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Nuclear Waste Policy Act
(Section 113)

Consultation Draft

Site Characterization Plan
Overview

Yucca Mountain Site, Nevada Research and Development Area, Nevada

January 1988

U.S. Department of Energy
Office of Civilian Radioactive Waste Management
Washington, DC 20585

DISCLAIMER

FOREWORD

As part of the process for siting the nation's first geologic repository for radioactive waste, the Department of Energy (DOE) is preparing a site characterization plan for the Yucca Mountain site in southern Nevada. As a step in the preparation of that plan, the DOE has provided a consultation draft of the plan to the State of Nevada and the U.S. Nuclear Regulatory Commission for information and review. The consultation draft of the site characterization plan is a lengthy document that describes in considerable detail the program that will be conducted to characterize the geologic, hydrologic, and other conditions relevant to the suitability of the site for a repository.

The Yucca Mountain site is one of three sites that the DOE currently plans to characterize; the other sites are the Deaf Smith County site in Texas and the Hanford site in the State of Washington. After site characterization has been completed and its results evaluated, the DOE will identify from among the three characterized sites the site that is preferred for the repository.

The overview presented here consists of brief summaries of important topics covered in the consultation draft of the site-characterization plan; it is not a substitute for the site-characterization plan. The arrangement of the overview is similar to that of the plan itself, with brief descriptions of the disposal system--the site, the repository, and the waste package--preceding the discussion of the characterization program to be carried out at the Yucca Mountain site. It is intended primarily for the management staff of organizations involved in the DOE's repository program--staff who might wish to understand the general scope of the site-characterization program, the activities to be conducted, and the facilities to be constructed rather than the technical details of site characterization.

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1. INTRODUCTION

The Yucca Mountain site is one of three candidate sites for the first geologic repository for radioactive waste.* On May 28, 1986, it was approved by the President for detailed study in a program of site characterization, which will be conducted by the Department of Energy (DOE). The purpose of this program is to obtain the information necessary to select a site for the repository and to obtain from the U.S. Nuclear Regulatory Commission (NRC) authorization to construct a repository. This necessary information describes the geologic, geoengineering, hydrologic, geochemical, climatological, and meteorological conditions at the site.

The DOE's plans for conducting the site-characterization program at the Yucca Mountain site are described in the consultation draft of the site characterization plan (SCP/CD); brief summaries of important topics covered in the SCP/CD are presented in this overview.

1.1 THE SITING AND THE LICENSING OF A REPOSITORY

The process of siting a repository, as specified by the Nuclear Waste Policy Act of 1982 (the Act), consists of several steps.** For the first repository, several of the steps have been completed, the most recent being the following:

1. The Secretary of Energy has nominated five sites as suitable for characterization and has issued environmental assessments to accompany each nomination.

2. The Secretary has recommended three of the nominated sites for characterization as candidate sites for the first repository, and the President has approved the recommendation. The three sites are the Yucca Mountain site in tuff in the State of Nevada, the Deaf Smith County site in salt in the State of Texas, and the Hanford site in basalt in the State of Washington.

3. The Secretary has made the preliminary determination that the recommended candidate sites are suitable for development as repositories.

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*The radioactive waste emplaced in the repository will consist of spent fuel from commercial nuclear reactors, high-level waste from defense activities, and a small quantity of commercial high-level waste from the West Valley Demonstration Project. For convenience, the term "radioactive waste" or simply "waste" is often used in this overview to mean spent nuclear fuel or high-level waste.

**The process specified by the Act may be changed by legislation pending before the Congress.

When site characterization is completed, the Secretary of Energy is to recommend to the President one of the three sites for the development of the first repository. This recommendation is to be accompanied by an environmental impact statement. The President is then to submit the recommendation to the Congress.

After the President's recommendation, the affected State may submit, within 60 days, a notice of disapproval to the Congress. This disapproval prevents the use of the site for a repository unless the Congress passes a joint resolution of repository-siting approval within the next 90 days of continuous session. If no notice of disapproval is submitted or if a notice is overturned by the joint resolution, the site designation becomes effective. If the notice is not overturned, the disapproval stands, and the President must recommend another site not later than 1 year after the disapproval.

When the site designation becomes effective, the DOE will submit to the NRC an application for authorization to construct the repository. The Act requires that this application be submitted not later than 90 days after the effective date of the site designation. The application will contain a description of the site, a description of the design of the repository and the waste package, and the results of an assessment performed to demonstrate that the disposal system--that is, the site and the natural barriers at the site, the repository, and the waste package--complies with the applicable regulations. The NRC will review the application and decide whether to authorize the construction of the repository. When an authorization has been received from the NRC, construction will begin.

When the repository is ready for operation, the DOE will submit an updated license application to the NRC to receive and possess waste at the site. When this license has been received, the DOE will begin to receive and emplace waste in the repository.

1.2 REGULATIONS FOR GEOLOGIC DISPOSAL

A repository for radioactive waste must meet some unprecedented requirements. It will have to keep highly radioactive material safely separated from the environment for very long periods of time. And it must require no human maintenance, because future generations cannot be expected to take on the burden of caring for the waste through times longer than recorded history. These requirements can be met in a geologic repository by emplacing the waste deep underground in rock that has been isolated from the sur ace environment for millions of years. The waste emplaced in such rock can reasonably be expected to remain isolated for as long as necessary.

To provide the required containment and isolation for the waste, the DOE will rely on a disposal system that will provide multiple barriers, both natural and engineered, to the transport of radionuclides. The natural barriers will consist of various geologic, hydrologic, and geochemical conditions present at the site; the engineered barriers will consist of the waste package, the seals for shafts and boreholes, and the underground facility.

Recognizing the hazard posed by the radioactive waste, the Congress directed in the Act that regulations designed to protect the health and safety of the public be promulgated by the U.S. Environmental Protection Agency (EPA) and the NRC and that guidelines for siting repositories be developed by the DOE. The regulations promulgated by these agencies are briefly discussed here, and, for the convenience of the reader, excerpts are reprinted in Appendix A.

Primary standards and technical criteria

The primary standards for geologic repositories are concerned with protecting the health and safety of the public from the hazards of the waste to be emplaced in the repository; they have been promulgated by the EPA in 40 CFR Part 191. The key provisions of these standards are (1) a limit on the amount of radioactivity that may enter the environment for 10,000 years after disposal, (2) limits on the radiation dose that can be delivered to any member of the public for 1000 years after disposal, and (3) requirements for the protection of ground water.*

The EPA standards are implemented and enforced by the NRC regulations in 10 CFR Part 60. These regulations consist of (1) procedures for the licensing of geologic repositories and (2) technical criteria to be used in the evaluation of license applications under those procedural rules. The procedural portion of 10 CFR Part 60 provides requirements for a site-characterization program and the associated site characterization plan. In addition to requiring that the EPA standards be met, the technical criteria of 10 CFR Part 60 provide a number of additional requirements: the NRC radiation-protection standards contained in 10 CFR Part 20, design criteria for the surface and underground facility of the repository, and three separate performance objectives for each of the three subsystems of the geologic disposal system: a minimum lifetime for the waste package, a limit on the release rate from the engineered barriers of the repository, and, for the natural system at the site, a minimum pre-waste-emplacement time of ground-water travel from the disturbed zone to the accessible environment.

DOE siting guidelines

As required by the Act, the DOE has developed guidelines for nominating and recommending sites for characterization and selecting sites for the development of repositories. Promulgated as 10 CFR Part 960, they are referred to here as the "siting guidelines." The siting guidelines are based on both the EPA and the NRC regulations.

The siting guidelines are divided into three groups: implementation, postclosure, and preclosure. The implementation guidelines are not directly used in the evaluation of sites; their purpose is to specify how the postclosure and preclosure guidelines are to be applied. The postclosure guide-

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*A decision on July 17, 1987, by the U.S. Court of Appeals for the First Circuit has vacated and remanded to the EPA for further proceedings the postclosure standards (Subpart B) in 40 CFR Part 191. (See also the footnote in Section 4.2 of this overview.)

lines govern the siting considerations that deal with the long-term performance of a repository--that is, performance after waste emplacement and repository closure. The preclosure guidelines govern the siting considerations that deal with the siting, construction, operation, and closure of the repository.

Both the postclosure and the preclosure guidelines are divided into system and technical guidelines. The postclosure system guideline defines general requirements for the performance of the total repository system after closure. The postclosure technical guidelines specify requirements for one or more elements of the system--the physical properties and physical phenomena at the site. The preclosure system guidelines address three different systems involving (1) preclosure radiological safety; (2) environment, socioeconomics, and transportation; and (3) the ease and cost of repository siting, construction, operation, and closure. Each preclosure system guideline is associated with a set of technical guidelines specifying requirements on various components of the system (e.g., population density and distribution, meteorology, surface characteristics).

Both the postclosure and the preclosure technical guidelines specify conditions that would disqualify or qualify sites, and they also specify conditions that would be considered favorable or potentially adverse.

Any disqualifying condition constitutes sufficient evidence to conclude, without further consideration, that the site is disqualified, and the presence or absence of almost all of these conditions may be verifiable without extensive data gathering or complex analysis. In the case of the qualifying conditions, on the other hand, no single condition is sufficient to qualify a site. In order to be qualified, a site must meet all of the qualifying conditions, and failure to meet any one of these conditions will disqualify the site. Failure to meet a qualifying condition can usually be determined only after site characterization or the concurrent investigations of environmental and socioeconomic conditions. The favorable and potentially adverse conditions are intended to be used primarily in the screening phase of site selection, during the search for potentially acceptable sites.

Most of the evaluations in the final environmental assessment led to preliminary findings, which are defined as lower-level findings in Appendix III of the siting guidelines. Final evaluations will be performed after site characterization is completed. These final evaluations will be used to make the higher-level findings necessary to demonstrate compliance with the system guidelines and each technical guideline; they will also be used in the comparative evaluation that will be performed to identify which of the characterized sites is to be recommended for the development of a repository.

1.3 THE SITE CHARACTERIZATION PLAN

Purpose and objectives

The basic purpose of the SCP is threefold: (1) to describe the site, the preliminary designs of the repository and the waste package, and the waste-emplacement environment in sufficient detail so that the basis for the site-characterization program can be understood; (2) to identify the issues to be resolved during site characterization, to identify the information needed to resolve the issues, and to present the strategy for resolving the issues; and (3) to describe general plans for the work needed to resolve outstanding issues. In this context, "issues" are defined as questions related to the performance of the repository system that must be resolved to demonstrate compliance with the applicable Federal regulations.

The SCP will be issued before the construction of exploratory shafts, and thus the NRC, the State of Nevada, and the public will be able to comment on the site-characterization program at an early phase of the program. This early review of the SCP will allow the DOE to make any program adjustments that may be necessary to accommodate the comments. This interactive process will continue throughout the program and will be documented in periodic progress reports, which are mentioned on the next page.

Contents and organization

Both the Act and the NRC's regulations in 10 CFR Part 60 specify requirements for the content of the SCP. In preparing the SCP/CD, the DOE has met both sets of requirements. (These requirements are given in the introduction to the SCP/CD, which also explains how the requirements are met.) The DOE has followed the guidance given by the NRC in Regulatory Guide 4.17 for the format and the organization of the plan. Furthermore, as explained in Section 4.2, the preparation of the SCP/CD was guided by an issue-resolution strategy whose objective was to ensure that site characterization would provide all the information needed for site selection and a construction authorization from the NRC.

The SCP/CD is divided into two parts: Part A, which provides descriptions of the site and of the conceptual designs of the repository and the waste package, and Part B, which presents the DOE's plans for the site-characterization program.

Part A consists of seven chapters. Chapters 1 through 5 discuss the available information on the natural conditions at the site. In particular, Chapter 1 presents the available data on the geologic conditions of the site and the region; Chapter 2 discusses the geoengineering properties of the rock units at the site; Chapters 3 and 4 discuss the hydrologic and geochemical conditions, respectively; and Chapter 5 is concerned with climate and meteorology. The uncertainties in the data presented in these chapters were used in identifying the information needed to resolve the issues and in developing the plans presented in Part B. Each chapter concludes with a summary that links the data and analyses presented in the chapter with the strategies and plans presented in Part B.

The last two chapters in Part A are concerned with the conceptual design of the repository (Chapter 6) and the waste package (Chapter 7). Like the preceding chapters, Chapters 6 and 7 conclude with a summary that links the design of the repository and the waste package to Part B by summarizing design issues and related information needs.

Part B, which consists of one large chapter (Chapter 8), describes the site-characterization program and is thus the most important part of the SCP/CD. It begins by presenting, in Section 8.0, the top-level strategy for determining that the repository will perform satisfactorily and then, in Section 8.1, discusses the rationale for the program, the site-specific hierarchy of issues that must be resolved during site characterization, and the general issue-resolution strategy that the DOE has adopted. Section 8.2 presents the site-specific issues hierarchy and a summary of the strategy for resolving each issue. Detailed descriptions of the issue-resolution strategies are given in Section 8.3, which also discusses the investigations planned for the site, the repository, the seal system, the waste package, and the assessment of repository performance. Also included in Chapter 8 are discussions of the activities that will be carried out during site characterization; schedules; quality assurance; and the decommissioning of the facilities used for characterization if Yucca Mountain is not selected as the site for a repository.

Periodic progress reports

To report the results of site characterization at Yucca Mountain, the DOE will issue progress reports, as required by the Act. These reports will also explain any changes that may be made in the test program as information is collected and evaluated and comments from the State of Nevada and the NRC are received. They will be submitted every 6 months to the NRC as well as the Governor and the legislature of the State of Nevada; they will also be made available to the public.

1.4 THE SCP/CD OVERVIEW

This overview of the SCP/CD is structured somewhat differently from the SCP/CD itself. After this introduction, Chapter 2 briefly describes the Yucca Mountain site, including a history of the process by which the site was selected for characterization and the characteristics that are pertinent to a geologic repository, as determined by investigations performed to date. Chapter 3 then summarizes the current design of the repository and the waste package for the site. Chapter 4 explains the site-characterization program. It begins by discussing the top-level strategy for determining that the repository will perform satisfactorily. Next it discusses the hierarchy of issues that must be addressed by the site-characterization program and summarizes the strategy for resolving the issues. Chapter 4 then briefly describes the investigations, dictated by these strategies, that will be conducted to obtain the needed information as well as the programs in which this information will be used to refine the design of the repository, the seals system, and the waste package and to assess the performance of the repository. Chapter 5 summarizes the various activities that will be carried out at the Yucca Mountain site during characterization, discusses the facilities that will be constructed for that purpose, and describes how these facilities will be decommissioned if the Yucca Mountain site is not selected for the development of a repository.

Two appendixes are included in this overview. Appendix A presents excerpts from the regulations governing repositories--namely, the environmental standards from 40 CFR Part 191, the technical criteria from 10 CFR Part 60, and the preclosure and postclosure siting guidelines from 10 CFR Part 960. Appendix B presents the issues and information needs for the Yucca Mountain site.

2. THE YUCCA MOUNTAIN SITE

This section presents a brief description of the Yucca Mountain site--its location, the host rock that would be used for the repository, and the features that are pertinent to the performance of a repository. Also included is a brief discussion of how Yucca Mountain was selected for characterization as a candidate site for a repository.

2.1 GENERAL DESCRIPTION

The Yucca Mountain site is in southern Nevada, about 100 miles by road northwest of Las Vegas (Figure 2-1); it is surrounded by Nye County. The site is on three adjacent parcels of land owned by the U.S. Government. Most of the site is on the Nellis Air Force Range; a smaller portion is part of the Nevada Test Site and is managed by the DOE; the remainder is managed by the Bureau of Land Management.

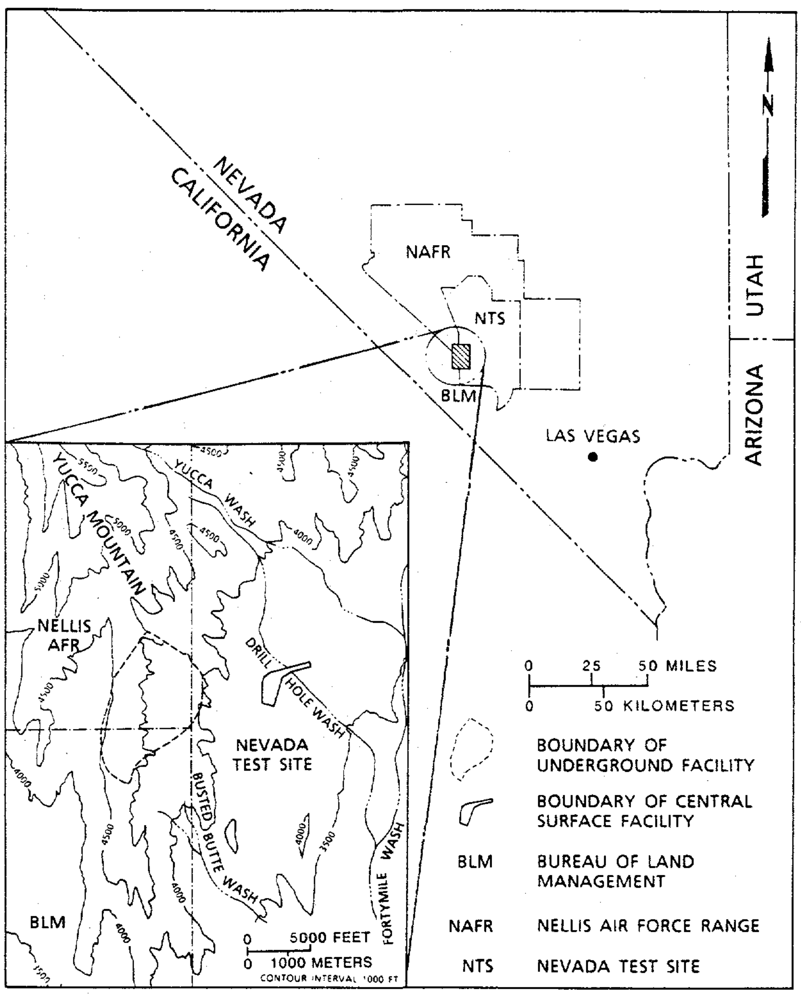

Figure 2-1. Location of the Yucca Mountain site in southern Nevada.

The site lies in the southern part of the Great Basin subprovince of the Basin and Range physiographic province--an arid region with linear mountain ranges and intervening valleys, very little rainfall, sparse vegetation, and a sparse population. Northern Yucca Mountain is about 5000 feet above sea level, more than 1200 feet above the western edge of Jackass Flats to the east, and more than 1000 feet above the eastern edge of Crater Flat to the west.

Yucca Mountain is part of a prominent group of north-trending, fault-block ridges that extend southward from Beatty Wash on the northwest to U.S. Highway 95 in the Amargosa Desert (Figure 2-2). The terrain at the site is controlled by high-angle normal faults and eastward-tilted volcanic rocks. Steep slopes (15 to 30 degrees) are found on the west-facing side of Yucca Mountain and along some of the valleys that cut into the more gently sloping (5 to 10 degrees) east side of Yucca Mountain. North of Yucca Mountain is the high terrain of Timber Mountain. To the west, along the west side of Crater Flat, alluvial fans extend from valleys that have been cut into Bare Mountain. Basalt cones and small lava flows are present on the surface of the southern half of Crater Flat.

Yucca Mountain is in the southern end of a large plateau known as the southern Nevada volcanic field, which was formed from eruptions occurring between about 8 and 16 million years. At Yucca Mountain, the volcanic rocks are at least 6500 feet thick. Their source was lava rising through volcanoes, causing explosive eruptions that produced ash flows and gases that escaped in the process. These explosions caused the molten material to rapidly expand and break up into particles of hot glass shards and crystals. These particles spread across the surrounding land. After coming to rest, the glass shards and crystals were subjected to various degrees of compaction and fusion, depending on the temperature and pressure. If the heat and the pressure were high enough, a rock known as "welded tuff" was formed. Eventually, the glassy shards tended to devitrify and develop crystals, but some of the rocks remained glassy and are called "vitric tuffs."

If a single ash flow cooled completely before being covered by another hot flow, it formed a single cooling unit with a densely welded, fractured center surrounded with less-welded parts above and below. The central parts of thick, densely welded zones may contain cavities called "lithophysae." The densely welded interior portions also generally contain closely spaced fractures. On the other hand, if several eruptions were closely spaced, complete cooling did not occur, and the result is a sequence called a "compound cooling unit." A glassy unit often occurs at the base or top of an ash flow where rapid cooling was caused by contact with the earth or the air.

Air-fall tuffs are commonly layered between the ash-flow tuffs. They came from ash that cooled in the air before falling to the ground. The resulting rock, known as bedded tuff, is nonwelded. It is more porous than welded tuff and generally contains fewer fractures.

At Yucca Mountain, the repository would be constructed in an ash-flow unit called the "Topopah Spring Member," which lies beneath a tuff unit called the Tiva Canyon Member. Both of these units are part of the Paintbrush Tuff. The tuff of these units erupted between about 12 and 13.2 million years ago. Lying below the Paintbrush Tuff are the tuffaceous beds of Calico Hills, the

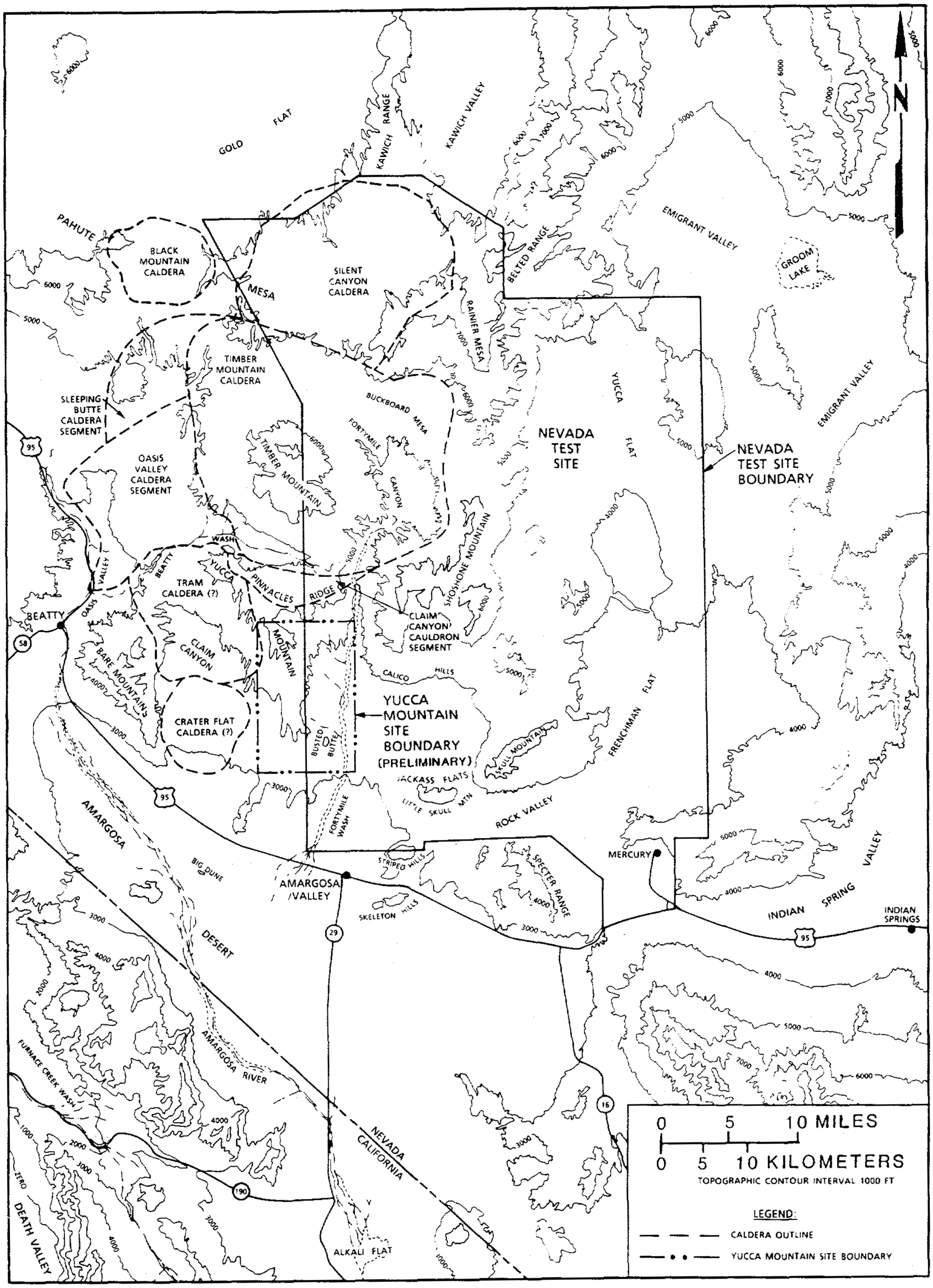

Figure 2-2. Physiographic features of Yucca Mountain and the surrounding region.

Crater Flat Tuff, and older tuffs. At Yucca Mountain, the Topopah Spring unit is about 1100 feet thick, thinning abruptly to the south and apparently also to the north, and it consists of a multiple-flow compound cooling unit. Most of the Topopah Spring unit is moderately to densely welded, devitrified tuff.

At Yucca Mountain, the water table is very deep, lying as much as 2500 feet below the land surface. Because rainfall is very low, there is little percolation of water downward through the unsaturated rocks above the water table.

2.2 THE HISTORY OF SITE SCREENING AND SELECTION

The screening process that led to the selection of Yucca Mountain for characterization started in 1977, when the U.S. Government decided to investigate the possibility of siting a repository at the Nevada Test Site (NTS). The NTS was selected for this investigation because it was used for nuclear operations, its land was withdrawn from public use, and the land was committed to long-term institutional control. Furthermore, the U.S. Geological Survey proposed that the NTS be considered for a number of geologic reasons, including the following:

- In southern Nevada, ground water does not discharge into rivers that flow to major bodies of surface water.
- Many of the rocks at the NTS have geochemical characteristics that are favorable for waste isolation (i.e., they would retard the migration of radionuclides).
- The paths of ground-water flow between potential sites for a repository and the points of ground-water discharge are long.
- Because the region is arid, the rate at which ground water is recharged is very low and therefore the amount of moving ground water is also very low, especially in the unsaturated rocks.

To be compatible with weapons testing at the NTS, site screening was eventually limited to the southwestern portion of the NTS and the adjacent land. This area was later named the Nevada Research and Development Area (NRDA), and three locations in this area were identified as the most attractive for preliminary testing.

One of these locations was Yucca Mountain, which contained a block of tuff that seemed to be large and thick enough for a repository. Because tuff had not previously been considered as a potential host rock for a repository, the government solicited the views of the National Academy of Sciences on investigating tuff as a host rock and received a favorable response. At about the same time, Yucca Mountain was recommended by the U.S. Geological Survey, which had compared the results of preliminary explorations at all three NRDA locations. In 1980, a formal analysis of 15 potential locations showed that Yucca Mountain was indeed preferred, with several potentially suitable horizons, and in February 1983 Yucca Mountain was formally identified as a potentially acceptable site.

In May 1986, the Secretary of Energy nominated the Yucca Mountain site as one of five sites suitable for characterization and recommended that it be characterized as one of three candidate sites for a repository; the Secretary's recommendation was approved by the President. The Secretary also made the preliminary determination, required by the Nuclear Waste Policy Act, that the Yucca Mountain site is suitable for development as a repository.

The nomination of Yucca Mountain as suitable for characterization was accompanied by an environmental assessment (EA)* that included an evaluation against the DOE siting guidelines (10 CFR Part 960). At the time of the EA evaluation, only preliminary findings of compliance with the guidelines could be made because site characterization had not been performed. To make the higher-level findings necessary to show that the site meets the guidelines requires data from site characterization or the environmental and socioeconomic studies that will be carried out concurrently with characterization. The collection of data for the higher-level findings will be accomplished as a part of the site-characterization program.

2.3 CHARACTERISTICS AND CONDITIONS PERTINENT TO A GEOLOGIC REPOSITORY

This section presents brief descriptions of the characteristics and conditions of the Yucca Mountain site that are pertinent to a geologic repository and will be given special attention in the site-characterization program discussed in Chapter 4. The descriptions cover geology, geoengineering, hydrology, geochemistry, and climate. They are based on currently available information and are derived from the detailed descriptions in Chapters 1 through 5 of the SCP/CD.

2.3.1 Geology

Information about the geologic history and conditions in the region surrounding Yucca Mountain has been collected for the past 80 years, first to support exploration for mineral and energy resources and later to support government activities at the Nevada Test Site. Since late 1977, information about the region and the site has been collected specifically for the repository program. The information has been obtained by reviewing published data, performing detailed geologic mapping of the Yucca Mountain area, conducting regional geophysical investigations, recording seismic data, and conducting other field studies. To date, 182 drillholes have been drilled and 23 trenches have been excavated within a radius of about 6 miles from the site to investigate the geologic conditions of Yucca Mountain.

Geologic conditions are intrinsic to the performance of a repository, and it was the geologic stability of certain rock formations that led to the selection of geologic repositories as the preferred means for the disposal of radioactive waste. To judge whether a site is geologically suitable, it is

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*U.S. Department of Energy, Environmental Assessment--Yucca Mountain Site, Nevada Research and Development Area, Nevada, DOE/RW-0073, May 1986.

necessary to know which phenomena or processes can be expected at the site over the 10,000-year period of waste isolation and which processes, though not expected, are sufficiently credible to warrant consideration. The likelihood that disruptive phenomena or processes will occur during the period required for waste isolation can be assessed from the geologic history of the past 2 million years (the Quaternary Period in geologic time). The geologic history of Yucca Mountain suggests that the phenomena of special interest in regard to the long-term stability of the region are faulting, seismicity, and volcanism. Also of interest is the occurrence of natural resources because exploration for resources in the future may lead to inadvertent intrusion into the repository. Brief descriptions of these phenomena are given below; they are based on the detailed discussions presented in Chapter 1 of the SCP/CD.

Faulting

The structural development of southern Nevada has been complex. Faulting at Yucca Mountain is primarily in response to extensional tectonism that has occurred continually in the Basin and Range Province for about the last 15 million years. Two overlapping phases are identified: (1) older extensional faulting associated with silicic volcanism from about 11 to about 7 million years ago and (2) basin-and-range faulting for about the past 7 million years.

The origin of the basin-and-range structures in the southern Great Basin has been attributed, in part, to right-lateral faulting along the western edge of North America during Cenozoic time (the last 66 million years). Western North America lies within a broad belt of right-lateral movement caused by differences in motion between the North American and the Pacific crustal plates. Some of the right-lateral movement occurs along the San Andreas fault and other similarly oriented faults in California. Such motion may have occurred at an earlier time in southern Nevada along the Walker Lane and the Las Vegas Valley shear zones in close proximity to the site (Figure 2-3). This motion and the related extensional faulting caused the crust to fragment into basins and ranges oriented along trends oblique to the right-lateral fault zones.

Yucca Mountain is a series of north-trending structural blocks that have been tilted eastward along west-dipping, high-angle normal faults. The proposed repository would be excavated in a rock stratum dipping eastward at about 5 to 8 degrees in a relatively unfaulted part of one typical structural block. It would be bounded on the west by the Solitario Canyon fault, on the northeast by the Drill Hole Wash fault, and on the east and southeast by the western edge of an imbricate normal fault zone. One moderately sized fault, designated the Ghost Dance fault, occurs in the repository area. The faults that have been interpreted from geologic mapping are shown in Figure 2-4.

Structural elements at Yucca Mountain include local faults related to the formation of calderas (i.e., collapse of volcanic centers) and longer faults of the basin-and-range style. The strata are gently tilted to the east and are offset by several north-trending high-angle faults, dipping chiefly to the west, that created several large north-trending structural blocks. Another fault system trends northwest in the northern part of Yucca Mountain. Recognized vertical offsets on faults within the proposed repository are about 15 feet or less, except for the Ghost Dance fault, which is offset about 125 feet at the southeast end of the proposed repository. Vertical displacement along

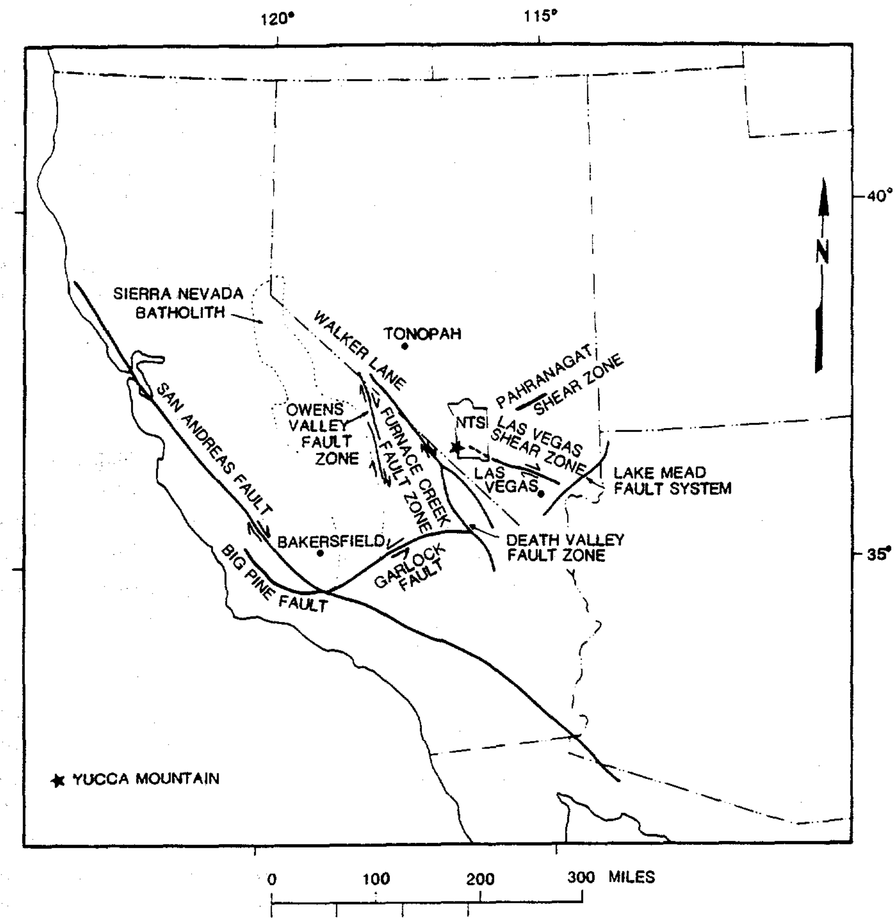


Figure 2-3. Major strike-slip faults of the southern Great Basin and vicinity.

the Solitario Canyon Fault diminishes from about 700 feet at the southern end to about 70 feet at the northwestern corner. For site-characterization purposes, fault movement during the Quaternary Period is of interest. Movement during Quaternary time has been demonstrated for four of the normal faults shown in Figure 2-4--the Windy Wash, Solitario Canyon, Bow Ridge, and Paintbrush Canyon faults--as well as the Bare Mountain fault, which is some 11 miles to the west of the site.

Seismicity

Yucca Mountain lies in an area of relatively low historical seismicity, on the southern margin of the East-West Seismic Belt in southern Nevada (Figure 2-5); this belt connects the north-trending Nevada-California Seismic Belt, about 100 miles west of Yucca Mountain, with the north-trending Intermountain Seismic Belt, about 150 miles to the east. Eight major earthquakes (with magnitudes M of 6.5 or more) have occurred within about 250 miles of Yucca Mountain: six in the Nevada-California Seismic Belt and two on or near the San Andreas fault. The closest large historical earthquake (M = 6) occurred in 1908 at a distance of 68 miles to the southwest.

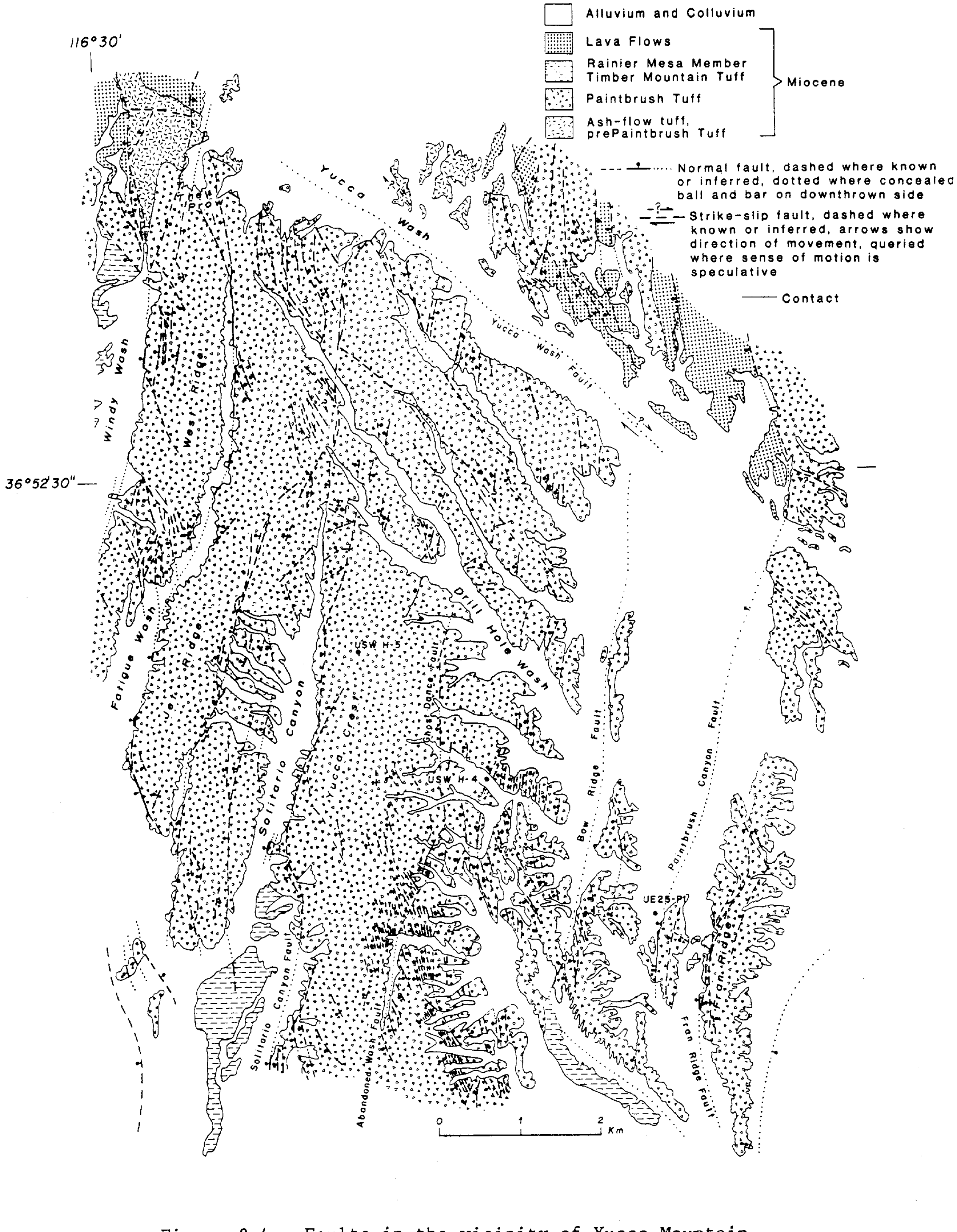


Figure 2-4. Faults in the vicinity of Yucca Mountain.

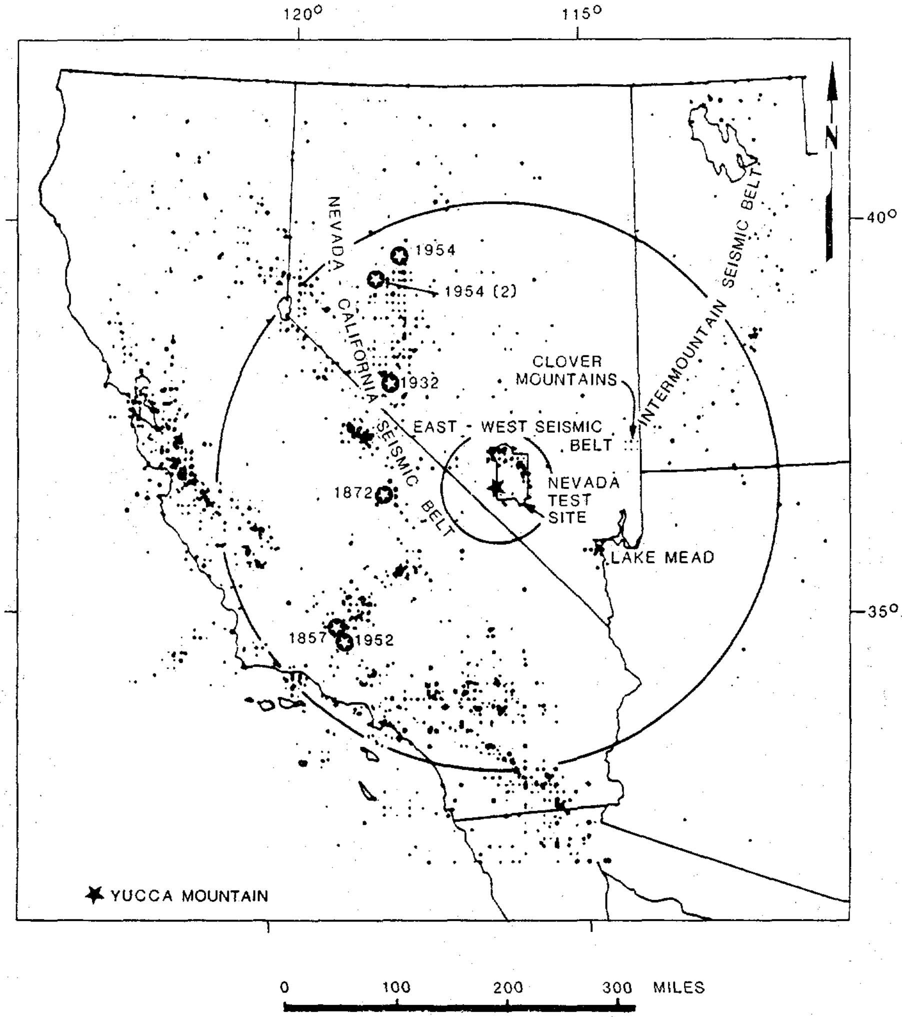


Figure 2-5. Seismicity of the southwestern United States, 1969 through 1978, showing earthquakes with a magnitude of 4 or more. The circles centered on the Yucca Mountain site have radii of about 60 and 250 miles. The stars show the locations of major (M = 6.5 or more) historical earthquakes.

Geologic field evidence suggests Yucca Mountain has been relatively stable for the past 11 million years. Recent seismic data are available from a 47-station seismic network that was installed within 100 miles of the site in 1978 and 1979 and a supplemental 6-station network that was deployed on Yucca Mountain in 1981. Within a radius of about 6 miles centered on the proposed repository, the release of seismic energy since 1978 has been two or three orders of magnitude lower than that in the surrounding region.

Estimates of vibratory ground motion for proposed repository facilities are currently based on the full-length rupture on the Paintbrush Canyon fault (see Figure 2-4). A deterministic estimate of the peak ground acceleration is 0.5g for an earthquake of M = 6.5. This value may change, because other faults are still being studied.

The Yucca Mountain area is tectonically quiet in comparison with adjacent parts of the Great Basin. However, its faults could experience periods of above-average slip rates within the next 10,000 years. Some of the major faults in the area of Yucca Mountain have moved repeatedly in the present tectonic framework during the Quaternary Period. Yucca Mountain is considered to lie in a belt of contemporary right-lateral shear and is possibly favorably oriented in the existing stress field for future movement. Relatively high seismic activity continues today along some right-lateral fault zones northwest and southwest of Yucca Mountain, and there is some evidence that moderate seismic activity and surface fault displacements have occurred during this century in the Walker Lane shear zone.

Volcanism

Volcanism migrated into the Yucca Mountain region by 16 million years ago, forming the southwestern Nevada volcanic field. In the Yucca Mountain area, it produced several large caldera complexes associated chiefly with silicic tuffs, the rock that makes up Yucca Mountain. By 6 to 8 million years ago volcanism became of the more quiescent basaltic-flow type. The youngest basalt-type volcanic feature in the area, located at the southern edge of Crater Flat, is the Lathrop Wells cinder cone. Several other relatively young cinder cones are located in Crater Flat, on the west side of Yucca Mountain (see Figure 2-2).

The explosive silicic volcanism during Cenozoic in the southern Great Basin is well documented through geologic and geophysical studies. The data suggest that the probability of silicic volcanism is negligible, but the possibility of new basaltic volcanism at Yucca Mountain is considered to be higher. Basalt has been the predominant product of volcanism in the southern Great Basin over the past 8 to 9 million years and is likely to be the future product. Basaltic volcanism during Cenozoic time (the last 66 million years) was expressed in localized low-volume eruptions of short duration, with the rate of magma production apparently declining over the past 4 million years.

Natural resources

In evaluating a candidate site for a repository, it is also necessary to consider the possibility that future generations might inadvertently intrude into the repository. The potential for such human interference depends largely on the potential for natural resources, such as oil, gas, geothermal, precious metals, industrial minerals, or ground water. Existing evidence does not indicate that Yucca Mountain contains commercially attractive natural resources.

Precious and base metal deposits (e.g., gold, silver, lead, copper, zinc, and molybdenum) have historically been the most important natural resources in Nevada. However, to date, only an estimated 5 percent of mineral districts in Nevada have been located in silicic tuffs. Yucca Mountain is composed of predominantly Tertiary silicic ash-flow tuffs. Hydrocarbon resources are not considered likely. Nonmetal resources like zeolite minerals or gravels are common elsewhere in the region, and therefore their existence at Yucca Mountain is unremarkable. Ground water of good quality is present deep below the site, but more easily accessible sources of good-quality water are present elsewhere in the region.

2.3.2 Geoengineering

Geoengineering properties are important in predicting the mechanical and thermal behavior of the host rock; they include strength and deformability, porosity, density, the frequency of fractures, heat conductivity, and in-situ stress. A detailed discussion of the geoengineering properties of the Yucca Mountain site can be found in Chapter 2 of the SCP/CD.

The current data base for the geoengineering properties of the Topopah Spring Member consists of the results of laboratory tests on core samples from Yucca Mountain and both field and laboratory tests on similar tuff units in the region. In particular, a field testing program in G-Tunnel at Rainier Mesa on the Nevada Test Site (see Figure 2-2) has provided valuable information. The G-Tunnel data came from a tuff that is considered a reasonable analog for the proposed repository horizon at Yucca Mountain in many aspects, including similar bulk, thermal, and mechanical properties. The current data base was derived mainly from tests performed on small-diameter cores (about 2.5 inches). It consists of approximately 100 tests of thermal conductivity, 300 tests of thermal expansion, 75 mineralogical-petrological analyses, 700 measurements of bulk properties (porosity, density), and 350 tests of mechanical properties.

The stratigraphic section at Yucca Mountain is composed of a sequence of welded and nonwelded tuffs. Some units are devitrified, and some are vitric. The portion of the Topopah Spring Member that has been selected as the potential host rock is moderately to densely welded and devitrified, with minor amounts of lithophysal cavities. This unit is expected to have high strength, to have adequate thermal conductivity, and to be relatively easy to excavate. However, the characteristics that affect thermal and mechanical properties, such as porosity, degree of saturation, and stress state are known to vary both laterally and vertically. Consequently, the thermal and mechanical properties are also likely to vary. This variability must be taken into account in evaluating the thickness and lateral extent of the potential host rock as well as in designing the underground repository and the seals for shafts and boreholes (see Chapter 3).

The in-situ stresses measured at the Nevada Test Site and at Yucca Mountain are low in comparison with the generally high strength of the host rock. The stresses measured at Yucca Mountain are consistent with those of other measurements in the region. Tunnels excavated in similar layered tuffs at the Nevada Test Site remain stable with minimal ground support, requiring only rock bolts and wire mesh; these tunnels are similar to the planned excavations at Yucca Mountain in terms of overburden loadings, dimensions of openings, and methods of excavation.

2.3.3 Hydrology

An important feature of a repository at Yucca Mountain is its location in the unsaturated zone--the zone between the surface of the land and the water table. Generally, any water that is present in this zone is under less than atmospheric pressure, and some of the voids in the rocks may contain air or other gases at atmospheric pressure. At Yucca Mountain, this unsaturated zone is thick enough to allow the construction of the repository about 660 to 1300 feet above the top of the water table.

Hydrologic investigations of the region surrounding the Yucca Mountain site were begun in the late 1950s to evaluate the hydrologic system at the Nevada Test Site, and in the 1960s studies directed at appraising the ground-water resource were begun. Hydrologic studies for the repository project were started in 1978. Since 1981, hydrogeologic test holes more than 1 mile deep have been drilled into the saturated zone, and tests have been performed to determine such parameters as the depth to the water table, the total water yield, hydraulic conductivity, transmissivity, and water chemistry. Multiple-well tests to determine the effective porosity and the nature and extent of the contribution of fractures to permeability are continuing. When the advantages of locating the proposed repository in the unsaturated zone became apparent, the emphasis of the studies shifted from the saturated zone to the unsaturated zone. Beginning in 1983, test holes deeper than 1000 feet were drilled into the unsaturated zone and have been used to monitor the ambient water saturation, potential, and flux in the rocks above, below, and in the proposed repository horizon. A detailed discussion of the hydrologic data pertinent to the Yucca Mountain site is given in Chapter 3 of the SCP/CD.

The unsaturated zone at Yucca Mountain consists of the tuffs described in Section 2.1. The proposed horizon for the repository is a moderately to densely welded tuff of relatively high fracture density. Current estimates are that only a small part of the rain that falls on Yucca Mountain (probably less than 0.02 inch of the approximately 6 inches that falls annually) percolates through the matrix of the unsaturated zone, and a small vertical ground-water flux is expected in the Topopah Spring tuff.

The water table under Yucca Mountain occurs in the fractured tuffs of the Calico Hills or the Crater Flat units; it slopes to the southeast from an elevation of 2600 to 2400 feet above sea level. This tuff aquifer is a part of the Alkali Flats-Furnace Creek Ranch ground-water basin, which discharges by evapotranspiration through the Franklin Lake Playa at Alkali Flats in California and may discharge at springs in Death Valley near Furnace Creek Ranch. Together with two adjoining subbasins, this ground-water basin is part of the Death Valley ground-water system. The principal source of recharge for the tuff aquifer is probably Pahute Mesa to the north and northwest of Yucca Mountain. The recharge and discharge areas for the hydrogeologic study area of the repository project are shown in Figure 2-6. The regional direction of ground-water flow is south and southwest (Figure 2-7). As elsewhere in the southern Great Basin, the ground-water basins tend to be closed, with no external drainage into rivers or major bodies of surface water.

In the unsaturated zone, ground water moves either by percolating through the rock matrix or by flowing within the fractures of the welded tuff. There is evidence that, under current conditions in the host rock, matrix flow is the dominant mechanism for vertical flow. The velocity of the flow depends on the degree of saturation. The variability in rock properties can lead to localized zones of higher saturation, where fracture flow may occur. The exact nature of the transition between matrix and fracture flow in partially saturated, fractured rocks is uncertain. There is also uncertainty about the potential for, and the extent of, flow along inclined zones of different permeabilities. Present estimates of the time of ground-water travel from the proposed repository to the underlying water table range from about 9000 to 80,000 years. The conceptual moisture-flow system in the unsaturated zone is shown in Figure 2-8.

In the saturated zone, the flow is likely to occur in fractures and to be more rapid than it is in the unsaturated zone. The pattern of ground-water movement is likely to be to the southeast of the site, although the general direction of movement in the Alkali Flat-Furnace Creek Ranch ground-water basin is to the southwest. The hydraulic gradient near the site is variable, and, southeast of the repository, it is nearly flat.

No perennial streams occur at or near Yucca Mountain. The only reliable sources of surface water are the springs in Oasis Valley, the Amargosa Desert,

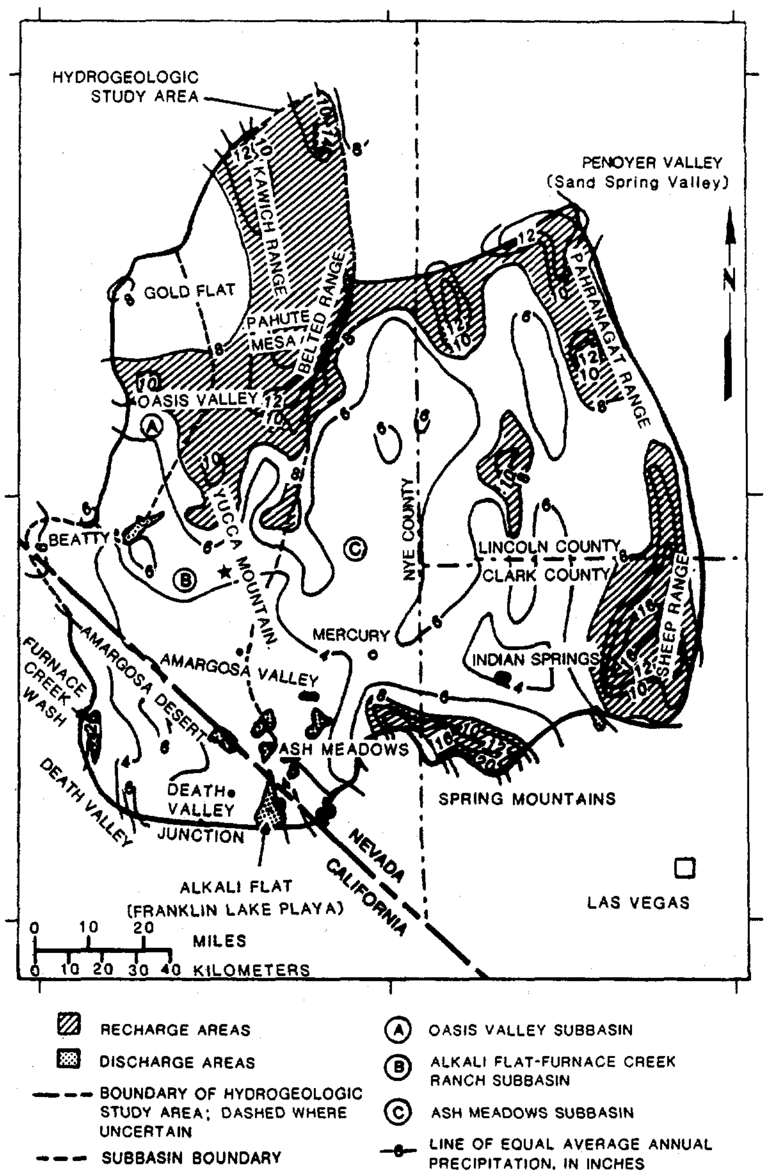


Figure 2-6. Ground-water recharge and discharge areas.

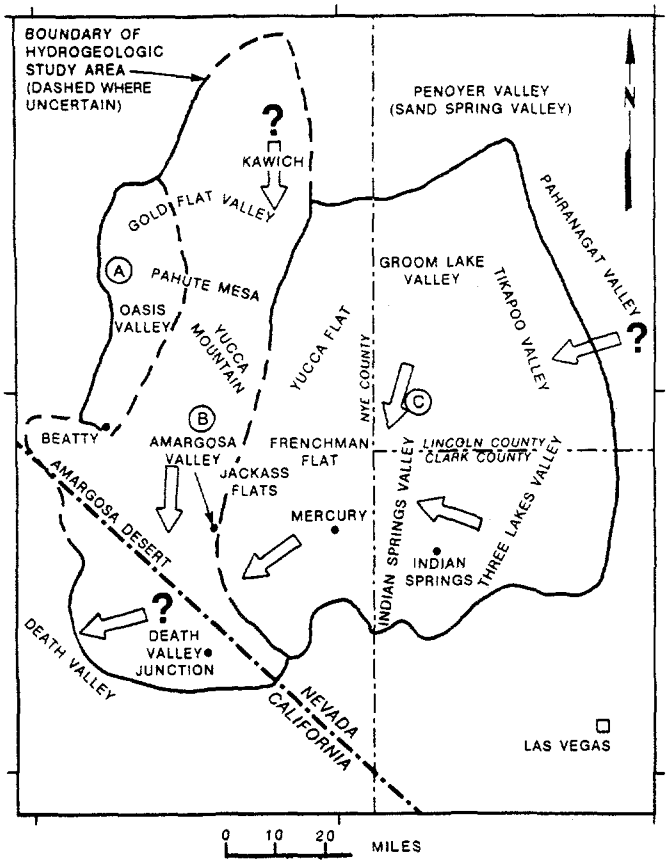


Figure 2-7. Regional direction of ground-water flow. Questionmarks indicate uncertainty. Key to subbasins: A = Oasis Valley, B = Alkali Flats-Furnace Creek Ranch, and C = Ash Meadows.

and Death Valley (see Figure 2-6). Because of the aridity of the region, most of the water discharged by the springs travels only a short distance before evaporating or infiltrating into the ground. During heavy rains, however, arroyos do occasionally experience transient floods.

2.3.4 Geochemistry

The geochemical environment of the host rock may affect the long-term performance of the repository by affecting the behavior of the engineered-barrier system (mainly the waste package) and by retarding the transport of radionuclides by ground water. To characterize this geochemical environment, geochemical data have been collected since late 1977. Current knowledge about the geochemical conditions at Yucca Mountain is summarized in Chapter 4 of the SCP/CD.

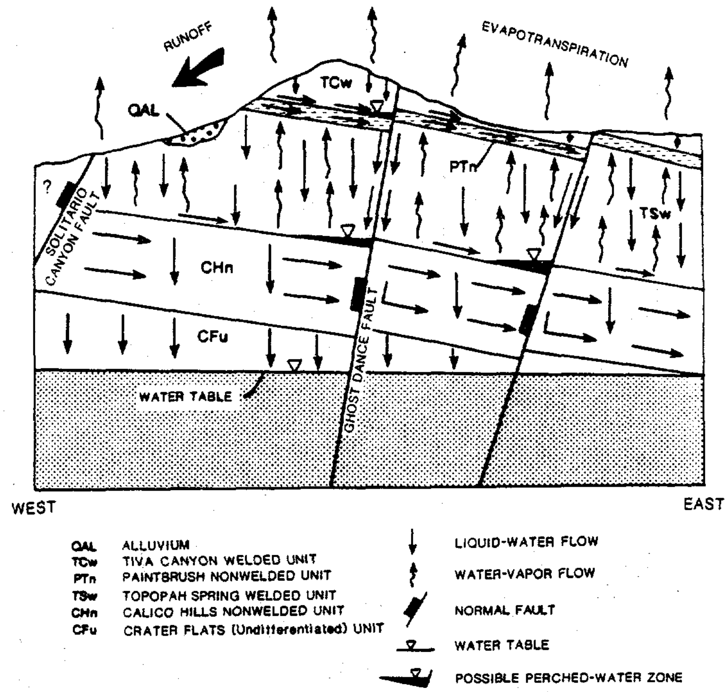


Figure 2-8. Generalized east-west section through Yucca Mountain showing conceptual moisture-flow system under natural conditions. Questionmark indicates uncertainty about unit. Stipled area represents the saturated zone.

the geochemical data have been obtained from samples taken at Yucca Mountain or its vicinity. Samples for mineralogic and petrologic studies have been taken from drill cores, sidewall samples, drill cuttings, and surface outcrops. Data on water chemistry have been obtained from ground-water samples taken from wells. Information on the stability of geochemical conditions has been obtained from laboratory experiments.

The waste-emplacement environment is expected to be oxidizing and will contain very little liquid water. The available information suggests that the mineral phases present in the rocks at Yucca Mountain are likely to remain stable after waste emplacement.

The characteristics of the ash-flow tuffs at Yucca Mountain, especially those of the nonwelded tuffs lying above and below the potential repository horizon, would allow several types of radionuclide retardation. For example, the chemical conditions are such that some of the key radionuclides (the actinides) are more likely to precipitate than to dissolve in any available liquid water. Another retardation mechanism is the matrix diffusion that is expected to occur in fractured rocks with a low matrix permeability: the ground water entering a fracture will diffuse into the matrix and back into the fracture, thus following a circuitous path of travel. In addition, minerals with a high sorption capacity--zeolites and clays--are present along potential paths of ground-water flow below the repository and in the saturated zone. Estimates are that, with very few exceptions, sorption alone would cause the average time of radionuclide travel to the accessible environment to be much longer (by much more than a factor of 10) than the time of ground-water travel.

2.3.5 Climate and meteorology

Climatic changes that may occur in the distant future--10,000 and even 100,000 years from now--are important to the long-term performance of a repository because a change from the current arid conditions might affect hydrologic conditions. At Yucca Mountain, the potential for a change in the amount of ground-water flux through the unsaturated zone and a rise in the water table is important because the thickness of the unsaturated zone below the repository could be decreased and the amount of water available for contact with the waste could be increased.

The climatic trend that can be expected in the next 10,000 to 100,000 years can be predicted from the changes in climate that occurred in the past 2 million years. The climates of the past can be deduced from the plant remains left thousands of years ago in the middens of pack rats, fossilized plant pollens, evidence of past lake positions preserved in deposits formed along their shorelines, and the sparse evidence of mountain glaciers in the Great Basin. Past positions of the water table can also be estimated by identifying spring deposits that represent the locations of discharges in the past. As described in Chapters 5 and 3 of the SCP/CD, such data have been collected and analyzed for the Yucca Mountain site.

All of the evidence accumulated to date suggests that the Yucca Mountain region has been arid to semiarid during the past 2 million years. The average annual precipitation during the last glacial maximum about 18,000 years ago was probably about 30 to 40 percent higher than the precipitation occurring at the present time. As discussed in Chapter 3 of the SCP/CD, some experts suggest that the general climate in Nevada became progressively more arid during the Quaternary Period. This change is attributed to the uplift of the Sierra Nevada and the Transverse mountain ranges: the rising mountain ranges are thought to have produced a rainshadow that affected the distribution and the amount of precipitation in Nevada.

Data on meteorological conditions in the Yucca Mountain region have been collected since 1922 at Beatty, Nevada, since 1949 at the Town of Amargosa Valley, and since the 1950s at the Nevada Test Site. In 1983, meteorological stations were installed at several elevations on Yucca Mountain to collect data on wind speed and direction, temperatures and temperature differences due to elevation, the standard deviation of vertical wind speed, precipitation, relative humidity, and dew point.

The existing climate in the vicinity of Yucca Mountain is classified as midlatitude desert. The most notable general meteorological characteristics are temperature extremes, particularly during the summer months, approaching 120°F; large ranges in the maximum and minimum temperatures; and an annual precipitation of less than 6 inches. Skies are mostly clear throughout the year, and the average relative humidity is low. Winds from the north dominate in the fall, in the winter, and into early spring but shift to a predominantly south to southwesterly direction in late spring and early summer. This annual average cycle is affected by the terrain, with upgradient winds occurring during daylight hours in almost all months.

3. THE DESIGN OF THE REPOSITORY AND THE WASTE PACKAGE

This chapter briefly describes the design of the engineered elements of the disposal system--the repository and the waste package. The description is based on the SCP conceptual design, which is to be followed by three more-advanced design steps: the advanced conceptual design, the license-application design, and the final procurement and construction design. The purpose of the SCP conceptual design was to concentrate on the design components that require site-characterization data and to identify the design-related information that must be collected during site characterization. The SCP conceptual design, therefore, was developed in sufficient detail to identify the needed site data, but it is an early conceptual design, and it is likely that the designs of both the repository and the waste package will change as data from site characterization are collected and more-detailed designs are developed.

3.1 THE REPOSITORY

A geologic repository will consist of surface facilities, underground facilities, and shafts and ramps connecting the surface and the underground facilities. In addition, when the repository is prepared for permanent closure, seals will be constructed for the shafts, ramps, and exploratory boreholes. The repository facilities will be designed to meet various functional and regulatory requirements, including the NRC's requirements in 10 CFR 60.111-113, 10 CFR 60.131-134, and 10 CFR 60.137 (see Appendix A).

A sketch of the proposed repository at Yucca Mountain is shown in Figure 3-1. A topographic map of the site, showing the locations of the underground facilities and the central surface facilities, is shown in Figure 3-2. An overall plan of the site is shown in Figure 3-3. A detailed discussion of the conceptual design of the repository can be found in Chapter 6 of the SCP/CD.

3.1.1 Surface facilities

The purpose of the surface facilities of the repository is to receive that waste and to prepare it for permanent disposal underground. They would be constructed on relatively flat terrain to the east of Yucca Mountain. They would consist of a central surface-facilities area, various outlying support facilities, and facilities that would provide access and ventilation for the underground repository. Both rail and highway access to the site would be provided.

The central surface-facilities area would be divided into three distinct functional areas used for waste receiving and inspection, waste operations, and general support facilities. The waste-operations area would include two waste-handling buildings and other facilities where radioactive material is handled.

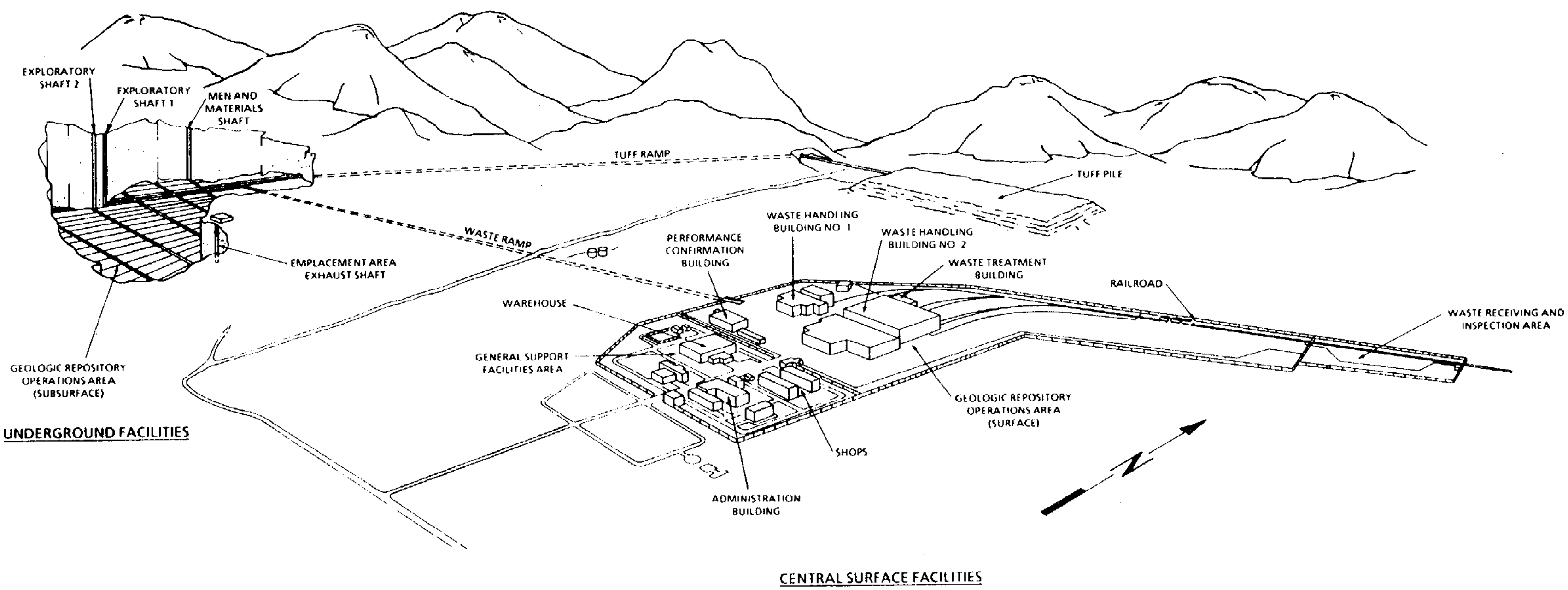


Figure 3-1. Perspective of the proposed repository at Yucca Mountain.

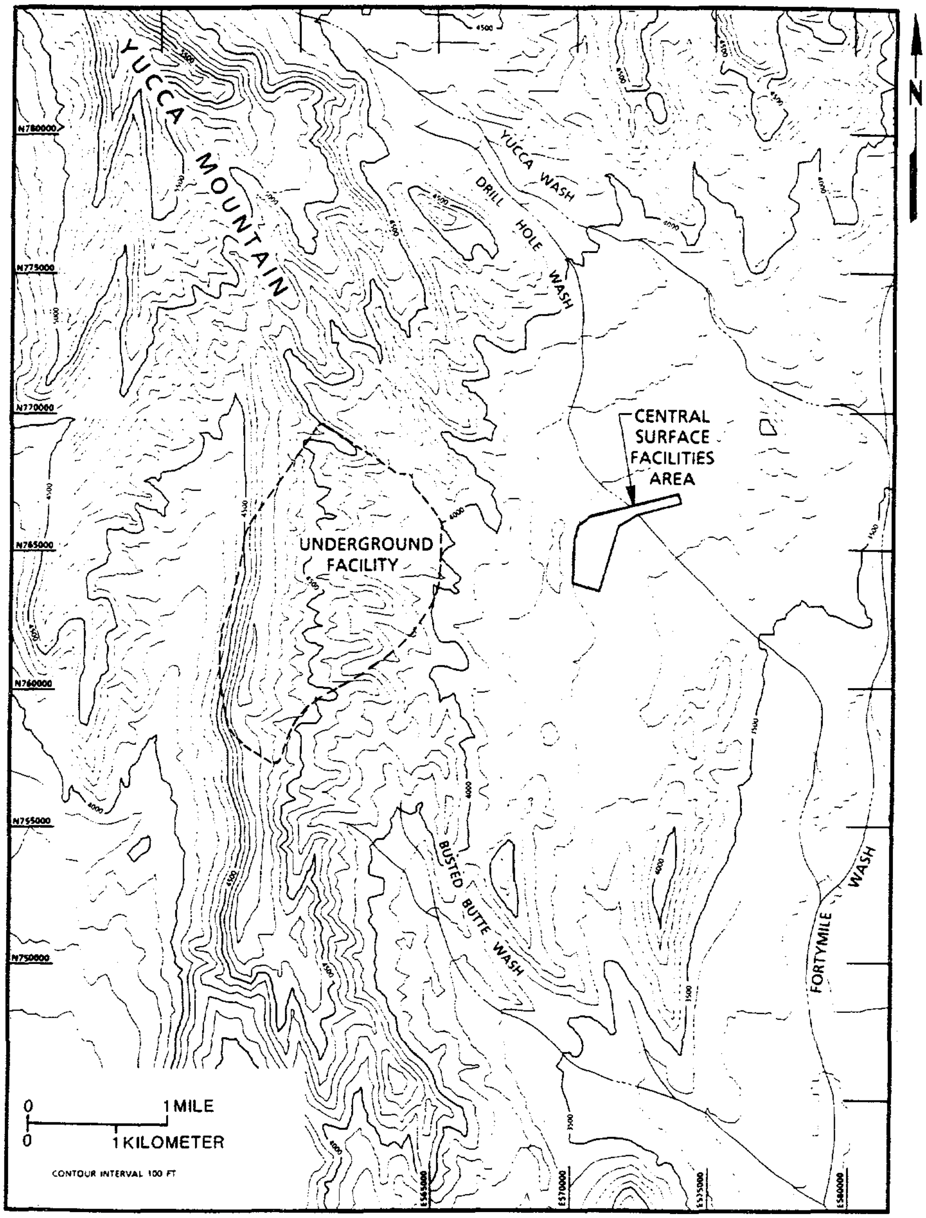


Figure 3-2. Topographic map of the Yucca Mountain site.

Two waste-handling buildings are included in the design because the repository would be constructed and operated in two phases. During phase 1, only waste-handling building 1, the smaller building, would be available; it would be used to receive spent fuel and to encapsulate it in disposal containers. During this phase, the repository would operate at a design receipt rate of 400 MTU per year. Full-capacity operation at 3000 MTU per year would be reached in phase 2, when the larger waste-handling building is completed.

During phase 2, waste-handling building 2 would have facilities for consolidating spent fuel into more-compact arrays than those used in the spent-fuel assemblies. Waste-handling building 1 would be used for preparing waste that does not require consolidation--that is, defense high-level waste, com-

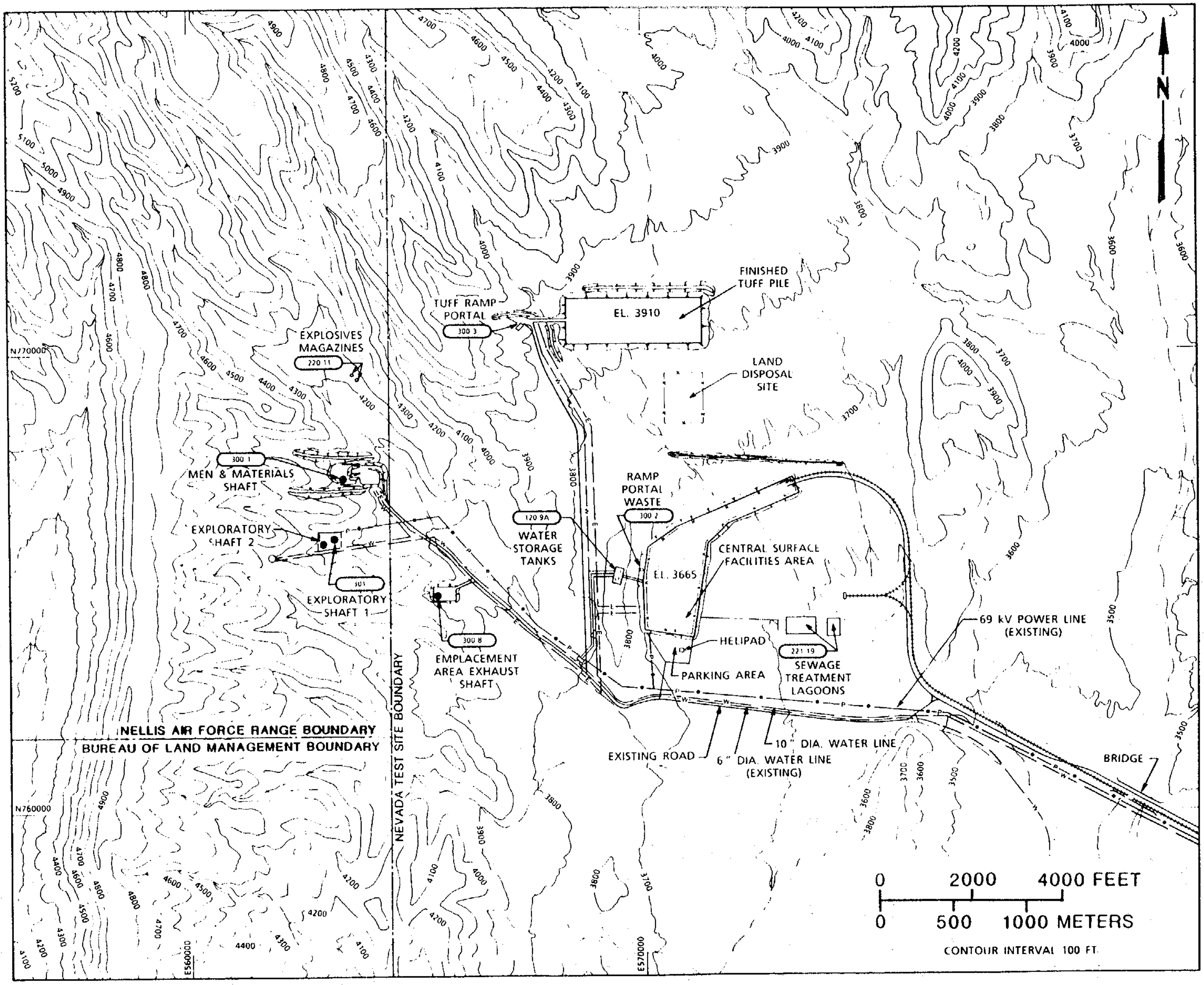


Figure 3-3. Overall site plan showing surface facilities and shafts.

mercial high-level waste, spent fuel that cannot be consolidated, and spent fuel consolidated at the reactor site or another waste-management facility. The types of waste handled at the repository and their preparation for disposal are discussed in more detail in Section 3.2.

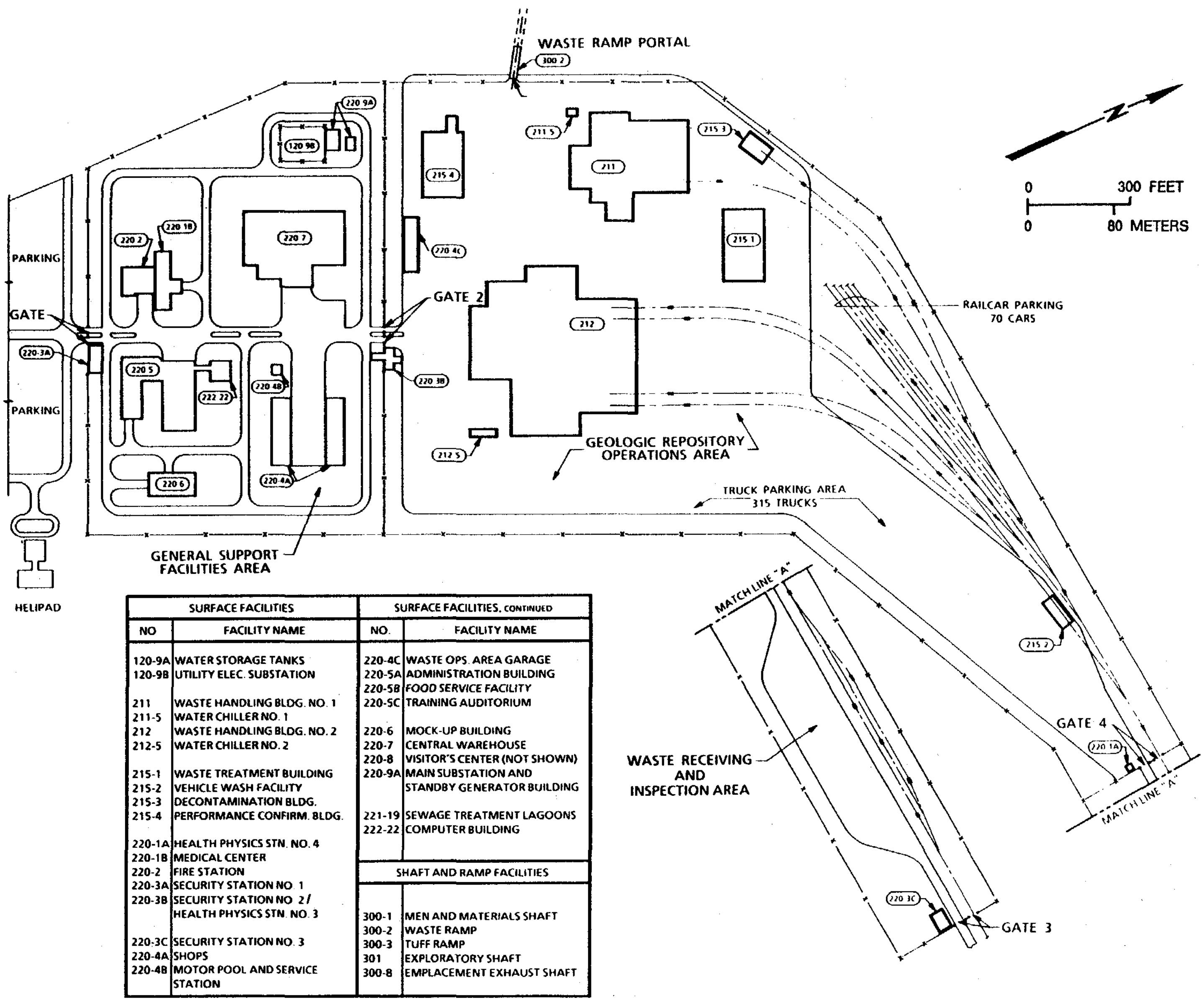
In waste-handling building 2, the spent fuel would be unloaded from the shipping cask it arrives in and transferred to an encapsulation, or packaging, station in a "hot" cell--a room provided with shielding against radiation and equipped with remotely controlled equipment for cutting the spent-fuel assemblies, consolidating the spent-fuel rods into a more compact array, and loading the consolidated fuel into disposal containers. The loaded containers would then be transferred to another station, where they would be filled with an inert gas, sealed by welding, and inspected for leaks. The sealed containers would be moved to a surface vault for temporary storage before transfer underground and emplacement in the disposal rooms. The storage vault in waste-handling building 2 would be large enough to hold about 130 containers of consolidated spent fuel. A small storage vault would also be provided in waste-handling building 1. The transfer and emplacement operations would be performed with specially designed transfer casks and transporters.

Other planned surface facilities include those used for testing the performance of waste packages; the decontamination building, which would be used to receive, decontaminate, and return to service any contaminated components and equipment (including casks and transport vehicles); and the waste-treatment building, which would be used to prepare for disposal the radioactive waste that is produced at the repository. Support facilities would provide such services as security, fire protection, administration, maintenance, and laboratories. The layout of the central surface-facilities area is shown in Figure 3-4.

3.1.2 Shafts and ramps

The surface facilities would be connected to the underground repository through two ramps and four shafts. One of the ramps, the waste ramp, would be used to transport the waste containers from the surface to the underground and to provide a fresh-air intake for the waste-emplacement area. This ramp would have a length of about 6600 feet, a slope of nearly 9 percent, and an excavated diameter of about 20 feet. Its portal would be in solid rock inside the central surface-facilities area. The second ramp, known as the tuff ramp, would be used for excavating and constructing the underground repository and for removing the excavated tuff from the underground to a point near the tuff pile on the surface; it would also serve as the primary exhaust airway for the underground development area. With a length of approximately 4630 feet, a slope of nearly 18 percent, and an excavation diameter of about 20 feet, the tuff ramp would contain a belt conveyor and the main electrical feeder for the underground facilities.

All four shafts would be located 1 to 1.5 miles west of the central surface-facilities area. Two of the shafts would be the exploratory shafts constructed for site characterization (see Chapter 5). Both of these shafts would be used as fresh-air intakes for the waste-emplacement area. The first exploratory shaft, with a depth of 1430 feet, would have a finished inside



SURFACE FACILITIES		SURFACE FACILITIES, CONTINUED	
NO	FACILITY NAME	NO.	FACILITY NAME
120-9A	WATER STORAGE TANKS	220-4C	WASTE OPS. AREA GARAGE
120-9B	UTILITY ELEC. SUBSTATION	220-5A	ADMINISTRATION BUILDING
		220-5B	FOOD SERVICE FACILITY
211	WASTE HANDLING BLDG. NO. 1	220-5C	TRAINING AUDITORIUM
211-5	WATER CHILLER NO. 1		
212	WASTE HANDLING BLDG. NO. 2	220-6	MOCK-UP BUILDING
212-5	WATER CHILLER NO. 2	220-7	CENTRAL WAREHOUSE
		220-8	VISITOR'S CENTER (NOT SHOWN)
215-1	WASTE TREATMENT BUILDING	220-9A	MAIN SUBSTATION AND STANDBY GENERATOR BUILDING
215-2	VEHICLE WASH FACILITY		
215-3	DECONTAMINATION BLDG.		
215-4	PERFORMANCE CONFIRM. BLDG.	221-19	SEWAGE TREATMENT LAGOONS
		222-22	COMPUTER BUILDING
220-1A	HEALTH PHYSICS STN. NO. 4		
220-1B	MEDICAL CENTER		SHAFT AND RAMP FACILITIES
220-2	FIRE STATION		
220-3A	SECURITY STATION NO. 1		
220-3B	SECURITY STATION NO. 2/ HEALTH PHYSICS STN. NO. 3	300-1	MEN AND MATERIALS SHAFT
		300-2	WASTE RAMP
220-3C	SECURITY STATION NO. 3	300-3	TUFF RAMP
220-4A	SHOPS	301	EXPLORATORY SHAFT
220-4B	MOTOR POOL AND SERVICE STATION	300-8	EMPLACEMENT EXHAUST SHAFT

Figure 3-4. Central surface-facilities area.

diameter of 12 feet. The second shaft would have a depth of 1100 feet and a finished inside diameter of 12 feet; in addition to providing ventilation air, it would serve as an emergency egress from the underground.

The other two shafts would be the men-and-materials shaft and the emplacement-area exhaust shaft; both would have an inside finished diameter of 20 feet. The men-and-materials shaft, 1090 feet deep, would contain a service elevator and a cage for moving people and materials between the surface and the underground; it would also serve as an air intake for the areas being excavated. The fourth shaft, with a depth of 1030 feet, would exhaust air from the waste-emplacement area.

3.1.3 Underground facilities

The underground repository, where the final emplacement of the waste would occur, would be constructed at a depth of about 1000 feet below the eastern flank of Yucca Mountain. The primary area for the underground repository is in the welded tuff of the Topopah Spring Member (see Chapter 2). The boundaries of this area are shown in Figure 3-2. The host rock in the primary area is sufficiently thick and large to accommodate the equivalent of 70,000 MTU: existing information about the site indicates that an area of 2095 acres would be available underground for waste emplacement; current plans call for using 1380 acres.

Layout

Three parallel main entry drifts would extend southwest through the underground facility to provide access to the waste-emplacement panels. One of the mains would be dedicated to transporting waste, another would be used for moving excavated tuff and bulk materials, and the third would be a service main dedicated to ventilation and electrical distribution systems.

The main component of the underground layout is the emplacement panel--a volume of rock in which the waste would be emplaced. The panels would be about 1400 feet wide, parallel to the main drifts, and 1500 to 3200 feet long, perpendicular to the main drifts. Spaced within each emplacement panel would be a number of emplacement drifts, in which boreholes would be drilled for the emplacement of waste. Access to the emplacement panels would be provided by panel-access drifts (see Figures 3-5 and 3-6). The preliminary layout calls out calls for 18 emplacement panels; this layout is based on an areal power density of 57 kilowatts per acre.

The development of the panels would begin in the northeast corner and progress in a clockwise direction.

Waste emplacement

Waste-emplacement operations would follow the order used for panel development. Waste emplacement would not begin until two panels had been completely developed, to allow separation between development and emplacement operations.

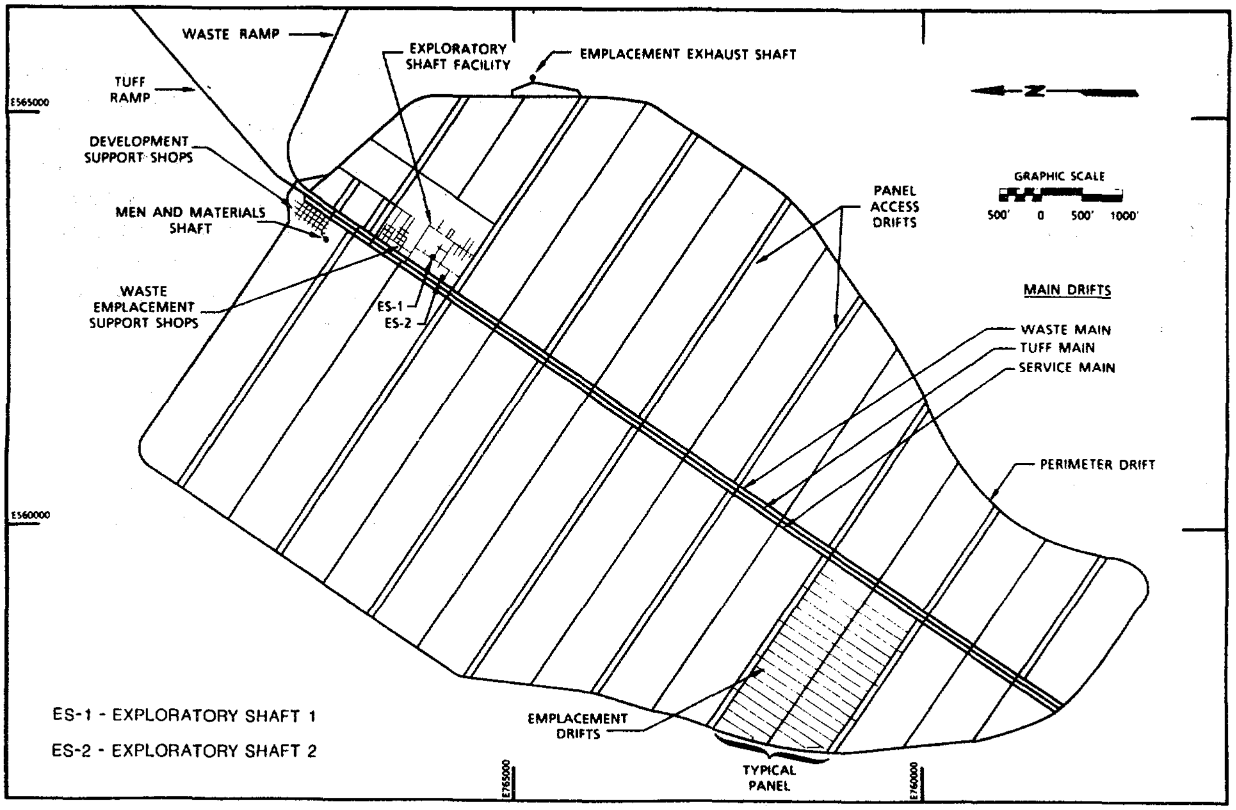


Figure 3-5. Underground repository layout for the vertical waste-emplacement configuration.

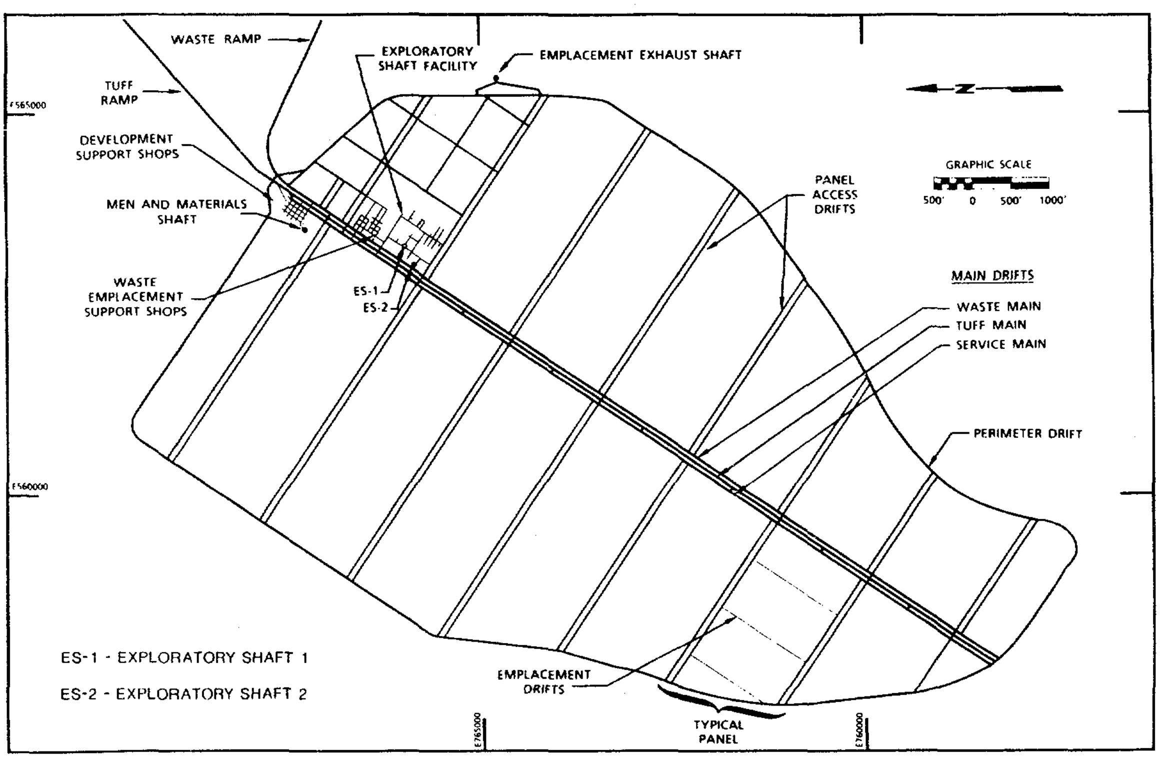


Figure 3-6. Underground repository layout for the horizontal waste-emplacement configuration.

In the SCP conceptual design, the reference waste-emplacement mode is vertical emplacement. In this mode (Figure 3-5), the boreholes, about 25 feet deep and about 30 inches in diameter, would be drilled vertically into the floor of the emplacement drifts, and a single container of waste would be emplaced in each borehole; a container of spent fuel would be 15.5 feet long and 26 inches in diameter (see Section 3.2). An alternative mode that has been considered is horizontal emplacement (Figure 3-6); in this mode, much longer boreholes, possibly extending nearly 400 feet, would be drilled horizontally into the walls of the emplacement drifts, with a number of waste containers emplaced in each hole. The emplacement drifts would, of course, be much farther apart for horizontal emplacement because the long borehole would be perpendicular to them. In either method, however, the emplacement panels are roughly the same size.

A vertical borehole with an emplaced waste package is shown in Figure 3-7. To protect the disposal container in vertical emplacement, a support

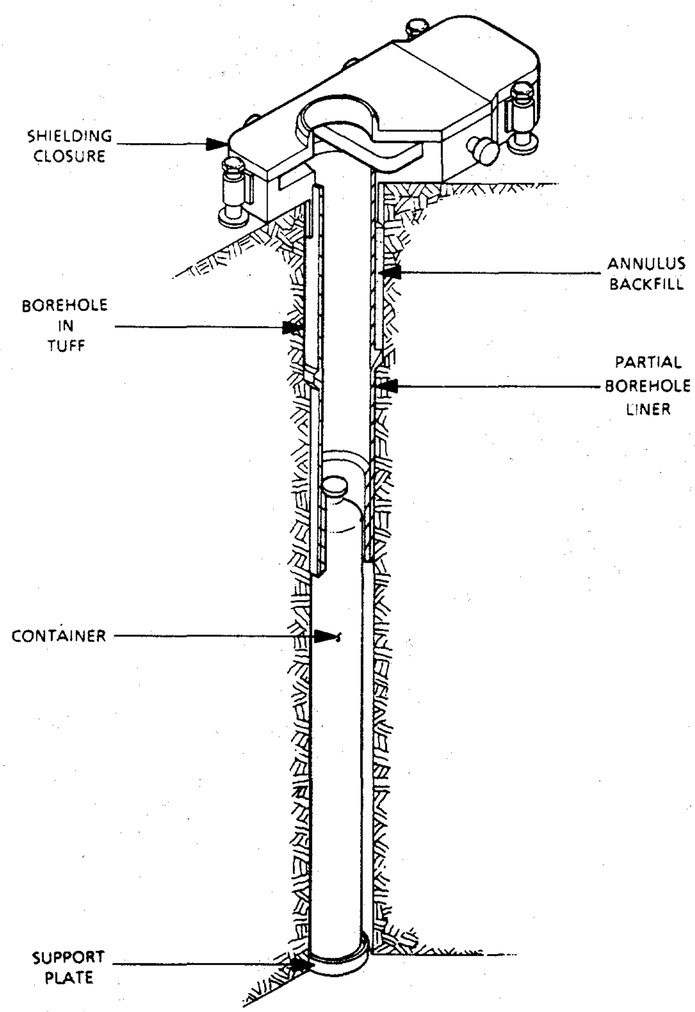


Figure 3-7. Diagram of a vertical waste-emplacement borehole.

plate would be inserted into the bottom of a vertical borehole and the borehole would be lined with a metal casing to a height exceeding that of the container. After the container has been emplaced in the borehole, a metal plug several inches thick would be inserted to provide shielding from radiation, crushed tuff would be packed around or on top of this shielding, and the borehole would be closed with a metal cover (see Figure 3-7).

The underground workings themselves would contain some areas devoted to special purposes, such as maintenance shops and training areas. The areas constructed during site characterization as part of the exploratory-shaft facility (see Chapter 5) would remain as part of these workings, but they would not be used for the emplacement of waste.

Ventilation

Two independent ventilation systems would serve the underground repository. One would provide air for the development of the repository while the other would provide air for the waste-emplacement operations. Connections between the systems would be sealed with bulkheads or airlocks. A positive-pressure system would be used for the development-area air circuit to prevent the in-leakage of air from the waste-emplacement area.

The basic layout of the ventilation system consists of four shafts, two ramps, three main airways, emplacement areas on either side of the main airways, and a perimeter airway that encircles the repository. For the development area, the intake air from the surface would be supplied by the men-and-materials shaft, and the tuff ramp would be used to return the air to the surface. For the waste-emplacement area, the two exploratory shafts and the waste ramp would be used for fresh-air intake, and the emplacement-area exhaust shaft would return the air to the surface. During normal operation, the return air from the waste-emplacement area would be exhausted directly to the atmosphere; however, should monitors detect a release of radioactive material, the return air would be routed through a set of filters before discharge.

No air cooling is expected to be required in the ventilation system for the development area. In the waste-emplacement area, drifts that have been filled with waste will require cooling for inspection, maintenance, or retrieval.

Construction methods and equipment

The excavation methods used at Yucca Mountain will depend on the shape and the dimensions of the opening and the properties of the rock around the opening. The DOE plans to use drilling and blasting for the excavation of all shafts. The use of tunnel-boring machines is proposed for the waste and tuff ramps, long-drive drifts, the waste main, and the perimeter drift. Drilling and blasting would be used for the remaining, shorter, drifts. Existing methods and equipment would be used for drilling vertical boreholes for waste emplacement. The equipment that would be used for drilling horizontal boreholes is being developed.

Ground support

The ground support currently proposed for a repository at Yucca Mountain consists of the use of rock bolts, grouted dowels, wire mesh, and shotcrete in varying degrees as required by local conditions.

3.1.4 Waste retrievability and closure

The emplaced waste would be retrievable for 50 years after the start of emplacement. Thus, after the waste-emplacement period, which is scheduled to last 26 years, a "caretaker" period of 24 years would begin. During both of these periods, various tests would be conducted to confirm that the repository is performing as expected. At the end of the caretaker period the repository would be prepared for permanent closure by backfilling the underground areas and permanently sealing the shafts and ramps; current plans for sealing and backfilling are briefly discussed in Section 3.1.5. The surface facilities would be decontaminated and decommissioned, and the site would be returned to its natural state to the extent practicable. Permanent site markers would also be erected to warn future generations of the presence of a repository.

3.1.5 Seals

The permanent closure of the repository will require the sealing of all shafts, ramps, exploratory boreholes, and the underground openings. The design objective for seals is to reduce, to the extent practicable, the potential for creating preferential pathways for ground water or radionuclide migration through existing pathways. In addition, the seals should deter human intrusion in the future and consist of components with sufficient longevity.

Proposed concepts for sealing shafts include surface barriers, shaft, fill, settlement plugs, and station plugs. The surface barrier would consist of a shaft cover, a collar core, and an anchor-to-bedrock plug seal. The shaft fill may consist of crushed tuff. The fill would be supported by the settlement plug, which would prevent the development of a surface depression, which could lead to the ponding of surface water. The station plug would be emplaced at the intersection of the shaft with the drifts of the repository; it would be designed to resist the lateral forces exerted by the shaft fill and thus control the settlement of the fill. A general arrangement for a shaft seal is shown in Figure 3-8.

Similar concepts are proposed for sealing the access ramps. If necessary, dams would be installed at intervals in the ramp to encourage the downward flow of water through the tuff rather than down the ramp. These dams would consist of a material that is less permeable than the undisturbed rock. However, the flow of water is expected to be negligible, and hence no dams may be needed.

Boreholes may be sealed by conventional cement plugging and the emplacement of granular material. More-detailed concepts for borehole sealing (i.e., boreholes that require special sealing methods, seal properties, and the types of seals important to the performance of the repository) will be established as the conceptual design progresses and data from site characterization are obtained.

Currently available data indicate that a significant number of water-bearing faults or fractures is not likely to be encountered in the repository horizon. Nonetheless, concepts have been developed to deal with water-bearing fractures. They include the use of drains, dams, grouting, and bulkheads for the vertical waste-emplacement mode and locating emplacement boreholes at the midheight of the drift walls for the horizontal emplacement mode.

Included in the category of seals is backfilling of the underground repository. Current plans for the repository at Yucca Mountain call for backfilling the underground openings at closure--rather than waste emplacement--because backfilling is not necessary to ensure mechanical stability during the retrievability period. The material selected for backfilling is the tuff excavated during the development of the underground facilities.

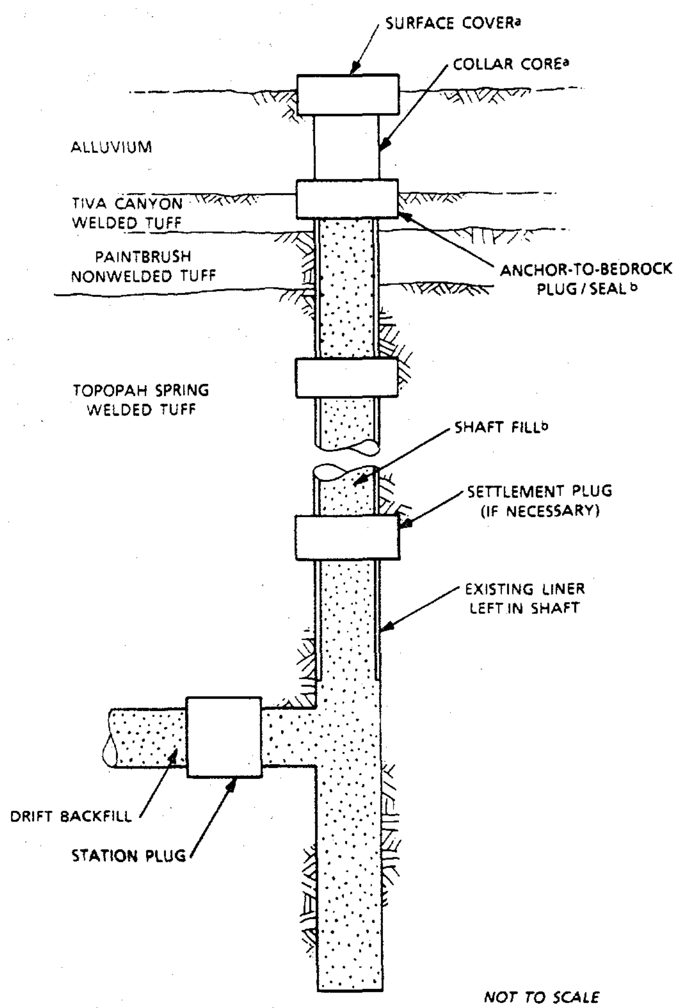


Figure 3-8. General arrangement for shaft seals.

3.2 THE WASTE PACKAGE

The waste package is defined in 10 CFR 60.2 and 10 CFR 960.2 as "the waste form and any containers, shielding, packing, and other absorbent materials immediately surrounding an individual waste container." For the Yucca Mountain site, the waste package consists of the waste form and a disposal container. Like the site and the repository, it is a component of the disposal system and, for the Yucca Mountain site, the principal engineered barrier.

The waste package would be designed to meet various functional and regulatory requirements, including those specified by the NRC in 10 CFR 60.113 and 60.135 (see Appendix A). Among these are the preclosure requirements for radiation protection and for maintaining the option to retrieve the emplaced waste. Also addressed by the design of the waste package would be the DOE's requirements in 10 CFR 960.5 that the production and the emplacement of the waste package be feasible with reasonably available technology, that the design of the waste package cannot make the application of reasonably available technology impractical for other portions of the repository system or operations, and that cost effectiveness be considered. For the postclosure period, the requirements include the performance objectives of providing substantially complete containment for the waste for a period of not less than 300 years and thereafter controlling the rate of radionuclide release from the engineered-barrier system. Contributing to the postclosure performance of the waste package would be the waste-emplacement environment, which is discussed at the end of this section, and the design of the waste-emplacement borehole, which will leave an air gap between the waste package and the host rock.

The description that follows is based on the detailed discussion of concepts and plans for the waste package in Chapter 7 of the SCP/CD. It should be noted that these concepts and plans are based on an early conceptual design--the SCP conceptual design. The design will continue to evolve as data from site characterization are obtained and the more-detailed phases of design are completed--the advanced conceptual design, the license-application design, and the final procurement and construction design.

The waste form is either spent fuel from commercial reactors or high-level waste. Most of the spent fuel would be consolidated at the repository or before shipment to the repository; the remainder would be disposed of as intact assemblies whenever fuel rods are damaged. The reference spent fuel is 10-year-old fuel from pressurized-water reactors (about two-thirds of all spent fuel) or boiling-water reactors (about one-third of the spent fuel). With a nominal burnup, the consolidated 10-year-old fuel will have a thermal decay power of about 3.3 kilowatts and a gamma dose rate at the outer surface of the container of approximately 5×10^4 rads per hour. The neutron dose rate will be about 1×10^4 neutrons per square centimeter per second. However, some spent-fuel packages will have thermal decay powers as low as 1.0 kilowatt.

The high-level waste, from both defense and commercial sources, would be in the form of borosilicate glass vitrified in stainless-steel canisters. The reference high-level-waste package will have a thermal power level in the range of 200 to 470 watts, depending on the source of and the age of the reprocessing wastes in the glass matrix. The gamma dose at the outer surface of the disposal container will be about 5.5 x 10^3 rads per hour, and the neutron dose rate is expected to be very low.

In the SCP conceptual design, the reference disposal container for both waste forms is a metal cylinder with an outside diameter of 26 inches. The walls of the container would be about three-eighths of an inch thick; the thickness was chosen to provide the strength necessary for handling. The length would vary from 10.5 feet for high-level waste (Figure 3-9) to about 15.5 feet for spent fuel (Figure 3-10). An alternative design that is being considered would include a ceramic liner inside the container.

In the SCP conceptual design, the reference material for the disposal container is 304L stainless steel, but other metals are being considered; they include Alloy 825 and three copper alloys. If another metal is selected, the thickness of the container walls would depend on its resistance to corrosion and its strength. After being loaded with the waste, the disposal container would be filled with an inert gas to provide a nonoxidizing environment, and the top of the container would be welded on. The top would have a fixture for lifting and lowering the container. A loaded container would weigh from 6000 to 14,000 pounds, depending on the quantity and the type of waste.

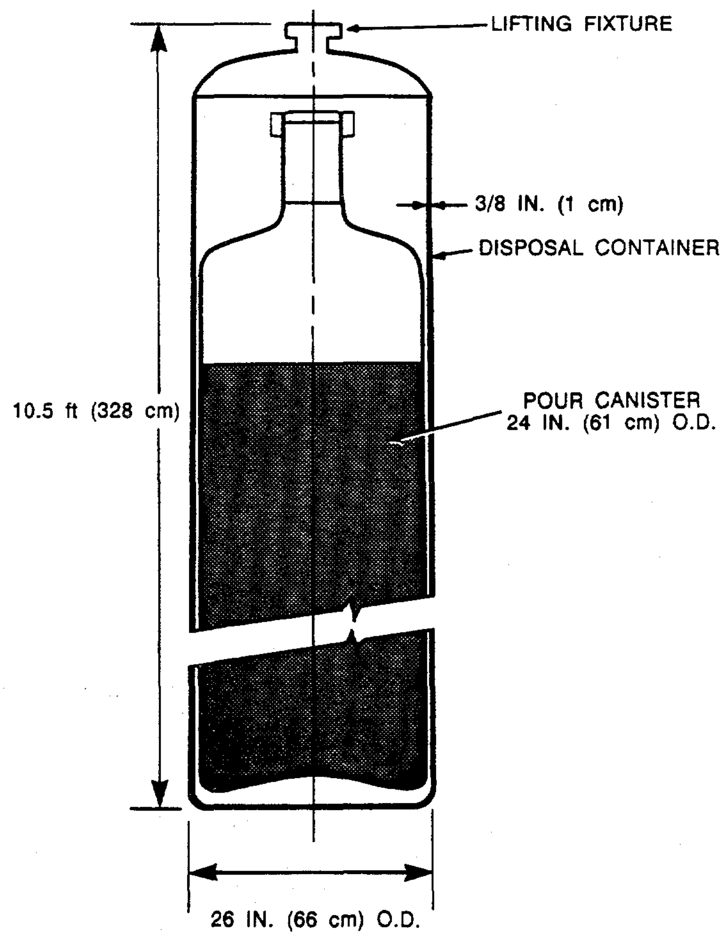


Figure 3-9. Waste package for high-level waste.

The containers for spent fuel would contain steel compartments designed to keep the spent fuel in a stable position and to help in loading the containers. To accommodate different types of spent fuel and to accommodate both consolidated and unconsolidated fuel, four arrangements for these compartments have been designed (Figure 3-11). In the two arrangements for consolidated fuel, the middle of the container is used for the hardware left after stripping the fuel rods from the assembly. To protect the spent fuel from oxidation, the container would be filled with argon gas before it is welded closed.

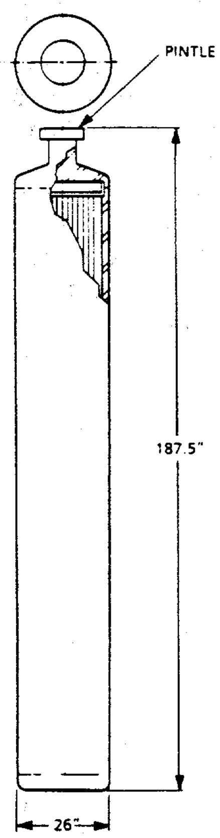


Figure 3-10. Waste package for spent fuel.

Neither fabrication nor closure processes for the disposal containers have been selected. However, rolled and welded pipe-manufacturing processes are representative of the conventional type of fabrication that may be involved in manufacturing the disposal containers. Many more-advanced techniques are under consideration.

The unsaturated rock of the Topopah Spring tuff would provide a waste-emplacement environment that would be favorable for the long-term performance of the waste package. For example, the pressure exerted on the disposal containers would be approximately 1 atmosphere. There would be no hydrostatic pressure because the repository would be located above the water table, and the waste packages would not bear a lithostatic load because the host rock is not expected to creep. The water available for the corrosion of containers

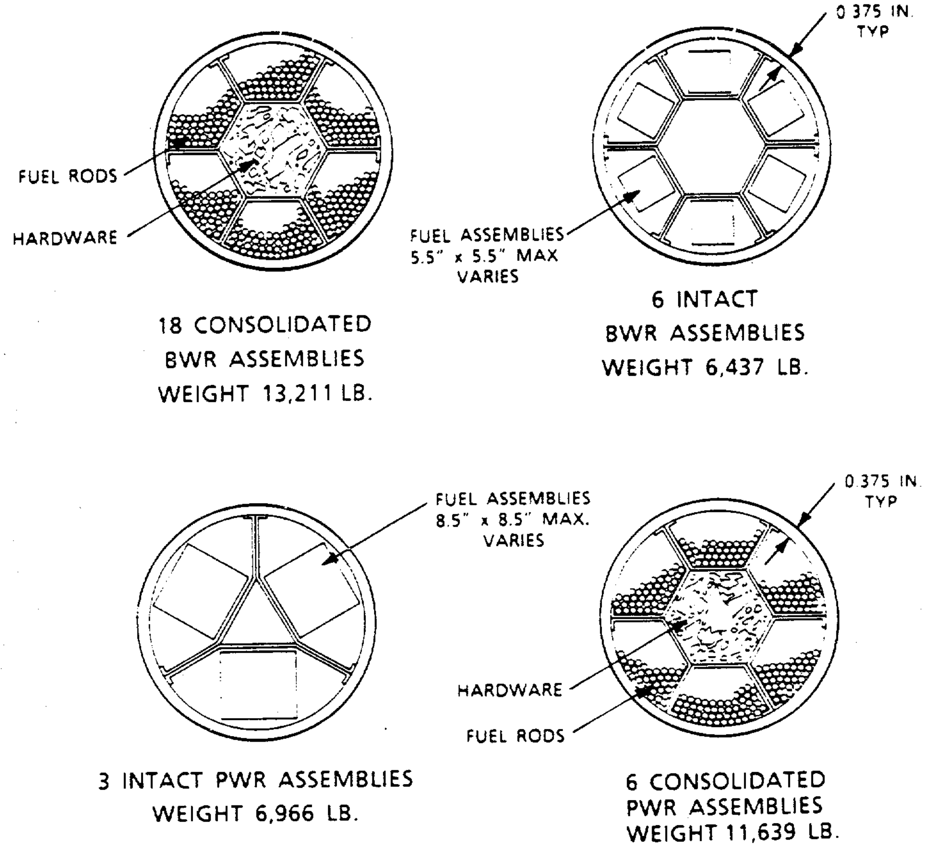


Figure 3-11. Alternative configurations for consolidated spent fuel.

and the dissolution of the waste form would be limited to very small amounts. Furthermore, during the first several hundred years, the heat emitted by the waste would dehydrate the host rock in the vicinity of the waste packages, preventing liquid water from coming into contact with the disposal container. This dried-out zone is predicted to extend more than 3 feet from the borehole into the rock and to remain dry for at least 300 years. A detailed discussion of the conditions expected in the waste-emplacement environment is given in Section 7.1 of the SCP/CD.

4. THE SITE-CHARACTERIZATION PROGRAM

Before any site can be recommended for development as a repository, it will be necessary to demonstrate that the performance of a repository at that site is likely to meet or exceed regulatory requirements. In order to do this, extensive information describing the site must be collected; designs for the repository, the seals, and the waste package must be developed; and the performance of the disposal system must be assessed. To collect the needed information, a carefully planned site-characterization program will be conducted. Such a program is required by the Act, by the NRC in 10 CFR Part 60, and by the siting guidelines (10 CFR Part 960).

The details of the site-characterization program planned for the Yucca Mountain site are presented in Chapter 8 of the SCP/CD, including the straegies for demonstrating regulatory compliance, the data needed for carrying out the strategies, the programs that will collect and analyze the needed data, and the field activities that will take place at and near the site. This chapter of the overview summarizes the strategies and reviews the programs that will collect and analyze the needed data. The field activities to be carried out during site characterization are briefly described in Chapter 5 of this overview.

This chapter begins, in Section 4.1, with a "top-level strategy" that identifies the general objectives for the disposal system and provides a simple explanation of the role the principal features of the Yucca Mountain site are expected to play in meeting these general objectives. This top-level strategy provides the framework by which to understand the detailed strategies for demonstrating regulatory compliance.

Section 4.2 briefly explains the two organizing principles for the SCP--a hierarchy of issues, which embody the regulations that govern the disposal system, and a general procedure for resolving those issues. This explanation is needed for understanding the discussion in Section 4.3, which is a highly compressed summary of the detailed strategies for resolving the issues and thereby demonstrating compliance with the regulations. The remaining sections of Chapter 4 then proceed to summarize the principal parts of the program. Section 4.4 reviews the plans for gathering and interpreting data describing the properties of the site. Organized by technical discipline, it discusses both the collection of data and the models in which these data will be used. Section 4.5 reviews plans for the development of the design for the repository and for the analyses that will support the design. Section 4.6 reviews plans for designing the seals for the repository; it also reviews the tests needed for developing the designs. Section 4.7 reviews the activities planned for designing the waste package and for the supporting analyses, including the tests needed to define the environmental conditions in which the waste package will reside after emplacement in the host rock.

The last section in this chapter, Section 4.8, reviews the analyses that will assess the performance of the disposal system, both for the period preceding permanent closure and for the much longer time after closure.

4.1 TOP-LEVEL STRATEGY FOR THE YUCCA MOUNTAIN SITE

This section presents the "top-level strategy"--a brief explanation of the role the features of the Yucca Mountain site are expected to play in achieving the general objectives for the system. As a consequence of this role, as will be explained, the program for characterizing this site puts considerable emphasis on the flow conditions in the unsaturated rocks in which the waste would be emplaced. It also emphasizes the geochemistry and other characteristics of the unsaturated rocks that could affect the performance of the waste packages, characteristics that could affect the radionuclide transport through the unsaturated rocks, and the geohydrologic characteristics of the saturated rocks deep beneath the site, as well as unlikely processes and events that could significantly affect these characteristics. The top-level strategy also emphasizes preclosure radiation safety and the effects of seismicity on the surface and underground facilities. This section discusses the basis for the emphasis on these areas in the site-characterization program.

The principal role of a disposal system is to isolate waste for a long period into the future. Therefore, the general objective for the system is to limit any radionuclide releases to the accessible environment. This objective will be achieved by selecting a site with suitable natural barriers to radionuclide release and by providing an appropriate system of engineered barriers. To provide additional assurance that the system will perform adequately, individual objectives have also been defined for these engineered and natural barriers and for the design of the disposal system. The general objective for the engineered barriers is that these barriers should effectively limit the release of radionuclides to the natural barriers. The general objective for the natural barriers is that the time of radionuclide travel to the accessible environment through these barriers should be very long. In particular, since ground water may transport radionuclides, the ground-water travel time should be very long. The general objectives for the design of the disposal system are that the operation of the repository should be safe and that its construction should not compromise its ability to meet the other general objectives.

These general objectives are compatible with the regulations promulgated by the NRC in 10 CFR Part 60. In these regulations, the NRC specifies postclosure-performance objectives, including the environmental standards set by the Environmental Protection Agency for releases to the accessible environment, individual protection, and ground-water protection; requirements on the containment to be provided by the set of waste packages and on the rate of release of radionuclides from the engineered-barrier system; and an objective for the pre-waste-emplacement ground-water travel time. The regulations also specify design criteria to ensure that the postclosure-performance objectives would be met and set preclosure-performance objectives for radiation protection. The detailed strategies for addressing these regulations are presented in Sections 8.1, 8.2, and 8.3 of the SCP/CD. The remainder of this section describes the top-level strategy for addressing the general objectives for the disposal system.

4.1.1 General objective for the disposal system

The major system elements that are expected to affect waste isolation at the Yucca Mountain site can be seen in Figure 4-1. As explained in Section 2.3.3 of this overview and in Chapter 3 of the SCP/CD, the currently available information suggests that small amounts of water are available to percolate slowly downward through Yucca Mountain. If the Yucca Mountain site is developed for a repository, water that moves through the unsaturated rock above the repository could continue down to the unsaturated rock unit in which the underground repository would be constructed. If any of this water could reach the emplaced waste, it might dissolve radionuclides and carry them in solution through the unsaturated rock below the repository to the saturated rock deep beneath the site. After reaching saturated rock, the water joins the much larger, horizontal flow there; therefore, radionuclides that are carried by the water could be transported by the flow in the saturated zone and move toward the accessible environment.

To reach the emplaced waste, the water would have to penetrate the engineered-barrier system. Figure 4-1 is not detailed enough to show the elements that compose the engineered-barrier system. For the purposes of defining the top-level strategy, the major elements of this system are the container and the waste form inside the container. There would also be an air gap between the container and the wall of the borehole in which the container would be emplaced.

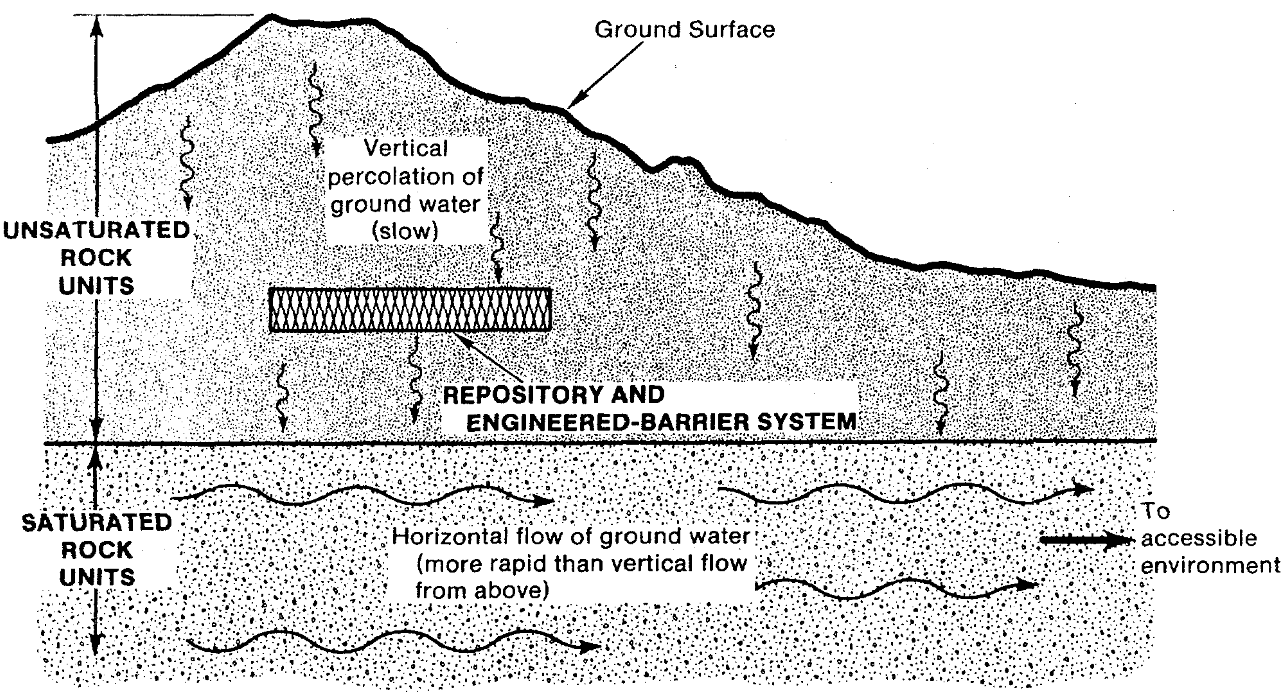


Figure 4-1. Schematic cross section through Yucca Mountain, showing the saturated and unsaturated rock, the repository (including the engineered-barrier system), and the principal paths of water flow.

This sequence of events--downward water movement, water penetration into the engineered-barrier system, downward transport of radionuclides to saturated rock, and horizontal transport--provides a way by which radionuclides could move from the Yucca Mountain repository to the accessible environment. According to the available evidence, the percolation flux at and below the repository horizon is very low. Furthermore, it appears that the percolation of water through the unsaturated rock units at this depth is primarily in the rock matrix rather than through fractures. If the water is tightly confined within the rock, as it appears to be, it would not be expected to move from the rock across the air gap to the waste container; the water would therefore not be expected to reach the waste. Furthermore, the results of preliminary studies suggest that the quantity of moving water is so small that any corrosion of the disposal container and the dissolution of radionuclides would be very limited even if the water could cross the air gap. The evidence also suggests that the movement of water in the rock matrix is very slow, and therefore the transport of any radionuclides dissolved in this water downward through the unsaturated rocks below the repository would be very slow. An additional characteristic of the unsaturated rock is the geochemistry of the water in the rock, which will determine the radionuclide dissolution and the retardation of radionuclide transport.

Therefore, the elements of the system that the DOE will investigate in the site-characterization program to evaluate the system with respect to the general objective are

- The unsaturated rock units.
- The saturated rock that lies below the unsaturated rock.
- The engineered-barrier system.

Concentrating on the characteristics of only one of these features, such as the slow movement of water through the unsaturated rocks below the repository, could reduce the cost of the site-characterization program. The DOE has decided, however, that it is prudent to consider initially the characteristics of all three of these features. Future evidence may show, for example, that the time of ground-water travel is shorter than currently estimated. If so, the DOE's strategy may need to focus on the other features. Choosing all of these features is a way of dealing with the uncertainties in each of them; it ensures that the site-characterization activities, guided by the strategy, will collect the data needed to evaluate the site with respect to the general objective. Analyses conducted during site characterization may indicate that other features should be considered as well. Conversely, information obtained during site characterization may show that fewer features need be taken into account. In either case, the top-level strategy can be revised appropriately.

One further sequence of events might contribute to a release under the current conditions at Yucca Mountain. If the waste containers are breached, the radionuclides that exist in the waste in gaseous form might move upward through the air spaces in the unsaturated rock above the repository. They might then reach the accessible environment at the ground surface above the repository. The available information is not complete enough to decide definitively whether this sequence is capable of producing significant releases. It is not clear, for example, that the waste form can release gaseous radionuclides rapidly enough or in sufficient quantities for the release to be important. The DOE will evaluate the potential for gaseous releases to determine the significance of this mode of release. The elements of the system that may affect gaseous releases at the site are the unsaturated rock above the repository and the engineered-barrier system. The current evidence is not sufficient to indicate whether the unsaturated rock would be effective. The available evidence does suggest, however, that the waste form is likely to allow only negligible amounts of volatile radionuclides to escape. The top-level strategy therefore focuses primarily on the ability of the engineered-barrier system to limit the rate at which gaseous radionuclides are released.

4.1.2 General objective for performance of the engineered-barrier system

The general objective for the engineered-barrier system is to limit the release of radionuclides to the natural barriers. In the top-level strategy the DOE has chosen to focus on three particular components to evaluate the performance of the engineered-barrier system:

- The container.
- The air gap between the container and the host rock.
- The waste form.

The container is expected to provide the principal barrier to the release of radionuclides from the engineered-barrier system. This barrier will be designed to provide substantially complete containment of the wastes during the early period when the heat and radiation emitted by the waste are at their peak. The limited availability of water in the unsaturated zone is expected to contribute to the ability of the container to limit the release of radionuclides to the natural barriers. In addition, the container materials will be chosen to be compatible with the geochemistry of the water in order to limit the degradation of containers in contact with any water.

The air gap between the container and the host rock is expected to increase the ability to limit the release of radionuclides. That is, because the percolation flux is expected to be low and because the water is expected to be tightly confined to the rock matrix, little water would be able to leave the rock and cross this air gap. Therefore, the amount of water available for contact with the waste packages is expected to be even less than the small amount in the host rock.

The waste form is chosen as an additional barrier to limit the rate of radionuclide release from the engineered-barrier system. Because of the low probability of early container failure and because of the small quantities of water available for waste-form dissolution and the leaching of radionuclides, the spent fuel or the glass matrix of the high-level waste is expected to limit the rate of release.

4.1.3 General objective for performance of the natural barriers

As explained above, the geologic setting can contribute to the isolation of the waste and the overall system performance by providing for a long time of radionuclide travel to the accessible environment. The DOE has chosen to focus on two barriers to determine the radionuclide-travel time:

- The unsaturated rock below the repository.
- The saturated rock below the unsaturated rock.

The current evidence suggests that the time of ground-water travel from the candidate repository horizon through the unsaturated units to the saturated zone is longer than 10,000 years. Furthermore, many of the radionuclides important to waste isolation will have even longer time of travel than the ground water because of geochemical and mechanical retardation processes. Therefore, these units are expected to provide an effective barrier to radionuclide transport. According to the available evidence, the saturated rock units can add at least a few hundred years--and possibly a few thousand years--to the total time required for radionuclides to move to the accessible environment, and these units will also be evaluated in the testing program.

4.1.4 General objectives for the design of the disposal system

The general design objectives of ensuring safe operation and not compromising the ability to meet the other general objectives have a number of implications for the site-characterization program. In particular, the surface and underground facilities must be designed to withstand potential ground motion or surface rupture. The available evidence suggests that the design can accommodate the range of seismicity expected at the site. Information about the expected frequency and magnitude of earthquake-related activity at the site will be needed to support the detailed design.

The design of the repository system must also address preclosure radiation safety, both in the surface and the underground facilities. It is expected that standard techniques will be adequate for assessing preclosure radiation safety. Although these assessments will not rely heavily on the characteristics of the site, some site investigations will be conducted to support them.

4.1.5 Priorities for the site-characterization program

Priorities for the testing program can be inferred from the choices made for the top-level strategy; that is, the elements identified and the expected role of these elements with regard to the general objectives suggest the priorities for the investigations of the site-characterization program. The top-level strategy for addressing these objectives at the Yucca Mountain site leads to the following areas of emphasis:

- The flow characteristics of the unsaturated zone.

- The site characteristics (e.g., geochemistry) that affect waste-package performance and the transport of radionuclides in the unsaturated zone and the geohydrologic characteristics of the saturated rocks that lie beneath the unsaturated zone.

- Unlikely processes or events that could significantly disturb the characteristics of the site.

- Preclosure radiation safety and the effects of seismicity on the surface and underground facilities.

The top-level strategy focuses strongly on the investigations of the characteristics of the flow in the unsaturated zone, relying heavily on the current view that the percolation flux is low and that the water in the unsaturated zone is tightly confined within the rock matrix. If these concepts can be confirmed, then the general objectives for the system and those for the postclosure performance of the engineered and natural barriers are very likely to be met. Therefore, the investigations of these concepts have the highest priority in the program. As a part of these investigations, the program will address alternative concepts, including flow in the fractures, the diversion of flow at rock interfaces, and the effect on the flow of structural features such as faults. The ability of the unsaturated rock to hold the water and to limit water contact with the waste packages will also be investigated.

Other site characteristics will also be investigated. That is, because of uncertainties are expected to remain in the flow characteristics of the unsaturated zone and to add confidence that the general objectives will be met, the top-level strategy also places emphasis on other characteristics of the site as discussed above. Therefore, at a somewhat lower level of priority, the program will give attention to the geochemistry and other characteristics of the unsaturated rocks that may affect the performance of the waste packages, those that may affect the transport of radionuclides in the unsaturated rocks, and the geohydrology of the saturated rocks deep below the site.

The site-characterization program must also investigate unlikely processes and events that could significantly affect site characteristics. For example, the possibilities for extreme climatic changes and faulting will be investigated to evaluate effects on percolation, local flux, and the elevation of the water table in relation to the repository horizon. The probability of occurrence and the potential effects of volcanism on the characteristics of the site will also be investigated.

The design of the disposal system must address preclosure concerns like the effect of seismicity on the design of the surface and the underground facilities. This concern is one of the most important at the site. Accordingly, the DOE is planning an extensive program to investigate seismicity that could affect the site. This program will evaluate the probability and the magnitude of ground motion and the potential for surface rupture at the Yucca Mountain site.

The investigations that will address these areas are discussed in Sections 8.3.1 through 8.3.4 of the SCP/CD. The organization, focus, and logic for these investigations are defined in the specific issue-resolution strategies that derived from the top-level strategy; these specific strategies are summarized in Section 8.2 of the SCP/CD and given in detail in Section 8.3.5 of the SCP/CD.

4.2 THE ISSUES HIERARCHY AND THE ISSUE-RESOLUTION STRATEGY

To ensure that all the required information will be available when needed, the DOE has developed two organizing principles for site characterization--the issues hierarchy and a general strategy for issue resolution. This section briefly discusses these principles; a more detailed discussion is given in Section 8.1 of the SCP/CD. Section 4.3 explains how they have been applied to planning site characterization at Yucca Mountain.

4.2.1 The issues hierarchy

The issues hierarchy is a three-tiered framework that lays out what must be known before a site can be selected and licensed. The highest tier consists of four "key issues," which are derived from the system guidelines in the DOE siting guidelines (see Appendix A); since the system guidelines are based on the EPA and NRC regulations in 40 CFR Part 191* and 10 CFR Part 60, respectively, the key issues embody the principal requirements of the regulations governing repositories.

There are four key issues. The first addresses the postclosure performance of the disposal system--that is, the general objectives discussed in Section 4.1. The second key issue addresses the safety of repository operations before closure. The third key issue addresses environmental and socioeconomic concerns. It is not considered in the SCP; plans for its resolution will be presented in other planning documents, with full opportunity at several stages for review and comment by interested parties. The fourth key issue addresses the ease and cost of repository construction, operation, closure, and decommissioning.

Each key issue is followed, in the second tier, by a group of issues related to performance and design. The performance issues generally address specific questions about compliance with regulatory requirements. They identify the information on site characteristics and design that is needed to assess the performance of the disposal system. The design issues address the information needed for the design of the repository, seals, and the waste package in the area defined by the key issue. In constructing each group of

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*The U.S. Court of Appeals for the First Circuit has vacated and remanded to the EPA for further proceedings the environmental standards for the disposal of spent fuel, high-level waste, and transuranic waste (Subpart B of 40 CFR Part 191). Some of the plans described in the consultation draft of the SCP were specifically designed to furnish data needed for demonstrating compliance with those standards as promulgated by the EPA in 1985. The basic information needed to demonstrate compliance with any disposal standards eventually promulgated by the EPA is expected to remain substantially the same, and therefore the approach to testing set forth in the SCP is expected to remain substantially the same. Nevertheless, any changes that may be made by the EPA to its standards will be evaluated by the DOE to ensure that the planned testing program will be adequate.

issues, an effort was made to include all the questions that must be answered to resolve the key issue.

The third tier consists of "information needs," which identify the technical information needed to answer the questions posed by the performance and the design issues. In developing the information needs, the DOE attempted to identify all the important information necessary for resolving the issues.

The issues hierarchy provides a framework for the site-characterization program and for explaining why the program is adequate and necessary. It also provides a forum for interactions between the DOE and the NRC on critical questions about the design and the performance of the disposal system.

Full statements of the three key issues that are addressed in the SCP, the associated issues, and the site-specific information needs that have been identified for the Yucca Mountain site are given in Appendix B.

4.2.2 The approach to issue resolution

To resolve the issues in the issues hierarchy, the DOE has adopted a general approach that guides the development of specific plans for resolving each issue. This approach is a procedure consisting of three principal parts: issue identification, performance allocation, and investigations.

Issue identification

Issue resolution begins with the identification of regulatory requirements, and from the requirements the issues are derived. A detailed description of the disposal system is also necessary.

Performance allocation

The second part of the general approach, called "performance allocation," provides the rationale for establishing particular site-characterization activities. It starts by using available information to develop a "licensing strategy"--a statement of the site features, engineered features, conceptual models, and analyses that the DOE expects to use in resolving the issue. The statement is called a "licensing strategy" because the combined statements developed for all the issues are the basis for current plans to show compliance with regulations. At present, the licensing strategy is preliminary: not enough information is available for a definitive plan, because site characterization is only beginning. But the strategy is sufficiently developed to guide planning for the tests and the analyses that are at present deemed to be necessary. Further development of the strategy will take place after the DOE has received and considered comments from the NRC and the State of Nevada and completed its own internal review.

The principal product of this licensing-strategy step is a statement of the disposal-system elements that the DOE currently intends to rely on in resolving the issue. This statement addresses the expected functions of these elements and the processes or factors that could affect those functions. The site-characterization program will investigate these elements to determine whether the disposal system will comply with the applicable regulations.

To guide the site-characterization program more explicitly, "performance measures" are established for the elements identified in the preceding step. These measures are system variables that describe the performance of the elements in the licensing strategy. Each performance measure is assigned a value called a "tentative goal." This tentative goal is not a "goal" in the sense that it must be met; it is simply a guide for developing a testing program, and it can be changed or even discarded once the testing program has been established. The goal is a conservative estimate that is consistent with a favorable resolution of the issue and the available information about the site.

Performance allocation then develops specific "information needs," which are the types of information needed to resolve the issue. The information needs include sets of parameters that will be used to evaluate the performance measures, the models needed for the evaluation, and other information needed to understand the characteristics of the site in terms of the issue.

Investigations

After plans have been developed for supplying the information needs, the next step is to proceed with the investigations called for in the plans. As soon as data become available from the investigations, analyses of the results begin; as more data are collected, the analyses continue, throughout site characterization and beyond. These analyses include the evaluations needed to resolve the issues. The collection of information continues until all of the information needs defined in the performance allocation have been satisfied. The information is then used in a concluding set of analyses to resolve the issues, and the resolution is documented.

Application

The entire issue-resolution procedure is intended to be iterative. For example, the licensing strategy or the goals for some performance measures may be changed in response to comments from the NRC or the State of Nevada or as new information becomes available or internal reviews provide new insights; if they are changed, the steps that follow will also be reexamined and their products revised. The analyses of the results of the investigations may produce new understandings that require the rethinking of earlier steps. Any of the steps may lead to revisions of earlier steps.

Dealing with uncertainty during performance allocation

An important objective of the planning for the site-characterization program is to identify and reduce uncertainties in the information about the disposal system. During performance allocation these uncertainties are addressed, in part, through the application of the multiple-barrier concept, the use of conservatism, and the consideration of alternative interpretations of existing information.

The use of multiple barriers to protect the public against the hazards posed by radioactive waste is embodied in the regulations governing separate elements of the disposal system. Since the issues hierarchy and the issue-resolution procedure address these individual requirements, the plans for site characterization do as well. In addition, the performance allocation for individual issues generally relies on multiple elements of the disposal system and on multiple processes operating within the elements.

Decisions about the reliance to be placed on elements of the system have been made conservatively. In other words, the decisions generally rest on underestimates of the performance of the elements. This practice provides additional assurance that the performance of the system is likely to meet or exceed the regulatory requirements.

In considering alternative interpretations of the existing information about the site, the DOE has used alternative conceptual models of systems and processes that are not well understood. For some issues this practice has led to alternative performance allocations. Alternative design considerations have also been part of planning site characterization.

4.3 STRATEGIES FOR THE YUCCA MOUNTAIN SITE

The DOE's general approach to issue resolution has been applied to each issue in the issues hierarchy, and site-specific information needs have been developed for the Yucca Mountain site. An overview of these strategies and the key information to be provided by the site-characterization program is given below, first for performance issues and then for design issues. This overview provides a general summary of the strategies; detailed information about the strategies and the performance allocation for each issue is given in Sections 8.2 and 8.3 of the SCP/CD. A complete listing of issues and information needs is presented in Appendix B.

4.3.1 Postclosure strategies

Postclosure performance

The postclosure-performance issues address the regulations that directly relate to the postclosure performance of the repository system--that is, the regulations that are directly related to the ability of the repository system to isolate the waste from the accessible environment. Issues 1.1 through 1.6 (see Appendix B and Section 4.8 for a list of these issues) address the postclosure performance objectives of 10 CFR 60.112 and 60.113, issue 1.7 addresses the NRC's requirements in 10 CFR 60.137 for a performance-confirmation program, and issue 1.8 addresses the siting criteria of 10 CFR 60.122. Issue 1.9 addresses the postclosure siting guidelines of 10 CFR Part 960. (For the convenience of the reader, the NRC's technical criteria and the siting guidelines are reproduced in Appendix A.)

The DOE's general strategy for ensuring satisfactory postclosure performance for a repository at Yucca Mountain has been described in Section 4.1. Using this general strategy as a foundation, the DOE has developed strategies for the resolution of the individual postclosure-performance issues.

The top-level strategy described in Section 4.1 relies on the unsaturated rocks at the Yucca Mountain site, the rocks in the saturated zone below the unsaturated rocks, and the engineered-barrier system. These elements were selected for the strategy because they can be tested and because they can be expected to--

- Limit the amount of water that (a) can come in contact with the waste packages, (b) corrode the waste containers, and (c) dissolve or leach the waste.

- Limit the movement of water through the unsaturated zone toward the accessible environment.

- Provide geochemical retardation for radionuclide transport.

- Limit the release of radionuclides from the engineered-barrier system.

The issue-resolution strategies identify performance measures for the system and for the elements listed above. The performance measures for the entire disposal system are the ratios of radionuclide releases to the EPA release limits, radionuclide concentrations in ground water, and radiation doses received by members of the public in the accessible environment. Among the performance measures for individual elements of the system are the time of ground-water travel to the accessible environment, the fraction of disposal containers that are breached, and the rate of radionuclide release from the breached containers.

The information that is needed to evaluate the performance measures has been defined and organized in the issue-resolution strategies as information needs. It includes the percolation flux and the flow characteristics of the unsaturated rocks, the geohydrologic characteristics of the saturated zone below the water table, the geochemical characteristics of the water and the rocks in both the unsaturated and the saturated zones, and the characteristics of the disposal containers and the waste form. The information needed to evaluate the gas-phase transport of carbon-14 includes the mean residence time of carbon-14 as a gas in the unsaturated rocks.

The DOE has also identified the information needed to evaluate possible future changes in the conditions at the site. These information needs address possible changes in the percolation flux in the unsaturated zone, in the elevation of the water table, in geochemical conditions, and in the performance of the engineered-barrier system. In particular, the DOE has identified information needs addressing possible future changes in climate, volcanic eruptions through the repository, igneous intrusions into the repository, faulting or other tectonic activity, flooding of the repository, and human intrusion to the degree that these phenomena or events could affect the performance of the repository. Finally, the DOE has identified the information needed to evaluate the potential direct radionuclide releases that might result from inadvertent human intrusion into the repository or from natural processes, such as igneous intrusion.

Postclosure design

There are three postclosure design issues under key issue 1 (see Appendix B for complete statements of the issues): issue 1.10, which addresses the design criteria in 10 CFR 60.135 for the waste package; issue 1.11, which addresses the design criteria in 10 CFR 60.133 for the repository; and issue 1.12, which addresses the design criteria in 10 CFR 60.134 for shaft and borehole seals.

The strategy for waste-package design is directed at meeting the performance goals of providing radionuclide containment for a limited period and limiting the rate of radionuclide release for the full 10,000-year period of isolation. Performance goals for the waste package address the concentration of chemical species in the ground water that could come in contact with the waste package, the quantity of such water over time, and the maximum stresses that the host rock could impose on the waste packages. The site information that is needed for waste-package design includes the geochemical characteristics of the ground water in the unsaturated zone, the hydrologic characteristics of the host rock, and the host-rock thermal and mechanical properties that control the behavior of the emplacement holes over time.

The design strategy for the repository after closure is directed at providing a repository that does not adversely affect those characteristics of the site that provide favorable performance and, to the extent possible, contributes to the containment and the isolation of the waste. The strategy requires flexibility in the layout of the underground repository so that local geologic features and anomalies, if any, can be accommodated during the construction of the repository and the emplacement of the waste; limiting the introduction of water to the repository; limiting excavation-induced changes in hydraulic conductivity; and, in setting a design heat load for the repository, considering both the beneficial and the potentially detrimental effects of heat on waste isolation. Needed information about the site includes the local stratigraphic sequence and structure of the host rock in the areas proposed for waste emplacement, the thermal and mechanical properties of the host rock, and the response of the host rock to stress changes induced by excavation and heat.

The strategy for the design of the shaft and ramp seals is to reduce the amount of ground water that can reach the waste-emplacement areas and to limit any transport of volatile radionuclides through the shafts. Seals in the underground facility will be designed to contain and drain ground water entering the emplacement drifts and to divert ground water away from the emplacement holes. The seals of boreholes will be designed to drain water down, thus diverting it from the the repository. Among the information needed for design are data on the hydrologic conditions in the repository area, including the identification of water-producing zones and their hydraulic properties. Other important items are the geochemical conditions in the host rock and the ground water in the host rock as well as the thermal, chemical, mechanical, and hydraulic properties of materials that are candidates for seals.

4.3.2 Preclosure strategies

Preclosure performance

The DOE has also developed strategies for resolving the issues that are related to the preclosure performance of the repository: radiation safety before closure (issues 2.1, 2.2, and 2.3), the retrievability of the waste (issue 2.4), and the siting guidelines (issues 2.5 and 4.1).

Radiation safety requires limiting the radiation doses that could be received by members of the public or by repository workers under normal operating conditions or after accidents. The strategy for limiting doses is to rely on engineered systems that provide confinement and shielding for radiation (including the waste package) as well as operating procedures for waste handling.

In the radiation-safety strategies, performance goals are related directly to the requirements of the applicable Federal regulations (10 CFR Part 20, 40 CFR Part 191, and 10 CFR Part 960) for limiting doses. Since the strategy for protection from radiation relies mainly on the design, the role of geologic information is largely to support the design. The information required from site characterization includes the atmospheric-dispersion characteristics of the site, which would affect the radiation exposure of the public after airborne releases of radioactive material; the shielding properties of the host rock, which are needed to characterize the radiation environment in the underground facilities; and information on the likelihood and magnitudes of natural phenomena (e.g., earthquakes, rockfalls) that could imperil structures, systems, and components important to safety.

To meet the regulatory requirement for retrievability (10 CFR 60.111), the ability to retrieve the waste from the repository will be maintained for 50 years from the start of waste emplacement. The design strategy for retrievability is to maintain access to the emplacement drifts during the retrievability period and during the additional period of time that would be required for the actual retrieval. The goal for the waste-emplacement design for Yucca Mountain (borehole, metal liner, shield plug, and cover) is to allow the retrieval of waste packages under any credible conditions.

The primary concerns for retrieval are the potential for the waste packages to become "stuck" in the emplacement borehole and the ability of the host rock and the shielding collar to provide effective radiation shielding during waste removal. Key information includes the characteristics and behavior of the host rock in the immediate area of the emplacement boreholes.

Preclosure design

The preclosure design issues are related to performance requirements for radiation safety, retrievability, technical feasibility, and cost. In particular, they address the design and production of waste packages (issues 2.6 and 4.3), the design of the repository (issues 2.7, 4.2, and 4.4), and the total costs of repository development (issue 4.5).

The strategy for the resolution of the preclosure design issues is constrained by the waste-package design and the postclosure design requirements (discussed above). Within these requirements and constraints, the strategy for the design is based on adapting available nuclear and mining technology to maintain a safe environment for the workers and the nearby public while providing cost-effective waste handling, waste emplacement, and repository closure. The strategies for the design issues set safety and functionality goals for radiation protection, the stability and longevity of mined openings, working environments (e.g., temperature, humidity), water control, and functional layout. The resolution of the repository-design issues requires information about the characteristics of the host rock, including the existing stress and temperature conditions, thermal properties, strength and deformation properties, the characteristics and locations of fractures and faults, the ground-motion potential, excavation characteristics, the basic orientation and thickness of portions suitable for waste emplacement, the ability to use reasonably available technology, and estimated costs.

4.3.3 Link to the site-characterization program

The issue-resolution strategies developed for the Yucca Mountain site have been used to identify the information to be obtained by the site-characterization program, which has three parts: the site program; the repository, seals, and waste-package design programs; and the performance-assessment program. Brief descriptions of these programs are given in the sections that follow.

The various activities conducted in the site program will be documented in site-investigation reports. These reports will continue to update and extend the data base available for use in design and performance-assessment activities. When designs and calculations are sufficiently mature, topical reports and, finally, issue-resolution reports will document the preliminary basis for seeking the NRC's concurrence that various regulatory and technical requirements can be met. Thus, by acquiring the site data and other information necessary for the resolution of performance and design issues, the DOE will systematically establish the basis for demonstrating compliance with the major technical and regulatory requirements.

4.4 SITE PROGRAM

The site program consists of the investigations planned to obtain the site information needed for the resolution of performance and design issues, including the demonstration of compliance with the NRC's siting criteria and higher-level findings for the DOE's siting guidelines. The rationale for identifying the information that is needed has been described in Section 4.2. The program is described in Section 8.3.1 of the SCP/CD.

As shown in Table 4-1, the site program is divided into the 16 characterization programs. The topics covered by these programs are based on the intended use of the data in issue resolution. Thus, for example, there are separate programs for preclosure and postclosure tectonics. Brief descriptions of the 16 programs are presented in the sections that follow.

4.4.1 Geohydrology

The geohydrology program is described in detail in Section 8.3.1.2 of the SCP/CD. Its purpose is to provide, for the resolution of the performance and design issues, information about geohydrologic characteristics, processes, and conditions.

The general approach to satisfying the performance and design requirements is to develop a credible geohydrologic model. The geohydrologic model

Table 4-1. The investigations to be conducted in the site program

Characterization program	Investigation
Geohydrology	Regional hydrologic system Unsaturated-zone hydrologic system Saturated-zone hydrologic system
Geochemistry	Water chemistry Mineralogy, petrology, and rock chemistry Stability of minerals and glasses Radionuclide retardation by sorption Radionuclide retardation by precipitation Radionuclide retardation by dispersive, diffusive, and advective processes Radionuclide retardation by all processes Retardation of gaseous radionuclides
Postclosure rock characteristics	Strategy for integrated drilling program Geologic framework of the site Three-dimensional models of rock characteristics
Climate	Rates of change in climate Effects of future climate on hydrologic characteristics
Erosion	Locations and rates of surface erosion Effects of future climate on locations and rates of erosion Effects of future tectonic activity on locations and rates of erosion
Rock dissolution	None
Postclosure tectonics	Volcanic activity Waste-package failure due to tectonic events Hydrologic changes due to tectonic events Changes induced by tectonic processes in the geochemical properties of the rocks

Table 4-1. The investigations to be conducted in the site program (continued)

Characterization program	Investigation
Human interference	Activities that might affect surface markers and monuments Value of natural resources Effects of exploiting natural resources
Population density and distribution	Not described in the SCP
Land ownership and mineral rights	Not described in the SCP
Meteorology	Regional meteorological conditions Local meteorological conditions Atmospheric and meteorological phenomena at the site Population centers relative to wind patterns Extreme-weather phenomena
Offsite installations	Determination of nearby industrial, transportation, and military installations and operations Potential impacts of nearby installations and operations
Surface characteristics	Topography of potential locations for surface facilities[a] Soil and bedrock properties
Thermal and mechanical rock properties	Spatial distribution of thermal and mechanical properties Spatial distribution of ambient stress and thermal conditions
Preclosure hydrology	Flood recurrence intervals and levels Locations of adequate water supplies Ground-water conditions within and above the potential host rock
Preclosure tectonics	Volcanic activity Fault displacement Vibratory ground motion Preclosure-tectonics data collection and analysis

[a]This investigation has already been completed.

will have three components: a model for the unsaturated zone, a model for the saturated zone, and a model for the surface-water system. The model for the unsaturated zone will be developed only at the site scale, whereas the models for the surface-water system and the saturated zone will be developed at both site and regional scales. The geohydrologic model will then be combined with the geochemical model and thermal-mechanical model to produce the site model. Each of these three models will consist of both numerical and conceptual models. The numerical models include a description of the geologic and hydrologic framework, initial and boundary conditions, processes at work within the geologic and hydrologic framework, and a hypothesis describing their interrelationships.

To collect the necessary data during site characterization, the geohydrology program consists of three investigations directed at describing the present and expected hydrologic system of the region, the unsaturated zone at the site, and the saturated zone at the site. The results will be used to predict the paths and rates of ground-water travel through the saturated and unsaturated zones; this information is important in assessing the performance of the total system in limiting the release of radionuclides to the accessible environment. Information from these investigations will also be used to help evaluate scenarios in which the performance of the repository is disturbed by various postulated processes or events.

The objective of the regional investigation is to describe the regional hydrologic system by developing models of hydrologic flow. Specific studies will collect data on the meteorological conditions in the region surrounding Yucca Mountain, runoff and steamflow, and the regional system of ground-water flow. The subjects of these studies will include regional potentiometric levels, ground-water recharge at Fortymile Wash, and evapotranspiration. Regional hydrochemical tests and analyses will also be performed.

The investigation of the hydrologic system in the unsaturated zone at the site will be directed at defining ground-water flow paths and calculating ground-water fluxes and velocities in the unsaturated zone. The results will be used to develop conceptual and numerical models that can be used to assess the combined effects of heat, water, and gas flow under present conditions and the conditions expected for the next 10,000 years. Specific studies will cover water infiltration and percolation; the movement of gases in the unsaturated zone; hydrochemical characteristics; and hydrologic mechanisms, including the flow mechanism in the rock mass (flow through fractures versus flow through the rock matrix) and flow associated with faults and bedding planes in the rocks. Of particular importance will be studies conducted in the exploratory-shaft facility (see Chapter 5), especially studies directed at characterizing the flow of ground water in and around fracture zones at the contacts between stratigraphic units. Supporting studies in the laboratory will investigate the hydraulic conductivity of the tuff matrix, the permeability of fractured tuff at the pressures and temperatures expected in the repository, and the water potential of a partially saturated tuff matrix at the expected temperatures.

Similarly, the investigation for the saturated zone is planned to produce models that can be used to calculate the paths, fluxes, and velocities of ground-water flow between the unsaturated zone and the accessible environment. Specific studies will collect data to characterize the ground-water flow system, including tests to determine the elevation of the water table, the hydraulic gradient, and the hydrochemistry of the saturated zone.

4.4.2 Geochemistry

The geochemistry program is discussed in detail in Section 8.3.1.3 of the SCP/CD. It is designed to provide the information necessary for developing a site geochemical model and to supply the geochemical information needed for the resolution of performance and design issues.

The development of a site geochemical model requires data on the configuration of the potential transport pathways in the rock matrix, fracture networks, fault-zone rock mass, and distribution coefficients for radionuclide species for all rock units within the controlled zone. The necessary data will be obtained by integrating the results of sorption studies with those of dynamic transport and diffusion studies. The information needed for the resolution of performance and design issues includes information from the geohydrology program on ground-water flow in saturated-zone units, values for hydrodynamic dispersion, and the solubility limits of chemical species associated with the liquid and gas-phase radionuclides. To evaluate present ground-water conditions as a basis for predicting future changes in ground-water chemistry, a ground-water chemistry model is being developed. The ground-water chemistry model, a conceptual model of mineral evolution, and data on sorption as a function of solid-phase composition will be used in sensitivity analyses to establish the factors controlling water composition.

Eight investigations are included in the geochemistry program. One addresses water chemistry within the potential emplacement horizon and along flow paths to the accessible environment; one of its objectives is to develop the ground-water chemistry model. The second investigation addresses mineralogy, petrology, and rock chemistry in the potential emplacement horizon and along flow paths to the accessible environment. The third investigation is concerned with the stability of minerals and glasses; it is directed at developing a conceptual model of mineral and glass evolution at Yucca Mountain to predict future mineral evolution through both natural processes and the thermal loading induced by the waste emplaced in the repository. The remaining five investigations will develop a data base on radionuclide retardation along flow paths to the accessible environment. They will include laboratory studies of radionuclide retardation by sorption; precipitation from solution; and the physical processes of dispersion, diffusion, and advection. The results of the laboratory studies of radionuclide retardation will be integrated, by means of numerical models, to address retardation by all processes along flow paths to the accessible environment. Three-dimensional transport models and other multidimensional process codes will be used in this effort to determine, characterize, and quantify the cumulative effects of all significant processes, physical and geochemical, acting on or controlling radionuclide transport at Yucca Mountain. The last investigation in the geochemistry program will investigate the retardation of gaseous radionuclides. Potential retardation mechanisms for gaseous radionuclide species will be identified and used to estimate rates of transport.

4.4.3 Postclosure rock characteristics

The program on postclosure rock characteristics is described in Section 8.3.1.4 of the SCP/CD. It is designed to provide the geologic and geophysical site data needed to develop a three-dimensional physical-property model and to supply the rock-characteristics data needed by performance and design issues. Its results will be used in the design of underground facilities and in predicting the time of ground-water travel, the lifetime of the waste packages, and the rates of radionuclide releases from the engineered-barrier system to the accessible environment. Also included in this program is the development of an integrated drilling program for all of the site-characterization activities.

The three-dimensional physical property model will generate a computer-based three-dimensional representation of the physical properties of rocks at the Yucca Mountain site. It will relate the geologic framework to the physical properties of rocks and integrate the results of the geologic, geohydrologic, geochemical, and thermal-mechanical models. The data base for the model will contain the distribution of parameter values for the physical properties in the property-dependent rock units. The model will summarize the geologic, hydrologic, geochemical, and thermal mechanical information for use in the resolution of the design and performance issues.

The physical-property model requires information on material properties, geometry, assumptions and hypotheses, and initial and boundary conditions. The model will be used to predict how a physical property changes spatially within and across the boundaries of the model, where the boundaries represent distinct changes in a property. The location of the physical-property boundaries will be based on the results of geologic and geophysical studies as well as the physical-property data from core samples. The geologic complexity of the Yucca Mountain site may cause large uncertainties in the variation of the properties between sample locations. Various interpolation methods will be used to estimate the variation in the value of a rock property between sample locations. The end use of the rock-property data determines the degree to which it is important to know precisely how a particular property varies with the distance from the sample location. Thus, the nature and the number of the rock-property investigations to be conducted during site characterization will depend on the level of confidence required for the numerical models that use the physical properties.

As shown in Table 4-1, three investigations are planned for the rock-characteristics program. One of these investigations will develop the physical-property model discussed above. Another will assess the geologic framework of the site. This investigation will use geophysical surveys, tests of magnetic properties, and stratigraphic correlations to help characterize the vertical and horizontal distribution of stratigraphic units. To help characterize the structural features of the site, geologic mapping in the exploratory-shaft facility and studies of the surface-fracture network will be used. The planned geologic and geophysical studies are intended to identify correlations between the properties of interest that can be directly measured and properties of interest that must be estimated. The results of the geologic studies will therefore be used to calibrate the geophysical data and provide additional sources for correlating parameter information.

Also included in the rock-characteristics program is the development of the strategy for all of the drilling to be conducted during site characterization. The siting of proposed boreholes is currently based on two strategies: (1) to characterize anomalies and gather data on underground conditions by siting boreholes to sample known or inferred features of interest and (2) to obtain a statistical distribution for needed parameters by random or gridded borehole siting to sample an entire volume of interest, without the consideration of specific geologic features. The overall purpose of the integration of drilling activities is to most efficiently meet the needs of the repository project.

The integration of borehole siting, sampling, and testing has several objectives that will be optimized by considering applicable tradeoffs: (1) coordinating sampling and testing programs to eliminate unnecessary sampling and testing; (2) ensuring that drilling and sampling methods meet applicable technical, regulatory, and scientific requirements; (3) maximizing the cost effectiveness of the drilling program; and (4) maximizing the returns from drilling to increase both the sampling of the underground volume of interest and data returns from in-situ monitoring. In addition, the integrated drilling program has the important objective of resolving various regulatory and technical questions, such as the potential alteration of surface and underground conditions at the site and the potential for creating preferential pathways for ground-water flow. In particular, the activities planned for the integrated drilling program will (1) develop and apply technical and regulatory positions on drilling through the potential waste-emplacement area; (2) analyze the potential effects of water-based drilling fluids on the unsaturated zone; (3) assess the effects on design and performance assessment if core samples cannot be obtained from the repository horizon and underlying strata because of items 1 and 2; (4) investigate alternative scheduling or alternative methods for drilling and coring; and (5) apply statistical methods to existing data to help determine the need for, and the potential siting of, future drillholes.

4.4.4 Climate

The details of the climate program are given in Section 8.3.1.5 of the SCP/CD. The program is designed to provide the climate information required for the resolution of performance and design issues.

The investigations in the climate program are directed at predicting the effects of future changes in climate on hydrologic conditions and estimating the ranges of future climatic conditions. The analysis of paleoclimates and paleoenvironments will assess the long-term variability of paleoclimates and provide the basis for estimating future climatic episodes. This analysis will also provide the basis for determining the potential effects of future climatic conditions on hydrologic conditions. The determination of the nature, probability, and timing of future climate scenarios will be derived from either a linked global-regional modeling approach or a separate empirical modeling approach, or both.

The climate program consists of investigations designed (1) to provide data on past and present climate conditions as well as predict future climate conditions and (2) to determine the effects of climate change on surface hydrology, unsaturated-zone hydrology, and saturated-zone hydrology. The climate program will use hydrologic models developed in the geohydrology program to simulate future hydrologic conditions due to changes in climate. Thus the geohydrology program also provides information to the climate program.

4.4.5 Erosion

The erosion program is presented in Section 8.3.1.6 of the SCP/CD. The program will collect information on geomorphic processes and conditions at the site needed for design as well as to supply site-specific erosion data that are required for the resolution of postclosure-performance issues.

Because erosion is not believed to pose a hazard to waste isolation at Yucca Mountain, only four investigations, including three field activities, are planned. Additional data that are needed will be obtained through the analysis and further evaluation of available geomorphic data as well as data collected for the meteorology and the hydrology programs. Many of the necessary parameters have been obtained and evaluated as part of the ongoing scientific studies at the Nevada Test Site (NTS) in support of the weapons testing progam. In most instances, data are not site specific and therefore not adequate for the resolution of performance and design issues.

One of the investigations will collect site-specific data on Quaternary erosion and stream incision rates, which will be used to calculate average erosion rates on Yucca Mountain and to develop a history of the downcutting episode(s) of Fortymile Wash. The second investigation consists of studies to assess the potential effects of future climatic changes on locations and rates of erosion. Previously established regional erosion rates suggest that future changes in the climatic regime will not significantly affect upland and hillslope erosion rates. The third investigation will evaluate the effects of tectonic activity on the rates of erosion, and the fourth investigation will address the potential effects of erosion on the baseline hydrologic, geochemical, and rock characteristics at Yucca Mountain.

4.4.6 Rock dissolution

Because the findings made for the environmental assessment are adequate to meet the requirement for higher-level findings in the siting guidelines, no additional studies are to evaluate rock dissolution. The geochemistry program includes studies on mineral stability that will assess geochemical retardation along flow paths.

4.4.7 Postclosure tectonics

The purpose of the postclosure-tectonics characterization program is to supply data on the probability and effects of tectonic "initiating events" that could alter existing conditions at Yucca Mountain and may adversely affect the performance of the repository. Tectonics information will also be used to accommodate site-specific tectonic conditions in design concepts for the geometry, layout, and emplacement borehole locations of the underground repository.

In addition to characterizing the effects of tectonic processes, the program will provide the data necessary to estimate the rates at which these processes operated during the Quaternary Period. This information will then be used to provide the predictions of future rates necessary to satisfy the requirements of the performance and design issues. The tectonic processes that will be evaluated are volcanism, igneous intrusion, faulting, folding, uplift, and subsidence. The tectonics program will estimate the probability of significant tectonic events related to these processes during the post-closure period and evaluate the effects of these events on possible direct releases related to the event, the lifetime of waste packages, and on the possible alteration of hydrologic and geochemical parameters that govern radionuclide transport times and release rates.

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

As shown in Table 4-1, five investigations are planned under this program. The first four investigations are directed at estimating the probabilities and effects that can initiate the disturbed performance scenarios evaluated in postclosure-performance assessment. Because the analysis and interpretation of different tectonic initiating events call for the same type of data, data-gathering activities were grouped separately under a fifth investigation that feeds data as required to the analysis activities associated with the postclosure-tectonics program. Data gathered under the preclosure-tectonics program will also be used in these analysis activities.

4.4.8 Human interference

The details of the human interference program are presented in Section 8.3.1.9 of the SCP/CD. The program is designed to identify, analyze, and evaluate the potential human activities that could adversely affect long-term repository performance or lead to inadvertent intrusion into the repository. The program will support the resolution of design and performance issues by estimating the likelihood and the effects of potential human intereference. Included in the analysis will be the long-term survivability of the surface markers, the most suitable locations for the surface markers, the natural resource potential of the site, and the potential effects of future resource exploration or extraction.

Three investigations are currently planned for this program (Table 4-1). The first investigation will identify all events, both natural and anthropogenic, that could destroy or degrade the surface markers and monuments. To determine the best locations for surface markers and monuments, the analysis will consider the magnitudes and locations of fault ruptures and seismically induced ground motion; the rates, magnitudes, and locations of potential igneous activity; and the potential effects of tectonic activity and future climatic conditions on locations and rates of erosion and deposition.

The second investigation will identify all resources at the site that could be marketable in the future. At present, the only commodity to be classified as a resource in the immediate vicinity of the site is ground water. It is expected that exploitation of this resource will become economically feasible in the near future. Existing scientific and institutional data will be integrated with information obtained during the characterization of the saturated zone 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 reasonable foreseeable future. These parameters will be considered in calculating the probability for human interference and in assessing the potential effects of ground-water exploitation on the baseline conditions at the site.

The final investigation will examine the potential effects of resource extraction on the baseline hydrologic, geochemical, and rock characteristics to determine whether the potential effects of resource exploitation can so affect the baseline characteristics of the site that repository performance would be affected. Included in this investigation will be an analysis of the human-interference events that might be the initiating events of the release scenarios evaluated in postclosure-performance assessment; the objective is to determine whether they are sufficiently credible or significant to warrant further consideration.

4.4.9 Population density and distribution

Data on population density and distribution are needed for the resolution of performance and design issues related to preclosure radiation safety. Since the collection of data on population density and distribution is not considered a site-characterization activity as defined in the Nuclear Waste Policy Act, no specific investigations or activities are described for this program in the SCP/CD.

4.4.10 Land ownership and mineral rights

Land ownership and mineral rights must be established to support the resolution of both preclosure- and postclosure-performance issues and to make the higher-level findings on two DOE siting guidelines. Since the plans and procedures for determining land ownership and mineral rights are not part of site characterization as defined by the Nuclear Waste Policy Act, no specific investigations or activities are described for this program in the SCP/CD (Section 8.3.1.11).

4.4.11 Meteorology

The meteorology program is described in Section 8.3.1.12 of the SCP/CD. It is designed to provide a complete understanding of the meteorology of the area and to supply information on average and extreme weather phenomena. This information will support the resolution of performance issues: it will be used in calculating the radiation doses that could be delivered to the public by releases from the repository because wind is the mechanism for the transport of airborne radionuclides. Information on average and extreme weather phenomena (e.g., tornadoes, extreme wind speeds, and temperature extremes) will be used in the design of the surface facilities of the repository. In addition, meteorological data will be used in the geohydrology program.

The investigations planned for the meteorology program are divided into two categories: (1) those concerned with only site conditions and (2) those associated with regional meteorological conditions. To collect the needed data, a monitoring program consisting of five towers has been implemented at Yucca Mountain. To gain an understanding of the regional meteorological conditions, existing data bases will be evaluated and their applicability to Yucca Mountain determined. These data will be combined with data from the site program to produce a data set that represents the regional meteorological conditions.

4.4.12 Offsite installations

The program for collecting information on offsite installations and operations is described in Section 8.3.1.13 of the SCP/CD. It will provide the data needed for the resolution of preclosure-performance and design issues. This program, which consists of two investigations, will provide the data base necessary to estimate the probabilities and effects of potential offsite accident initiators. One of the investigations will identify all nearby industrial, transportation, and military installations and operations, both nuclear and nonnuclear. The second investigation will evaluate the potential impacts of those nearby installations and operations on the repository and its operations.

4.4.13 Surface characteristics

The surface-characteristics program is discussed in Section 8.3.1.14 of the SCP/CD. Its objective is to collect the data needed to site and design the surface facilities and underground openings, to demonstrate that the construction, operation, and closure of the repository will be safe and technically feasible, and to determine that the costs will be reasonable. This program consists of two investigations: topography and soil and bedrock conditions. No new studies are needed for topography, because the requirements for topographical data have been satisfied. The investigation of soil and bedrock properties consists of an exploratory program that will investigate and characterize the soils and rock strata beneath the site, a laboratory program that will determine the physical and mechanical properties of the rocks and soils, and a field testing and measurement program.

4.4.14 Thermal and mechanical rock properties

The program designed to collect information on thermal and mechanical rock properties is described in Section 8.3.1.15 of the SCP/CD. It will provide information on thermal and mechanical rock properties and on ambient stress and temperature conditions to support the resolution of performance and design issues, including the development of design criteria for the underground repository, seals, and waste packages.

Two investigations consisting of nine studies are planned to collect the required rock-characteristics data (Table 4-1). One will address the spatial distribution of thermal and mechanical properties. It will include laboratory studies of rock density and porosity, volumetric heat capacity, thermal conductivity, thermal expansion, response to compression, tensile strength, and the mechanical properties of fractures. In addition, it will include excavation investigations in the exploratory-shaft facility as well as studies, also conducted in the exploratory-shaft facility, of thermomechanical and mechanical properties.

The second investigation will collect data on the spatial distribution of ambient stress and thermal conditions. It will consist of both surface-based studies and studies in the exploratory-shaft facility.

4.4.15 Preclosure hydrology

The preclosure hydrology program is described in Section 8.3.1.16 of the SCP/CD. This program is designed to provide the site-specific hydrologic information needed for the design of the repository, the shafts, and seals and to support the resolution of several performance and design issues. The information to be supplied includes information on the hazards associated with flooding and debris flows; the location of adequate and alternative water supplies for the construction, operation, and closure of the repository; and information on the underground hydrologic conditions in and above the host horizon.

The preclosure hydrology program consists of three investigations. One of these that will determine (1) flood recurrence intervals and levels at the potential locations of surface facilities. Another will identify the locations of adequate water supplies; it will evaluate existing water-well data and obtain new site-specific data to ensure the availability of sufficient water for repository construction and operation. The third investigation addresses ground-water conditions within and above the potential host rock to determine the technical feasibility of constructing a repository (i.e., the access ramps, shafts, underground facilities, and seals) in the unsaturated zone, the compatibility of repository-related activities with the geohydrologic setting, and the ability to construct the repository by means of available technology and at reasonable cost. Detailed information for this investigation will be obtained and evaluated through the geohydrologic program.

4.4.16 Preclosure tectonics

The preclosure-tectonics program, described in Section 8.3.1.17 of the SCP/CD, is intended to provide an understanding of and to characterize the tectonic events or processes that could affect the structures, systems, or components considered to be important to preclosure safety, waste retrieval, or the performance of seals. The data on tectonic processes and events will support the resolution of both design and performance issues.

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

As shown in Table 4-1, the program consists of four investigations. The first three investigations provide the analysis and assessment of geologic data necessary to satisfy performance and design requirements. Each of these investigations considers a tectonic process that could be significant in the location or design of surface or underground facilities: volcanic activity, fault displacement, and vibratory ground motion. The data-gathering activities that supply the basic geologic field data required by the analysis and assessment investigations are grouped together in the fourth investigation.

4.5 REPOSITORY PROGRAM

The SCP repository program consists of the site-characterization activities that are associated with designing the repository. It includes design analysis and the development of a reference design. The site information needed for design is described in the site program summarized in Section 4.4.

The SCP repository program is based on the strategies for resolving the four repository-design issues in the issues hierarchy: issues 1.11, 2.7, 4.2, and 4.4 (see Appendix B for a listing of the issues and information needs). The program is also tied to four of the performance issues: issue 2.4 (waste retrievability) and issues 2.1, 2.2, and 2.3 (preclosure radiation safety). In addition to providing the technical basis for planning the repository program, these issues and their information needs also provide a framework for organizing the activities of the program.

The design of the repository is directed at meeting the requirements of the two different phases: preclosure and postclosure. For the preclosure phase, the design is concerned mainly with providing the facilities and equipment that will permit the emplacement of waste in the repository while protecting the health and safety of the public. For the postclosure phase, the repository design is concerned with providing engineered barriers that contribute to the containment and isolation of radionuclides and with minimizing adverse effects of construction and operation on the waste-isolation ability of the site.

The postclosure design of the repository is addressed through the information needs of issue 1.11. Design concepts for the orientation, layout, and depth of the underground facility will be developed; they will consider the amount of usable waste-emplacement area versus the needed area and the need for flexibility in layout to accommodate local geologic conditions, and drainage and moisture control. The importance of limiting water usage in the underground repository will be evaluated as will the chemical changes that can be induced in the host rock from the introduction of construction materials. Since the excavation of the underground openings and the heat of the emplaced waste will cause changes in the hydraulic conductivity of the rock mass, these effects will be analyzed and design constraints will be established. Analyses will be performed to establish the heat loading of the repository and to predict the thermal and mechanical response of the host rock. Their results will also be used to establish the spacing of the waste-emplacement boreholes and the emplacement configuration. An important consideration in determining the heat loading and borehole spacing will be the temperature of the host rock in the immediate vicinity of the waste packages: this temperature should be high enough to vaporize water, thus preventing liquid water from reaching the packages for as long as possible.

Preclosure design is addressed by issues 2.7, 4.2, and 4.4. The information needs of issue 2.7 are concerned with the radiation-safety aspects of the design and are closely related to the requirements for radiation safety addressed in the strategies for issues 2.1, 2.2, and 2.3. Design studies will be directed toward demonstrating compliance with the design criteria in 10 CFR Part 60 pertaining directly to radiation protection, including criteria for structures, systems, and components important to safety. These design activities are largely independent of site characterization.

The information needs of issue 4.2 address the design and operating procedures needed to protect the nonradiological safety of workers. Initial designs and operating procedures will be developed concurrently with the construction of the exploratory-shaft facility. The construction of this facility will provide an opportunity to evaluate various excavation methods in the host rock, to demonstrate the installation and use of ground-support devices, and to monitor the behavior of rock-support devices. The ESF will also be used to evaluate dust generation and control as well conditions important to the ventilation system, such as moisture and the presence of gases.

The information needs of issue 4.4 address the feasibility of the technology required to design, construct, operate, and close the repository. Within this general scope, the overall design of the surface facilities and the underground facility as a repository system is addressed. Much of the design work planned for other repository-design issues (issues 1.11, 2.7, and 4.2) is addressed by the design information needs under issue 4.4. Two important steps toward developing an overall repository design will be the preparation of the repository operations plan for the repository and the completion of the design requirements for the various systems and components of the repository. These steps will deal with underground development as well as the four basic tasks of the repository during the preclosure period: the receipt and preparation of the waste, waste emplacement, waste retrieval (if necessary), and closure. The design helps to develop and demonstrate the equipment needed for operations, including equipment for waste handling and emplacement, for drilling the emplacement holes (for horizontal or vertical emplacement) and for retrieving the waste packages.

A variety of design analyses to evaluate thermal, structural, hydrologic, and seismic phenomena will be performed to support the design. Thermal and thermal-mechanical analyses of underground openings and the effects of the heat from the emplaced waste will be performed to evaluate the stability of shafts, drifts, and emplacement boreholes. These analyses will use various numerical and empirical models to predict behavior during repository operations. Ground-support analyses will be performed to evaluate support options and to select the design for ground support. Seismic analyses will be used to evaluate the effects of ground motion on the surface facilities and the underground facilities. In addition, ventilation analyses will be performed to evaluate options for repository layout and to identify requirements for ventilation equipment.

4.6 SEALS PROGRAM

The seals program includes materials testing, design analysis, and design development for the sealing of shafts and ramps, underground drifts, and boreholes at the site. The activities to be conducted during site characterization were developed on the basis of the issue-resolution strategy for the seal-design issue, issue 1.12. The overall strategy that guides the seal design is to control the water that may be encountered in the unsaturated zone and divert it away from the emplaced waste.

Since the postclosure seals will generally not be installed until the underground repository is closed, design development and seal testing will take place over a period extending far beyond site characterization. Plans for work during site characterization are aimed at developing design concepts and evaluating seal materials for consideration after site characterization and before repository closure.

Design-tradeoff studies will be performed to select the appropriate configurations for seal components, placement methods, and materials. Such tradeoff studies will evaluate the quantities of ground water that could enter the facility from faults and the potential for drainage through drift floors, shafts, and ramps. Various placement methods will be evaluated as the design concepts and seal materials become better defined.

Laboratory testing of potential seal materials will be performed in conjunction with waste-package materials. These tests will evaluate cementitious and earthen materials for their physical, mechanical, thermal, and hydrologic properties. In addition, the chemical stability of these materials and their reactivity with the host rock over time will be evaluated. Also planned are laboratory tests of the crushed host rock (tuff) to evaluate its use for filling the shafts and backfilling the drifts of the repository.

The design of the seals will require a good deal of information from the site programs on geohydrology, rock characteristics, and geochemistry; this information will be used to locate the seals, to refine the functional requirements for the seals, and to design for long-term physical and chemical compatibility of the seals with the other components of the repository.

Models of seal performance will be developed as the design advances. The models will evaluate both saturated and unsaturated flow through the seals as well as the thermal and mechanical behavior of the seals over time.

4.7 WASTE PACKAGE

The SCP waste-package program is defined as the activities that are to be conducted during site characterization and are associated with developing the design of the waste package. The program includes materials testing, design analysis, and the development of a reference design. The waste-package program is based on the resolution strategies for the three waste-package design issues (issues 1.10, 2.6, and 4.3--see Appendix B) and the two performance issues related to waste containment and limiting the rate of radionuclide release from the engineered-barrier system (issues 1.4 and 1.5, respectively). In addition to providing the technical bases for planning the waste-package program, these issues and their information needs also provide a means of organizing the activities in the program.

The information needs of issues 1.10, 1.4, and 1.5 represent most of the work in the waste-package part of the site-characterization program. Under issue 1.10, a number of studies will be directed at characterizing the host-rock environment in the immediate vicinity of the waste packages. Laboratory tests and modeling analyses will be conducted to evaluate geochemical changes in the immediate vicinity of the waste packages. The tests will examine the composition of ground water in the host rock, the interactions of the host rock with water at elevated temperatures, and the dissolution of the minerals in the rock. Also evaluated will be the effects of repository-construction materials (e.g., grout, concrete), radiation, and the products of waste-package corrosion on the chemical behavior of the ground water and minerals.

Laboratory tests and analyses will be performed to establish the hydrologic properties, processes, and conditions in the vicinity of the waste packages. Laboratory tests on fractured and unfractured samples will examine the flow properties of the host rock for gases, vapors, and liquids.

Thermal and mechanical analyses and the waste package and the host rock around the emplacement of holes will be performed to evaluate temperature distribution histories and the stability of the emplacement boreholes over time.

Tests in the exploratory-shaft facility will be performed to establish the applicability of the laboratory studies described above to the conditions at the Yucca Mountain site. The specific tests have not yet been defined.

Other activities that are part of the postclosure waste-package design under issue 1.10 include the analysis and design development associated with addressing each of the waste-package design criteria of 10 CFR Part 60, completing a reference design for the waste package, and establishing the configuration for the emplacement of the waste package in the underground repository.

A number of activities important to postclosure waste-package design are included under issues 1.4 and 1.5. The information needs of issue 1.4 (radionuclide containment within the set of waste packages) include the evaluation of a number of different materials for the disposal container; they include copper and copper-based alloys as well as austenitic materials (iron- and nickel-based alloys). Laboratory testing of metal container materials will be performed to examine their mechanical, microstructural, and physical properties; states of stress in the container; and the characterization of the integrity of the welds. An evaluation of the feasibility of using ceramic liners inside the containers may also lead to the testing of ceramics. Laboratory tests will be performed to evaluate degradation mechanisms that may occur in the thermal and environmental conditions after waste emplacement; the tests will be performed on copper and copper alloys, several austenitic materials, and ceramics. The degradation process of particular concern is stress-corrosion cracking for copper and for austenitic materials.

The information needs of issue 1.5 (which is concerned with controlling the release of radionuclides from the engineered-barrier system) includes the evaluation of the characteristics and behavior of the waste form after containment is lost. Laboratory tests will be performed on a variety of spent-fuel types as well as the vitrified high-level waste. Spent-fuel testing will evaluate the dissolution and leaching of the the spent fuel, oxidation of the fuel, and corrosion of the cladding in which the spent fuel is contained. Leach testing will be performed on the vitrified high-level waste.

In addition to the testing and analyses summarized above, the design of the waste package will require modeling of the overall behavior of the waste package in the emplacement environment over time and the processes by which radionuclides can be transported out of the waste package.

Issues 2.6 and 4.3 deal with the preclosure aspects of waste-package design and require no additional site information beyond that described above. The information needs for these issues address the design criteria of 10 CFR Part 60 that are concerned with radiation safety during transportation and handling, the control or prohibition of specific materials as part of the package, and the unique identification of each package; they also address the identification and evaluation of production techniques for the fabrication, closure, and inspection of the waste package.

4.8 PERFORMANCE ASSESSMENT

The performance-assessment program will develop analytical techniques and provide the analytical evaluations for the resolution of the performance issues. In particular, the purpose of the program is to calculate performance measures for each of these issues and to compare the results with the goals set for them. This section presents brief summaries of plans for the assessment of preclosure safety, the assessment of postclosure performance, and the development, validation, and verification of models. Detailed plans for the performance-assessment program for the Yucca Mountain site are given in Section 8.3.5 of the SCP/CD.

4.8.1 Preclosure safety

Six issues are addressed by the preclosure-safety assessment program: issues 2.1 through 2.5 and 4.1. Issues 2.1, 2.2, and 2.3 are concerned with the preclosure radiation safety of the repository, issue 2.4 is concerned with waste retrievability, and issues 2.5 and 4.1 address higher-level findings for two groups of preclosure siting guidelines.

Assessment of preclosure safety

The assessment of preclosure safety will be conducted for the phases of repository construction, operation, waste retrieval (if necessary), closure, and decommissioning. It is directed mainly at the resolution of key issue 2 (preclosure radiation safety) and the following related performance issues:

- The radiation safety of the general public under normal conditions (issue 2.1).
- The radiation safety of the repository workers under normal conditions (issue 2.2).
- The radiation safety of the general public and the repository workers under accident conditions (issue 2.3).

Complete statements of these issues and the information needs can be found in Appendix B. The strategy for the assessment of preclosure safety is described in Sections 8.2.2.2 and 8.3.5.1 of the SCP/CD.

The DOE is developing a preclosure-risk assessment methodology that will establish the procedures, computer codes, assumptions, and data bases to be used in these safety assessments. This methodology will be used to analyze the radiation-exposure risks of both routine operations and accidents at the repository; it will also be used to analyze accidents that do not lead to releases of radioactive material but may be hazardous for other reasons.

The general analytical approach to the resolution of issues 2.1 and 2.2 (radiation-exposure risks of routine operations) consists of four steps:

1. The evaluation of the design of the repository and the waste package, including the thickness of barriers and radiation shields, the characteristics of the ventilation system, and the containment characteristics of the waste form.
2. The identification of radiation-source characteristics, which depend on the design of the repository and the waste package, operating procedures, relevant environmental conditions, radionuclide transport, potential releases from offsite facilities, and radon releases from the excavation of the underground repository.

3. The development of dispersion and pathway models.

4. Calculation of the radiation exposures that might be received by the general public or by the workers at the repository.

The activities to be performed for the resolution of issues 2.1 and 2.2 are discussed in Sections 8.3.5.3 and 8.3.5.4, respectively, of the SCP/CD.

The general analytical approach to assessing the radiation-exposure risks of accidents at the repository (issue 2.3) will employ techniques of probabilistic risk assessment in addition to deterministic, conservative methods of analysis. The activities to be performed for the resolution of issue 2.3 are discussed in Section 8.3.5.5 of the SCP/CD.

The results of the preclosure-safety assessment will be used to guide the design of the repository and the development of operating procedures, to demonstrate compliance with regulatory requirements, to identify items important to safety, and to support the site-selection process.

Higher-level findings for preclosure siting guidelines

Two other performance issues are addressed by the preclosure-safety assessment program: issues 2.5 and 4.1. Both are concerned with higher-level findings for the DOE siting guidelines for the preclosure period. (A complete list of the preclosure siting guidelines can be found in Appendix A). Issue 2.5 covers the preclosure system guideline on radiological safety and the qualifying and disqualifying conditions of the associated technical guidelines (population density and distribution, site ownership and control, meteorology, and offsite installations and operations). The evidence needed to support the remaining higher-level findings will be made available through the information and analyses that support the resolution of issues 2.1 and 2.2.

Issue 4.1 covers the preclosure system guideline on the ease and cost of siting, construction, operation, and closure and the associated technical guidelines on surface characteristics, rock characteristics, hydrology, and tectonics. As explained in Section 8.3.5.7 of the SCP/CD, the evidence needed to support the higher-level findings for these guidelines will be obtained through the information, analyses, and assessments that support the resolution of design issues 4.2 through 4.5.

Waste retrievability

The last performance issue included in the preclosure-safety assessment program is issue 2.4--the ability to retrieve the waste emplaced in the repository, as required by 10 CFR 60.111; the resolution of this issue is discussed in SCP/CD Section 8.3.5.2.

Waste retrieval would involve four functions--(1) access to the emplacement boreholes, (2) access to the waste packages, (3) removal of the waste package from the emplacement borehole, and (4) waste-package transport to the surface facilities. The requirement to ensure that these functions could be performed has produced significant constraints on the design of the repository. Because of its close relationship to design, issue 2.4 is closely related to design issue 4.4 (preclosure design and technical feasibility), and its resolution will depend on the design activities, supporting analyses, and demonstrations performed to satisfy the information needs of issue 4.4.

4.8.2 Postclosure performance

The program for postclosure-performance assessment addresses issues 1.1 through 1.9. Issues 1.1 through 1.6 are concerned with the postclosure-performance objectives of 10 CFR Part 60, issue 1.7 addresses the need to develop a performance-confirmation program, and issues 1.8 and 1.9 address site-related requirements of 10 CFR Part 60 and 10 CFR Part 960, respectively.

The first six postclosure-performance issues address the following performance objectives of 10 CFR Part 60:

- System performance objective for the cumulative radionuclide release to the accessible environment (issue 1.1).
- System performance objective for radiation doses delivered to individuals in the accessible environment (issue 1.2).
- System performance objective for ground-water protection (issue 1.3).
- The performance of the engineered-barrier system in providing containment by the waste package (issue 1.4).
- The engineered-barrier performance objective for rates of radionuclide release from the engineered-barrier system (issue 1.5).
- Site performance objective for ground-water travel time (issue 1.6).

Complete statements of these issues and the associated information needs can be found in Appendix B.

The current plans for resolving these issues for a repository at the Yucca Mountain site are based on the current conceptual models of the site characteristics and the current understanding of the processes and events that could or may occur at the site in the future. Preliminary analyses of the behavior of this system have been conducted; they have contributed heavily to the planning. Detailed strategies for each issue are presented in Section 8.3.5 of the SCP/CD.

The performance-assessment activities that will be planned for the resolution of issue 1.1 include the following:

1. The identification of potentially significant processes and events.
2. The development of classes of scenarios for the releases of radionuclides to the accessible environment involving those processes and events.

3. The screening of the scenario classes in terms of the probability of occurrence and the potential releases associated with them.

4. The development of appropriate computational models for the evaluation of the scenario classes.

5. The calculation of probability distributions for the cumulative release to the accessible environment, taking into account uncertainties in the parameters of the computational models and the probability of occurrence of each scenario class.

The performance-assessment activities that are planned for the resolution of issues 1.2 and 1.3 are closely related to those for issue 1.1. In accordance with the regulations, the analyses will focus on the undisturbed performance of the repository system--that is, the behavior that would be predicted if the system is not disrupted by inadvertent human intrusion or the occurrence of unlikely natural processes or events. For issue 1.2, the assessments will evaluate the radiation doses that could be received by any member of the public in the accessible environment. For issue 1.3, the assessments will evaluate the potential radionuclide contamination of any special sources of ground water.

The performance-assessment activities planned for issue 1.4 include the following:

1. Evaluation of the engineered waste-package environment, including the thermal and fluid conditions in the vicinity of the waste packages.

2. Evaluation of the performance of the disposal container under these conditions, taking into account the properties of container materials, the nature of welds, the presence of mechanical defects, and potential modes of degradation.

3. Evaluation of the performance of the waste form, including any potential releases of volatile radionuclides at grain boundaries or in gaps, the behavior of spent-fuel cladding, and the potential rate of radionuclide release from the waste-form matrix.

Issue 1.5 is concerned with the rate of release from the engineered-barrier system. The planned activities include compiling and integrating data on the waste form (spent fuel and vitrified high-level waste) and the design of the waste package, determining the sets of parameter values to be used in assessing the performance of the waste package, developing geochemical models to analyze the release of radionuclides from the waste form and their behavior after release, developing models for determining mechanism for radionuclide releases from spent fuel and vitrified waste, developing models for assessing waste-package performance, and calculating the rates of radionuclide releases from the waste package and the engineered-barrier system by both deterministic and probabilistic methods.

Issue 1.6 is concerned with the performance of the site in terms of the ground-water travel time. The performance-assessment activities planned for resolving this issue include the following:

1. The development and validation of computational models for predicting the ground-water travel time.

2. The determination of the extent of the disturbances of the flow system due to repository construction and waste emplacement.

3. The identification of paths of likely radionuclide travel from the disturbed zone to the accessible environment.

4. The calculation of the pre-waste-emplacement ground-water travel time along the fastest path of likely radionuclide travel from the disturbed zone to the accessible environment.

The performance-assessment activities for performance issues 1.7, 1.8, and 1.9 are essentially the same as those for performance issues 1.1 through 1.6, which directly address the postclosure performance objectives of 10 CFR Part 60. Performance issue 1.7 addresses the requirements for a performance-confirmation program as defined in 10 CFR 60.137.

Pérformance issue 1.8 addresses the siting criteria of 10 CFR 60.122. The detailed strategy for its resolution defines the DOE's approach to the evaluation of favorable and potentially adverse conditions at the site and the determination that an appropriate combination of these conditions together with the engineered-barrier system will allow the performance objectives related to waste isolation to be met.

Performance issue 1.9 addresses the postclosure siting guidelines of 10 CFR Part 960. The performance-assesssment activities for this issue are related to the evaluation of the site against these guidelines and the comparison of sites. The types of activities are the same as those for performance issues 1.1 through 1.7. However, the specific activities to be conducted are slightly more general in this case; that is, the analyses for issues 1.1 through 1.6 involve evaluations of the system for 10,000 years or less after permanent closure. The siting guidelines, on the other hand, require evaluations for longer periods in some cases. In particular, the comparison of sites will involve calculations of system performance for 100,000 years after closure. Therefore, although the types of performance-assessment activities are the same as those described above, specific analyses will be somewhat different.

4.8.3 Performance-assessment modeling

The analyses that will be conducted in assessing the performance of the disposal system will rely heavily on numerical models. For example, a particular performance measure will be calculated by using appropriate models that take into account the processes and events that may significantly affect the measure. The numerical models will be based on conceptual models for the system and on empirical or theoretical relationships for the processes considered to be important in these conceptual models.

The numerical models that will be used in the performance assessments for licensing will be verified and validated. That is, the analytic techniques for performing the calculations will be tested to ensure that they correctly perform the operations, and the conceptual models and the empirical and theoretical relationships will be evaluated to ensure that they adequately represent the physical system to be analyzed.

Verification that the analytic techniques correctly perform the operations will involve quality control and quality assurance in the development of the technique, the benchmarking of the techniques against other related techniques, and the evaluation of carefully chosen examples, including those with analytic solutions. The verification of a particular analytic technique may require substantial effort but is a relatively straightforward process.

The validation of the conceptual models and empirical and theoretical relationships, on the other hand, is expected to be more difficult because the validation process must address in a fundamental way the uncertainties in the description of the system itself. Such uncertainties include those in the specifications of the input parameters for the system and those in the conceptual model itself (e.g., in its geometrical configuration, major features, and boundary and initial conditions).

The DOE will attempt to address parameter uncertainty by considering bounding values for parameters or by taking parameter variations explicitly into account through stochastic modeling. Since parameter uncertainties to some extent reflect uncertainties in the conceptual model of the system, the bounding-modeling or stochastic-modeling approaches will also be useful in resolving the conceptual uncertainties. However, the validation of conceptual models is also expected to involve additional activities, including (1) explicit treatment of alternative conceptual models, (2) study of the sensitivity of performance-measure values to uncertainties in the conceptual model and in the specifications of parameters, and (3) peer review by qualified experts. Plans for specific verification and validation activities will be made during the planning of model development and application.

5. SITE CHARACTERIZATION

In order to carry out the site-characterization program described in Section 4, the DOE will conduct various activities at the Yucca Mountain site. These activities will consist of surface-based tests and tests conducted in an exploratory-shaft facility. Various laboratory tests and analyses will also be performed. In conducting the site-characterization activities, care will be taken to avoid environmental and socioeconomic impacts. If the Yucca Mountain site is found to be unsuitable for a repository, the facilities at the site will be decommissioned.

The drilling of boreholes, the construction of the exploratory shafts in the exploratory-shaft facility, and any underground excavations will be performed in such a way that the integrity of the site is not compromised. These activities will be controlled to avoid any significant adverse impacts that might affect the safety of the repository during preclosure operations or the waste-isolation capability of the site after closure.

5.1 SURFACE-BASED TESTS

The surface-based tests to be conducted during site characterization will include two general types of activities: tests performed at the ground surface and tests performed in boreholes and trenches. These tests are described in Section 8.3.1 of the SCP/CD; the description that follows briefly summarizes information from the detailed discussions in those sections.

5.1.1 Tests performed at the surface

One group of studies performed at the ground surface will monitor precipitation and stream flow. The plans for this work call for 24 flumes to be installed in various drainage areas on and around Yucca Mountain; they will measure flow rates and allow estimates of runoff to be made. Precipitation gages will be installed at these locations and at four other sites.

A second group of studies comprises geophysical surveys. This work, performed at the ground surface, will play a major role in providing information on the spatial distribution of rock characteristics. Faults and shallow subsurface structure will be investigated by two techniques: shallow seismic reflection, which will use portable small-scale vibrator sources in as many as 10 traverses up to 3.1 miles long, and shallow seismic refraction, which will use portable seismographs and repetitive hammer sources. Deep seismic reflection techniques will also be used; they will include, as a test of their use, a 9.3-mile-long survey using a Vibroseis energy source. An east-west profile and two or three cross profiles centered on Yucca Mountain will be studied with explosive sources; this regional seismic-refraction survey will require the use of shot holes drilled at about 6-mile intervals, each containing as much as 4000 pounds of dynamite. Images of the subsurface at the repository location will be obtained by vertical seismic profiling: geophones will be placed in the exploratory shaft or in boreholes drilled for other purposes, and vibrator trucks will provide seismic sources.

Other geophysical surveys will use portable equipment to measure magnetic intensity and gravitational acceleration. Another regional study, a magnetotelluric survey, will measure the conductivity of the earth in the area. This type of survey uses arrays of electrodes and a magnetometer sensor consisting of a loop of wire, 30 to 300 feet in length, buried a few inches below the ground surface.

A third group of studies to be peformed at the surface will map various features of the Yucca Mountain area. Geologic mapping at a scale of 1:12,000 will cover about 50,000 acres. Surficial deposits will also be mapped; some soil pits will be dug in support of this effort. Intensive mapping of surface stratigraphy and geomorphic features will take place in a broad area, with special attention in areas of exposed bedrock and in Fortymile Wash and its tributaries.

5.1.2 Drilling and trenching tests

As many as 300 to 350 shallow drillholes, 70 deep drillholes, and 20 trenches may be used in site characterization. These estimates are preliminary, and the number of deep drillholes may be smaller, depending on the final design of certain drilling programs. These holes and trenches will be used for a variety of purposes.

Several boreholes will be used for studies of the unsaturated zone. They will be drilled with unconventional dry methods to depths as deep as about 1500 feet; some will reach only to about 500 feet. After drilling and packer testing, these holes will be instrumented at isolated intervals along their depths. Among the instruments to be emplaced in such holes are temperature sensors, pressure sensors, tensiometers, thermocouple psychrometers, and gas-sampling apparatus. Monitoring of these holes will continue for several years.

Eight other deep holes are intended to study the water table and the saturated zone. Drilled with conventional methods, they will extend to depths 100 or 200 feet below the water table. These holes will be logged during drilling. They will be maintained for future monitoring purposes and for possible sampling and flow testing. Sampling of water from existing holes is also planned; special methods are required to obtain samples representative of the conditions that existed before those holes, drilled with air foam, were made. One pumping test will be conducted across the Solitario Canyon fault to investigate the conductivity of the fault zone.

In one complex of three deep holes, a series of single-well and multiple-well pumping tests will be conducted. In the single-well tests a submersible pump will remove water from a selected rock interval; the pressure in other intervals will be monitored during and after the pumping. The multiple-well tests will involve pumping from a selected interval in one well and injecting into a selected interval of a second well. Chemical tracers may be mixed with the injected water. Another kind of test will involve allowing a tracer to drift into a rock formation and then pumping it out again. Tests like these will help to determine whether single-well testing can supply needed information; if it can, other single-well tests will be conducted in other deep holes.

Three deep holes will reach to depths of approximately 5000 feet. Drilled north and south of Yucca Mountain and in Drill Hole Wash, they will provide core, 2.5 inches in diameter, for geologic studies.

At two locations a hole will be drilled to a depth of at least 1000 feet for measuring in situ stress by the hydrofracturing method. Because these tests will be intended to improve the understanding of the regional stress conditions, the holes will probably be drilled more than 5 miles from the site. The holes will be equipped with packers that will be located in competent bedrock for testing by injection of water. Depending on the results of the first tests of this type, more hydrofracturing work may be performed.

Three holes will be drilled to depths of 600 to 800 feet in Fortymile Wash. They will be used in studies of induced infiltration using a small pond and in studies of natural infiltration during precipitation events.

A series of shallow infiltration-monitoring holes will be drilled to depths less than about 50 feet in 24 locations (74 such holes already exist at the site). At some of these locations, small ponds, about 250 square feet in area, will be constructed to induce infiltration artificially; a static water level will be maintained in these ponds. Other studies will use simulations of rainfall for artificial infiltration.

A number of holes will be drilled to various depths for additional studies. Four holes will be drilled over magnetic anomalies that may be due to igneous intrusions or buried volcanic material. Some shallow holes will be drilled for collecting water samples in the region and for gathering samples from lake systems throughout the Great Basin. Several holes may be drilled near an existing trench near the Bow Ridge fault; these holes would recover mineral samples from depths below the trench. A horizontal hole may be drilled into the Solitario Canyon fault structure if such drilling is found to be feasible.

Still under consideration is a plan to drill as many as 35 to 40 deep boreholes in a grid pattern. These holes would provide statistical information about rock properties in the repository block; continuous core samples would be taken from each hole. This work would be done in phases; the data obtained in each phase would be evaluated before a decision to proceed with the next phase.

Aproximately 20 trenches, in addition to those existing around the site, are planned. The trenches will be dug by bulldozers or articulated shovels in locations to be determined after field reconnaissance. They will typically be 4 to 10 feet deep, 6 to 12 feet wide, and up to 500 feet long. Trenches are planned for investigating fault zones and systems in the region around Yucca Mountain. They may also be used for studying lake and playa deposits, in paleoflood evaluations and studies of soil properties, for sampling vein deposits, and in the surficial mapping mentioned above. Paleoclimate studies may require as many as 40 smaller, shallower trenches.

Tentative plans call for as many as thirty studies of fractures and joints in exposed bedrock in the immediate vicinity of Yucca Mountain. These studies would not require trenching or drilling, but they might require clearing of surface material by spraying water or blowing air over the bedrock.

5.2 TESTS IN THE EXPLORATORY-SHAFT FACILITY

This section describes the exploratory-shaft facility and the tests to be performed there.

5.2.1 The exploratory-shaft facility

The exploratory-shaft facility (ESF) will be constructed at Coyote Wash on the eastern side of Yucca Mountain. It will consist of support facilities on the surface, two exploratory shafts, and underground testing rooms and drifts.

Surface facilities

The surface facilities will include leveled pads for equipment and buildings; roads; buildings and trailers; shaft collars, hoists, and headframes; construction-support facilities; utilities; and fire-protection, life-support, and communications systems. The proposed layout is shown in Figure 5-1. The road, power lines, and water lines have already been built up to the boundary of the Nevada Test Site. Auxiliary facilities will be constructed at Jackass Flats, about 12 miles away. The land required for all of the surface facilities is about 14 acres.

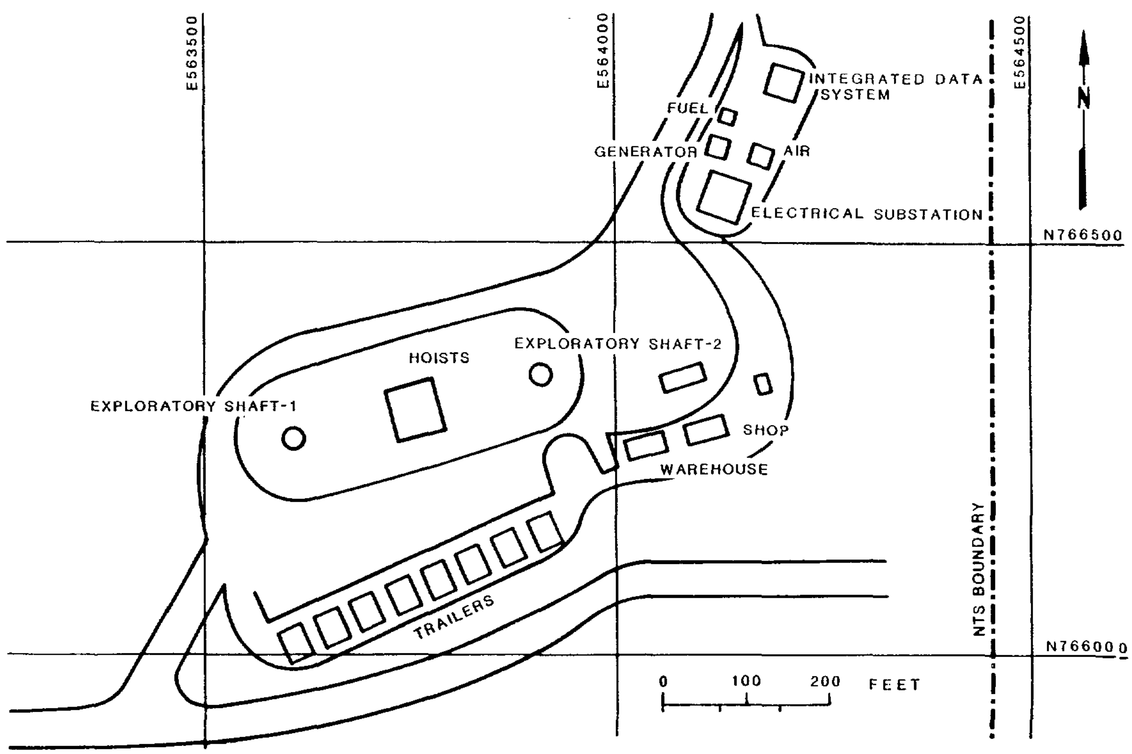

Figure 5-1. Conceptual surface layout for the site of the exploratory-shaft facility.

Leveled pads, requiring the clearing of vegetation and grading, will be built for the shafts, buildings, parking, and storage areas. The access road has already been improved to accommodate heavy equipment; additional roads will be built to the exploratory shafts, the explosives-storage area, and the water tank. Temporary buildings and trailers will be used to provide shop and repair facilities, a warehouse, and a hoist house. Three magazines for the storage of explosives will be built away from the other ESF buildings. The utilities will provide the electrical power, water, and sewage systems necessary to support surface and underground activities.

The shaft collars will provide a stable upper foundation for supporting the concrete liner of the shaft, anchoring the hoist and headframe assembly, and mounting the pipes and vents needed for the underground services. The collars for both shafts will be in bedrock and consist of reinforced concrete extending from the surface to approximately 90 feet below the surface (Figure 5-2). The hoists, hoist house, and headframes for both shafts will provide the necessary hoisting capacity for removing mined rock as well as moving people and materials to and from the surface.

The construction-support facilities and the mine plant will provide above-ground support for underground construction and operations. The major construction-support facilities will be a concrete batch plant, an area for storing the mined rock, a pond for storing the waste water from the mine, and laydown areas for supplies and equipment. The major equipment in the mine plant will be ventilation fans with supply lines to the shaft collar, water pipes, and pipes for carrying mine waste water from the shaft collar to the mine-waste-water pond.

The auxiliary facilities at Jackass Flats will include laboratories and an administration and engineering building. The latter will provide office space and accommodate a visitors center.

<u>Shafts and underground test facilities</u>

<u>Exploratory shafts</u>. There will be two exploratory shafts: one for exploratory testing and the second to provide the necessary support. The first shaft will be a vertical hole sunk from a leveled pad on the east flank of Yucca Mountain, at an elevation of about 4130 feet. The entire shaft will be lined with concrete and have an inside diameter of 12 feet. The completed shaft will be equipped with the necessary internal structures, conduits, piping, ventilation ducts, and conveyances to move people and materials to and from the surface and to support mining and testing. The bottom of the shaft will have a sump for collecting and pumping out any water. Also provided will be space for conveyance overrun and rope stretch, which are required for mine hoisting safety.

The first exploratory shaft will have a total depth of about 1480 feet. It will extend through the lower boundary of the proposed repository horizon into the tuffaceous beds of the Calico Hills. The shaft will penetrate about 45 feet of the nonwelded zeolite-containing interior of the Calico Hills, leaving about 280 feet of the Calico Hills tuff undisturbed above the static water level.

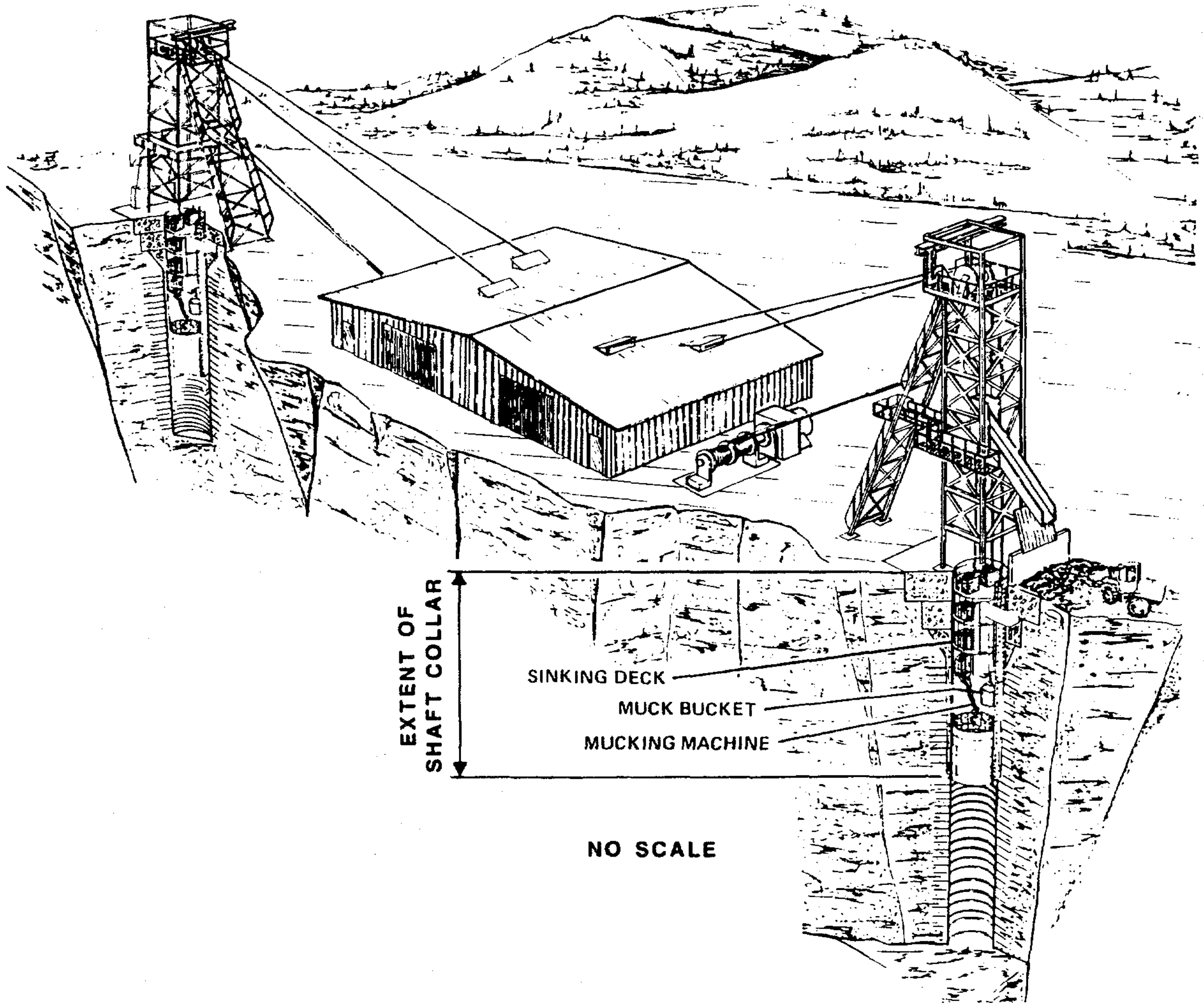

Figure 5-2. Typical hoist, headframe, and collar for an exploratory shaft.

The sinking of the first exploratory shaft will be routine except for testing. A typical sequence of operations will consist of drilling a number of small blast holes, loading the holes with explosives, blasting, and removing the rubble. After the shaft has advanced several feet, the rubble has been removed, and any loose rock has been cleaned off the walls, the walls of the shaft will be mapped, rock and water samples will be taken, and other tests will be conducted in the freshly exposed interval of wall rock. Because the main purpose of the first exploratory shaft is to provide access for scientific investigations, the time devoted to testing will be as needed to achieve the testing objectives. When the shaft-mapping sequence is completed, the mining operations will resume. The alternating sequence of mining and testing will continue throughout the sinking of the shaft.

The second exploratory shaft will be used to move people, materials, and mined rock; to provide additional ventilation for the exploratory drifts; and to provide an emergency exit from the facility. This shaft will be sunk from a leveled pad at the same elevation as the first shaft and extend to just below the main test level at 1055 feet. Like the first shaft, it will be lined with concrete and have an inside diameter of 12 feet. It will be connected to the first shaft by a drift.

Although its construction will start later, the second exploratory shaft will be completed several months before the first exploratory shaft because it will be used for little or no testing. The connecting drift to the first exploratory shaft and a lower demonstration breakout room will be constructed on the main test level after the second shaft is completed.

Underground facilities. The first exploratory shaft will provide access to breakout rooms and stations at three depths: the level of the upper demonstration breakout room (600 feet), the main test level (1055 feet), and the Calico Hills level (1360 feet).

The upper demonstration breakout room at 600 feet will be near the upper boundary of the proposed repository horizon. This depth was selected in order to have access to rock with a lithophysae content of approximately 15 percent; such rock may be encountered at places in the proposed repository horizon. This information will assist in predicting the thermal and mechanical response of rocks with a high lithophysae content. In addition, the constructability and stability of the drifts will be established for both vertical and horizontal waste-emplacement modes.

At the 600-foot level there will be two types of rooms. One will be a station excavated directly off the exploratory shaft. It will provide a reinforced area for unloading equipment and handling mined rock. The second will be the upper demonstration breakout room. It will be mined off the station and used for testing.

At about 1055 feet, the main test level, a lateral drift will be mined from the second exploratory shaft after the sinking of the first exploratory shaft has been completed. This area has been designed to provide maximum flexibility for testing inside the proposed repository horizon. It will include an early operations area for evaluating the host rock in the areas where the test alcoves and drifts are currently planned. Three long exploratory drifts will provide access to specific features inside the proposed repository block: (1) the Ghost Dance fault, (2) the Drill Hole Wash structure, and (3) the imbricate normal fault zone to the east.

The drift to the Ghost Dance fault will be approximately 1200 feet long and head northwest from the operations area on the main test level. It will provide access to features potentially important to the design and performance of the repository since the fault is a potential pathway for water moving from the surface to the water table. The drift will allow direct observation, the collection of samples, and other measurements needed to model the hydrologic environment. Information about the nature of the fault zone and possibly the degree of fault offset may also be obtained from this drift.

The drift to the Drill Hole Wash structure will also examine structural features that may be important to the construction and performance of the repository. If the investigation shows little or no faulting, the area that is proposed for the repository could be substantially increased. The hydrologic character of the rock structures below the Drill Hole Wash will be studied from this drift. Because the wash tends to concentrate surface water and channel it along a specific path, this may be an area where the water flux is higher than average. Studies in this area may resolve concerns about seasonal changes in water flux and the movement of water down a fracture zone. This drift will extend northeast from the operations area on the main test level.

The purpose of the drift southeast from the operations area to the imbricate normal fault zone is to study the width of the fault zone, the strike and dip of the faults, and the location of these faults at the proposed repository depth. These studies will aid in determining the eastern boundary and the total size of the repository block. Hydrologic studies will also be performed to determine whether the imbricate normal fault zone could be a pathway for ground water.

At the 1360-foot level, a station and a drill room will be constructed in the nonwelded tuff of the Calico Hills unit. The drill room will be used to obtain rock core for the study of rock characteristics.

A cutaway view of the exploratory-shaft facility showing the surface facilities, the exploratory shafts, the main test level, and other features is shown in Figure 5-3. The layout of the underground excavations is shown in Figure 5-4.

5.2.2 Tests in the exploratory-shaft facility

The tests planned for the exploratory-shaft facility will collect information on the geologic, hydrologic, geoengineering, and geochemical environment in the host rock. They are divided into two categories: construction-phase tests and in-situ tests.

Construction-phase tests

The construction-phase tests include all test activities that begin during the construction of the first exploratory shaft except those that are conducted in drifts or alcoves on the main test level after the two shafts are connected.

The walls of the first exploratory shaft will be mapped and photographed in detail during the shaft-sinking operations. At each 6.6-foot interval of depth in the shaft, the sinking operations will wait while the walls are cleaned, mapped, and photographed and hand samples are collected. The drifts and breakout rooms will also be mapped 6.6-foot intervals. The mapping will take place before any rockbolts or mesh is installed unless such precautions are necessary for safety reasons.

If perched water or fracture flow is observed during the mapping operations, the sinking of the shaft or the excavation of the drift will be temporarily interrupted to test the wet zone. Holes will be drilled with dry methods to allow the emplacement of instruments that will measure and monitor hydrologic properties like hydraulic head and flow rate. Samples of the water will be collected for chemical analysis.

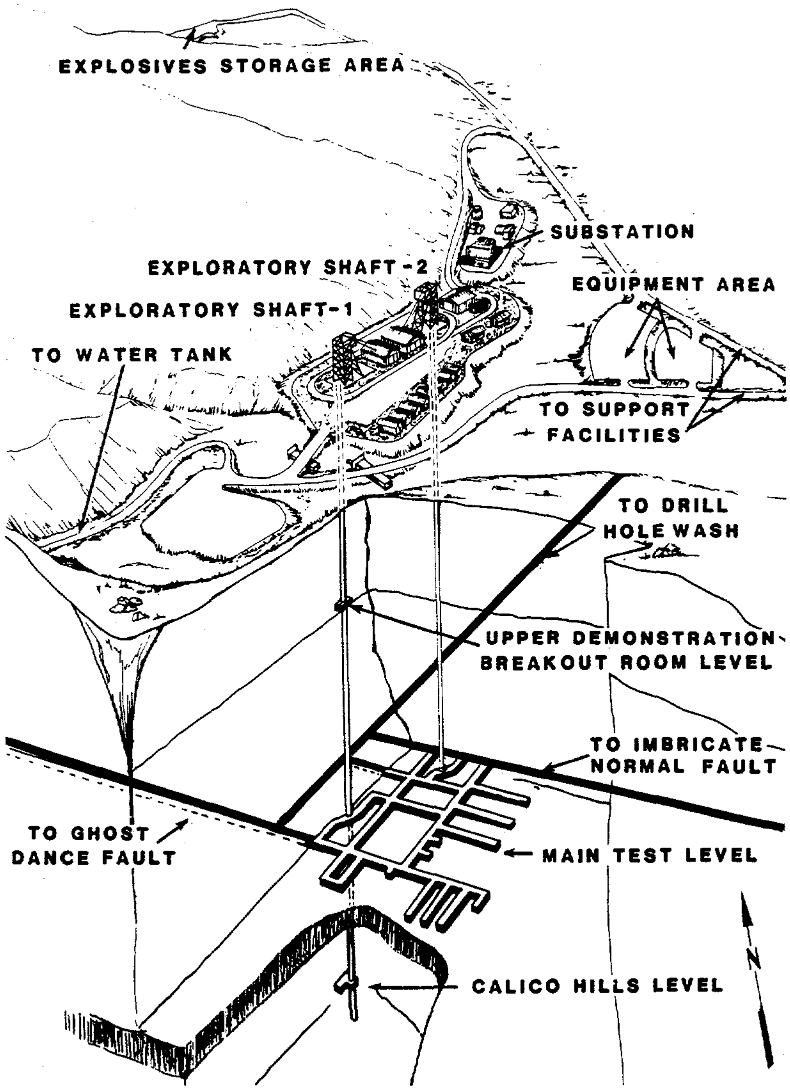

Figure 5-3. Conceptual illustration of the exploratory-shaft facility.

At each of the three main shaft levels described above, instruments will be installed to determine horizontal stress, to measure the convergence of the rock, and to measure the loading of the shaft liner. These instruments will include three radial borehole extensometers and six hydraulic pressure cells. They will be monitored after the shaft sinking resumes.

During the shaft sinking, samples of rock will be collected from the shaft bottom for analysis of chlorine-36. These samples must be as free as possible from contamination by water used in excavation or from chlorine in the explosives used in excavation. They will be collected before any washing of the shaft walls. Approximately 30 depths along the shaft have been selected as collection points for these samples, and special blasting methods may be needed at those points in order to produce samples of the proper size.

Tests designed to reveal the effects of excavation will be conducted at the two upper main levels in the shaft. At those levels the excavation will stop while rooms are developed around the shaft; nine holes will be drilled into the floor of each room to measure changes in stress, displacement, and pneumatic transport. Most of these holes will be parallel to the main shaft, in the rock mass adjacent to where the shaft opening will be after sinking resumes. The holes will range from 23 to 100 feet deep. Geophysical logging will be performed in all the holes. Core will be taken from some holes. After monitoring instruments have been emplaced in the holes, the shaft sinking can resume; permeability measurements will be made in the holes after each two rounds of blasting.

At 12 different levels 2 radial coreholes will be drilled from the shaft for hydrologic testing and monitoring. These 30-foot-long holes will be logged, and instruments will be permanently installed in them. These instruments--thermocouples, strain-gauge pressure transducers, semiconductor pressure transducers, thermocouple psychrometers, and heat-dissipation probes--will be monitored.

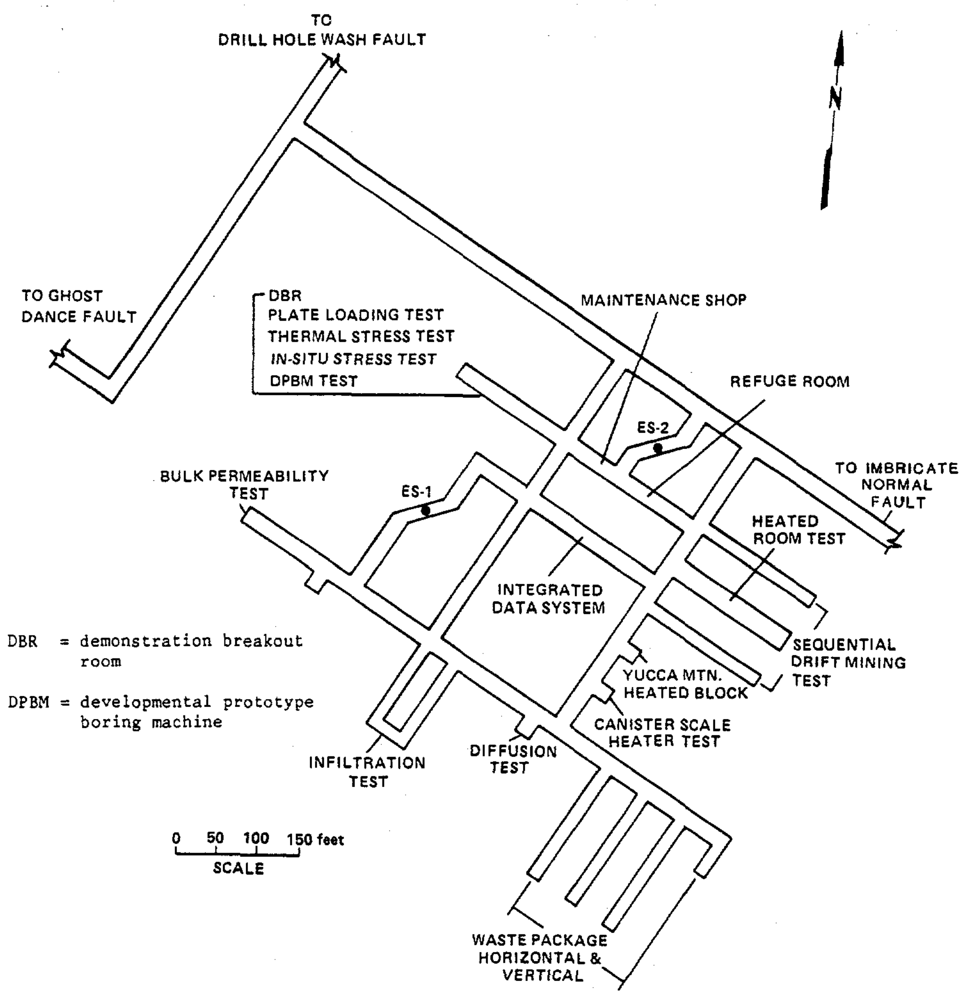

Figure 5-4. Layout of the central underground area of the exploratory-shaft facility, showing the locations of various tests and the two exploratory shafts (ES-1 and ES-2).

uration state will be gradually changed while transport phenomena in the rock are observed. A test drift with a raised testing floor will be constructed; an array of horizontal holes will be drilled from another drift access into the volume of rock under the testing floor. These holes will be instrumented for automatic monitoring of the phenomena that occur when water is introduced to the testing floor. The testing floor will be isolated from the ventilation system.

A bulk permeability test will also require the construction of a special test room. The walls of this room will contain groups of holes that are instrumented with pressure, temperature, and other environmental sensors. This arrangement will permit small-scale packer testing to be performed in conjunction with a large-scale test in the same volume of rock; the results of the testing will permit the evaluation of scale effects. The pneumatic pressure in the test room can be raised for the small-scale testing; the large-scale testing will be conducted by operating the ventilation pressure system while monitoring the environment in the test room.

The hydrogeology of the Calico Hills unit may be studied by means of a 250-foot horizontal borehole from the lowest shaft station, a 250-foot vertical borehole down from the main facility level, and a 350-to-400-foot vertical hole from the lowest level down to the water table. If done, all these holes will be logged and tested.

Bulk samples of rock, at least 12 inches in diameter, will be collected from the shaft excavation at depths no more than 50 feet apart. Extra samples will be taken at zones with unusually high moisture content.

Two parallel drifts will be drilled sequentially in an evaluation of the drift mining. After the first of these drifts has been completed, instrumentation holes will be drilled from it into the rock where the second drift will be constructed. As the second drift is excavated, data from these instrumented holes will be supplemented by measurements of drift convergence in the first drift.

A heated-block test will subject a 2-meter cube of jointed rock to controlled conditions of stress and temperature that will simulate repository conditions after the emplacement of waste. In a specially constructed alcove, four slots cut in the floor will form the sides of a cube whose top is the leveled floor and whose bottom is connected to rock mass. Instruments inserted into the slots will exert pressure on the sides of the cube, and electrical heaters in holes outside the cube will control its temperature. Instrument holes drilled into the cube will permit measurements of stress, displacement, and temperature during cycles of varying stress and temperature induced in the cube.

Another experiment will simulate the environment around a canister-scale emplacement borehole. A corehole will be drilled into the wall of a special drift; a heater will be placed in this hole. Other, smaller holes will be drilled around this heater hole for the emplacement of thermocouples; other holes will contain extensometers, deformation gauges, moisture monitors, and radon monitors. In addition to this large experiment, a small-scale heater experiment will be conducted in the wall of the upper breakout room.

Plate-loading tests will use an established technique for observing and characterizing the deformability of rock mass in drifts and tunnels. An apparatus installed across the diameter of a drift will increase the outward force on the walls; the effects of this increased force will be monitored by instruments placed in boreholes drilled in the roof and floor of the drift where the testing is done. One or more of these tests may be performed in the upper breakout room.

A slot-strength test is planned for the measurement of in-situ stress and rock-mass strength. This test will use a pair of horizontal boreholes about 2 feet apart with a slot cut between them. An instrument inserted into the slot will exert pressure in the slot, and borehole stressmeters in the two holes will monitor the response of the rock. Acoustic emission sensors will allow the pressure to be increased up to the onset of rock failure.

Overcoring-stress measurements and borehole-dilatometer studies will be performed at all three levels. Small coreholes will be drilled first, to a depth of 50 feet. Then these holes will be overcored, and stress-relief measurements will be made about every 1 to 2 feet down the length of the hole.

A test of a developmental prototype boring machine will take place to determine the feasibility of drilling and lining long horizontal holes for emplacing waste. A specially developed boring machine will bore a 37-inch-diameter hole; the objective of the test will be to produce a 250-foot hole with a deviation of 2 inches or less in each 100 feet of boring. This test will be conducted in the main test level.

A diffusion test will determine the extent to which nonsorbing tracers can diffuse into the pores of two tuff units penetrated by the shaft. Holes will be drilled about 30 feet into the tuffs; an effort will be made to ensure that the bottoms of the holes are as free from fractures as possible. Packers will be installed in these holes, and a tracer solution will be injected. After an undetermined period of time, the packer will be withdrawn, and the hole will be overcored. The overcores will be examined to determine how the tracer moved into the rock.

Tests of the waste-package environment will be a complex series of instrumented simulations using electric-resistance heaters in packages resembling horizontal and vertical waste packages. Coreholes for heaters, 12 inches in diameter and 20 or 40 feet long, will be supplemented by additional, longer coreholes that will contain instruments for monitoring. These tests will simulate the thermal loads expected from waste packages; they will also produce loads far in excess of the expected loads.

5.3 QUALITY ASSURANCE

Quality assurance consists of all planned and systematic actions necessary to ensure that the geologic repository will perform satisfactorily. All organizations participating in the site-characterization program will develop and implement a documented quality-assurance program that meets the quality-assurance requirements of the Nuclear Regulatory Commission.

Each item and activity during site characterization is assigned a level of quality assurance, which determines what requirements for control and documentation need to be followed. The level of quality assurance is consistent with the relative importance of the item and activity to public health and safety.

5.4 ENVIRONMENTAL AND SOCIOECONOMIC IMPACTS

In conducting the site-characterization program, care will be taken to minimize adverse environmental and socioeconomic impacts. As reported in the environmental assessment for the Yucca Mountain site, no significant adverse impacts are expected to result from site characterization. Nonetheless, the DOE will monitor site-characterization activities that might have significant environmental and socioeconomic impacts and, to the extent practicable, will implement mitigation measures if necessary. Plans to monitor and mitigate those impacts will be developed in consultation with the State of Nevada before starting the particular site-characterization activities.

5.5 DECOMMISSIONING

If Yucca Mountain is found to be unsuitable as a repository, the exploratory-shaft facility will be decommissioned. If no alternative use for the exploratory-shaft facility is identified by the responsible State and Federal agencies, the decommissioning of the surface and underground facilities will begin as soon as possible. The surface facilities will be removed, and the land will be stabilized and rehabilitated. Equipment will be removed from the shaft stations, underground drifts, and test rooms. The shaft liners will be left in place. The underground excavations and shafts will be backfilled with the rock removed during excavation.

Trenches will be backfilled with the material that was originally excavated, and drillholes will be sealed with a ground-matching grout of a density that corresponds to that of the surrounding rock.

Since no radioactive materials will be used at the site during site characterization, no decontamination will be required after site characterization. The radioactive materials in the geophysical tools used to investigate the movement of ground water during exploratory drilling are fully contained and retrievable; they are routinely used in geologic investigations and do not require any decontamination.

Appendix A

EXCERPTS FROM REGULATIONS:

ENVIRONMENTAL STANDARDS FROM 40 CFR PART 191,
TECHNICAL CRITERIA FROM 10 CFR PART 60,
AND POSTCLOSURE AND PRECLOSURE GUIDELINES FROM 10 CFR PART 960

Subpart A—Environmental Standards for Management and Storage

§ 191.03 Standards.

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

(b) Management and storage of spent nuclear fuel or high-level or transuranic radioactive wastes at all facilities for the disposal of such fuel or waste that are operated by the Department and that are not regulated by the Commission or Agreement States shall be conducted in such a manner as to provide reasonable assurance that the combined annual dose equivalent to any member of the public in the general environment resulting from discharges of radioactive material and direct radiation from such management and storage shall not exceed 25 millirems to the whole body and 75 millirems to any critical organ.

§ 191.04 Alternative standards.

(a) The Administrator may issue alternative standards from those standards established in 191.03(b) for waste management and storage activities at facilities that are not regulated by the Commission or Agreement States if, upon review of an application for such alternative standards:

(1) The Administrator determines that such alternative standards will prevent any member of the public from receiving a continuous exposure of more than 100 millirems per year dose equivalent and an infrequent exposure of more than 500 millirems dose equivalent in a year from all sources, excluding natural background and medical procedures; and

(2) The Administrator promptly makes a matter of public record the degree to which continued operation of the facility is expected to result in levels in excess of the standards specified in 191.03(b).

(b) An application for alternative standards shall be submitted as soon as possible after the Department determines that continued operation of a facility will exceed the levels specified in 191.03(b) and shall include all information necessary for the Administrator to make the determinations called for in 191.04(a).

(c) Requests for alternative standards shall be submitted to the Administrator, U.S. Environmental Protection Agency, 401 M Street, SW., Washington, DC 20460.

Subpart B—Environmental Standards for Disposal

§ 191.13 Containment requirements.

(a) Disposal systems for spent nuclear fuel or high-level or transuranic radioactive wastes shall be designed to provide a reasonable expectation, based upon performance assessments, that the cumulative releases of radionuclides to the accessible environment for 10,000 years after disposal from all significant processes and events that may affect the disposal system shall:

(1) Have a likelihood of less than one chance in 10 of exceeding the quantities calculated according to Table 1 (Appendix A); and

(2) Have a likelihood of less than one chance in 1,000 of exceeding ten times the quantities calculated according to Table 1 (Appendix A).

(b) Performance assessments need not provide complete assurance that the requirements of 191.13(a) will be met. Because of the long time period involved and the nature of the events and processes of interest, there will inevitably be substantial uncertainties in projecting disposal system performance. Proof of the future performance of a disposal system is not to be had in the ordinary sense of the word in situations that deal with much shorter time frames. Instead, what is required is a reasonable expectation, on the basis of the record before the implementing agency, that compliance with 191.13 (a) will be achieved.

§ 191.14 Assurance requirements.

To provide the confidence needed for long-term compliance with the requirements of 191.13, disposal of spent nuclear fuel or high-level or transuranic wastes shall be conducted in accordance with the following provisions, except that these provisions do not apply to facilities regulated by the Commission (see 10 CFR Part 60 for comparable provisions applicable to facilities regulated by the Commission):

(a) Active institutional controls over disposal sites should be maintained for as long a period of time as is practicable after disposal; however, performance assessments that assess isolation of the wastes from the accessible environment shall not consider any contributions from active institutional controls for more than 100 years after disposal.

(b) Disposal systems shall be monitored after disposal to detect substantial and detrimental deviations from expected performance. This monitoring shall be done with techniques that do not jeopardize the isolation of the wastes and shall be conducted until there are no significant concerns to be addressed by further monitoring.

(c) Disposal sites shall be designated by the most permanent markers, records, and other passive institutional controls practicable to indicate the dangers of the wastes and their location.

(d) Disposal systems shall use different types of barriers to isolate the wastes from the accessible environment. Both engineered and natural barriers shall be included.

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*A decision on July 17, 1987, by the U.S. Court of Appeals for the First Circuit has required the Environmental Protection Agency to reconsider its postclosure standards (Subpart B) in 40 CFR Part 191.

(e) Places where there has been mining for resources, or where there is a reasonable expectation of exploration for scarce or easily accessible resources, or where there is a significant concentration of any material that is not widely available from other sources, should be avoided in selecting disposal sites. Resources to be considered shall include minerals, petroleum or natural gas, valuable geologic formations, and ground waters that are either irreplaceable because there is no reasonable alternative source of drinking water available for substantial populations or that are vital to the preservation of unique and sensitive ecosystems. Such places shall not be used for disposal of the wastes covered by this Part unless the favorable characteristics of such places compensate for their greater likelihood of being disturbed in the future.

(f) Disposal systems shall be selected so that removal of most of the wastes is not precluded for a reasonable period of time after disposal.

§ 191.15 Individual protection requirements.

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

§ 191.16 Ground water protection requirements.

(a) Disposal systems for spent nuclear fuel or high-level or transuranic radioactive wastes shall be designed to provide a reasonable expectation that, for 1,000 years after disposal, undisturbed performance of the disposal system shall not cause the radionuclide concentrations averaged over any year in water withdrawn from any portion of a special source of ground water to exceed:

(1) 5 picocuries per liter of radium-226 and radium-228;

(2) 15 picocuries per liter of alpha-emitting radionuclides (including radium-226 and radium-228 but excluding radon); or

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

(b) If any of the average annual radionuclide concentrations existing in a special source of ground water before construction of the disposal system already exceed the limits in 191.16(a), the disposal system shall be designed to provide a reasonable expectation that, for 1,000 years after disposal, undisturbed performance of the disposal system shall not increase the existing average annual radionuclide concentrations in water withdrawn from that special source of ground water by more than the limits established in 191.16(a).

§ 191.17 Alternative provisions for disposal.

The Administrator may, by rule, substitute for any of the provisions of Subpart B alternative provisions chosen after:

(a) The alternative provisions have been proposed for public comment in the **Federal Register** together with information describing the costs, risks, and benefits of disposal in accordance with the alternative provisions and the reasons why compliance with the existing provisions of Subpart B appears inappropriate;

(b) A public comment period of at least 90 days has been completed, during which an opportunity for public hearings in affected areas of the country has been provided; and

(c) The public comments received have been fully considered in developing the final version of such alternative provisions.

Appendix A—Table for Subpart B

TABLE 1.—RELEASE LIMITS FOR CONTAINMENT REQUIREMENTS

[Cumulative releases to the accessible environment for 10,000 years after disposal]

Radionuclide	Release limit per 1,000 MTHM or other unit of waste (see notes) (curies)
Americium-241 or -243	100
Carbon-14	100
Cesium-135 or -137	1,000
Iodine-129	100
Neptunium-237	100
Plutonium-238, -239, -240, or -242	100
Radium-226	100
Strontium-90	1,000
Technetium-99	10,000
Thorium-230 or -232	10
Tin-126	1,000
Uranium-233, -234, -235, -236, or -238	100
Any other alpha-emitting radionuclide with a half-life greater than 20 years	100
Any other radionuclide with a half-life greater than 20 years that does not emit alpha particles	1,000

Application of Table 1

Note 1: *Units of Waste.* The Release Limits in Table 1 apply to the amount of wastes in any one of the following:

(a) An amount of spent nuclear fuel containing 1,000 metric tons of heavy metal (MTHM) exposed to a burnup between 25,000 megawatt-days per metric ton of heavy metal (MWd/MTHM) and 40,000 MWd/MTHM;

(b) The high-level radioactive wastes generated from reprocessing each 1,000 MTHM exposed to a burnup between 25,000 MWd/MTHM and 40,000 MWd/MTHM;

(c) Each 100,000,000 curies of gamma or beta-emitting radionuclides with half-lives greater than 20 years but less than 100 years (for use as discussed in Note 5 or with materials that are identified by the Commission as high-level radioactive waste in accordance with part B of the definition of high-level waste in the NWPA);

(d) Each 1,000,000 curies of other radionuclides (i.e., gamma or beta-emitters with half-lives greater than 100 years or any alpha-emitters with half-lives greater than 20 years) (for use as discussed in Note 5 or with materials that are identified by the Commission as high-level radioactive waste in accordance with part B of the definition of high-level waste in the NWPA); or

(e) An amount of transuranic (TRU) wastes containing one million curies of alpha-emitting transuranic radionuclides with half-lives greater than 20 years.

Note 2: *Release Limits for Specific Disposal Systems.* To develop Release Limits for a particular disposal system, the quantities in Table 1 shall be adjusted for the amount of waste included in the disposal system compared to the various units of waste defined in Note 1. For example:

(a) If a particular disposal system contained the high-level wastes from 50,000 MTHM, the Release Limits for that system would be the quantities in Table 1 multiplied by 50 (50,000 MTHM divided by 1,000 MTHM).

(b) If a particular disposal system contained three million curies of alpha-emitting transuranic wastes, the Release Limits for that system would be the quantities in Table 1 multiplied by three (three million curies divided by one million curies).

(c) If a particular disposal system contained both the high-level wastes from 50,000 MTHM *and* 5 million curies of alpha-emitting transuranic wastes, the Release Limits for that system would be the quantities in Table 1 multiplied by 55:

$$\frac{50{,}000\ \text{MTHM}}{1{,}000\ \text{MTHM}} + \frac{5{,}000{,}000\ \text{curies TRU}}{1{,}000{,}000\ \text{curies TRU}} = 55$$

Note 3: *Adjustments for Reactor Fuels with Different Burnup.* For disposal systems containing reactor fuels (or the high-level wastes from reactor fuels) exposed to an average burnup of less than 25,000 MWd/MTHM or greater than 40,000 MWd/MTHM, the units of waste defined in (a) and (b) of Note 1 shall be adjusted. The unit shall be multiplied by the ratio of 30,000 MWd/MTHM divided by the fuel's actual average burnup, except that a value of 5,000 MWd/MTHM may be used when the average fuel burnup is below 5,000 MWd/MTHM and a value of 100,000 MWd/MTHM shall be used when the average fuel burnup is above 100,000 MWd/MTHM. This adjusted unit of waste shall then be used in determining the Release Limits for the disposal system.

For example, if a particular disposal system contained only high-level wastes with an average burnup of 3,000 MWd/MTHM, the unit of waste for that disposal system would be:

$$1{,}000 \text{ MTHM} \times \frac{(30{,}000)}{(5{,}000)} = 6{,}000 \text{ MTHM}$$

If that disposal system contained the high-level wastes from 60,000 MTHM (with an average burnup of 3,000 MWd/MTHM), then the Release Limits for that system would be the quantities in Table 1 multiplied by ten:

$$\frac{60{,}000 \text{ MTHM}}{6{,}000 \text{ MTHM}} = 10$$

which is the same as:

$$\frac{60{,}000 \text{ MTHM}}{1{,}000 \text{ MTHM}} \times \frac{(5{,}000 \text{ MWd/MTHM})}{(30{,}000 \text{ MWd/MTHM})} = 10$$

Note 4: *Treatment of Fractionated High-Level Wastes.* In some cases, a high-level waste stream from reprocessing spent nuclear fuel may have been (or will be) separated into two or more high-level waste components destined for different disposal systems. In such cases, the implementing agency may allocate the Release Limit multiplier (based upon the original MTHM and the average fuel burnup of the high-level waste stream) among the various disposal systems as it chooses, provided that the total Release Limit multiplier used for that waste stream at all of its disposal systems may not exceed the Release Limit multiplier that would be used if the entire waste stream were disposed of in one disposal system.

Note 5: *Treatment of Wastes with Poorly Known Burnups or Original MTHM.* In some cases, the records associated with particular high-level waste streams may not be adequate to accurately determine the original metric tons of heavy metal in the reactor fuel that created the waste, or to determine the average burnup that the fuel was exposed to. If the uncertainties are such that the original amount of heavy metal or the average fuel burnup for particular high-level waste streams cannot be quantified, the units of waste derived from (a) and (b) of Note 1 shall no longer be used. Instead, the units of waste defined in (c) and (d) of Note 1 shall be used for such high-level waste streams. If the uncertainties in such information allow a range of values to be associated with the original amount of heavy metal or the average fuel burnup, then the calculations described in previous Notes will be conducted using the values that result in the smallest Release Limits, except that the Release Limits need not be smaller than those that would be calculated using the units of waste defined in (c) and (d) of Note 1.

Note 6: *Uses of Release Limits to Determine Compliance with 191.13* Once release limits for a particular disposal system have been determined in accordance with Notes 1 through 5, these release limits shall be used to determine compliance with the requirements of 191.13 as follows. In cases where a mixture of radionuclides is projected to be released to the accessible environment, the limiting values shall be determined as follows: For each radionuclide in the mixture, determine the ratio between the cumulative release quantity projected over 10,000 years and the limit for that radionuclide as determined from Table 1 and Notes 1 through 5. The sum of such ratios for all the radionuclides in the mixture may not exceed one with regard to 191.13(a)(1) and may not exceed ten with regard to 191.13(a)(2).

For example, if radionuclides A, B, and C are projected to be released in amounts Q_a, Q_b, and Q_c, and if the applicable Release Limits are RL_a, RL_b, and RL_c, then the cumulative releases over 10,000 years shall be limited so that the following relationship exists:

$$\frac{Q_a}{RL_a} + \frac{Q_b}{RL_b} + \frac{Q_c}{RL_c} < 1$$

Appendix B—Guidance for Implementation of Subpart B

[**Note:** The supplemental information in this appendix is not an integral part of 40 CFR Part 191. Therefore, the implementing agencies are not bound to follow this guidance. However, it is included because it describes the Agency's assumptions regarding the implementation of Subpart B. This appendix will appear in the Code of Federal Regulations.]

The Agency believes that the implementing agencies must determine compliance with §§ 191.13, 191.15, and 191.16 of Subpart B by evaluating long-term predictions of disposal system performance. Determining compliance with § 191.13 will also involve predicting the likelihood of events and processes that may disturb the disposal system. In making these various predictions, it will be appropriate for the implementing agencies to make use of rather complex computational models, analytical theories, and prevalent expert judgment relevant to the numerical predictions. Substantial uncertainties are likely to be encountered in making these predictions. In fact, sole reliance on these numerical predictions to determine compliance may not be appropriate: the implementing agencies may choose to supplement such predictions with qualitative judgments as well. Because the procedures for determining compliance with Subpart B have not been formulated and tested yet, this appendix to the rule indicates the Agency's assumptions regarding certain issues that may arise when implementing §§ 191.13, 191.15, and 191.16. Most of this guidance applies to any type of disposal system for the wastes covered by this rule. However, several sections apply only to disposal in mined geologic repositories and would be inappropriate for other types of disposal systems.

Consideration of Total Disposal System. When predicting disposal system performance, the Agency assumes that reasonable projections of the protection expected from all of the engineered and natural barriers of a disposal system will be considered. Portions of the disposal system should not be disregarded, even if projected performance is uncertain, except for portions of the system that make negligible contributions to the overall isolation provided by the disposal system.

Scope of Performance Assessments. Section 191.13 requires the implementing agencies to evaluate compliance through performance assessments as defined in § 191.12(q). The Agency assumes that such performance assessments need not consider categories of events or processes that are estimated to have less than one chance in 10,000 of occurring over 10,000 years. Furthermore, the performance assessments need not evaluate in detail the releases from all events and processes estimated to have a greater likelihood of occurrence. Some of these events and processes may be omitted from the performance assessments if there is a reasonable expectation that the remaining probability distribution of cumulative releases would not be significantly changed by such omissions.

Compliance with Section 191.13. The Agency assumes that, whenever practicable, the implementing agency will assemble all of the results of the performance assessments to determine compliance with § 191.13 into a "complementary cumulative distribution function" that indicates the probability of exceeding various levels of cumulative release. When the uncertainties in parameters are considered in a performance assessment, the effects of the uncertainties considered can be incorporated into a single such distribution function for each disposal system considered. The Agency assumes that a disposal system can be considered to be in compliance with § 191.13 if this single distribution function meets the requirements of § 191.13(a).

Compliance with Sections 191.15 and 191.16. When the uncertainties in undisturbed performance of a disposal system are considered, the implementing agencies need not require that a very large percentage of the range of estimated radiation exposures or radionuclide concentrations fall below limits established in §§ 191.15 and 191.16, respectively. The Agency assumes that compliance can be determined based upon "best estimate" predictions (e.g., the mean or the median of the appropriate distribution, whichever is higher).

Institutional Controls. To comply with § 191.14(a), the implementing agency will assume that none of the active institutional controls prevent or reduce radionuclide releases for more than 100 years after disposal. However, the Federal Government is committed to retaining ownership of all disposal sites for spent nuclear fuel and high-level and transuranic radioactive wastes and will establish appropriate markers and records, consistent with § 191.14(c). The Agency assumes that, as long as such passive institutional controls endure and are understood, they: (1) can be effective in deterring systematic or persistent exploitation of these disposal sites; and (2) can reduce the likelihood of inadvertent, intermittent human intrusion to a degree to be determined by the implementing agency. However, the Agency believes that passive institutional controls can never be assumed to eliminate the chance of inadvertent and intermittent human intrusion into these disposal sites.

Consideration of Inadvertent Human Intrusion into Geologic Repositories. The most speculative potential disruptions of a mined geologic repository are those associated with inadvertent human intrusion. Some types of intrusion would have virtually no effect on a repository's containment of waste. On the other hand, it is possible to conceive of intrusions (involving widespread societal loss of knowledge regarding radioactive wastes) that could result in major disruptions that no reasonable repository selection or design precautions could alleviate. The Agency believes that the most productive consideration of inadvertent 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.

Frequency and Severity of Inadvertent Human Intrusion into Geologic Repositories. The implementing agencies should consider the effects of each particular disposal system's site, design, and passive institutional controls in judging the likelihood and consequences of such inadvertent exploratory drilling. However, the Agency assumes that the likelihood of such inadvertent and intermittent drilling need not be taken to be greater than 30 boreholes per square kilometer of repository area per 10,000 years for geologic repositories in proximity to sedimentary rock formations, or more than 3 boreholes per square kilometer per 10,000 years for repositories in other geologic formations. Furthermore, the Agency assumes that the consequences of such inadvertent drilling need not be assumed to be more severe than: (1) Direct release to the land surface of all the ground water in the repository horizon that would promptly flow through the newly created borehole to the surface due to natural lithostatic pressure—or (if pumping would be required to raise water to the surface) release of 200 cubic meters of ground water pumped to the surface if that much water is readily available to be pumped; and (2) creation of a ground water flow path with a permeability typical of a borehole filled by the soil or gravel that would normally settle into an open hole over time—not the permeability of a carefully sealed borehole.

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Performance Objectives

§ 60.111 Performance of the geologic repository operations area through permanent closure.

(a) ***Protection against radiation exposures and releases of radioactive material.*** **The geologic repository operations area shall be designed so that until permanent closure has been completed, radiation exposures and radiation levels, and releases of radioactive materials to unrestricted areas, will at all times be maintained within the limits specified in Part 20 of this chapter and such generally applicable environmental standards for radioactivity as may have been established by the Environmental Protection Agency.**

(b) ***Retrievability of waste.*** **(1) The geologic repository operations area shall be designed to preserve the option of waste retrieval throughout the period during which wastes are being emplaced and, thereafter, until the completion of a preformance confirmation program and Commission review of the information obtained from such a program. To** satisfy this objective, the geologic repository operations area shall be designed so that any or all of the emplaced waste could be retrieved on a reasonable schedule starting at any time up to 50 years after waste emplacement operations are initiated, unless a different time period is approved or specified by the Commission. This different time period may be established on a case-by-case basis consistent with the emplacement schedule and the planned performance confirmation program.

(2) This requirement shall not preclude decisions by the Commission to allow backfilling part or all of, or permanent closure of, the geologic repository operations area prior to the end of the period of design for retrievability.

(3) For purposes of this paragraph, a reasonable schedule for retrieval is one that would permit retrieval in about the same time as that devoted to construction of the geologic repository operations area and the emplacement of wastes.

§ 60.112 Overall system performance objective for the geologic repository after permanent closure.

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

§ 60.113 Performance of particular barriers after permanent closure.

(a) *General provisions.* (1) *Engineered barrier system.* (i) The engineered barrier system shall be designed so that assuming anticipated processes and events: (A) Containment of HLW will be substantially complete during the period when radiation and thermal conditions in the engineered barrier system are dominated by fission product decay; and (B) any release of radionuclides from the engineered barrier system shall be a gradual process which results in small fractional releases to the geologic setting over long times. For disposal in the saturated zone, both the partial and complete filling with groundwater of available void spaces in the underground facility shall be appropriately considered and analysed among the anticipated processes and events in designing the engineered barrier system.

(ii) In satisfying the preceding requirement, the engineered barrier system shall be designed, assuming anticipated processes and events, so that:

(A) Containment of HLW within the waste packages will be substantially complete for a period to be determined by the Commission taking into account the factors specified in § 60.113(b) provided, that such period shall be not less than 300 years nor more than 1,000 years after permanent closure of the geologic repository; and

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

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

(b) On a case-by-case basis, the Commission may approve or specify some other radionuclide release rate, designed containment period or pre-waste-emplacement groundwater travel time, provided that the overall system performance objective, as it relates to anticipated processes and events, is satisfied. Among the factors that the Commission may take into account are—

(1) Any generally applicable environmental standard for radioactivity established by the Environmental Protection Agency;

(2) The age and nature of the waste, and the design of the underground facility, particularly as these factors bear upon the time during which the thermal pulse is dominated by the decay heat from the fission products;

(3) The geochemical characteristics of the host rock, surrounding strata and groundwater; and

(4) Particular sources of uncertainty in predicting the performance of the geologic repository.

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

Land Ownership and Control

§ 60.121 Requirements for ownership and control of interests in land.

(a) *Ownership of land.* (1) 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.

(2) These lands shall be held free and clear of all encumbrances, if significant, such as: (i) Rights arising under the general mining laws; (ii) easements for right-of-way; and (iii) all other rights arising under lease, rights of entry, deed, patent, mortgage, appropriation, prescription, or otherwise.

(b) *Additional controls.* Appropriate controls shall be established outside of the controlled area. DOE shall exercise any jurisdiction and control over surface and subsurface estates necessary to prevent adverse human actions that could significantly reduce the geologic repository's ability to achieve isolation. The rights of DOE may take the form of appropriate possessory interests, servitudes, or withdrawals from location or patent under the general mining laws.

(c) *Water rights.* (1) DOE shall also have obtained such water rights as may be needed to accomplish the purpose of the geologic repository operations area.

(2) Water rights are included in the additional controls to be established under paragraph (b) of this section.

Siting Criteria

§ 60.122 Siting criteria.

(a)(1) A geologic setting shall exhibit an appropriate combination of the conditions specified in paragraph (b) of this section so that, together with the engineered barriers system, the favorable conditions present are sufficient to provide reasonable assurance that the performance objectives relating to isolation of the waste will be met.

(2) If any of the potentially adverse conditions specified in paragraph (c) of this section is present, it may compromise the ability of the geologic repository to meet the performance objectives relating to isolation of the waste. In order to show that a potentially adverse condition does not so compromise the performance of the geologic repository the following must be demonstrated:

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

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

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

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

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

(b) *Favorable conditions.* (1) The nature and rates of tectonic, hydrogeologic, geochemical, and geomorphic processes (or any of such processes) operating within the geologic setting during the Quaternary Period, when projected, would not affect or would favorably affect the ability of the geologic repository to isolate the waste.

(2) For disposal in the saturated zone, hydrogeologic conditions that provide—

(i) A host rock with low horizontal and vertical permeability;

(ii) Downward or dominantly horizontal hydraulic gradient in the host rock and immediately surrounding hydrogeologic units; and

(iii) Low vertical permeability and low hydraulic gradient between the host rock and the surrounding hydrogeologic units.

(3) Geochemical conditions that—(i) Promote precipitation or sorption of radionuclides; (ii) Inhibit the formation of particulates, colloids, and inorganic and organic complexes that increase the mobility of radionuclides; or (iii) Inhibit the transport of radionuclides by particulates, colloids, and complexes.

(4) Mineral assemblages that, when subjected to anticipated thermal loading, will remain unaltered or alter to mineral assemblages having equal or increased capacity to inhibit radionuclide migration.

(5) Conditions that permit the emplacement of waste at a minimum depth of 300 meters from the ground surface. (The ground surface shall be deemed to be the elevation of the lowest point on the surface above the disturbed zone.)

(6) A low population density within the geologic setting and a controlled area that is remote from population centers.

(7) Pre-waste-emplacement groundwater travel time along the fastest path of likely radionuclide travel from the disturbed zone to the accessible environment that substantially exceeds 1,000 years.

(8) For disposal in the unsaturated zone, hydrogeologic conditions that provide—

(i) Low moisture flux in the host rock and in the overlying and underlying hydrogeologic units;

(ii) A water table sufficiently below the underground facility such that fully saturated voids contiguous with the water table do not encounter the underground facility;

(iii) A laterally extensive low-permeability hydrogeologic unit above the host rock that would inhibit the downward movement of water or divert downward moving water to a location beyond the limits of the underground facility;

(iv) A host rock that provides for free drainage; or

(v) A climatic regime in which the average annual historic precipitation is a small percentage of the average annual potential evapotranspiration.

(c) *Potentially adverse conditions.* The following conditions are potentially adverse conditions if they are characteristic of the controlled area or may affect isolation within the controlled area.

(1) Potential for flooding of the underground facility, whether resulting from the occupancy and modification of floodplains or from the failure of existing or planned man-made surface water impoundments.

(2) Potential for foreseeable human activity to adversely affect the groundwater flow system, such as groundwater withdrawal, extensive irrigation, subsurface injection of fluids, underground pumped storage, military activity or construction of large scale surface water impoundments.

(3) Potential for natural phenomena such as landslides, subsidence, or volcanic activity of such a magnitude that large-scale surface water impoundments could be created that could change the regional groundwater flow system and thereby adversely affect the performance of the geologic repository.

(4) Structural deformation, such as uplift, subsidence, folding, or faulting that may adversely affect the regional groundwater flow system.

(5) Potential for changes in hydrologic conditions that would affect the migration of radionuclides to the accessible environment, such as changes in hydraulic gradient, average interstitial velocity, storage coefficient, hydraulic conductivity, natural recharge, potentiometric levels, and discharge points.

(6) Potential for changes in hydrologic conditions resulting from reasonably foreseeable climatic changes.

(7) Groundwater conditions in the host rock, including chemical composition, high ionic strength or ranges of Eh-pH, that could increase the solubility or chemical reactivity of the engineered barrier system.

(8) Geochemical processes that would reduce sorption of radionuclides, result in degradation of the rock strength, or adversely affect the performance of the engineered barrier system.

(9) Groundwater conditions in the host rock that are not reducing.

(10) Evidence of dissolutioning such as breccia pipes, dissolution cavities, or brine pockets.

(11) Structural deformation such as uplift, subsidence, folding, and faulting during the Quaternary Period.

(12) Earthquakes which have occurred historically that if they were to be repeated could affect the site significantly.

(13) Indications, based on correlations of earthquakes with tectonic processes and features, that either the frequency of occurrence or magnitude of earthquakes may increase.

(14) More frequent occurrence of earthquakes or earthquakes of higher magnitude than is typical of the area in which the geologic setting is located.

(15) Evidence of igneous activity since the start of the Quaternary Period.

(16) Evidence of extreme erosion during the Quaternary Period.

(17) The presence of naturally

occurring materials, whether identified or undiscovered, within the site, in such form that:

(i) Economic extraction is currently feasible or potentially feasible during the foreseeable future; or

(ii) Such materials have greater gross value or net value than the average for other areas of similar size that are representative of and located within the geologic setting.

(18) Evidence of subsurface mining for resources within the site.

(19) Evidence of drilling for any purpose within the site.

(20) Rock or groundwater conditions that would require complex engineering measures in the design and construction of the underground facility or in the sealing of boreholes and shafts.

(21) Geomechanical properties that do not permit design of underground opening that will remain stable through permanent closure.

(22) Potential for the water table to rise sufficiently so as to cause saturation of an underground facility located in the unsaturated zone.

(23) Potential for existing or future perched water bodies that may saturate portions of the underground facility or provide a faster flow path from an underground facility located in the unsaturated zone to the accessible environment.

(24) Potential for the movement of radionuclides in a gaseous state through air-filled pore spaces of an unsaturated geologic medium to the accessible environment.

Design Criteria for the Geologic Repository Operations Area

§ 60.130 Scope of design criteria for the geologic repository operations area.

Sections 60.131 through 60.134 specify minimum criteria for the design of the geologic repository operations area. These design criteria are not intended to be exhaustive, however. Omissions in §§ 60.131 through 60.134 do not relieve DOE from any obligation to provide such safety features in a specific facility needed to achieve the performance objectives. All design bases must be consistent with the results of site characterization activities.

§ 60.131 General design criteria for the geologic repository operations area.

(a) *Radiological protection.* The geologic repository operations area shall be designed to maintain radiation doses, levels, and concentrations of radioactive material in air in restricted areas within the limits specified in Part 20 of this chapter. Design shall include—

(1) Means to limit concentrations of radioactive material in air;

(2) Means to limit the time required to perform work in the vicinity of radioactive materials, including, as appropriate, designing equipment for ease of repair and replacement and providing adequate space for ease of operation;

(3) Suitable shielding;

(4) Means to monitor and control the dispersal of radioactive contamination;

(5) Means to control access to high radiation areas or airborne radioactivity areas; and

(6) A radiation alarm system to warn of significant increases in radiation levels, concentrations of radioactive material in air, and of increased radioactivity released in effluents. The alarm system shall be designed with provisions for calibration and for testing its operability.

(b) *Structures, systems, and components important to safety. (1) Protection against natural phenomena and environmental conditions.*

The structures, systems, and components important to safety shall be designed so that natural phenomena and environmental conditions anticipated at the geologic repository operations area will not interfere with necessary safety functions.

(2) *Protection against dynamic effects of equipment failure and similar events.* The structures, systems, and components important to safety shall be designed to withstand dynamic effects such as missile impacts, that could result from equipment failure, and similar events and conditions that could lead to loss of their safety functions.

(3) *Protection against fires and explosions.* (i) The structures, systems, and components important to safety shall be designed to perform their safety fuctions during and after credible fires or explosions in the geologic repository operations area.

(ii) To the extent practicable, the geologic repository operations area shall be designed to incorporate the use of noncombustible and heat resistant materials.

(iii) The geologic repository operations area shall be designed to include explosion and fire detection alarm systems and appropriate suppression systems with sufficient capacity and capability to reduce the adverse effects of fires and explosions on structures, systems, and components important to safety.

(iv) The geologic repository operations area shall be designed to include means to protect systems, structures, and components important to safety against the adverse effects of either the operation or failure of the fire suppression systems.

(4) *Emergency capability.* (i) The structures, systems, and components important to safety shall be designed to maintain control of radioactive waste and radioactive effluents, and permit prompt termination of operations and evacuation of personnel during an emergency.

(ii) The geologic repository operations area shall be designed to include onsite facilities and services that ensure a safe and timely response to emergency conditions and that facilitate the use of available offsite services (such as fire, police, medical and ambulance service) that may aid in recovery from emergencies.

(5) *Utility services.* (i) Each utility service system that is important to safety shall be designed so that essential safety functions can be performed under both normal and accident conditions.

(ii) The utility services important to safety shall include redundant systems to the extent necessary to maintain, with adequate capacity, the ability to perform their safety functions.

(iii) Provisions shall be made so that, if there is a loss of the primary electric power source or circuit, reliable and timely emergency power can be provided to instruments, utility service systems, and operating systems, including alarm systems, important to safety.

(6) *Inspection, testing, and maintenance.* The structures, systems, and components important to safety shall be designed to permit periodic inspection, testing, and maintenance, as necessary, to ensure their continued functioning and readiness.

(7) *Criticality control.* All systems for processing, transporting, handling, storage, retrieval, emplacement, and isolation of radioactive waste shall be designed to ensure that a nuclear criticality accident is not possible unless at least two unlikely, independent, and concurrent or sequential changes have occurred in the conditions essential to nuclear criticality safety. Each system shall be designed for criticality safety under normal and accident conditions. The calculated effective multiplication factor (k_{eff}) must be sufficiently below unity to show at least a 5% margin, after allowance for the bias in the method of calculation and the uncertainty in the experiments used to validate the method of calculation.

(8) *Instrumentation and control systems.* The design shall include provisions for instrumentation and control systems to monitor and control the behavior of systems important to safety over anticipated ranges for normal operation and for accident conditions.

(9) *Compliance with mining regulations.* To the extent that DOE is not subject to the Federal Mine Safety and Health Act of 1977, as to the construction and operation of the geologic repository operations area, the design of the geologic repository operations area shall nevertheless include such provisions for worker protection as may be necessary to provide reasonable assurance that all structures, systems, and components important to safety can perform their intended functions. Any deviation from relevant design requirements in 30 CFR, Chapter I, Subchapters D, E, and N will give rise to a rebuttable presumption that this requirement has not been met.

(10) *Shaft conveyances used in radioactive waste handling.* (i) Hoists important to safety shall be designed to preclude cage free fall.

(ii) Hoists important to safety shall be designed with a reliable cage location system.

(iii) Loading and unloading systems for hoists important to safety shall be designed with a reliable system of interlocks that will fail safely upon malfunction.

(iv) Hoists important to safety shall be designed to include two independent indicators to indicate when waste packages are in place and ready for transfer.

§ 60.132 Additional design criteria for surface facilities in the geologic repository operations area.

(a) *Facilities for receipt and retrieval of waste.* Surface facilities in the geologic repository operations area shall be designed to allow safe handling and storage of wastes at the geologic repository operations area, whether these wastes are on the surface before emplacement or as a result of retrieval from the underground facility.

(b) *Surface facility ventilation.* Surface facility ventilation systems supporting waste transfer, inspection, decontamination, processing, or packaging shall be designed to provide protection against radiation exposures and offsite releases as provided in § 60.111(a).

(c) *Radiation control and monitoring.* (1) *Effluent control.* The surface facilities shall be designed to control the release of radioactive materials in effluents during normal operations so as to meet the performance objections of § 60.111(a).

(2) *Effluent monitoring.* The effluent monitoring systems shall be designed to measure the amount and concentration of radionuclides in any effluent with sufficient precision to determine whether releases conform to the design requirement for effluent control. The monitoring systems shall be designed to include alarms that can be periodically tested.

(d) *Waste treatment.* Radioactive waste treatment facilities shall be designed to process any radioactive wastes generated at the geologic repository operations area into a form suitable to permit safe disposal at the geologic repository operations area or to permit safe transportation and conversion to a form suitable for disposal at an alternative site in accordance with any regulations that are applicable.

(e) *Consideration of decommissioning.* The surface facility shall be designed to facilitate decontamination or dismantlement to the same extent as would be required, under other parts of this chapter, with respect to equivalent activities licensed thereunder.

§ 60.133 Additional design criteria for the underground facility.

(a) *General criteria for the underground facility.* (1) The orientation, geometry, layout, and depth of the underground facility, and the design of any engineered barriers that are part of the underground facility shall contribute to the containment and isolation of radionuclides.

(2) The underground facility shall be designed so that the effects of credible disruptive events during the period of operations, such as flooding, fires and explosions, will not spread through the facility.

(b) *Flexibility of design.* The underground facility shall be designed with sufficient flexibility to allow adjustments where necessary to accommodate specific site conditions identified through in situ monitoring, testing, or excavation.

(c) *Retrieval of waste.* The underground facility shall be designed to permit retrieval of waste in accordance with the performance objectives of § 60.111.

(d) *Control of water and gas.* The design of the underground facility shall provide for control of water or gas intrusion.

(e) *Underground openings.* (1) Openings in the underground facility shall be designed so that operations can be carried out safely and the retrievability option maintained.

(2) Openings in the underground facility shall be designed to reduce the potential for deleterious rock movement or fracturing of overlying or surrounding rock.

(f) Rock excavation. The design of the underground facility shall incorporate excavation methods that will limit the potential for creating a preferential pathway for groundwater to contact the waste packages or radionuclide migration to the accessible environment.

(g) *Underground facility ventilation.* The ventilation system shall be designed to—(1) Control the transport of radioactive particulates and gases within and releases from the underground facility in accordance with the performance objectives of § 60.111(a).

(2) Assure continued function during normal operations and under accident conditions; and

(3) Separate the ventilation of excavation and waste emplacement areas.

(h) *Engineered barriers.* Engineered barriers shall be designed to assist the geologic setting in meeting the performance objectives for the period following permanent closure.

(i) *Thermal loads.* The underground facility shall be designed so that the performance objectives will be met taking into account the predicted thermal and thermomechanical response of the host rock, and surrounding strata, groundwater system.

§ 60.134 Design of seals for shafts and boreholes.

(a) *General design criterion.* Seals for shafts and boreholes shall be designed so that following permanent closure they do not become pathways that compromise the geologic repository's ability to meet the performance objectives or the period following permanent closure.

(b) *Selection of materials and placement methods.* Materials and placement methods for seals shall be selected to reduce, to the extent practicable:

(1) The potential for creating a preferential pathway for groundwater to contact the waste packages or (2) for radionuclide migration through existing pathways.

Design Criteria for the Waste Package

§ 60.135 Criteria for the waste package and its components.

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

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

(b) *Specific criteria for HLW package design. (1) Explosive, pyrophoric, and chemically reactive materials.* The waste package shall not contain explosive or pyrophoric materials or chemically reactive materials in an amount that could compromise the ability of the underground facility to contribute to waste isolation or the ability of the geologic repository to satisfy the performance objectives.

(2) *Free liquids.* The waste package shall not contain free liquids in an amount that could compromise the ability of the waste packages to achieve the performance objectives relating to containment of HLW (because of chemical interactions or formation of pressurized vapor) or result in spillage and spread of contamination in the event of waste package perforation during the period through permanent closure.

(3) *Handling.* Waste packages shall be designed to maintain waste containment during transportation, emplacement, and retrieval.

(4) *Unique identification.* A label or other means of identification shall be

provided for each waste package. The identification shall not impair the integrity of the waste package and shall be applied in such a way that the information shall be legible at least to the end of the period of retrievability. Each waste package identification shall be consistent with the waste package's permanent written records.

(c) *Waste form criteria for HLW. High-level radioactive waste that is emplaced in the underground facility shall be designed to meet the following criteria:*

(1) *Solidification.* All such radioactive wastes shall be in solid form and placed in sealed containers.

(2) *Consolidation.* Particulate waste forms shall be consolidated (for example, by incorporation into an encapsulating matrix) to limit the availability and generation of particulates.

(3) *Combustibles.* All combustible radioactive wastes shall be reduced to a noncombustible form unless it can be demonstrated that a fire involving the waste packages containing combustibles will not compromise the integrity of other waste packages, adversely affect any structures, systems, or components important to safety, or compromise the ability of the underground facility to contribute to waste isolation.

(d) *Design criteria for other radioactive wastes.* Design criteria for waste types other than HLW will be addressed on an individual basis if and when they are proposed for disposal in a geologic repository.

Performance Confirmation Requirements

§ 60.137 General requirements for performance confirmation.

The geologic repository operations area shall be designed so as to permit implementation of a performance confirmation program that meets the requirements of Subpart F of this part.

Subpart C—Postclosure Guidelines

§ 960.4 Postclosure guidelines.

The guidelines in this Subpart specify the factors to be considered in evaluating and comparing sites on the basis of expected repository performance after closure. The postclosure guidelines are separated into a system guideline and eight technical guidelines. The system guideline establishes waste containment and isolation requirements that are based on NRC and EPA regulations. These requirements must be met by the repository system, which contains natural barriers and engineered barriers. The engineered barriers will be designed to complement the natural barriers, which provide the primary means for waste isolation.

§ 960.4-1 System guideline.

(a) *Qualifying Condition.* The geologic setting at the site shall allow for the physical separation of radioactive waste from the accessible environment after closure in accordance with the requirements of 40 CFR Part 191, Subpart B, as implemented by the provisions of 10 CFR Part 60. The geologic setting at the site will allow for the use of engineered barriers to ensure compliance with the requirements of 40 CFR Part 191 and 10 CFR Part 60 (see Appendix I of this Part).

§ 960.4-2 Technical guidelines.

The technical guidelines in this Subpart set forth qualifying, favorable, potentially adverse, and, in five guidelines, disqualifying conditions on the characteristics, processes, and events that may influence the performance of a repository system after closure. The favorable conditions and the potentially adverse conditions under each guideline are *not* listed in any assumed order of importance.

§ 960.4-2-1 Geohydrology.

(a) *Qualifying Condition.* The present and expected geohydrologic setting of a site shall be compatible with waste containment and isolation. The geohydrologic setting, considering the characteristics of and the processes operating within the geologic setting, shall permit compliance with (1) the requirements specified in § 960.4-1 for radionuclide releases to the accessible environment and (2) the requirements specified in 10 CFR 60.113 for radionuclide releases from the engineered-barrier system using reasonably available technology.

(b) *Favorable Conditions.* (1) Site conditions such that the pre-waste-emplacement ground-water travel time along any path of likely radionuclide travel from the disturbed zone to the accessible environment would be more than 10,000 years.

(2) The nature and rates of hydrologic processes operating within the geologic setting during the Quaternary Period would, if continued into the future, not affect or would favorably affect the ability of the geologic repository to isolate the waste during the next 100,000 years.

(3) Sites that have stratigraphic, structural, and hydrologic features such that the geohydrologic system can be readily characterized and modeled with reasonable certainty.

(4) For disposal in the saturated zone, at least one of the following pre-waste-emplacement conditions exists:

(i) A host rock and immediately surrounding geohydrologic units with low hydraulic conductivities.

(ii) A downward or predominantly horizontal hydraulic gradient in the host rock and in the immediately surrounding geohydrologic units.

(iii) A low hydraulic gradient in and between the host rock and the immediately surrounding geohydrologic units.

(iv) High effective porosity together with low hydraulic conductivity in rock units along paths of likely radionuclide travel between the host rock and the accessible environment.

(5) For disposal in the unsaturated zone, at least one of the following pre-waste-emplacement conditions exists:

(i) A low and nearly constant degree of saturation in the host rock and in the immediately surrounding geohydrologic units.

(ii) A water table sufficiently below the underground facility such that the fully saturated voids continuous with the water table do not encounter the host rock.

(iii) A geohydrologic unit above the host rock that would divert the downward infiltration of water beyond the limits of the emplaced waste.

(iv) A host rock that provides for free drainage.

(v) A climatic regime in which the average annual historical precipitation is a small fraction of the average annual potential evapotranspiration.

Note.—The DOE will, in accordance with the general principles set forth in § 960.1 of these regulations, revise the guidelines as necessary, to ensure consistency with the final NRC regulations on the unsaturated zone, which were published as a proposed rule on February 16, 1984, in 49 FR 5934.

(c) *Potentially Adverse Conditions.* (1) Expected changes in geohydrologic conditions—such as changes in the hydraulic gradient, the hydraulic conductivity, the effective porosity, and the ground-water flux through the host rock and the surrounding geohydrologic units—sufficient to significantly increase the transport of radionuclides to the accessible environment as compared with pre-waste-emplacement conditions.

(2) The presence of ground-water sources, suitable for crop irrigation or human consumption without treatment, along ground-water flow paths from the host rock to the accessible environment.

(3) The presence in the geologic setting of stratigraphic or structural features—such as dikes, sills, faults, shear zones, folds, dissolution effects, or brine pockets—if their presence could significantly contribute to the difficulty of characterizing or modeling the geohydrologic system.

(d) *Disqualifying Condition.* A site shall be disqualified if the pre-waste-emplacement ground-water travel time from the disturbed zone to the accessible environment is expected to be less than 1,000 years along any pathway of likely and significant radionuclide travel.

§ 960.4-2-2 Geochemistry.

(a) *Qualifying Condition.* The present and expected geochemical characteristics of a site shall be compatible with waste containment and isolation. Considering the likely chemical interactions among radionuclides, the host rock, and the ground water, the characteristics of and the processes operating within the geologic setting shall permit compliance with (1) the requirements specified in § 960.4-1 for radionuclide releases to the accessible environment and (2) the requirements specified in 10 CFR 60.113 for radionuclide releases from the engineered-barrier system using reasonably available technology.

(b) *Favorable Conditions.* (1) The nature and rates of the geochemical processes operating within the geologic setting during the Quaternary Period would, if continued into the future, not affect or would favorably affect the ability of the geologic repository to isolate the waste during the next 100,000 years.

(2) Geochemical conditions that promote the precipitation, diffusion into the rock matrix, or sorption of radionuclides; inhibit the formation of particulates, colloids, inorganic complexes, or organic complexes that increase the mobility of radionuclides; or inhibit the transport of radionuclides by particulates, colloids, or complexes.

(3) Mineral assemblages that, when subjected to expected repository conditions, would remain unaltered or would alter to mineral assemblages with equal or increased capability to retard radionuclide transport.

(4) A combination of expected geochemical conditions and a volumetric flow rate of water in the host rock that would allow less than 0.001 percent per year of the total radionuclide inventory in the repository at 1,000 years to be dissolved.

(5) Any combination of geochemical and physical retardation processes that would decrease the predicted peak cumulative releases of radionuclides to the accessible environment by a factor of 10 as compared to those predicted on the basis of ground-water travel time without such retardation.

(c) *Potentially Adverse Conditions.* (1) Ground-water conditions in the host rock that could affect the solubility or the chemical reactivity of the engineered-barrier system to the extent that the expected repository performance could be compromised.

(2) Geochemical processes or conditions that could reduce the sorption of radionuclides or degrade the rock strength.

(3) Pre-waste-emplacement ground-water conditions in the host rock that are chemically oxidizing.

§ 960.4-2-3 Rock characteristics.

(a) *Qualifying condition.* The present and expected characteristics of the host rock and surrounding units shall be capable of accommodating the thermal, chemical, mechanical, and radiation stresses expected to be induced by repository construction, operation, and closure and by expected interactions among the waste, host rock, ground water, and engineered components. The characteristics of and the processes operating within the geologic setting shall permit compliance with (1) the requirements specified in § 960.4-1 for radionuclide releases to the accessible environment and (2) the requirements set forth in 10 CFR 60.113 for radionuclide releases from the engineered-barrier system using reasonably available technology.

(b) *Favorable Conditions.* (1) A host rock that is sufficiently thick and laterally extensive to allow significant flexibility in selecting the depth, configuration, and location of the underground facility to ensure isolation.

(2) A host rock with a high thermal conductivity, a low coefficient of thermal expansion, or sufficient ductility to seal fractures induced by repository construction, operation, or closure or by interactions among the waste, host rock, ground water, and engineered components.

(c) *Potentially Adverse Conditions.* (1) Rock conditions that could require engineering measures beyond reasonably available technology for the construction, operation, and closure of the repository, if such measures are necessary to ensure waste containment or isolation.

(2) Potential for such phenomena as thermally induced fractures, the hydration or dehydration of mineral components, brine migration, or other physical, chemical, or radiation-related phenomena that could be expected to affect waste containment or isolation.

(3) A combination of geologic structure, geochemical and thermal properties, and hydrologic conditions in the host rock and surrounding units such that the heat generated by the waste could significantly decrease the isolation provided by the host rock as compared with pre-waste-emplacement conditions.

§ 960.4-2-4 Climatic changes.

(a) *Qualifying Condition.* The site shall be located where future climatic conditions will not be likely to lead to radionuclide releases greater than those allowable under the requirements specified in § 960.4-1. In predicting the likely future climatic conditions at a site, the DOE will consider the global, regional, and site climatic patterns during the Quaternary Period, considering the geomorphic evidence of the climatic conditions in the geologic setting.

(b) *Favorable Conditions.* (1) A surface-water system such that expected climatic cycles over the next 100,000 years would not adversely affect waste isolation.

(2) A geologic setting in which climatic changes have had little effect on the hydrologic system throughout the Quaternary Period.

(c) *Potentially Adverse Conditions.* (1) Evidence that the water table could rise sufficiently over the next 10,000 years to saturate the underground facility in a previously unsaturated host rock.

(2) Evidence that climatic changes over the next 10,000 years could cause perturbations in the hydraulic gradient, the hydraulic conductivity, the effective porosity, or the ground-water flux through the host rock and the surrounding geohydrologic units, sufficient to significantly increase the transport of radionuclides to the accessible environment.

§ 960.4-2-5 Erosion.

(a) *Qualifying Condition.* The site shall allow the underground facility to be placed at a depth such that erosional processes acting upon the surface will not be likely to lead to radionuclide releases greater than those allowable under the requirements specified in § 960.4-1. In predicting the likelihood of potentially disruptive erosional processes, the DOE will consider the climatic, tectonic, and geomorphic evidence of rates and patterns of erosion in the geologic setting during the Quaternary Period.

(b) *Favorable Conditions.* (1) Site conditions that permit the emplacement of waste at a depth of at least 300 meters below the directly overlying ground surface.

(2) A geologic setting where the nature and rates of the erosional processes that have been operating during the Quaternary Period are predicted to have less than one chance in 10,000 over the next 10,000 years of leading to releases of radionuclides to the accessible environment.

(3) Site conditions such that waste exhumation would not be expected to occur during the first one million years after repository closure.

(c) *Potentially Adverse Conditions.* (1) A geologic setting that shows evidence of extreme erosion during the Quaternary Period.

(2) A geologic setting where the nature and rates of geomorphic processes that have been operating during the Quaternary Period could, during the first 10,000 years after closure, adversely affect the ability of the geologic repository to isolate the waste.

(d) *Disqualifying Condition.* The site shall be *disqualified* if site conditions do not allow all portions of the underground facility to be situated at least 200 meters below the directly overlying ground surface.

§ 960.4-2-6 Dissolution.

(a) *Qualifying Condition.* The site shall be located such that any subsurface rock dissolution will not be likely to lead to radionuclide releases greater than those allowable under the requirements specified in § 960.4-1. In predicting the likelihood of dissolution within the geologic setting at a site, the DOE will consider the evidence of dissolution within that setting during the Quaternary Period, including the locations and characteristics of dissolution fronts or other dissolution features, if identified.

(b) *Favorable Condition.* No evidence that the host rock within the site was subject to significant dissolution during the Quaternary Period.

(c) *Potentially Adverse Condition.* Evidence of dissolution within the geologic setting—such as breccia pipes, dissolution cavities, significant volumetric reduction of the host rock or surrounding strata, or any structural collapse—such that a hydraulic interconnection leading to a loss of waste isolation could occur.

(d) *Disqualifying Condition.* The site shall be *disqualified* if it is likely that, during the first 10,000 years after closure, active dissolution, as predicted on the basis of the geologic record, would result in a loss of waste isolation.

§ 960.4-2-7 Tectonics.

(a) *Qualifying Condition.* The site shall be located in a geologic setting where future tectonic processes or events will not be likely to lead to radionuclide releases greater than those allowable under the requirements specified in § 960.4-1. In predicting the likelihood of potentially disruptive tectonic processes or events, the DOE will consider the structural, stratigraphic, geophysical, and seismic evidence for the nature and rates of tectonic processes and events in the geologic setting during the Quaternary Period.

(b) *Favorable Condition.* The nature and rates of igneous activity and tectonic processes (such as uplift, subsidence, faulting, or folding), if any, operating within the geologic setting during the Quaternary Period would, if continued into the future, have less than one chance in 10,000 over the first 10,000 years after closure of leading to releases of radionuclides to the accessible environment.

(c) *Potentially Adverse Conditions.* (1) Evidence of active folding, faulting, diapirism, uplift, subsidence, or other tectonic processes or igneous activity within the geologic setting during the Quaternary Period.

(2) Historical earthquakes within the geologic setting of such magnitude and intensity that, if they recurred, could affect waste containment or isolation.

(2) Indications, based on correlations of earthquakes with tectonic processes and features, that either the frequency of occurrence or the magnitude of earthquakes within the geologic setting may increase.

(4) More-frequent occurrences of earthquakes or earthquakes of higher magnitude than are representative of the region in which the geologic setting is located.

(5) Potential for natural phenomena such as landslides, subsidence, or volcanic activity of such magnitudes that they could create large-scale surface-water impoundments that could change the regional ground-water flow system.

(6) Potential for tectonic deformations—such as uplift, subsidence, folding, or faulting—that could adversely affect the regional ground-water flow system.

(d) *Disqualifying Condition.* A site shall be disqualified if, based on the geologic record during the Quaternary Period, the nature and rates of fault movement or other ground motion are expected to be such that a loss of waste isolation is likely to occur.

§ 960.4-2-8 Human interference.

The site shall be located such that activities by future generations at or near the site will not be likely to affect waste containment and isolation. In assessing the likelihood of such activities, the DOE will consider the estimated effectiveness of the permanent markers and records required by 10 CFR Part 60, taking into account site-specific factors, as stated in §§ 960.4-2-8-1 and 960.4-2-8-2, that could compromise their continued effectiveness.

§ 960.4-2-8-1 Natural resource.

(a) *Qualifying Condition.* This site shall be located such that—considering permanent markers and records and reasonable projections of value, scarcity, and technology—the natural resources, including ground water suitable for crop irrigation or human consumption without treatment, present at or near the site will not be likely to give rise to interference activities that would lead to radionuclide releases greater than those allowable under the requirements specified in § 960.4–1.

(b) *Favorable Conditions.* (1) No known natural resources that have or are projected to have in the foreseeable future a value great enough to be considered a commercially extractable resource.

(2) Ground water with 10,000 parts per million or more of total dissolved solids along any path of likely radionuclide travel from the host rock to the accessible environment.

(c) *Potentially Adverse Conditions.* (1) Indications that the site contains naturally occurring materials, whether or not actually identified in such form that (i) economic extraction is potentially feasible during the foreseeable future or (ii) such materials have a greater gross value, net value, or commercial potential than the average for other areas of similar size that are representative of, and located in, the geologic setting.

(2) Evidence of subsurface mining or extraction for resources within the site if it could affect waste containment or isolation.

(3) Evidence of drilling within the site for any purpose other than repository-site evaluation to a depth sufficient to affect waste containment and isolation.

(4) Evidence of a significant concentration of any naturally occurring material that is not widely available from other sources.

(5) Potential for foreseeable human activities—such as ground-water withdrawal, extensive irrigation, subsurface injection of fluids, underground pumped storage, military activities, or the construction of large-scale surface-water impoundments—that could adversely change portions of the ground-water flow system important to waste isolation.

(d) *Disqualifying Conditions.* A site shall be disqualified if—

(1) Previous exploration, mining, or extraction activities for resources of commercial importance at the site have created significant pathways between the projected underground facility and the accessible environment; or

(2) Ongoing or likely future activities to recover presently valuable natural mineral resources outside the controlled area would be expected to lead to an inadvertent loss of waste isolation.

§ 960.4–2–8–2 Site ownership and control.

(a) *Qualifying Condition.* The site shall be located on land for which the DOE can obtain, in accordance with the requirements of 10 CFR Part 60, ownership, surface and subsurface rights, and control of access that are required in order that potential surface and subsurface activities as the site will not be likely to lead to radionuclide releases greater than those allowable under the requirements specified in § 960.4–1.

(b) *Favorable Condition.* Present ownership and control of land and all surface and subsurface rights by the DOE.

(c) *Potentially Adverse Condition.* Projected land-ownership conflicts that cannot be successfully resolved through voluntary purchase-sell agreements, nondisputed agency-to-agency transfers of title, or Federal condemnation proceedings.

Subpart D—Preclosure Guidelines

§ 960.5 Preclosure guidelines.

The guidelines in this Subpart specify the factors to be considered in evaluating and comparing sites on the basis of expected repository performance before closure. The preclosure guidelines are separated into three system guidelines and eleven technical guidelines.

§ 960.5–1 System guidelines.

(a) *Qualifying Conditions*—(1) *Preclosure Radiological Safety.* Any projected radiological exposures of the general public and any projected releases of radioactive materials to restricted and unrestricted areas during repository operation and closure shall meet the applicable safety requirements set forth in 10 CFR Part 20, 10 CFR Part 60, and 40 CFR 191, Subpart A (see Appendix II of this part).

(2) *Environment, Socioeconomics, and Transportation.* During repository siting, construction, operation, closure, and decommissioning the public and the environment shall be adequately protected from the hazards posed by the disposal of radioactive waste.

(3) *Ease and Cost of Siting, Construction, Operation, and Closure.* Repository siting, construction, operation, and closure shall be demonstrated to be technically feasible on the basis of reasonably available technology, and the associated costs shall be demonstrated to be reasonable relative to other available and comparable siting options.

§ 960.5–2 Technical guidelines.

The technical guidelines in this Subpart set forth qualifying, favorable, potentially adverse, and, in seven guidelines, disqualifying conditions for the characteristics, processes, and events that influence the suitability of a site relative to the preclosure system guidelines. These conditions are separated into three main groups: Preclosure radiological safety; environment, socioeconomics, and transportation; and ease and cost of siting, construction, operation, and closure. The first group includes conditions on population density and distribution, site ownership and control, meteorology, and offsite installations and operations. The second group includes conditions related to environmental quality and socioeconomic impacts in areas potentially affected by a repository and to the transportation of waste to a repository site. The third group includes conditions on the surface characteristics of the site, the characteristics of the host rock and surrounding strata, hydrology, and tectonics. The individual technical guidelines within each group, as well as the favorable conditions and the potentially adverse conditions under each guideline, are not listed in any assumed order of importance. The technical guidelines that follow establish conditions that shall be considered in determining compliance with the qualifying conditions of the preclosure system guidelines. For each technical guideline, an evaluation of qualification or disqualification shall be made in accordance with the requirements specified in Subpart B.

Preclosure Radiological Safety

§ 960.5–2–1 Population Density and Distribution.

(a) *Qualifying Condition.* The site shall be located such that, during repository operation and closure, (1) the expected average radiation dose to members of the public within any highly populated area will not be likely to exceed a small fraction of the limits allowable under the requirements specified in § 960.5–1(a)(1), and (2) the expected radiation dose to any member of the public in an unrestricted area will not be likely to exceed the limit allowable under the requirements specified in § 960.5–1(a)(1).

(b) *Favorable Conditions.* (1) A low population density in the general region of the site.

(2) Remoteness of site from highly populated areas.

(c) *Potentially Adverse Conditions.* (1) High residential, seasonal, or daytime population density within the projected site boundaries.

(2) Proximity of the site to highly populated areas, or to areas having at least 1,000 individuals in an area 1 mile

by 1 mile as defined by the most recent decennial count of the U.S. census.

(d) *Disqualifying Conditions.* A site shall be *disqualified* if—

(1) Any surface facility of a repository would be located in a highly populated area; or

(2) Any surface facility of a repository would be located adjacent to an area 1 mile by 1 mile having a population of not less than 1,000 individuals as enumerated by the most recent U.S. census; or

(3) The DOE could not develop an emergency preparedness program which meets the requirements specified in DOE Order 5500.3 (Reactor and Non-Reactor Facility Emergency Planning, Preparedness, and Response Program for Department of Energy Operations) and related guides or, when issued by the NRC, in 10 CFR Part 60, Subpart I, "Emergency Planning Criteria."

§ 960.5-2-2 Site Ownership and Control.

(a) *Qualifying Condition.* The site shall be located on land for which the DOE can obtain, in accordance with the requirements of 10 CFR 60.121, ownership, surface and subsurface rights, and control of access that are required in order that surface and subsurface activities during repository operation and closure will not be likely to lead to radionuclide releases to an unrestricted area greater than those allowable under the requirements specified in § 960.5-1(a)(1).

(b) *Favorable Condition.* Present ownership and control of land and all surface and subsurface mineral and water rights by the DOE.

(c) *Potentially Adverse Condition.* Projected land-ownership conflicts that cannot be successfully resolved through voluntary purchase-sell agreements, nondisputed agency-to-agency transfers of title, or Federal condemnation proceedings.

§ 960.5-2-3 Meteorology.

(a) *Qualifying Condition.* The site shall be located such that expected meteorological conditions during repository operation and closure will not be likely to lead to radionuclide releases to an unrestricted area greater than those allowable under the requirements specified in § 960.5-1(a)(1).

(b) *Favorable Condition.* Prevailing meteorological conditions such that any radioactive releases to the atmosphere during repository operation and closure would be effectively dispersed, thereby reducing significantly the likelihood of unacceptable exposure to any member of the public in the vicinity of the repository.

(c) *Potentially Adverse Conditions.* (1) Prevailing meteorological conditions such that radioactive emissions from repository operation of closure could be preferentially transported toward localities in the vicinity of the repository with higher population densities than are the average for the region.

(2) History of extreme weather phenomena—such as hurricanes, tornadoes, severe floods, or severe and frequent winter storms—that could significantly affect repository operation or closure.

§ 960.5-2-4 Offsite installations and operations.

(a) *Qualifying Condition.* The site shall be located such that present projected effects from nearby industrial, transportation, and military installations and operations, including atomic energy defense activities, (1) will not significantly affect repository siting, construction, operation, closure, or decommissioning or can be accommodated by engineering measures and (2), when considered together with emissions from repository operation and closure, will not be likely to lead to radionuclide releases to an unrestricted area greater than those allowable under the requirements specified in § 960.5-1(a)(1).

(b) *Favorable Condition.* Absence of contributing radioactive releases from other nuclear installations and operations that must be considered under the requirements of 40 CFR 191, Subpart A.

(c) *Potentially Adverse Conditions.* (1) The presence of nearby potentially hazardous installations or operations that could adversely affect repository operation or closure.

(2) Presence of other nuclear installations and operations, subject to the requirements of 40 CFR Part 190 or 40 CFR 191, Subpart A, with actual or projected releases near the maximum value permissible under those standards.

(d) *Disqualifying Condition.* A site shall be disqualified if atomic energy defense activities in proximity to the site are expected to conflict irreconcilably with repository siting, construction, operation, closure, or decommissioning.

Environment, Socioeconomics, and Transportation

§ 960.5-2-5 Environmental quality.

(a) *Qualifying Condition.* The site shall be located such that (1) the quality of the environment in the affected area during this and future generations will be adequately protected during repository siting, construction, operation, closure, and decommissioning, and projected environmental impacts in the affected area can be mitigated to an acceptable degree, taking into account programmatic, technical, social, economic, and environmental factors; and (2) the requirements specified in § 960.5-1(a)(2) can be met.

(b) *Favorable Conditions.* (1) Projected ability to meet, within time constraints, all Federal, State, and local procedural and substantive environmental requirements applicable to the site and the activities proposed to take place thereon.

(2) Potential significant adverse environmental impacts to present and future generations can be mitigated to an insignificant level through the application of reasonable measures, taking into account programmatic, technical, social, economic, and environmental factors.

(c) *Potentially Adverse Conditions.* (1) Projected major conflict with applicable Federal, State, or local environmental requirements.

(2) Projected significant adverse environmental impacts that cannot be avoided or mitigated.

(3) Proximity to, or projected significant adverse environmental impacts of the repository or its support facilities on, a component of the National Park System, the National Wildlife Refuge System, the National Wild and Scenic Rivers System, the National Wilderness Preservation System, or National Forest Land.

(4) Proximity to, and projected significant adverse environmental impacts of the repository or its support facilities on, a significant State or regional protected resource area, such as a State park, a wildlife area, or a historical area.

(5) Proximity to, and projected significant adverse environmental impacts of the repository and its support facilities on, a significant Native American resource, such as a major Indian religious site, or other sites of unique cultural interest.

(6) Presence of critical habitats for threatened or endangered species that may be compromised by the repository or its support facilities.

(d) *Disqualifying Conditions.* Any of the following conditions shall *disqualify* a site:

(1) During repository siting, construction, operation, closure, or decommissioning the quality of the environment in the affected area could not be adequately protected or projected environmental impacts in the affected area could not be mitigated to an acceptable degree, taking into account

programmatic, technical, social, economic, and environmental factors.

(2) Any part of the restricted area or repository support facilities would be located within the boundaries of a component of the National Park System, the National Wildlife Refuge System, the National Wilderness Preservation System, or the National Wild and Scenic Rivers System.

(3) The presence of the restricted area or the repository support facilities would conflict irreconcilably with the previously designated resource-preservation use of a component of the National Park System, the National Wildlife Refuge System, the National Wilderness Preservation System, the National Wild and Scenic Rivers System, or National Forest Lands, or any comparably significant State protected resource that was dedicated to resource preservation at the time of the enactment of the Act.

§ 960.5-2-6 Socioeconomic impacts.

(a) *Qualifying Condition.* The site shall be located such that (1) any significant adverse social and/or economic impacts induced in communities and surrounding regions by repository siting, construction, operation, closure, and decommissioning can be offset by reasonable mitigation or compensation, as determined by a process of analysis, planning, and consultation among the DOE, affected State and local government jurisdictions, and affected Indian tribes; and (2) the requirements specified in § 960.5-1(a)(2) can be met.

(b) *Favorable Conditions.* (1) Ability of an affected area to absorb the project-related population changes without significant disruptions of community services and without significant impacts on housing supply and demand.

(2) Availability of an adequate labor force in the affected area.

(3) Projected net increases in employment and business sales, improved community services, and increased government revenues in the affected area.

(4) No projected substantial disruption of primary sectors of the economy of the affected area.

(c) *Potentially Adverse Conditions.* (1) Potential for significant repository-related impacts on community services, housing supply and demand, and the finances of State and local government agencies in the affected area.

(2) Lack of an adequate labor force in the affected area.

(3) Need for repository-related purchase or acquisition of water rights, if such rights could have significant adverse impacts on the present or future development of the affected area.

(4) Potential for major disruptions of primary sectors of the economy of the affected area.

(d) *Disqualifying Condition.* A site shall be disqualified if repository construction, operation, or closure would significantly degrade the quality, or significantly reduce the quantity, of water from major sources of offsite supplies presently suitable for human consumption or crop irrigation and such impacts cannot be compensated for, or mitigated by, reasonable measures.

§ 960.5-2-7 Transportation.

(a) *Qualifying Condition.* The site shall be located such that (1) the access routes constructed from existing local highways and railroads to the site (i) will not conflict irreconcilably with the previously designated use of any resource listed in § 960.5-2-5(d) (2) and (3); (ii) can be designed and constructed using reasonably available technology; (iii) will not require transportation system components to meet performance standards more stringent than those specified in the applicable DOT and NRC regulations, nor require the development of new packaging containment technology; (iv) will allow transportation operations to be conducted without causing an unacceptable risk to the public or unacceptable environmental impacts, taking into account programmatic, technical, social, economic, and environmental factors; and (2) the requirements of § 960.5-1(a)(2) can be met.

(b) *Favorable Conditions.* (1) Availability of access routes from local existing highways and railroads to the site which have any of the following characteristics:

(i) Such routes are relatively short and economical to construct as compared to access routes for other comparable siting options.

(ii) Federal condemnation is not required to acquire rights-of-way for the access routes.

(iii) Cuts, fills, tunnels, or bridges are not required.

(iv) Such routes are free of sharp curves or steep grades and are not likely to be affected by landslides or rock slides.

(v) Such routes bypass local cities and towns.

(2) Proximity to local highways and railroads that provide access to regional highways and railroads and are adequate to serve the repository without significant upgrading or reconstruction.

(3) Proximity to regional highways, mainline railroads, or inland waterways that provide access to the national transportation system.

(4) Availability of a regional railroad system with a minimum number of interchange points at which train crew and equipment changes would be required.

(5) Total projected life-cycle cost and risk for transportation of all wastes designated for the repository site which are significantly lower than those for comparable siting options, considering locations of present and potential sources of waste, interim storage facilities, and other repositories.

(6) Availability of regional and local carriers—truck, rail, and water—which have the capability and are willing to handle waste shipments to the repository.

(7) Absence of legal impediment with regard to compliance with Federal regulations for the transportation of waste in or through the affected State and adjoining States.

(8) Plans, procedures, and capabilities for response to radioactive waste transportation accidents in the affected State that are completed or being developed.

(9) A regional meteorological history indicating that significant transportation disruptions would not be routine seasonal occurrences.

(c) *Potentially Adverse Conditions.* (1) Access routes to existing local highways and railroads that are expensive to construct relative to comparable siting options.

(2) Terrain between the site and existing local highways and railroads such that steep grades, sharp switchbacks, rivers, lakes, landslides, rock slides, or potential sources of hazard to incoming waste shipments will be encountered along access routes to the site.

(3) Existing local highways and railroads that could require significant reconstruction or upgrading to provide adequate routes to the regional and national transportation system.

(4) Any local condition that could cause the transportation-related costs, environmental impacts, or risk to public health and safety from waste transportation operations to be significantly greater than those projected for other comparable siting options.

Ease and Cost of Siting, Construction, Operation, and Closure

§ 960.5-2-8 Surface characteristics.

(a) *Qualifying Condition.* The site shall be located such that, considering the surface characteristics and conditions of the site and surrounding area, including surface-water systems and the terrain, the requirements specified in § 960.5–1(a)(3) can be met during repository siting, construction, operation, and closure.

(b) *Favorable Conditions.* (1) Generally flat terrain.

(2) Generally well-drained terrain.

(c) *Potentially Adverse Condition.* Surface characteristics that could lead to the flooding of surface or underground facilities by the occupancy and modification of flood plains, the failure of existing or planned man-made surface-water impoundments, or the failure of engineered components of the repository.

§ 960.5-2-9 Rock characteristics.

(a) *Qualifying Condition.* The site shall be located such that (1) the thickness and lateral extent and the characteristics and composition of the host rock will be suitable for accommodation of the underground facility; (2) repository construction, operation, and closure will not cause undue hazard to personnel; and (3) the requirements specified in § 960.5–1(a)(3) can be met.

(b) *Favorable Conditions.* (1) A host rock that is sufficiently thick and laterally extensive to allow significant flexibility in selecting the depth, configuration, and location of the underground facility.

(2) A host rock with characteristics that would require minimal or no artificial support for underground openings to ensure safe repository construction, operation, and closure.

(c) *Potentially Adverse Conditions.* (1) A host rock that is suitable for repository construction, operation, and closure, but is so thin or laterally restricted that little flexibility is available for selecting the depth, configuration, or location of an underground facility.

(2) In situ characteristics and conditions that could require engineering measures beyond reasonably available technology in the construction of the shafts and underground facility.

(3) Geomechanical properties that could necessitate extensive maintenance of the underground openings during repository operation and closure.

(4) Potential for such phenomena as thermally induced fracturing, the hydration and dehydration of mineral components, or other physical, chemical, or radiation-related phenomena that could lead to safety hazards or difficulty in retrieval du 'ng repository operation.

(5) Existing faults, shear zones, pressurized brine pockets, dissolution effects, or other stratigraphic or structural features that could compromise the safety of repository personnel because of water inflow or construction problems.

(d) *Disqualifying Condition.* The site shall be *disqualified* if the rock characteristics are such that the activities associated with repository construction, operation, or closure are predicted to cause significant risk to the health and safety of personnel, taking into account mitigating measures that use reasonably available technology

§ 960.5-2-10 Hydrology.

(a) *Qualifying Condition.* The site shall be located such that the geohydrologic setting of the site will (1) be compatible with the activities required for repository construction, operation, and closure; (2) not compromise the intended functions of the shaft liners and seals; and (3) permit the requirements specified in § 960.5–1(a)(3) to be met.

(b) *Favorable Conditions.* (1) Absence of aquifers between the host rock and the land surface.

(2) Absence of surface-water systems that could potentially cause flooding of the repository.

(3) Availability of the water required for repository construction, operation, and closure.

(c) *Potentially Adverse Condition.* Ground-water conditions that could require complex engineering measures that are beyond reasonably available technology for repository construction, operation, and closure.

(d) *Disqualifying Condition.* A site shall be disqualified if, based on expected ground-water conditions, it is likely that engineering measures that are beyond reasonably available technology will be required for exploratory-shaft construction or for repository construction, operation, or closure.

§ 960.5-2-11 Tectonics.

(a) *Qualifying Conditions.* The site shall be located in a geologic setting in which any projected effects of expected tectonic phenomena or igneous activity on repository construction, operation, or closure will be such that the requirements specified in § 960.5–1(a)(3) can be met.

(b) *Favorable Condition.* The nature and rates of faulting, if any, within the geologic setting are such that the magnitude and intensity of the associated seismicity are significantly less than those generally allowable for the construction and operation of nuclear facilities.

(c) *Potentially Adverse Conditions.* (1) Evidence of active faulting within the geologic setting.

(2) Historical earthquakes or past man-induced seismicity that, if either were to recur, could produce ground motion at the site in excess of reasonable design limits.

(3) Evidence, based on correlations of earthquakes with tectonic processes and features, (e.g., faults) within the geologic setting, that the magnitude of earthquakes at the site during repository construction, operation, and closure may be larger then predicted from historical seismicity.

(d) *Disqualifying Condition.* A site shall be disqualified if, based on the expected nature and rates of fault movement or other ground motion, it is likely that engineering measures that are beyond reasonably available technology will be required for exploratory-shaft construction or for repository construction, operation, or closure.

Appendix B

ISSUES AND INFORMATION NEEDS FOR THE YUCCA MOUNTAIN SITE

Issues and information needs for the Yucca Mountain site (page 1 of 10)

Issue	Information need No.	Statement of information need
		Key issue 1 Will the mined geologic disposal system at Yucca Mountain isolate the radioactive waste from the accessible environment after closure in accordance with the requirements set forth in 40 CFR Part 191, 10 CFR Part 60, and 10 CFR Part 960?
PERFORMANCE ISSUES		
Issue 1.1: Will the mined geologic disposal system meet the system performance objective for limiting radionuclide releases to the accessible environment as required by 10 CFR 60.112 and 40 CFR 191.13?	1.1.1	Site information needs to calculate releases to the accessible environment
	1.1.2	A set of potentially significant release scenario classes that address all events and processes that may affect the geologic repository
	1.1.3	Calculational models for predicting releases to the accessible environment attending realizations of the potentially significant release scenario classes
	1.1.4	Determination of the radionuclide releases to the accessible environment associated with realizations of potentially significant release scenario classes
	1.1.5	Probabilistic estimates of the radionuclide releases to the accessible environment considering all significant release scenarios
Issue 1.2: Will the mined geologic disposal system meet the requirements for limiting individual doses in the accessible environment as required by 40 CFR 191.15?	1.2.1	Determination of doses to the public in the accessible environment through liquid pathways
	1.2.2	Determination of doses to the public in the accessible environment through gaseous pathway
Issue 1.3: Will the mined geologic disposal system meet the requirements for the protection of special sources of ground water as required by 40 CFR 191.16?	1.3.1	Determination whether any Class 1 or special sources of ground water exist at Yucca Mountain, within the controlled area, or within 5 km of the controlled area boundary
	1.3.2	Determine for all special sources whether concentrations of waste products in the ground water during the first 1,000 years after disposal could exceed the limits established in 40 CFR 191.16

Issue	Information need No.	Statement of information need
		Key issue 1 (continued)
PERFORMANCE ISSUES (continued)		
Issue 1.4: Will the waste package meet the performance objective for containment as required by 10 CFR 60.113?	1.4.1	Waste package design features that affect the performance of the container
	1.4.2	Material properties of the container
	1.4.3	Scenarios and models needed to predict the rate of degradation of the container material
	1.4.4	Estimates of the rates and mechanisms of container degradation in the repository environment for anticipated and unanticipated processes and events, and calculation of the failure rate of the container as a function of time
	1.4.5	Determination of whether the requirement for substantially complete containment of the waste packages is met for anticipated processes and events
Issue 1.5: Will the waste package and repository engineered barrier systems meet the performance objective for limiting radionuclide release rates as required by 10 CFR 60.113?	1.5.1	Waste package design features that affect the rate of radionuclide release
	1.5.2	Material properties of the waste form
	1.5.3	Scenarios and models needed to predict the rate of radionuclide release from the waste package and engineered barrier system
	1.5.4	Determination of the release rates of radionuclides from the waste package and engineered barrier system for anticipated and unanticipated events
	1.5.5	Determination of the amount of radionuclides leaving the near-field environment of the waste package
Issue 1.6: Will the site meet the performance objective for prewaste-emplacement ground-water travel time as required by 10 CFR 60.113?	1.6.1	Site information and design concepts needed to identify the fastest path of likely radionuclide travel and to calculate the ground-water travel time along that path

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

Issues and information needs for the Yucca Mountain site (page 4 of 10)

Issue	Information need No.	Statement of information need
		Key issue 1 (continued)
DESIGN ISSUES		
Issue 1.10: Have the characteristics and configurations of the waste packages been adequately established to (a) show compliance with the postclosure design criteria of 10 CFR 60.135 and (b) provide information for the resolution of the performance issues?	1.10.1	Design information needed to comply with postclosure criteria from 10 CFR 60.135 (a) for consideration of the interactions between the waste package and its environment
	1.10.2	Reference waste package designs
	1.10.3	Reference waste package emplacement configurations
	1.10.4	Postemplacement near-field environment
Issue 1.11: Have the characteristics and configurations of the repository and the repository engineered barriers been adequately established to (a) show compliance with the postclosure design criteria of 10 CFR 60.133 and (b) provide information for the resolution of the performance issues?	1.11.1	Site characterization information needed for design
	1.11.2	Characteristics of waste package needed for design of the underground facility
	1.11.3	Design concepts for orientation, geometry, layout, and depth of the underground facility to contribute to waste containment and isolation, including flexibility to accommodate site-specific conditions
	1.11.4	Design constraints to limit water usage and potential chemical changes
	1.11.5	Design constraints to limit excavation-induced changes in rock mass premeability
	1.11.6	Repository thermal loading and predicted thermal and thermomechanical response of the host rock
	1.11.7	Reference postclosure repository design
Issue 1.12: Have the characteristics and configurations of the shaft and borehole seals been adequately established to (a) show compliance with the postclosure design criteria of 10 CFR 60.134 and (b) provide information to support resolution of the performance issues?	1.12.1	Site, waste package, and underground facility information needed for design of seals and their placement methods

Issue	Information need No.	Statement of information need
	Key issue 1 (continued)	
DESIGN ISSUES (continued)	1.12.2	Materials and characteristics of seals for shafts, drifts, and boreholes
	1.12.3	Placement method for seals for shafts, drifts, and boreholes
	1.12.4	Reference design of seals for shafts, drifts, and boreholes

Issue		Information need No.	Statement of information need
	Key issue 2 Will the projected releases of radioactive materials to restricted and unrestricted areas and the resulting radiation exposures of the general public and workers during repository operation, closure and decommissioning at Yucca Mountain meet applicable safety requirements set forth in 10 CFR Part 20, 10 CFR Part 60, 10 CFR Part 960, and 40 CFR Part 191?		
PERFOMANCE ISSUES			
Issue 2.1:	During repository operation, closure, and decommissioning (a) will the expected average radiation dose received by members of the public within any highly populated area be less than a small fraction of the allowable limits and (b) will the expected radiation dose received by any member of the public in an unrestricted area be less than the allowable limits as required by 10 CFR 60.111; 40 CFR 191 Subpart A, and 10 CFR Part 20?	2.1.1	Site and design information needed to assess preclosure radiological safety
Issue 2.2:	Can the repository be designed, constructed, operated, closed, and decommissioned in a manner that ensures the radiological safety of workers under normal operations as required by 10 CFR 60.111 and 10 CFR Part 20?	2.2.1	Determination of radiation environment in surface and subsurface facilities due to natural and man-made radioactivity
		2.2.2	Determination that projected worker exposures and exposure conditions under normal conditions meet applicable requirements
Issue 2.3:	Can the repository be designed, constructed, operated, closed, and decommissioned in such a way that credible accidents do not result in projected radiological exposures of the general public at the nearest boundary of the unrestricted area, or workers in the restricted area, in excess of applicable limiting values?	2.3.1	Determination of credible accident sequences and their respective frequencies applicable to the repository
		2.3.2	Determination of the predicted releases of radioactive material and projected public and worker exposures and exposure conditions under accident conditions and that these meet applicable requirements

Issue	Information need No.	Statement of information need
		Key issue 2 (continued)
PERFORMANCE ISSUES (continued)		
Issue 2.4: Can the repository be designed, constructed, operated, closed, and decommissioned so that the option of waste retrieval will be preserved as required by 10 CFR 60.111?	2.4.1	Site and design data required to support retrieval
	2.4.2	Determination that access to the waste emplacement boreholes can be provided throughout the retrievability period for normal and credible abnormal conditions
	2.4.3	Determination that access to the waste packages can be provided throughout the retrievability period for normal and credible abnormal conditions
	2.4.4	Determination that the waste can be removed from the emplacement boreholes for normal and off-normal conditions
	2.4.5	Determination that the waste can be transported to the surface and delivered to the waste-handling surface facilities for normal and credible abnormal conditions
	2.4.6	Determination that the retrieval requirements set forth in 10 CFR 60.111(b) are met using reasonably available technology
Issue 2.5: Can the higher-level findings required by 10 CFR Part 960 be made for the qualifying condition of the preclosure system guideline and the disqualifying and qualifying conditions of the technical guidelines for population density and distribution, site ownership and control, meteorology, and offsite installations and operations?		No additional information needs identified
DESIGN ISSUES		
Issue 2.6: Have the characteristics and configurations of the waste packages been adequately established to (a) show compliance with the preclosure design criteria of 10 CFR 60.135 and (b) provide information for the resolution of the performance issues?	2.6.1	Design information needed to comply with preclosure criteria from 10 CFR 60.135(b) for materials, handling, and identification of waste packages
	2.6.2	Design information needed to comply with preclosure criteria from 10 CFR 60.135(c) for waste forms

Issues and information needs for the Yucca Mountain site (page 8 of 10)

Issue	Information need No.	Statement of information need
		Key issue 2 (continued)
DESIGN ISSUES (continued)		
Issue 2.6 (continued)	2.6.3	Waste acceptance specifications
Issue 2.7: Have the characteristics and configurations of the repository been adequately established to (a) show compliance with the preclosure design criteria of 10 CFR 60.130 through 60.133, and (b) provide information for the resolution of the performance issues?	2.7.1	Determination that the design criteria in 10 CFR 60.131 through 60.133 and any additional appropriate design objectives pertaining to radiological protection have been met
	2.7.2	Determination that the design criteria in 10 CFR 60.131 through 60.133 and any additional appropriate design objectives pertaining to the design and protection of structures, systems, and components important to safety have been met
	2.7.3	Determination that the design criteria in 10 CFR 60.131 through 60.133 and any appropriate additional design objectives pertaining to criticality control have been met
	2.7.4[a]	Determination that the design criteria in 10 CFR 60.131 through 60.133 and any appropriate additional design objectives pertaining to compliance with mining regulations have been met
	2.7.5[a]	Determination that the design criteria in 10 CFR 60.131 through 60.133 and any appropriate additional design objectives pertaining to waste treatment have been met

Issue	Information need No.	Statement of information need
		Key issue 4 Will the construction, operation (including retrieval), closure, and decommissioning of the mined geologic disposal system be feasible at Yucca Mountain on the basis of reasonably available technology and will the associated costs be reasonable in accordance with the requirements set forth in 10 CFR Part 960?
PERFORMANCE ISSUES		
Issue 4.1: Can the higher-level findings required by 10 CFR Part 960 be made for the qualifying condition of the preclosure system guideline and the disqualifying and qualifying conditions of the technical guidelines for surface characteristics, rock characteristics, hydrology, and tectonics?		No additional information needs identified
DESIGN ISSUES		
Issue 4.2: Are the repository design and operating procedures developed to ensure the nonradiological health and safety of workers adequately established for the resolution of the performance issues?	4.2.1	Site and performance assessment information needed for design
Issue 4.3: Are the waste package production technologies adequately established for the resolution of the performance issues?	4.3.1	Identification and evaluation of production technologies for fabrication, closure, and inspection of the waste package
Issue 4.4: Are the technologies of repository construction, operation, closure, and decommissioning adequately established to support resolution of the performance issues?	4.4.1	Site and performance assessment information needed for design
	4.4.2	Characteristics and quantities of waste and waste packages needed for design
	4.4.3	Plan for repository operations during construction, operation, closure, and decommissioning
	4.4.4	Repository design requirements for construction, operation, closure, and decommissioning
	4.4.5	Reference preclosure repository design

Issue	Information need No.	Statement of information need
		Key issue 4 (continued)
DESIGN ISSUES (continued)		
Issue 4.4: (continued)	4.4.6	Development and demonstration of required equipment
	4.4.7	Design analyses, including those addressing impacts of surface conditions, rock characteristics, hydrology, and tectonic activity
	4.4.8	Identification of technologies for surface facility construction, operation, and decommissioning
	4.4.9	Identification of technologies for underground facility construction, operation, and closure
	4.4.10	Determination that the seals for shafts, drifts, and boreholes can be emplaced with reasonably available technology
Issue 4.5: Are the costs of the waste packages and the repository adequately established for the resolution of the performance issues?	4.5.1	Estimate the costs of the reference and alternative waste packages
	4.5.2	Estimate the costs of the reference and alternative repository designs
	4.5.3	Estimate the life cycle costs of the reference and alternative total system design

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