternary faults at Yucca Mountain	A	Study plan approved	5/90
		B	Decision on the application of methods to be used in determining the subsurface geometry of Quaternary faults	10/90
		C	Draft reports available to DOE on the results of gravity and aeromagnetic surveys of the site area	6/91 9/93
		D	Report available to DOE on seismic reflection data in site area	1/94
8.3.1.17.4.8	Evaluation of the stress field within and proximal to the site area	A	Study plan approved	6/90
		B	Complete geologic corehole drilling (USW G-7)	1/91
		C	Complete shallow in situ stress hole drilling	5/91
		D	Draft report available to DOE on the evaluation of theoretical stress distributions associated with potential tectonic settings	10/92

Table 8.3.1.17-11. Major events and planned completion dates for studies in the preclosure tectonics program (page 12 of 15)

Study number	Brief description of study	Major event[a]	Event description	Date
8.3.1.17.4.8	Evaluation of the stress field within and proximal to the site area (continued)	E	Draft report available to DOE on the stress field within the site area	11/93
		F	Draft report available to DOE on the evaluation of data on paleostress orientation at and proximal to the site	12/93
8.3.1.17.4.9 (ongoing)	Determination of the tectonic geomorphology of the Yucca Mountain region	A	Draft of interpretive report on uplift and subsidence of the Yucca Mountain region	12/88
		B	Study plan approved	7/90
		C	Draft report available to DOE on the evaluation of the impact of future uplift, subsidence, and faulting on erosion	8/91
		D	Draft report available to DOE on Quaternary faulting within 100 km of Yucca Mountain based on morphometric and morphologic analysis	11/91
		E	Draft report/map on the geomorphology of Yucca Mountain available to DOE	8/92

Table 8.3.1.17-11. Major events and planned completion dates for studies in the preclosure tectonics program (page 13 of 15)

Study number	Brief description of study	Major event[a]	Event description	Date
8.3.1.17.4.9	Determination of the tectonic geomorphology of the Yucca Mountain region (continued)	F	Draft report available to DOE on the age and extent of tectonically stable areas at and near Yucca Mountain	9/92
8.3.1.17.4.10 (ongoing)	Geodetic leveling	A	Study plan approved	1/89
		B	Complete releveling of networks and survey nets	3/89 4/91 4/93
		C	Report available to DOE on the analysis of geodetic leveling at Yucca Mountain; continue Yucca Mountain base station network monitoring as performance confirmation	1/94
		D	Report available to DOE on the GPS survey of selected base stations at Yucca Mountain and vicinity	1/94
8.3.1.17.4.11 (ongoing)	Analysis of existing releveling data	A	Study plan approved	7/90
		B	Resurvey network	4/91 4/93

Table 8.3.1.17-11. Major events and planned completion dates for studies in the preclosure tectonics program (page 14 of 15)

Study number	Brief description of study	Major event[a]	Event description	Date
8.3.1.17.4.11	Analysis of existing releveling data (continued)	C	Draft report available to DOE on historical and current lateral crustal movement	9/93
8.3.1.17.4.12 (ongoing)	Development and synthesis of tectonic models	A	Study plan approved	9/90
		B	Beatty 1:100,000 geologic map available to DOE	8/91
		C	Begin tectonic modeling	9/91
		D	Beatty 1:100,000 fault map available to DOE	1/92
		E	Preliminary regional tectonic model available to DOE	9/92
		F	Draft report available to DOE on the synthesis of aero-matic data, Beatty 1:100,000 Quadrangle	11/92
		G	Draft report available to DOE on the synthesis of gravity data, Beatty 1:100,000 Quadrangle	2/93

Table 8.3.1.17-11. Major events and planned completion dates for studies in the preclosure tectonics program (page 15 of 15)

Study number	Brief description of study	Major event[a]	Event description	Date
8.3.1.17.4.12	Development and synthesis of tectonic models (continued)	H	Draft of interpretive report on tectonic scenarios available to DOE	9/93

[a]The letters in this column key major events shown in Figure 8.3.1.17-14.

The study-level schedules, in combination with information provided in the logic diagrams for this program (Figures 8.3.1.17-1, -3, -4 and -5), are intended to provide the reader with a basic understanding of the relationships between major elements of the site, performance, and design programs. The information provided in Table 8.3.1.17-11 and Figure 8.3.1.17-14, however, should be viewed as a snapshot in time.

The overall program schedule presented here is consistent with the Draft Mission Plan Amendment (DOE, 1988a). The site characterization program will undergo a series of refinements following issuance of the statutory SCP. Refinements will consider factors both internal and external to the site characterization program, such as changes to the quality assurance program. Such refinements are to be considered in ongoing planning efforts, and changes that are implemented will be reflected in the semiannual progress reports. Additional schedule information for activities within site program studies are to be provided in SCP support documents. Summary schedule information for the preclosure tectonics program can be found in Section 8.5.1.1 and 8.5.6.

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Accession Number: HQO.881201.0002