DOE/RW-0198

DEVA

Nuclear Waste Policy Act
(Section 113)

Site Characterization Plan
Overview

Yucca Mountain Site, Nevada Research and Development Area, Nevada

December 1988

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

Available from:

U.S. Department of Energy
Office of Scientific and Technical Information
Post Office Box 62
Oak Ridge, TN 37831

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FOREWORD

The Yucca Mountain site in Nevada has been designated by law for detailed study as the candidate site for the first U.S. geologic repository for spent nuclear fuel and high-level waste. The detailed study--called "site characterization"--will be conducted to obtain the information necessary to determine the suitability of the site for a repository and, if the site is suitable, to obtain from the Nuclear Regulatory Commission authorization to construct the repository.

As part of the site-characterization process, the Department of Energy (DOE) has prepared a site characterization plan (SCP) for the Yucca Mountain site. The SCP is a nine-volume document, more than 6,000 pages long, that describes in considerable detail the activities that will be conducted to characterize the geologic, hydrologic, and other conditions relevant to the suitability of a site for a repository. To ensure that the SCP is available to the public, the DOE has placed copies of the SCP in its public reading rooms around the country and in public libraries in Nevada. Individual copies are available upon request. Persons wishing to comment on the SCP during the 90-day comment period beginning January 15, 1989, should either review the document at one of the public libraries or reading rooms or request an individual copy from the DOE's Yucca Mountain Project Office, whose address is given below.

To help the public better understand both the SCP and the site-characterization program, the DOE has prepared this overview and the SCP Public Handbook. The overview presents summaries of selected topics covered in the SCP; it is not a substitute for the SCP. The organization of the overview is similar to that of the SCP itself, with brief descriptions of the Yucca Mountain site, the repository, and the containers in which the waste would be packaged, followed by a discussion of the characterization program to be carried out at the Yucca Mountain site.

This overview is intended primarily for those persons who want to understand the general scope and basis of the site-characterization program, the activities to be conducted, and the facilities to be constructed without spending the time necessary to become familiar with all of the technical details presented in the SCP. For the readers of the SCP, the overview will be useful as a general guide to the plan.

The SCP Public Handbook is a short document that contains brief descriptions of the SCP process and the contents of the SCP. It also explains how the public can submit comments on the SCP and lists the libraries and reading rooms at which the SCP is available.

Copies of the SCP, the SCP Overview, and the SCP Public Handbook can be obtained by contacting the Yucca Mountain Project Office, U.S. Department of Energy, Box 98518, Las Vegas, Nevada 89193.

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Chapter 1

INTRODUCTION

As directed by the U.S. Congress, the U.S. Department of Energy (DOE) has been conducting a program for siting the nation's first geologic repository for radioactive waste.* The process and the schedule for this program were specified in the Nuclear Waste Policy Act of 1982. One of the sites included in that program is Yucca Mountain, Nevada, which the DOE has been studying for about 10 years. In May 1986, the DOE recommended and the President approved the Yucca Mountain site as one of three candidate sites for detailed study. In December 1987, in the Nuclear Waste Policy Amendments Act, the Yucca Mountain site was designated by the Congress for characterization as the single candidate site for a geologic repository.

The Yucca Mountain site has not been selected for a repository; rather, it has been designated as the only "candidate site" to be characterized at this time. A comprehensive program of detailed investigations will be conducted at Yucca Mountain to determine whether it is suitable for a repository. If the site is suitable, then the DOE must demonstrate to the Nuclear Regulatory Commission (NRC) that the site meets regulations intended to protect the health and safety of the public both during repository operations and after the repository has been permanently closed. In order to demonstrate to the NRC that the repository system--that is, the site, the repository, and the waste package--would perform as required, the DOE must also develop designs for the repository and the waste package (i.e., the waste and the container in which it is packaged for disposal) and conduct scientific assessments to determine that the performance of the repository system would meet all applicable regulations.

The comprehensive program referred to above is known as the "site-characterization program" and is described in a multivolume document called the "site characterization plan," or the "SCP." The site-characterization program and the SCP are explained in this overview.

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*The radioactive waste emplaced in a 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. For convenience, the words "radioactive waste" and "waste" are often used in this overview to mean spent nuclear fuel or high-level waste.

The remainder of this chapter briefly discusses the purposes of, and the requirements for, site characterization (Section 1.1); the purposes of the SCP, the requirements for the SCP, and the organization and level of detail in the SCP (Section 1.2); the process established for participation by the NRC, the State of Nevada, and the public, as well as the purpose of the consultation draft of the SCP (Section 1.3); the siting process after site characterization (Section 1.4); and the organization of this overview (Section 1.5).

1.1 SITE CHARACTERIZATION

Purpose of site characterization

The purpose of site characterization is to obtain the information necessary to determine whether the Yucca Mountain site is suitable for a repository and, if so, to obtain from the NRC authorization to construct a repository. The information to be collected will serve to establish (1) whether a repository can be constructed and operated at that site without adversely affecting the health and safety of the public during repository operations and (2) whether the waste emplaced in the repository will remain isolated from the general environment for thousands of years.

Legislative and regulatory requirements

Requirements for site suitability and licensing are specified in two sets of regulations:

- The general guidelines for the recommendation of suitable sites that were developed pursuant to Section 112 of the Nuclear Waste Policy Act and issued by the DOE as Part 960 of Title 10 of the Code of Federal Regulations (10 CFR Part 960).

- The regulations promulgated for the licensing of geologic repositories by the NRC in Part 60 of Title 10 of the Code of Federal Regulations (10 CFR Part 60).

The NRC regulations implement and enforce the environmental standards issued for the management and disposal of radioactive waste by the Environmental Protection Agency in Part 191 of Title 40 of the Code of Federal Regulations (40 CFR Part 191).

A site-characterization program that will provide the information needed to address these requirements is mandated by Section 113 of the Nuclear Waste Policy Act, as amended. It is also required by the DOE's general siting guidelines in 10 CFR Part 960 and the NRC's regulations in 10 CFR Part 60.

Activities conducted during site characterization

In order to determine the suitability of the site, information is needed on the geologic, geoengineering, hydrologic, geochemical, climatological, and meteorological conditions at the site. This information is obtained by investigations conducted both from the surface and underground.

The surface-based investigations will include tests performed at the surface of the ground and tests performed in boreholes and trenches. The underground investigations will be made in special facilities to be constructed at Yucca Mountain. These facilities will consist of two exploratory shafts excavated to the depth of the proposed repository and underground rooms and tunnels for testing. To support these facilities, the DOE will provide various structures and buildings on the surface, such as a hoisthouse for the shafts and temporary buildings used for offices and laboratories.

Although no significant adverse impacts are expected to result from site characterization, the DOE will monitor activities that might have significant environmental and socioeconomic effects and will implement appropriate mitigation measures that may be necessary.

The DOE does not currently plan to use any radioactive materials in site characterization with the exception of well-logging tools that contain short-lived radioactive materials and are commonly used in geologic and hydrologic exploration. After these tools have been removed, no radioactive material will be left behind at the site.

1.2 THE SITE CHARACTERIZATION PLAN

Purpose of the SCP

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, including the issues related to site suitability; to present the strategy for resolving the issues; and to identify the information needed to resolve the issues.

3. To describe general plans for the work needed to obtain the information deemed necessary and to resolve outstanding issues.

The information deemed necessary includes the information needed to prepare the environmental impact statement required under Section 114(f) of the Nuclear Waste Policy Act, as amended.

In the context of items 2 and 3, "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.

Requirements for the contents of the SCP

The Nuclear Waste Policy Act, as amended, specifies that the SCP include a description of the Yucca Mountain site, a description of the planned site-characterization activities, a description of the packaging to be used for the waste, a conceptual design of the repository, and any other information that the NRC may specify. The requirements of the Act are repeated by the NRC in its regulations (10 CFR Part 60), which include some additional specifications (e.g., requirements for a quality-assurance program).

In preparing the SCP, the DOE has met both sets of requirements. (A complete list of the requirements is given in the introduction to the SCP, which also explains how the requirements are met.) In addition, the DOE has followed NRC guidance for the format and the organization of the SCP. Furthermore, as explained in Section 5.2 of this overview, the preparation of the SCP was guided by an issue-resolution strategy whose objective was to ensure that site characterization would provide the information needed for determining whether the Yucca Mountain site is suitable for a repository and for obtaining a construction authorization from the NRC.

Organization of the SCP

The SCP is divided into two parts: Part A, which describes the site and the conceptual designs of the repository and the waste package, and Part B, which presents the DOE's rationale and plans for the site-characterization program. In addition, a comprehensive index is provided to help readers find the various sections of the SCP in which topics of interest to them are addressed.

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. In all of these chapters, the available information is evaluated in terms of the regulatory requirements and the data needed in order to have confidence that the information is sufficient to describe a particular condition or characteristic. The results of these evaluations were considered

in developing the plans presented in Part B. Each of the first five chapters in Part A concludes with a summary that links the data and analyses presented in that 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 the issue-resolution strategies that are the basis for this program. It begins by presenting, in Section 8.0, the top-level strategy for determining whether the repository will perform satisfactorily. Section 8.1 discusses the overall 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. 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. The rest of Chapter 8 discusses the activities that will be carried out during site characterization, including the tests to be performed, the construction and design of the exploratory shafts, and the potential impacts of site characterization on the waste-isolation capabilities of the site (Section 8.4); the schedule for site-characterization activities (Section 8.5); the quality-assurance program for site characterization (Section 8.6); and the decommissioning of the facilities used for characterization if Yucca Mountain is not found to be suitable as a repository site (Section 8.7).

Level of detail

The contents of the SCP and its level of detail reflect earlier consultations with the NRC staff and the State of Nevada. The SCP presents general information on the activities to be conducted, the sequence of activities, the priorities assigned to activities, and general schedules for the site-characterization program. The detailed descriptions of site-characterization studies and activities will be given in study plans. Each study plan will be made available before the start of new onsite activities, in accordance with previous agreements with the staff of the NRC.

Not included in the SCP are the activities that will be performed to collect data on environmental and socioeconomic conditions. Plans for these activities are described in other documents, principally the Environmental Monitoring and Mitigation Plan and the Socioeconomic Monitoring and Mitigation Plan.

1.3 THE SCP PROCESS

Legislative requirements for the SCP process

Section 113 of the Nuclear Waste Policy Act, as amended, specifies that, before starting to construct exploratory shafts at Yucca Mountain, the DOE must meet the following two requirements:

1. Submit to the NRC and to the Governor and the Legislature of the State of Nevada a site characterization plan (SCP) for their review and comment.

2. Make the SCP available to the public and hold public hearings to inform the residents of the Yucca Mountain area of the SCP and to receive their comments.

To meet both of these requirements, the DOE is submitting copies of the SCP to the NRC and to the Governor and the Legislature of Nevada.

To ensure that the SCP is available to the public, the DOE has placed copies of the SCP in its public reading rooms around the country and in public libraries in Nevada. Individual copies are available upon request.* To help the public understand the SCP, the DOE has prepared this overview and the SCP Public Handbook and has widely circulated both of these documents. In addition, the DOE has informed the public through its regular Project Update Meetings and briefed Federal, State, and local officials as requested.

During site characterization, the DOE is required by the Nuclear Waste Policy Act, as amended, and by NRC regulations to report not less than once every 6 months to the NRC and to the Governor and the Legislature of Nevada on the nature and extent of site-characterization activities and the information that is collected.

To comply with this requirement, the DOE will issue semiannual progress reports during characterization at Yucca Mountain. These reports will summarize the results of site-characterization activities and will explain any changes that may be made in the test program as information is collected and evaluated or as comments from the State of Nevada and the NRC are received and evaluated. In addition to the NRC and the Governor and the Legislature of Nevada, these reports will also be submitted to the affected units of local government, and they will be available to the public.

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*Copies of the SCP may be requested from the Yucca Mountain Project Office, U.S. Department of Energy, Box 98518, Las Vegas, Nevada 89193.

Participation by the State of Nevada and affected units of local government

The Nuclear Waste Policy Act of 1982 (the Act), as amended, gives the State of Nevada and affected units of local government* a specific role in the repository-siting process. This role includes review of the DOE's technical activities, including the SCP, the periodic progress reports that the DOE will issue during site characterization, the results of site characterization, the designs for the repository and the waste package, and the results of performance assessments. The Act also requires the DOE to provide the State and the affected units of local government with financial assistance to perform these review activities.

The consultation draft of the SCP

On January 8, 1988, the DOE issued a consultation draft of the SCP for the Yucca Mountain site to the State of Nevada and the NRC. The purpose of the consultation draft of the SCP was to facilitate a consultation process that was expected to improve the quality of the SCP and to assist in defining a site-characterization program that will generate the information necessary for siting, designing, and licensing a geologic repository. In addition, the consultation process was intended to accomplish the following:

1. Provide an advance forum for the DOE to explain the organization and the content of the SCP.

2. Provide an advance forum for consulting with the State of Nevada and the NRC staff on concerns they may have and, if possible, for resolving those concerns.

Preliminary comments on the consultation draft were submitted to the DOE by the NRC staff in March 1988, and final comments were submitted in May 1988. In addition, comments were received from the U.S. Geological Survey in April 1988 and from the Edison Electric Institute and the Utility Nuclear Waste Management Group in August 1988. The State of Nevada submitted comments in September 1988. (Copies of all the comments are available for inspection in all of the DOE's public

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*An affected unit of local government is defined in the Nuclear Waste Policy Act, as amended, as "the unit of local government with jurisdiction over the site of a repository or a monitored retrievable storage facility. Such term may, at the discretion of the Secretary (of Energy), include units of local government that are contiguous with such unit." In the State of Nevada, Nye County is an affected unit by definition because it contains the Yucca Mountain site. Clark County and Lincoln County have applied for, and have been granted, the status of affected unit of local government.

reading rooms and in the NRC's public document rooms in Washington, D.C., and at the University of Nevada in Las Vegas.)

The SCP, as issued, represents a significant revision of the consultation draft of the SCP. The revision reflects the comments received before the end of the comment period designated for the consultation process (June 1988). (Comments received after that date will be considered in preparing the semiannual progress reports.) During the consultation period, the DOE held several technical meetings and workshops with the NRC and the State of Nevada. During the first half of this consultation period, the purpose of these interactions was to discuss the NRC's comments on the consultation draft; during the last half, the purpose was to discuss with the NRC and the State of Nevada the DOE's approach to addressing some of the NRC's major concerns. Interactions with the NRC and the State are expected to continue on selected topics during the site-characterization period.

In addition to providing an opportunity to obtain and address external comments on the consultation draft of the SCP, the consultation period served another useful purpose: it allowed the DOE to review and reevaluate the plans and schedules for the site-characterization program described in the consultation draft. In defining this program initially, the DOE placed primary emphasis on the technical sufficiency of the proposed investigations to ensure that all the needed information would be obtained. During the consultation period, the DOE carefully evaluated the planned activities to ensure that the tests included in the SCP are not only sufficient but also necessary; in the process, the program and the SCP were revised and an integrated schedule for the various site, design, and performance-assessment programs was developed.

The consultation period also provided the DOE with the opportunity to continue the development and implementation of a qualified quality-assurance program for site characterization.

1.4 THE SITING PROCESS AFTER SITE CHARACTERIZATION

In addition to its requirements for the process of site characterization, the Nuclear Waste Policy Act, as amended, specifies other steps in the process for siting and licensing a repository.

At any point in the site-characterization process, the DOE could uncover a major disqualifying flaw at the Yucca Mountain site. The discovery and confirmation of such a flaw would bring site-characterization activities to a halt; similarly, at the end of the site-characterization process, the DOE could reach the conclusion that the site is unsuitable. In either case, if the Yucca Mountain site is determined to be unsuitable for a repository, then the DOE must stop all site-characterization activities at the site, notify the Congress and the Governor and the

Legislature of Nevada of the termination, and recommend further action to the Congress to provide for the permanent disposal of the waste. This recommendation for further action is to be made not later than 6 months after the determination of unsuitability.

If, after site characterization, the site is found to be suitable, the Secretary of Energy will submit a report to the President to recommend Yucca Mountain for development as a repository. This report will be accompanied by an environmental impact statement. If the President approves, the recommendation will go to the Congress.

Within 60 days after the Congress has received this recommendation, the State of Nevada may submit a notice of disapproval to the Congress. This will prevent the development of the site as 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 of disapproval is overturned by a joint resolution, then the site designation will become effective. At that time, the Secretary will submit an application to the NRC for authorization to construct the repository.

This application will contain a description of the site, a description of the design of the repository and the waste package, and the results of assessments performed to demonstrate that the repository complies with the applicable regulations. The NRC will review the application and decide whether to authorize the construction of the repository. If NRC authorization is received, construction may begin.

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

If, however, the State's notice of disapproval is not overturned by the Congress, the site cannot be used for developing a repository.

1.5 ORGANIZATION OF THE SCP OVERVIEW

This SCP overview is structured somewhat differently from the SCP 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 presents information about preliminary designs for the repository and the containers in which the waste would be packaged for disposal.

Chapter 4 of this overview discusses the various activities that will be conducted at the Yucca Mountain site during characterization and

describes the facilities that will be constructed for that purpose. It also discusses the analyses that have been conducted to determine that the activities conducted during site characterization will not significantly affect the ability of the site to provide waste isolation.

Chapter 5, the longest and most detailed of the overview chapters, explains the basis for the site-characterization program. It begins by discussing the top-level strategy for determining whether a repository would perform satisfactorily at Yucca Mountain. Next it discusses the hierarchy of issues that must be addressed by the site-characterization program and summarizes the DOE's preliminary strategies for resolving the issues. Chapter 5 then briefly describes the investigations that will be conducted to obtain the information needed to support these strategies and the programs in which this information will be used. These include (1) refining the designs of the repository, the system to seal the repository, and the waste package and (2) assessing the performance of the repository. Chapter 5 is followed by a glossary.

Included in this overview is an appendix that presents the issues and information needs for the Yucca Mountain site.

Chapter 2

THE YUCCA MOUNTAIN SITE

This chapter briefly describes 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. It starts with a brief summary of the process that led to the selection of Yucca Mountain for characterization as a candidate site for a repository.

2.1 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 part of the NTS and the adjacent land. 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 (see Section 2.2.3) 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 locations. In 1980, a formal analysis of 15 potential locations showed that Yucca Mountain was preferred, with several potentially suitable horizons. In February 1983, after the enactment of the Nuclear Waste Policy Act of 1982, Yucca Mountain was formally identified as one of nine potentially acceptable sites.

In May 1986, after preparing an environmental assessment,* 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 of 1982, that the Yucca Mountain site is suitable for development as a repository. On December 21, 1987, the Congress enacted the Nuclear Waste Policy Amendments Act of 1987, which directed the DOE to characterize only one site as a candidate for the first repository, and that site was identified as Yucca Mountain. The Amendments Act was signed into law by the President on December 22, 1987.

2.2 GENERAL DESCRIPTION OF THE SITE

2.2.1 Location and land ownership

The Yucca Mountain site is in southern Nevada, in Nye County, about 100 miles by road northwest of Las Vegas (Figure 2-1). As shown in Figure 2-2, the Yucca Mountain site is on various Federal lands: public lands managed by the Bureau of Land Management (BLM) of the Department of the Interior; the Nellis Air Force Range, withdrawn from the public domain for use by the Air Force (the Department of Defense), but managed by the BLM; and the Nevada Test Site, withdrawn from the public domain and reserved for use by the DOE.

2.2.2 General description

The site lies in the southern part of the Great Basin--an arid region with linear mountain ranges and intervening valleys, very little rainfall, sparse vegetation, and a sparse population. Northern Yucca Mountain is about 5,000 feet above sea level, more than 1,200 feet above the western edge of Jackass Flats to the east, and more than 1,000 feet above the eastern edge of Crater Flat to the west.

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

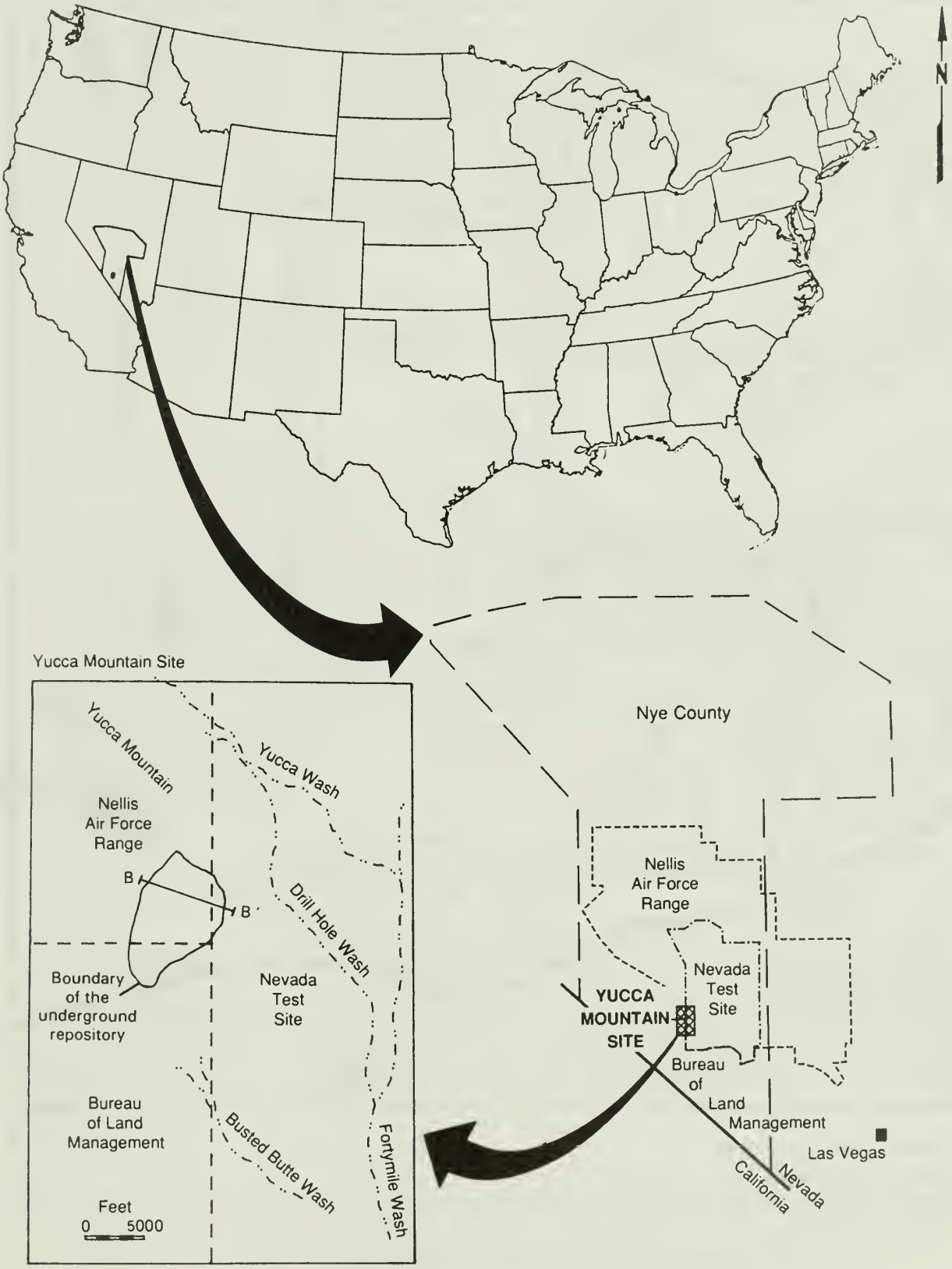

Figure 2-1. Location of the Yucca Mountain site in southern Nevada. The line labeled B-B' marks the location of the cross section shown in Figure 2-3.

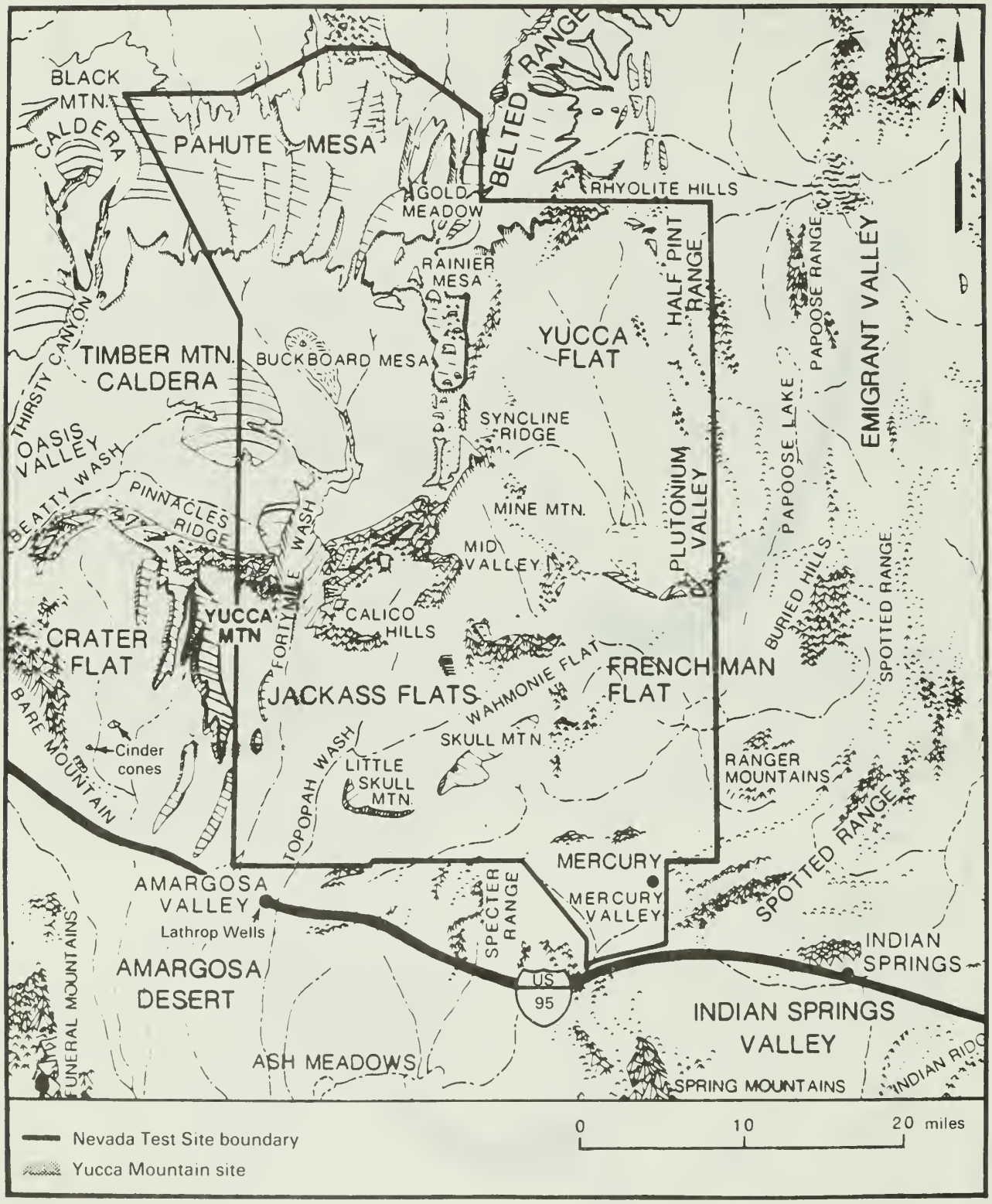

Figure 2-2. Physiographic features of Yucca Mountain and the surrounding region.

Yucca Mountain is part of a prominent group of north-trending ridges that extend southward from Beatty Wash on the northwest to U.S. Highway 95 in the Amargosa Desert (Figure 2-2). 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, fans of stream-deposited sediments extend from valleys that have been cut into Bare Mountain. A few basalt cones and small lava flows are present on the surface of the southern half of Crater Flat.

At Yucca Mountain, the water table is very deep, lying as much as 2,500 feet below the land surface. Because rainfall is very low and the evaporation rate is very high, it is believed that there is little percolation of water downward through the unsaturated rocks above the water table.

2.2.3 The origin and formation of tuff

The tuff in the Yucca Mountain region was formed from volcanic eruptions occurring between 8 and 16 million years ago. At Yucca Mountain, the volcanic rocks are at least 6,500 feet thick. Their source was magma rising through the earth's crust, which resulted in explosive eruptions that produced ash flows and gases. Because of rapidly decreasing pressure and cooling, the molten material explosively expanded upon eruption and broke 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 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." A glassy unit often occurs at the base or the top of an ash flow, where rapid cooling was caused by contact with the earth or the air.

If a single ash flow was completely cooled before being covered by another hot flow, it formed a single cooling unit with a densely welded, fractured center. The central parts of thick, densely welded zones may contain cavities called "lithophysae." The densely welded interior parts also generally contain closely spaced fractures. On the other hand, if several eruptions occurred close together and the ash flow did not cool completely between eruptions, the result is a sequence called a "compound cooling unit."

Air-fall tuffs commonly occur 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.

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 that will be given special attention in the site-characterization program discussed in Chapter 5. The descriptions cover geologic, geoengineering, hydrologic, geochemical, and climatic conditions.

2.3.1 Geology

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. Furthermore, geologic conditions are important to the design of a repository. To judge whether a site is geologically suitable, all significant processes and events important to waste isolation must be considered, including the natural processes and events that are expected to occur at the site over the next 10,000 years and the potentially disruptive processes and events that are not expected but 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 approximately 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 the effects of faulting, seismicity, and volcanic activity. The design of the repository requires information on stratigraphy, lithology, and seismicity. The assessment of past faulting and volcanic activity will provide a basis for determining the potential for disruptive tectonic events both before and after the closure of the repository. Information on the seismicity of the region and the site will be a primary source of data in developing the design of the surface facilities of the repository; this information will also be used in estimating the probabilities of disruptive events for the assessment of long-term performance after closure. Also of interest is the occurrence of natural resources because exploration for resources in the future could lead to inadvertent human 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.

Sources of available data

Information about the geologic history and conditions in the region surrounding Yucca Mountain has been collected since the early 1900s, 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. This information has been obtained by reviewing published data, performing detailed geologic mapping of the Yucca Mountain area, conducting regional geophysical investigations, recording seismic-monitoring data, and conducting other field studies. To date, more than 180 holes have been drilled (with about 40 holes being more than 300 feet deep) and more than 20 trenches have been excavated within about 6 miles of the site to investigate the geologic conditions of Yucca Mountain. Since 1978, more than 50 seismic-monitoring stations have been installed within 100 miles of the site. Six of these stations were installed in 1981 at the site itself.

Stratigraphy and lithology

Yucca Mountain is underlain by a sequence of silicic volcanic rocks from more than 3,000 to about 10,000 feet thick and dipping 5 to 10 degrees to the east at the location of the proposed repository. These rocks consist mainly of welded and nonwelded ash-flow and air-fall tuffs (see Section 2.2.3). Volcanic flows and breccias (rock consisting of sharp, angular fragments cemented together or embedded in a fine-grained matrix) commonly occur underground in the northern part of Yucca Mountain but are rare in the southern part. The rocks beneath the volcanic sequence of Yucca Mountain are known from only one of the boreholes in the Yucca Mountain area. This hole, which is on the eastern flank of the mountain, has penetrated rocks of Silurian age (about 400 million years old) in a unit known as the lower carbonate aquifer, which lies at a depth of about 4,000 feet. Data from gravity surveys suggest that the volcanic rocks may extend to a depth of about 10,000 feet below the ground surface under much of Yucca Mountain. In the northern part of Yucca Mountain, the Eleana Formation, which was deposited in Mississippian time (345 to 310 million years ago), may occur at a depth of 7,200 to 7,900 feet. It has been postulated that in the northern part of the mountain, the basement rocks that lie beneath the volcanic rocks contain a deep-seated granitic body.

At Yucca Mountain, the repository would be constructed in an ash-flow unit called the "Topopah Spring Member," which is part of the rock formation known as the "Paintbrush Tuff. Of the four members of the Paintbrush Tuff, the Topopah Spring is the lowermost, thickest, and most extensive in the Yucca Mountain area. At Yucca Mountain, the Topopah Spring unit is about 1,100 feet thick, but it thins abruptly to the south and apparently also to the north. The Topopah Spring unit was formed approximately 12 to 13 million years ago; it consists of a multiple-flow, compound cooling unit, and most of it is moderately to densely welded, devitrified tuff. Lying below the Paintbrush Tuff are the tuffaceous beds of Calico Hills, the Crater Flat Tuff, and older tuffs.

Although the available data have allowed the selection of the Topopah Spring tuff as the horizon for the proposed repository, additional data are needed for the final engineering design.

Volcanic activity

In the region of the Yucca Mountain site, volcanic activity started about 16 million years ago, forming the southwestern Nevada volcanic field. In the area of the site, it produced several large caldera complexes associated chiefly with the explosive eruptions of silicic tuffs, the rock that makes up Yucca Mountain. By 6 to 8 million years ago, the volcanic activity had changed into the more-quiescent basaltic-flow type. Basalt-type volcanic activity in the region is characterized by low-volume eruptions of short duration, with the rate of magma production apparently declining over the past 4 million years. The youngest basalt-type volcanic feature in the area, located at the southern edge of Crater Flat, is the Lathrop Wells cinder cone. The age of the Lathrop Wells cone is not certain, but this cone may have been formed as little as 20,000 years ago or less. Several other relatively young (less than 2 million years old) cinder cones are being investigated in the region of Yucca Mountain.

The explosive silicic volcanism that occurred in the southern Great Basin during Cenozoic time (the last 66 million years) 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 may 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 therefore more likely to be the product over the next 10,000 years.

Faulting

In southern Nevada, the development of geologic structures has been complex. An expression of this complex development is the faulting at Yucca Mountain, which can be seen from the cross section shown in Figure 2-3. This faulting occurred mainly in response to the tectonic activity that has occurred in the Basin and Range Province for about the last 15 million years. Two overlapping phases have been 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 basin-and-range structures in the southern Great Basin have been attributed, in part, to right-lateral faulting along the western edge of North America. 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 2-4). This motion and the related extensional faulting caused the crust to fragment into basins and ranges oriented along northerly trends oblique to the right-lateral fault zones.

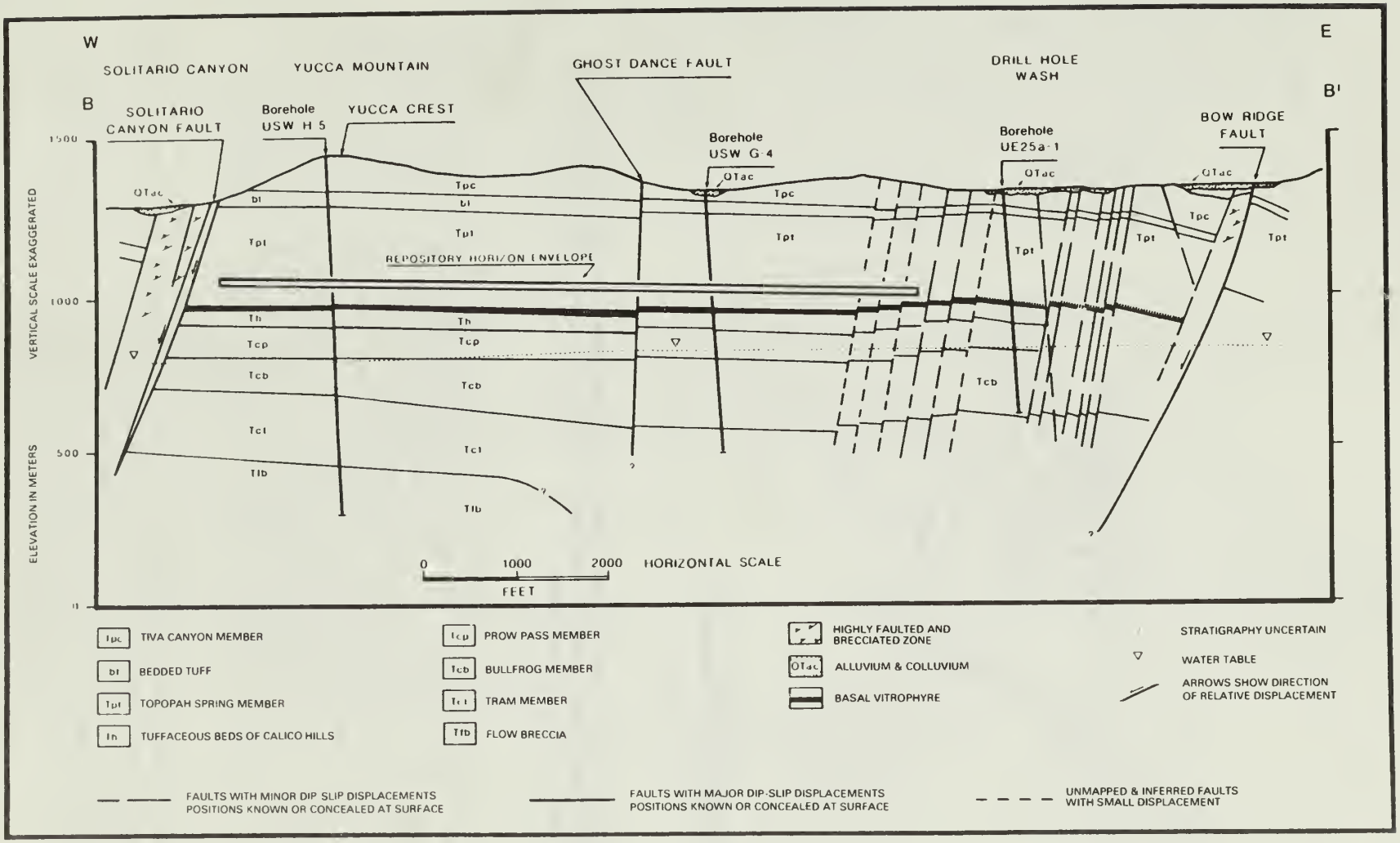

Figure 2-3. East-west geologic cross section for the Yucca Mountain site (see Figure 2-1 for the location of B-B'). This figure shows the relative positions of various tuff units at the site, including the unit proposed for the repository, and the fault zones that are closest to the site.

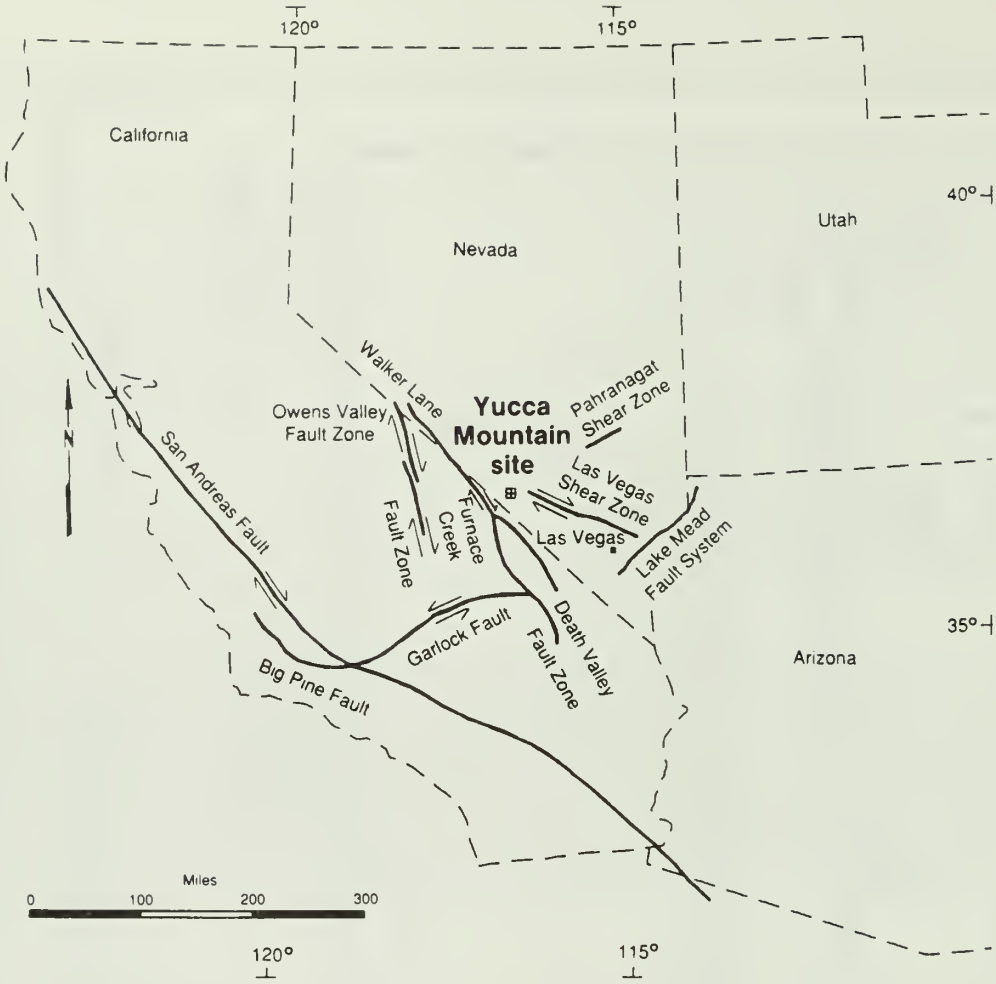

Figure 2-4. Major strike-slip faults of the southern Great Basin and vicinity. Strike-slip faults are faults along which there has been horizontal movement in opposite directions on either side, as shown by the arrows.

Yucca Mountain is a series of north-trending structural blocks that have been tilted eastward along west-dipping, high-angle normal faults. The underground facilities for the proposed repository would be excavated in a rock unit dipping eastward at about 5 to 10 degrees in a relatively unfaulted part of one of these structural blocks. This block is bounded on the west by the Solitario Canyon fault, on the northeast by the Drill Hole Wash structure, and on the east and southeast by the western edge of an imbricate normal fault zone. One fault, the Ghost Dance fault, transects the underground repository. The faults that have been interpreted from geologic mapping are shown in Figure 2-5.

The faults at Yucca Mountain include local faults related to the formation of calderas (collapses of volcanic centers) and longer faults of the basin-and-range type. 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

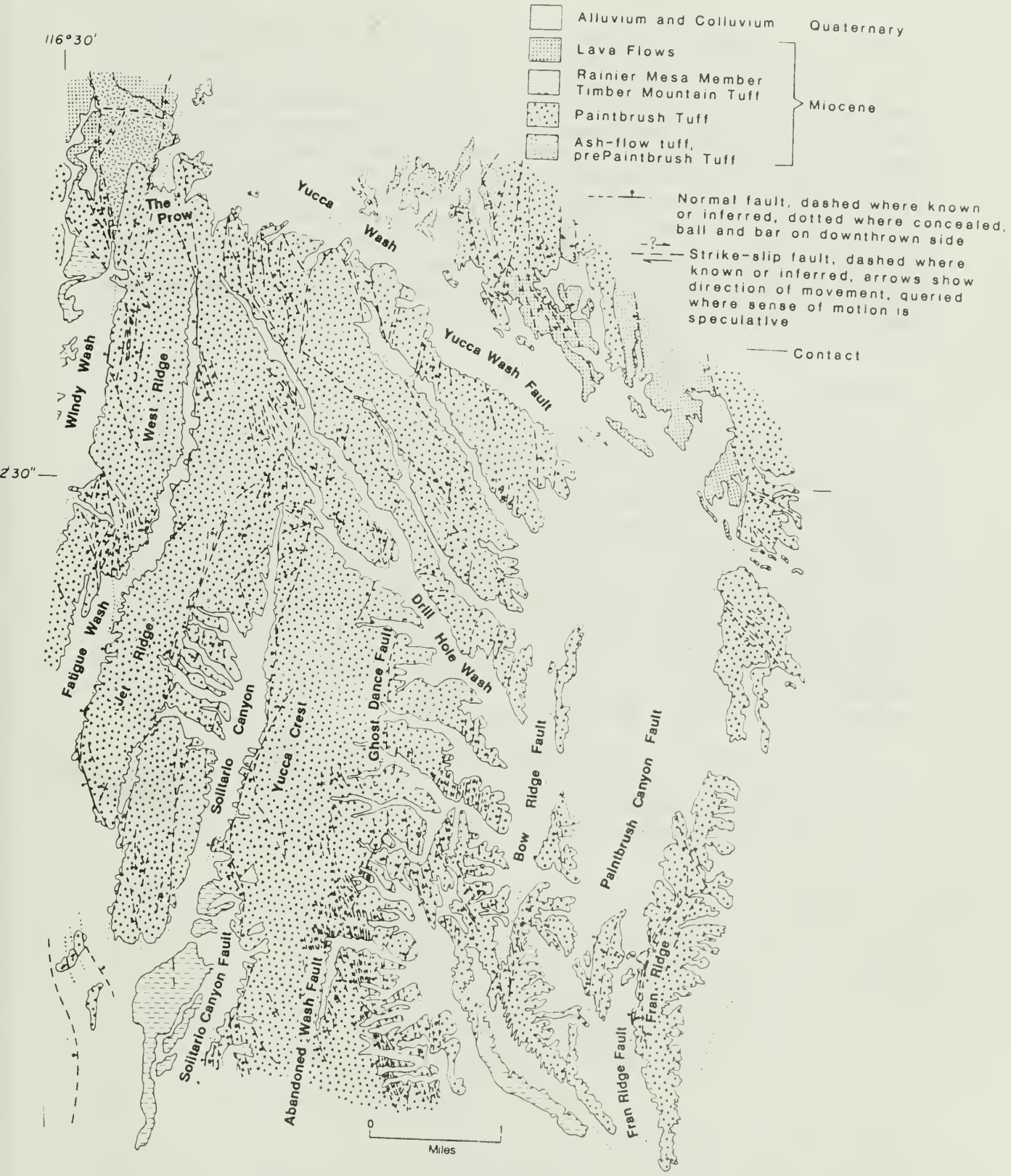

Figure 2-5. Faults in the vicinity of Yucca Mountain.

part of Yucca Mountain. Recognized vertical offsets on faults within the area proposed for the underground facilities of the 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 underground facilities. Vertical displacement along the Solitario Canyon fault diminishes from about 700 feet at the southern end to about 70 feet at the northwestern corner. For assessing the suitability of the site and obtaining data for the design of the surface facilities of the repository, fault movement since the start of the Quaternary Period, about 2 million years ago, is of primary interest. There is evidence of some movement during Quaternary time at four of the normal faults shown in Figure 2-5--the Windy Wash, Solitario Canyon, Bow Ridge, and Paintbrush Canyon faults--and the Bare Mountain fault, which is some 11 miles to the west of the site.

Seismicity

The Yucca Mountain site is about 100 miles to the east of the Nevada-California seismic belt and about 150 miles to the northwest of the Intermountain seismic belt. As shown in Figure 2-6, the site is in a region of diffuse seismicity (earthquake activity). During the time for which records are available (the past 150 years), 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 nearest recorded major earthquake was the 1872 Owens Valley event (with an estimated magnitude of about 8-1/4) about 90 miles west of Yucca Mountain. However, the area surrounding Yucca Mountain (including the eastern Mojave Desert and the southwest quadrant of the Nevada Test Site) has been relatively quiet seismically during the past 150 years.

In some instances, earthquake epicenters in the southern Great Basin are apparently clustered on north- to northeast-trending mapped faults and regional structures. However, in the vicinity of Yucca Mountain, it has not, in general, been possible to correlate earthquakes with specific faults or tectonic structures.

Geologic field evidence suggests that in terms of major tectonic activity 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 installed at Yucca Mountain in 1981. Measurements made since 1978 show that within about 6 miles from the proposed repository the release of seismic energy has been 100 or 1,000 times lower than that in the surrounding region.

Estimates of vibratory ground motion for proposed repository facilities are currently based on a full-length rupture on the Bare Mountain fault. If an earthquake with a magnitude of 6.8 occurred on this fault, the peak ground acceleration would be expected to be 0.4g. This acceleration value has been used for preliminary designs of the repository,

but it may change as additional data are collected during site characterization.

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 repeatedly experienced small-scale movement during the Quaternary Period. The stress configuration at Yucca Mountain favors right-lateral strike-slip on north-striking faults, normal slip on northeast-striking faults, and left-lateral strike-slip on east-northeast-striking faults. Relatively high seismic activity continues today along some right-lateral fault zones northwest and southwest of Yucca Mountain, and there is some evi-

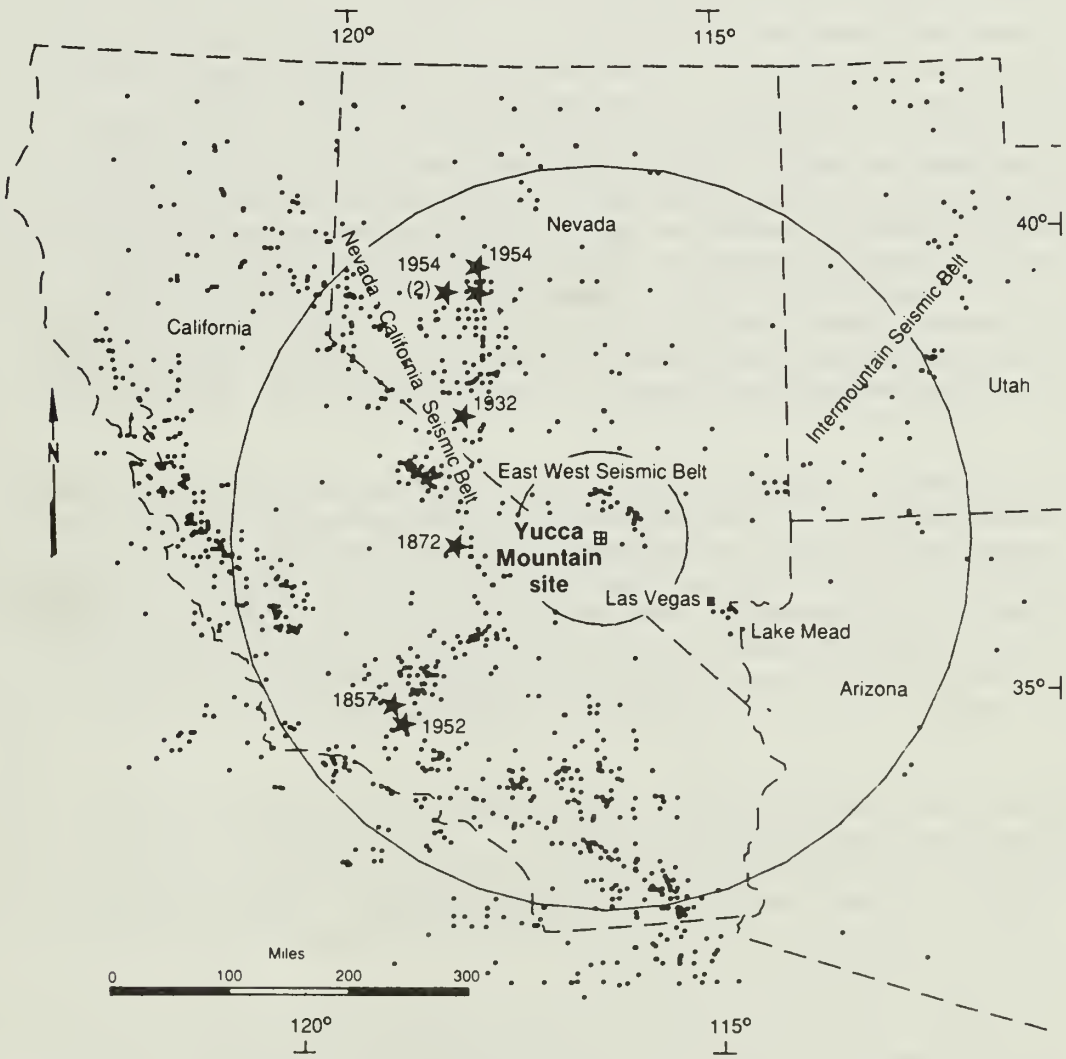

Figure 2-6. Seismicity of the southwestern United States, 1969 through 1978, showing earthquakes with a magnitude of 4 or more. The circles centered on the Yucca Mountain site have radii of about 60 and 250 miles. The stars show the locations of major (M = 6.5 or more) historical earthquakes.

dence that moderate seismic activity and surface fault displacements have occurred during this century in the Walker Lane shear zone.

Natural resources

In evaluating a candidate site for a repository, it is necessary to consider the possibility that future generations might inadvertently intrude into the repository in search of natural resources. Such an intrusion could result in a direct release of radionuclides or it could interfere with the performance of the repository in other ways, such as shortening travel paths to the accessible environment. There is general agreement that the potential for human intrusion depends mainly on the presence of natural resources (e.g., minerals, oil and gas, geothermal resources, and ground water) or geologic conditions that are favorable for the occurrence of natural resources.

The information currently available for the Yucca Mountain site does not indicate that the site is attractive for exploration because the rocks on the surface do not show evidence of mineralization; past mining or exploration; and the alterations characteristic of economic deposits of precious metals (e.g., gold and silver) and base metals. The geophysical surveys conducted to date have not indicated the presence of any geophysical anomalies that would suggest the presence of minerals. In comparison, many of these features are present at Bare Mountain, north-northwestern Yucca Mountain, the Calico Hills, and the Wahmonie District, and these areas are considered likely prospects for exploration. On the basis of present knowledge, gold, silver, mercury, uranium, and base metals are considered to be speculative, undiscovered resources at the site.

The oil-and-gas (hydrocarbon) potential at the Yucca Mountain site is considered to be low in the case of oil and somewhat greater in the case of gas, depending on the location. To the north, the potential hydrocarbon-source rocks beneath the volcanic rocks at Yucca Mountain appear to be relatively mature, which indicates that a high thermal gradient was present in this area, and the thermal gradient would have driven off the bulk of hydrocarbons. To the south, the thermal gradients were lower, and hence some gas may have been preserved in the rocks.

The site does have geothermal resources that are classified as low-temperature (less than 190°F) resources. The site's potential for exploration is considered to be very low because shallow resources of this type are widely available throughout Nevada. The geothermal resources that are more likely to be exploited are those classified as moderate- or high-temperature resources.

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. Nonetheless, the potential for water supply and demand in the future will be evaluated.

2.3.2 Geoengineering

The behavior of tuff as an engineering material must be understood to design, construct, operate, and close a repository at Yucca Mountain. A repository is different from ordinary mines and tunnels because the waste emplaced in it adds heat and radiation to the rock mass and because of the need for long-time stability. The heat changes the temperature field, which in turn changes the state of stress and possibly the distribution and flow of moisture in the unsaturated-rock mass. In addition to potential effects on the flow of moisture in the unsaturated zone, geoengineering properties are important in the construction and operation of the repository because they control, among other things, the stability of the waste-emplacement holes. The latter affects both near-term performance (e.g., worker safety, waste retrievability) and long-term performance (the integrity of the disposal container). A detailed discussion of the geoengineering properties of the Yucca Mountain site can be found in Chapter 2 of the SCP.

The current data base for the geoengineering properties of the tuffs at Yucca Mountain is derived from two sources: (1) the results of laboratory tests on small-diameter (2.5 inches) core samples from Yucca Mountain and outcrop samples from the vicinity of the site and (2) 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 volcanic section of the rocks at Yucca Mountain is composed of a sequence of welded and nonwelded tuffs. Some units are devitrified, and some are vitric. The part 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 cavities. The results of laboratory experiments show that saturated and dehydrated rock samples have different thermal conductivities that are dependent on variations in the porosity of the rock and the mineral composition.

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 spatially. This variability must be taken into account in designing the underground repository and the seals for shafts and boreholes (see Chapter 3).

Because the tuffs at Yucca Mountain are similar to those of Rainier Mesa, the site of the G-Tunnel, the mining experience of the G-Tunnel should be applicable to the Yucca Mountain site. This experience indicates that controlled-blasting techniques can be used to excavate the welded tuff. In addition, roof bolts and wire mesh should be sufficient to stabilize the openings, and the available data indicate that no unusual support systems will be required during the excavations of the exploratory shafts or the repository.

2.3.3 Hydrology

The hydrologic conditions at the site are critical to the long-term performance of the repository because hydrologic conditions may affect the behavior of the waste package and because the movement of ground water is the principal mechanism for transporting radionuclides to the accessible environment. In addition, hydrologic conditions must be considered for the preclosure period because they may affect the construction and operation of the repository and the safety of workers.

An important feature of a repository at Yucca Mountain is its location in the unsaturated zone. The unsaturated zone is the rock mass (and the fluids contained in this rock mass) between the surface of the land and the water table. In the unsaturated zone, most of the pores in the rock matrix are not completely filled with water (i.e., the rocks are unsaturated). The percentage of pore space that is filled with water is expressed as the degree of saturation. Saturation generally varies spatially within and between rock units. Water within the partially saturated pores of the unsaturated zone is held under tension, which in effect produces a net negative "pressure," or potential. In contrast, in the saturated zone the interconnected pores are completely filled with water, the water is under hydrostatic compression, and the pressure in the water-filled pores is positive. The boundary between the two zones defines the water table, which is the surface at which liquid-water is at atmospheric pressure. At Yucca Mountain, the unsaturated zone is thick enough to allow the construction of a 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, 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 1,000 feet were drilled into the unsaturated zone, and these holes have been used to monitor the ambient water saturation, potential, and flux in the rocks above, below, and in the proposed repository horizon. Ambient water potentials have been monitored in one test well since 1983. The data from rock samples show a wide variation in hydrologic properties among the various hydrogeologic units in the unsaturated zone. The mechanisms of water flow and storage (as liquid water, water vapor, or both) at any location in the system depend largely on the amount of water entering the system as

net infiltration. A detailed discussion of the hydrologic data pertinent to the Yucca Mountain site is given in Chapter 3 of the SCP.

Because little is known about the occurrence and movement of water deep within unsaturated, fractured tuffs, an extensive program of field investigations and theoretically based studies is planned during site characterization to provide a comprehensive understanding of the hydrologic conditions in the unsaturated zone at Yucca Mountain.

The unsaturated zone at Yucca Mountain consists of the tuffs described in Section 2.2.3. 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 to the deeper units of the unsaturated zone, and only 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 and the Crater Flat units; it slopes to the southeast from an elevation of 2,600 to 2,400 feet above sea level. The water table forms the upper boundary of a tuff aquifer that is a part of the Alkali Flats-Furnace Creek ground-water subbasin. This basin 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 2-7. The regional direction of ground-water flow is south and southwest (Figure 2-8). 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 by percolating through the rock matrix and by flowing within the fractures of the welded tuff. There is evidence that, under current saturation 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 the interfaces between zones of different per-

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*However, as noted in Section 5.4.2, alternative hypotheses about flow mechanisms are possible, and these hypotheses will be tested during site characterization.

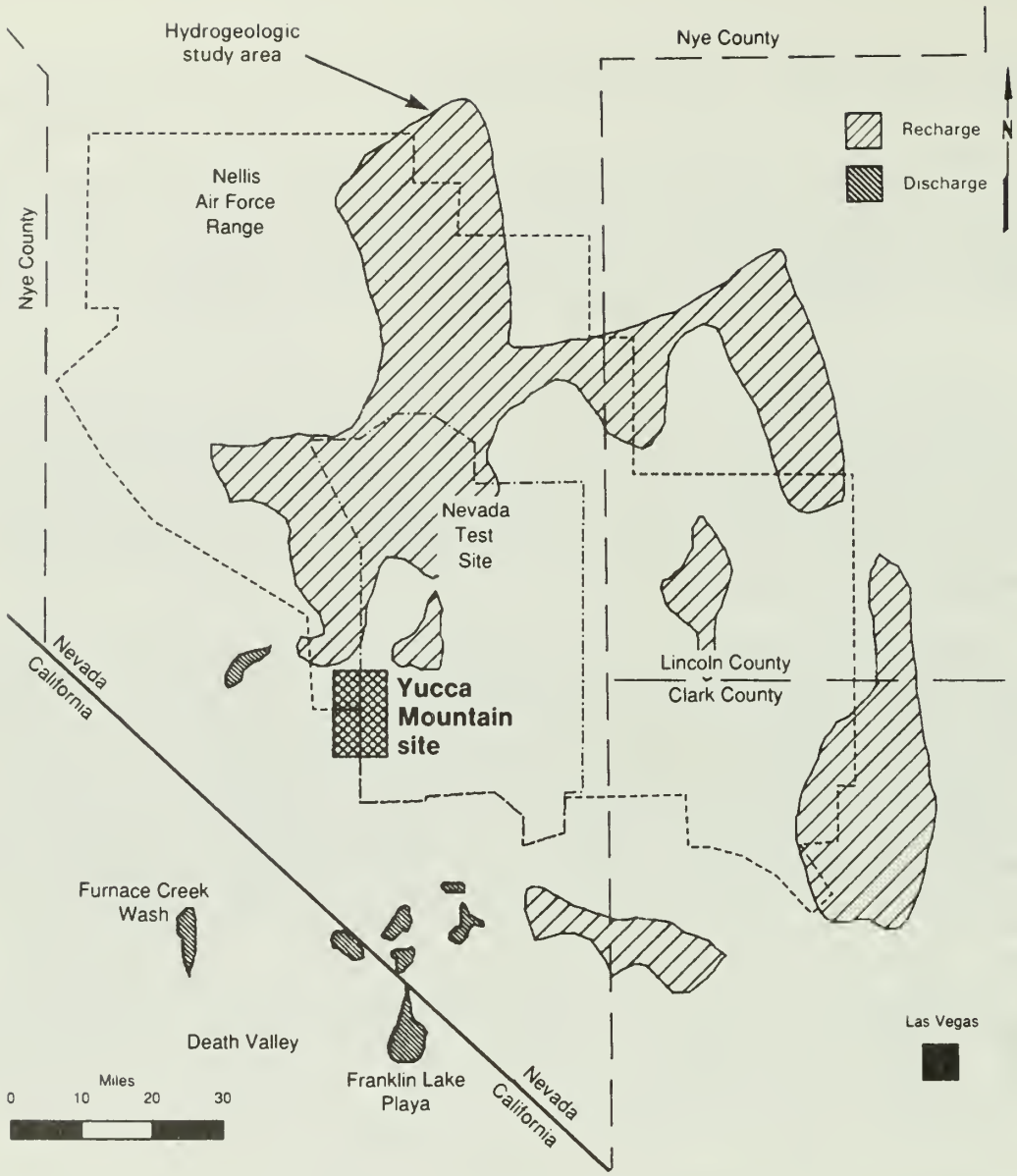

Figure 2-7. Ground-water recharge and discharge areas.

meabilities. Present estimates of the time of ground-water travel from the proposed repository to the underlying water table range from about 9,000 to 80,000 years. The conceptual ground-water-flow system in the unsaturated zone is shown in Figure 2-9.

In the saturated zone, water will tend to flow laterally, downgradient. The flow is likely to occur in fractures and therefore to be more rapid than flow that is confined within the rock matrix. 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 ground-water basin is to the southwest. The hydraulic gradient near the site appears to be steep, while southeast of the repository it is nearly flat.

Figure 2-8. Regional direction of ground-water flow. Questionmarks indicate uncertainty.

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, and Death Valley (see Figure 2-8). 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, transient floods do occasionally occur in the arroyos.

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. To characterize this geochemical envi-

Figure 2-9. Generalized east-west section through Yucca Mountain showing conceptual moisture-flow system under natural conditions.

ronment, geochemical data have been collected since late 1977. Current knowledge of the geochemical conditions at Yucca Mountain is summarized in Chapter 4 of the SCP.

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 ground water sampled from boreholes that penetrate the host rock and the surrounding units in the area proposed for the repository is of the sodium bicarbonate type, with a low concentration of total dissolved solids (200 to 400 milligrams per liter). The dominant cations in the Yucca Mountain ground water are sodium, calcium, potassium, and magnesium. Sodium is the most abundant cation, accounting for 65 to 95 percent of the cations present. Measurements of the oxidation-reduction potential and the dissolved-oxygen content of the ground water that have been analyzed indicate that most of the waters are oxidizing. (This characteristic must be considered in designing the waste package.) Overall, only minor variations in the composition of ground water have been observed in and adjacent to Yucca Mountain, and variations over time are also minor. However, the only water available to date for

chemical analysis has come from boreholes in the saturated zone. When the exploratory shafts are constructed, water from the voids in unsaturated tuff, any water flowing in fractures in unsaturated tuff, and water from any perched-water zones in Yucca Mountain will be sampled, where possible, and analyzed.

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 remain in solution 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 radionuclides that are carried by flow in a fracture will diffuse into the matrix and back into the fracture, thus requiring a longer time for travel than does the water traveling through the fracture. 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.

2.3.5 Climate and meteorology

Climatic changes that may occur in the distant future--in the next 10,000 years and more--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 level 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 will be predicted from the changes in climate that occurred during the Quaternary Period in geologic time (approximately 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 any glaciation that may have occurred in the Great Basin. The influences of climate on the elevation of the water table can also be estimated by identifying spring deposits that represent the locations of ground-water discharges in the past. As described in Chapters 3 and 5 of the SCP, such data are being collected and analyzed for the Yucca Mountain site.

The evidence accumulated to date suggests that the region of the Yucca Mountain site 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 30 to 40 percent higher than the precipitation occurring at the present time. As discussed in Chapter 3 of the SCP, some experts suggest that the general climate in

southern 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 a midlatitude-desert climate. The most notable general meteorological characteristics of such a climate 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.

Chapter 3

THE DESIGN OF THE REPOSITORY AND THE WASTE PACKAGE

This chapter briefly describes the design of the engineered elements of the repository system--the repository and the waste package. The description is based on the SCP conceptual designs for the repository and the waste package. These designs were completed in 1987 and are 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 designs 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 designs, therefore, were developed in sufficient detail to identify the needed site data, but these are early conceptual designs and can be expected to change as data from site characterization are collected and more-detailed designs are developed. Furthermore, as discussed in the Sections 3.1.1, 3.1.3, and 3.2 of this overview, the designs may be affected by other factors, such as changes in the waste-management system resulting from the 1987 amendments to the Nuclear Waste Policy Act.

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 those of the Nuclear Regulatory Commission (NRC).

The description given here of the surface facilities of the repository is based on the SCP and on the SCP conceptual-design report;* this design was completed before the enactment of the Nuclear Waste Policy Amendments Act of 1987, which has authorized changes in the waste-management program that may affect the design of the repository and especially the surface facilities. The SCP conceptual design is based on a waste-management system that was assumed to consist of a geologic repository and waste-transportation system. Furthermore, the design is based on the assumption that the repository will perform all of the waste preparation before emplacement underground, including the consol-

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*Sandia National Laboratories, Site Characterization Plan Conceptual Design Report, SAND-84-2641, Albuquerque, N.M., 1987.

idation of spent fuel into more-compact arrays. Finally, it was assumed that the repository will be developed in two phases to allow the earliest possible acceptance of spent fuel at the repository and will therefore contain two waste-handling buildings, as described below in Section 3.1.1.

As explained in the draft 1988 Mission Plan Amendment,* the DOE has reevaluated the phased-development approach because the Nuclear Waste Policy Act, as amended, authorizes the construction and operation of a facility for monitored retrievable storage (MRS) subject to certain conditions. This reevaluation took into consideration the schedule and the capabilities of the MRS facility, which could perform some or all of the waste-preparation functions allocated to the repository in the SCP conceptual design. The results indicate that, with an MRS facility in the system, it is preferable to develop the repository in a single phase, with only one waste-handling building, and that such one-phased development would not entail a delay in the schedule for waste acceptance. Moreover, the DOE is performing system studies to determine whether spent fuel should be consolidated and, if so, where the consolidation should be performed. Thus, the more-advanced designs of the repository may be significantly different from those described here and in the SCP, but the design differences are not expected to require changes in plans for site characterization.

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

3.1.1 Surface facilities

The purpose of the surface facilities of the repository is to receive the waste and to prepare it for permanent disposal underground. These facilities would be built to the east of Yucca Mountain, on ground that is relatively flat. They would consist of central surface facilities, various outlying support facilities, and facilities that would provide access and ventilation for the underground repository. A railspur would be constructed for the waste that is shipped by rail, and a road would be built for waste shipped by truck.

The central surface-facilities area would be divided into three distinct functional areas used for waste receiving and inspection, waste

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*U.S. Department of Energy, Draft 1988 Mission Plan Amendment, DOE/RW-0187, Washington, D.C., 1988.

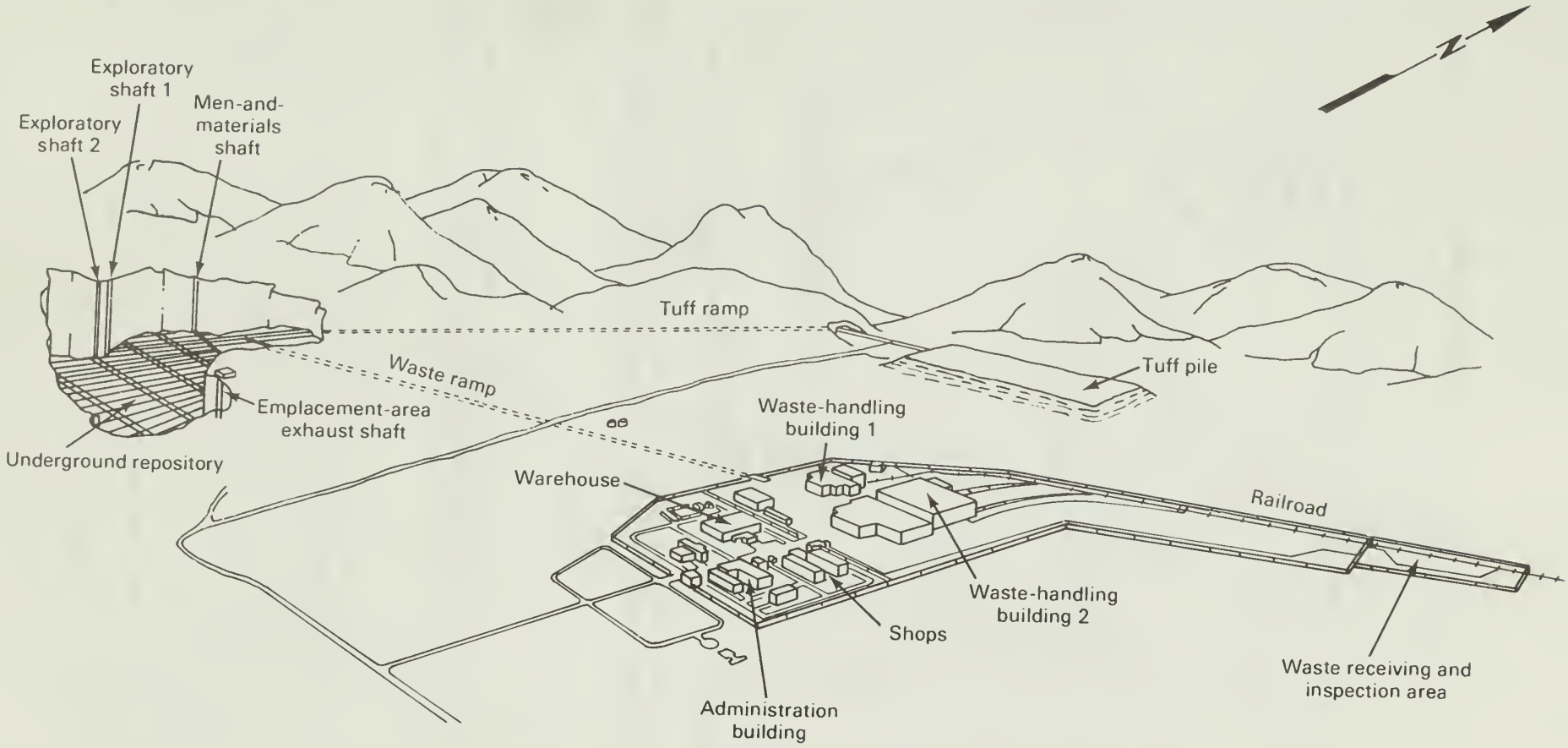


Figure 3-1. Perspective of the proposed repository at Yucca Mountain.

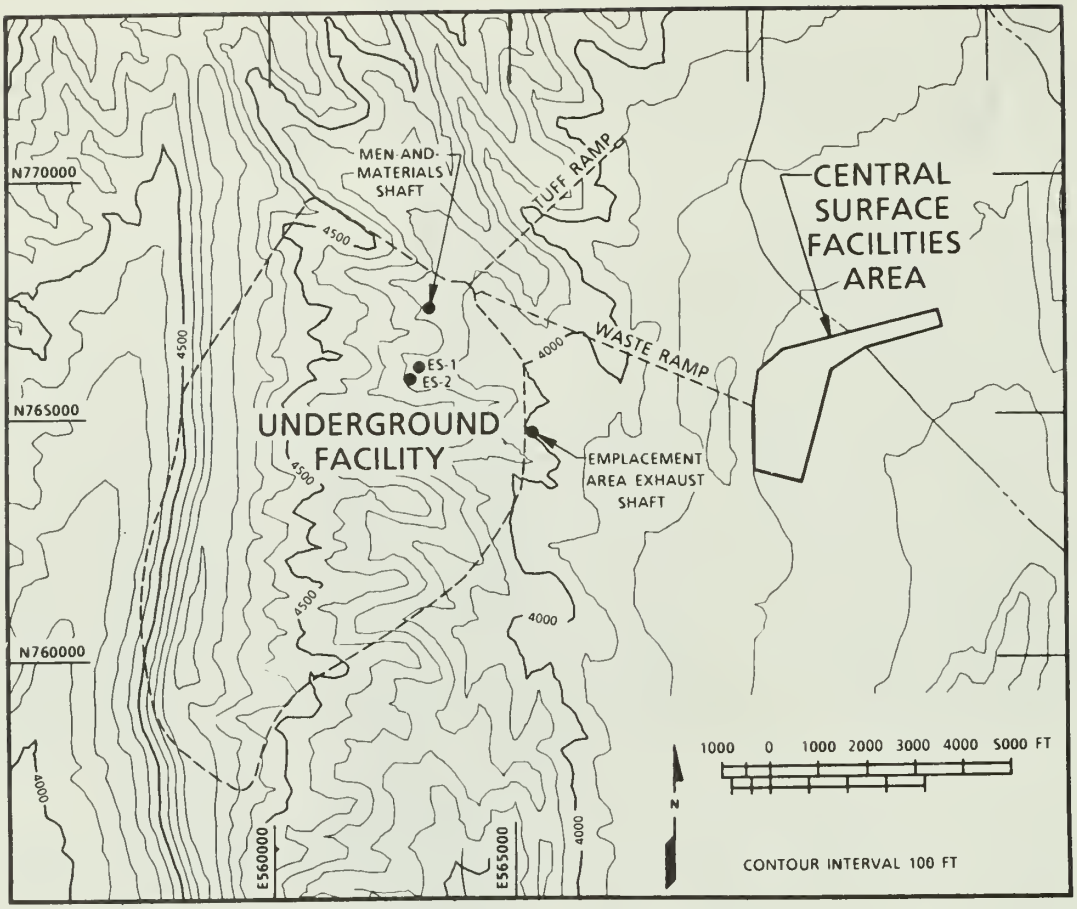


Figure 3-2. Topographic map showing the locations of the underground and the central surface facilities of the repository. The locations of the exploratory shafts are indicated by ES-1 and ES-2.

operations, and general support facilities. The waste-operations area would include two waste-handling buildings and other facilities where radioactive material is handled and prepared for emplacement in the underground repository.

Two waste-handling buildings are included in the SCP conceptual design because it was assumed that the repository would be constructed and operated in two phases. During phase 1, only waste-handling building 1, the smaller building, would be available, and the repository would receive only spent fuel. In waste-handling building 1, spent fuel would be unloaded from the shipping cask it arrived in and loaded into disposal containers (see Section 3.2 for a description of these containers). The containers would be filled with an inert gas to protect the spent fuel from oxidation, sealed by welding, inspected for leaks, and loaded into transfer casks. These casks would be used to move the containers to the waste-handling ramp (see Section 3.1.2) and then to the

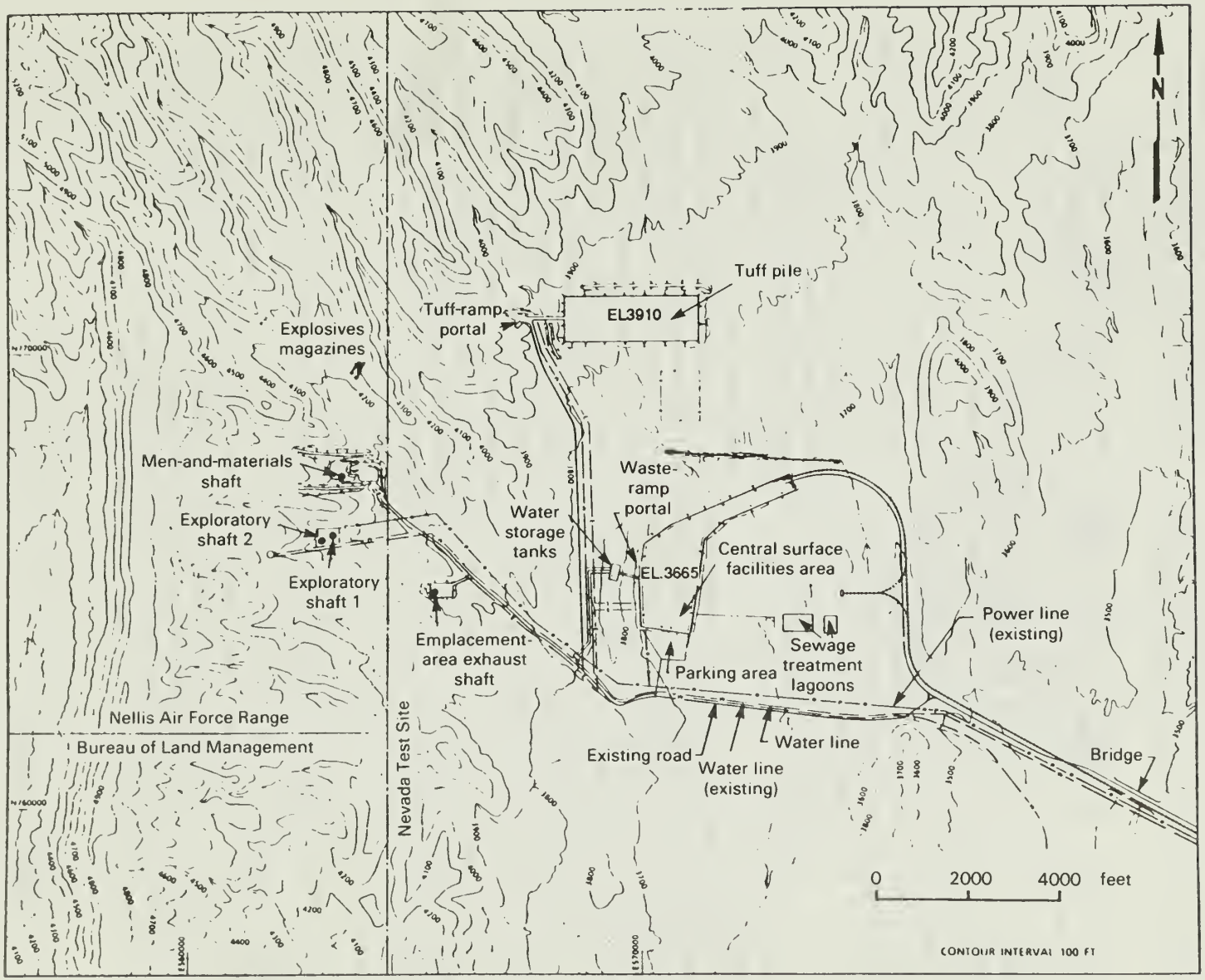


Figure 3-3. Overall site plan showing surface facilities and shafts.

underground repository. During phase 1, the repository would be operated at a limited capacity, receiving spent fuel at a rate of 400 metric tons of heavy metal (MTHM) per year. Full-capacity operation at 3,000 MTHM per year would be reached during phase 2, when the larger waste-handling building would be completed.

During phase 2, both of the waste-handling buildings would be available. Waste-handling building 2 would be used for handling most of the spent fuel received by the repository; it would have facilities for consolidating the 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, commercial 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 from radiation and equipped with remotely controlled equipment for cutting the spent-fuel assemblies, consolidating the spent-fuel rods into more-compact arrays, 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. All waste-transfer operations would be performed with transfer casks and transporters specially designed to provide shielding against radiation (see Figure 3-4).

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 3-5.

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

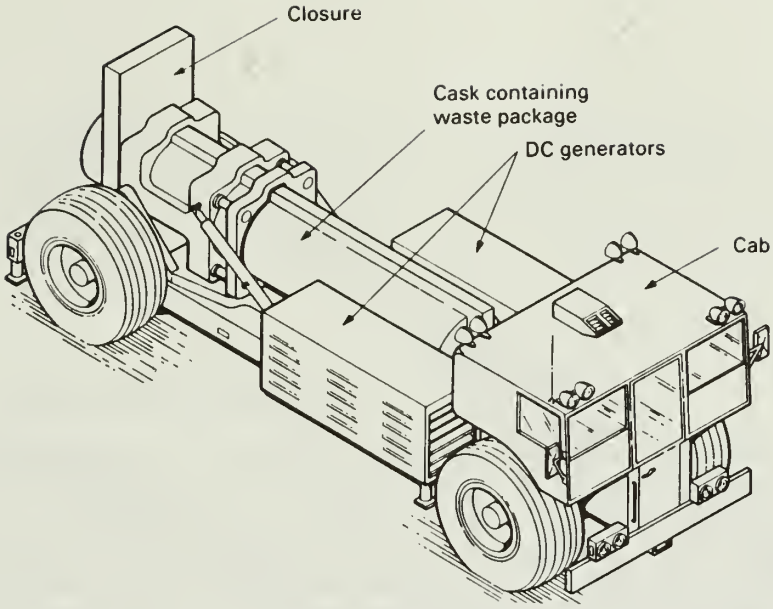
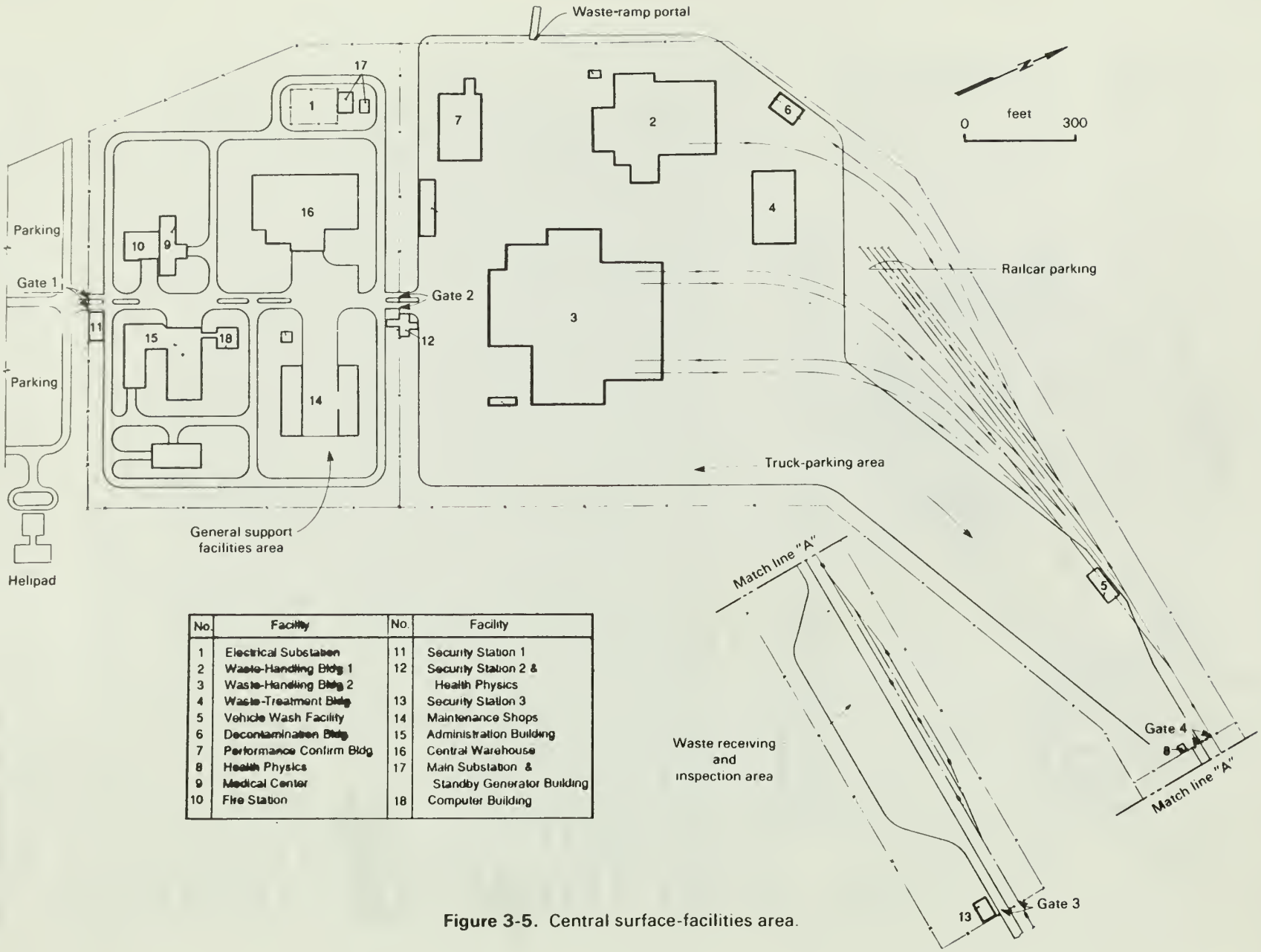


Figure 3-4. Waste transporter in the transport mode. At the emplacement borehole, the cask is raised to the vertical position and the waste package is lowered into the borehole.

surface to the underground and to provide a fresh-air intake for the waste-emplacement area. This ramp would have a length of about 6,600 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 needed for the excavation and construction of the underground repository because it would be used to move mined rock from the underground areas to the surface. In addition, this ramp would house the main electrical feeder for the underground facilities and also serve as the primary exhaust airway for the underground-development area, which is discussed in the next section. The tuff ramp would extend close to the tuff pile, on which the mined rock will be stored. Equipped with a belt conveyor, this ramp would have a length of approximately 4,630 feet, a slope of nearly 18 percent, and an excavation diameter of about 20 feet. The locations of both ramps can be seen in Figures 3-1 and 3-2, and the locations of the portals for the ramps can be seen in Figure 3-3.

All four shafts would be located 1 to 1.5 miles west of the central surface-facilities area (see Figures 3-1 and 3-2). Two of the shafts would be the exploratory shafts constructed for site characterization (see Chapter 4). Both of these shafts would be used as fresh-air intakes for the waste-emplacement area, which is described in the next section. Both would have a depth of about 1,100 feet and a finished inside diameter of 12 feet. The second shaft would provide ventilation air and also provide an emergency exit from the underground. A more detailed description of the exploratory shafts and their construction is given in Chapter 4 of this overview and in Section 8.4 of the SCP.

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, 1,090 feet deep,



No.	Facility	No.	Facility
1	Electrical Substation	11	Security Station 1
2	Waste-Handling Bldg 1	12	Security Station 2 & Health Physics
3	Waste-Handling Bldg 2	13	Security Station 3
4	Waste-Treatment Bldg	14	Maintenance Shops
5	Vehicle Wash Facility	15	Administration Building
6	Decontamination Bldg	16	Central Warehouse
7	Performance Confirm Bldg	17	Main Substation & Standby Generator Building
8	Health Physics	18	Computer Building
9	Medical Center		
10	Fire Station		

Figure 3-5. Central surface-facilities area.

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 1,030 feet, would exhaust air from the underground 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 1,000 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 over a sufficiently large area to accommodate the equivalent of 70,000 metric tons of heavy metal. Existing information about the site indicates that an area of 2,095 acres would be available underground for waste emplacement; current plans call for using 1,380 acres.

Layout

Three parallel main entry drifts would extend southwest through the underground facility to provide access to the waste-emplacement areas, called "emplacement panels." One of the mains would be dedicated to transporting waste, another would be used for moving mined rock and bulk materials, and the third would be a service main for the 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 1,400 feet wide and 1,500 to 3,200 feet long. Each emplacement panel would contain a number of emplacement drifts, in which boreholes would be drilled for the emplacement of waste. The emplacement panels would be reached through panel-access drifts (see Figure 3-6). The preliminary layout calls for 18 emplacement panels; this layout was based on the heat expected to be emitted from the waste (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 developing the waste-emplacement panels in the rock. Waste emplacement would not begin until two panels have been completely developed, to allow separation between development mining and waste-emplacement operations and thus protect the development workers from exposure to radiation.

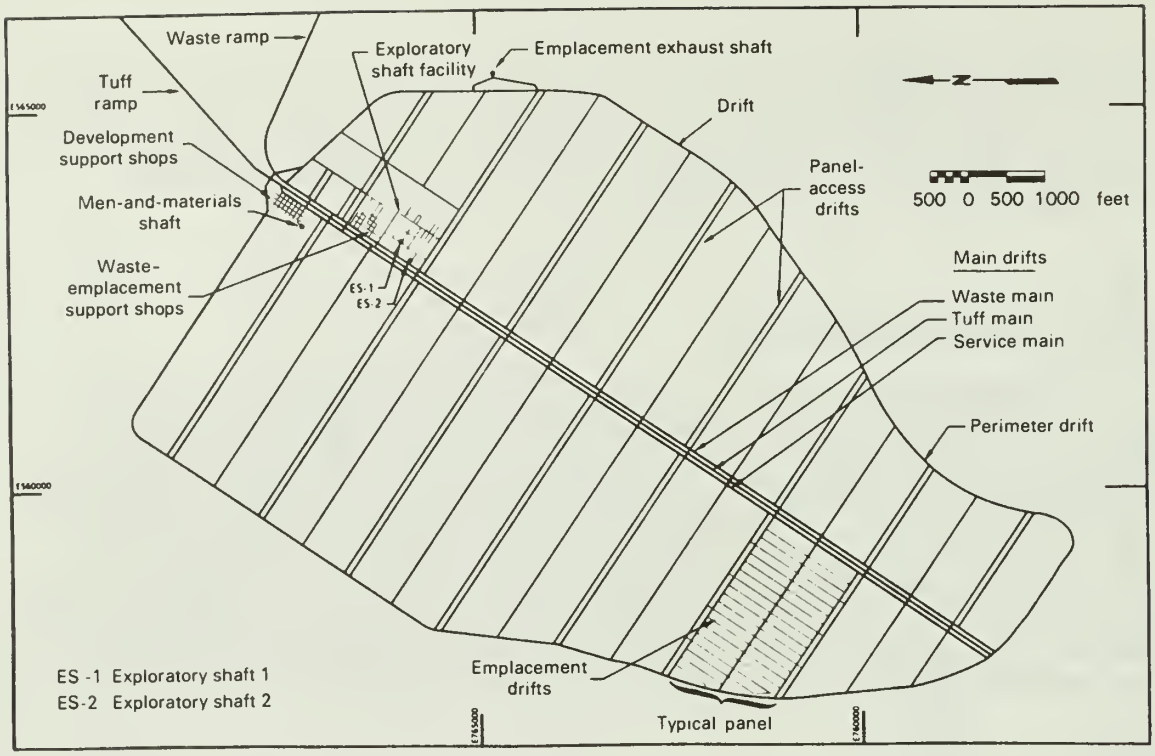


Figure 3-6. Underground repository layout for vertical waste emplacement.

In the SCP conceptual design, it was assumed that the containers of waste would be emplaced in vertical boreholes drilled into the floors of the waste-emplacement panels. However, the use of horizontal boreholes is also being considered, and the final decision on the mode to be used has not been made. In the vertical emplacement mode (Figure 3-6), 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). In the horizontal emplacement mode, boreholes would be drilled horizontally into the walls of the emplacement drifts. In either mode, the waste-emplacement panels would be 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 plate would be inserted into the bottom of a vertical borehole and the borehole would be lined with a metal casing starting at the top of the hole and extending past the top of the container. After the container was placed 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 repository would contain some areas that are not used for waste disposal, such as maintenance shops and training areas.

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 waste-emplacement operations. Connections between the systems would be sealed with bulkheads or air-locks. A positive-pressure system would be used for the development-area ventilation system 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 would encircle 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

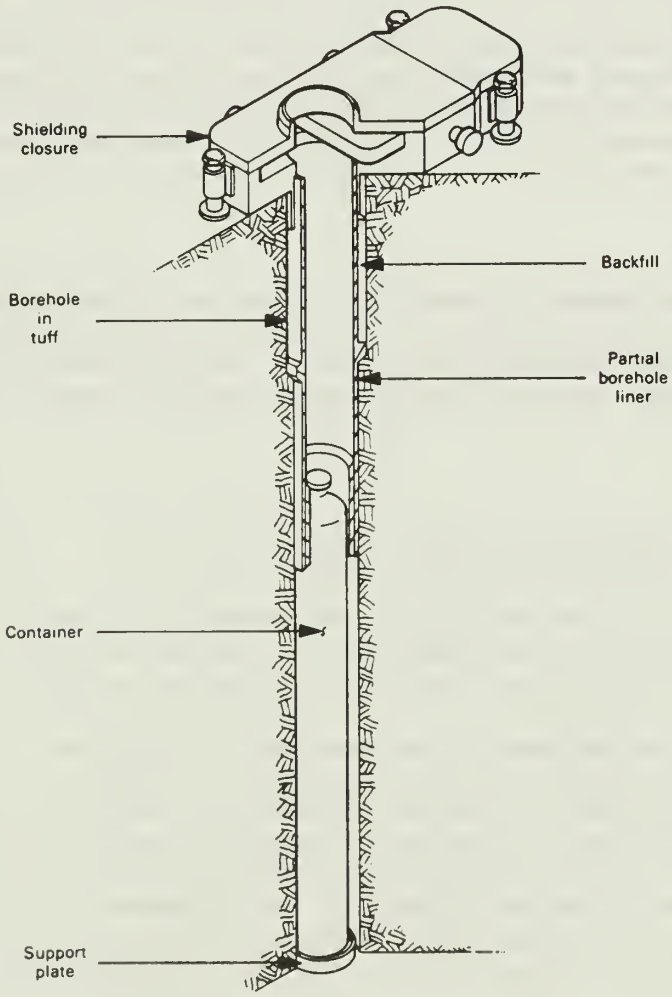


Figure 3-7. Vertical waste-emplacement borehole.

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 methods used to mine the repository at Yucca Mountain and to sink the shafts 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 DOE is developing the equipment that would be used for drilling horizontal boreholes if horizontal emplacement is selected.

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 cement-based compounds that would be sprayed onto rock surfaces to prevent minor rock falls. These measures would be used in varying degrees as required by local conditions.

3.1.4 Waste retrievability and closure

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 was 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 below. 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 seals will be designed to reduce, to the extent practicable, the potential for creating preferential pathways for ground water or radionuclide migration through existing pathways.

Proposed concepts for sealing the shafts of the repository include surface barriers, shaft fill, settlement plugs, and station plugs. The surface barrier would consist of a shaft cover, a collar core, and a plug seal that is anchored to the bedrock. The shaft fill may be 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 ramps to encourage the downward flow of water through the tuff rather than down the ramp. These dams would be made of a material that is less permeable than the undisturbed rock. However, the flow of water is expected to be negligible, and 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 design progresses and data from site characterization are obtained.

Currently available data indicate that a significant number of water-bearing faults or fractures are 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, even though backfilling is not included in the regulatory definition of seals. 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 for operations and retrievability. The material selected for backfilling is the tuff excavated during the development of the underground facilities.

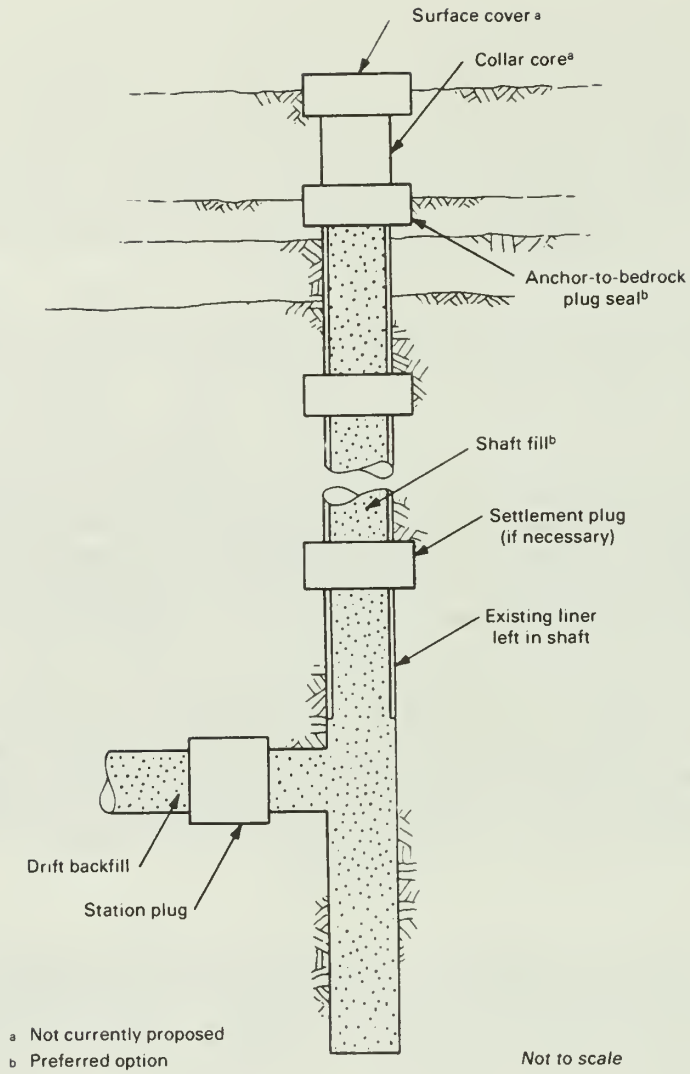


Figure 3-8. General arrangement for shaft seals.

3.2 THE WASTE PACKAGE

The waste package is defined by the NRC 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, the waste package is an element of the repository system and, for the Yucca Mountain site, it is the principal engineered barrier. This section discusses the functional and regulatory requirements for the waste package and briefly describes the preliminary waste-package design that was developed for the SCP.

3.2.1 Functional and regulatory requirements

The waste package will be designed to meet various functional and regulatory requirements, including those specified by the NRC in 10 CFR Part 60. 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 will be the DOE's requirements in the siting guidelines (10 CFR Part 960). According to these requirements, the production and the emplacement of the waste package must be feasible with reasonably available technology, and the design of the waste package cannot make the application of reasonably available technology impractical for other parts of the repository system or operations. 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. In evaluating the postclosure performance of the waste package, it is necessary to consider the expected waste-emplacement environment at Yucca Mountain, 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.

3.2.2 Description of the waste package

The description that follows is based on the detailed discussion of concepts and plans for the waste package in Chapter 7 of the SCP. It should be noted that these concepts and plans are based on an early conceptual design--the SCP conceptual design. As already mentioned at the beginning of this chapter, 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. In addition, the design of the waste package will depend on the DOE's decision about spent-fuel consolidation. The advanced conceptual design of the waste package will be preceded by a number of studies, including evaluations of alternative concepts and configurations, the selection of materials for the containers, the development of structural and handling criteria, and the evaluation of conditions inside the waste package. The results of these studies will support the development of requirements and the selection of concepts for the advanced conceptual design.

The waste form

The waste form is either spent fuel from commercial reactors (both pressurized-water reactors and boiling-water reactors) or high-level waste from defense or commercial sources. In the SCP conceptual design, it was assumed that 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 in the reactor, 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 50,000 rads per hour. The neutron dose rate will be about 10,000 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 solidified 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 and the age of the wastes in the glass matrix. The gamma dose at the outer surface of the disposal container will be about 5,500 rads per hour, and the neutron dose rate is expected to be very low.

The disposal container

In the SCP conceptual design, the disposal container for both waste forms is a sealed thin-walled 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 of the container would vary from 10.5 feet for high-level waste (Figure 3-9) to about 15.5 feet for spent fuel (Figure 3-10).

The disposal container would be made of corrosion-resistant material. The reference container material is stainless steel, but other metals that are being considered seem to be more promising, including nickel-based alloys, copper, and copper-based alloys. If another metal is selected, the thickness of the container walls would depend on that metal's resistance to corrosion and its strength. Also considered for spent fuel is a container consisting of a metal shell with a ceramic liner.

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 closed. The top would have a fixture for lifting and lowering the container. A loaded container would weigh from 6,000 to 14,000 pounds, depending on the quantity and the type of 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. To protect the spent fuel from oxidation, the container would be filled with argon gas before being welded closed.

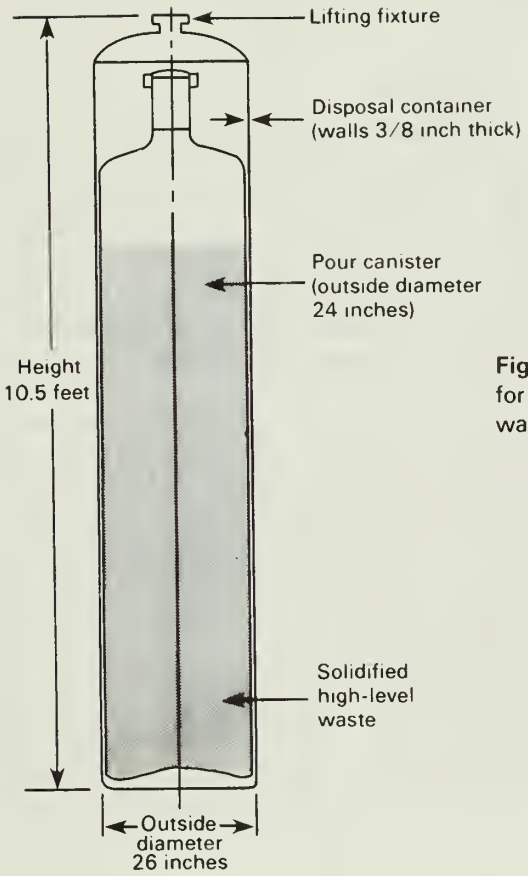


Figure 3-9. Disposal container for defense and civilian high-level waste.

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 waste-emplacement environment

The unsaturated rock of the Topopah Spring tuff is expected to 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 be subjected to loads induced by the creeping of the rock because the host rock is not expected to creep. The water available for the corrosion of containers and the dissolution of the waste form is expected to be limited to very small amounts. It should also be noted that, during the

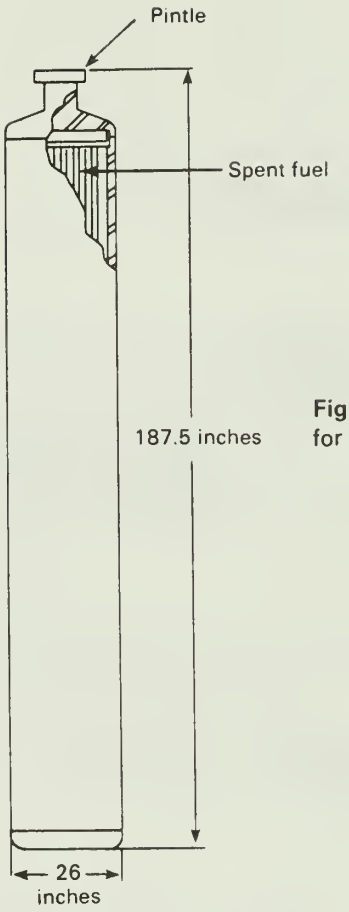


Figure 3-10. Disposal container for spent nuclear fuel.

first several hundred years, the heat emitted by the waste would tend to dry out the host rock in the vicinity of the waste packages and thus aid in preventing liquid water from coming into contact with most of the disposal containers. (However, in assessing the performance of the waste package, the DOE will not rely on this phenomenon.) A detailed discussion of the conditions expected in the waste-emplacement environment is given in Section 7.1 of the SCP.

Chapter 4

SITE CHARACTERIZATION

In order to characterize the Yucca Mountain site and to obtain data for the design of the repository, the DOE will conduct a variety of scientific and engineering tests. Some of the tests will be performed from the surface, and some will be performed underground in an exploratory-shaft facility, which will consist of two shafts and underground excavations. This facility and the tests to be performed at the site are described in this chapter, which is based mainly on information presented in Section 8.4 of the SCP.

Other important topics discussed here are the precautions taken to (1) ensure that the data collected in the exploratory-shaft facility will be representative of the Yucca Mountain site, (2) preclude interference between tests and interference between tests and the construction of the exploratory shafts, and (3) ensure that the construction of the exploratory shafts and the other site-characterization activities will not adversely affect the ability of the site to isolate waste if a repository is built. In addition, this chapter contains information about the schedule for the site-characterization program, the quality-assurance program, the potential for environmental and socioeconomic impacts, and the steps that will be taken to decommission the site-characterization facilities if the Yucca Mountain site is found to be unsuitable for a respository.

4.1 SURFACE-BASED TESTS

The surface-based tests to be conducted during site characterization will include two general types of activities: tests performed at the surface of the ground and tests performed in boreholes and trenches. These tests are described in Sections 8.3.1 and 8.4.2.2 of the SCP; the description that follows briefly summarizes information from the detailed discussions in those sections.

4.1.1 Locations of surface-based tests

The locations of the surface-based activities can be divided into four areas or groups, each of which extends farther away from the area selected for the underground facilities of the proposed repository. The first area defines the boundary of the underground repository as currently envisioned. A tunnel to be mined along this boundary is called the "perimeter drift." The second area is the controlled area, which extends for up to about 3 miles beyond the perimeter drift. The third area represents various locations outside the controlled area yet within

the site area, and the fourth area consists of locations away from the site. The locations of ongoing and proposed surface-based tests in the vicinity of the site are shown in Figures 4-1 and 4-2, respectively.

4.1.2 Site preparation for surface-based testing

Surface-based testing will require site preparation, including the construction of access roads and graded areas for drilling. Two types of roads will be constructed for surface-based testing: bladed gravel roads and one-lane unimproved dirt tracks or trails. The bladed roads will generally be used for heavy vehicles and equipment, such as the equipment used for drilling boreholes. Depending on the type of use, these roads will be maintained to level ruts after storms and watered to control dust.

Graded drill pads will be constructed for deep drilling. These pads will include areas for parking and storing equipment. For boreholes drilled with liquids, lined pits will be constructed on the pad for collecting the drilling liquids and cuttings. The liquids in the pits will be allowed to evaporate, and, after drilling has been completed, the pits will be backfilled and reclaimed.

4.1.3 Tests performed at the surface

Among the tests performed at the surface, geophysical surveys will play a major role in site characterization because they will provide information on faulting and the spatial distribution of rock characteristics and structures. One class of geophysical tools, seismic techniques, provides images of the variations within bodies of rock by using sound waves transmitted through rock from a source to detectors.

The seismic techniques to be used at Yucca Mountain include shallow and deep refraction and reflection surveys. These techniques will be used to determine two- and three-dimensional patterns of faults, lateral changes in characteristics within rock beds, vertical changes in rock characteristics, the extent and thickness of surficial gravel deposits, and the nature of deep structures under the area proposed for the repository.

For surveys with shallow seismic reflection, the DOE will use portable small-scale vibrating energy sources in as many as 10 traverses up to about 3 miles long. Deep-seismic-reflection techniques will include, as a test of their use, a survey, about 9 miles long, with a truck-mounted vibrating energy source. For shallow seismic refraction, portable seismographs and repetitive hammer sources will be used. 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

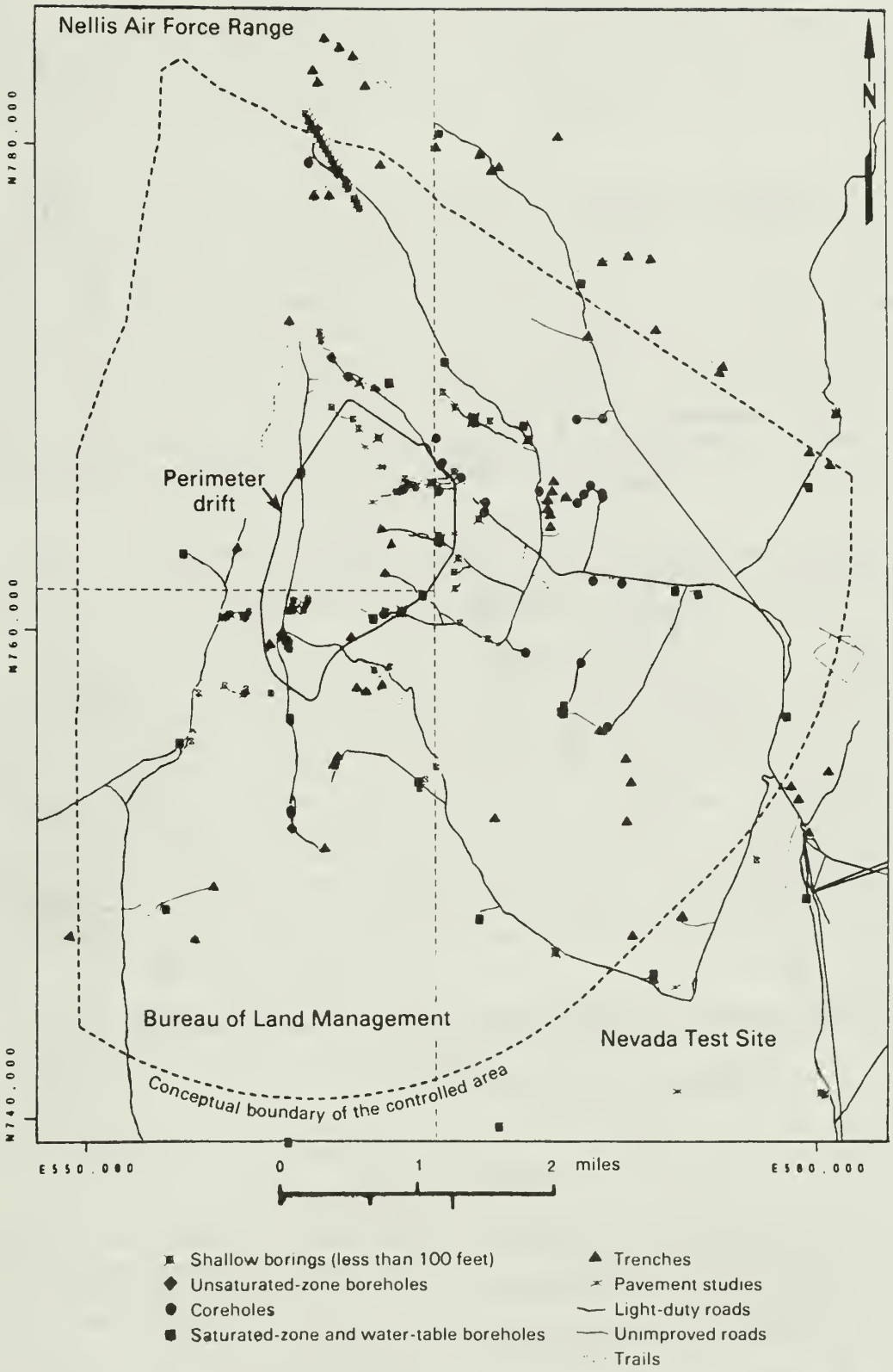
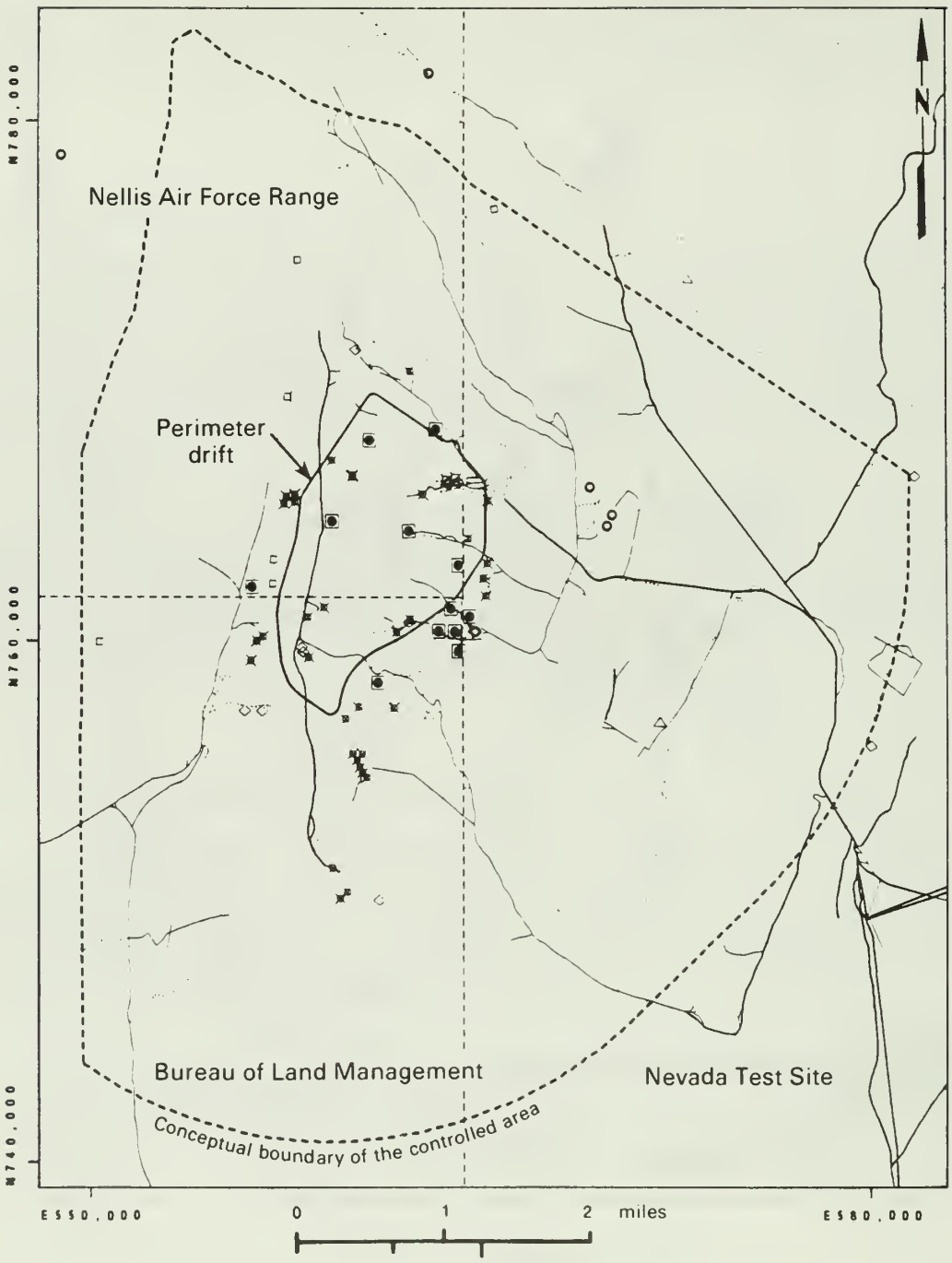


Figure 4-1. Locations of ongoing surface-based tests in the vicinity of the site.



- Shallow boreholes in the unsaturated zone (less than 100 feet)
- Unsaturated-zone boreholes
- Holes for the systematic drilling program
- Coreholes
- Saturated-zone and water-table boreholes
- Trenches
- Exploratory shafts
- Light-duty roads
- Unimproved roads
- Trails

Figure 4-2. Locations of proposed surface-based tests in the vicinity of the site.

6-mile intervals. If feasibility testing is successful, images of the rocks beneath the proposed 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 that measure potential fields will use portable equipment to measure small-scale variations, caused by structures in the rocks, in the magnetic and gravitational fields of the earth. The magnetics and gravity techniques allow a more precise determination of the locations and orientations of rock structures that are near the surface than is possible with the seismic technique and provide data that can be used to model the geometric configuration of buried rock structures. 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 beneath the ground level.

With the exception of the seismic profiling, which may require boreholes or the use of explosives, the above geophysical surveys are done without appreciable disturbance to the land and the rocks.

Extensive mapping is planned for various features in the area of Yucca Mountain. Geologic mapping at a scale of 1:12,000 will cover about 50,000 acres. Intensive mapping of surface rock types and landforms will be made over a broad area, with special attention to exposed bedrock and areas in Fortymile Wash and its tributaries. Surficial deposits will also be mapped; some soil pits and trenches will be dug to support this effort. In addition, studies of exposed bedrock will be made in order to map and measure faults, fractures, and joints. Tentative plans call for as many as 30 such studies in exposed bedrock in the immediate vicinity of Yucca Mountain. These studies would not require trenching or drilling, but they may require clearing of the thin surface material over the bedrock.

Other tests performed at the surface include streamflow monitoring, meteorological monitoring, and radiometric monitoring.

4.1.4 Trenching

Some 25 trenches, in addition to those that have already been excavated, are planned for studies of faulting in the region around Yucca Mountain, including the Bare Mountain, Mine Mountain, Stagecoach Road, Cane Spring, and Windy Wash fault zones and the Paintbrush Canyon, Bow Ridge, Ghost Dance, and Solitario Canyon faults. One or two of these trenches will be inside the perimeter drift, 16 or 17 will be inside the controlled area, and the rest will be outside the controlled area. In addition, one new trench will be excavated for the studies of calcite-

silica veins along faults, and the associated existing trench along the Bow Ridge fault will be deepened and widened. Studies of past climates may require as many as 40 smaller, shallower trenches.

The trenches will be dug by bulldozers or backhoes in locations to be determined after field reconnaissance. They will typically be 10 to 20 feet deep, 10 to 16 feet wide, and possibly thousands of feet long. The trenches inside and close to the perimeter drift will have a length of 100 feet or less. The longest trenches will be about 1 mile east of the perimeter drift, in Midway Valley (see Figure 2-2), which would be the site for the surface facilities of the repository.

4.1.5 Drilling activities

As many as 350 shallow and 70 deep boreholes may be used in site characterization, but many of these holes have already been drilled. These holes will be used for a variety of purposes.

4.1.5.1 Studies of the unsaturated zone

Three separate but integrated drilling programs will be undertaken to study the hydrologic properties, moisture content, and moisture movement in the unsaturated zone: the site-vertical-borehole program, the multipurpose-borehole program, and the systematic drilling program. Drilling and coring for the hydrologic studies will be dry (without drilling mud) to minimize the contamination of samples and to reduce the effects on hydrologic conditions. The vertical boreholes will be instrumented, and both the vertical boreholes and the multipurpose boreholes will be tested. Testing will also be conducted in the boreholes of the systematic drilling program, but these boreholes will not be continuously monitored.

Vertical boreholes at the site

In this program, 17 vertical boreholes will be used to characterize the natural conditions that affect the movement of water and gases. The boreholes will be dry drilled and cored. The locations of individual boreholes are based on the need to examine the effects of faulting, topographic relief, and surface drainage on hydrologic conditions at depth. The data collected will be used to develop, verify, and calibrate models of the hydrology of the unsaturated zone at the Yucca Mountain site and for several other purposes.

Seven of the 17 boreholes have already been drilled. Some of them penetrate only about 250 feet deep, to the top of the Topopah Spring welded unit (the host unit for the proposed repository). Others will penetrate not only the horizon proposed for the repository but also most

of the unsaturated portion of the rock unit beneath the repository (the Calico Hills unit). The remaining 10 boreholes will be drilled to just above the water table, about 1,700 feet deep. Two of these holes have already been drilled.

After drilling, intervals in these boreholes will be sealed off and tested with air pressure. Where boreholes are close together, gas tracers will be used to make larger-scale measurements of the vertical and lateral flow properties of the rock between boreholes. After testing, measuring instruments will be emplaced within sealed intervals in the holes. Most of the instruments to be emplaced in such holes will measure temperatures, pressures, and moisture in the rock matrix, but some will sample the gases in the rock. Monitoring in these holes will continue for several years.

Multipurpose boreholes

Before starting to construct the exploratory shafts, the DOE plans to drill a vertical borehole near the location of each of the two shafts to detect and characterize any water-saturated rock layers (perched-water zones) that may be present and to characterize the hydrologic conditions existing before the construction of the exploratory shafts. In addition, the baseline data collected from these planned boreholes and monitoring during shaft construction will allow the DOE to evaluate whether the construction of the shafts and the underground drifts could affect the testing. If necessary, a third multipurpose borehole may be drilled halfway between the two shafts.

The DOE plans to drill each multipurpose borehole to the same depth as the respective shaft (about 1,105 and 1,155 feet deep). After drilling, a surface casing will be cemented in place, and geophysical logging and air-pressure testing will begin. This borehole testing will be repeated throughout the construction of the exploratory shafts and while tests are conducted in the shafts.

Systematic drilling program

Twelve boreholes will be drilled in a systematic drilling program within or very near the boundary defined by the perimeter drift to collect core samples and data on stratigraphy, basic physical properties, fracture characteristics, mineral composition, and in-situ hydrologic conditions. These data will be used in modeling flow and transport in the unsaturated zone. Seven of the boreholes will be distributed across the site in locations selected to ensure that representative data will be obtained through the integration of the various drilling programs. The remaining five boreholes will be clustered immediately to the southeast of the perimeter drift. All of them will be drilled to about 200 feet below the water table. Nonwelded and partially welded intervals of rock will be continuously cored, and welded intervals will be continuously cored if feasible; otherwise they will be cored at selected intervals.

4.1.5.2 Studies of the saturated zone

To study the saturated zone at and near the Yucca Mountain site, the DOE will drill eight new water-table boreholes and one deep hydrologic borehole; the latter will be located in the Solitario Canyon. In addition, pumping tests will be conducted in existing hydrologic boreholes.

Water-table boreholes

To study the water table and the saturated zone in the vicinity of the site, 8 deep boreholes will be drilled in addition to the 16 boreholes that have already been drilled for that purpose. Two of the new boreholes, to be located in Crater Flat, will be used to evaluate potentiometric levels in the region of the site. The others will be added to the existing 25-borehole network that is used to monitor potentiometric levels at and near the site. The objectives of this drilling program are to better understand the configuration of the potentiometric surface, to analyze the character and magnitude of water-level fluctuations to determine their causes, and to measure water-level variations with time. The boreholes will also be used to sample the upper part of the saturated zone and to sample gases immediately above the water table.

All of these boreholes will extend to 100 or 200 feet below the static water level (1,300 to 2,000 feet below ground surface), and all but two will be drilled by conventional methods, using air foam. Speal methods will be used to obtain water samples that are representative of predrilling conditions. The two remaining holes, to be drilled near the Solitario Canyon fault, will be drilled dry by a method to be selected during feasibility studies. Except for a cemented surface casing, the boreholes will be uncased.

Hydrologic borehole in the Solitario Canyon

A borehole will be drilled to a depth of 3,000 feet in the Solitario Canyon, just inside the perimeter drift. Together with an existing borehole (USW H-6), it will be used in a variety of multiple-well tests to obtain information about potentiometric levels and to test the hydrologic properties of the Solitario Canyon fault. This borehole will be drilled without drilling fluid, at least through the unsaturated zone.

Pumping tests

A series of single-well and multiple-well pumping tests will be conducted in the existing complex of water-table boreholes (the C-hole complex) about 5000 feet southeast of the perimeter-drift boundary. The locations of these holes were selected to be representative of the pathways available for ground-water flow through the saturated zone to the accessible environment. In the single-well tests, a submersible pump will remove water from a selected rock interval; the pressure in this and other intervals will be monitored during and after 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 aid in determining whether single-well testing can supply the needed information; if it can, other single-well tests will be conducted in other deep holes.

4.1.5.3 Studies of regional potentiometric levels

As already mentioned, two of the water-table holes will be drilled in Crater Flat to study potentiometric levels in the region of the site. These data are needed for estimating the directions of ground-water flow and hydraulic gradients. The new holes will be drilled deep enough to penetrate the water table. Additional data will be obtained from instruments installed by the DOE in boreholes owned by a commercial mining company in the Amargosa Desert. In addition, the DOE will conduct a general reconnaissance to locate previously drilled older wells, mine shafts, and springs that may yield information about regional potentiometric levels.

4.1.5.4 Infiltration studies

The DOE will study both natural and artificial infiltration in the vicinity of Yucca Mountain in order to define the upper boundary conditions for ground-water flow; these conditions are important in modeling flow through the unsaturated zone. For the studies of natural infiltration, shallow infiltration-monitoring holes will be drilled to depths of less than about 50 feet in 24 locations; these studies will also use the 74 holes already drilled for this purpose.

The artificial-infiltration studies will consist of four different types of infiltration experiments: double-ring infiltrometer measurements, ponding, small-plot rainfall simulation, and large-plot rainfall simulation. The infiltrometer measurements will be performed in the boreholes described above for natural-infiltration studies.

Ponding experiments will also be conducted at the sites of existing drillholes. For these experiments, small ponds, about 250 square feet in area, will be constructed and filled with water to induce infiltration artificially. A dye tracer will be mixed with the ponded water to trace pathways, and the water will be tagged with a chemical tracer. After ponding, rock in areas of intense fracturing will be excavated as much as 25 feet deep, and the pathways of flow will be mapped from observations of the tracer. As many as six such excavations will be made. In addition, shallower excavations similar to trenches will also be made. At the end of the experiments, all of the excavations will be filled in.

The rainfall-simulation studies will be conducted in both small plots (about 10 square feet) and in large plots (100 to 300 square feet) to detect and sample moisture, measure the moisture potential, and measure surface runoff. In the small-plot experiments, which will be conducted first, an array of four 5-foot monitoring holes will be drilled and instrumented, and several tests with a few hundred gallons of water will be conducted at each plot. In the large-plot studies, monitoring holes 10 to 50 feet deep will be drilled, and several tests with a few thousand gallons of water will be made at each plot.

4.1.5.5 Other studies

A number of holes will be drilled to various depths for additional studies. A horizontal hole may be drilled into the Solitario Canyon fault if such drilling is found to be feasible. This borehole, tentatively located about 2,000 feet north-northwest of the perimeter drift, will be sufficiently long to penetrate the zone of fracturing or alteration associated with the fault (i.e., up to 1,000 feet long).

Three deep holes will reach to depths of approximately 5,000 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. Four holes about 1,000 feet deep will be drilled in Crater Flat to investigate magnetic anomalies that may represent buried features related to volcanic activity. Several holes about 200 feet deep may be drilled near Exile Hill, just east of the site, to obtain mineral samples. Farther east of the site, in Fortymile Wash, three deep boreholes penetrating the water table and several shallow holes are planned for water-recharge studies. At other locations in the region of the site holes will be drilled to a depth of at least 1000 feet for measuring in-situ stress by the hydrofracturing method. Finally, at the site itself, two shallow exploratory holes will be drilled in Midway Valley to obtain more data on the location proposed for the surface facilities of the repository.

4.2 TESTS IN THE EXPLORATORY-SHAFT FACILITY

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

4.2.1 The exploratory-shaft facility

The exploratory-shaft facility (ESF) will be constructed on Dead Yucca Ridge 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. 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 4-3.

4.2.1.1 Surface facilities

The surface facilities will include graded pads for equipment and buildings; roads; buildings and trailers; shaft collars, hoists, and headframes; construction-support facilities; utilities; and a mined-rock pile. The proposed layout is shown in Figure 4-4, and a site plan is shown in Figure 4-5. 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 east of the proposed site. The land required for all of the surface facilities is about 14 acres.

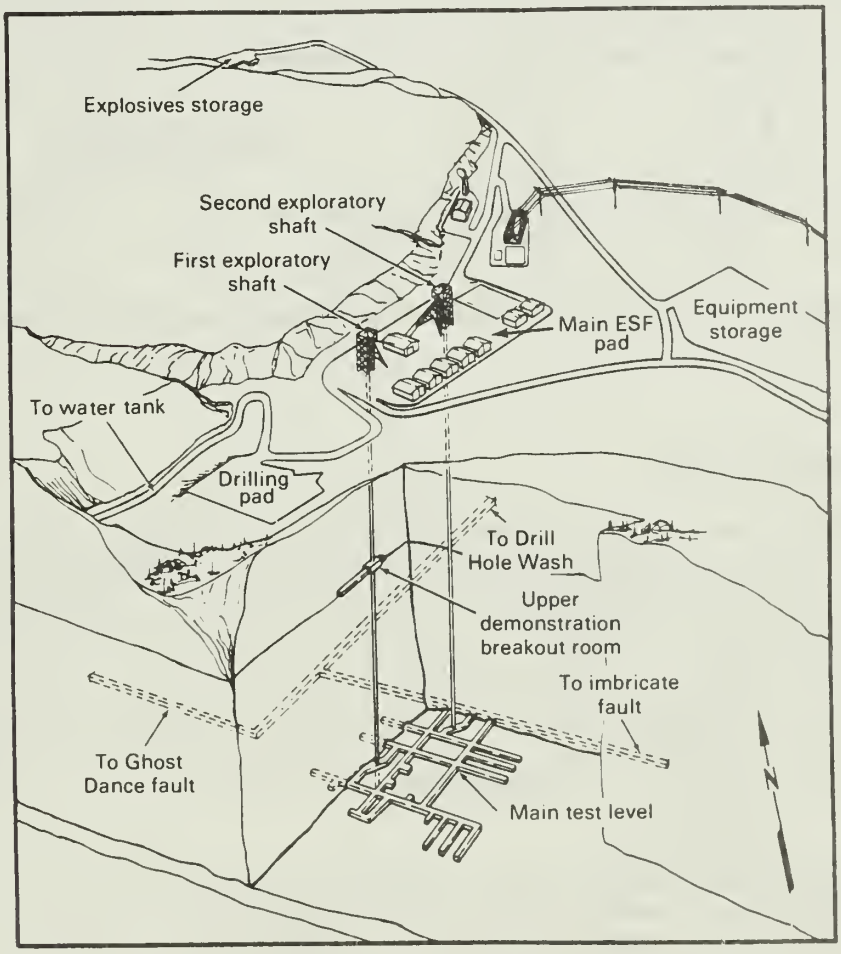


Figure 4-3. Cutaway view of the exploratory-shaft facility.

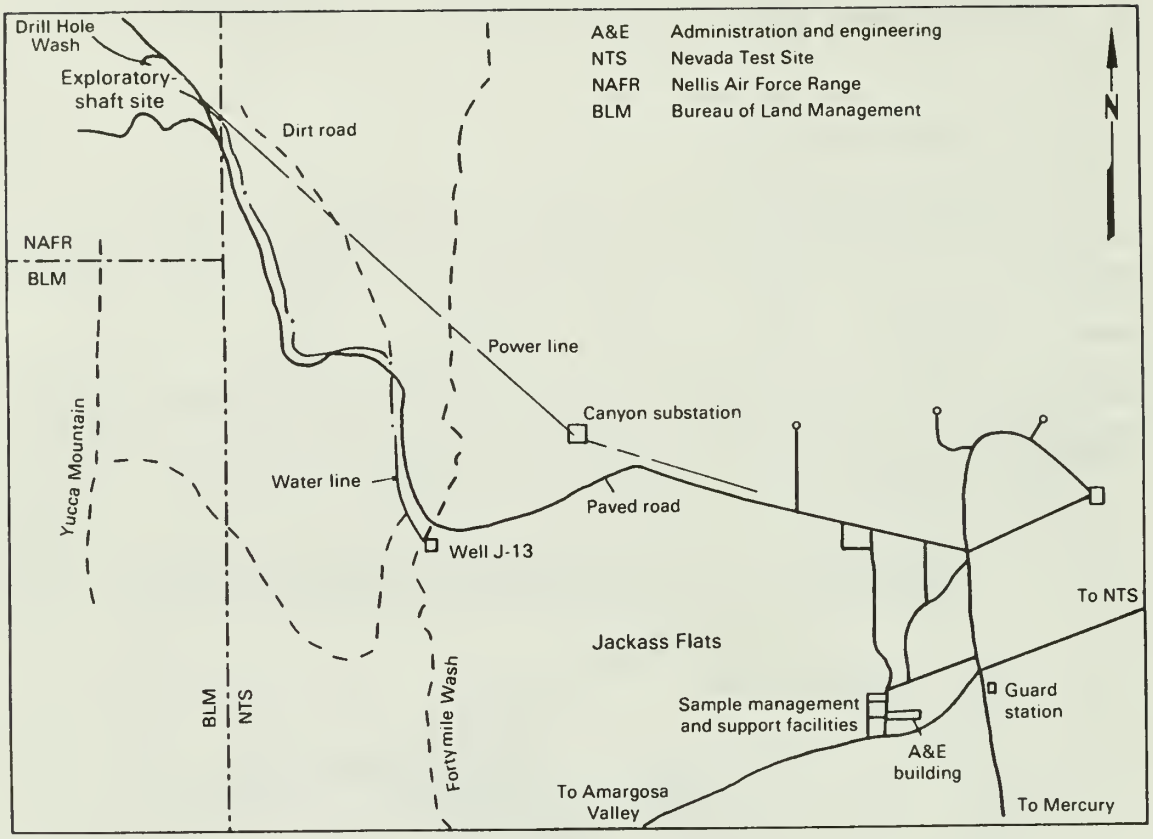


Figure 4-4. The proposed layout of the surface facilities for the exploratory-shaft facility.

Graded pads and roads

Several pads will be needed to accommodate various surface facilities for ESF construction and operation. Among them will be the main pad, which will accommodate the shafts, headframes, hoist house, and various temporary buildings and trailers. The main ESF pad will be roughly rectangular, 700 feet long and 480 feet wide. To control surface-water runoff, it is designed to slope away from the collars of the shafts. The pad is above the level of the probable maximum flood projected for the ESF site. To protect the pad from sheet runoff from the hillside on the north, ditches will be built along the northern and western edges of the pad.

Separate pads will be built for an electrical power substation, equipment storage, bunkers for storing explosives, a water tank, and mined-rock storage. The concrete batch plant will use an existing pad inside the Nevada Test Site.

The existing access road from Jackass Flats to the boundary of the Nevada Test Site has already been improved to accommodate heavy equipment; it is 24 feet wide and has an oil-and-chip surface. This road will be extended to the main ESF pad. Additional roads will be built to the exploratory shafts, the explosives-storage area, and the water tank; these roads will be graded dirt or gravel access routes.

The pads and roads will be built with earth-moving equipment. When necessary, hard rock will be removed by blasting. To limit damage to the surrounding rocks, the blasting will be carefully controlled in accordance with the NRC's requirements in 10 CFR Part 60, Subpart G.

Buildings

The buildings on or near the ESF main pad will consist of a change house for workers, a shop, a hoist house for the shafts, a building for the integrated data system, and trailers used for offices and for the preparation of samples collected during site characterization. A water pumphouse and warehouse facilities--a building and protected storage--will be provided on the auxiliary pads. All of the buildings in the ESF surface facilities will be temporary, and, with one exception, all will

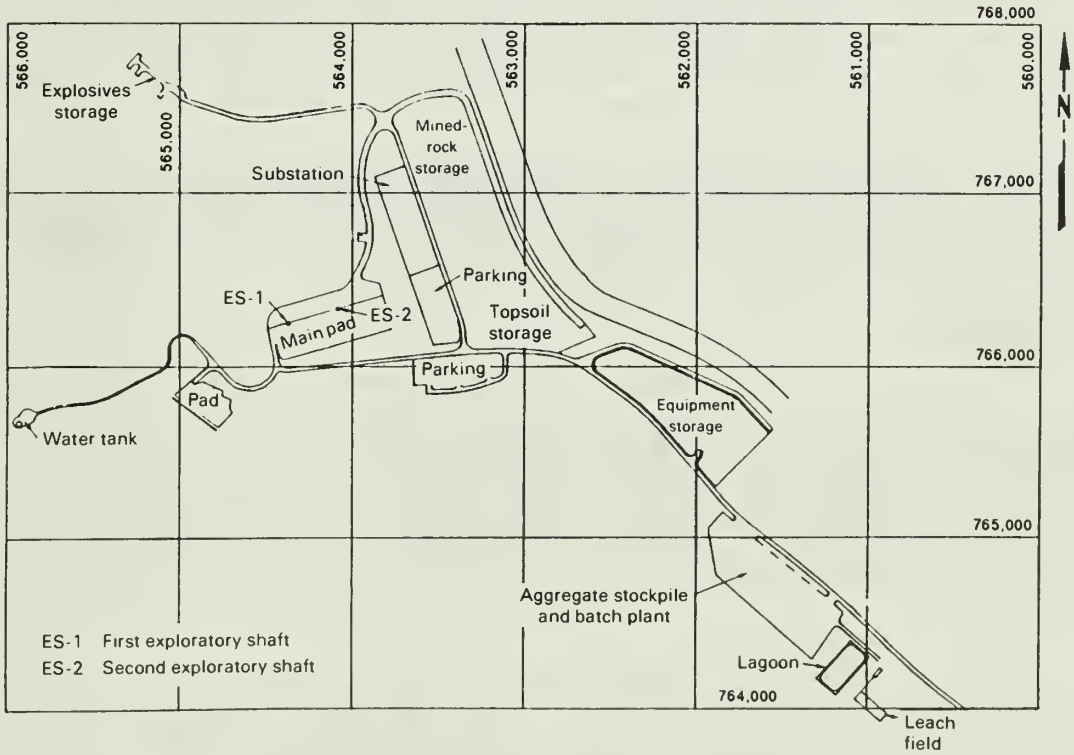


Figure 4-5. Site plan for the exploratory-shaft facility.

be prefabricated metal structures. The one exception is the housing for the integrated data system, which will be a prebuilt modular building.

North of the ESF main pad an auxiliary pad will be built for three bunkers that will be used to store explosive materials: one for explosives, one for detonators, and one for primer makeup. These bunkers will be isolated from the main ESF pad by a high hill.

Most activities that do not directly support the construction and operation of the exploratory-shaft facility will be conducted from the auxiliary facilities at Jackass Flats. These auxiliary facilities will include laboratories, a sample-management facility, and an administration and engineering building. The latter will provide office space and accommodate a visitors center.

The ESF plant and construction-support facilities

The ESF plant and the construction-support facilities provide the aboveground equipment and systems needed to support underground construction. The major equipment provided in the ESF plant includes ventilation fans with ductwork through the shaft collars, air compressors with supply lines to the shaft collars, water-supply piping to the shafts, and waste-water piping from the shafts to the waste-water pond. The major construction-support facilities include several structures mentioned above under "Buildings" (bunkers for explosives, shops, the warehouse), the concrete batch plant, an area for storing the mined rock, a pond for storing the waste water from the shafts, and laydown areas for supplies and equipment.

The ventilation system will supply the underground working areas with air. To ensure safe working conditions, instruments will be installed underground to continuously monitor radon, carbon monoxide and other gases, temperature, humidity, and air speed.

Utilities

A substation will be constructed to provide electrical power. It will be supplied from an existing overhead powerline that extends from the Canyon substation in Jackass Flats to the boundary of the Nevada Test Site. This substation will supply power to the hoists, air compressors, ventilation fans, surface buildings, and underground facilities. Standby electrical power for systems critical to the safety of workers and to the collection of data will be provided by diesel generators.

According to current plans, water for the exploratory-shaft facility will be supplied from well J-13, which is on the Nevada Test Site, about 3 miles east of the boundary of the proposed repository. The water will be distributed through an existing buried plastic pipe and pumped by two stations--one at the well and a booster pump station about halfway to the site. The water will be pumped to a tank located west of and above the ESF site. All water used during site characterization

will be tagged with an appropriate, nontoxic chemical tracer. Drinking water will be provided separately.

Two systems will be provided for the disposal of waste water: one for sanitary waste water and one for mine waste water. The former will use a septic tank in a leach-field system to accommodate the sanitary wastes produced by an expected population of 200 persons. This waste water will be disposed of downhill from the exploratory-shaft facility, well away from the water supply and activities involving people.

The second waste-water system will handle all of the water from mining activities. This waste water will be processed to separate oils and disposed of in a settling-and-evaporation pond located east of the main ESF pad, about 2,000 feet beyond the boundary of the repository block. The fluids pumped into this pond will include drilling fluids, such as bentonitic muds with water-control agents, polymer foams, and any other water used for construction. The mine waste water will be tagged with a tracer and treated before being discharged into the tail end of Coyote Wash.

Mined-rock pile

All rock removed during the construction of the exploratory shafts and underground excavations will be stored at the surface in a mined-rock pile located east of the ESF main pad. The pile is designed to accommodate more than 160,000 cubic yards of rock.

Shaft collars, hoists, and headframes

A shaft collar will be constructed for each exploratory shaft. It 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 anchored in bedrock. They will be constructed of reinforced concrete extending from about 1 foot above the surface to about 15 feet below the finished grade. The shaft collar can be seen in the drawing of the exploratory shafts in Figure 4-6.

The hoists, hoist house, and headframes for both of the exploratory shafts will provide the hoisting capacity needed for removing mined rock and for moving people and materials to and from the surface. They will be erected after the shaft collars are in place. As shown in Figure 4-6, the hoist house will be built halfway between the two shafts and will service both shafts.

4.2.1.2 Exploratory shafts

Two exploratory shafts will be constructed at the Yucca Mountain site. One will be used for exploratory testing, while the second will be used to provide various support services, such as ventilation. The

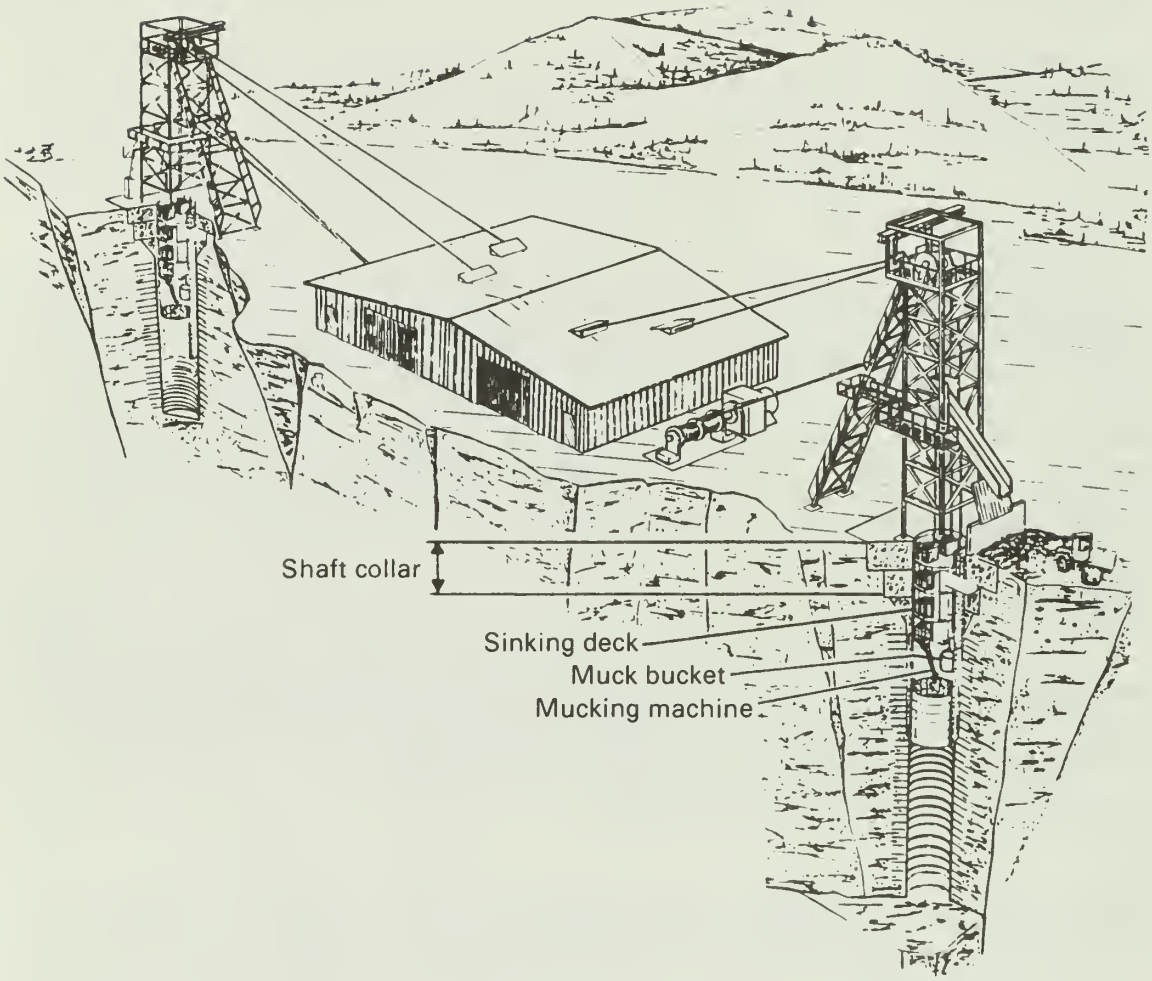


Figure 4-6. Drawing (not to scale) of a typical hoist, headframe, and collar for an exploratory shaft.

shafts will be centrally located on the main ESF pad (see Figure 4-5) and spaced 300 feet apart. Both shafts will have a finished inside diameter of 12 feet, and both will be lined with concrete.

First exploratory shaft

The construction of the first exploratory shaft (ES-1), referred to as the "scientific shaft," will begin after the headframe has been erected, the hoist has been installed, and the collar of the shaft has been constructed. This shaft will be a vertical hole about 1,105 feet deep. 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 sinking of the first exploratory shaft will accommodate a variety of site-characterization tests, including geologic mapping of the walls of the shaft, the drilling of radial boreholes, and vertical seismic profiling. If perched water is encountered during the sinking of the shaft, perched-water tests will also be conducted. Because sufficient time will be provided to successfully complete the mapping, sampling, and other testing, the sinking of the shaft will proceed very slowly.

Except for testing, the sinking of the first exploratory shaft will be a routine mining operation. 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 construction of the shaft has advanced several feet and the smoke, dust, and fumes have cleared, the miners will clean off any loose rock from the walls. Scientists will then go down to collect rock samples from the bottom of the shaft, assisted by the miners. The miners will load the rubble at the bottom of the shaft into buckets for hoisting to the surface, and the scientists will map and photograph the walls of the shaft. The mapping and photographing will be done after each round of blasting or before the rock is obscured by lining or ground support. The other tests will be conducted at selected elevations. When the scientists have completed their work, the miners will prepare the next blasting round, and this alternating sequence of mining and testing will continue throughout the sinking of the shaft. After several blasting rounds, the concrete for the liner of the shaft will be poured, in 20-foot segments. The liner will be made of unreinforced concrete that is at least 1 foot thick where the shaft intersects welded tuff. Where specified by scientists, blockouts will be installed in the liner to protect anchors for instruments, drill collars, and the like before the liner is poured.

Vital to the construction of the shaft will be the drilling of an advance probe hole in the center of the shaft. The probe hole, which will be about 200 feet deep, will be cored; it is expected to provide immediate and advance information to the mining contractor and the principal scientific investigators about the presence of perched water and ground conditions. The data collected from this probe hole will be compared with data collected from the multipurpose borehole described in Section 4.1.5.1 in order to ascertain that the design of items important to safety or waste isolation is adequate.

At a depth of 600 feet, a breakout room and a shaft station will be constructed (see Section 4.2.1.3 for a description of these rooms). The breakout room and the shaft station will be excavated by drilling and blasting, and the walls and the roof of the excavation will be geologically mapped by the scientists after entry is safe. After the construction tests scheduled for the demonstration breakout room have been completed, the sinking of the shaft will continue until the main test level

at 1,055 feet is reached. Here another shaft station will be excavated. Below the main test level, a tailshaft of about 50 feet will be sunk to accommodate conveying equipment and the sump.

Every effort will be made to limit the amount of water that is used in constructing the shafts, but small amounts of water will be used to flush out the cuttings from the blasting holes and to suppress dust and fumes after blasting. Some water will also be used during testing. All water introduced into the shafts and the underground testing areas will be tagged with nontoxic chemical tracers to distinguish it from ground water. Most of the construction water that is not absorbed and removed with the rubble will be collected by pumps located at the bottom of the shaft and pumped to the surface.

Second exploratory shaft

The second exploratory shaft (ES-2) 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 underground. 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 1,055 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 few tests will be made in it. After the second shaft is completed, the connecting drift to the first exploratory shaft and a lower demonstration breakout room will be constructed off the second shaft on the main test level. The connecting drift will be mined by drilling and blasting.

4.2.1.3 Underground facilities

The first exploratory shaft will provide access to breakout rooms and stations at two levels: the level of the upper demonstration breakout room (600 feet) and the main test level (about 1,055 feet). The stations will be excavated directly off the exploratory shaft, whereas the breakout room at the 600-foot depth will be excavated off the station.

The upper demonstration breakout room at 600 feet will be near the upper stratigraphic boundary of the proposed repository horizon. The information obtained from tests in this breakout room will help to predict the thermal and mechanical response of rocks with a high content of lithophysae. In addition, the constructability and stability of the drifts will be established for both vertical and horizontal waste emplacement modes. The station, which will be reinforced with rock bolts, wire mesh, steel sets, and lagging, will provide a protected area for

unloading equipment and handling the rubble produced by the excavation of the breakout room.

At about 1,055 feet, the main test level, a lateral drift will be mined from the second exploratory shaft after the first exploratory shaft has been sunk. 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 areas where the test alcoves and drifts are currently planned.

The general arrangement of the operations area at the main test level is shown in Figure 4-7. This figure shows the drifts that will be mined first and the locations of various tests that will be conducted underground.

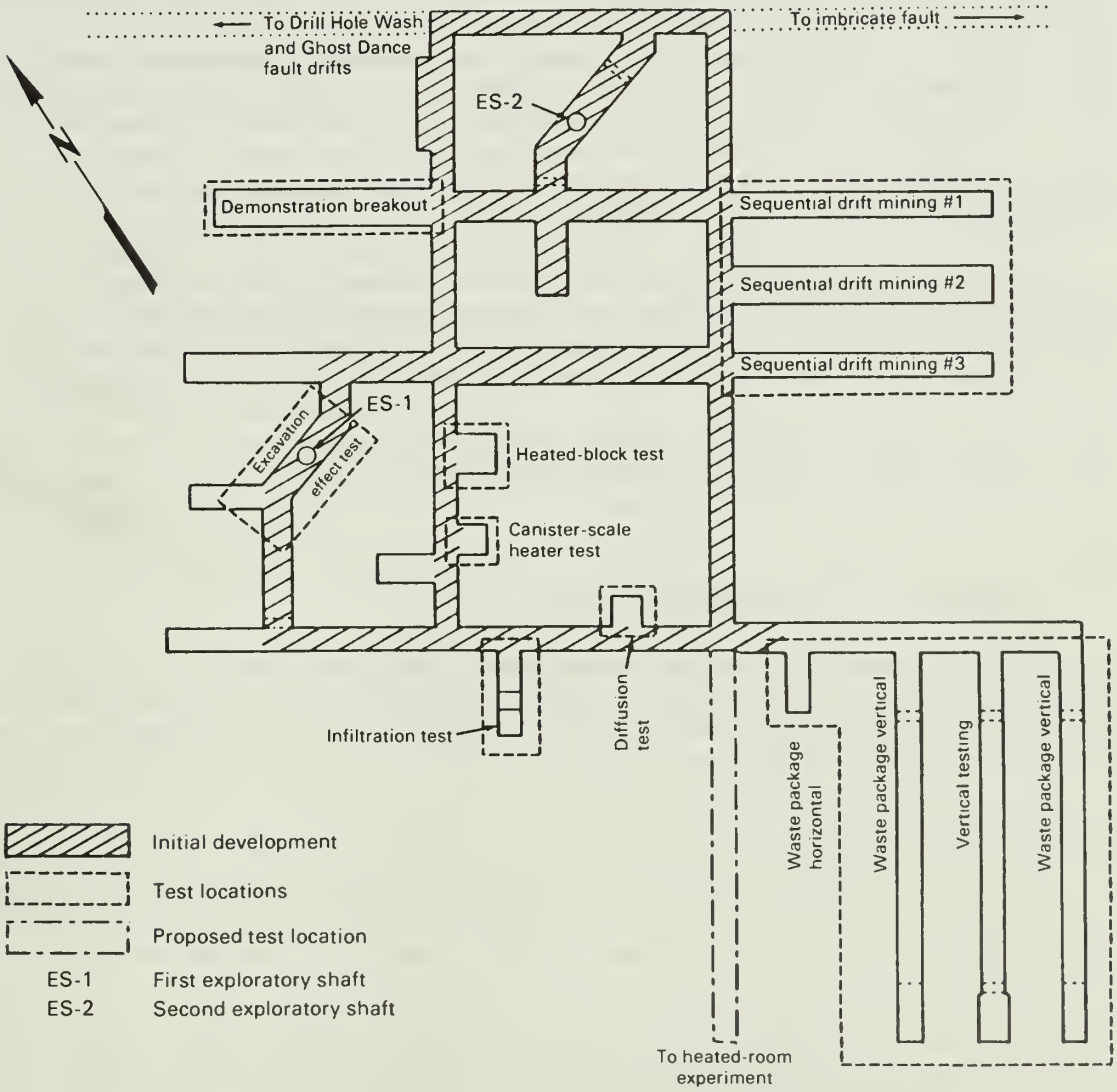


Figure 4-7. General arrangement of the main-test-level area in the exploratory-shaft facility.

Three long exploratory drifts will be mined to provide access to specific features inside the proposed repository block: (1) the Ghost Dance fault, (2) the Drill Hole Wash structure, and (3) a proposed drift to the imbricate-normal-fault zone to the east. The drift to the Ghost Dance fault will be about 1,200 feet long and head northwestward 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 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. The hydrologic character of the rock structures beneath 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 the rate of ground-water flow and the movement of water down a fracture zone. This drift will extend northeastward from the operations area on the main test level.

The purpose of the drift southeastward 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.

4.2.2 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.

As already mentioned, the walls of the first exploratory shaft will be mapped and photographed in detail during the shaft-sinking operations. Geologic mapping of the first exploratory shaft will take place immediately after each round of excavation is completed and after the

newly exposed walls have been cleaned and surveyed. The drifts and breakout rooms will also be mapped. The mapping will be done before any mesh or rockbolts are installed unless such precautions are necessary for safety reasons. The walls of the second exploratory shaft will also be mapped and photographed.

In general, the testing activities planned for the first exploratory shaft will not be duplicated in the second shaft. Such testing is not expected to provide new information because the conditions in the rock surrounding the shafts are expected to be similar; in addition, the designs of the shafts and the methods of construction are essentially the same. However, two types of investigation will be conducted in the second shaft: perched-water tests and geologic mapping of shaft walls. The mapping in the second shaft will produce a complete photographic record like that obtained in the first shaft, but the detailed mapping along datum lines will be at greater intervals. The data collected in the second shaft will be used to test the hypothesis that the rock conditions do not vary significantly between the two shafts. If this hypothesis is proved false, additional testing in the second shaft will be considered.

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 for testing and sampling. Holes will be drilled by dry-drilling 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.

At both of the main shaft levels described in Section 4.2.1.3, 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 six hydraulic-pressure cells and three radial-borehole extensometers. They will be monitored after shaft sinking resumes.

During the shaft sinking, samples of rock will be collected from the shaft bottom for the 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 depth intervals 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 in the upper demonstration breakout room and the main test level in the first exploratory shaft. At each level multiple small-diameter holes will be drilled. 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 be up to 100 feet deep. Geophys-

ical logging will be performed in each hole, and core will be taken from some holes.

At nine different levels two radial coreholes will be drilled from the shaft for hydrologic testing and monitoring. These 30-foot-long holes will be logged, and instruments for measuring temperatures, pressures, moisture, heat dissipation, etc., will be monitored.

In order to sample natural fractures, 10 or 12 large-diameter cores will be obtained from the walls of the breakout room and station at the main test level. The pilot hole drilled for this coring will penetrate a fracture identified in mapping. A rockbolt anchor will immobilize the fracture for subsequent overcoring.

In-situ-phase tests

Tests started on the main test level after the shafts are connected or conducted elsewhere in the exploratory-shaft facility after the shafts are sunk are called "in-situ-phase tests." These tests are described in Section 8.4.2.3.1 of the SCP.

Three parallel drifts will be excavated sequentially to evaluate the effects of drift mining on the host rock (see Figure 4-7). Two of these drifts will be 16 feet wide, whereas the third drift, located between the other two drifts, will be 25 feet wide. Instrumentation holes will be drilled to monitor above, below, and adjacent to the central drift. The sensors installed in these holes will measure stress release, changes in bulk permeability, and the deformation of the rock mass.

A canister-scale heater test (see Figure 4-7 for location) will simulate the environment around a waste-emplacement borehole. A corehole will be drilled into the wall of a special drift, and 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 such instruments as extensometers, deformation gauges, moisture monitors, and radon monitors. In addition to this large-scale experiment, a small-scale heater experiment will be conducted in the wall of the upper breakout room.

A heated-block test will subject a 2-meter cube of jointed rock to controlled conditions of stress and temperature--conditions simulating 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 the rock mass. Instruments inserted into the slots will apply pressure to the sides of the cube, and electrical heaters in holes outside the cube will control its temperature. Instrument holes will be drilled into the cube to permit measurements of stress, displacement, and temperature during cycles of varying stress and temperature induced in the cube.

To measure thermal-mechanical responses in fractured welded tuff at a drift-size scale, the DOE plans to conduct a heated-room experiment. At a location to be determined, the DOE will excavate a drift representative of repository-size drifts and will heat the rock around this drift. Instruments will be installed to measure the effects of heat on the deformation of the rock mass, thermal conductivity, heat capacity, the thermal expansion coefficient, and the like. Another objective is to estimate the region in which the stress state is changed by heating. The results of this experiment will provide data for evaluating both preclosure and postclosure design.

Plate-loading tests will use an established technique for observing and characterizing the deformability of the 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.

Overcoring-stress measurements and studies of borehole dilation will be performed at both test 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.

As discussed in Chapters 2 and 5, a favorable feature of the Yucca Mountain site is the presence of a thick unsaturated zone. It is therefore important for the DOE to obtain more information on how moisture moves through the rock matrix and through fractures in the rocks in the unsaturated zone. To this end, infiltration tests (see Figure 4-7 for location) will be conducted to observe and measure the flow of fluids through a network of fractures under controlled conditions.

Bulk-permeability tests will be conducted to measure air and water permeability and hydraulic conductivity in relatively large volumes of minimally disturbed host rock (Topopah Spring welded tuff). The DOE plans to conduct these tests at four separate locations selected on the basis of detailed fracture maps. At each location, a small-diameter hole 100 to 200 feet deep will be air cored and logged. If preliminary results show the hole suitable for testing, three additional holes subparallel to the first will be air cored, logged, and instrumented.

A diffusion test (Figure 4-7) will determine the extent to which nonsorbing tracers can diffuse into the pores of the tuff units penetrated by the shaft. At four locations to be selected on the main test level, 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, a suitable nonsorbing-tracer solution will be injected, and the holes will be capped. After a period of 3 to 12 months, the holes will be overcored, and the cores will be sent to a laboratory to determine how the traced moved into the rock.

The DOE will also conduct experiments to estimate the shear strength of jointed rock masses at various scales. These experiments will be conducted on the main test level, in several areas chosen to be representative of the geologic conditions expected in the repository.

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.

4.3 ENSURING THAT DATA ARE REPRESENTATIVE

Because the tests conducted in the exploratory-shaft facility will be an important part of site characterization, the data obtained in the facility will be most useful if they accurately represent the conditions throughout the Yucca Mountain site. The characteristics of the rock mass at and near the exploratory-shaft facility should be typical enough to allow an adequate assessment of processes that occur throughout the site. And the conditions at the location of the exploratory-shaft facility should not require construction methods that would not be typical of the methods to be used elsewhere at the site.

These requirements were included in a broad range of criteria that guided the process by which a location was selected for the exploratory-shaft facility. Much of the weighting used in the selection dealt with specific concerns about representativeness. The location that was selected allows the DOE to explore specific rock horizons that will receive the most extensive investigations. It avoids potentially adverse structures, which are not typical of the site. However, it does allow investigators to reach those structures by further underground exploration.

As a check that the selected location is indeed representative of the Yucca Mountain site, the DOE recently performed an analysis that examined the current information about the rock characteristics at the location of the exploratory-shaft facility and throughout the site. Using statistical comparisons whenever the data permit them, the analysis concluded that, in most of the important characteristics, the location of the exploratory-shaft facility is as representative of the site as any single location can be. The location may not be truly representative of the mineral composition of the repository horizon (the Topopah Spring Member of the Paintbrush Tuff Formation) across the site, and the Calico Hills unit below the location may be somewhat atypical. This possible lack of representativeness will be addressed by the surface-based drilling program (Section 4.1), which will use systematic sampling to determine the spatial variability of rock characteristics over the

site. A detailed discussion of the representativeness of the location of the exploratory-shaft facility and of the objectives of the surface-based drilling program is given in Section 8.4.2.1.5 of the SCP.

As described in Section 8.3.1 of the SCP, the DOE's investigations will be extensive, with intensive coverage of the immediate site area. The results of surface-based and underground activities (e.g., geologic mapping, geophysical surveys, exploratory drilling) will be used in multiple approaches to develop an understanding of the spatial variability of the hydrogeologic characteristics of the rock. Included in these approaches will be the development of descriptions of geologic, hydrologic, or geochemical characteristics that are based on observations and scientific inference. Additional borings and geophysical surveys may be necessary to enhance the data base.

The planned characterization program is based on general technical criteria, statistical concepts, and site-specific information to the extent practicable. There is abundant information from Yucca Mountain and similar locations about the geologic, hydrologic, geochemical, or other conditions and processes that are pertinent to the performance of the site. This general and site-specific information is the basis for the conceptual understanding of site conditions and processes that was used in planning the site-characterization program. It also supports the expectation that representative data will be collected.

4.4 PREVENTING TEST INTERFERENCE

An important guideline for arranging the experiment areas in the exploratory-shaft facility is ensuring that the tests will not interfere with one another, invalidating their results. Moreover, the construction of the exploratory-shaft facility and the operations that take place in it should not interfere with the tests. The DOE has analyzed these possibilities to evaluate the potential for interference.

The study of test-to-test interference is described in Section 8.4.2.3.6.1 of the SCP. It began with a description of the tests to be performed in the exploratory-shaft facility. From this description the study proceeded to derive, for each test, the constraints that the test will impose on the underground layout of the experiment areas and to estimate, for each test, its zone of influence--the spatial extent of the alterations the test will induce in its surroundings. The zones of influence were estimated by examining the thermal, mechanical, hydrologic, and geochemical effects of each test. For some tests the location and the extent of instrumentation also were found to influence the surroundings. This information was then translated into the standoff distances that are required for each test. When these standoff requirements were overlain onto the design drawings of the experimental areas, they revealed possible interferences. The interferences were then eliminated by changing the timing of the tests or their physical layout.

The study of the potential for interference from the construction and operation of the exploratory-shaft facility consisted of two evaluations, as discussed in Section 8.4.2.3.6.2 of the SCP. One evaluation compared the controls placed on construction and operation--for example, plans to limit blast-induced damage and limits on the use of liquids--with the constraints imposed by the tests, mentioned in the preceding paragraph. This evaluation determined whether the controls are sufficient to satisfy the constraints. The second evaluation began with the constraints. It determined whether each constraint would be satisfied by the planned ESF construction and operations. This evaluation included studies of the sensitivity of each test to the changes that may occur in its environment because of ESF construction or operations, such as sensitivity to changes induced by ventilation or by dust from mining. This two-part study concluded that the planned construction and operations are consistent with the constraints imposed by the tests and that all those constraints are met by the ESF design.

Included in the evaluations mentioned above was an evaluation of the potential for shaft-to-shaft interference. As described in Section 4.2.1.2, the first exploratory shaft will be used for scientific investigations, and its construction will be periodically interrupted to make measurements or to install instruments. The second exploratory shaft will be constructed at the same time, using the same methods. It was therefore necessary to determine that the construction of the second shaft will not interfere with measurements of hydrologic or structural conditions in the first shaft. As discussed in Section 8.4.2.3.6.2 of the SCP, the principal means for precluding such shaft-to-shaft interference are the distance between the shafts, the method of construction, and controls on the use of fluids in shaft construction. The evaluations of the potential for interference indicate that (1) general hydrologic interference between shafts is not likely, (2) significant reductions in the probability of such interference are not likely to be gained by increasing the distance between the shafts or by changing the sequence of shaft construction, (3) mechanical interference or unacceptable interference from blasting in the second shaft is not expected, and (4) the location and separation of the shafts are consistent with operational and industrial-safety considerations.

4.5 POTENTIAL EFFECTS ON WASTE ISOLATION

The activities conducted during site characterization--the construction of the exploratory-shaft facility, the tests performed in the facility, and any other tests conducted at the site--must not make the site unsuitable for use as a repository; in other words, they must be conducted in a manner that will limit any adverse effects on the long-term isolation that the site is expected to provide. To be sure that the site-characterization activities meet this guideline, the DOE has conducted analyses to examine their potential effects on waste isolation. The results of these analyses are very briefly summarized here; a detailed discussion is given in Section 8.4.3 of the SCP.

The analyses studied possible effects from five types of activity: (1) activities conducted at the surface (e.g., road construction, dust control, trenching, ponding tests, and drill-pad construction), (2) surface-based drilling activities (e.g., boreholes), (3) the construction of the exploratory shafts, (4) the underground excavation of drifts and testing areas, and (5) tests in the exploratory-shaft facility. These activities were evaluated in terms of potential effects in three general areas. The analyses in the first area, hydrology, examined the infiltration of water from the surface, ground-water flow in the rock matrix and in fractures, the possibility that the water is redistributed in the unsaturated zone, and the movement of water vapor. They examined the possibilities that site-characterization activities might change the magnitude of the ground-water flux, change the composition of the ground water, alter the existing distribution of hydrologic properties, or create preferential pathways for radionuclide migration.

In the second area, geochemistry, the studies examined the possibility that site-characterization activities might change the existing geochemical conditions at the site. These studies paid special attention to the liquids other than water that the construction and operation of the exploratory-shaft facility and other activities will introduce into the site.

Studies in the third area, thermal and mechanical alterations, examined the potential effects of ESF construction on the thermal and mechanical properties of the rock in which the exploratory-shaft facility is constructed. These studies paid particular attention to the effects of blasting and excavating.

From these analyses, the DOE proceeded to evaluate the changes that site-characterization activities would create in the site. The analyses showed that some effects--for example, changes in the moisture content of the rock immediately surrounding the exploratory shafts--are temporary and would not be expected to affect the ability of the site to isolate waste in the long term. Other effects, however, will be essentially permanent. An obvious example of such an effect is the presence of the backfilled shafts themselves.

The DOE was then able to evaluate the potential effects of these changes on the ability of the site to provide waste isolation. This evaluation, which is described in Section 8.4.3.3.1 of the SCP, was conducted in three parts. First, the DOE evaluated potential effects on the conditions now existing at the site. In the other two parts of the evaluation, the DOE addressed potential effects on future conditions. In the second part, the DOE examined the possibility that the lingering effects of the exploratory-shaft facility and other activities conducted during site characterization would adversely affect the conditions that would be present at the site if natural changes that are likely to occur in the next 10,000 years actually did occur. In the third part of the examination, the DOE considered potentially disruptive events that, though unlikely, are sufficiently credible to warrant consideration. This part examined whether the presence of the lingering effects would

adversely affect the site's waste-isolation capability under the conditions that would be likely to result from the disruptive events.

The results of these examinations indicated that neither the temporary nor the permanent changes produced by site-characterization activities are likely to affect the ability of the Yucca Mountain site to provide waste isolation. The changes are not likely to significantly alter the important features of the unsaturated zone, which is the principal barrier that will provide waste isolation. The changes that might occur in the hydrologic, geochemical, or mechanical properties of the site will be temporary or confined to small areas near the shafts or boreholes. None of these changes appears to be large enough to affect the movement of radionuclides. Furthermore, no waste would be emplaced near any of the penetrations, and neither the sealed boreholes nor the backfilled exploratory-shaft facility is expected to furnish any preferential pathways for the movement of radionuclides from the waste. An especially important part of these evaluations examined in detail the effects of an unexpected future flooding of the shafts themselves. Such flooding had been suggested as a possible way in which the shafts could contribute to a loss of isolation capability. This particular study assumed that unrealistically large amounts of water would flood the shafts, and it concluded that, even under those conditions, the shafts would not provide a pathway for water to enter the repository and come into contact with the waste containers.

4.6 QUALITY ASSURANCE

The DOE's quality-assurance program consists of all planned and systematic actions necessary to ensure that the Yucca Mountain site will be thoroughly characterized and that the geologic repository will perform satisfactorily in service. All organizations participating in the site-characterization program have developed and are implementing a documented quality-assurance program that meets the quality-assurance requirements of the Nuclear Regulatory Commission. A comprehensive description of the quality-assurance program for site characterization is given in Section 8.6 of the SCP.

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 or activity to public health and safety or waste isolation.

4.7 ENVIRONMENTAL AND SOCIOECONOMIC IMPACTS

In conducting the site-characterization program, care will be taken to minimize adverse environmental and socioeconomic impacts. As discussed in the DOE's environmental assessment for the Yucca Mountain

site,* no significant adverse impacts are expected from site characterization. Nonetheless, the DOE will monitor the site-characterization activities that might have potential for significant adverse environmental and socioeconomic effects and will implement appropriate mitigation measures that may be necessary. General plans for monitoring and mitigating those impacts are presented in the Environmental Monitoring and Mitigation Plan (EMMP) and the Socioeconomic Monitoring and Mitigation Plan (SMMP). The EMMP and the SMMP provide that periodic reports be issued on the results of environmental and socioeconomic monitoring.

4.8 DECOMMISSIONING

If the Yucca Mountain site is found to be unsuitable for 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 restored. 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 rock removed during excavation.

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

Current plans for site-characterization activities do not include the use of radioactive tracers or uncontained radioactive materials. However, the DOE does plan to use geophysical logging tools that contain radioactive sources. Such tools are commonly used to investigate the movement of ground water during exploratory drilling. The radioactive sources in these tools are fully contained and retrievable, as explained in Chapter 4 of the environmental assessment for the Yucca Mountain site.* Since contained, retrievable geophysical logging tools are the only radioactive materials that the DOE plans to use during site characterization, no decontamination is expected to be needed after site characterization. Nevertheless, if other radioactive materials were used, plans for decontamination would be developed in consultation with appropriate Federal and State agencies.

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

Chapter 5

THE SITE-CHARACTERIZATION PROGRAM

Before the Yucca Mountain site can be recommended for use as a repository, the DOE will have to demonstrate that a repository at Yucca Mountain would satisfy the safety regulations promulgated for geologic disposal. In order to do this, extensive information describing the site must be collected and analyzed; designs for the repository, the seals, and the waste package must be developed; and the performance of the repository system--that is, the site, the repository, and the waste package--must be assessed. To collect the needed information, the DOE is conducting a carefully planned program of site characterization. Such a program is required by the Nuclear Waste Policy Act as amended, by the Nuclear Regulatory Commission (NRC) in Part 60 of Title 10 of the Code of Federal Regulations (10 CFR Part 60),* and by the DOE's siting guidelines in Part 960 of Title 10 of the Code of Federal Regulations (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, including the strategies for demonstrating compliance with regulations, the data needed for carrying out the strategies, the programs that will collect and analyze the needed data, and the field activities to be conducted at and near the site. This chapter of the overview summarizes the strategies and reviews the programs for collecting and analyzing the needed data. The field activities to be conducted during site characterization have been briefly described in the preceding chapter.

This chapter begins, in Section 5.1, with a "top-level strategy" that identifies the general objectives for the repository 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 compliance with regulations.

Section 5.2 briefly explains the two organizing principles for the SCP--a hierarchy of issues, which embody the regulations that govern the repository system, and a general procedure for resolving those issues.

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*U.S. Nuclear Regulatory Commission, "Disposal of High-Level Radioactive Wastes in Geologic Repositories," Code of Federal Regulations, Title 10, Part 60, 1988.

**U.S. Department of Energy, "General Guidelines for the Recommendation of Sites for the Nuclear Waste Repositories," Code of Federal Regulations, Title 10, Part 960, 1984.

This explanation is needed for understanding the discussion in Section 5.3, which is a highly compressed summary of the detailed strategies for resolving the issues. The remaining sections of this chapter summarize the principal parts of the program. Section 5.4 reviews the plans for gathering and interpreting data describing the properties of the Yucca Mountain site and the host rock. Organized by technical discipline, it discusses both the collection of data and the models in which these data will be used. Section 5.5 reviews plans for designing the repository and for the analyses that will support the design. Section 5.6 reviews plans for designing the seals for the repository; it also reviews the tests needed for developing the designs. Section 5.7 reviews the activities planned for designing the waste package and for the supporting analyses, including the tests needed to define the environmental conditions to which the waste package will be exposed after being emplaced in the host rock.

The last section in this chapter, Section 5.8, reviews the analyses that will assess the performance of the repository system, both for the period preceding the permanent closure of the repository and for the much longer time after closure. For the convenience of the reader, the technical terms used in this chapter are defined in the glossary at the end of this overview.

5.1 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. Because of this role, as will be explained, the program for characterizing this site puts considerable emphasis on the ground-water-flow conditions in the unsaturated rocks in which the waste would be emplaced.* Other important features of the unsaturated rocks are the geochemical properties and other characteristics that could affect the performance of the waste packages and the characteristics that could affect the transport of radionuclides through the unsaturated rocks. In addition, the geohydrologic conditions in the saturated rocks deep beneath the site will be characterized. Because the features mentioned above will be relied on in achieving the general objectives for the system, it is necessary to investigate any disruptive processes and events that could significantly alter the features. The top-level strategy also emphasizes preclosure radiation safety and the effects of seismicity on the surface and underground facilities of the repository. This section explains why the above-mentioned features and characteristics have been selected for emphasis during site characterization.

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*The reader may find that the descriptions in Chapter 2 of the site and the host rock are helpful in understanding this section.

The principal role of a repository system is to isolate waste for a long period into the future. Therefore, the general objective for the repository system is to limit any radionuclide releases to the accessible environment, as defined by regulations (see glossary). This objective is to be achieved by selecting a site with suitable natural barriers to the release of radionuclides and by providing a system of engineered barriers that is designed specifically for the conditions present at the site. 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 repository system. The general objective for the engineered barriers is that these barriers should limit the release of radionuclides to the natural barriers. The general objective for the natural barriers is to provide such conditions that any transport of significant quantities of radionuclides through these barriers to the accessible environment is likely to take a very long time. In particular, since ground water may transport radionuclides, the time of ground-water travel should be very long. There are also two general objectives for the design of the repository system: the operation of the repository should be safe, and its construction should not compromise the ability of the repository 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 (see footnote on page 89) for releases of radionuclides to the accessible environment, the protection of individual members of the public, and the protection of ground water; requirements on the containment to be provided by the set of waste packages and on the rate of radionuclide release from the engineered-barrier system; and an objective for the time of ground-water travel under the conditions present at the site before the emplacement of any radioactive waste in the repository. The NRC regulations also specify design criteria to ensure that the postclosure-performance objectives would be met and set preclosure-performance objectives for protection against radiation and for maintaining the option to retrieve the waste before the closure of the repository. The detailed strategies for addressing these regulations are presented in Sections 8.1 and 8.3 of the SCP. The remainder of this section describes the top-level strategy for addressing the general objectives for the repository system.

5.1.1 General objectives for the repository system

As explained in Section 2.3.3 of this overview and in Chapter 3 of the SCP, the currently available information suggests that only small amounts of water are available for percolation downward through Yucca Mountain, and this percolation occurs very slowly. 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 reached the waste emplaced in the repository, 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 would join 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. For the purposes of defining the top-level strategy, the major elements that compose the engineered-barrier system are the disposal container and the waste form inside the disposal container. There would also be an air gap between the container and the wall of the borehole in which the container would be emplaced (see Section 3.2).

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 a repository at the Yucca Mountain to the accessible environment. According to the available evidence, the rate of percolation (i.e., 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 retained within the rock matrix, as it appears to be, it would not be expected to move from the rock across the air gap to the disposal 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 its geochemical properties, which would control the rate and the extent to which radionuclides are dissolved by the water contained in the rock as well as the retardation of radionuclide transport.

Therefore, the elements of the repository 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.

In addition to transport by ground water, one other sequence of events might contribute to a release of radionuclides under the current conditions at Yucca Mountain. If the disposal containers are breached, gaseous radionuclides that are present in spent fuel (e.g., carbon-14) might move upward through the air spaces in the unsaturated rock above the repository. If the gaseous radionuclides are released from the metal cladding that encases the spent-fuel pellets and also released from the containers in which the spent fuel is encapsulated, 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 of radioactive material. It is not clear, for example, that the waste form--the spent-fuel rods--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 of release for gaseous radionuclides.

5.1.2 General objective for the 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 disposal container to limit the release of radionuclides to the natural barriers. In addition, the materials of which the container is made will be chosen to be compatible with the geochemical properties of the water in order to prolong the life of containers in contact with any water.

The air gap between the disposal container and the host rock is expected to increase the ability to limit the release of radionuclides; that is, because the percolation rate 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 to cross this air gap. Therefore, the amount of liquid 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.

5.1.3 General objective for the performance of the natural barriers

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

- 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 take even longer than the ground water to reach the accessible environment because their travel will be retarded by geochemical and mechanical processes. Therefore, these units are expected to provide an effective barrier to the transport of radionuclides. 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.

5.1.4 General objectives for the design of the repository 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 the underground facilities must be designed to withstand potential ground motion or surface rupture at the site. The available evidence suggests that the design can accommodate the range of seismic activity expected at the site. Information about the expected frequency and the magnitude of seismic 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.

5.1.5 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 components identified and the expected role of these components 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., geochemical conditions) that affect the performance of the waste package and the transport of radionuclides in the unsaturated zone and the geohydrologic characteristics of the saturated rocks that lie beneath the unsaturated zone.
- Future processes or events that could significantly disturb the site characteristics important to waste isolation and are sufficiently credible to warrant consideration.
- Preclosure radiation safety and the effects of seismic activity 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 rate is low and that the water in the unsaturated zone is tightly confined within the rock matrix. If these concepts are correct, 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 fractures, the lateral movement of water at rock interfaces in the unsaturated zone, 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.

Because of uncertainties in these concepts and to add confidence that the general objective will be met, other site characteristics will also be investigated. 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 geochemical and other characteristics of the unsaturated rocks that may affect the performance of the waste packages and the transport of radionuclides in the unsaturated rocks and the geohydrologic characteristics of the saturated rocks deep below the site.

The site-characterization program must also address the processes and events that might occur in the future and affect those characteristics of the site that are important to waste isolation. The processes and events to be investigated are those that are sufficiently credible, on the basis of currently available data, to warrant consideration. For example, the possibilities for extreme climatic changes or faulting will be investigated to evaluate potential effects on the percolation of water, the local flux, and the elevation of the water table in relation to the repository horizon. The probability of occurrence and the potential effects of volcanic and other igneous activity on the characteristics of the site will also be investigated. A general list of the potentially disruptive processes and events that are sufficiently credible for the Yucca Mountain site to warrant consideration is given in Table 5-1.

The design of the repository system must address preclosure concerns like the effect of seismic activity. Accordingly, the DOE is planning an extensive program to investigate seismotectonic activity that could affect the site. This program will evaluate the probability and the magnitude of ground motion and potential surface rupture at the Yucca Mountain site.

This description of the general priorities that can be inferred from the top-level strategy serves as a broad introduction to the remainder of this overview and to Section 8.3 of the SCP. The investigations that will address the features and processes discussed here are discussed in Section 5.4 of this overview and in Sections 8.3.1 through 8.3.4 of the SCP. The organization, focus, and logic for these investigations are defined in the specific issue-resolution strategies that are derived from the top-level strategy (see Section 5.1 of this overview). These specific strategies are given in Section 8.3.5 of the SCP.

Table 5-1. Processes and events that could significantly affect the characteristics of the Yucca Mountain site that are important to waste isolation

1.	Extreme changes in climate
2.	Stream-induced erosion
3.	Faulting and seismicity
4.	Magmatic intrusion
5.	Extrusive magmatic activity
6.	Extensive irrigation
7.	Intentional withdrawal of ground water
8.	Exploratory drilling
9.	Mining for resources
10.	Human control of climate
11.	Surface flooding and impoundments
12.	Regional changes in the tectonic regime
13.	Folding, uplift, and subsidence

5.2 THE ISSUES HIERARCHY AND THE ISSUE-RESOLUTION STRATEGY

To ensure that all 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. Section 5.3 explains how these principles have been applied to planning site characterization at Yucca Mountain.

5.2.1 The issues hierarchy

The issues hierarchy is a three-tiered framework that lays out what must be known before a site could be selected and licensed. The highest tier consists of four "key issues," which are derived from the system guidelines in the DOE siting guidelines. Because the system guidelines are based on the EPA and NRC regulations in 40 CFR Part 191* and 10 CFR

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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.

Part 60, respectively, the key issues embody the principal requirements of the regulations for repositories.

There are four key issues. The first addresses the postclosure performance of the repository system (the general objectives discussed in Section 5.1). The second key issue addresses the safety of repository operations before closure. The third key issue addresses environmental and socioeconomic concerns. (These concerns are 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 repository 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 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 planning 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 repository system.

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

5.2.2 The issue-resolution strategy

To resolve the issues in the issues hierarchy, the DOE has adopted a general strategy that guides the development of specific plans for resolving each issue. This strategy, outlined in Figure 5-1, consists of four distinct parts: issue identification, performance allocation, data collection and analysis, and documentation of issue resolution.

Issue identification

Issue resolution begins with the identification of regulatory requirements (step 1 in Figure 5-1). From these requirements the issues

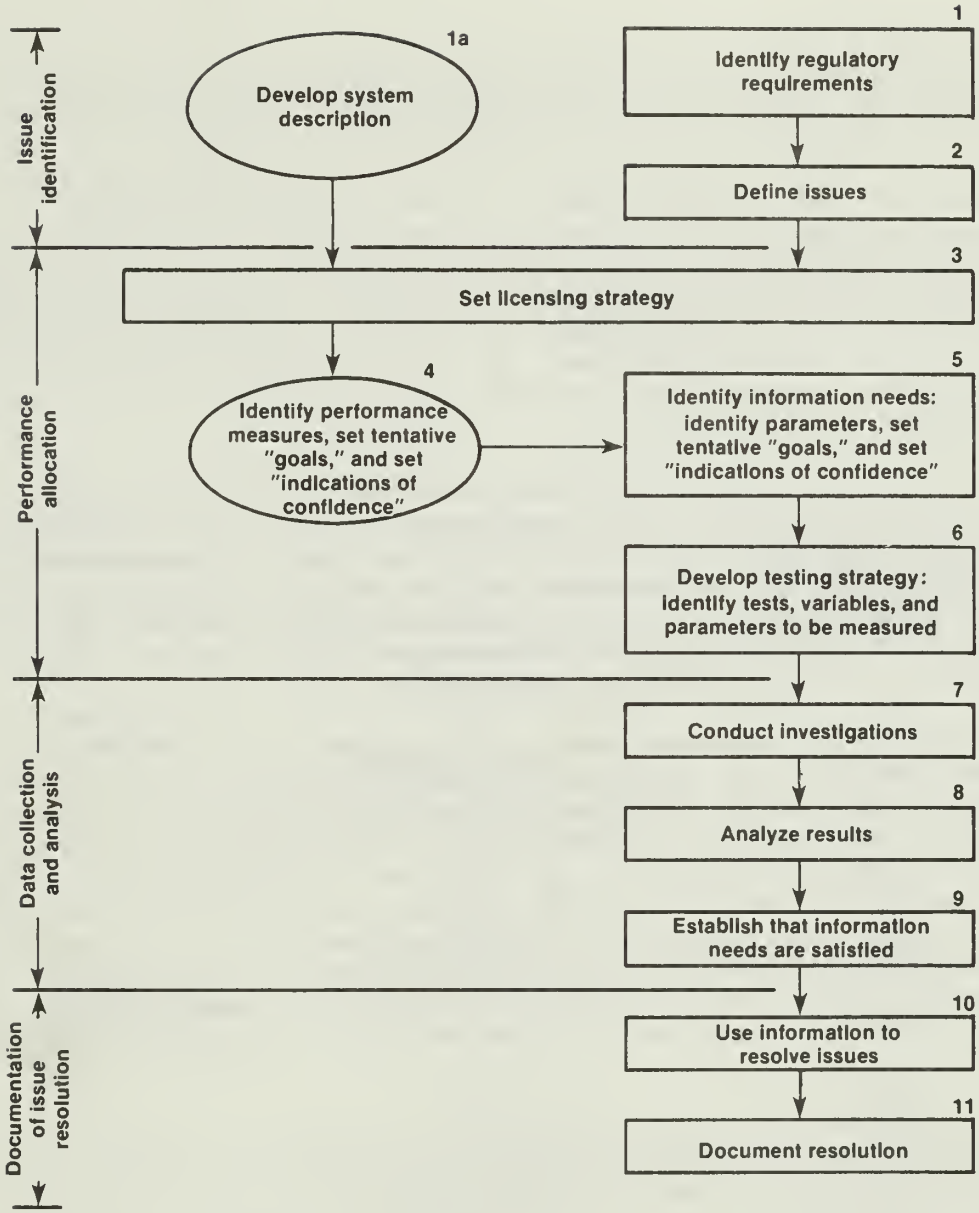

Figure 5-1. Issue-resolution strategy.

are derived (step 2). In addition, because plans for resolving each issue depend on the current understanding of the site, this part of the strategy includes a step (step 1a in Figure 5-1) in which conceptual models and working hypotheses for the site are identified and preliminary designs based on these concepts are specified.

Performance allocation

The second part of the general strategy, called "performance allocation," provides the rationale for establishing particular site-

characterization activities. As shown in Figure 5-1, it is a process consisting of four steps. The process starts by using available information to develop a "licensing strategy" (step 3 in Figure 5-1), which is 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 from site characterization has been collected for a definitive plan. But the strategy is sufficiently developed to guide planning for the tests and the analyses that are currently believed to be necessary.

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

To guide the site-characterization program more explicitly, "performance measures" are established (step 4 in Figure 5-1) for the components identified in the preceding step. These measures are system variables that describe the performance of the components. 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 with the available information about the site.

The performance-allocation process then develops specific "information needs" (step 5 in Figure 5-1), 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.

The last step in performance allocation (step 6 in Figure 5-1) is the development of the testing strategy--that is, the definition of the work that will produce the needed information.

To develop the licensing strategy, identify performance measures, set tentative performance goals, and identify information needs, performance allocation relies heavily on the current conceptual models of the site. Because of this dependence, the site-characterization program includes investigations that will address the uncertainties in the conceptual models. The discussions of these investigations in Section 8.3 of the SCP include detailed tables that identify the conceptual models of concern, the uncertainties in these models, the significance of these

uncertainties to the resolution of performance and design issues, alternative hypotheses that are consistent with existing data, and the activities that will address the uncertainties.

Data collection and analysis

This part of the issue-resolution strategy covers steps 7, 8, and 9 in Figure 5-1: conduct investigations, analyze results, and establish that information needs are satisfied. The process involved in these steps is shown in Figure 5-2.

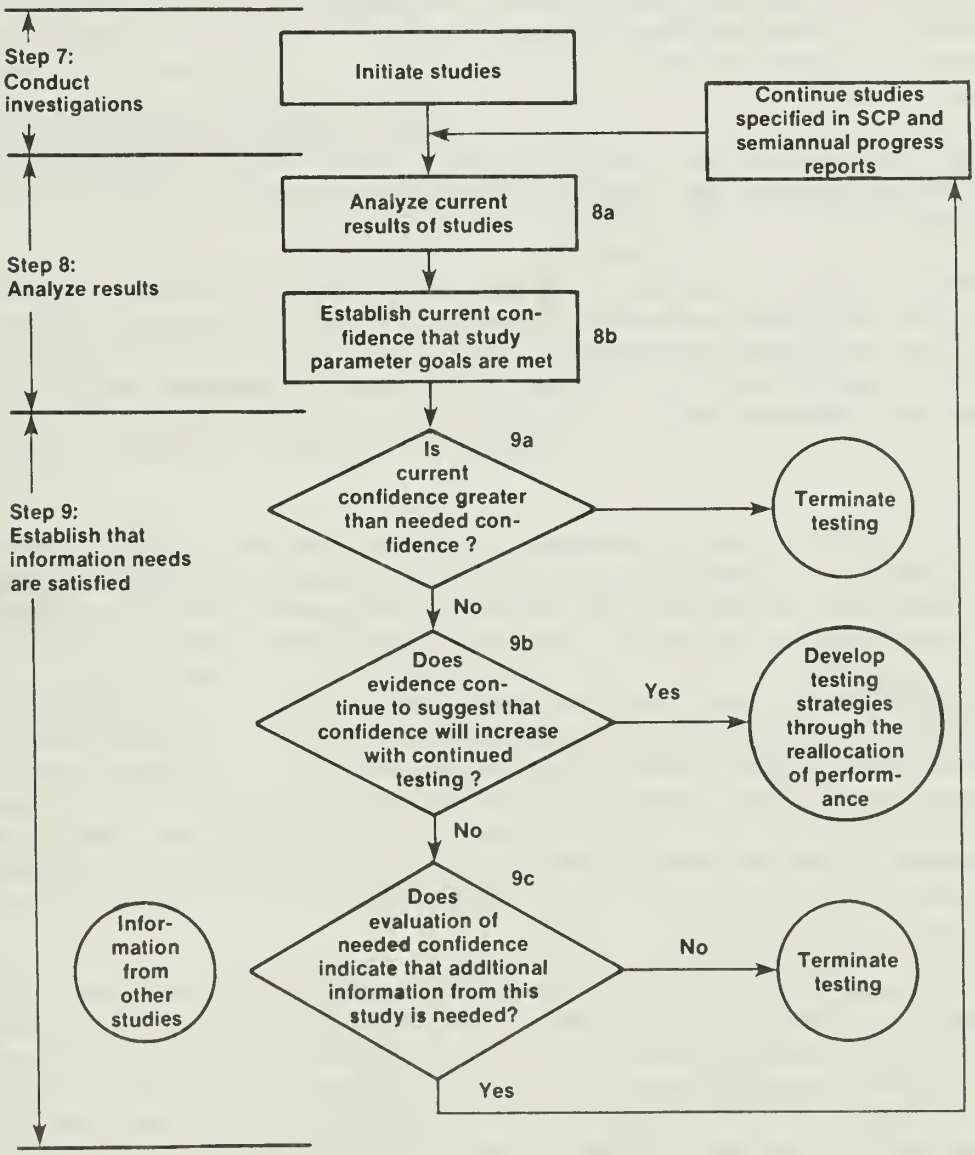

Figure 5-2. The process of data collection and analysis.

The data-analysis step (steps 8a and 8b in Figure 5-2) is associated with two fundamental premises. First, a full performance assessment cannot be conducted after each study to determine whether the information obtained is sufficient to resolve the issues. Full assessments will require some information that will be available only when site characterization has been completed. Therefore, to establish the adequacy of the information obtained, the DOE will evaluate individual elements of the site-characterization program without resorting to full performance assessments.

The second premise is related to the conceptual models and hypotheses that serve as the basis for the current licensing strategy. If all of these models and hypotheses are confirmed by the tests conducted during site characterization, then the testing specified in the testing strategies should be sufficient to resolve all performance and design issues. However, it is not likely that all hypotheses will be confirmed, and therefore some of the conceptual models and the associated strategies may need to be changed. For this reason, the DOE will analyze the results of testing as the testing proceeds to determine whether the testing strategy should be modified.

The principal result of the data-analysis step is an estimate of the confidence that the parameter goals specified for a particular study are met. This estimate must take into account uncertainties in the parameters and uncertainties in the underlying models and hypotheses. In some cases, the estimates will be quantitative, but in many cases the estimates will be based mainly on judgment, supported with appropriate documentation.

To establish that information needs are satisfied, the current confidence in the parameter goals will be compared with the confidence level specified first in the SCP and later in the semiannual progress reports (step 9a in Figure 5-2). If the needed confidence level is exceeded, the testing specified for the particular study can be terminated; if not, the testing will continue until the next review. However, some testing may be terminated without determining that the needed confidence level has been exceeded (steps 9b and 9c in Figure 5-2). For example, testing will be terminated if the evidence obtained in site characterization suggests that continuing that particular type of testing will not further increase confidence. Testing will also be terminated if other studies suggest that the information to be produced by the testing in question is less important than originally thought.

The process of data collection and analysis will involve reviews and judgments at three levels of detail: the level of the study, which is part of the investigations conducted during site characterization; the level of the investigation; and the level of the issue being resolved. At the study level, the judgments will be technical evaluations of the current confidence that parameter goals are met and technical evaluations of whether the confidence can be increased by additional testing. These evaluations will provide the basis for recommendations to continue the testing program or to terminate some of the testing.

At the investigation level, both technical and management judgment will be used. For example, if a technical evaluation at the study level results in a recommendation to terminate testing, the recommendation will be given both a technical and a management review to ensure that the objectives of the investigation encompassing the study are not jeopardized. In addition, at the investigation level, information from all of the studies will be reviewed to determine whether information from particular studies is no longer needed and those studies can be terminated.

At the issue level, management judgment will be used to review the recommendations made at the study and the investigation levels. These issue-level reviews will determine whether the information obtained in site characterization is adequate for resolving a particular issue, taking into account the concerns of outside organizations, such as the NRC.

Documentation of issue resolution

The last part of the issue-resolution strategy is the documentation of issue resolution (steps 10 and 11 in Figure 5-1). It involves assembling and evaluating the available information, developing a position on each issue and technical concern for the site, obtaining an independent review of the positions as appropriate, and documenting the positions. The objective is to use the information obtained from site characterization to determine whether the site is suitable and, if so, whether the DOE has sufficient data to support a successful application for a license from the NRC.

In deciding on the approach to be used in this part of the strategy, the DOE recognized that some uncertainties are likely to remain even after site characterization. Although these uncertainties would not necessarily preclude reasonable assurance that the site is suitable for a repository, they must be addressed in the issue-closure process.

The first part of the documentation process is using information to resolve an issue. It begins by assembling, for a particular issue, the information available from site investigations and design (step 10a). In many cases this will happen after all testing and design associated with a given issue are completed, but in some cases it may happen earlier. For example, it may be found that a particular barrier can be expected to perform so well that less information about another barrier is needed.

The available information will be used to make periodic evaluations of the performance measures for a particular issue. An evaluation will also be made of the full range of uncertainties in the performance measures (step 10c), including the validity of models and alternative conceptual models. The results of the performance-measure evaluations will be used to assess the level of confidence that the applicable technical criteria will be met (step 10d). This confidence will depend on the range of uncertainties that remain.

The remaining uncertainties will be addressed by analyzing alternative designs and taking into account the resolution of other issues and technical concerns. The analysis of alternative designs will determine whether one design is superior to another for the resolution of the issue; it may also show that the resolution of the issue is not affected by the design options being considered.

The next step (step 10e) is to determine whether the current level of confidence in meeting the technical criteria is adequate. This determination will be a judgment based on available information and not on preset criteria, but guidance for these judgments will be provided by the goals for the performance measures and the confidence level needed for the goals.

The second part of the documentation process (step 11) is documenting the resolution of an issue. This begins by using the results of the analyses conducted in step 10 to develop a documented position on the issue or technical concern in a position paper, which will be prepared under a quality-assurance program that complies with the NRC's requirements in 10 CFR Part 60, Subpart G.

The last step in the issue-resolution strategy is to formally document the resolution of each issue to support the development of the license application. The resolution of each issue in the issues hierarchy will be documented in an issue-resolution report. Throughout the issue-resolution process, the DOE will solicit the views of, and interact with, the NRC and other organizations on selected key topics.

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 about plans or test results. If they are changed, the steps that follow in the issue-resolution strategy will also be reexamined and their products revised. 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 the issue-resolution strategy.

The rationale for future changes in the issue-resolution strategy (e.g., revised licensing strategies and performance allocations) will be documented in the semiannual progress reports.

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 repository 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 from the hazards posed by radioactive waste is embodied in the regulations governing separate elements of the repository 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 repository system and on multiple processes operating within the elements.

Decisions about the reliance to be placed on various elements of the repository system (Section 5.1) have been made conservatively. In other words, in making the decisions, the DOE generally deliberately underestimated 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.

5.3 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 site characterization 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 Section 8.3 of the SCP. A complete listing of issues and information needs is presented in the appendix.

5.3.1 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 the appendix and Section 5.8 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.

The DOE's general strategy for ensuring satisfactory postclosure performance for a repository at Yucca Mountain has been described in Section 5.1. 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 5.1 relies on the unsaturated zone at the Yucca Mountain site, the saturated zone below the unsaturated zone, 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 can (1) come in contact with the waste packages, (2) corrode the waste containers, and (3) dissolve or leach the waste.

- Limit the movement of water (the principal mechanism for radionuclide transport) 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 repository system and for the elements listed above. The performance measures for the entire repository system are directly related to the EPA's postclosure standards in 40 CFR Part 191; they are therefore (1) the ratios of any radionuclide releases to the release limits specified in the EPA's overall performance standard, (2) limits on any radionuclide concentrations in ground water, and limits on any 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 could be breached, and the rate of radionuclide release from any breached containers.

The information 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 any 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 the appendix 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 the design of the waste package 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 waste 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, contribute to waste containment and isolation. The strategy requires flexibility in the layout of the underground repository so that local geologic features and anomalies, if any, could 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 repository will be designed to contain and drain any 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.

5.3.2 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 compliance with 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. The strategy for limiting doses is to rely on engineered systems that provide confinement and shielding for radiation (including the waste package) and operating procedures for waste handling.

In the radiation-safety strategies, performance goals are related directly to the requirements of the applicable Federal regulations (i.e., 10 CFR Part 20, 40 CFR Part 191, and 10 CFR Part 960) for protection from radiation. 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 if an airborne release of radioactive material were to occur; 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 the magnitude of natural phenomena (e.g., earthquakes) that could endanger 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 would be maintained for 50 years from the start of waste emplacement. The design strategy for waste retrievability is to maintain access to the waste-emplacement drifts during the retrievability period and during the additional period of time that would be required for 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 in regard to retrieval are the potential for the waste packages to become "stuck" in the emplacement boreholes 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, and technical feasibility. In particular, they address the design and production of waste packages (issues 2.6 and 4.3) and the design of the repository (issues 2.7, 4.2, and 4.4). A comparative evaluation of the costs of repository development (issue 4.5) is no longer needed under the amended Nuclear Waste Policy Act as only one site, rather than three, is being characterized.

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 workers and any members of the public who may be nearby while providing cost-effective waste handling, waste emplacement, and repository closure. The strategies for the design issues set safety and function goals for radiation protection, the stability and longevity of mined openings, the working environment (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, and the ability to use reasonably available technology.

5.3.3 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 consists of programs for the site; the design of the repository, the seals, and the waste package; and performance assessment. 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 that is used 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.

5.4 SITE PROGRAM

The site program consists of the investigations planned to obtain the site information needed for the resolution of performance and design issues in the issues hierarchy; it is part of the issue-resolution strategy described in Section 5.2. The program, is divided into 16 characterization programs (e.g., geohydrology, geochemistry, postclosure tectonics), which are briefly described in Section 5.4.3 of this overview and discussed at length in Section 8.3.1 of the SCP.

5.4.1 Strategy for the site program

The strategy for conducting the site program is based on the issues in the issues hierarchy, on the description of the disposal system (i.e., the available information about the site and the design of the repository and the waste package), and the uncertainties associated with the description of the system. In developing the program, performance allocation was used to identify information needs and develop testing strategies, as described in Section 5.2. Investigations that address the information needs will be conducted, and the results will be analyzed. If the DOE can determine that the information needs are met at the needed level of confidence, then the information collected in the site program will be used to resolve the design and performance issues. However, it may be necessary to change the testing strategy during site characterization. For example, if the information that is collected leads to a significant change in the conceptualization of the Yucca Mountain site, it may be necessary to redefine the information needs and to modify the testing strategy. The testing strategy may also be changed if significantly better techniques for investigation or analysis become available--techniques that will reduce uncertainties previously considered to be irreducible. If the uncertainties in the information obtained about the site cannot be reduced to an acceptable level and alternative tests cannot be identified, then it may be necessary for the DOE to reevaluate the suitability of the site for a repository.

The site program has been carefully designed to meet its objectives because it is based on a rationale that includes the following elements:

- The use of a flexible and iterative strategy for issue resolution.

- The use of performance allocation to ensure that the site investigations will acquire the information needed to resolve performance and design issues.

- Explicit testing of the hypotheses associated with alternative conceptual models.

- Studies that focus on particular phenomena of concern (e.g., the movement of water in the unsaturated zone, the potential effects of tectonic processes and events on the elevation of the water table).

- The use of probabilistic as well as deterministic methods to evaluate the performance of the site.

- Extensive internal and external technical reviews.

5.4.2 Alternative conceptual models

Conceptual models must be developed to provide a description of the physical system at the site and to develop numerical models that can be used to predict the behavior of this system in quantitative terms. Each conceptual model is based on a set of hypotheses about the physical domain and geometry, the key features and properties of the system, processes and events that may be important, and boundary conditions. These hypotheses are consistent with each other and compatible with the available data. However, each conceptual model is associated with some uncertainty, and this uncertainty is indicated by the admissibility of alternative conceptual models; that is, more than one set of hypotheses may be internally consistent and compatible with available data. One of the principal objectives of the site program is to reduce the uncertainty in the conceptualization of the physical system.

To discriminate between alternative conceptual models, systematic hypothesis testing is being used. The objective is to eliminate untenable hypotheses and to identify which alternative conceptual models are admissible.

To ensure that all potentially tenable alternative conceptual models are given comprehensive consideration and to document this consideration, hypothesis-testing tables have been developed for the pertinent disciplines. Such tables have been developed for investigations related to geohydrology, geochemistry, rock characteristics, climate, preclosure and postclosure tectonics, the presence of natural resources that could lead to human intrusion, and the thermal and mechanical properties of the rocks.

The hypothesis-testing tables summarize information in five categories: (1) the current representation of the physical system at the site; (2) a judgment of the uncertainty in the current hypothesis and a

rationale for the judgment; (3) alternative hypotheses; (4) judgments of the significance of the uncertainties in terms of the identified information needs and the sensitivity of the information needs to the uncertainties; and (5) the studies or activities needed to reduce the uncertainties. Categories 1, 2, and 3 are self-explanatory, but it may be useful to explain categories 4 and 5.

The role of category 4 is to link the alternative conceptual models to their significance in the resolution of performance and design issues. Alternative conceptual models will be considered mainly in terms of their effects on the information needs associated with performance and design issues. Thus, the significance of each model depends on how sensitive the information needs are to the assumptions on which the model is based. Category 5 identifies the activities that will be performed to discriminate between competing hypotheses or to otherwise reduce the estimated uncertainty. Where necessary, these activities will cut across scientific disciplines and program lines; for example, the hypothesis-testing table for the hydrology of the unsaturated zone lists activities conducted under three different programs (postclosure tectonics, geochemistry, and thermal and mechanical rock properties).

5.4.3 Characterization programs

As shown in Table 5-2, the site program is divided into 16 characterization programs. The topics covered by these programs are based on the intended use of the data in issue resolution; for example, there are separate programs for preclosure and postclosure tectonics. Brief descriptions of the 16 programs are given in the sections that follow.

5.4.3.1 Geohydrology

The geohydrology program is described in detail in Section 8.3.1.2 of the SCP. Its purpose is to provide, for the resolution of 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 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 for the site, whereas the models for the surface-water system and the saturated zone will be developed for both the site and the region. 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

Table 5-2. 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
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 Data collection
Human interference	Activities that might affect surface markers and monuments Value of natural resources Effects of exploiting natural resources

Table 5-2. The investigations to be conducted in the site program (continued)

Characterization program	Investigation
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.

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 repository 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 hydrologic system of the region 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 the regional levels to which water from a given aquifer will rise by hydrostatic pressure (i.e., 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 4), 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, rates, 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

5.4.3.2 Geochemistry

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

The development of a geochemical model for the site requires data on the configuration of potential transport pathways in the rock matrix; fracture networks; the rock mass in fault zones; and, for all rock units within the controlled zone, the factors, known as distribution coefficients, that are used to calculate to what extent each radionuclide will be sorbed. The necessary data will be obtained by integrating the results of sorption studies with the results of studies on dynamic transport and diffusion. The information needed for resolving 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 liquid and gaseous radionuclides. To evaluate the present ground-water conditions as a basis for predicting future changes in ground-water chemistry, a model of the ground-water chemistry is being developed. The ground-water-chemistry model, a conceptual model of the evolution of minerals, and data on sorption as a function of solid-phase composition will be used in sensitivity analyses to establish the factors controlling the composition of the ground water.

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 potential flow paths to the accessible environment. The third investigation is concerned with the stability of minerals and glasses; its results will be used in 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.

For the remaining five investigations in the geochemistry program, the objective is to develop a data base on the retardation of radionuclides along potential flow paths to the accessible environment. These investigations will include laboratory studies of radionuclide retardation by (1) sorption; (2) precipitation from solution; and (3) the physical processes of dispersion, diffusion, and advection. The results of these laboratory studies 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, that may affect or control radionuclide transport at Yucca Mountain. The last investigation in the geochemistry program will investigate the retardation of gaseous radio-

nuclides. Potential retardation mechanisms for gaseous radionuclide species will be identified and used to estimate rates of transport.

5.4.3.3 Rock characteristics

The program on postclosure rock characteristics is described in Section 8.3.1.4 of the SCP. 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 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 model will summarize the geologic, hydrologic, geochemical, and thermal-mechanical information for use in resolving 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 5-2, 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 that can be directly measured and the properties 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 a 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: (1) coordinating sampling and testing programs to eliminate unnecessary sampling and testing; (2) maximizing the cost effectiveness of the drilling program; and (3) maximizing the returns from drilling to increase both the sampling of the underground area that is of interest in repository development and data from in-situ monitoring. In addition, the integration will help ensure that drilling and sampling methods meet applicable regulatory and scientific requirements.

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 groundwater flow (see Section 4.3). 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 boreholes.

5.4.3.4 Climate

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

The objective of the climate program is to predict the effects of future changes in climate on hydrologic conditions and estimate the

ranges of future climatic conditions. The analysis of the climates and the environments of the past will assess the long-term variability of past climates and provide the basis for estimating future climatic episodes. This analysis will also provide the basis for determining the potential effects of future climate 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 and predict future climate conditions and (2) to determine the effects of climate changes on the surface-water system, the hydrologic conditions in the unsaturated zone, and the hydrologic conditions in the saturated zone. 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.

5.4.3.5 Erosion

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

Because the information available to date indicates that erosion does not pose a hazard to waste isolation at Yucca Mountain, only four investigations, including three field activities, are planned. If additional data are needed, they 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 design and performance issues.

One of the investigations will collect site-specific data on erosion and stream-incision rates during the Quaternary Period (about the last 2 million years). These data will be used to calculate average erosion rates at Yucca Mountain and to develop a history of the downcutting episode or episodes in Fortymile Wash. The second investigation will assess the potential effects of future climatic changes on the locations and rates of erosion. Previously established regional erosion rates suggest that future changes in the climatic regime will not significantly affect upland and hill-slope 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.

5.4.3.6 Rock dissolution

In the case of rock dissolution, the findings that were made for the environmental assessment* meet the requirement for higher-level findings in the DOE's siting guidelines, and hence the DOE does not plan to conduct any investigations on rock dissolution. (Rock dissolution was retained in Table 5-2 because it is part of the generic issues identified for sites in three different host rocks.) There is no evidence that the host rock at the Yucca Mountain site was subject to dissolution during the Quaternary Period, nor is there any reason to suspect that dissolution within the site would provide a hydraulic interconnection between the host rock and the immediately surrounding geohydrologic units. The minerals that compose the rock in and around the site are considered to be insoluble, and no significant dissolution is expected to occur even at the elevated temperatures in the underground repository.

5.4.3.7 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 the design of the repository, including the geometric configuration, layout, and emplacement-hole locations of the proposed underground repository.

In addition to characterizing the effects of tectonic processes, the program will provide the data needed for estimating the rates at which these processes operated during the last 2 million years (the Quaternary Period). This information will be used to predict future rates for the resolution of design and performance issues. The tectonic processes that will be evaluated are volcanic activity, igneous intrusion, faulting, folding, uplift, and subsidence. The evaluation will include estimating the likelihood that significant tectonic events related to these processes will occur during the postclosure period and evaluating how these tectonic events might affect (1) any possible direct releases of radionuclides to the environment that might result from such an event, (2) the durability of the waste packages, and (3) the hydrologic and geochemical parameters that govern radionuclide transport times and release rates.

A variety of information sources will be used to evaluate tectonic processes and events, including earthquake observations, fault measure-

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

ments, 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 design and performance issues.

As shown in Table 5-2, five investigations are planned under this program. For the first four investigations, the main objectives are to estimate probabilities and the events that can initiate the disturbed-performance scenarios evaluated in postclosure-performance assessment. The analyses conducted in these four investigations call for the same type of data, which will be collected in the fifth investigation. The data collected in the preclosure-tectonics program (Section 5.4.3.16) will also be used in these analyses.

5.4.3.8 Human interference

The details of the human-interference program are presented in Section 8.3.1.9 of the SCP. 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 interference. Included in the analysis will be the long-term survivability of the surface markers and monuments that will be erected to warn future generations of the presence of a repository, the most suitable locations for the markers and monuments, the natural-resource potential of the site, and the potential effects of future resource exploration or extraction on the waste-isolation capability of the repository.

Three investigations are currently planned for this program (Table 5-2). The first investigation will identify all events that could destroy or damage the surface markers and monuments, including natural events and human activties. 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 the exploitation of this resource will become economically feasible in the near future. Existing scientific and institutional data will be integrated with information obtained from 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 reasonably 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 could initiate the release scenarios evaluated in the postclosure-performance assessment; the objective is to determine whether they are sufficiently credible or significant to warrant further consideration.

5.4.3.9 Population density and distribution

Data on population density and distribution are needed for resolving design and performance 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 as amended, no specific investigations or activities are described for this program in the SCP. Information on population density and distribution will be provided by studies being conducted in other parts of the repository program.

5.4.3.10 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. Information on land ownership and mineral rights will be provided by studies being conducted in other parts of the repository program.

5.4.3.11 Meteorology

The meteorology program is described in Section 8.3.1.12 of the SCP. It is designed to provide a complete understanding of the meteorological conditions of the area and to supply information on average and extreme weather phenomena. This information will support the res-

olution 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 only with site conditions and (2) those associated with regional meteorological conditions. To collect the needed data, a monitoring program 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.

5.4.3.12 Offsite installations

The program for collecting information on offsite installations and operations is described in Section 8.3.1.13 of the SCP. It will provide the data needed for the resolution of preclosure design and performance issues. This program, which consists of two investigations, will provide the data needed to estimate the probabilities and effects of offsite events that could initiate an accident at the repository (e.g., an aircraft crash). 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 effects of the nearby installations and their operations on the repository and its operations.

5.4.3.13 Surface characteristics

The surface-characteristics program is discussed in Section 8.3.1.14 of the SCP. Its objective is to collect the data needed to select the location of the surface facilities and underground openings of the repository; to design the surface facilities; and to demonstrate that the construction, operation, and closure of the repository would be safe and technically feasible. This program consists of two investigations: (1) topography and (2) soil-and-bedrock conditions. No new studies are needed for topography, because sufficient topographical data are available. For the soil-and-bedrock properties, the SCP describes an investigation consisting of an exploratory program that will investigate and characterize the soils and the rocks beneath the site, a laboratory program that will determine the physical and mechanical properties of the rocks and soils, and a program of field testing and measurements.

5.4.3.14 Thermal and mechanical rock properties

The program designed to collect information on the thermal and mechanical properties of the rock is described in Section 8.3.1.15 of the SCP. It will provide information on thermal and mechanical rock properties and on ambient stress and temperature conditions to support the resolution of design and performance 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 data on the thermal and mechanical properties of the rocks (Table 5-2). 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 studies in the exploratory-shaft facility as well as studies, also conducted in the exploratory-shaft facility, of thermal-mechanical 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.

5.4.3.15 Preclosure hydrology

The preclosure-hydrology program is described in Section 8.3.1.16 of the SCP. 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 design and performance 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 repository; and information on the underground hydrologic conditions in and above the rock horizon proposed for the repository.

The preclosure-hydrology program consists of three investigations. One of these that will determine 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 that sufficient water would be available for the construction, operation, closure, and decommissioning of the repository. (In order to use the water, the DOE will have to obtain water-appropriation permits from the Nevada State Engineer.)

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.

5.4.3.16 Preclosure tectonics

The preclosure-tectonics program, described in Section 8.3.1.17 of the SCP, 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 scenarios for specific tectonic events 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 5-2, 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 to 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.

5.5 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 that can be used in further planning. The site information needed for design is described in the site program summarized in the preceding section (Section 5.4).

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 the appendix for a listing of the issues and in-

formation needs). The program is also tied to four 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 two different phases: the preclosure phase and the postclosure phase. For the preclosure phase, the principal objective of the design effort is to provide 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 main objective of the design of the repository is to provide engineered barriers that contribute to the containment and the isolation of radionuclides and to minimize any ad- verse 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 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 from 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. These 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 the water contained in the host rock, thus helping to prevent liquid water from reaching most of 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 (ESF). 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 and the underground facilities of the repository 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 boreholes, 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.

5.6 SEALS PROGRAM

The seals program includes materials testing, design analysis, and design development for sealing 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 generally would 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 geohydrologic conditions, rock characteristics, and geochemical conditions. 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.

5.7 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 the appendix) 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 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 of the waste package and the host rock around the emplacement holes will be performed to evaluate temperature-distribution histories and the stability of the emplacement holes 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 metals for the disposal container (copper and copper-based alloys as well as iron- and nickel-based alloys) and ceramics; the latter would be used in an alternative configuration that includes a liner for the disposal container. Laboratory tests will be performed to examine the mechanical, microstructural, and physical properties of the various metals; to evaluate mechanisms, such as stress-corrosion cracking, that may occur in the thermal and environmental conditions after waste emplacement and lead to the breaching of the container; to determine states of stress in the container; and to characterize the integrity of the welds.

The information needs of issue 1.5 (which is concerned with controlling the release of radionuclides from the engineered-barrier system)

include the evaluation of the characteristics and the behavior of the waste form after the loss of containment. Laboratory tests will be performed on a variety of spent-fuel types as well as high-level waste, which will be solidified in borosilicate glass. For spent-fuel, these tests will examine the oxidation of the fuel, corrosion of the metal tube (the cladding) in which the fuel pellets are contained, dissolution of the fuel pellets, and the leaching of radionuclides from the fuel pellets. For high-level waste, the tests will examine the leaching of radionuclides from the borosilicate glass.

In addition to the testing and analyses summarized above, the design of the waste package will require models 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.

5.8 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 the postclosure performance of the repository system, 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.

5.8.1 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.

5.8.1.1 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 the appendix. The strategy for the assessment of preclosure safety is described in Section 8.3.5.1 of the SCP.

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 and the operational features of the repository and relevant environmental conditions, such as potential radionuclide-transport pathways, potential releases from offsite facilities, and radon releases from the excavation of the underground repository.
3. The evaluation of radionuclide transport with 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.

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

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 process of determining the suitability of the site.

5.8.1.2 Higher-level findings for the 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. 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, 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, 4.3, and 4.4. Issue 4.5, which addresses comparative evaluations of repository costs for various siting options, is no longer applicable under the Nuclear Waste Policy Act, as amended.

5.8.1.3 Waste retrievability

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

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.

5.8.2 Postclosure performance

The program for assessing the postclosure performance of the repository system 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 the appendix.

The current plans for resolving these issues for a repository at the Yucca Mountain site are based on the various conceptual models that are currently used to describe the characteristics of the site and the cur-

rent understanding of the processes and events that could or may occur at the site in the future. The plans also address the need to evaluate alternative conceptual models and to test the hypotheses on which these conceptual models are based. Detailed strategies for each issue are presented in Section 8.3.5 of the SCP.

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 accord ance 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 (see Table 5-1). 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 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 gaseous radionuclides from spent fuel; the behavior of the spent-fuel cladding; and, in the case of high-level waste, the potential rate of radionuclide release from the waste-form matrix (the borosilicate glass).

Issue 1.5 is concerned with the rate of release from the engineered-barrier system. Planned activities include compiling and integrating data on the waste form (spent fuel and high-level waste solidified to borosilicate glass) and the design of the waste package, developing geochemical models for analyzing the release of radionuclides from the waste form and their behavior after release, developing models for determining mechanisms for radionuclide releases from spent fuel and high-level 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--

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

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 these paths and the calculation of the travel time along the fastest path of likely radionuclide travel from the disturbed zone to the accessible environment.

Performance issue 1.7 addresses the requirements for a performance-confirmation program as defined by the NRC in 10 CFR 60.137 and 10 CFR Part 60, Subpart F. The primary purpose of the performance-confirmation program is to provide added assurance that the postclosure-performance objectives will be met. 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.

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 are essentially the same as those for performance issues 1.1 through 1.6. In the case of the guidelines, however, the DOE is also planning to evaluate the expected performance of the repository system for 100,000 years after repository closure, in addition to evaluating performance for 10,000 years, as required by the Environmental Protection Agency in 40 CFR Part 191.

5.8.3 Performance-assessment modeling

The analyses that will be conducted in assessing the performance of the repository 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, using both field and laboratory data. 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 require quality control and quality assurance in developing the technique, benchmarking the techniques against other related techniques, and evaluating 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 uncer-

tainties 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 tests of the hypotheses that underlie the conceptual models are identified in Section 8.3.5.20 of the SCP.

GLOSSARY

access drift	In the underground repository, a mined passageway that connects the main drift and the perimeter drifts, providing access to the waste-emplacement drifts. In the vertical waste-emplacement configuration, there is also a midpanel access drift that supplies additional ventilation.
accessible environment	The atmosphere, land surfaces, surface waters, oceans, and all of the lithosphere that is beyond the controlled area.
actinides	Radioactive elements in the series beginning with atomic number 89 and continuing through 103.
adsorption	The condensation of gases, liquids, or dissolved substances on solids.
advanced conceptual design	The phase in the design of the repository and the waste package in which selected design alternatives will be explored and design criteria and concepts will be refined. This phase will be followed by the license-application design.
advection	The transport of dissolved solids by ground-water flow.
air-fall tuff	See "ash-fall tuff."
aquifer	A rock formation, group of formations, or a part of a formation that contains sufficient water- saturated permeable material to yield significant quantities of water to wells and springs.
arid	A climate characterized by dryness, with insufficient precipitation for plant life or for crops without irrigation.
ash-fall tuff	A tuff deposited by volcanic ash settling out of the atmosphere, forming a blanketing deposit of relatively uniform thickness regardless of the underlying terrain.

ash-flow tuff	A tuff deposited by a volcano-derived hot density current. It can be either welded or unwelded. Since it often fills in channels, the thickness of the resulting deposit depends on the underlying terrain.
backfill	As a noun, the general fill that is placed in the excavated areas of the underground repository. Backfill materials may be either tuff that had been excavated in developing the repository or other earthen materials. As a verb, the process of refilling an excavation.
barrier	Any material or structure that prevents or substantially delays the movement of water or radionuclides.
basin-and-range faulting	Faulting characterized by normal (extensional) fault movements. Regional geologic structure dominated by generally subparallel fault-block mountains separated by broad basins filled with stream-deposited sediments.
boiling-water reactor	A nuclear reactor system that uses boiling water in its primary cooling system. Steam from the primary cooling system turns turbines to generate electricity.
borehole	A hole made with a drill, auger, or other tools in order to explore the rocks that it penetrates. Boreholes are used to search for minerals, supply water for blasting, and proving the positions of faults.
borosilicate glass	A silicate glass containing at least 5 percent boric acid and used to solidify high-level waste.
breccia	Rock consisting of sharp, angular fragments cemented together or embedded in a fine-grained matrix.
burnup	A measure of nuclear-fuel consumption in a reactor; it is expressed either as a percentage of the fuel atoms that have undergone fission or as the amount of energy produced per unit weight of fuel.

calcite-silica veins	Deposits of calcite and opaline silica, occurring at the surface and in fault zones in the area of Yucca Mountain.
caldera	A volcanic collapse structure, generally on the order of miles in diameter, formed during the eruption of large ash-fall and ash-flow deposits.
Calico Hills	A tuff formation located beneath the horizon of the proposed repository at Yucca Mountain.
candidate site	An area that is recommended and approved for site characterization under Section 112 of the Nuclear Waste Policy Act or undergoing site characterization under Section 113.
cask	A receptacle that holds one or more spent-fuel assemblies or disposal containers and provides shielding from radiation during transportation to a repository or within a repository.
cladding	The metallic outer sheath of a nuclear fuel element. The cladding is usually made of stainless steel or a zirconium alloy.
closure	The final backfilling of the open areas of the underground repository, culminating in the sealing of the shafts, ramps, and boreholes.
collar	The top or the uppermost portion of a shaft. The collar is a concrete ring that is anchored in bedrock and is used to support the headframe.
compressive strength	The maximum compressive stress that can be applied to a material, under given conditions, before failure occurs.
conductivity	See "hydraulic conductivity" or "thermal conductivity."

consolidation	An operation performed on spent-fuel assemblies in which the hardware that holds the spent-fuel rods together is removed and the fuel rods are formed into a closely packed bundle for insertion into a canister or container.
contact	As used in geology, a plane or irregular surface between two rock layers of different types or ages.
container	See "disposal container."
containment	The confinement of radioactive waste within a designated boundary.
controlled area	A surface location (and the underground area beneath that location) that encompasses no more than 100 square kilometers (38.6 square miles) and extends horizontally no more than 5 kilometers (3.1 miles) in any direction from the outer boundary of the original location of the radio- active wastes in a repository.
decommissioning	The permanent removal from service of the surface facilities and components of the repository. It is to be performed in accordance with regulatory requirements and environmental policies.
decontamination	The removal of unwanted material (especially radioactive material) from the surface of or from within another material.
defense high-level waste	High-level waste generated by activities related to national defense, including the manufacture of nuclear weapons, the operation of naval reactors, and research and development at weapons laboratories.
demonstration breakout	A horizontal passageway, located in an exploratory shaft, that will be used for rock-mechanics tests during site characterization.
development area	The underground area that is being prepared for the emplacement of waste in the repository. Development includes the excavation of emplacement drifts and boreholes, the installation of rock supports in the drifts, and outfitting the emplacement holes with

	liners and covers. When the development of a waste-emplacement panel has been completed, bulkheads are installed to seal the panel from the development area and the panel is added to the ventilation circuit of the waste-emplacement area, thus becoming part of the waste-emplacement area.
direct release	A postulated sequence of events in which radionuclides are carried directly to the surface.
displacement	A general term for the relative movement of the opposing sites of a fault.
disposal container	The metal-barrier portion of the waste package that is placed around the waste form.
disqualifying condition	A condition that, if present at a site, would eliminate that site from further consideration for development as a repository.
disruptive event	A natural or man-induced event that would change the geohydrologic, geochemical, or rock characteristics of a site from their present conditions or adversely affect the expected performance of the engineered-barrier system.
disturbed zone	That portion of the controlled area, excluding the shafts and ramps, whose physical or chemical properties are predicted to change as a result of underground-repository construction or heat generated by the emplaced waste such that the resultant change of properties could have a significant effect on the performance of the repository.
dose	See "radiation dose."
dose limit	The limit established by the Environmental Protection Agency or the Nuclear Regulatory Commission for the exposure of people to radiation.
drainage basin	A region or area bounded by a divide and occupied by a drainage system; specifically, the tract of country that contributes water to a particular stream channel or system of channels or to a lake, reservoir, or other body of water.

drift	A horizontal, or nearly horizontal, mined passageway.
drilling fluid	The medium, such as water or air, that is used in drilling to remove the cuttings from the drill bit, to carry cuttings to the surface for disposal, to cool the bit, to stabilize the borewall in open intervals, and to energize downhole drilling tools.
effective porosity	The amount of interconnected pore space and fracture openings available for the transmission of fluids; it is expressed as the ratio of the volume of the interconnected pores and fracture openings to the volume of the rock.
emplacement borehole	See "waste-emplacement borehole."
emplacement drift	A mined passageway in which emplacement boreholes are located.
engineered-barrier system	As defined in by the NRC in 10 CFR Part 60, the waste packages and the underground facility. As defined by the DOE in 10 CFR Part 960, the man-made components of a disposal system designed to prevent the release of radionuclides from the underground facility or into the geohydrologic setting.
epicenter	The point on the earth's surface directly above the exact underground location of an earthquake.
evapotranspiration	The portion of precipitation that is returned to the air through direct evaporation or by transpiration from plants.
exploratory shaft	A vertical shaft deep enough to allow the characterization of the horizon in which the radioactive waste would be emplaced.
exploratory-shaft facility	The exploratory shafts, any underground structures, and underground openings constructed for the purpose of site characterization.

fault	A fracture or zone of fractures along which there has been displacement of the sides relative to one another, parallel to the fracture or zone of fractures. See also "normal fault."
final procurement and	The phase of design during which the final drawings and specifications for procurement and construction will be completed. This design phase represents the Title II design. It is preceded by the license-application design.
flatjack	A hollow metal cushion formed of two nearly flat plates, butt-welded around the edges, and inflated under controlled pressure to bear against restraints. A flatjack is used to test in-situ stress and rock-mass deformability.
flow path	The theoretical line that ground water follows in moving from a recharge area to a discharge area.
fracture	A general term for any break in a rock, whether or not it causes displacement, due to mechanical failure by stress. Fractures include cracks, joints, and faults.
fracture flow	The movement of water through a fracture system.
general siting guidelines	Technical criteria established by the DOE for use in selecting repository sites.
geothermal energy	Energy obtained from the heat stored in the earth's crust by using underground reservoirs of steam or hot water.
geothermal gradient	The rate at which the temperature of the earth's crust increases with depth.
high-level waste	The highly radioactive material resulting from the reprocessing of spent nuclear fuel, including liquid waste produced directly in reprocessing and any solid material derived from such liquid waste that contains fission products (nuclides produced by the fission of a heavier element) in sufficient concentrations; and other highly radioactive material that the NRC, consistent with existing law, determines by rule requires permanent isolation.

ground water	All underground water as distinct from surface water.
guidelines	See "general siting guidelines."
headframe	The steel frame at the top of a shaft. It supports the sheave or pulley for the hoisting cables and serves various other purposes.
higher-level finding	The finding that must be made for each of the qualifying and disqualifying conditions of the DOE's general siting guidelines (10 CFR Part 960).
host rock	The rock in which radioactive waste is emplaced. (At Yucca Mountain, the likely host rock will be the welded tuff of the Topopah Spring Member of the Paintbrush Tuff Formation.)
hot cell	An enclosure, with shielding against radiation, in which radioactive materials can be manipulated by remote control.
human interference	The inadvertent effects of future human activities on waste isolation, including such activities as extensive ground-water withdrawal or irrigation. See also "human intrusion."
human intrusion	Human activities, conducted at the repository site, that inadvertently result in direct contact with waste materials or the creation of pathways to the accessible environment.
hydraulic conductivity	The volume of water that will move through a medium in a unit of time under a unit hydraulic gradient through a unit area measured perpendicular to the direction of the flow.
hydraulic gradient	A change in the static presssure of ground water, expressed in terms of the height of water above a datum, per unit of distance in a given direction.
hydraulic head	The height above sea level to which a column of water can be supported by the static pressure at that point. The total hydraulic head is the sum of the elevation head (elevation above an arbitrary location) and the pressure head.

igneous intrusion	(1) The process of emplacement of magma in preexisting rock, (2) magmatic activity, or (3) the igneous rock formed by magmatic activity within the surrounding rock.
intermittent stream	A stream that flows only occasionally, as after a rainstorm, during wet weather, or during part of the year.
isolation	See "waste isolation."
issue	A question relating to the performance of the repository system that must be resolved to demonstrate compliance with the applicable Federal regulations,including 10 CFR Part 60, 10 CFR Part 960, 40 CFR Part 191, and 20 CFR Part 20.
joint	A surface of fracture or parting in a rock, without displacement.
lateral flow	Any flow where the major flow component is horizontal.
license application	An application for a license from the U.S. Nuclear Regulatory Commission to construct a repository.
license-application design	The design phase that completes the resolution of the design and licensing issues identified and assessed in earlier design phases and develops the design of the items necessary to demonstrate compliance with the design requirements and performance objectives of 10 CFR Part 60. This design phase is preceded by the advanced conceptual design and followed by the final procurement and construction design.
licensing	The process of obtaining the permits and authorizations required to site, construct, operate, close, and decommission a repository.
liner	A metal sleeve placed in a waste-emplacement borehole to prevent sloughed rock from interfering with the emplacement or the retrieval of waste packages.
lithophysae	Bubblelike structures in rocks, generally hollow, composed of concentric shells of finely crystalline alkali feldspar, quartz, and other materials.

lithostatic load	The force exerted on an object or underground structure by the weight of the overlying rock.
lithostatic pressure	The stress to which a rock formation is subjected by the weight of the overlying rocks.
magnetic survey	A survey made with a magnetometer on the ground or in the air to identify local variations, or anomalies, in the total intensity, component intensity, or component direction of the earth's magnetic field.
main drift	One of the three main mined passageways that run from the base of the repository ramps and the men-and-materials shaft through the underground repository and provide access to the waste-emplacment panels.
matrix	Relatively fine-grained material in which coarser fragments or crystals are embedded; also called "groundmass."
mechanical	A term applied to (1) the material properties that govern the physical response of a material to applied physical stress or (2) the analysis of that response
mineral assemblages	The minerals that compose a rock, especially an igneous or metamorphic rock. The term includes the different kinds and relative abundances of minerals, but excludes the texture and the fabric of the rock.
mitigation	(1) Avoiding an impact altogether by not taking a certain action or parts of an action; (2) minimizing impacts by limiting the degree or the magnitude of the action and its implementation; (3) rectifying an impact by repairing, rehabilitating, or restoring the affected environment; (4) reducing or eliminating an impact over time by preservation or maintenance operations during the life of the action; or (5) compensating for the impact by replacing or providing substitute resources or environments.

multiple-barrier system	The system of natural and engineered barriers, operating independently or relatively independently, that acts to contain and isolate the waste.
natural barrier	The physical, mechanical, chemical, and hydrologic characteristics of the geologic environment that individually and collectively act to minimize or preclude radionuclide transport.
natural system	A host rock suitable for repository construction and waste emplacement and the surrounding rock formations. Includes the natural barriers that provide (1) waste isolation by limiting radionuclide transport to the accessible environment and (2) conditions that will minimize the potential for human interference in the future.
neutron probe	A probe that measures the intensity of radiation (neutrons or gamma rays) artificially produced when rocks around a borehole are bombarded by neutrons from a synthetic source. The results are recorded on a neutron log.
normal fault	A fault in which the hanging wall appears to have moved downward in relation to the footwall. The angle of the fault is usually 45 to 90 degrees, measured from the horizontal.
overcoring	(1) The drilling of a core that encompasses a preexisting smaller-diameter hole. (2) A process for determining stress components in a rock mass. The process consists of drilling a small-diameter hole, inserting deformation-sensing devices, and then drilling a larger hole concentrically with the first hole, thus relieving the stress in the rock cylinder. The measured deformations are related to stresses through elastic relationships.
oxidation-reduction reaction	A chemical reaction in which one or more electrons are transferred between two or more chemical constituents of the system.
pack-rat midden	Preserved plant remains, dung, and refuse long ago deposited in rock cavities by rodents.

packer	A removable devise used in drilled holes to isolate one part of a borehole from another in order to carry out studies of particular formations or parts thereof.
perched water	Unconfined water separated from an underlying body of ground water by an unsaturated zone. Perched ground water is held up by a perching bed whose permeability is so low that water percolating downward through it is not able to bring water in the underlying unsaturated zone above atmospheric pressure.
performance allocation	A part of the process for developing strategies for the resolution of issues and used to guide the site-characterization program.
performance assessment	Any analysis that predicts the behavior of a system or a component of a system under a given set of constant or transient conditions.
performance confirmation	A program of tests, experiments, and analyses that will be conducted to evaluate the accuracy and adequacy of the information used to determine with reasonable assurance that the performance objectives for the period after permanent closure can be met.
performance goal	A specific value assigned to a performance measure as part of the performance-allocation process.
performance measure	A physical quantity that describes the performance of a system, system element, structure, component, or process in meeting the licensing strategy for an issue.
performance objective	The predetermined standard or specification used to evaluate the acceptability of each system, structure, or component during a performance assessment. Different performance objectives may be suitable for the preclosure and postclosure periods.
performance parameter	In performance allocation, a physical quantity (either measurable or calculable) used to evaluate a performance measure.

perimeter drift	The mined passageway that encircles the waste-emplcement area in the underground repository, advancing in a clockwise direction as the emplacement area is developed. It functions as the exhaust airway for the emplacement area.
permanent closure	See "closure."
permeability	In hydrology, the ability of a medium (rock, sediment, or soil) to transmit ground water. Permeability depends on the size and the shape of the pores in the medium and how the pores are interconnected.
phenocryst	A large crystal in a groundmass of smaller crystals or glass.
pillar	A solid mass of rock left standing to support a mine roof.
pintle	Handling fixture on a disposal container. The pintle is a knob welded to one end of the disposal container.
pneumatic testing	Pressure testing by the use of air pressure.
porosity	The ratio of the total volume of interstices in rock or soil to its total volume, expressed as a percentage or as a fraction.
postclosure	The period of time after the closure of the geologic repository.
potentially acceptable site	Any site at which, after geologic studies and field mapping but before detailed geologic data gathering, the DOE undertakes preliminary drilling and geophysical testing for the definition of site location.
potentiometric surface	An imaginary surface representing the total head of ground water and defined by the level to which water will rise in a well. It is usually represented by a contour map in which each point tells how high the water would rise in a well tapping that aquifer at that point.
preclosure	The period of time before and during the closure of the geologic repository.

preclosure radiation safety	The siting and design considerations important in protecting the public and the repository workers from exposures to radiation during repository operations and before repository closure.
pressure head	The height of a column of liquid supported, or capable of being supported, by pressure at a point in the liquid.
pressurized-water reactor	A reactor system that uses pressurized water in the primary cooling system. Steam formed in a secondary cooling system is used to turn turbines to generate electricity.
pre-waste-emplacement	Before the authorization of repository construction by the Nuclear Regulatory Commission.
principal stress	A stress that is perpendicular to one of three mutually perpendicular planes that intersect at a point in a body on which the shearing stress is zero; a stress that is normal to the principal plane of stress. The three principal stresses are identified as least, or minimum; intermediate; and greatest, or maximum.
probable maximum flood	The most severe flood that can be reasonably postulated under the assumptions of the probable maximum precipitation and hydrologic conditions favorable for maximum flood runoff.
pumping test	A test made with a pump in a new well to determine its water-yielding capacity or a test, made on a sample of water from a well, to determine the quality of water.
quality assurance	All the planned and systematic actions necessary to provide adequate confidence that a structure, system, or component is constructed to plans and specifications and will perform satisfactorily.
radial borehole test	A survey method in which potential electrodes are moved along radii about a borehole containing a fixed current electrode. The second current electrode (the infinite electrode) is a great distance away.

radiation dose	The quantity of radiation absorbed per unit of mass by the human body or any portion of the body.
radioactive decay	A spontaneous nuclear transformation (disintegration) in which nuclear particles or electromagnetic energy (alpha particles, beta particles, or gamma rays) are emitted.
radiolysis	The decomposition of molecules (often the water molecule) due to interactions with gamma radiation.
radionuclide	An unstable nuclide that decays toward a stable state at a characteristic rate by the emission of ionizing radiation.
radionuclide retardation	A process that causes the time required for a given radionuclide to move between two locations to be longer than the time of ground-water travel. This process consists of physical and chemical interactions between the radionuclide and the geohydrologic unit through which the radionuclide travels.
reasonably available technology	Technology that exists and has been demonstrated or for which the results of any requisite development, demonstration, or confirmatory testing efforts before application will be available within the required time period.
recurrence interval	The average time interval between the occurences of a geologic or hydrologic event of a given or greater magnitude.
release limit	A regulatory limit on the concentration or the amount of radioactive material released to the environment; usually expressed as a radiation dose.
repository system	The geologic setting at the site, the waste package, and the repository all acting together to contain and isolate the waste.
resistivity survey	Any electrical exploration method in which electrical current is introduced in the ground by two contact electrodes and differences in potential are measured between two or more other electrodes.

retardation	See "radionuclide retardation."
retrievability	The capability that is provided by the repository system--by means of design approaches, construc- tion methods, and operating procedures--to allow waste retrieval to be performed.
retrievability period	The time during which emplaced waste is capable of being retrieved. For design purposes, this period begins with the emplacement of the first waste and ends 50 years thereafter at the end of the caretaker period.
retrieval	The act of intentionally removing radioactive waste from the underground location at which the waste had been previously emplaced for disposal.
saturated zone	That part of the earth's crust beneath the water table in which all voids, large and small, are ideally filled with water under pressure greater than that of the atmosphere.
secondary mineral	A mineral formed later than the rock,enclosing it, usually at the expense of an earlier-formed primary mineral. The formation of secondary minerals is due to weathering, metamorphism, or solution.
seismic	Pertaining to, characteristic of, or produced by earthquakes or earth vibrations.
seismic acceleration	The acceleration associated with the passage of seismic waves at the surface or underground, as applicable.
seismometer	An instrument that detects and measures ground motion and produces a signal proportional to the displacement of the point where the instrument is in contact with the earth.
settlement plug	A plug of cast concrete or similar material placed in a shaft and anchored to the surrounding bedrock to support the overlying backfill in the shaft.
shaft collar	See "collar."

shaft liner	A structural lining, usually made of concrete, steel, or timber, that provides safe rock suport and aids in preventing water from entering the shaft.
shear	A stress state that produces a strain causing contiguous parts of a rock body to slide relative to each other in a parallel direction. Also the surfaces and zones of failure by shear or surfaces along which differential movement has taken place.
shear strength	The internal resistance of a rock body to shear stress, typically including a frictional part and a part independent of friction called cohesion.
shear stress	That component of stress that acts tangential to the place through any given point on a rock body.
shield plug	A cylinder of concrete, steel, or other dense material used to plug waste-emplacement boreholes after the emplacement of the waste. Its main function is to provide shielding against radiation.
shielding	The material interposed between a source of radiation and personnel to protect against exposures to radiation.
shipping cask	A specially designed and certified massive metal container that provides shielding and containment for the safe transportation of radioactive materials through the public domain.
sorption	The binding, on a microsocopic scale, of one substance to another.
sorptive minerals	Minerals, such as zeolites, that have the ability to take up large amounts of some molecules or ions. These molecules or ions can be in liquid or gaseous form.
spent nuclear fuel	Fuel that has been withdrawn from a nuclear reactor following irradiation, the constituent elements of which have not been separated by reprocessing.
static water table	The average level of ground water that does not vary over time.

study plan	A plan that describes the coordination of the site-characterization work in more detail that that given in the SCP.
surface facilities	All operations and support facilities located at the surface of the site, both in the case of the exploratory-shaft facility and the repository.
surface rupture	Deformation of the surface due to a momentary loss of cohesion or loss of resistance to differential stress and a release of stored elastic energy
system	See "repository system."
system guidelines	The system guidelines of the DOE's general siting guidelines; they establish the preclosure and the postclosure requirements for the repository system.
system performance	The complete behavior of a system in response to the conditions, processes, and events that may affect it.
thermal	A term applied to the material properties that govern the flow of heat and the resultant temperature of a material or a term for the analysis of that response (e.g., thermal properties, thermal analysis).
thermal conductivity	(1) The time rate of heat transfer by conduction, through a unit thickness, across a unit area for a unit difference in temperature. (2) A measure of the ability of a material to conduct heat.
thermal loading	The application of heat to a system, usually measured in terms of the watt density. The thermal loading for a repository is the watts per acre produced by the radioactive waste in the disposal area.
thermal-mechanical	An adjective applied to the material properties that govern the physical response of a material to applied thermal stress or to the analysis of that response.
tracer	A material, such as a dye, introduced into the ground-water system in order to aid studies of ground-water movement.

transfer cask	A shielded container for moving highly radioactive material.
trenching	The digging of shallow trenches to expose the underlying stratigraphy, structure, etc., for inspection and sampling.
tuff	A compacted deposit of volcanic ash and dust that may contain rock and mineral fragments incorporated during eruption or transport.
unconfined compression test	A test in which a rock sample is loaded axially to failure without the application of confining pressure.
unconfined compressive strength	The load per unit area at which an unconfined prismatic or cylindrical specimen of soil or rock will fail in an unconfined compression test.
underground repository	The underground structure, including openings and backfill materials, but excluding shafts, boreholes, and their seals.
unsaturated flow	The flow of water under such conditions that the voids of the porous media (rocks or sediments) are only partially filled with water, the remainder of the pore space being taken up by air.
unsaturated zone	The zone between the land surface and the water table. Generally, water in this zone is under less than atmospheric pressure and some of the voids may contain air or other gases at atmospheric pressure. Beneath flooded areas or in perched-water bodies, the water pressure locally may be greater than atmospheric.
vitric	Said of igneous material that is characteristically glassy (i.e., contains more than 75 percent glass).
waste	Spent nuclear fuel or high-level radioactive waste.
waste-emplacement borehole	A borehole used specifically for the emplacement of the waste.
waste form	The radioactive waste materials and any encapsulating or stabilizing matrix.

waste isolation	The inhibition of the transport of radioactive material so that the amounts and concentrations of this material entering the accessible environment will be kept within prescribed limits.
waste package	The waste form and any containers, shielding, packing, and other absorbent materials immediately surrounding an individual waste container.
water potential	The total energy with which a rock matrix holds a unit weight of pore fluid.
water table	That surface in a body of ground water at which the water pressure is atmospheric.
water yield	The runoff from a drainage basin; precipitation minus evapotranspiration.
zeolites	A group of minerals containing sodium, calcium, barium, strontium, and potassium and characterized by the ease with which they exchange these ions.

Appendix

ISSUES AND INFORMATION NEEDS FOR THE YUCCA MOUNTAIN SITE

Issues and information needs for the Yucca Mountain site

Issues	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 associated with realizations of the potentially significant release scenario classes
	1.1.4	Determination of the radionuclide releases to the accessible environment considering all significant release scenarios
	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

Issues and information needs for the Yucca Mountain site (continued)

Issues	Information need No.	Statement of information need
	Key issue 1 (continued)	
PERFORMANCE ISSUES (continued)		
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 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

Issues and information needs for the Yucca Mountain site (continued)

Issues		Information need No.	Statement of information need
		Key issue 1 (continued)	
PERFORMANCE ISSUES (continued)			
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 CFR 10 CFR 60.113?	1.6.1	Site information and design concepts needed to identify the fastest path of likely radionuclide travel and to calculate the ground-water travel time along that path
		1.6.2	Calculational models to predict ground-water travel times between the disturbed zone and the accessible environment
		1.6.3	Identification of the paths of likely radionuclide travel from the disturbed zone to the accessible environment and identification of the fastest path

Issues and information needs for the Yucca Mountain site (continued)

Issues	Information need No.	Statement of information need
	Key issue 1 (continued)	
PERFORMANCE ISSUES (continued)		
Issue 1.6 (continued)		
	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 (continued)

Issues	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

Issues and information needs for the Yucca Mountain site (continued)

Issues	Information need No.	Statement of information need
	Key issue 1 (continued)	
DESIGN ISSUES (continued)		
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
	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

Issues and information needs for the Yucca Mountain site (continued)

Issues	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?
PERFORMANCE ISSUES		
Issue 2.1: During repository operation, closure, and decommissioning (a) will the expected average radiation dose received by members of the public within any highly populated area be less than a small fraction of the allowable limits and (b) will the expected radiation dose received by any member of the public in an unrestricted area be less than the allowable limits as required by 10 CFR 60.111; 40 CFR 191 Subpart A, and 10 CFR Part 20?	2.1.1	Site and design information needed to assess preclosure radiological safety
Issue 2.2: Can the repository be designed, constructed, operated, closed, and decommissioned in a manner that ensures the radiological safety of workers under normal operations as required by 10 CFR 60.111 and 10 CFR Part 20?	2.2.1	Determination of radiation environment in surface and subsurface facilities due to natural and man-made radioactivity
	2.2.2	Determination that projected worker exposures and exposure conditions under normal conditions meet applicable requirements

Issues and information needs for the Yucca Mountain site (continued)

Issues	Information need No.	Statement of information need
	Key issue 2 (continued)	
PERFORMANCE ISSUES (continued)		
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 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

Issues and information needs for the Yucca Mountain site (continued)

Issues	Information need No.	Statement of information need
	Key issue 2 (continued)	
PERFORMANCE ISSUES (continued)		
Issue 2.4 (continued)		
	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
	2.6.3	Waste acceptance specifications

Issues and information needs for the Yucca Mountain site (continued)

Issues	Information need No.	Statement of information need
	Key issue 2 (continued)	
DESIGN ISSUES (continued)		
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

Issues and information needs for the Yucca Mountain site (continued)

Issues	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 associated cost 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 non-radiological 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

Issues and information needs for the Yucca Mountain site (continued)

Issues	Information need No.	Statement of information need
	Key issue 4	
DESIGN ISSUES (continued)		
Issue 4.3: Are the waste package production technologies adequately established for the resolution of the performance issues?	4.3.1	Identification and evaluation of production technologies for fabrication, closure, and inspection of the waste package
Issue 4.4: Are the technologies of repository construction, operation, closure, and decommissioning adequately established to support resolution of the performance issues?	4.4.1	Site and performance assessment information needed for design
	4.4.2	Characteristics and quantities of waste and waste packages needed for design
	4.4.3	Plan for repository operations during construction, operation, closure, and decommissioning
	4.4.4	Repository design requirements for construction, operation, closure, and decommissioning
	4.4.5	Reference preclosure repository design
	4.4.6	Development and demonstration of required equipment
	4.4.7	Design analyses, including those addressing impacts of surface conditions, rock characteristics, hydrology, and tectonic activity
	4.4.8	Identification of technologies for surface facility construction, operation, and decommissioning

Issues and information needs for the Yucca Mountain site (continued)

Issues	Information need No.	Statement of information need
	Key issue 4	
DESIGN ISSUES (continued)		
Issue 4.4 (continued)		
	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.

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Accession No.: HQO.881201.0001