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Chapter 6

Nuclear Waste Policy Act
(Section 113)

CONCEPTUAL DESIGN OF A REPOSITORY

Consultation Draft

F

Site Characterization Plan

Yucca Mountain Site, Nevada Research and Development Area, Nevada

Volume III

PART A

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

The purpose of this chapter is to describe the basis for facility design, the completed facility conceptual design, the completed analytical work relating to the resolution of design issues, and a brief description of future design-related work. The basis for design and the conceptual design information presented in this chapter meet the requirements of the Nuclear Waste Policy Act of 1982, Section 113(b)(1)(C)(NWPA, 1983) and 10 CFR 60.17(c), for a conceptual repository design that takes into account site-specific requirements. The description of completed analytical work allows the reader to become familiar with the analytical methods and data used in the design of repository facilities and that form the basis for related site characterization activities. This information is presented to permit a critical evaluation of planned site characterization activities.

The presentation of material in this chapter is grouped to provide insight into several different aspects of the conceptual design activity. Section 6.1 presents a summary overview of the various legislation, regulatory requirements, U.S Department of Energy (DOE) orders, and State requirements that were considered in developing the repository conceptual design. Section 6.2 presents a summary of the repository conceptual design. The purpose of the conceptual design was to establish project feasibility, identify information on site characteristics that would be needed for future design efforts, and to obtain a preliminary cost estimate for facility construction and operation. The summary is brief, and focuses on the site related aspects of the design. The complete conceptual design is contained in the Site Characterization Plan-Conceptual Design Report (SNL, 1987). This document is referred to as the SCP-CDR throughout Chapter 6. The conceptual design is a preliminary step in the overall repository design process that helps to guide the gathering of information for later design phases. Design concepts may be refined and design detail will be provided in the later phases of design. Section 6.4 presents a summary of work completed to date relevant to answering questions about repository facility performance. The section is arranged topically according to licensing-related questions, called issues (Section 8.2 is an introduction to the issues). Plans for future activities to obtain additional information relative to these issues are contained in Section 8.3.2. Section 6.3 provides a cross reference for the reader between the information identified in U.S Nuclear Regulatory Commission (NRC) Regulatory Guide 4.17 (NRC, 1987), and Sections 6.1, 6.4, and 8.3.2 of this document.

The Site Characterization Plan-Conceptual Design (SCP-CD) completes the first of four repository design phases described in the Mission Plan (DOE, 1985a). The phases are as follows:

1. Site Characterization Plan-Conceptual Design.

2. Advanced conceptual design.

3. License application design.

4. Final procurement and construction design.

The results of preliminary site investigations are presented in Chapters 1 through 5 of this document; site data that had the principal effect on facility design are contained in Chapters 1, 2, 3, and 4 (Geology, Geoengineering, Hydrology, and Geochemistry). Some information contained in Chapter 5 (Climatology and Meteorology) was used in the siting of surface facilities. Waste package design is discussed in Chapter 7, and preclosure and postclosure performance assessment plans are presented in Chapter 8. Descriptions of the information that will be obtained during site characterization and the plans for obtaining this information are also presented in Chapter 8.

If the Yucca Mountain site is selected as the site for the first repository, the mined geologic disposal system (MGDS) surface and underground facilities will be constructed on federally owned land on and adjacent to the Nevada Test Site (NTS) in southern Nevada. Yucca Mountain is a north-trending fault-block ridge. Its crest is more than 370 m above the western edge of Jackass Flat (to the east) and 300 m above the eastern edge of Crater Flat (to the west). The location for MGDS surface facilities is on the gently sloping alluvial fan that forms the western edge of Jackass Flats, and the location for the MGDS underground facilities is beneath Yucca Mountain.

The design requirements, which have had the greatest impact on facility design, are as follows:

1. The underground facilities shall contribute to the containment and isolation of radionuclides (10 CFR 60.133(a)(1)).

2. The underground facilities shall be designed to permit retrieval of waste (10 CFR 60.133(c)).

3. All MGDS facilities shall be constructed, operated, decommissioned, and closed using reasonably available technology (10 CFR 960.5-1(a)(3)).

4. The MGDS facilities shall be capable of receiving, preparing, and emplacing waste equivalent to 70,000 metric tons of uranium (MTU) in a period of 25 yr (Table 2-2 in DOE, 1985a).

Consistent with the requirements for emplacing nuclear waste in a mined geologic disposal setting, the underground facility has been designed to limit disruption to the natural environment and thereby contribute to the containment and isolation of the waste. To inhibit subsidence, a low extraction ratio (the ratio of the excavated area to the total underground area) has been maintained. To limit the possible tendency for the extension of fractures from the surface into the underground facilities, the thermally induced loading (loading due to the decay of the radioactive materials in the nuclear waste) has been distributed over a large area. Further, the underground facilities have been located above the water table. Therefore, water that could contact the waste containers and transport waste to the accessible environment has been limited. Also, selected repository operations are planned to limit the quantity of water used (i.e., emplacement borehole drilling) and therefore the potential for change in the waste container environment.

The underground facility design provides for retrieval of waste by providing stable underground openings for a time period sufficient to allow waste emplacement and retrieval operations in accordance with the DOE Mission Plan (DOE, 1985a) and 10 CFR Part 60. Further, design constraints have been imposed such that the temperature rise in the underground facilities will not hamper retrieval of emplaced waste during the time period specified in 10 CFR Part 60. Currently available technology is used in all operational phases of the Yucca Mountain MGDS although some demonstration of the use of the technology in MGDS applications is needed. This use of currently available technology is reflected in the conceptual design summarized in this chapter and presented in detail in the SCP-CDR. The Yucca Mountain MGDS is designed to receive and emplace waste equivalent to 400 MTU for the first three years of operation, 900 MTU in the fourth year, 1,800 MTU in the fifth year, and 3,400 MTU in each succeeding year until the full 70,000 MTU have been emplaced. Under this schedule, it will take just under 25 yr to emplace waste equivalent to 70,000 MTU.

Data obtained during preliminary site investigations indicate that Yucca Mountain and the area of Jackass Flats immediately to the east of Yucca Mountain are suitable for construction and operation of MGDS facilities (Section 2.2.4 in DOE, 1986b). Yucca Mountain consists of a layered sequence of welded, nonwelded, and bedded tuff in which conventional hard-rock mining practice will yield stable underground openings. The waste emplacement horizon, located within the welded ash-flow portion of the Topopah Spring Member of the Paintbrush Tuff and designated as unit TSw2, is in the unsaturated zone, 200 to 400 m above the water table. The surface facilities for waste receiving, unloading, preparation, and storage are founded on alluvial material on the western edge of Jackass Flats.

The location of all MGDS underground facilities in the unsaturated zone will reduce and possibly eliminate the problems associated with control of ground water during underground development. Because ground-water inflow is not expected to be an operational problem, installation of seals in the shafts and ramps is not planned before decommissioning of the MGDS. However, seals will be installed as part of MGDS facility closure operations.

The surface and underground facilities at the Yucca Mountain site are planned so that either shaft or ramp access from the surface to the underground could be used. Four shafts and two ramps are incorporated in the conceptual design. Two of the four shafts are planned to be constructed as part of the exploratory shaft facility (ESF). These two exploratory shafts (ES) would provide underground access and ventilation for the ESF before construction of the MGDS underground facilities and serve as ventilation intake shafts during repository operations. The remaining shafts (the men-and-materials shaft and a ventilation exhaust shaft) and ramps (the surface-to-underground waste transfer ramp and the mined-materials removal ramp) would be constructed as part of the initial development activities for the Yucca Mountain MGDS. A distinctive feature of the Yucca Mountain repository conceptual design is the use of a ramp access for spent-fuel and high-level waste transfer from the surface storage facilities to the underground facilities. The ramp access permits the use of a vehicle to remove the waste container from surface storage, convey the container to the waste emplacement borehole, and emplace the container in the waste emplacement borehole. The use of a ramp and transporter eliminates the need for intermediate handling equipment and the associated facilities and operating personnel.

Site-specific geologic, rock characteristics, and hydrologic information is required for MGDS facility design. However, sufficient latitude exists in the conceptual design of MGDS facilities to accept substantial variations in the site properties without major redesign of either the surface or the underground facilities.

The design process is an ongoing one that requires periodic documentation of the status of the design. For example, the status of the Yucca Mountain MGDS design studies has been reported previously in the environmental assessment (EA) for the Yucca Mountain Site (DOE, 1986b). The current design, documented in this chapter and in the SCP-CDR (SNL, 1987), reflects both maturing design concepts and more recent guidance. Specifically, the current design reflects the use of the DOE Mission Plan (DOE, 1985a) and the Generic Requirements for a Mined Geologic Disposal System (GR) (DOE, 1984b; Appendix D of DOE, 1986d).

To document this design in a timely manner, it was necessary to stop making changes in the guidance and the design in about mid-1986. It is recognized that several changes have occurred since that time and that additional design studies have been initiated (or completed) since that time. These changes will be reflected in future designs for the Yucca Mountain repository. Some of the changes and studies that may impact the design are briefly mentioned below.

Changes in the future designs are expected to occur as a result of more recent guidance presented in the Draft Mission Plan Amendment (DOE, 1987b) and in the revised Generic Requirements (GR) document (DOE, 1986d). The principal impact of these changes is likely to be on the schedule for waste acceptance, the evaluation of the feasibility of using shorter horizontal boreholes, and variations in the second exploratory shaft.

The reference emplacement orientation is vertical emplacement with a single waste container in a vertical borehole. The alternative orientation is horizontal emplacement with as many as 18 waste containers in a horizontal borehole. A study is currently being conducted that will assess the feasibility of variations in the horizontal emplacement concept. This study will compare short horizontal borehole options, with one to three containers in a borehole, to the present long, horizontal borehole concept. Items for comparison include reliability, retrievability, thermomechanical effects, cost, licensability, and other relevant factors.

The exploratory shafts have also been the subject of continuing design studies. These studies address concerns that were identified during public and NRC reviews of the EA as well as more recent reviews. The most significant items include the location of the shaft and related surface facilities, shaft diameter and construction method changes for the second exploratory shaft, investigation of structural features by drifting, and the rearrangement of the exploratory shaft underground facilities.

An issues hierarchy approach to MGDS design and performance activities has been adopted by the DOE. The issues hierarchy identifies the design and performance issues that the DOE feels must be resolved before MGDS license application. For each issue in this hierarchy, an issue resolution strategy (IRS) is developed and implemented. A characterization program has also been identified that will provide the site data needed to support issue resolution. The methodology adopted by the DOE for the development of an IRS for site characterization activities at the Yucca Mountain site is presented in Section 8.1.2 of this document. Issue resolution strategies are presented in Section 8.3 for those issues requiring information that will be obtained during site characterization. Readers should familiarize themselves with the material contained in Sections 8.1, 8.2, and in the following subsections of 8.3 and 8.4 before reading this chapter:

Chapter 8 section	Issue	Subject
8.3.2.2	1.11	Configuration of underground facilities (postclosure)
8.3.2.3	2.7	Repository design criteria for radiological safety
8.3.2.4	4.2	Nonradiological health and safety
8.3.2.5	4.4	Preclosure design and technical feasibility
8.3.3.2	1.12	Seal characteristics
8.3.5.2	2.4	Waste retrievability
8.3.5.3	2.1	Public radiological exposures--normal conditions
8.3.5.4	2.2	Worker radiological safety--normal conditions
8.3.5.5	2.3	Accidental radiological releases
8.4.2		Underground test facility

This chapter is divided into four sections. Section 6.1 contains a summary of the design basis used for the conceptual design of the Yucca Mountain repository facilities. The summary is based on requirements contained in the SCP-CDR, Sections 2.4 and 2.6 and the geologic and hydrologic site properties determined during preliminary site investigations (reported in SCP Chapters 1, 2, and 3). Section 6.2, contains a summary description of the conceptual design of the Yucca Mountain MGDS surface and subsurface facilities. The summary description is based on the SCP-CDR. Section 6.3 provides a relationship among the topics identified in NRC Regulatory Guide 4.17 (NRC, 1987); the facility design requirements and elements in Sections 6.1 and 6.2, respectively. The status of completed work and plans for future work are presented in Section 6.4 and the IRS and identification of data needs are presented in Section 8.3 (Stein, 1986). Section 6.4 is organized around the seven issues that require repository design information for their resolution. For each issue, the status of completed work, the plans for future work, and the design data needs are discussed.

6.1 DESIGN BASIS

6.1.1 REPOSITORY DESIGN REQUIREMENTS

This section briefly discusses the repository functions and associated requirements that are the basis for the development of the repository design. These requirements for the design, construction, licensing, and operation of a repository for the disposal of spent fuel, commercial, and defense high-level waste (DHLW) are derived from legislation and implementing regulations directly addressing radioactive waste disposal (DOE, 1985a). Additional Federal, State, and local regulations, DOE Orders, and DOE guidance are included.

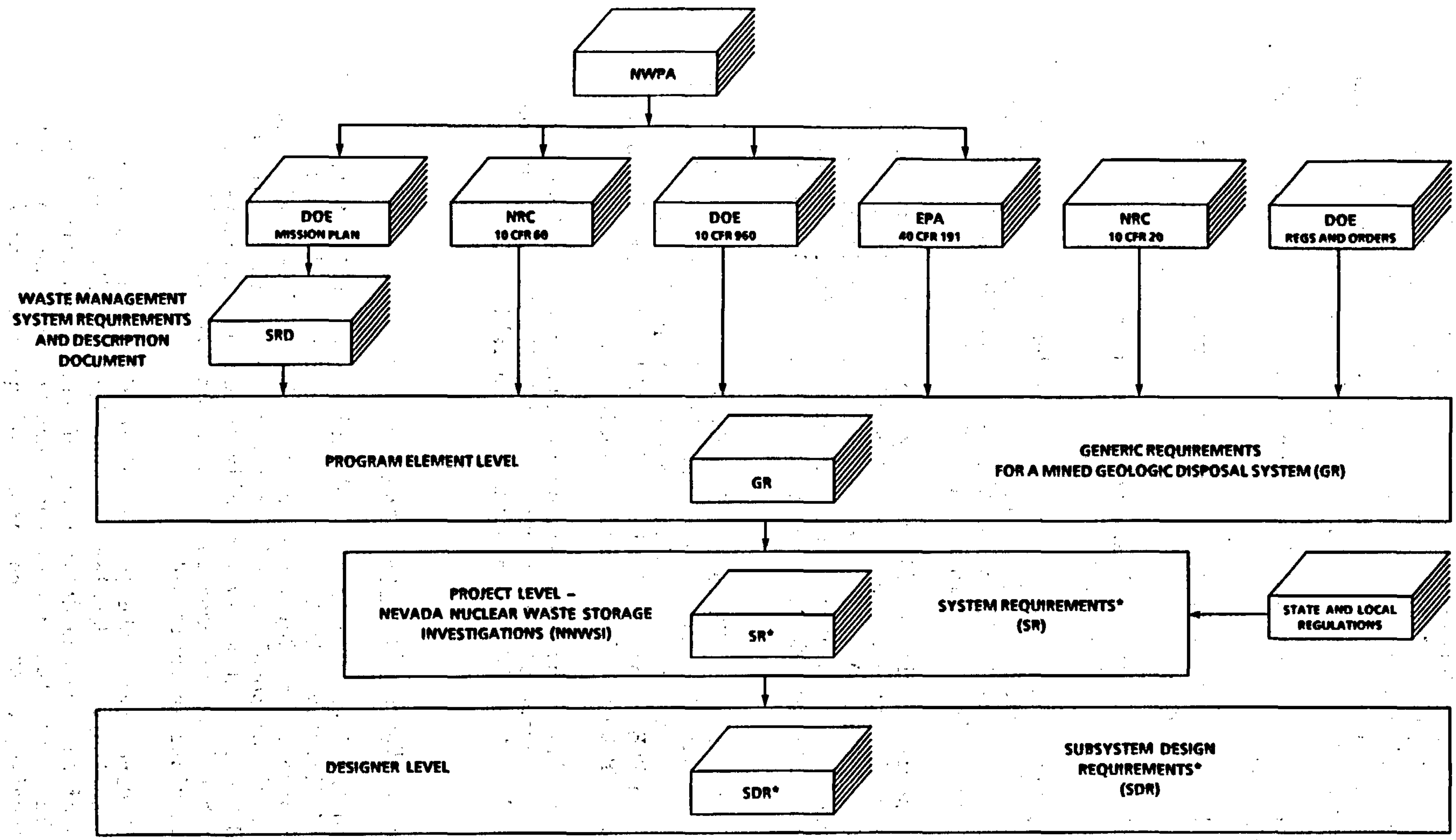
A description of the design requirements for the repository is contained in the Site Characterization Plan-Conceptual Design Report (SNL, 1987). (This report is referred to as the SCP-CDR throughout this section. The conceptual design is referred to as the SCP-CD.) The design criteria contained in the SCP-CDR include definitions of project scope, legal and functional requirements, design parameters, applicable codes, standards, regulations, and other criteria.

Section 6.1.1 summarizes information contained in Sections 2.4 and 2.6 of the SCP-CDR. The development of these design requirements from original source requirements is depicted in Figure 6-1.

The current conceptual design for the Yucca Mountain repository is found in the SCP-CDR. The design addresses the design constraints that have been imposed by site conditions at Yucca Mountain as well as by legal requirements. The site conditions are those that are understood before formal site characterization. The Federal legal constraints are those imposed by the Nuclear Waste Policy Act of 1982 (NWPA, 1983), the NRC, the DOE, and the U.S. Environmental Protection Agency (EPA) regulations.

6.1.1.1 Legal requirements

The legal requirements for the disposal of high-level radioactive waste in geologic repositories begin with the Nuclear Waste Policy Act of 1982



* THESE DOCUMENTS ARE CURRENTLY PUBLISHED AS APPENDICES TO THE SCP-CDR.
[SDR IS CURRENTLY BEING REVISED AND WILL BE TITLED "REPOSITORY DESIGN REQUIREMENTS" (RDR)].

DOE - DEPARTMENT OF ENERGY
NRC - U.S. NUCLEAR REGULATORY COMMISSION
EPA - U.S. ENVIRONMENTAL PROTECTION AGENCY

Figure 6-1. Relationship of subsystem design requirements to primary requirements.

(NWPA, 1983). The purpose of this act is "to provide for the development of repositories for the disposal of high-level radioactive waste and spent nuclear fuel, to establish a program of research, development, and demonstration regarding the disposal of high-level waste and spent nuclear fuel, and for other purposes." The NWPA does the following:

1. Assigns the DOE the responsibility for siting, constructing, and operating repositories.

2. Directs the NRC to develop technical requirements for licensing the disposal of radioactive waste in mined geologic repositories.

3. Directs the EPA to establish environmental standards for the disposal of radioactive waste.

As required by the NWPA, new parts have been added to Titles 10 and 40 of the Code of Federal Regulations (CFR) to specifically address nuclear waste repositories. Applicable CFR parts that were considered during conceptual design activities are summarized in Table 6-1.

Because the repository will be licensed by the NRC to receive and possess high-level radioactive waste, the NRC requirements cited directly or by reference in 10 CFR Part 60 will form the basis for repository design. Appropriate DOE Orders will be used to direct the design in areas not specifically addressed by 10 CFR Part 60 or requirements included in 10 CFR Part 60 by reference.

In addition to the recent CFR parts, for those requirements for which Federal sovereign immunity has not been waived, DOE intends to comply with the applicable State of Nevada regulations to the extent that they are not inconsistent with the DOE responsibilities under NWPA. The regulations considered for the SCP-CD are identified in Table 6-2.

DOE also has specified that the California Administrative Codes for mines be used in the conceptual design process (DOE, 1984). The portions of the codes considered in the SCP-CD are summarized in Table 6-3.

6.1.1.2 Department of Energy functional requirements

In addition to the legal requirements described in Section 6.1.1.1, the DOE has established directives that apply to a repository. These directives consist of (1) guidance and policy issued by the Office of Geologic Repositories for the geologic disposal of radioactive waste and (2) requirements in the form of DOE Orders that apply generally to all DOE projects and are written to establish policy and procedures for DOE activities. These directives are summarized in Table 6-4.

From these DOE directives, the functional requirements and specific guidance for the repository are developed. Functional requirements are primary statements of purpose and definitions of what repository subsystems must accomplish. The basic function of the Yucca Mountain nuclear waste repository is to receive, prepare, and dispose of spent nuclear fuel and

Table 6-1. Parts of the Code of Federal Regulations considered in the conceptual design[a] (page 1 of 7)

Part of CFR	Description	Requirements
10 CFR Part 20, "Standards for Protection Against Radiation"	Prescribes allowable exposure levels for personnel in restricted areas and for members of the public in unrestricted areas due to normal operational releases.	Annual dose limits for • personnel in restricted area: 5 rem whole body or individual organs, 75 rem to hands and feet, and 30 rem to skin. • members of the public in unrestricted areas: 0.5 rem whole body. Allowable concentration limits (CL) for individual radionuclides in air and water are specified.
10 CFR Part 60, "Disposal of High-Level Radioactive Wastes in Geologic Repositories"	<u>Subpart B - Licenses</u>: Prescribes rules governing the licensing of the DOE to receive and possess source, special nuclear, and byproduct material at a geologic repository operations area.	For licensing the NRC requires • an application consisting of general information, a safety analysis report, and an environmental report. • in order to authorize construction, there must be reasonable assurance that - the radioactive materials described in the application can be received, possessed, and disposed of without unreasonable risk to the health and safety of the public; - the activities proposed in the application will not be inimical to the common defense and security; and - environmental qualities are protected. • in order to issue a license to receive and possess source, special nuclear, or byproduct material at a geologic repository operations area, - construction of the geologic repository operations area has been substantially completed in conformity

Table 6-1. Parts of the Code of Federal Regulations considered in the conceptual design[a] (page 2 of 7)

Part of CFR	Description	Requirements
10 CFR Part 60 (continued)		with the application as amended, the provisions of the Atomic Energy Act, and rules and regulations of the commission. The activities to be conducted at the geologic repository operations area will be in conformity with the application as amended, the provisions of the Atomic Energy Act, and the Energy Reorganisation Act, and the rules and regulations of the Commission; and the issuance of the license will not be inimical to the common defense and security and will not constitute an unreasonable risk to the health and safety of the public. • in a license amendment for permanent closure - the DOE shall submit an application to amend the license before decommissioning and shall update its environmental report.
	<u>Subparts D, E, and F</u>: Include general record keeping and reporting requirements, technical criteria, repository and waste package performance requirements, and performance confirmation requirements.	NRC requires that DOE records, reports, tests, and inspections include • the records and reports required for the licensed activity; • the construction record of the geologic repository operations area; • a written report on each significant deficiency found in the characteristics of the site, and design and construction of the geologic repository operations area; tests the NRC deems appropriate or necessary for the administration of 10 CFR Part 60;

Table 6-1. Parts of the Code of Federal Regulations considered in the conceptual design[a] (page 3 of 7)

Part of CFR	Description	Requirements
10 CFR Part 60 (continued)		• a performance confirmation program in accordance with 10 CFR 60, Subpart F; • NRC inspections of the premises of the geologic repository operations area and adjacent DOE access areas; NRC inspection of DOE activity records; and • provision of office space for NRC inspectors. NRC technical criteria requirements include • the performance objectives for protection against radiation exposures and releases of radioactive material, as well as for retrievability of waste in the geologic repository operations area through permanent closure must be met and assurance that releases of radioactive materials to the accessible environment following permanent closure will conform to EPA standards must be provided; • the land on which the geologic repository operations area and the controlled area are located must be under the jurisdiction and control of DOE or be withdrawn and reserved for this use and be free and clear of all significant encumbrances; • the geologic setting and engineered barriers system must have sufficient favorable conditions present to provide reasonable assurance that the performance objectives relating to waste isolation will be met;

Table 6-1. Parts of the Code of Federal Regulations considered in the conceptual design[a] (page 4 of 7)

Part of CFR	Description	Requirements
10 CFR Part 60 (continued)		• the minimum design criteria specified for the geologic repository operations area and the additional design criteria for the surface facilities, the underground facility, and the design of seals for shafts and boreholes must be met; • the design criteria for the waste package and its components must be met; and • the geologic repository operations area must be designed to permit implementation of a performance confirmation program meeting the requirements of 10 CFR Part 60, Subpart F. NRC requires a performance confirmation program that • confirms geotechnical and design parameters and • monitors and tests waste packages.
	Subpart G - Quality Assurance: Identifies quality assurance requirements for the geologic repository and its subsystems or components. (Provisions to ensure compliance with long-term containment requirements, similar to EPA's 40 CFR 191.13, will be added to this regulation.)	NRC requires that the quality assurance program • applies to all systems, structures, and components important to safety; • applies to design and characterization of barriers important to waste isolation and related activities; and • is implemented by DOE based on 10 CFR 50 Appendix B.

Table 6-1. Parts of the Code of Federal Regulations considered in the conceptual design[a] (page 5 of 7)

Part of CFR	Description	Requirements
10 CFR Part 960, "General Guidelines for the Recommendation of Sites for the Nuclear Waste Repositories"	Contains guidelines that specify the factors considered in evaluating and comparing sites on the basis of expected repository performance before and after closure.	DOE preclosure system guidelines include[b] • Any projected radiological exposures of the general public and any projected releases of radioactive materials to restricted and unrestricted areas during repository operation and closure shall meet the applicable safety requirements set forth in 10 CFR Part 20, 10 CFR Part 60, and 40 CFR 191, Subpart A. • during repository siting, construction, operation, and decommissioning, the public and the environment shall be adequately protected from the hazards posed by the disposal of radioactive wastes • repository siting, construction, operation, and closure shall be demonstrated to be technically feasible on the basis of reasonably available technology, and the associated costs shall be demonstrated to be reasonable relative to other available and comparable siting options. DOE postclosure system guideline requires that[b] • the geologic setting at the site shall allow for the physical separation of radioactive waste from the accessible environment after closure in accordance with the requirements of 40 CFR Part 191, Subpart B, as implemented by the provisions of 10 CFR Part 60. The geologic setting at the site will allow for the use of engineered barriers to ensure compliance with the requirements of 40 CFR Part 191 and 10 CFR Part 60.

Table 6-1. Parts of the Code of Federal Regulations considered in the conceptual design[a] (page 6 of 7)

Part of CFR	Description	Requirements
40 CFR Part 191, "Environmental Standards for the Management and Disposal of Spent Nuclear Fuel, High-Level, and Transuranic Radioactive Wastes"	Sets standards for radiation doses and the release of radioactive materials. <u>Subpart A: Management and Storage</u> <u>Subpart B: Disposal</u> Appendix A is Table 1, the allowable release quantities. Appendix B contains guidance for implementation of Subpart B, the environmental standards for disposal. Final Rule issued August 15, 1985. Published September 19, 1985 <u>Federal Register</u> Vol. 50, No. 182, p. 3806ff	EPA requires that • the management and storage of spent nuclear fuel, high-level, or transuranic radioactive wastes shall be conducted in a manner to provide reasonable assurance that the combined annual radiation dose to any member of the public from these operations shall not exceed 25 mrem to the whole body, 75 mrem to the thyroid, or 25 mrem to any other organ (40 CFR 191.03) for 1,000 yr (40 CFR 191.15); • disposal systems for high-level or transuranic wastes shall be designed to provide a reasonable expectation based upon performance assessments, that the cumulative releases of radionuclides to the accessible environment for 10,000 yr after disposal shall (1) have a likelihood of less than one chance in 10 of exceeding the quantities calculated according to Table 1 of 40 CFR 191, Appendix A and (2) have a likelihood of less than one chance in 1,000 of exceeding 10 times the quantities calculated according to Table 1 of 40 CFR 191, Appendix A. • assurance requirements applicable to non-NRC regulated facilities include reliance on active institutional controls for 100 yr only, post-emplacement site monitoring to verify performance, placement of passive institutional controls, avoidance of areas where subsurface resources are likely to be extracted, and design for waste recovery (40 CFR 191.14[c]); and

Table 6-1. Parts of the Code of Federal Regulations considered in the conceptual design[a] (page 7 of 7)

Part of CFR	Description	Requirements
40 CFR Part 191 (continued)		• special sources of groundwater not to be degraded below EPA's drinking water standards for 1,000 yr after disposal (40 CFR 191.16).

[a]49 CFR Parts 171-178, covering transport of radioactive material, is considered to cover an offsite activity and is therefore not addressed in the conceptual design. DOE = Department of Energy, NRC = U.S Nuclear Regulatory Commission, EPA = U.S. Environmental Protection Agency.

[b]The statements of the preclosure and postclosure system guidelines are intended to convey that all disqualifying, qualifying, favorable, and potentially adverse conditions in 10 CFR Part 960 were considered in the conceptual design, as appropriate for this stage of design.

[c]Alternative dose standards for waste management and storage activities at facilities not regulated by the NRC or Agreement States do not apply (40 CFR 191.04). Provisions to ensure compliance with the long-term performance requirements, 40 CFR 191.14, apply only to facilities not regulated by the NRC.

Table 6-2. State of Nevada regulations considered in the conceptual design

Regulations	Description
Nevada Revised Statutes (NRS, Title 40, Chapter 444), Public Health and Safety, Sanitation, 1986	Solid waste disposal standards
Nevada Revised Statutes (NRS, Title 40, Chapter 445), Public Health and Safety, Water Controls; Air Pollution, 1986	Water and air quality standards
Nevada Revised Statutes (NRS, Title 40, Chapter 459), Public Health and Safety, Hazardous Materials, 1986	Hazardous and radioactive waste management standards
Nevada Revised Statutes (NRS, Title 45, Chapter 501), Wildlife, Administration and Enforcement, 1986	Wildlife protection standards
Nevada Revised Statutes (NRS, Title 46, Chapter 512), Mines and Minerals, Inspection and Safety of Mines, 1986	Health and safety standards applicable to mining activities
Nevada Revised Statutes (NRS, Title 48, Chapter 533), Water, Adjudication of Vested Water Rights; Appropriation of Public Waters, 1986	Water resources standards
Nevada Revised Statutes (NRS, Title 48, Chapter 533), Water, Underground Water and Wells, 1986	Water resources standards

[a]NRS = Nevada Revised Statutes.

Table 6-3. State of California administrative codes considered in the conceptual design

Regulation	Description
Tunnel Safety Orders, Administrative Code, Title 8, Chapter 4, Subchapter 20, State of California	Tunnel safety standards
Mine Safety Orders, Administrative Code, Title 8, Chapter 4, Subchapter 17, State of California	Mine safety standards including items such as design and selection of conveyors and components[c]

[a]Mandatory compliance to these codes required by DOE Order 5480.4 (DOE, 1984a), Attachment 2. Exemptions to compliance with the State of California Codes must be approved by the DOE Assistant Secretary, Policy, Safety, and Environment.

[b]California Administrative Code (1981a).

[c]California Administrative Code (1981b).

other high-level nuclear wastes. The DOE and functional requirements for the repository are summarized in Table 6-5. The performance confirmation and closure phase functions and specific requirements are summarized in Table 6-6.

6.1.1.3 Mined geologic disposal system for waste

A system requiring licensing by the NRC, which is used for the disposal of high-level radioactive waste in excavated geologic media, is referred to as a mined geologic disposal system (MGDS). The MGDS acts to isolate the disposed radioactive waste from the accessible environment and to ensure the protection of the public health and safety and the quality of the environment.

The environmental standards for the disposal of high-level waste are provided by 40 CFR Part 191. These standards are supplemented by the NRC regulations under which the MGDS is designed, constructed, and operated. The MGDS is composed of the site, the repository, and the waste package (DOE, 1984b). It is recognized that the entire system will act to provide containment and isolation of the waste and that the system will be composed of multiple natural, engineered, and institutional barrier components. These multiple barriers act to reinforce each other to provide containment or isolation capability. The advantage of this approach is that reliance placed on any one barrier will not be so great as to jeopardize the successful functioning of the overall system. In designing each subsystem to perform

Table 6-4. Department of Energy directives considered in the conceptual design (page 1 of 2)

Directive	Description	Requirements
Mission Plan for the Civilian Radioactive Waste Management Program (DOE, 1985a)	Using governing regulations, explicitly defines the mission of the repository and the requirements for its performance. States the broad basis for anticipating the kinds of scientific, engineering, and environmental information required for a repository. Identifies a hierarchy of unresolved questions for which information can be collected to provide answers.	Requires a very thorough subsurface exploration program to ensure that the natural barriers of the site provide waste isolation.
Generic Requirements for a Mined Geologic Disposal System (GR) (DOE, 1984b)	Contains a functional description of the generic structure of a mined geologic disposal system and explicitly prescribes the minimum set of functional requirements and performance criteria to be be satisfied. Organized by systems, with the mined geologic disposal system subdivided into the waste package, repository, and site subsystems during preclosure and engineered, natural, and institutional barrier subsystems after closure.	Reconfirms the Federal regulatory requirements including the requirement that any or all of the emplaced waste must be retrievable in about the same length of time as that devoted to construction and emplacement, starting at any time up to 50 yr after emplacement operations are initiated. Compiles DOE orders applicable to specific subsystems and components.
DOE Order 6410.1, "Management of Construction Projects" (DOE, 1983b)	Establishes policies and procedures to be followed during the planning and execution of DOE construction programs and projects. Includes an outline of the fundamental objectives of conceptual design and describes the content of a conceptual design report.	Establishes a framework to ensure planning, design, and construction of DOE facilities are properly managed.

Table 6-4. Department of Energy directives considered in the conceptual design (page 2 of 2)

Directive	Description	Requirements
DOE Order 6430.1, "General Design Criteria Manual" (DOE, 1983a)	Provides the general criteria for the conceptual design of DOE projects. Includes references to the codes, standards, guides, DOE orders, and other directives that are to be followed.	Provides general design criteria that ensures implementation of DOE policy covering • the basic architectural and engineering disciplines, • certain types of known facility requirements of the DOE, and • specialized requirements based on programmatic and operating experience.
DOE Order 4320.1A, "Site Development and Facility Utilization Planning" (DOE, 1983c)	Establishes policies and procedures for the site development and facility utilization planning of real property at sites owned, leased, or controlled by DOE for production, separation, research, development, or demonstration.	Requires production of a "Site Development and Facility Utilization Plan" to encompass projected programmatic needs, or other activity projections within financial, physical, or other imposed constraints.
DOE Order 5440.1B, "Implementation of the National Environmental Policy Act;" (DOE, 1982) DOE Order 5480.1B, "Environmental Protection, Safety, and Health Protection Program for DOE Operations;" (DOE, 1986b) DOE Order 5480.3, "Safety Requirements for the Packaging and Transportation of Hazardous Materials, Hazardous Substances, and Hazardous Wastes;" (DOE, 1985b) and DOE Order 5480.4, "Environmental Protection, Safety, and Health Protection Standards" (DOE, 1984a)	Establishes policies, procedures, and the general framework for the environmental protection, safety, and health protection programs.	Specifies and provides requirements for the application of mandatory environmental protection, safety, and health standards.

Table 6-5. Functional requirements of repository facilities (page 1 of 4)

Repository facilities and components	Functional requirements
Site preparation for facilities Clearing Communications Drainage control Explosive distribution system Fencing Grading Landscaping Layout Railroad Roads Utilities (i.e., water, sewage, electrical, fuel)	Provide auxiliary facilities and general services during construction, operation, closure, and decommissioning of the repository (Section 1.2.4 of the Generic Requirements document (GR) (DOE, 1984b)).
Surface facilities	Receive, prepare, and store radioactive waste (GR 1.2.2). The surface facilities must be able to
Waste-handling facilities Building and structures Handling and packaging equipment Hot cells Heating, ventilation, and air conditioning Support facilities Surface storage Utilities	Accept spent fuel from pressurized water reactors with a nominal burnup of 32.5 GWd/MTU[a] and from boiling water reactors with a nominal burnup of 27.5 GWd/MTU; Accept during Stage 1, beginning in 1998, 400 MTU/yr of spent fuel waste with the possibility that some waste will have been consolidated at reactors; Accept during Stage 2, 900 MTU of waste in 2001; 1,800 MTU in 2002 and 3,400 MTU/yr thereafter, with the possibility of consolidating spent fuel waste at the repository; Receive truck and rail deliveries of incoming waste for up to 80% by rail and up to 70% by truck; Be capable of converting to 100% waste receipt by rail or truck;

Table 6-5. Functional requirements of repository facilities (page 2 of 4)

Repository facilities and components	Functional requirements
Waste-handling facilities (continued)	Accept canisters containing 650 MTU of West Valley high-level waste if Yucca Mountain is the first repository built and operated; Accept up to 15,000 canisters of solidified defense high-level waste at the rate of its generation by defense facilities; and Provide surface storage of 100 MTU of spent fuel during Stage 1 and 750 MTU during Stage 2.
Balance of the plant Administrative offices Air and steam facility Backfill and packing Backup generators Change room Chemical storage facility Control facility Cooling and chilled water facility Explosives storage area Fire stations Fuel storage facility Laboratory facilities Maintenance yard Medical building Potable water system Security stations Sewage systems Tuff pile Visitor's center Warehousing areas	Provide auxiliary facilities and general services during the construction, operation, closure, and decommissioning of the repository.

Table 6-5. Functional requirements of repository facilities (page 3 of 4)

Repository facilities and components	Functional requirements
Waste-handling facilities (continued)	
Exhaust shaft filter building Building and filters Equipment Utilities and support	Provide a ventilation exhaust system that is capable of controlling the discharge of airborne radioactive materials to the environment within the release limits established under 10 CFR 20, Appendix B, Table II, and the dose equivalent limits in 40 CFR 191.03 (GR 1.2.2.5).
Shafts and Ramps Type Emplacement exhaust shaft Exploratory shafts Men-and-materials shaft Tuff ramp	Provide surface openings necessary for transporting radioactive waste from the surface to the emplacement areas and to provide necessary subsurface facilities required for handling excavated tuff, equipment and supplies, and adequate quantities of supply and exhaust air (GR 1.2.1). The requirements are
Components Equipment Excavation Fixtures Hoists and headframes Lining Seals Utilities Ventilation ducting	Establish necessary subsurface openings for disposal operations and Provide subsurface facilities for handling excavated tuff and materials, utilities, ground-water control, and ventilation.
Underground facilities Emplacement operations Waste transporters and emplacement equipment	Move radioactive waste from the surface storage vault to the underground emplacement horizon and to emplace waste underground in prepared locations (GR 1.2.2).

Table 6-5. Functional requirements of repository facilities (page 4 of 4)

Repository facilities and components	Functional requirements
Underground facilities (continued)	
Underground support Contamination control Control room Emergency medical and rescue Fire protection Maintenance Materials and hardware Mine water control Operations support Ventilation	Provide auxiliary facilities and general services during the construction operation, closure, and decommissioning of the repository (GR 1.2.4).
Underground utilities Chilled water Communications Compressed air Electrical Potable water Waste disposal (sanitary and solid)	Provide water, fuel, sanitary and solid waste disposal, electric power, communications, and other utility services to meet the construction, operation, and closure needs of the repository (GR 1.2.5).

[a]GWd/MTU = gigawatt days per metric ton of uranium.

Table 6-6. Performance confirmation and closure phases

Name	Description	Function	Specific requirement
Performance confirmation phase	The geologic repository operations area shall be designed to preserve the option of waste retrieval throughout the period of waste emplacement and until the performance confirmation program has been completed and reviewed by the U.S. Nuclear Regulatory Commission (NRC). Performance confirmation refers to a program of tests, experiments, and analyses conducted to evaluate the accuracy and adequacy of the information used to determine with reasonable assurance that the performance objectives for the period after permanent closure will be met.	Provide data through the performance confirmation program that indicates - actual subsurface conditions during construction and waste emplacement operations are within the limits assumed in the licensing review; and - natural and engineered systems and components required for repository operation, which are designed or assumed to operate as barriers after permanent closure, are functioning as intended and anticipated (10 CFR 60.140(a)).	Preserve the option of waste retrieval throughout the waste emplacement period and until the performance confirmation program has been completed and reviewed by NRC and a license amendment for permanent closure has been issued. Begin performance confirmation during site characterization and continue until permanent closure (10 CFR 60.140).
Closure and decommissioning phase	Begins after successful completion of the performance confirmation program. Consists of those activities required to shut down and permanently prevent access to the nuclear wastes stored at the repository.	Close and seal underground and repository access systems. Decommission and decontaminate surface facilities. Implement the procedures, records assembly, and physical barriers of the institutional barrier system.	

its function, however, care will be taken to ensure that interactions between the subsystems are considered and that no component will unacceptably affect the planned performance of another component.

Additional information on barriers important to waste isolation can be found in Section 6.1.5. The components of the MGDS are discussed in Section 6.1.1.3.1 through 6.1.1.3.4.

6.1.1.3.1 Site

The Yucca Mountain site must provide natural barriers for waste containment and isolation. These barriers must keep radionuclides from reaching man in unacceptable quantities by (1) maintaining the waste in its emplaced location for a given period of time (providing waste containment), (2) limiting radionuclide mobility through the geohydrologic environment to the biosphere (providing isolation), and (3) making human interference difficult, principally by locating the repository deep in a host rock. The functional requirement of natural barriers is to minimize or substantially delay the movement of radionuclides to the accessible environment (Section 2.1, DOE, 1984b). An overburden of at least 200 m is defined as a minimum requirement in 10 CFR 960.4-2-5(d). The selected site must contain a host rock considered suitable for constructing the repository and containing the waste, as well as surrounding rock formations that provide adequate isolation. Desirable geohydrologic features include low ground-water flux and velocity, long radionuclide transport paths to the biosphere, and long-term geologic stability. Design values considered in design activities to date for seismic activity and other natural phenomena (SNL, 1987) are presented in Table 6-7.

6.1.1.3.2 Repository

In designing and operating the repository, there are three overall capabilities that must be considered. The repository must be designed to safely emplace waste, retain the option to retrieve waste, and provide the long-term containment and isolation of the waste. The safety and retrieval aspects of design involve considerations of worker radiological and nonradiological health and safety as well as considerations of excavation stability both from the perspective of worker safety and maintenance of access to emplacement boreholes, should retrieval be initiated. The long-term containment and isolation of the waste involve both using engineered barriers that maintain the capabilities of the system and limiting the negative effects of the engineered portions of the repository on the surrounding site. The limitation of negative or adverse effects of the repository on the surrounding rock mass must be a principal consideration during repository design and construction. The adverse impacts that must be limited include the thermal and radiation effects of the waste on the host rock and hydrology, the effects of excavation on the surrounding rock, and the impacts of penetrations, such as boreholes, on ground-water flow paths. Far-field thermal constraints can be satisfied by distributing spent fuel in such a way that the initial maximum areal power density is 57 kW/acre (Johnstone et al., 1984).

Table 6-7. Design values considered for natural phenomena for design activities to date

Natural phenomena	Requirement	Design value
Earthquake	Analyze risks due to seismic activity.	0.40g horizontal
	Determine the peak acceleration, and use for conceptual repository design.	0.27g vertical
Wind	Determine wind velocities to be used in the design of Class II and Class III elements using the 100-yr-mean recurrence level in accordance with DOE Order 6430.1 (DOE,1983a) and ANSI A58.1 (1982).	80 mph
Tornado	Designs for structures, systems, and components requiring tornado protection shall be designed for tornado loads based on the tornado characteristics specified in ANSI/ANS-2.3 (1983).	180 mph
Flood	Surface facilities shall be protected against the probable maximum flood as defined by ANSI/ANS 2.8 (1981) by channel lining and diversionary structures.	Refer to Sections 6.1.2.5.1 and 6.2.4.2 for additional discussion on flooding.

The repository also must contribute to the assurance of long-term containment and isolation by providing for monitoring of system characteristics that are indicative of repository performance. Data from the system monitoring will be analyzed to evaluate the performance of the repository and to verify compliance with the performance objectives established by the NRC.

6.1.1.3.3 Waste package

The waste package is a system of engineered components that may include waste form, stabilizer, canister, container, and packing material designed to contain nuclear waste for an extended period of time. It contributes to waste retrievability through the required periods and acts as a barrier to waste migration and release into the geologic system (DOE, 1985a). The waste package is described in Chapter 7 and the issue resolution strategies related to the waste package are addressed in Sections 8.3.4, 8.3.5.9, and 8.3.5.10.

6.1.1.4 Public safety considerations

To ensure that public safety will be considered during design, specific design requirements for safety have been identified. These requirements are identified as radiological protection, design classifications, and safety design considerations.

A number of stages are involved in the process leading from site characterization through repository construction and operation. At each stage, steps will be taken to protect the quality of the environment and to mitigate any significant environmental impacts. The operations stage is the portion of the process during which offsite radiological safety will be of greatest concern. This stage includes the activities of waste emplacement, possible waste retrieval, and permanent closure. During the operations stage, instantaneous doses must be in compliance with 10 CFR Part 20 and the combined annual dose equivalent to any member of the public may not exceed 25 mrem to the whole body, 75 mrem to the thyroid, and 25 mrem to any critical organ (40 CFR 191.03). In addition to the annual dose specified in 40 CFR 191.03, there is a dose limit of 100 mrem in any seven consecutive days for an individual continuously present in the unrestricted area (10 CFR 20.105). Following closure, the MGDS shall be capable of isolating the nuclear waste from the accessible environment for 10,000 yr so that the release of radionuclides to the accessible environment will be no greater than the limits specified in 40 CFR 191.13. The accessible environment includes (1) the atmosphere, (2) land surface, (3) surface water, (4) oceans, and (5) all the lithosphere that is outside the controlled area. The controlled area includes both the surface location, identified by passive institutional controls that encompass no more than 100 km^2 and extend horizontally no more than 5 km in any direction from the outer boundary of the original location of the radioactive wastes in the MGDS, and the subsurface underlying such a surface location (40 CFR 191.12).

Following emplacement the annual release rate of any radionuclide shall not exceed the limits established in 10 CFR 60.113(b). As defined in 10 CFR Part 60, favorable pre-waste emplacement ground-water travel times along the fastest path of likely radionuclide travel from the disturbed zone to the accessible environment are those that substantially exceed 1,000 yr (10 CFR 60.122). The ultimate releases of radioactivity to the environment over a 1,000-yr period following emplacement must not exceed the release limits for ground-water protection and individual protection requirements identified in 40 CFR Part 191. To accomplish this goal, the repository performance must preclude any individual from receiving more than 25 mrem to the whole body or 75 mrem to any critical organ for 1,000 yr following disposal (40 CFR 191.15). No offsite source of ground water designated as "special" or Class I by the EPA may be contaminated in excess of the Primary Interim Drinking Water Standards (40 CFR Part 141) for 1,000 yr following disposal (40 CFR 191.16).

6.1.1.4.1 Radiological protection design requirements

As specified in 10 CFR 60.131(a), the geologic repository operations area shall be designed to maintain radiation doses, levels, and concentrations of radioactive material in air in restricted areas within the limits specified in 10 CFR Part 20. The design shall include the following:

1. Means to limit concentrations of radioactive material in air.
2. Means to limit the time required to perform work in the vicinity of radioactive materials including, as appropriate, designing equipment for ease of repair and replacement and providing adequate space for ease of operation.
3. Suitable shielding.
4. Means to monitor and control the dispersal of radioactive contamination.
5. Means to control access to high-radiation areas or airborne radioactivity areas.
6. A radiation alarm system to warn of significant increases in radiation levels, of concentrations of radioactive materials in air, and of increased radioactivity released in effluents. The alarm system shall be designed with provisions for calibration and for testing its operability (10 CFR 60.131(a)).

6.1.1.4.2 Design classifications

The requirement to provide confinement for radioactive materials necessitates a more rigorous design treatment for some design elements than for others. The design classifications are presented in Sections 6.1.4 and 6.1.5.

6.1.1.4.3 Safety design considerations

Structures, systems, and components are identified as being important to safety if, due to natural phenomena or anticipated environmental conditions, they fail to perform their intended function, and an accident could result that causes a dose greater than 500 mrem to the whole body or any organ of an individual in an unrestricted area (10 CFR 60.2).

As required in 10 CFR 60.131(b), the structures, systems, and components important to safety shall be designed so that

1. Natural phenomena and environmental conditions will not interfere with safety functions.

2. Dynamic effects, such as earthquakes, will not interfere with safety functions.

3. During and after fires or explosions, safety functions will be performed.

4. Control of radioactive wastes and radioactive effluents can be maintained with safe and timely response to emergency conditions.

5. Utility services important to safety can perform under both normal and accident conditions. Redundant systems shall be included to the extent necessary.

6. Inspection testing and maintenance can be performed to ensure that readiness and continued functioning are not impaired.

7. A criticality accident is not credible.

8. Instrumentation and control systems are functional over anticipated ranges for normal and accident conditions.

9. Compliance with mining regulations will be ensured.

10. Shaft conveyances will fail safely upon malfunction.

Additional information can be found in Section 6.1.4 on items important to safety.

6.1.1.5 Site constraints

The repository will be designed and constructed to prevent the failure of safety systems due to the effect of natural phenomena and environmental conditions and will be in accordance with 10 CFR 60.131(b). Design requirements used in the SCP-CD for site constraints known to have significant impacts are summarized in Table 6-7. Site properties to be used for design values are provided in Section 6.1.2. For information on structures, systems, and components important to safety, refer to Section 6.1.4.

6.1.1.6 Operations scheduling

The SCP-CD was based on the waste acceptance schedule, presented in Table 6-8, provided in the DOE Mission Plan (DOE, 1985a). A new acceptance schedule has been presented in the Draft Mission Plan Amendment (DOE, 1987b). This schedule will be used as a basis for the advanced conceptual design (ACD). The new schedule is not anticipated to have any significant impact on the plans for site characterization (Stein, 1987b).

The schedule of operations presented here is based on a combination of the reference schedule and possible schedule durations provided by the Mission Plan (DOE, 1985a), the Generic Requirements document (DOE, 1984b) and

Table 6-8. Waste acceptance schedule[a]

Year	Facilities: Waste-handling building 1	Facilities: Waste-handling building 2	Waste type: Spent fuel	Waste type: High-level waste[b,c]	Total	Cumulative total
1998	400[d]		400		400	400
1999	400		400		400	800
2000	400		400		400	1,200
2001	400	500	900		900	2,100
2002	400	1,400	1,800		1,800	3,900
2003	400	3,000	3,000	400	3,400	7,300
2004	400	3,000	3,000	400	3,400	10,700
2005	400	3,000	3,000	400	3,400	14,100
2006	400	3,000	3,000	400	3,400	17,500
2007	400	3,000	3,000	400	3,400	20,900
2008	400	3,000	3,000	400	3,400	24,300
2009	400	3,000	3,000	400	3,400	27,700
2010	400	3,000	3,000	400	3,400	31,100
2011	400	3,000	3,000	400	3,400	34,500
2012	400	3,000	3,000	400	3,400	37,900
2013	400	3,000	3,000	400	3,400	41,300
2014	400	3,000	3,000	400	3,400	44,700
2015	400	3,000	3,000	400	3,400	48,100
2016	400	3,000	3,000	400	3,400	51,500
2017	400	3,000	3,000	400	3,400	54,900
2018	400	3,000	3,000	400	3,400	58,300
2019	400	3,000	3,000	400	3,400	61,700
2020	400	3,000	3,000	400	3,400	65,100
2021	400	3,000	3,000	400	3,400	68,500
2022	400	1,100	1,100	400	1,500	70,000
Total	10,000	60,000	62,000	8,000		70,000

[a]Mission Plan (DOE, 1985a).

[b]Approximate waste acceptance for high-level waste from atomic energy defense activities and commercial high-level waste from the West Valley Demonstration Project Quantities have been normalized to MTU on a curie-equivalent basis. Direct comparison with spent fuel is not appropriate because defense high-level waste (DHLW) and commercial high-level waste (CHLW) result from the reprocessing of spent fuel. Actual acceptance rates are to be negotiated between Defense Programs and the DOE.

[c]The first repository currently is designed to begin operating in two stages. This example shows the acceptance of DHLW and CHLW in waste-handling building I after waste-handling building 2 reaches its maximum receipt rate in the year 2003.

[d]Units are metric tons of uranium per year.

a document describing retrievability strategy (Flores, 1986). A reconciliation of these schedules is provided in Section 6.2.9 (retrieval). Figure 6-2 illustrates the preliminary schedule of repository operations used for the conceptual design.

6.1.1.6.1 Construction schedule

To receive spent fuel by 1998 as required by the Nuclear Waste Policy Act of 1982, the DOE has elected to construct and operate the repository in two stages (SNL, 1987). The rate of waste receipt is planned to increase until full processing capacity is reached. The construction and testing of the first waste-handling building (WHB-1) and the construction of the emplacement area, Stage 1, is scheduled to be completed in 53 months. Construction of the second waste-handling building (WHB-2), Stage 2, is scheduled to be completed in 90 months.

6.1.1.6.2 Waste handling and disposal schedule

WHB-1 is scheduled to be ready to receive unconsolidated commercial spent fuel in January 1998 and to continue for 3 yr at a rate of 400 MTU/yr (Table 6-8). During the planned transition from Stage 1 to Stage 2, spent fuel would be handled in both WHB-1 and WHB-2.

After the transition period, WHB-1 could be used for preparing defense high-level waste (DHLW) for disposal. West Valley high-level waste (WVHLW) could be prepared for disposal at the same time. The combined total of DHLW and WVHLW that could be handled at WHB-1 is 8,000 MTU.

During this time, WHB-2 is scheduled to reach its full capacity for receiving, consolidating, and packaging spent fuel. The planned disposal rate for waste packaged at both WHB-1 and WHB-2 is 3,400 MTU/yr. The total capacity of the repository for design purposes is 70,000 MTU.

6.1.1.6.3 Caretaker and closure schedule

The caretaker period begins with the emplacement of the last waste package and continues through the NRC review of and concurrence with the performance confirmation program. It is assumed for design purposes that the caretaker period will extend for 25 yr as shown in Figure 6-2. During this period, repository personnel would be reduced to the number necessary for maintenance activities. Permanent closure will occur for design purposes either after the caretaker period or after waste retrieval. Closure operations would require approximately 4 to 10 yr during this period depending on whether the horizontal or vertical emplacement orientation was used.

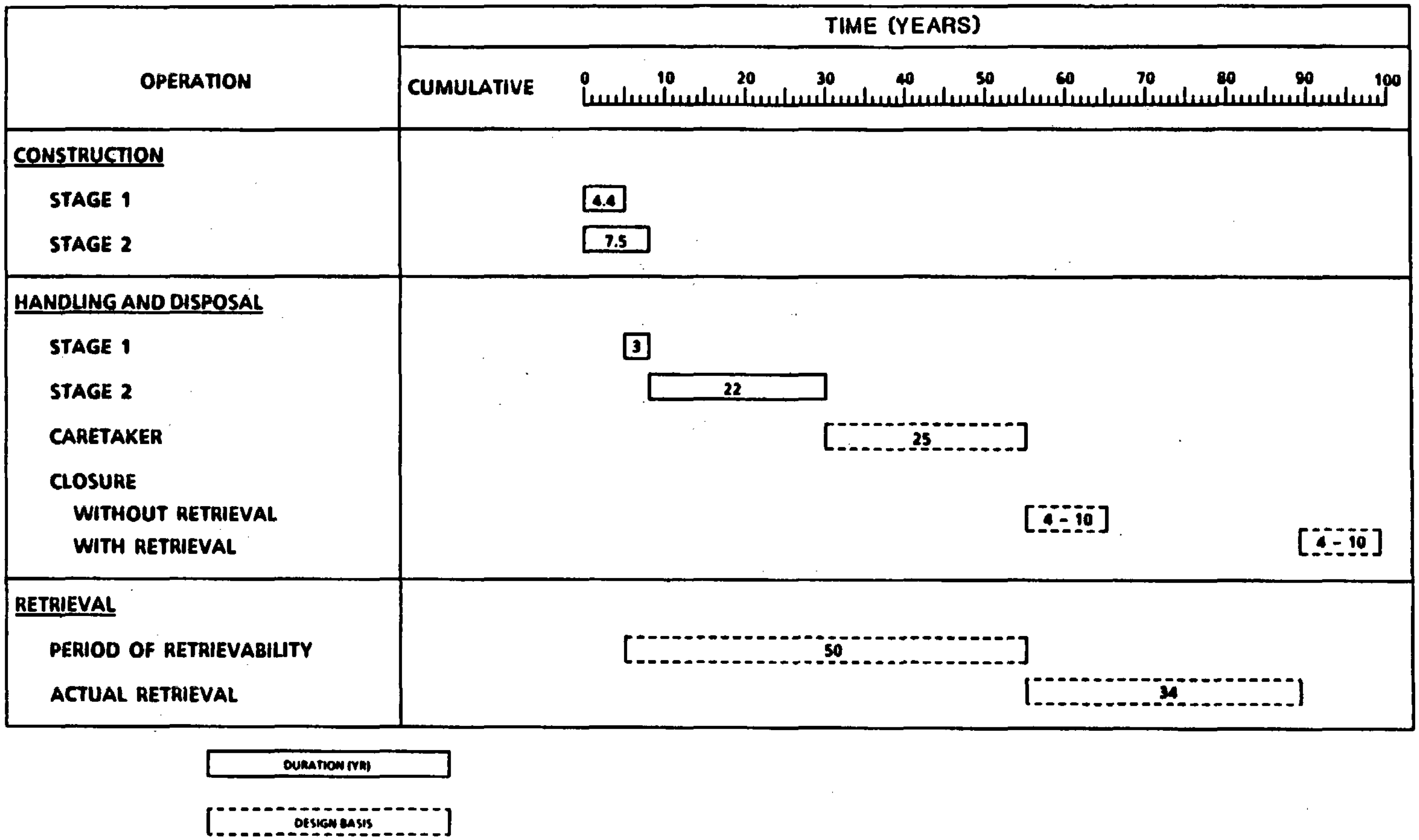


Figure 6-2. Schedule of repository construction and operation.

6.1.1.6.4 Waste retrieval schedule

It is assumed for design purposes that the period of retrievability is a maximum of 50 yr. This period begins when the first waste is emplaced and ends when the performance confirmation program is completed. It is assumed that the time period required to retrieve all waste packages, actual retrieval, is approximately equal to the construction period (6 yr) plus the emplacement period (28 yr), 34 yr, using the schedule from the Generic Requirements document (DOE, 1984b). Additional information concerning the retrieval process and equipment is presented in Section 6.2.9.

6.1.1.7 Retrievability-related design criteria

The conceptual design incorporated many retrievability-related design criteria. To understand the criteria, it is important to briefly synopsize the philosophy used to date relative to retrieval. The current conceptual design reflects a retrieval philosophy that is based on regulatory requirements and is consistent with DOE guidance (DOE, 1984b; Appendix D, DOE, 1986a; DOE, 1985a). This philosophy is summarized in the following:

1. The design of the repository at Yucca Mountain will incorporate the option to retrieve the emplaced waste as a planned contingency operation. Therefore, the equipment and facilities necessary to carry out full repository retrieval need not be constructed at the time of repository construction.

2. The inclusion of the retrieval option will not compromise the safety of the repository, nor will it compromise the ability of the repository to isolate the emplaced waste.

3. The method of retrieval will anticipate off-normal conditions and will be designed to operate under expected off-normal conditions. (In this chapter the term off-normal is used to identify conditions expected to occur infrequently. In future documents the term off-normal will be replaced with the term abnormal.)

4. The design of facilities and equipment for retrieval will be based upon technology that is reasonably available at the time of license application. In addition, the design of retrieval methods and proof-of-principle demonstrations must be completed at the time of license application.

The current list of design criteria was developed using the retrieval philosophy indicated above, the retrieval strategy report (Flores, 1986), and the performance allocation process described for retrieval in Section 8.3.5.2. The current design criteria for retrieval are as follows:

1. The access and drifts will remain usable for at least 84 yr.

2. The borehole liner lifetime will be at least 84 yr.

3. The design basis for the actual retrieval period is 34 yr.

4. The time required for the removal of a waste package will not exceed twice the amount of time required for emplacement of the waste package.

5. For the vertical emplacement concept, the temperature in the access drifts will not exceed 50°C for 50 yr after waste emplacement.

6. For the horizontal emplacement concept, the temperature in the emplacement drifts will not exceed 50°C for 50 yr after waste emplacement.

7. The time required to modify the environment in closed drifts for unprotected workers will not exceed 8 weeks.

8. The worker dose rate during removal operations will not exceed the allowable limit for emplacement operations.

9. For operations areas, all applicable air quality standards will be met.

10. The ability to remove the waste under normal and selected off-normal conditions will be demonstrated.

11. The maximum liner deflection is 5 cm for the vertical emplacement concept and 8 cm for the horizontal concept.

12. For the horizontal emplacement concept, the minimum radius of curvature for the liner is 34 m (110 ft) over the length of a waste package.

13. The ability to perform the retrieval operations using reasonably available technology is required.

This list will be revised as the design and the performance allocation work are refined. In addition, as more definition of off-normal conditions is obtained, additional design criteria will be developed and included in the design basis documents (SNL, 1987; Section 2.4).

6.1.1.8 Waste containment and isolation-related design criteria

Criteria related to waste isolation and containment are important in the design of a repository. The postclosure design criteria identified in 10 CFR 60.133 have been directly considered in establishing four principal functions related to containment and isolation that the postclosure waste disposal system must perform; these functions are as follows:

1. Provide orientation, geometry, layout, and depth of the underground facility such that the facility contributes to containment and isolation taking into account flexibility to accommodate site-specific conditions (10 CFR 60.133(a)(1) and 10 CFR 60.133(b)).

2. Limit water usage and potential chemical effects, thereby contributing to containment and isolation of radionuclides and assisting engineered barriers in meeting performance objectives (10 CFR 60.133(a)(1) and 10 CFR 60.133(h)).

3. Limit potential for excavation-induced changes in rock mass permeability (10 CFR 60.133(f)).

4. Provide thermal loading taking into account performance objectives and thermomechanical response of the host rock (10 CFR 60.133(i), 10 CFR 60.133(e)(2), and 10 CFR 60.133(h)).

To aid in ensuring that these functions can be performed, design criteria have been established for use in the designs prepared to date.

The current design criteria related to waste containment and isolation are as follows:

1. Ensure the usable area for the repository will have greater than 200 m overburden, be within the TSw2 portion of the Topopah Spring Member, be more than 70 m above the water table, and be in the primary area.

2. Design accesses, drifts, and boreholes so that drainage is away from containers.

3. Limit quantity of cement, shotcrete, and grout used in borehole and drift construction.

4. Limit quantity of organics introduced during underground construction.

5. Limit underground water usage during underground development to that required for dust control and proper equipment function; remove all excess water.

6. Limit repository extraction ratio to less than 30 percent for vertical emplacement (<10 percent for horizontal) and limit drift spans to less than 10 m (35 ft).

7. Limit potential for subsidence by backfilling underground openings during decommissioning.

8. Limit impact on surface environment by limiting surface temperature rise to less than 6 Celsius degrees.

9. Establish borehole spacing to assure that areal power density of 57 Kw/acre is not exceeded, borehole wall temperatures remain below 275°C, and rock mass temperature at 1 m into rock is below 200°C. This spacing must consider the 50°C at 50-yr criteria identified in retrieval-related criteria (Section 6.1.1.7).

Additional criteria planned for use during the advanced conceptual design (ACD) and the licensing application design (LAD) are provided in Section 8.3.2.2 where performance measures and goals are documented.

6.1.2 REFERENCE DESIGN DATA BASE

In this section a summary of the geologic and geotechnical data used for the repository design is presented. The reference design data base is a subset of the Reference Information Base (RIB) (Appendix Q of SNL, 1987) which is currently being developed. The RIB will be revised periodically and will contain all reference technical information for the NNWSI Project that support analyses for site characterization, design, and performance assessment. The RIB contains a summary of all physical, thermal, and mechanical data including recommended values and ranges that pertain to site characteristics. The recommended values and ranges will change as more site specific data become available.

The SCP-CDR (SNL, 1987, Appendix O) is the primary source of geotechnical information for thermal and mechanical analyses. This appendix of the SCP-CDR includes a complete set of design data including the required ranges for parametric and sensitivity analyses. Also, more sophisticated material models evolved that required data that were previously uncompiled and not analyzed. The more recent data supplement the older data and, in general, do not replace it. This section contains the data that were used in the conceptual design.

The sources of the data are discussed, and appropriate sections of Chapters 1 through 6 are referenced as needed. A description of the principal site characteristics that form the basis for the design required to perform the design analyses is provided.

Specific consideration is given to site geology (stratigraphy and structure), in situ stress and thermal conditions, hydrologic regime, rock strength, rock discontinuities, thermal properties, and seismic-tectonic conditions in the context of the design. A reasonably expected range for each characteristic is established, determined through quantitative analysis or engineering judgment, as appropriate. Discussions of the methods used to establish these ranges follows.

The mean values and standard deviations for site parameters have been determined using data obtained during preliminary site investigations (Chapters 1-5). The value of the standard deviation relative to the mean value for a given parameter is currently being used as a measure of the uncertainty associated with that parameter. The data currently available from preliminary testing do not permit any better quantification of uncertainties than those obtained by this method and do not permit the identification of probability density functions for the site characterization parameters. Essentially all data presented contain the uncertainty related to limited samples from the few boreholes that exist at the site. The number of tests needed to quantify the uncertainties in the context of addressing design and performance issues are discussed in Chapter 8.

6.1.2.1 Site geology

Information regarding site geology is important to site selection and location (Figure 6-3), surface facilities location, and underground boundaries constraints. The site geology also provides the framework for all geotechnical and hydrological data collected. The data provided in Chapter 2, Geoengineering, combined with the three-dimensional geologic perspective of the site presented in Chapter 1, Geology, permit the development of a conceptual geologic model for design analyses. A detailed description of the regional and site geology is given in Chapter 1 and provides essential background information for the design data base. The information presented in Chapter 1 results from extensive field mapping of the site and adjacent areas, study of core taken from drillholes, and geophysical methods applied both at the surface and in the drillholes. Specifically, Section 1.2 (stratigraphy and lithology), characterizes the lithostratigraphic sequences and their major unconformities, ages, ranges and thickness, spatial extent, major rock units, and vertical and lateral variation. Also, Section 1.3 (structural geology and tectonics of the candidate area and site) contains a characterization of the structural elements, for example faults, fractures, and joints. Specific aspects of the site topography, stratigraphy, and structure most important to design and performance are given here.

6.1.2.1.1 Topography and terrain

An understanding of the topography and terrain of the site and vicinity is important to the design for a number of reasons. For example, locations of surface facilities and accesses to them are influenced by terrain (Section 6.2.2, Current repository design description). Local topographic variations are important in assessing flood potential (Section 6.1.2.6). Topographic variations influence the underground design in terms of determination of the usable area while maintaining the required amount of overburden (the overlying material above the horizon of interest). Also, in situ stresses are influenced, in part, by local topography.

The Yucca Mountain site lies within the Basin and Range physiographic province, a broad region of generally linear mountain ranges and intervening valleys. The site is in the southern part of the Great Basin, a subdivision of the Basin and Range Province. Figure 6-4 shows the physiographic features in the region. The elevation of northern Yucca Mountain is approximately 1,500 m. This is more than 370 m above the western edge of Jackass Flats to the east and more than 300 m higher than the eastern edge of Crater Flat to the west of Yucca Mountain.

Yucca Mountain is a prominent group of north-trending fault-block ridges that extend southward from Beatty Wash on the northwest to U.S. Highway 95 in the Amargosa Desert. The terrain at the site is controlled by high angle normal faults and volcanic rocks that tilt eastward. The terrain is locally steep (15 to 30°) on the west-facing side of Yucca Mountain and along some of the valleys that cut into the more gently sloping (5 to 10°) east side of Yucca Mountain. The valley floors are covered by alluvium. Alluvial and colluvial fans extend down from the lower slopes of the ridges. Fortymile Wash is cut from 13 to 26 m into the surface of Jackass Flats. North of

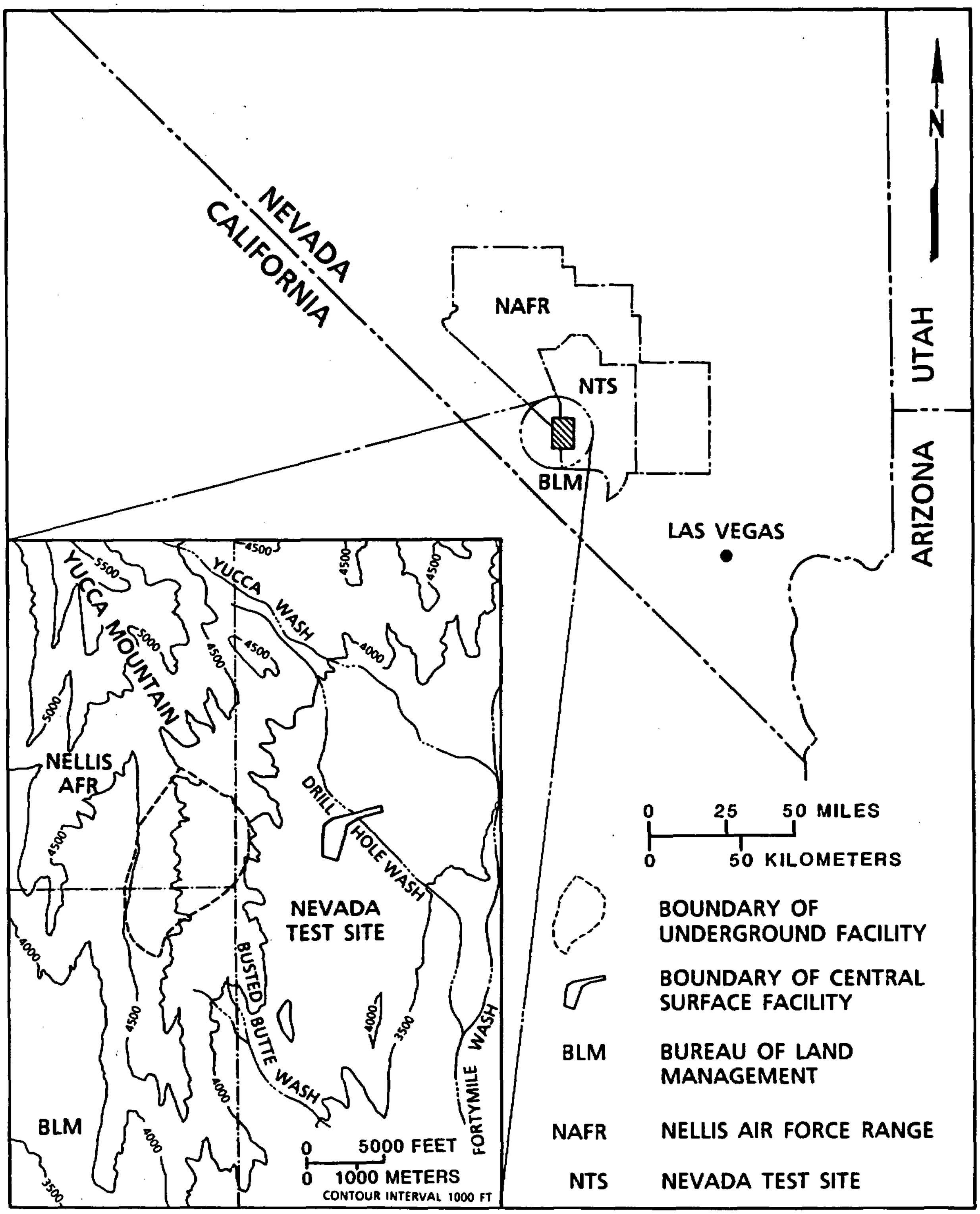


Figure 6-3. Location of Yucca Mountain site in southern Nevada. Modified from SNL (1987).

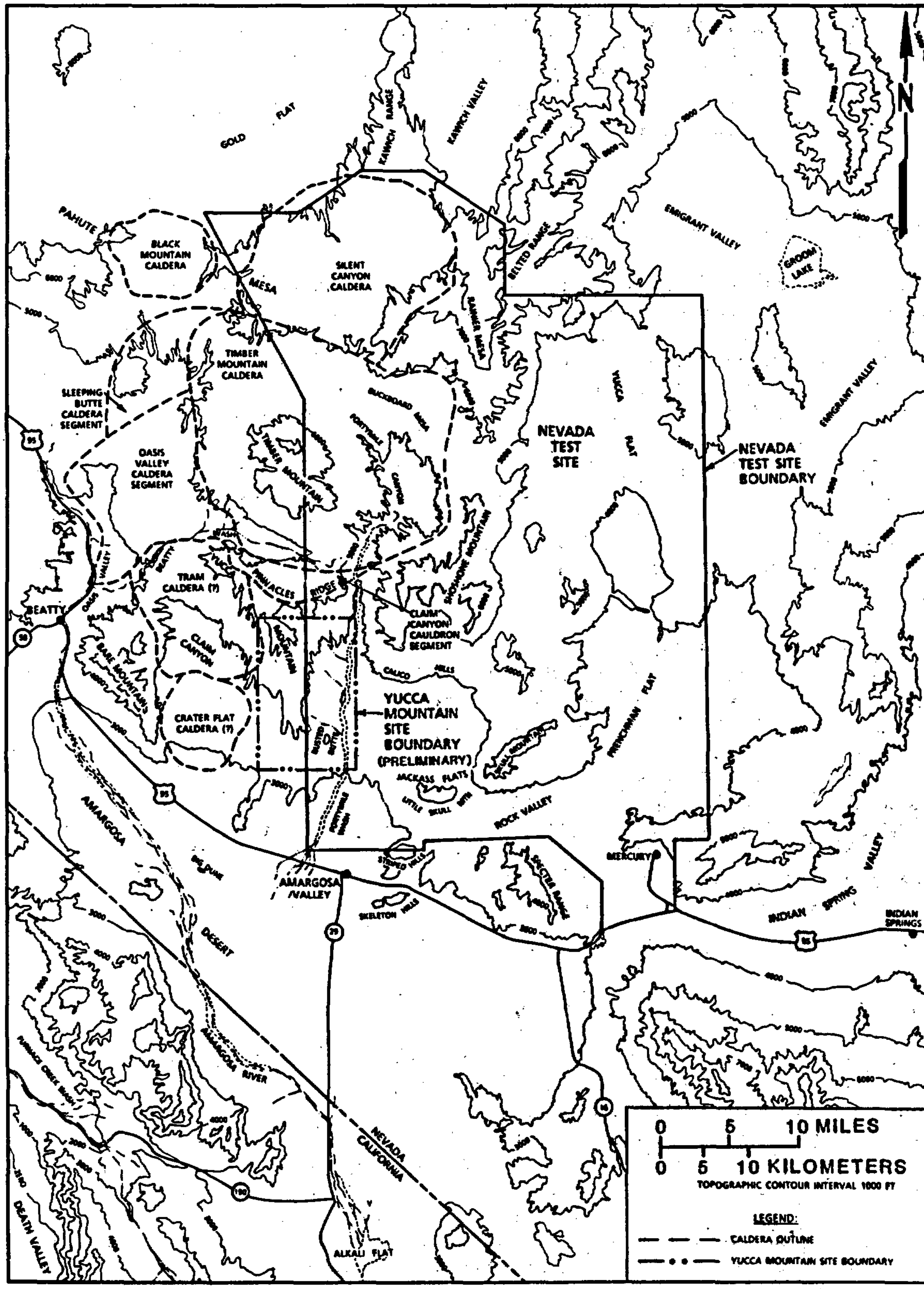


Figure 6-4. Physiographic features of Yucca Mountain and surrounding region. Modified from SNL (1987).

Yucca Mountain is the high, rugged volcanic terrain of Pinnacles Ridge. To the west of Yucca Mountain, along the west side of Crater Flat, steep alluvial fans extend from deep valleys that have been cut into Bare Mountain. Basalt cones and small lava flows are present on the surface of the southern half of Crater Flat. The topographic expression of these physiographic features is shown in Figure 6-5.

6.1.2.1.2 Near-surface soil and rock

The physical and engineering properties of the near-surface soil and rock are required for design because they influence the selection of specific locations for surface facilities and associated structural foundations. Limited preliminary investigations, consisting of four test pits and eight exploratory borings, contributed to the selection of a reference site for the central surface facilities for the purpose of the conceptual design (Neal, 1985). In general, the top 0.3 to 0.7 m of the site is a loose, fine-grained sandy soil overlying approximately 2 m of material that is partly to wholly cemented with calcite (caliche). Below the caliche layer is an 11- to 50-m-thick layer of very dense, gravelly, sandy alluvial material, which overlies the ash-flow tuff bedrock. Section 2.7.3 provides a detailed description of the geoengineering properties of the near-surface soil and rock.

A summary of the physical and engineering properties of the surface materials (Ho et al., 1986) at the proposed location of the central surface facilities is presented in Table 6-9. These properties are based on preliminary tests on samples of the underlying uncemented surface materials at the proposed surface facilities location. Samples were taken at depths of 4 m or less. The combination of the paucity of data and the fact that certain of the recommended values and ranges are based entirely on engineering judgment attach a fair degree of uncertainty to the values listed. Because the facility foundations are based on soils deeper than those tested, and because confining stresses increase with depth, the estimated values of the parameters were considered suitable for the SCP-CD.

6.1.2.1.3 Stratigraphy and lithology

The stratigraphy identifies, in part, the thermal/mechanical medium for disposal of the radioactive waste. Yucca Mountain consists of a layered sequence of ash-flow tuffs that are welded, nonwelded, and bedded tuff as detailed in Chapter 1, Geology. The ranges in thickness, spatial extent, and vertical and lateral variations of the stratigraphic units as determined from core, surface mapping, and geophysical techniques are described in Section 1.2. Definition of these stratigraphic units and their variability is important on all scales in order to understand possible scenarios of thermomechanical response. Within the stratigraphic units, variations in the degree of welding, devitrification, and zeolitization have been identified. These variations in physical and mineralogic characteristics can affect the thermomechanical response. The exact manifestations of these effects as they apply to the mechanical and thermal properties are uncertain at this time.

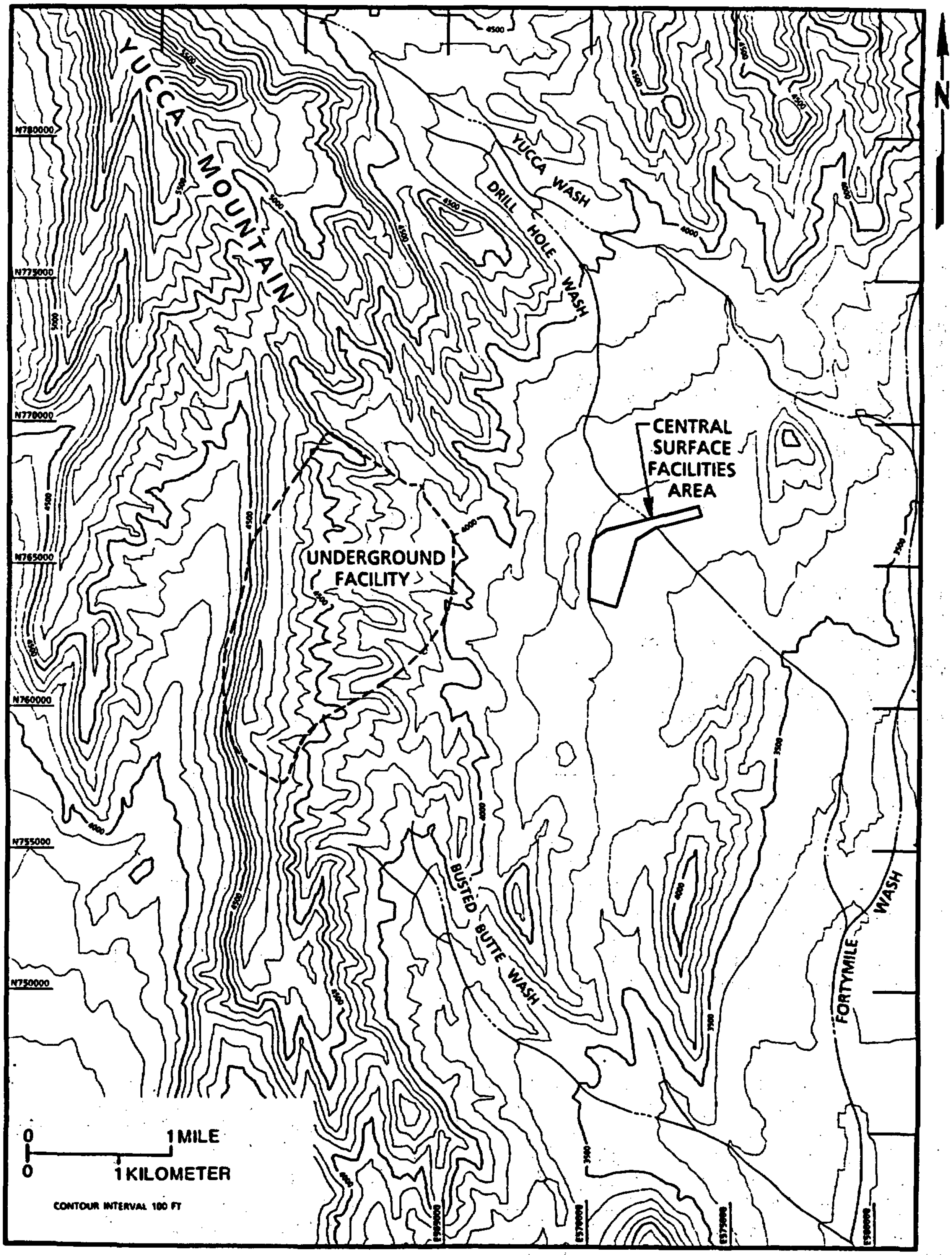


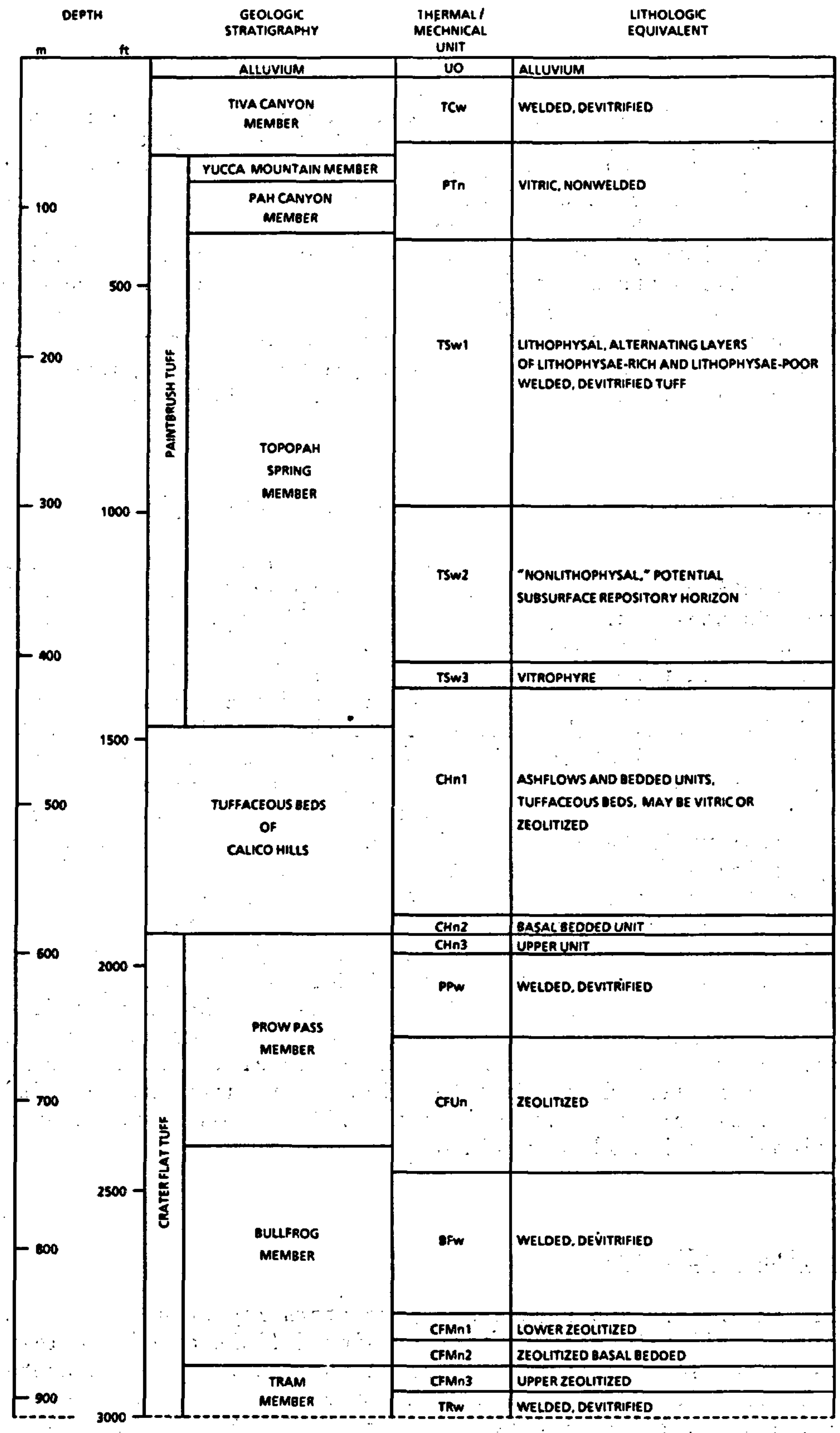
Figure 6-5. Site topographic map.

Table 6-9. Summary of physical and engineering properties of surface materials[a]

Property[b]	Value
PHYSICAL PROPERTIES	
Soil classification	GP to GM[c]
Natural moisture content	7.2%
Absorption	7.9%
In situ density	1.62-1.79 g/cm^3 (101-112 pcf)
Percent of maximum dry density	93.5-100%
Specific gravity of soil solids	2.43
Void ratio	0.37
Optimum moisture content at maximum dry density	12.0-14.7%
ENGINEERING PROPERTIES[d]	
Young's modulus	0.7-1.4 GPa (10,000-20,000 psi)
Poisson's ratio	0.30-0.35
Modulus of subgrade reaction	5,536-8,304 g/cm^3 (200-300 psi)
Cohesion	0
Angle of internal friction	33-37°
Allowable bearing pressure[e]	0.3 MPa (6,000 psf)

[a]Information taken from Ho et al. (1986).
[b]Values and ranges of physical properties are from test pit SFS-3.
[c]Unified Soil Classification: GP includes poorly graded gravels, gravel-sand mixtures, and few or no fines; GM includes silty gravels, and gravel-sand silt mixtures, which may be poorly graded.
[d]Estimated from index properties.
[e]For footings wider than 4 ft, subject to verification that settling for large structures will be tolerable.

However, redundancy in testing has made it possible to quantify probable effects of these physical and mineralogic characteristics on measured mechanical and thermal properties, as discussed under sample selection logic in the introduction to Chapter 2 and in Section 2.1.5. Furthermore, assessment of site stratigraphy coupled with mechanical and thermal properties testing resulted in the thermal/mechanical stratigraphy (discussed under stratigraphic framework for testing in the introduction to Chapter 2) presented in Figure 6-6 (SNL, 1987, Figure 2-8).



THE "NONLITHOPHYSAL" PORTION OF THE TOPOPAH SPRING MEMBER MAY CONTAIN A SMALL PERCENTAGE OF LITHOPHYSAE

Figure 6-6. Correlation between the thermal/mechanical stratigraphy and the geologic stratigraphy. Modified from SNL (1987).

6.1.2.1.4 Structure

Structural elements such as faults and fractures are used in the empirical and analytical models presented in Section 8.3.2.4 because they are significant factors in evaluating rock mass behavior. Spatial variations in the occurrence of these structural elements introduce a degree of uncertainty in analyses addressing the thermomechanical response of the rock mass. A discussion of the history and relationship of the fractures and faults and maps showing locations and attitudes of these features are included in Section 1.3.2.2. Site-specific subsurface expression of these features is important to underground design because they introduce uncertainty in the determination of the potential thermomechanical response. Specific data on these rock discontinuities is presented in Section 6.1.2.3.4.

6.1.2.1.5 Three-dimensional thermal/mechanical stratigraphy model

The thermal/mechanical stratigraphy (discussed under stratigraphic framework for testing in the introduction to Chapter 2 and shown in Figure 6-6) for Yucca Mountain tuffs (Ortiz et al., 1985) is a stratigraphic definition based on rock properties rather than on classical geologic guidelines. It is defined through a stratigraphic breakdown of the tuffs at Yucca Mountain based on unit-specific bulk, thermal, and mechanical properties. Definition of the thermal/mechanical stratigraphy, coupled with stratigraphic and structural characterizations of the type summarized in the previous section, has permitted a three-dimensional model of the site to be developed (Ortiz et al., 1985). The three-dimensional geometric relationships of the thermal/mechanical units have been estimated using a modeling technique described by Nimick and Williams (1984). Input data for the model consist of depths of contact between thermal/mechanical units in existing drillholes at Yucca Mountain. These data permit derivation of an equation that describes a three-dimensional surface representing each thermal/mechanical unit. The surface descriptions are adjusted to account for fault offset (Section 1.3.2.2). Thus, the three-dimensional model provides the spatial distribution of each thermal/mechanical unit through both stratigraphic and structural control (Figure 6-7). Uncertainty in the model is related to sparse data and assumptions linked to the interpolation of surfaces, unit definitions, and model algorithms. As additional drillhole data are obtained, the three-dimensional model will be refined.

6.1.2.2 In situ conditions

In situ temperature and stress are parameters important to the design of the underground facilities because they provide definition of the initial and boundary conditions for all thermomechanical analyses. These parameters are detailed in Section 2.5.2 (Thermal and thermomechanical properties of rock at the site) and Section 2.6 (Existing stress regime). Reference values, a reasonable expected range, and uncertainties in these site characteristics, all consistent with Chapter 2, are presented in the following sections.

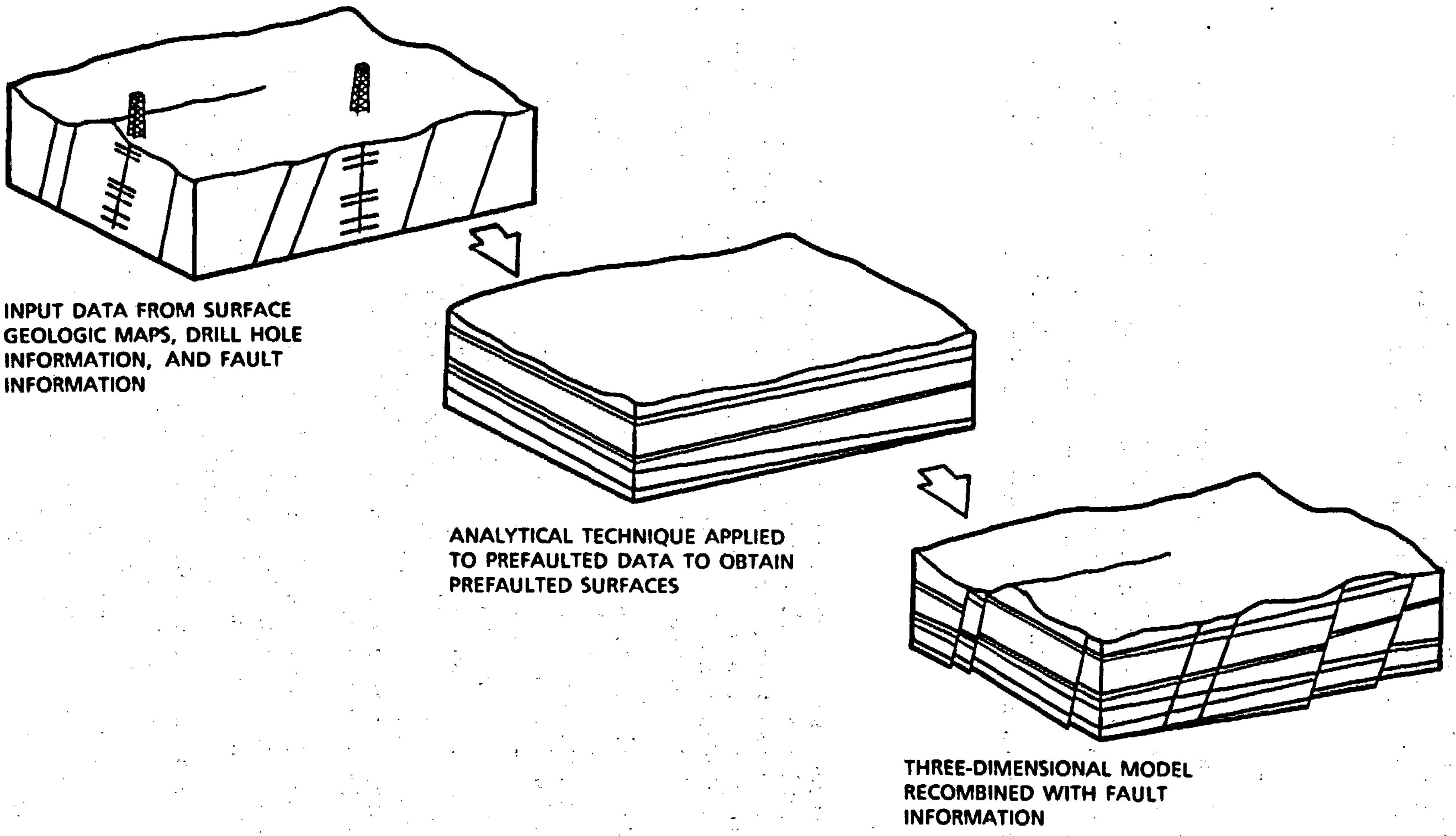


Figure 6-7. Schematic development of the three-dimensional model. Modified from SNL (1987).

The underground facilities would be located in the unsaturated zone above the water table. Therefore, the pore pressure was assumed to be zero for design purposes and the degree of saturation was treated as a physical property.

6.1.2.2.1 Temperature

The geothermal characteristics, including temperature, thermal properties, and heat flux, of the site are discussed in Section 1.3.2.5 (Geothermal regime). In situ rock temperatures have been measured in drillholes at Yucca Mountain (Sass and Lachenbruch, 1982). Drillholes USW G-1, USW G-2, USW H-1, and UE-25a#1 indicate an average temperature of 26°C (Table 6-10) derived from a range of 23 to 29°C temperatures observed at a repository depth of approximately 300 m (200-500 m) (Section 1.3.2.5.2). Some uncertainty in the range presented may exist and is attributed to the paucity of data.

6.1.2.2.2 Stress

The in situ stress state, characterized by the specification of the magnitude and direction of the three principal stresses, is the stress state upon which excavation and thermal stresses are superposed. Stock et al. (1985), in analyzing the stress state at the site from stress measurements at Yucca Mountain, concluded that the maximum principal stress is near vertical, and the minimum and intermediate principal stresses are near horizontal.

The magnitude of the vertical stress, which is assumed to be the maximum principal stress, is determined by multiplying the mass density of the overburden by the acceleration of gravity times the depth to the point of interest. For a given locale, the vertical stress increases nearly linearly with depth, depending on vertical variations in density related to stratigraphy and possibly degree of saturation. For a given elevation within the repository area, the vertical stress can vary horizontally by about 1 MPa because of topographic variations and differing amounts of overburden (Bauer et al., 1985a). A reasonable range in the vertical stress is approximately 5 to 10 MPa for repository horizons (Stock et al., 1984), depending on elevation and local topographic variations.

The orientation of the minimum horizontal stress ranges from N.50°W. to N.65°W. according to measurements (Stock et al., 1984) and regional structures (Carr, 1974). The magnitude of the minimum horizontal stress is often expressed as the ratio of minimum horizontal stress to the vertical stress, K_o. A working range of K_o between 0.3 and 0.8 is recommended based on regional tectonics, stress measurements, and finite-element modeling (Bauer et al., 1985a). The lower bound for K_o was established by finite-element modeling, which considered only gravity loading. A single stress measurement (Stock et al., 1984), which is inconsistent with all others at Yucca Mountain, shows the minimum horizontal stress to be equal to the vertical stress. There is additional evidence that suggests that the two horizontal stresses are not equal (Ellis and Swolfs, 1983).

Table 6-10. Mean values and ranges for principal stresses and temperature

Parameter	Mean value[a]	Range
Vertical stress (MPa)	7.0 (1,015 psi)	5.0 to 10.0
Minimum horizontal to vertical stress ratio	0.55	0.3 to 0.8
Bearing of minimum horizontal stress	N.57°W.	N.50°W. to N.65°W.
Maximum horizontal to vertical stress ratio	0.65	0.3 to 1.0
Bearing of maximum horizontal stress	N.32°E.	N.25°E. to N.40°E.
Temperature (°C)	26	23 to 29

[a]Mean value for depths of approximately 300 m.

The maximum horizontal stress (N.25°E. to N.40°E.) is oriented perpendicular to the minimum horizontal stress. On the basis of existing data and observations, it is assumed that the magnitude of the horizontal stress is less than or equal to the vertical stress. Ancillary evidence pertaining to the magnitude of the maximum horizontal stress is consistent with the range presented (Ellis and Swolfs, 1983; Stock et al., 1985).

6.1.2.3 Geotechnical data

Geotechnical data, including physical, mechanical, thermal, and discontinuity properties, are important to design because these data are the material properties used in design analyses (Section 8.3.2.5), which assess the response of the rock mass to excavation and thermally induced loads. The design values for each thermal and mechanical unit (discussed under the "current data base" heading in the introduction to Chapter 2) are presented in Tables 6-11, 6-12, and 6-13. These tables document the design values used in developing and evaluating the SCP conceptual design. The values presented in the column titled variability evaluation represent more recent results of data analyses and establish ranges for properties in some instances. Some of the information contained in these tables is not as current as the information contained in Chapter 2. These values are derived from detailed analyses of laboratory and field data and numerical analyses. The introductory section (sample selection logic) in Chapter 2 describes the details of the

Table 6-11. Physical properties of intact rock and rock mass for thermal/mechanical units[a] at Yucca Mountain[b]

Thermal/ mechanical unit	Grain density (g/cc) Design value[c]	Grain density Variability evaluation[d] value	Grain density Variability evaluation range	Porosity Design value	Porosity Variability evaluation value	Porosity Variability evaluation range	In situ saturation Design value	In situ saturation Variability evaluation value	In situ saturation Variability evaluation range	Bulk density at in situ saturation (g/cc) Design value	Bulk density at in situ saturation Variability evaluation value	Dry bulk density (g/cc) Design value	Dry bulk density Variability evaluation value
TCw	2.51	2.51	±0.04	0.114	0.11	±0.04	0.8	0.67	±0.23	2.32	2.31	2.23	2.23
PTn	2.37	2.37	±0.15	0.448	0.45	±0.15	0.8	0.61	±0.15	1.67	1.58	1.31	1.30
TSw1[e]	2.53	2.54	±0.04	0.148	0.14	±0.04	0.8	0.65	±0.19	2.27	2.25	2.15	2.15
TSw1[f]	2.53	2.53	±0.02	0.348	0.35[g]	±0.03[g]	0.8	0.65	±0.19	2.00	NA[h]	1.65	NA
TSw2	2.55	2.55	±0.03	0.121	0.12	±0.03	0.8	0.65	±0.19	2.34	2.32	2.25	2.24
TSw3	2.39	2.39	±0.02	0.043	0.04	±0.03	0.8	0.65	±0.19	2.34	2.32	2.25	2.29
CHn1v	2.34	2.34	±0.05	0.365	0.36	±0.09	0.8	0.90	±0.06	1.78	1.82	1.49	1.50
CHn1z	2.41	2.41	±0.06	0.327	0.33	±0.04	0.8	0.91	±0.06	1.96	1.92	1.63	1.61
CHn2z	2.54	2.54	±0.12	0.286	0.29	±0.06	1.0	1.0[i]	NA	1.96	2.09	1.63	1.80
CHn3z	2.41	2.41	±0.04	0.360	0.36	±0.08	1.0	1.0[i]	NA	1.96	1.90	1.63	1.54
PPw	2.58	2.58	±0.04	0.240	0.24	±0.07	1.0	1.0[i]	NA	2.20	2.20	1.96	1.96
CFUn	2.43	2.43	±0.07	0.297	0.30	±0.08	1.0	1.0[i]	NA	2.00	2.00	1.17	1.70
BFw	2.60	2.60	±0.04	0.238	0.24	±0.08	1.0	1.0[i]	NA	2.23	2.22	1.98	1.98
CFMn1	2.41	2.41	±0.06	0.246	0.25	±0.05	1.0	1.0[i]	NA	2.09	2.06	1.83	1.81
CFMn2	2.52	2.52	±0.06	0.242	0.24	±0.03	1.0	1.0[i]	NA	2.09	2.16	1.83	1.92
CFMn3	2.44	2.44	±0.07	0.267	0.27	±0.03	1.0	1.0[i]	NA	2.09	2.05	1.83	1.78
TRw	2.63	2.63	±0.04	0.188	0.19	±0.05	1.0	1.0[i]	NA	2.32	2.32	2.14	2.13

[a]Thermal/mechanical units are defined in Figure 6-6.
[b]See Appendix O of SNL (1987).
[c]Design values represent the basis for the SCP-CDR.
[d]Variability evaluation represents more recent results of data analyses and establishes ranges for properties.
[e]Nonlithophysal layers in unit TSw1.
[f]Lithophysal layers in unit TSw1.
[g]For lithophysal layers, the total porosity is $\phi_m \cdot M + \phi_A \cdot A + \phi_L$, where ϕ_m is matrix porosity, ϕ_A is the porosity of the vapor-phase-altered material, ϕ_L is the volume fraction lithophysal cavities, and M and A are volume fractions of matrix and vapor-phase-altered material, respectively (Price et al, 1985).
[h]NA = not available.
[i]These units are at least partly below the water table. For the purpose of thermal/mechanical analyses, they have been assigned a saturation of 1.0.

Table 6-12. Mechanical properties of intact rock for thermal/mechanical units[a] at Yucca Mountain[b] (page 1 of 3)

Thermal/mechanical unit	Young's modulus (GPa)			Poisson's ratio			σ_c (MPa)[e]		
	Design value[c]	Variability evaluation[d]		Design value	Variability evaluation		Design value	Variability evaluation	
		value	range		value	range		value	range
TCw	30.8	40.0	±11.1	0.10	0.24	NA[f]	155	240	±163.5
PTn	2.2	3.8	±3.9	0.18	0.16	NA	7	19	±10.9
TSw1[g]	23.9	31.7	±17.9	0.13	0.25	±0.05	114	127	±16
TSw1[h]	15.2	15.5	±3.2	0.16	0.16	±0.03	18	16	±5
TSw2	31.1	30.4	±6.3	0.22	0.24	±0.06	171	166	±65
TSw3	25.0	NA	NA	0.11	NA	NA	46	NA	NA
CHn1v	4.8	7.1	±4.4	0.15	0.16	NA	17	27	±12.4
CHn1z	7.1	7.1	±2.1	0.16	0.16	±0.08	27	27	±9
CHn2z	8.6	11.5	±4.0	0.20	0.16	NA	34	40	±12.7
CHn3z	5.0	7.1	±4.4	0.17	0.16	NA	18	27	±11.0
PPw	12.1	16.3	±7.8	0.20	0.13	NA	51	57	±30.6
CFUn	7.6	7.6	±3.8	0.16	0.16	NA	31	31	±11
BFw	10.8	10.8	±4.7	0.13	0.13	±0.02	42	42	±14
CFMn1	11.5	15.2	±5.2	0.14	0.16	NA	48	52	±19.4
CFMn2	11.9	16.3	±3.4	0.18	0.16	NA	50	57	±13.1
CFMn3	9.9	13.2	±2.7	0.15	0.16	NA	40	45	NA
TRw	7.6	17.6	±3.8	0.18	0.13	NA	72	72	±23

Table 6-12. Mechanical properties of intact rock for thermal/mechanical units[a] at Yucca Mountain[b] (page 2 of 3)

Thermal/ mechanical unit	Cohesion (MPa)			ϕ(°)[i]			Tensile strength (MPa)		
	Design value	Variability evaluation value	Variability evaluation range	Design value	Variability evaluation value	Variability evaluation range	Design value	Variability evaluation value	Variability evaluation range
TCw	45	51.0	±20.26	29.7	44.0	±0.20	17.6	17.9	NA
PTn	3	8.0	±4.18	6.6	8.5	±0.08	1.0	1.0	NA
TSw1[g]	35	36.0	±11.40	27.4	34.9	±0.15	14.6	12.0	±4.6
TSw1[h]	8	11.0	NA	14.3	12.5	NA	1.0	1.0	NA
TSw2	50	34.0	±11.40	29.2	23.5	±0.15	16.9	15.2	NA
TSw3	NA	NA	NA	NA	NA	NA	NA	NA	NA
CHn1v	7	11.0	±4.28	13.4	12.0	±0.08	1.0	1.0	NA
CHn1z	10	10.9	±1.6	15.8	7.6	±2.60	1.0	1.0	NA
CHn2z	12	15.0	±3.33	18.5	16.4	±0.06	3.0	2.6	NA
CHn3z	7	11.0	±3.74	13.7	12.0	±0.07	1.0	1.0	NA
PPw	17	20.0	±7.04	21.4	21.0	±0.12	6.8	6.9	NA
CFUn	11	14.0	±5.51	17.8	15.6	±0.10	2.1	1.8	NA
BFw	14	20.0	±8.21	21.6	21.0	±0.14	7.0	6.9	NA
CFMn1	17	19.0	±5.21	21.0	19.9	±0.09	6.3	6.0	NA
CFMn2	17	20.0	±2.93	21.3	21.0	±0.05	6.7	6.9	NA
CFMn3	14	17.0	±2.83	19.7	18.0	±0.05	4.6	4.3	NA
TRw	23	27.0	±9.11	24.8	27.6	±0.14	11.3	11.1	NA

Table 6-12. Mechanical properties of intact rock for thermal/mechanical units[a] at Yucca Mountain[b] (page 3 of 3)

Footnotes

[a]Thermal/mechanical units are defined in Figure 6-6.
[b]See Appendix O of SNL (1987).
[c]Design values represent the basis for the Site Characterization Plan-Conceptual Design.
[d]Variability evaluation represents more recent results of data analyses and establishes ranges for properties.
[e]σ_c = unconfined compressive strength.
[f]NA = not available.
[g]Nonlithophysal portions of Unit TSw1.
[h]Lithophysal portions of Unit TSw1.
[i]ϕ = angle of internal friction.

Table 6-13. Mechanical properties and modeling parameters for fractures in thermal/mechanical units[a] at Yucca Mountain[b] (page 1 of 2)

Thermal/ mechanical unit	Unstressed aperture (μm) Design value[d]	Variability evaluation[c] UB[e]	RV[f]	LB[g]	Half-closure stress (MPa) Design value	Variability evaluation UB	RV	LB	Shear stiffness (MPa/m) Design value	Variability evaluation UB	RV	LB	Joint cohesion Design value	Variability evaluation UB	RV	LB
TCw	NA[h]	36.0	18.0	3.0	NA	2.0	1.1	0.5	NA	10^7	10^6	10^5	1.0	0.2	0.1	0
PTn	NA	26.0	5.4	5.4	NA	2.8	1.2	1.2	NA	10^7	10^6	10^5	1.0	0.2	0.1	0
TSw1	NA	36.0	18.0	3.0	NA	2.0	1.1	0.5	NA	10^7	10^6	10^5	1.0	0.2	0.1	0
TSw2	NA	36.0	18.0	3.0	NA	2.0	1.1	0.5	NA	10^7	10^6	10^5	1.0	0.2	0.1	0
TSw3	NA	36.0	18.0	3.0	NA	2.0	1.1	0.5	NA	10^7	10^6	10^5	1.0	0.2	0.1	0
CHn1v	NA	26.0	5.4	5.4	NA	2.8	1.2	1.2	NA	10^7	10^6	10^5	1.0	0.2	0.1	0
CHn1z	NA	26.0	5.4	5.4	NA	2.8	1.2	1.2	NA	10^7	10^6	10^5	0.4	0.2	0.1	0
CHn2z	NA	26.0	5.4	5.4	NA	2.8	1.2	1.2	NA	10^7	10^6	10^5	0.4	0.2	0.1	0
CHn3z	NA	26.0	5.4	5.4	NA	2.8	1.2	1.2	NA	10^7	10^6	10^5	0.4	0.2	0.1	0
PPw	NA	36.0	18.0	3.0	NA	2.0	1.1	0.5	NA	10^7	10^6	10^5	1.0	0.7	0.1	0
CFUn	NA	26.0	5.4	5.4	NA	2.8	1.2	1.2	NA	10^7	10^6	10^5	0.4	0.7	0.1	0
BFw	NA	36.0	18.0	3.0	NA	2.0	1.1	0.5	NA	10^7	10^6	10^5	1.0	0.7	0.1	0
CFMn1	NA	26.0	5.4	5.4	NA	2.8	1.2	1.2	NA	10^7	10^6	10^5	0.4	0.7	0.1	0
CFMn2	NA	26.0	5.4	5.4	NA	2.8	1.2	1.2	NA	10^7	10^6	10^5	0.4	0.7	0.1	0
CFMn3	NA	26.0	5.4	5.4	NA	2.8	1.2	1.2	NA	10^7	10^6	10^5	0.4	0.7	0.1	0
TRw	NA	36.0	18.0	3.0	NA	2.0	1.1	0.5	NA	10^7	10^6	10^5	1.0	0.7	0.1	0

Table 6-13. Mechanical properties and modeling parameters for fractures in thermal/mechanical units[a] at Yucca Mountain[b] (page 2 of 2)

Thermal/ mechanical unit	Friction coefficient				JCS_o[(i)]				JRC_o[(j)]				ϕ_r[(k)]			
	Design value[d]	Variability evaluation			Design value	Variability evaluation			Design value	Variability evaluation			Design value	Variability evaluation		
		UB	RV	LB		UB	RV	LB		UB	RV	LB		UB	RV	LB
TCw	0.80	0.8	0.54	0.2	NA	406.5	243.0	79.5	NA	12	9	6	NA	38.7	28.4	11.3
PTn	0.80	0.8	0.59	0.2	NA	6.8	17.7	28.6	NA	8	5	2	NA	38.7	30.5	11.3
TSw1	0.80	0.8	0.54	0.2	NA	68.5	135.1	201.7	NA	12	9	6	NA	38.7	28.4	11.3
TSw2	0.80	0.8	0.54	0.2	NA	113.0	171.0	229.0	NA	12	9	6	NA	38.7	28.4	11.3
TSw3	0.80	0.8	0.54	0.2	NA	13.0	46.0	79.0	NA	12	9	6	NA	38.7	28.4	11.3
CHn1v	0.80	0.8	0.59	0.2	NA	39.1	26.7	14.3	NA	8	5	2	NA	38.7	30.5	11.3
CHn1s	0.55	0.8	0.54	0.2	NA	36.0	27.0	18.0	NA	8	5	2	NA	38.7	28.4	11.3
CHn2s	0.55	0.8	0.59	0.2	NA	52.6	39.9	27.2	NA	8	5	2	NA	38.7	30.5	11.3
CHn3s	0.55	0.8	0.59	0.2	NA	37.7	26.7	15.7	NA	8	5	2	NA	38.7	30.5	11.3
PPw	0.80	0.8	0.59	0.2	NA	87.6	56.6	26.0	NA	12	9	6	NA	38.7	30.5	11.3
CFUn	0.55	0.8	0.64	0.2	NA	56.0	37.5	19.0	NA	8	5	2	NA	38.7	32.6	11.3
BFw	0.80	0.8	0.59	0.2	NA	56.0	42.0	28.0	NA	12	9	6	NA	38.7	30.5	11.3
CFMn1	0.55	0.8	0.64	0.2	NA	71.9	52.5	33.1	NA	8	5	2	NA	38.7	32.6	11.3
CFMn2	0.55	0.8	0.64	0.2	NA	69.7	56.6	43.5	NA	8	5	2	NA	38.7	32.6	11.3
CFMn3	0.55	0.8	0.64	0.2	NA	NA	45.0	NA	NA	8	5	2	NA	38.7	32.6	11.3
TRw	0.80	0.8	0.59	0.2	NA	96.0	72.0	46.0	NA	12	9	6	NA	38.7	30.5	11.3

[a] Thermal/mechanical units defined in Figure 6-6.
[b] See Appendix O of SNL (1987).
[c] Variability evaluation values represent more recent results of data analyses and establishes ranges for properties.
[d] Design values represent the basis for the Site Characterization Plan-Conceptual Design.
[e] UB = upper bound.
[f] RV = recommended value.
[g] LB = lower bound.
[h] NA = not applicable.
[i] JCS_o = joint wall compressive strength.
[j] JRC_o = joint wall roughness coefficient.
[k] ϕ_r = residual friction angle.

philosophy and procedures for assessing how representative the data base is of the in situ material. The logic for determining the recommended mechanical properties and their definitions is contained in Section 2.3 (mechanical properties of rock units - large scale). The range presented for each material property warrants discussion here.

6.1.2.3.1 Physical properties

Physical properties, which include porosity, grain density, and bulk density, are important to the understanding of the physical nature of the mechanical and thermal responses of tuff and are presented in Table 6-11.

Total porosity is the ratio of the volume of void space to the total volume of a material and includes matrix porosity, lithophysal porosity, and fracture porosity. Porosity is important to the understanding of bulk density and thermal/mechanical properties. For example, porosity is used to define the maximum water content that can exist in the rock in the 100 percent saturated state. Water content is important in understanding thermal properties (Section 2.4) and in performing thermal and mechanical analyses (Section 8.3.2.2). The term "lithophysal" is applied to the TSw1 unit that contains lithophysae (lithophysal cavities and associated vapor-phase-altered material). The TSw2 unit is referred to as "nonlithophysal", although it may contain a small percentage of lithophysae (See Figure 6-6). Price et al. (1985) provides a detailed description of lithophysae and the partitioning of porosity in unit TSw1. Lithophysae can locally increase the porosity of the rock mass to values of about 35 percent. This understanding is important because the reference state, and consequent bulk and thermal properties, is based on hydrologic considerations that indicate that lithophysal voids are not saturated when the matrix is less than 100 percent saturated. For all thermal and mechanical units total porosities presented neglect the potential contribution of fracture porosity. Fracture porosity is the ratio of void-volume of fractures to the volume of the portion of the rock mass under consideration. Because the total porosities for the thermal/mechanical units are two orders of magnitude greater than the fracture porosities reported, their potential effect on thermal properties, which is a volumetric contribution, in the context of the following discussion is considered negligible. The effect of fractures is considered important to the mechanical response and is discussed in Section 6.1.2.3.3 (strength properties). Additional details of the connection between porosity and physical, thermal and mechanical properties are contained within the individual sections on these subjects.

Grain density is defined as the grain weight divided by the grain volume; whereas bulk density is defined as the sum of the grain plus pore water weight divided by the bulk volume. These two parameters are important in understanding thermal properties (Section 2.4), and performing thermomechanical analyses (Section 8.3.2.2). The range presented for bulk density represents plus and minus one standard deviation from the mean and accounts for some of the variability discussed in Section 6.1.2.1.

The saturation states for thermal/mechanical units located above the water table were obtained from laboratory measurements on cores taken from the site (Montazer and Wilson, 1984). A 100 percent saturation state was assumed for thermal/mechanical units located below the water table. Thermal conductivity for all units and thermal capacitance for the units below the water table (PPw and underlying units) are for a nominal saturation of 1.0 (100 percent saturation), whereas thermal capacitance is calculated using saturations from Montazer and Wilson (1984) for units above the water table (CHn3 and overlying units).

6.1.2.3.2 Deformability properties

Deformability properties are important parameters necessary to perform analyses (Section 8.3.2.5) that determine the mechanical response induced by excavation (mechanical) and waste emplacement (thermomechanical). In the context of the reference design data base, deformability properties are defined as those properties of intact rock, fractures, and rock mass that relate stress to strain before the onset of yield (Section 6.1.2.3.3).

For intact rock, the deformability properties of interest are Young's modulus and Poisson's ratio (Table 6-12). The design value is the mean determined from available laboratory measurements or from empirical relationships (Section 2.1.4.2) and represents the value used in the Site Characterization Plan-Conceptual Design. The value and range provided in the columns labeled variability evaluation in Table 6-12 represent more recent results of data analyses. These values were determined through analysis of data collected on approximately 300 samples deformed at a standard set of conditions (Section 2.1.2.2).

Limited data were collected to investigate potential environmental effects upon elastic and strength properties. The environmental effects investigated included strain rate (Section 2.1.2.3.1.1), temperature (Section 2.1.2.1.3), and scale (Price, 1986). The mean value of the elastic properties determined from each of these investigations falls within the range determined by the tests run at the standard set of conditions. This implies that the tuff behaves as an elastic solid for the range of conditions investigated.

Other deformability properties required for analytical techniques applied to determine the mechanical response of fractured rock in Section 6.4.10 are the shear and normal stiffness of joints. Table 6-13 provides values for some of these properties. The shear stiffness values and coefficients of friction are derived from very limited laboratory measurements on tuff (Olsson, 1987). These data contain uncertainties because the data base is small and is built on data for artificial saw-cut surfaces. However, the stiffness and coefficient-of-friction values listed on Table 6-13 fall within the range of measured values for natural fractures in other works (Sun et al., 1985). Therefore, it is not expected that the results of the design analyses that use these values will change significantly as data on natural fractures are collected. Also, it is generally predicted that slippage along joints will be small and confined to regions very near underground openings, within the influence of the proposed ground support design. The normal stiffness values define the hyperbolic normal stress versus displacement relationship for fractures (Thomas, 1982). These data were obtained from natural and artificial fracture surfaces. Some fractures observed are coated or filled. The mechanical properties of these fillings may affect the mechanical response. As such, the range of shear stiffness and coefficient-of-friction values listed for use in design sensitivity analyses is large enough to account for this potential uncertainty.

For the rock mass, the deformability properties must incorporate the sum of contributed effects from the matrix and fractures (mechanical and geometric characteristics) (Table 6-14). The rock mass deformability properties are used in analyses (Section 8.3.2.2) in the same manner as elastic material properties. The design value of the deformation modulus is one-half of the design value of the intact rock value, and the range is given by plus and minus one standard deviation to the mean. The design value and range have been chosen based on engineering judgment; therefore, a degree of uncertainty is attached to them. The design value is supported by field measurements in similar rocks (Zimmerman et al., 1984), however, which suggest that 50 percent of the intact value is representative.

The design value and range of the Poisson's ratio for the rock mass is the same as that for intact rock (Table 6-14). Field results from the heated block experiment (Zimmerman et al., 1984) performed in densely welded tuff at G-Tunnel support this recommendation. Because field measurement of this parameter at the potential site is lacking, there is uncertainty in the design value and range presented. However, it is not expected that the design will be significantly affected by minor changes in the Poisson's ratio for the rock mass.

6.1.2.3.3 Strength properties

Strength is of fundamental importance to underground design because stability assessments are based on a comparison of the stresses predicted through analyses and the strength criterion considered. The strength criteria are either incorporated in analysis methods or are used to interpret analyses (Section 6.1.3).

The Mohr-Coulomb criterion (Jaeger and Cook, 1979) is currently used to define a strength criterion for intact rock. The linear criterion may be defined by the unconfined compressive strength and the angle of internal friction (Section 2.1.2.3, matrix compressive and tensile strengths). The design value is the mean determined from available laboratory measurements or from empirical relationships (Section 2.1.2.2) and the range is given by plus and minus one standard deviation from the mean, and represents the value used for the SCP-CD (Table 6-12). These values were determined through analysis of data collected on approximately 300 samples deformed at a standard set of conditions (Section 2.1.2.2).

There is no prescribed method for determining a rock mass strength criterion nor is there a reliable field test with which the rock mass strength can be measured. It is reasoned that the strength criterion for the rock mass should incorporate the sum of contributions from the intact rock, lithophysal porosity (where present), fractures (mechanical and geometric characteristics), scale effects, and environmental conditions. The strength

Table 6-14. Mechanical properties of the rock mass for thermal/mechanical units[a] at Yucca Mountain[b]

Thermal/ mechanical unit	Deformation modulus (GPa)			Poisson's ratio			σ_c (MPa)[e]			Cohesion (MPa)			ϕ (deg)[f]		
	Design value[c]	Variability evaluation[d]		Design value	Variability evaluation		Design value	Variability evaluation		Design value	Variability evaluation		Design value	Variability evaluation	
		value	range		value	range		value	range		value	range		value	range
TCw	15.4	20.0	±5.55	0.10	0.10	NA[g]	77.5	120.0	±81.75	22.5	26.0	±10.13	29.7	44.7	±0.20
PTn	1.1	1.9	±1.95	0.18	0.19	NA	3.5	9.5	±5.45	1.6	4.0	±2.09	6.6	8.5	±0.08
TSw1[h]	15.1	15.9	±4.2	0.20	0.22	±0.05	75.0	63.5	±33.30	22.1	18.0	±5.70	29.2	34.9	±0.15
TSw1[i]	7.6	7.6	±3.2	0.16	0.16	±0.05	18.0	16.0	±5.00	7.0	5.5	NA	14.3	12.5	NA
TSw2	15.1	15.2	±4.2	0.20	0.22	±0.05	75.4	83.0	±33.30	22.1	17.8	±5.70	29.2	23.5	±0.15
TSw3	15.1	NA	NA	0.20	NA	NA	75.4	NA	NA	22.1	NA	NA	29.2	NA	NA
CHn1v	2.4	3.6	±2.2	0.15	0.15	NA	8.5	13.5	±6.20	3.4	5.5	±2.14	13.4	12.0	±0.08
CHn1s	3.5	3.6	±2.1	0.17	0.16	±0.08	13.5	13.5	±4.50	5.1	5.4	±1.08	15.8	7.6	±2.60
CHn2s	3.5	5.8	±2.0	0.17	0.20	NA	13.5	20.0	±6.35	5.1	7.5	±1.67	15.8	16.4	±0.06
CHn3s	3.5	3.6	±2.2	0.17	0.18	NA	13.5	13.5	±5.50	5.1	5.5	±1.87	15.8	12.0	±0.07
PPw	6.1	8.2	±3.9	0.20	0.19	NA	25.5	28.5	±15.30	8.5	10.0	±3.52	21.1	21.0	±0.12
CFUn	3.8	3.8	±2.95	0.16	0.16	NA	15.5	15.5	±9.25	5.5	7.0	±2.76	17.8	15.6	±0.10
BFw	5.4	5.4	±2.35	0.13	0.13	±0.02	21.0	21.0	±7.00	7.0	10.0	±4.10	21.6	21.0	±0.14
CFMn1	5.4	7.6	±2.60	0.15	0.14	NA	22.3	26.0	±9.70	7.7	9.9	±2.61	20.5	19.9	±0.09
CFMn2	5.4	8.2	±1.7	0.15	0.17	NA	22.3	28.5	±6.55	7.7	10.0	±1.47	20.5	21.0	±0.05
CFMn3	5.4	6.6	±1.35	0.15	0.15	NA	22.3	22.5	NA	7.7	8.9	±1.42	20.5	18.0	±0.05
TRw	8.8	8.8	±0.10	0.18	0.19	NA	36.0	36.0	±11.50	11.5	13.5	±4.56	24.8	27.6	±0.14

[a]Thermal/mechanical units defined in Figure 6-6.
[b]See Appendix O of SNL, (1987).
[c]Design values represent the basis for the Site Characterization Plan-Conceptual Design Report (SNL, 1987).
[d]Variability evaluation values represent more recent results of data analyses and establish ranges for properties.
[e]σ_c = unconfined compressive strength.
[f]ϕ = angle of internal friction.
[g]NA = not available.
[h]Nonlithophysal portions of unit TSw1.
[i]Lithophysal portions of unit TSw1.

criterion provided is meant to provide a working range for engineering analyses.

Two approaches were taken simultaneously to assess the rock mass strength. These approaches were either included in analyses or were used to interpret analyses (Table 6-14). One approach involved providing an estimate of the strength criterion for intact blocks of rock in situ. In this instance, a Mohr-Coulomb strength criterion was used. The rock mass strength was assumed to be 50 percent of the unconfined compressive strength of the rock matrix and the coefficient of friction was assumed to be equal to that of intact rock. The goal of this assumption was to capture the potential effects of scale, temperature, and time on the strength of intact blocks of rock. The results of the analyses were routinely reviewed to determine whether this criterion had been exceeded.

The second approach involved providing an estimate of the propensity for slip along joints. The strength criterion for joints is given by the slip condition, which is defined by the cohesion and coefficient of friction (Jaeger and Cook, 1979). The cohesion is the fracture shear strength at zero normal stress. The range of joint cohesion presented is derived from laboratory data on ground surfaces (Table 6-13). A cohesion value of zero is a realistic minimum value for the range presented. The upper bound given is that determined from experimental work. Uncertainty in the upper limit results from the lack of sufficient data on real joints.

The recommended value for the friction coefficient is derived from data provided in Morrow and Byerlee (1984). The lower value listed for the friction coefficient in Table 6-13 is a value considered representative for certain clay gouges (Shimamoto and Logan, 1981; Morrow et al., 1982). Only a small percentage (about 2 percent) of the fractures at Yucca Mountain are clay filled (Spengler and Chornack, 1984). This value is a probable realistic lower value for these clay-filled fractures. The upper value is set from the range in values listed (Olsson and Jones, 1980; Teufel, 1981; Morrow and Byerlee, 1984) as a result of examining a variation in the environmental test conditions (e.g., rate and temperature effects). The overall range presented is based on laboratory measurements of the friction coefficient for ground surfaces under various environmental conditions (Sections 2.2.2.1). Uncertainties in the range exist because of the lack of sufficient measurements on real fractures; however, the range presented and considered by design analyses is fairly encompassing for earth materials.

The potential exists for scale-dependence of the fracture slip parameters (Barton, 1982). These effects and their impact on analysis results are currently being evaluated and will be studied further during site characterization.

Increasing time (rate effects) and increasing temperature will act to decrease the strength of intact rock (Paterson, 1978). On preexisting fractures and sawcuts, increasing time (Dieterich 1972a, 1972b), decreasing rates (Scholz et al., 1972; Scholz and Engelder, 1976), and increasing temperature (Friedman et al., 1974) all act to increase the coefficient of friction (the shear stress needed to cause sliding on a shear fracture).

The dominant deformation mechanism for intact tuff at repository conditions is fracture (Price, 1983). Since fracture in rock is a time-dependent thermally activated process (Handin and Carter, 1981), increasing time (decreasing rate) and increasing temperature will both act to weaken intact rock. Limited experimental data on tuff at elevated temperatures (Olsson and Jones, 1980; Olsson, 1982; Price, 1983) and low strain rates (Price et al., 1982) are, thus far, inconclusive in quantifying potential strength changes (Section 2.1.2.3.1). Data from the 15 tests completed to date are inconclusive in quantifying changes. Variations are present not only in temperature but also in other test conditions (pressure, strain rate, and confining pressure) and in intrinsic rock properties (density and porosity). The temperatures (<200°C) are expected to dry out the rock mass, thus strengthening it. In an attempt to account for potential time effects, most laboratory tests have been performed on fully saturated rocks, incorporating potential thermomechanical effects characteristic of time-dependent thermally-activated fracture. The deformation mechanisms active on stressed fracture surfaces are undoubtedly microfracture and crystal plasticity owing to the high stress concentrations due to the relatively low real area of contact (Teufel and Logan, 1978). Since these two mechanisms are also time-dependent thermally activated processes, increasing time (decreasing rate) and increasing temperature both act to facilitate local plastic deformation at point contacts, thus causing an increase in the real area of contact. This phenomenon is manifested in tuff as an increase in the frictional strength (Teufel, 1981).

The tensile strength of a fractured rock mass can be locally very close to zero, which is the tensile strength of individual fractures. The tensile strength of the intact rock portion of the rock mass (Table 6-12) helps define the strength criterion in the vicinity of the origin of the Mohr-Coulomb diagram. Thus, the rock mass tensile strength is meant to be a modeling parameter rather than a material property. The design value for the tensile strength of intact rock is then scaled down to account for potential effects of flaws encountered in larger size samples or in blocks of rocks more representative of the field scale defined by the fracture spacing. The rock mass tensile strength value is expected to be determined by the relationship between tensile strength and unconfined compressive strength (modified Griffith criterion) presented in Jaeger and Cook (1979).

6.1.2.3.4 Geometric characteristics of discontinuities

The geometric and mechanical characteristics of discontinuities such as faults, fractures, and joints are important to design because these characteristics, coupled with intact rock properties, allow for assessment of rock mass thermomechanical response through the empirical and analytical techniques presented in Section 8.3.2.2.

The geometric description of faults pertinent to design includes distribution, offset characteristics orientation, spacing, length, and width. This information is detailed in Section 1.3.2.2 and its relation and impact on underground design is discussed in Section 6.2.6. Uncertainties exist in terms of extrapolation of faults and their description underground. A comprehensive three-dimensional subterranean geologic description of the site area (Ortiz et al., 1985) provides a means of extrapolating surface data to depth when combined with drillhole data. This type of analysis allows for an understanding of the geometrical relationships of faults to the design. Although the mechanical properties of the fault zones at depth remain an uncertainty, bounding calculations that consider realistic variations of these properties have been performed as part of the design process (Hustrulid, 1984b). Also, in similar lithology and in situ stress conditions at G-Tunnel, faults have been encountered at depth and have not presented any significant complications in terms of opening usability or ground support implementation.

Field characterization of fractures and joints (fractures without evidence of shear displacement) is included in Section 1.3.2.2 and summarized in Table 6-15. This characterization includes a map showing the location and trend of all known joint sets. For each joint set the areal distribution, attitude, length, and frequency are presented. Surface data, combined with subsurface data (Spengler et al., 1981; Maldonado and Koether, 1983; Scott and Castellanos, 1984; Spengler and Chornack, 1984), allow for reasonable estimates of the two- and three-dimensional characteristics and the variations of joints and fractures to be determined. The variations in the characteristics observed are related to the limited sampling available (vertical boreholes) and the fact that many of the fractures at the site are near vertical, and thus sampling may be biased. Also, there are very little data on the subsurface attitude of fractures. The potential combination of vertical and horizontal fractures has been considered in the design of ground support for underground openings.

6.1.2.4 Thermal properties

Thermal properties--thermal expansion coefficient, thermal conductivity, and thermal capacitance--are important in determining the time-varying extent of thermally induced stresses and displacements resulting from emplacement of radioactive waste. Theoretical considerations coupled with field measurements and analysis (Zimmerman, 1983; Blanford and Osnes, 1987) imply that, in general, laboratory-determined thermal properties may be directly applicable at the rock mass scale.

6.1.2.4.1 Thermal expansion coefficient

The design value and range for the thermal expansion coefficient for the rock mass is the same as that for intact rock for each thermal/mechanical unit. The design value is given as the mean of measurements for intact samples and the range is given in plus and minus one standard deviation to the mean (Table 6-16).

Uncertainties in the range are the result of sample-to-sample inhomogeneities. Also, calculated expansion coefficients are qualitatively consistent with measurements. The uncertainties are not likely to significantly affect the design because of the observed agreement between measured and calculated

Table 6-15. Recommended values for fracture frequency in thermal/mechanical units[a] at Yucca Mountain[b] (page 1 of 2)

Thermal/mechanical unit	Fracture frequency (fractures per meter) at intervals of angles of inclination[c]								
	0°-10°	10°-20°	20°-30°	30°-40°	40°-50°	50°-60°	60°-70°	70°-80°	80°-90°
TCw[d]	0.40[e] 0.90[f] 0.05[g]	0.80 1.90 0.09	0.50 1.00 0.05	0.50 1.00 0.05	0.40 0.60 0.10	0.50 0.90 0.20	1.20 2.00 0.70	2.1 2.80 1.20	15.7 28.0 1.9
PTn	0.20 NA[h] NA	0.30 NA NA	0.20 NA NA	0.10 NA NA	0.20 NA NA	0.10 NA NA	0.40 NA NA	0.3 NA NA	2.8 NA NA
TSw1[d,i]	0.20 0.50 0.05	0.20 0.60 0.05	0.20 0.60 0.05	0.10 0.30 0.05	0.20 0.40 0.05	0.20 0.50 0.05	0.30 0.70 0.10	1.7 2.60 0.70	13.2 32.5 2.5
TSw2[d,i]	0.20 0.50 0.05	0.20 0.60 0.05	0.20 0.60 0.05	0.10 0.30 0.05	0.20 0.40 0.05	0.20 0.50 0.05	0.30 0.70 0.10	1.7 2.60 0.70	13.2 32.5 2.5
TSw3[d,i]	0.20 0.50 0.05	0.20 0.60 0.05	0.20 0.60 0.05	0.10 0.30 0.05	0.20 0.40 0.05	0.20 0.50 0.05	0.30 0.70 0.10	1.7 2.60 0.70	13.2 32.5 2.5
CHn1v[d]	0.05 0.05 0.05	0.05 0.05 0.05	0.05 0.05 0.05	0.05 0.05 0.05	0.05 0.05 0.05	0.05 0.05 0.05	0.08 0.09 0.05	0.5 1.50 0.05	0.8 1.2 0.1
CHn1z[d]	0.05 0.05 0.05	0.05 0.05 0.05	0.05 0.05 0.05	0.05 0.05 0.05	0.05 0.05 0.05	0.05 0.05 0.05	0.08 0.09 0.05	0.5 1.50 0.05	0.8 1.2 0.1
CHn2[d]	0.05 0.05 0.05	0.05 0.05 0.05	0.05 0.05 0.05	0.05 0.05 0.05	0.05 0.05 0.05	0.05 0.05 0.05	0.08 0.09 0.05	0.5 1.50 0.05	0.8 1.2 0.1
CHn3[d]	0.05 0.05 0.05	0.05 0.05 0.05	0.05 0.05 0.05	0.05 0.05 0.05	0.05 0.05 0.05	0.05 0.05 0.05	0.08 0.09 0.05	0.5 1.50 0.05	0.8 1.2 0.1
PPw[d]	0.05 0.05 0.05	0.10 0.20 0.05	0.08 0.10 0.05	0.10 0.20 0.05	0.08 0.10 0.05	0.10 0.20 0.05	0.30 0.50 0.05	0.6 0.70 0.50	1.0 1.7 0.2
CFUn	0.05 NA NA	0.05 NA NA	0.05 NA NA	0.05 NA NA	0.05 NA NA	0.05 NA NA	0.10 NA NA	0.01 NA NA	0.04 NA NA
BFw	0.05 0.05 0.05	0.05 0.05 0.05	0.05 0.05 0.05	0.05 0.06 0.05	0.20 0.40 0.05	0.30 0.50 0.05	0.60 1.30 0.05	1.4 3.80 0.10	6.5 18.9 0.2
CFMn1	0.05 NA NA	0.05 NA NA	0.05 NA NA	0.05 NA NA	0.05 NA NA	0.05 NA NA	0.05 NA NA	0.1 NA NA	0.4 NA NA
CFMn2	0.05 NA NA	0.05 NA NA	0.05 NA NA	0.05 NA NA	0.05 NA NA	0.05 NA NA	0.05 NA NA	0.1 NA NA	0.4 NA NA

Table 6-15. Recommended values for fracture frequency in thermal/mechanical units[a] at Yucca Mountain[b] (page 2 of 2)

Thermal/ mechanical unit	Fracture frequency (fractures per meter) at intervals of angles of inclination[c]																	
	0°-10°		10°-20°		20°-30°		30°-40°		40°-50°		50°-60°		60°-70°		70°-80°		80°-90°	
CFMn3	0.05	NA NA	0.05	NA NA	0.05	NA NA	0.05	NA NA	0.05	NA NA	0.05	NA NA	0.05	NA NA	0.1	NA NA	0.4	NA NA
TRw	0.07	0.09 0.05	0.06	0.06 0.05	0.05	0.06 0.05	0.05	0.05 0.05	0.05	0.05 0.05	0.05	0.05 0.05	0.30	0.50 0.05	0.2	0.20 0.20	3.9	7.0 0.7

[a]Thermal/mechanical units are defined on Figure 6-6.
[b]See Appendix O of SNL (1987). No specific design value was used at the onset of the conceptual design.
[c]Fracture frequencies were calculated as the average (arithmetic mean) of values from the four drillholes for which information is available. A mean value and a range are presented only for those units represented in at least two of the drillholes of Table 6 of Appendix O (SNL, 1987). Angles of inclination are presented in degrees measured downward from the horizontal.
[d]Represented in at least two drillholes.
[e]Mean value.
[f]Upper bound.
[g]Lower bound.
[h]NA = not available.
[i]Units TSw1, TSw2, and TSw3 are assumed to have the same fracture frequencies for this table.

Table 6-16. Thermal properties for intact rock and rock mass for each thermal/mechanical unit[a] at Yucca Mountain[b] (page 1 of 2)

Thermal/mechanical unit	Thermal conductivity (W/mK)						Coefficient of thermal expansion ($10^{-6}K^{-1}$)									Thermal capacitance (J/cm³ k)			
	Saturated[c]			Dry			Pretransition			Transition			Posttransition			Saturated[c]		Dry	
	Design value	Variability evaluation[d] mean	Variability evaluation[d] range	Design value	Variability evaluation mean	Variability evaluation range	Design value	Variability evaluation mean	Variability evaluation T(°C)	Design value	Variability evaluation mean	Variability evaluation (T°C)	Design value	Variability evaluation Mean	Variability evaluation T(°C)	Design value	Variability evaluation value	Design value	Variability evaluation value
TCw	2.00	1.84[f]	±0.12[f]	1.90	1.41[f]	±0.13[f]	10.7	8.8[f]	25-200[f]	NA[g]	NA	NA	NA	NA	NA	2.24	2.18	1.86	1.88
PTn	1.17	1.35	±0.06	1.02	1.02	±0.19	5.0	5.3[h]	25-150[h]	5.0	3.5	150-350	NA	NA	NA	2.59	2.24	1.09	1.09
TSw1[i]	2.07	2.07[i]	±0.16[i]	1.91	1.90[i]	±0.18[i]	10.7	8.8[i,f]	25-200[i,f]	31.8	31.8	200-350	NA	NA	NA	2.25	2.09[i]	1.88	1.98[i]
TSw1[j]	1.16	1.50[j]	NA	0.85	0.79[j]	NA	10.7	NA[j]	25-200[j]	31.8	NA	NA	NA	NA	NA	1.88	1.87[j,k]	1.38	1.38[j,k]
TSw2	2.07	1.84	±0.12	1.91	1.41	±0.13	10.7	8.8	25-200	31.8	24.0	200-350	NA	NA	NA	2.25	2.16	1.88	2.17
TSw3	2.07	1.33	±0.08	1.91	1.34	±0.12	10.7	5.3	25-150	31.8	3.5	150-250	NA	NA	NA	2.25	2.04	1.88	2.45
CHnlv	1.21	1.35	±0.06	1.02	1.02	±0.19	5.0	5.3[h]	25-150[h]	5.0[h]	3.5[h]	150-250[h]	NA	NA	NA	2.46	2.61	1.24	1.26
CHnls	1.35	1.48	±0.17	1.03	1.01	±0.14	6.7	6.7	25-T_b	-56.0	-56.0	T_b-150	-4.5	-4.5	150-300	2.46	2.61	1.37	1.36
CHn2	1.35	1.61	±0.04	1.03	1.21	±0.04	6.7	6.7[l]	25-T_b[l]	-56.0	-56.0[l]	T_b-150[l]	-4.5	-4.5[l]	150-300[l]	2.46	2.62	1.37	1.51
CHn3	1.35	1.43[m]	±0.03[m]	1.03	1.04[n]	±0.05[m]	6.7	6.7[l]	25-T_b[l]	-56.0	-56.0[l]	T_b-150[l]	-4.5	-4.5[l]	150-300[l]	2.46	2.66	1.37	1.30
PPw	2.00	2.00[n]	±0.27[n]	1.35	1.35[n]	±0.30[n]	8.3	8.3[n]	25-T_b[n]	-12.0	-12.0[n]	T_b-125[n]	10.9	10.9[n]	>125[n]	2.64	2.65	1.64	1.65
CFUn	1.43	1.43	±0.03	1.04	1.04	±0.05	6.7	6.7[l]	25-T_b[l]	-56.0	-56.0[l]	T_b-150[l]	-4.5	-4.5[l]	150-300[l]	2.67	2.68	1.43	1.43
BFw	2.00	2.00	±0.27	1.35	1.35	±0.30	8.3	8.3	25-T_b	-12.0	-12.0	T_b-125	10.9	10.9	>125	2.65	2.66	1.66	1.66
CFMn1	1.48	1.43	±0.00	1.13	1.11	±0.07	6.7	6.7[l]	25-T_b[l]	-56.0	-56.0[l]	T_b-150[l]	-4.5	-4.5[l]	150-300[l]	2.59	2.56	1.53	1.52
CFMn2	1.48	1.61[o]	±0.04[o]	1.13	1.21[o]	±0.04[o]	6.7	6.7[l]	25-T_b[l]	-56.0	-56.0[l]	T_b-150[l]	-4.5	-4.5[l]	150-300[l]	2.59	2.61	1.53	1.61
CFMn3	1.48	1.46	NA	1.13	1.11	NA	6.7	6.7[l]	25-T_b[l]	-56.0	-56.0[l]	T_b-150[l]	-4.5	-4.5[l]	150-300[l]	2.59	2.62	1.53	1.50
TRw	2.09	2.09	±0.18	1.79	1.79	±0.37	8.3	8.3[n]	25-T_b[n]	-12.0	-12.0[n]	T_b-125[n]	10.9	10.9[n]	>125[n]	2.57	2.58	1.79	1.79

Table 6-16. Thermal properties for intact rock and rock mass for each thermal/mechanical unit[a] at Yucca Mountain[b] (page 2 of 2)

Footnotes

[a]Thermal/mechanical units defined in Figure 6-6.
[b]See Appendix O of SNL (1987).
[c]Thermal conductivity data for all units and thermal capacitance data for PPw and underlying units are for a nominal saturation of 1.0, whereas thermal capacitance data for CHn3 and overlying units are calculated using saturations from Montaser and Wilson (1984).
[d]Variability evaluation represents more recent results of data analyses and establishes ranges for properties.
[e]Design values represent the basis for the Site Characterisation Plan-Conceptual Design.
[f]Assumed to be the same as correlative property for TSw2.
[g]NA = not available.
[h]Assumed to be the same as correlative property for TSw3.
[i]Nonlithophysal layers in unit TSw1.
[j]Lithophysal layers in unit TSw1.
[k]For lithosphysal layers, the total porosity is $\phi_m \cdot M + \phi_A \cdot A + \phi_L$, where ϕ_m is matrix porosity, ϕ_A is the porosity of vapor-phase altered material, ϕ_L is the volume fraction lithophysal cavities, and M and A are volume fractions of matrix and vapor-phase-altered material, respectively (Price et al. 1985).
[l]Assumed to be the same as correlative property for CHnlz.
[m]Assumed to be the same as correlative property for CFUn.
[n]Assumed to be the same as correlative property for BFw.
[o]Assumed to be the same as correlative property for CHn2.

coefficients. Further, this parameter is not currently expected to vary beyond the range presented.

6.1.2.4.2 Thermal conductivity

The design value and range for the thermal conductivity for the rock mass is the same as that for the intact rock for each thermal/mechanical unit. The design value is given as the mean of measurements for intact samples, and the range presented is plus and minus one standard deviation from the mean. The conductivity at saturated conditions is calculated using methods described in Section 2.4.2.1.2. There is a difference between measured and calculated dry thermal conductivities because of mineralogic dehydration (Section 2.4.2.1.1). For certain units, there is a lack of experimental data. For these units the mean and range of units with similar physical and mineralogic properties are used.

Uncertainties in both the mean and the range for all units are the result of sample-to-sample inhomogeneities. The range captures the effect of the sample-to-sample inhomogeneities. For certain thermal/mechanical units (as noted), there is a lack of experimental data. For these units, the mean and range of units with similar mineralogic and bulk properties are used to derive values of thermal conductivity. In general, these units are either at some distance from the emplacement horizon or are not volumetrically significant in terms of accommodation of mechanical or thermal/mechanical loads. Thus, use of these derived conductivity values is considered legitimate for the far-field nature of the analyses. Further, variations in thermal conductivity for these distant, volumetrically insignificant units would not lead to conclusions different from those drawn already from far-field analyses.

6.1.2.4.3 Thermal capacitance

The design values for the thermal capacitance of the rock mass are assumed to be the mean of values calculated for intact samples, and the range presented is plus and minus one standard deviation from the mean (Table 6-16). No NNWSI Project measurements of thermal capacitance or specific heat have yet been made on tuffs. For the SCP-CD these parameters were calculated, assuming a constant heat capacity for the silicate mineral assemblage of 0.84 J/g °C, water heat capacity of 4.18 J/g °C, and air heat capacity much smaller (Tillerson and Nimick, 1984). Calculated values of the thermal capacitance (heat capacity/density product) show a broad range that depends on both porosity and degree of saturation. By considering reasonable variations in both the porosity and degree of saturation, the uncertainty in the range considered is small. This is because even with the most extreme ranges in saturation state, the variation in the volumetric heat capacity is small.

6.1.2.5 Hydrologic considerations

Hydrologic considerations, including the infiltration (water flux entry into the soil at the ground surface), percolation, (water flux through the rock units below the ground surface), hydraulic conductivity (capability of the rock to transmit water), and flood potential are factors important to design stability (Section 6.2.6.3), ventilation (Section 6.2.6.5), and sealing (Section 6.2.8). Infiltration, percolation, and hydraulic conductivity are discussed in the context of surface and ground water.

6.1.2.5.1 Surface water

The surface hydrology of the site influences the design of the surface facilities through both the location and flow frequencies of surface runoff. In addition, infiltration of surface runoff, which is a potential recharge source, influences the subsurface design. 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. Because of the extreme aridity of this region, where the annual precipitation averages about 20 percent of the potential evapotranspiration, most of the spring discharge travels only a short distance before evaporating or infiltrating back into the ground. Infiltration rates are low (<3 to 4 mm/yr) because of low precipitation, high runoff, and high evaporation rates.

Rapid runoff during heavy precipitation flows in the normally dry washes for brief periods of time. Local flooding can occur where the water exceeds the capacity of the channels. The potential for flooding at Yucca Mountain is described in detail in Section 6.1.2.6. In contrast to washes, the terminal playas may contain standing water for days or weeks after severe storms. Runoff from precipitation at Yucca Mountain drains into Fortymile Wash on the east and Crater Flat on the west, and both areas drain into the normally dry Amargosa River. If runoff is very high, water in the Amargosa River flows into the playa in southern Death Valley.

6.1.2.5.2 Ground water

Yucca Mountain lies within the Death Valley ground-water system, a large and diverse area in southern Nevada and adjacent parts of California composed of many mountain ranges and topographic basins that are hydraulically connected at depth. In general, ground water within the Death Valley system travels toward Death Valley, although much of it discharges before reaching Death Valley. Ground water in the Death Valley system does not enter neighboring ground-water systems.

The Death Valley ground-water system is divided into several ground-water basins. Apparently ground water moving beneath Yucca Mountain discharges at Alkali Flat and perhaps at Furnace Creek in Death Valley, but not in Ash Meadows or Oasis Valley. Yucca Mountain is in the Alkali Flat-Furnace Creek Ranch ground-water basin, at a position between the Ash Meadows and the Oasis Valley basins (Waddell, 1982).

Geologic formations in southern Nevada have been grouped into broad hydrogeologic units (Winograd and Thordarson, 1975; Montazer and Wilson, 1984; Peters et al., 1984; and Rush et al., 1984). Several of the units (aquifers) transmit water in sufficient quantities to supply water needs; whereas other units (aquitards) have relatively low permeabilities that tend to retard the flow of ground water. The geologic and hydrologic properties of the aquifers vary widely. The lower and upper carbonate aquifers and the welded tuff aquifers store and transmit water chiefly along the fractures. In contrast, the valley-fill alluvial aquifers store and transmit water chiefly through interstitial pore openings. The lower carbonate and valley-fill aquifer are the main sources of ground water in the eastern part of the NTS.

The unsaturated zone within the boundary of the primary repository area at Yucca Mountain is about 500 to 700 m thick. Within the site, the local water table slopes to the southeast and south, from an elevation of 800 m to as low as 730 m above sea level. The regional water table is 200 to 400 m below the horizon proposed for the emplacement area.

Most of the annual precipitation, approximately 150 mm (Montazer and Wilson, 1984), is returned to the atmosphere by evaporation and plant transpiration. A small part of the precipitation on Yucca Mountain percolates through the matrix of the unsaturated zone. Czarnecki (1985) calculated a recharge rate of about 0.5 mm/yr for the precipitation zone that includes Yucca Mountain. The principal source of recharge for the tuff aquifer is probably Pahute Mesa to the north and northwest of Yucca Mountain. The general direction of regional ground-water flow is south-southeast toward points of natural discharge at Alkali Flat and perhaps westward to Furnace Creek in Death Valley.

The potential repository horizon, the densely welded Topopah Spring Member, is located above the ground-water table. The in situ saturation of the Topopah Spring Member is estimated to be 65 ±19 percent and estimated percolation rates through this zone on the order of 0.5 mm/yr (Montazer and Wilson, 1984). The saturated hydraulic conductivity of the tuff rock mass (matrix plus fractures) is about 365,000 mm/yr (Sinnock et al., 1984, as derived from Thordarson, 1983). This value compares with a saturated value of approximately 0.6 mm/yr (Peters et al., 1984) for matrix flow through the Topopah Spring Member. It should be emphasized that the values of unsaturated conductivity depend on moisture content and are less than saturated conductivities. At 84 percent saturation, the upper bound, it is uncertain whether fracture flow is involved.

Thus, the magnitude of the saturated hydraulic conductivity of the rock mass is governed almost entirely by the presence of fractures. However, because the units within and above the proposed emplacement horizon are unsaturated, the in situ hydraulic conductivity of the tuff is significantly less than the saturated value.

Exploratory drilling at the site has not encountered any saturated zones above the water table that can be definitely identified as perched water, and it is not expected that any major perched water zones will be encountered. Some localized zones of saturation may exist within fault zones or beneath areas of high infiltration of surface runoff.

Ground water flowed from fractures at G-Tunnel (in Rainier Mesa) following drift excavation, but the flow eventually ceased (Thordarson, 1983). Similar localized flow from faults could occur within the prospective emplacement horizon and is being considered in design.

The depth to the carbonate aquifer beneath the primary repository area has not been determined, but can be inferred to be much more than the 1,250 m observed in drillhole UE-25p#1 located 2.5 km east of the primary area. At drillhole UE-25p#1, the hydraulic head in the carbonate rocks is 20 m higher than in the overlying tuffaceous rocks (Waddell et al., 1984). Because water cannot move in the direction of higher hydraulic head, it is concluded that ground water in the tuff aquifers beneath Yucca Mountain does not enter the carbonate aquifer.

Deep regional movement of ground water south and east of Yucca Mountain occurs chiefly through the lower carbonate aquifer. As a result of the complex geologic structures, flow paths are complex and poorly defined.

6.1.2.6 Flood characteristics

Because of the rugged terrain and meteorological conditions at the Yucca Mountain site, brief, but intense localized precipitation occurs periodically. In the vicinity of the site, Fortymile Wash and three of its principal tributaries, Yucca Wash, Drill Hole Wash, and Busted Butte Wash, have been analyzed for the 100-yr flood, 500-yr flood, and regional maximum flood (Squires and Young, 1984). Since it is shown that, for a 100-yr flood, water does not exceed the banks of the incised channels, the manifestations of a 50-yr flood are not presented. The flood zones in the surface facilities area considered in the flood analyses are shown in Figure 6-8 (Squires and Young, 1984). The flood history and potential are described in Section 3.2.1.

In the flood analyses performed thus far, except for the men-and materials-shaft area described in Section 6.2.4.2, maximum flood flows are derived from Crippen and Bue (1977), who present graphs of peak discharges versus drainage areas for measured historical floods with envelope curves above the plotted floods. The envelope curves represent the maximum potential flood for a given drainage area.

The flood flows for return periods of 100 to 500 yr are based on analysis of regional streamflow records at sites on the perimeter of the Nevada Test Site and Nellis Air Force Range, which are representative of the repository site. To determine the regional maximum flood, data were used from maximum flood flows that have been measured at other locations within the region, including all or parts of Nevada, California, Utah, Arizona, and New Mexico (Crippen and Bue, 1977). In this method, flood flows at the site are derived only on the basis of the area of the drainage basin. For example, the site-specific characteristics, such as ground slope, runoff and infiltration, are not represented.

In this preliminary analysis, it is concluded that the flood flows along Fortymile Wash would remain within the incised channel throughout the study

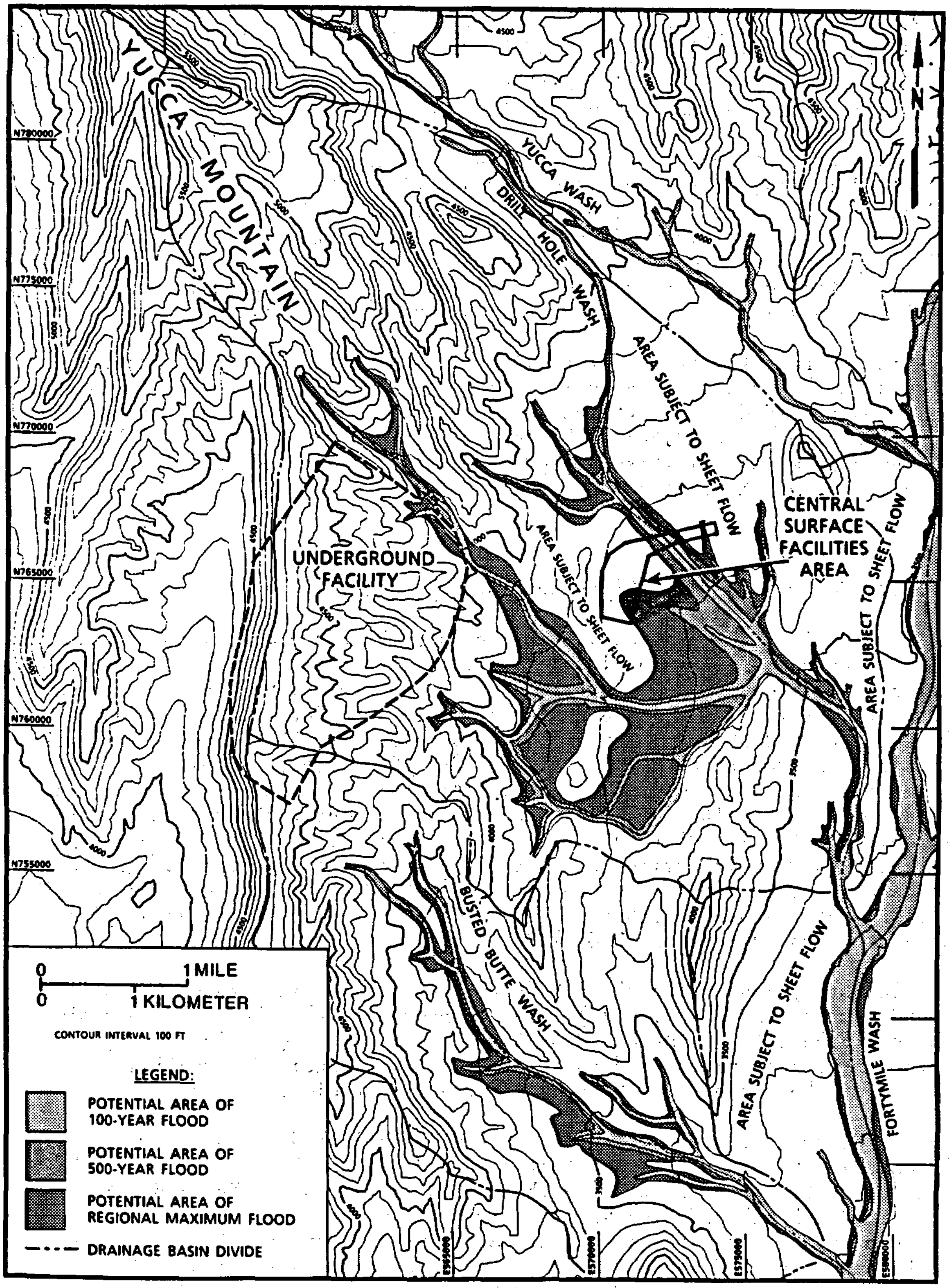


Figure 6-8. Site topography and flood potential areas. Modified from Squires and Young (1984).

area. In addition, at the Busted Butte and Drill Hole Wash drainages, the 500-yr flood would exceed stream-channel capacities at several places and the regional maximum flood would inundate sizable areas in the central parts of the watersheds. It is concluded that at Yucca Wash, flood flows of all three magnitudes would remain within the stream channel.

The later stages of design will be based on probable maximum flood (PMF) flows and levels, determined in accordance with ANSI/ANS 2.8 (1981). This method takes into account site-specific characteristics, including terrain, soil, and rock conditions of the drainage basin. This method is used by the U.S. Army Corps of Engineers for dam design and by the nuclear power industry for protection of safety-related facilities. The PMF method is more site-specific and severe than the regional maximum flood analyses.

In general, the surface facilities important to safety and underground entries at the repository site will be protected against the PMF by channels and dikes provided to divert the upland runoff and by setting finish grade elevations above the adjacent PMF levels. This design effort will be continued as more definitive topographic maps at selected locations and PMF calculations become available.

6.1.2.7 Seismic considerations pertinent to design

Evaluation of ground motion at the Yucca Mountain site must address two types of events: (1) natural seismicity (earthquakes) and (2) underground nuclear explosions (UNEs), which are conducted periodically at the Nevada Test Site (NTS). The seismic design criteria used for the SCP-CD is a vibratory ground motion input of 0.40g, developed on the basis of information contained in current documents (USGS, 1984; DOE, 1986c; URS/Blume, 1986) and seismologic and engineering judgment. This value may be revised and possibly increased as a result of ongoing studies, particularly the characterization of faults in the immediate vicinity of the site, for use in future design analysis. A seismic design criteria of 0.4g envelops the maximum ground acceleration expected from ground motion induced by a maximum yield UNE (700 kilotons) at the NTS, which is equal to 0.32g based on a mean value plus three standard deviations (DOE, 1986c).

The study supporting the SCP-CD used probabilistic methods to estimate ground motion (URS/Blume, 1986). This approach established a seismogenic zoning of the site region based on the history of the seismic events, late Quaternary strain rates, and the mode of later Cenozoic deformation in order to predict the ground motion hazard in the site region.

An occurrence model for UNEs was also established in this study, using historical data of NTS testing that occurred before the Threshold Test Ban Treaty. Probable future testing that would be nearest to Yucca Mountain will occur in the Buckboard Mesa area. This area, which is approximately 15 miles from the repository site, is closer to the repository site than any of the locations on the NTS where testing actually occurs. A maximum yield of 700 kilotons was established for a UNE at Buckboard Mesa in order to avoid significant damage in the surrounding region. The current testing limit of

150 kilotons, established by the Threshold Test Ban Treaty, produces negligible ground motion at the repository site.

The ground motions used in the SCP-CD are (1) an acceleration value of 0.4g with a return period of 2,000 yr for natural earthquakes and (2) an acceleration value of 0.15g based on the mean of observed responses plus 2 standard deviations for UNEs (Table 6-17).

In an additional study that is in process, faults in the vicinity of the site are assumed to be active. Fault-specific, random earthquake-occurrence models have been developed to predict the hazards caused by ground motion and fault displacements. The earthquake occurrence was determined from published fault-length and slip-rate information. The faults considered include the Bow Ridge, Paintbrush, Ghost Dance, Midway Valley, and Severe Wash faults.

Technology exists for designing surface facilities for accelerations much larger than those described previously; typical examples include the Diablo Canyon nuclear power plant and San Onofre nuclear power plant. Published literature also shows that structures can be designed to resist moderate surface displacement before any catastrophic failure could occur (Reed et al., 1979).

It is provisionally assumed that the peak accelerations at the emplacement level are half those at the surface. This assumption is based on an attenuation of ground motion with depth derived from UNE test data and other published information on earthquakes (Carpenter and Chung, 1985; URS/Blume, 1986). Carpenter and Chung (1985) indicate that up to surface-shaking levels (0.5g), no tunnel collapses have been observed because of shaking alone. They also point out that tunnels in poor soil and rock are more susceptible to damage than are tunnels deep in rock and that damage to all classes of deep tunnels consisted primarily of minor rockfalls and formation of new cracks, except where active faults intersected tunnels. In these instances, although severe damage occurred, the damage is localized and is readily repaired using existing technology. Hence, it can be seen that the use of current technology permits designing underground facilities that can withstand the levels of acceleration described above. The topic of borehole stability during a seismic event was not addressed as part of the SCP-CD effort. This topic will be addressed in future design activities after the impacts, if any, of borehole collapse on containment, isolation, and retrievability have been assessed.

Plans for continued work to identify design values for ground motion and surface rupture for use in more advanced design phases are discussed further in Section 8.3.1.17.

6.1.2.8 Dust characteristics

Dust characteristics, including particle size distribution, composition, and mass concentration, are important for determination and maintenance of acceptable air quality. Such information is needed for the detailed design of the ventilation systems and the surface aspects of the muck pile. Detailed calculations of dust concentration have not been performed for the

Table 6-17. Peak ground accelerations at the surface used in conceptual design[a] (SNL, 1987)

Seismic event	Acceleration (g)		Return period (yr)
	Horizontal	Vertical	
Design earthquake	0.40	0.27	2,000
Design underground explosion	0.15	0.18	NA[b]

[a]URS/Blume, 1986.
[b]NA = not applicable.

conceptual design. Dust composition is expected to be similar to that of the rock being excavated. Data on particle size distribution and mass concentration are currently lacking.

6.1.3 ANALYTICAL TOOLS FOR GEOTECHNICAL DESIGN

The process of developing and analyzing a geotechnical design for a repository, including identifying and resolving analytical design problems, is accomplished through application of the issue resolution strategy (IRS) to the design issues identified in Section 6.4. The IRS methodology has been adopted by the DOE and is presented in detail in Section 8.1.2. As applied to the design issues, the IRS includes the use of analytical tools (or methods) and techniques in (1) identifying specific problems involved in resolving an issue; (2) separating these design problems into their component parts; (3) determining the functions, processes, performance measures, performance goals, and confidence required in meeting the performance goals; (4) selecting an empirical or numerical solution method that can be used to judge whether the goals are met; (5) identifying the parameters needed to use the selected solution method; (6) establishing the ranges and confidence levels required for these parameters; (7) obtaining these parameters from site characterization activities or other sources; and (8) using the selected solution method and the parameters to judge whether the performance goals will be met.

Analyses are presented in Section 6.4 for nine design issues. In the analytical approach subsection of Section 6.4.2.2, the analytical methods (tools) used to address specific design issues are described. The computer-aided numerical methods (codes) used during the issue resolution process are identified, and the following information is stated for each code:

1. Code name.
2. Author.

3. Ownership.
4. Design area for which the code was used.
5. A description of the calculations that the code performs.

6.1.4 STRUCTURES, SYSTEMS, AND COMPONENTS IMPORTANT TO SAFETY

Title 10 CFR 60, Subpart G, Quality Assurance, requires that the DOE apply a quality assurance (QA) program to structures, systems, and components important to safety. This QA program must also be applied to items important to waste isolation. Items (structures, systems, and components) important to safety or waste isolation are placed on a Q-list. A Q-list is a convenient way to call attention to items that require the 10 CFR 60, Subpart G, QA program. This section discusses the identification of items important to safety; items important to waste isolation are the subject of Section 6.1.5.

Items important to safety are defined as "those engineered structures, systems, and components essential to the prevention or mitigation of an accident that could result in a radiation dose to the whole body, or any organ, of 0.5 rem or greater at or beyond the nearest boundary of the unrestricted area at any time until the completion of permanent closure" (10 CFR 60.2). The NRC and the DOE have advocated the use of probabilistic risk assessment (PRA) techniques to determine the items important to safety. A method was developed based on a preliminary radiological safety analysis (PRSA) given in Appendix F of the SCP-CDR, which used a PRA approach. A preliminary identification of items important to safety has been performed using this method. A detailed report of the study to identify items important to safety can be found in Appendix L of the SCP-CDR. In the following discussion, a brief description of the radiological safety analysis method developed to identify items important to safety will be presented. The method is also illustrated in Figure 6-9. The results of the study will also be presented in the form of a preliminary list of items important to safety.

The PRSA method employed in Appendix F of the SCP-CDR basically follows the NRC methodology for a simplified and streamlined level 3 PRA described in the PRA Procedures Guide (NRC, 1983). The level of detail of the PRSA varies at each step, depending on the data and design information currently available. Since the primary objective of the PRSA was to provide a numerical basis for the development of a preliminary list of items important to safety, only accident scenarios resulting in public exposures were considered in detail.

After developing facility and system models, both internal and external initiating events were identified and screened by a panel of experienced design and safety analysis engineers. The basis for the screening was the potential of an event to contribute to a significant offsite release of radioactive materials. Using the event-tree technique, accident scenarios were then developed for those initiating events surviving the first screening process. Event trees are graphic depictions of the sequence of events that occurs following an initiating event. The construction of an event tree is an inductive process in that one goes from the specific (i.e., the initiating event) to the general (i.e., all the possible results of the initiating

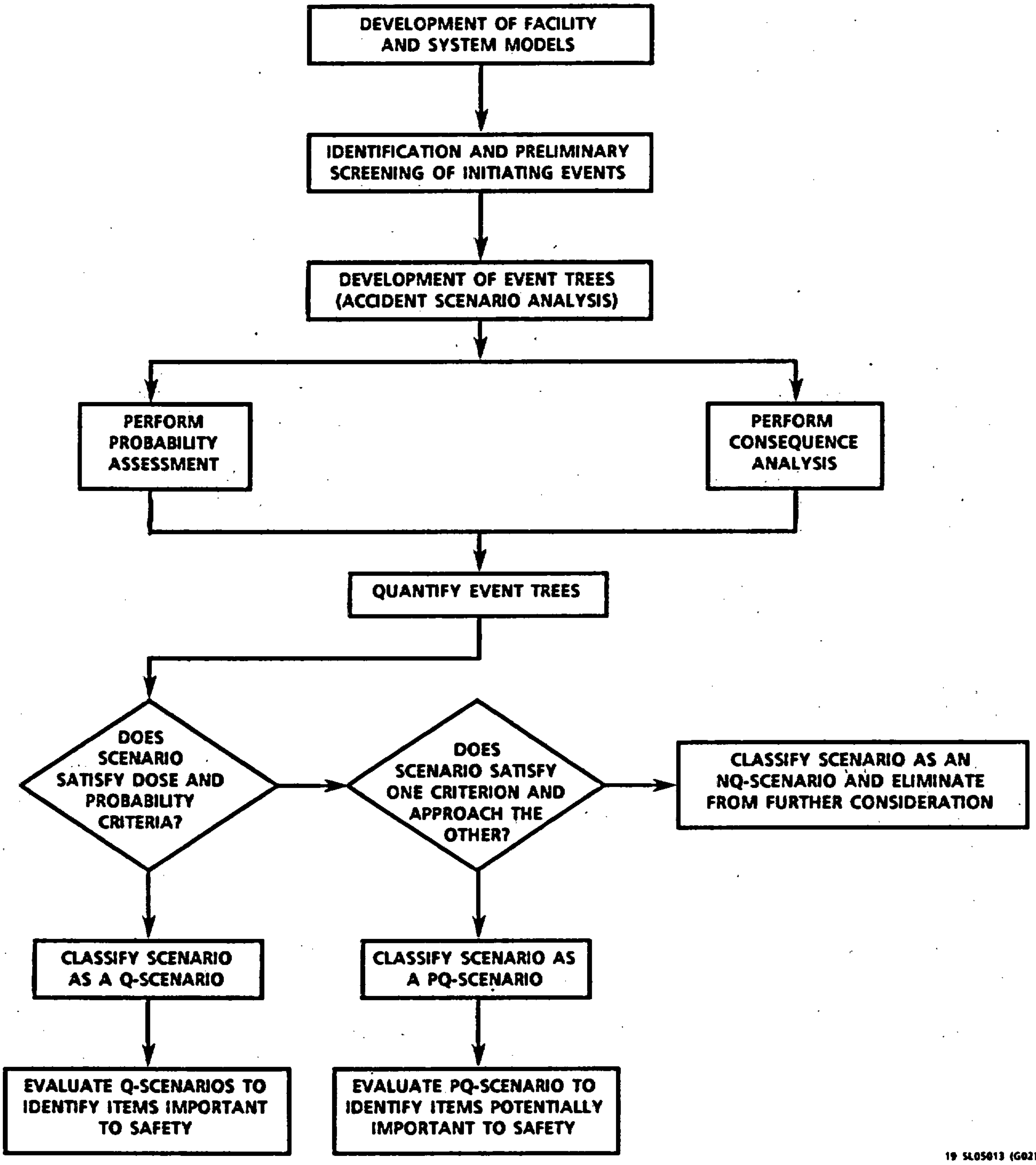


Figure 6-9. Q-List methodology for items important to safety.

event). The key factor for developing an event tree for each surviving initiating event was the selection and definition of the intermediate events. Event trees were constructed in detail appropriate to the level of design detail available and as necessary to adequately characterize the accident. Because of lack of data and design details, fault trees were not completely developed and analyzed; however, variations of conventional fault tree or fault diagrams were developed for most intermediate events. Fault trees are graphic depictions of the possible events that might lead to an intermediate event on an event tree. Constructing a fault tree is a deductive process in that one goes from the general--all possible ways for the intermediate event to come about--to the specific, the intermediate event. The use of fault diagrams provides important insight into the probabilities of intermediate events.

After event trees were developed, the probability of each initiating event and each intermediate event was evaluated, as were the consequences of accident scenarios. The probability and consequence analyses were performed in parallel. Both historical data and the judgment of a panel of engineers experienced in safety analyses were used in estimating probabilities. Consequence analyses involved the development of models and estimates of radionuclide releases, dispersion, and transport into the environment as well as calculation of doses. The results of the probability and consequence analyses were used to quantify the event trees. Briefly, the event trees are quantified by assigning probabilities to each intermediate event and consequences to each branch (or accident scenario) of the event tree.

On the basis of the results of the event tree quantifications, all accident scenarios that resulted in either dose consequences of more than 0.05 rem at the site boundary and probabilities of more than 10^{-8} per yr were selected as reference accident scenarios. The reference accident scenarios were identified by simplifying, or pruning, the event trees of all the accident scenarios that did not fall within the limitations established for the dose consequences and probability criteria. The initial list of items important to safety was derived from the reference scenarios and the numerical results of the analyses.

The reference accident scenarios were developed using the physical systems described in Section 6.2. Ramp access for waste emplacement operation, when compared to shaft access, substantially reduced the number of accident scenarios that needed to be considered. The ramp access to the underground area allows the use of a single transport cask permanently mounted on a transport vehicle to

1. Collect the waste container from the surface storage vault using the collection/emplacement mechanism contained within the transport cask;

2. Transport the waste container to the underground area by way of the access ramp;

3. Transport the waste container to the waste emplacement borehole by way of the main entry, panel access, and emplacement drifts; and

4. Emplace the waste container in the emplacement borehole using the collection/emplacement mechanism contained within the transport cask.

The use of the ramp access thus eliminates two waste container transfer operations that are normally associated with shaft access to the underground. The transfers that are eliminated are

1. Transfer of the waste container from the surface storage vault into the shaft transfer cask and

2. Transfer of the waste container from the shaft transfer cask into the waste emplacement transporter.

Ten reference scenarios associated with waste emplacement operations were identified that might lead to a release of radioactive materials from the repository facilities. These scenarios are described in the following table.

Event	Description
SURFACE STORAGE VAULT	
Container transfer mechanism (CTM) failure	During transfer an equipment failure occurs and the container is dropped, possibly causing a breach. All waste forms are considered in the scenarios.
Shielded underground transporter collision	The transporter inadvertently hits the the CTM or runs into facility wall. The CTM or transporter is carrying a a container and a breach occurs.
Shielded underground transporter moves	A transporter moves inadvertently during waste loading and a container breach occurs due to shearing.
UNDERGROUND AND EMPLACEMENT AREA	
Waste transporter coasts down ramp (run-away transporter)	Mechanical failure causes a transporter to coast from top of ramp and strike the ramp wall, particularly near the bottom where the ramp is curved. Cask breach and/or fuel ignition in the transporter is possible.

Event	Description
Transporters collide on ramp	A transporter inadvertently travels up the ramp while a second transporter is going down resulting in a head-on collision and a fire and/or an explosion. Breach of cask is possible.
Container drops into emplacement hole (vertical emplacement mode)	A transporter grapple fails or a container pintle fails during emplacement.
Unwanted movement of transporter	A transporter inadvertently moves during emplacement resulting in a shearing force and container breach.
Secondary vehicle has collision with loaded transporter	A small secondary vehicle has collision with a transporter during an emplacement operation resulting in possible container breach and secondary fire in the transporter.
Exhaust filter building fire	A fire occurs due to an electrical short or a worker accident, and HEPA filters and/or equipment for ventilation are damaged.
Loss of HEPA filter system	The radiation monitor may not activate the HEPA bypass system, or equipment failure may occur causing normal releases or accident releases given a common mode or coincidence failure.

Reference accident scenarios that could potentially lead to significant offsite releases of radioactive material and dose consequences were developed using the previously described method. The following two criteria were used to screen the reference accident scenarios for scenarios that could lead to the identification of items important to safety:

1. Dose criterion: An accident scenario could potentially lead to the identification of items important to safety if the calculated off-site public dose was greater than or equal to 0.5 rem; otherwise, the accident scenario is not significant with respect to items important to safety.

2. Probability criterion: An accident scenario could potentially lead to the identification of items important to safety if the probability of occurrence of the scenario is greater than 10^{-5} per yr; otherwise the scenario is not considered significant with respect to items important to safety.

In performing this second screening, the probability, including its uncertainty, were compared with the above criteria. If, and only if, an accident scenario passes both screening criteria, the accident scenario is classified as a Q scenario. Q scenarios then are further analyzed to determine which of the structures, systems, or components involved in the scenario are important to safety. A structure, system, or component is important to safety if it is essential to either the prevention of the scenario or the mitigation of the scenario dose consequence.

Scenarios that are not significant with respect to items important to safety are classified as either a non-Q scenario (NQ scenario) or a potential-Q scenario (PQ scenario). All NQ scenarios are eliminated from further consideration in identifying items important to safety.

Any scenario not immediately identified as a Q scenario, but which, as further study and design take place, is judged to have a reasonable potential to be upgraded to a Q scenario is classified as a PQ scenario. Two criteria were used to decide between PQ and NQ. First, a scenario was classified as a PQ scenario even if no analyses had been performed if the item or scenario was sufficiently similar to others historically classified as PQ scenarios or when practical consideration indicated it could be a Q scenario. Second, if the analysis determined that either the consequences or probability exceeded the criteria and the other was sufficiently close that a change in assumptions or data could cause the criteria to be exceeded, the scenario was classified as a PQ scenario. A variation of this second criteria was that when both consequence and probability were below the threshold but sufficiently close that a change in assumption or data could move it over, it was classified as a PQ scenario.

Once a scenario is classified as a Q scenario or a PQ scenario, that scenario is further analyzed to determine which of the items involved in the scenario should be placed on the list of items important to safety or potentially important to safety. Further analysis of the scenario involves the evaluation of the systems, structures, and components involved in the scenario to determine what role the item plays in the scenario. Items whose failure causes the loss of consequence mitigation processes or whose failure directly causes the release of radioactive materials are classified as important to safety or potentially important to safety and placed on the Q list or PQ list, depending on which type of scenario is being evaluated. Current plans will make these items PQ items, as well as items important to safety, subject to a QA level I program that satisfies the requirements of 10 CFR 60, Subpart G. A potentially-important-to-safety list is consistent with DOE guidance (DOE, 1987c).

The results to date have not identified any Q scenarios, or consequently, any Q-list items. However, this result is based on incomplete and preliminary data and design. For example, an airplane-crash scenario was not based on actual data and will have to be reexamined. Consequently, all items that have been classified as potential Q-list items will be treated as if they were Q-listed during future design until the design detail and available data support a definitive analysis and conclusion.

The preliminary PQ list is presented in Table 6-18. For a complete discussion of the methods and analyses used in classifying the items listed in Table 6-18, the reader is referred to the SCP-CDR (Appendices F and L of SNL, 1987). The work reported in these appendices includes the effects of mitigative features (i.e., radiation alarms and filtration systems) in some of the accident scenarios. Since the time these analyses were conducted, however, a decision has been made not to use mitigative features in the Q-list analyses. As a result, the analyses presented in the two appendices were re-examined to remove any reductions in radiological dose consequence or probability of occurrence that accrued from the mitigative features. This re-examination resulted in the PQ list given in Table 6-18. No Q-list items resulted from this re-examination.

In addition, as the design is developed, i.e., the reference configuration of the LAD and additional data become available, the complete sequence of the Q-list method will be implemented again to refine, correct, and validate the initial results. A detailed discussion of the methods used in determining items important to safety is given in Appendix F of the SCP-CDR, and the results of the analysis of items important to safety is given in Appendix L.

6.1.5 BARRIERS IMPORTANT TO WASTE ISOLATION

Barriers important to waste isolation are defined by the DOE (DOE, 1987b) as the barriers, structures, systems, and components that are relied on to achieve the postclosure performance objectives in 10 CFR 60, Subpart E. The engineered barriers that meet this definition are placed on the Q-list. The natural barriers that meet this definition are not placed on the Q-list, because they cannot be designed. Instead, their ability to isolate the waste is given special protection through an "activities list," which contains all the activities that might adversely affect the natural barriers and for which design criteria are not meaningful.

The identification of barriers important to waste isolation is accomplished through the performance-allocation process. Barriers at the Yucca Mountain site that satisfy the definition have therefore been identified by examining the performance allocations in Chapter 8 of this document. Each of the four postclosure performance objectives is represented by an issue in the issues hierarchy and a corresponding section in Chapter 8. In that section is a performance allocation, which selects the barriers that the DOE currently expects to rely on for demonstrating, in the license application, that the performance objective will be met. The engineered barriers named in the allocation are placed on the Q-list; the natural barriers receive protection through the activities list.

The first performance objective in 10 CFR 60.112 deals with the allowable releases of radioactivity from the repository to the accessible environment. Section 8.3.5.13, which treats this performance objective as

Table 6-18. Potential Q-list for items important to safety at the Yucca Mountain repository

Items	Locations	Initiating events
Crane, shipping cask	Cask receiving and preparation area	Crane drops a shipping cask
Hot cell structure	Packaging hot cell	Earthquake causes hot cell structure failure
Crane	Unloading hot cell Consolidation hot cell Packaging hot cell	Earthquake causes crane to drop on fuel assemblies
Vehicle stop	Cask receiving and preparation area	Vehicle with cask falls in cask preparation pit (detailed analysis not performed)
Fire protection system	Waste-handling building	Fire involving radioactive material is a dispersion promoter (detailed analysis not yet performed)
Cask transfer mechanism (CTM)	Surface storage vault	CTM drops container with consolidated fuel rods
Transport cask	Underground facility and ramp	Transporter coasts down the waste ramp and strikes the wall of the ramp or main access drift

Issue 1.1, describes the plans for demonstrating that this performance objective will be met. The performance allocation for Issue 1.1 relies largely on natural barriers: the saturated and unsaturated zones. The primary reliance is on the unsaturated zone; the principal unsaturated zone rock units in this allocation are the Calico Hills nonwelded zeolitic unit and the Calico Hills nonwelded vitric unit. The waste package, an engineered barrier, is relied on as a primary barrier only for releases of gaseous radionuclides. From these allocations, the waste package would be proposed for inclusion on the Q-list. The waste package, however, consists of two subelements: the waste container and the waste form inside the container.

The waste form does not appear on the Q-list, because it will not be engineered as part of the repository design. The waste container is therefore proposed for inclusion on the Q-list of items important to isolation. The proposed activities list includes the activities that have a potential for adversely affecting the waste-isolation capabilities of the Calico Hills nonwelded zeolitic unit, the Calico Hills nonwelded vitric unit, and the saturated zone.

The second performance objective in 10 CFR 60.113 deals with the time during which the waste package must provide substantially complete containment of the high-level waste. Section 8.3.5.9, which treats this performance objective as Issue 1.4, allocates performance to the emplacement environment of the waste package, which is the Topopah Spring welded unit in the immediate vicinity of the emplaced waste; to the waste container; and, to the waste form inside the container. This allocation suggests that the waste container should be placed on the Q-list of items important to waste isolation. For the reason given above, the waste form does not appear on the Q-list. Activities that have the potential for adversely affecting the waste-isolation capabilities of the Topopah Spring welded unit are placed on the activities list.

The third performance objective in 10 CFR 60.113 deals with the allowed releases from the engineered-barrier system. Section 8.3.5.10, which treats this performance objective as Issue 1.5, allocates performance to the emplacement environment of the waste package, which is the Topopah Spring welded unit in the immediate vicinity of the emplaced waste, and to the waste form. This allocation suggests no additions to the Q list or the activities list beyond those suggested by the first two performance objectives.

The fourth performance objective in 10 CFR 60.113 deals with the required ground-water travel time at the repository site. Section 8.3.5.12, which treats this performance objective as Issue 1.6, allocates primary performance to the Calico Hills nonwelded zeolitic unit and the Calico Hills nonwelded vitric unit. It allocates secondary performance to the Topopah Spring welded unit and to the saturated zone. Although some allocation is made to other units, the reliance on them is merely "auxiliary." The allocation in Section 8.3.5.12 suggests no additions to the Q-list or the activities list beyond those suggested by the first two performance objectives.

In summary, the proposed Q-list for items important to waste isolation contains the waste container. The proposed activities list includes activities that have the potential for adversely affecting the waste-isolation capabilities of the Topopah Spring welded unit, the Calico Hills nonwelded zeolitic unit, the Calico Hills nonwelded vitric unit, and the saturated zone.

6.2 CURRENT REPOSITORY DESIGN DESCRIPTION

This section summarizes the current repository conceptual design. The design information reflects current design concepts being considered for the Yucca Mountain repository site. These concepts include both the vertical, which is the reference configuration, and horizontal emplacement configurations. The design descriptions make reference to design documents and focus on design features that are influenced by site characteristics. Where uncertainties in site or other SCP-related design parameters are identified, plans for bounding design parameters or for performing preliminary sensitivity analyses are referenced.

6.2.1 BACKGROUND

Preliminary designs for the potential Yucca Mountain repository were schematic and had sufficient detail to formulate concepts to address feasibility and to support development of criteria for the generation of the present repository conceptual design. The design effort was divided into four distinct areas: (1) surface repository design, (2) underground repository design, (3) special waste emplacement and retrieval equipment design, and (4) design of the waste emplacement envelope. The waste package design is described in Chapter 7.

The Site Characterization Plan-Conceptual Design Report (SNL, 1987) elaborates on the repository design described herein. (This report is referred to as the SCP-CDR throughout Section 6.2.) The SCP-CDR provides a detailed description of the repository conceptual design, including discussions concerning the design methods.

The conceptual design of the surface and underground facilities depicted in this document represents the status of the work completed in May 1986. These efforts are summarized herein and include the status of work completed to date on the design for the capability of receiving, processing, and emplacing of spent fuel waste and defense high-level waste (DHLW). The effort reflects the waste delivery rates identified in Section 6.1.1 (repository design requirements), characteristics, and throughput rates resulting from new waste package designs. It is important for the reader to recognize that the repository design presented in the SCP is conceptual and will be refined as a result of site characterization activities, described in Section 8.3, and the completion of subsequent phases of repository design. Subsequent design phases include the advanced conceptual design (ACD), license application design (LAD), and final procurement construction design (FPCD).

6.2.2 OVERALL FACILITY DESIGN

The proposed repository site at Yucca Mountain is in southern Nevada, about 137 km (85 mi) by air and 161 km (100 mi) by road northwest of Las Vegas. The proposed site is located on Federal land currently under the separate control of the DOE, the Bureau of Land Management, and the U.S. Air Force.

The currently proposed highway and rail access routes to the site are shown in Figure 6-10. For the purpose of conceptual design a new access road is proposed to originate at U.S. Highway 95 approximately 0.8 km west of the town of Amargosa Valley and to extend about 27 km northward to the site. Likewise, a new railroad is proposed to originate at Dike Siding, about 18 km northeast of Las Vegas, and extend about 137 km to the site. A new bridge, or bridges, crossing Fortymile Wash would be necessary for highway and rail access to the site.

An illustration of the current repository design concept is presented in Figure 6-11. The proposed repository complex is composed of surface and underground facilities linked by a combination of shafts and ramps. Figure 6-12 shows the overall site plan of the current design, including the surface facilities, and the shafts. The location of site characterization boreholes is discussed in Section 8.3.1.4.1.

The underground facilities would be located below the ridgeline of Yucca Mountain within the Topopah Spring Member of the Paintbrush Tuff. Both vertical (Figure 6-13) and horizontal (Figure 6-14) emplacement configurations are discussed. Details pertaining to the current design of these configurations and the integration of the exploratory-shaft facility with the underground facilities are discussed in Sections 6.2.5 and 6.2.6.

The main or central surface facilities are proposed to be built on gently sloping terrain at the eastern base of Yucca Mountain. The proposed repository location was selected based on a preliminary assessment of soils, topography, and the need for an efficient interface with the ramps and shafts that provide access to the underground facilities (Neal, 1985). The main surface facilities would be segregated into three adjacent areas: (1) the waste-receiving and inspection area, (2) the waste operations area, (3) and the general support facilities area. The waste operations area would include the waste-handling buildings and other facilities where radioactive material would be handled. A ramp would be used for transporting waste from the surface to the underground disposal area. Another ramp would be used for conveying mined tuff to the surface. Four vertical shafts (two exploratory shafts, an exhaust shaft, and a men-and-materials shaft) would be located near the northeast boundary of the underground disposal area and would be used for underground ventilation and access for personnel, supplies, and equipment.

The Johnstone et al. (1984) report discusses the ranking of the rock strata at Yucca Mountain that is best suited for the underground repository. The host rock for the proposed underground repository is located within a thick unsaturated zone below Yucca Mountain. This unit is the welded, ash-flow tuff portion of the Topopah Spring Member of the Paintbrush Tuff Formation (Section 6.1.2).

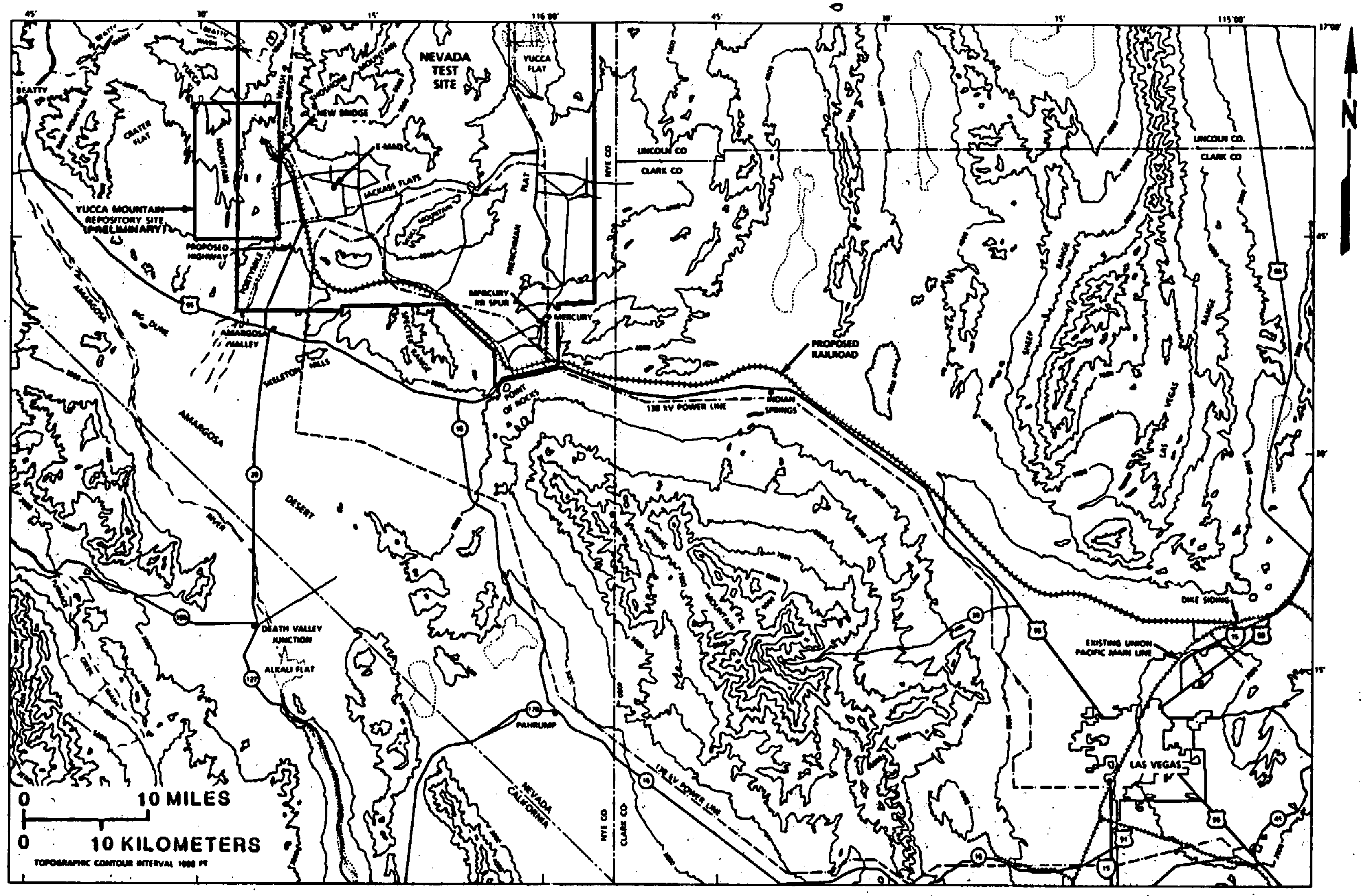


Figure 6-10. Highway and rail access routes for proposed Yucca Mountain repository.

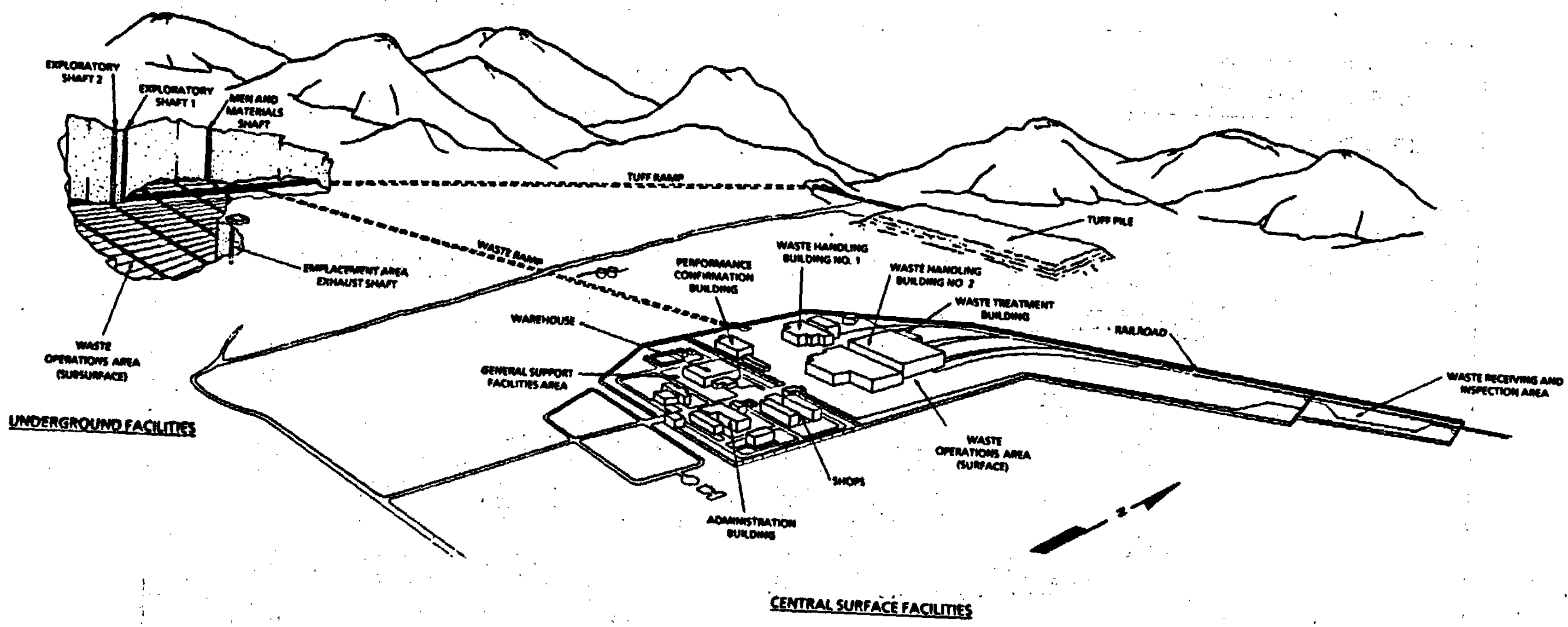


Figure 6-11. Perspective of the proposed Yucca Mountain repository.

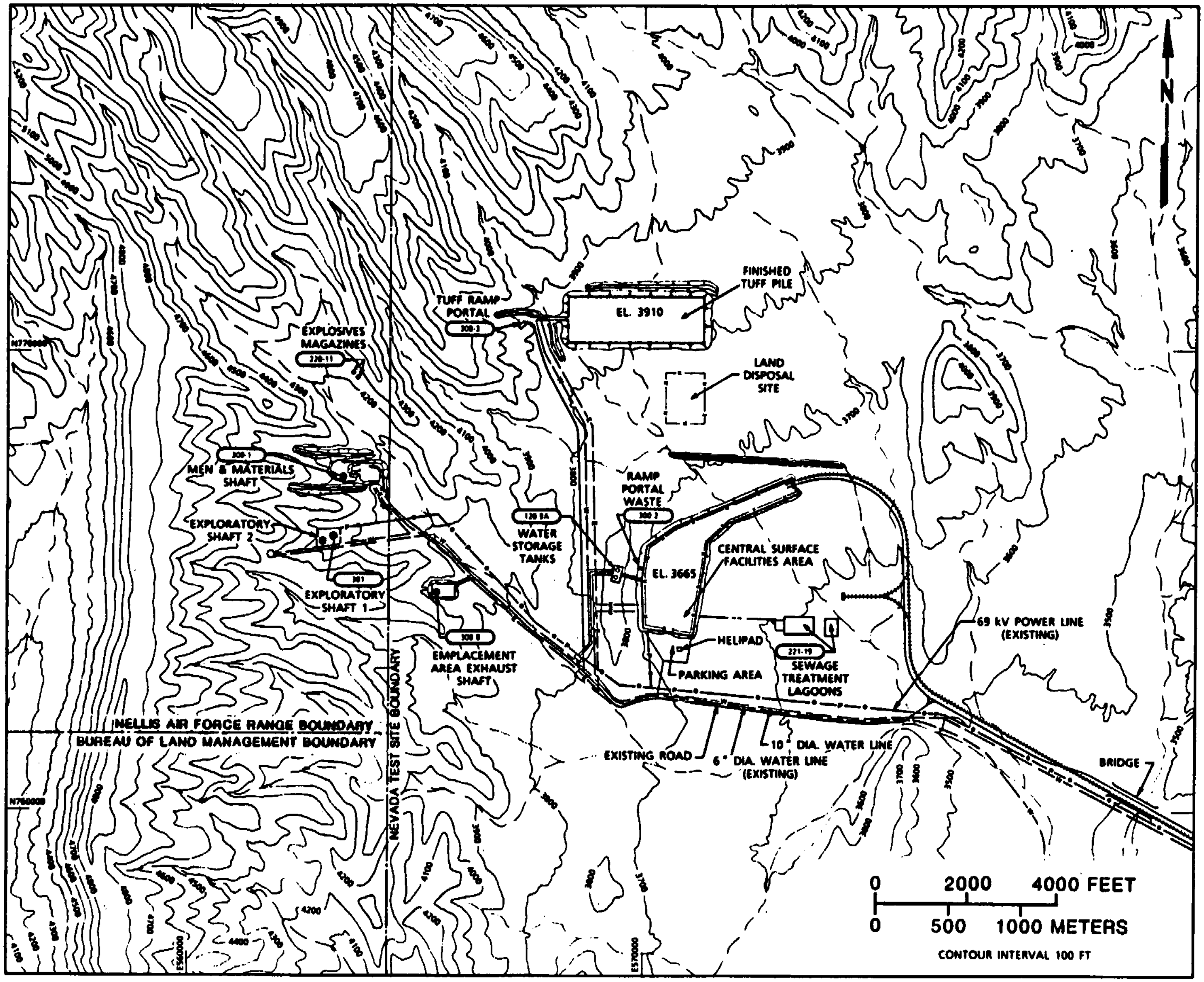


Figure 6-12. Overall site plan showing surface facilities and shafts.

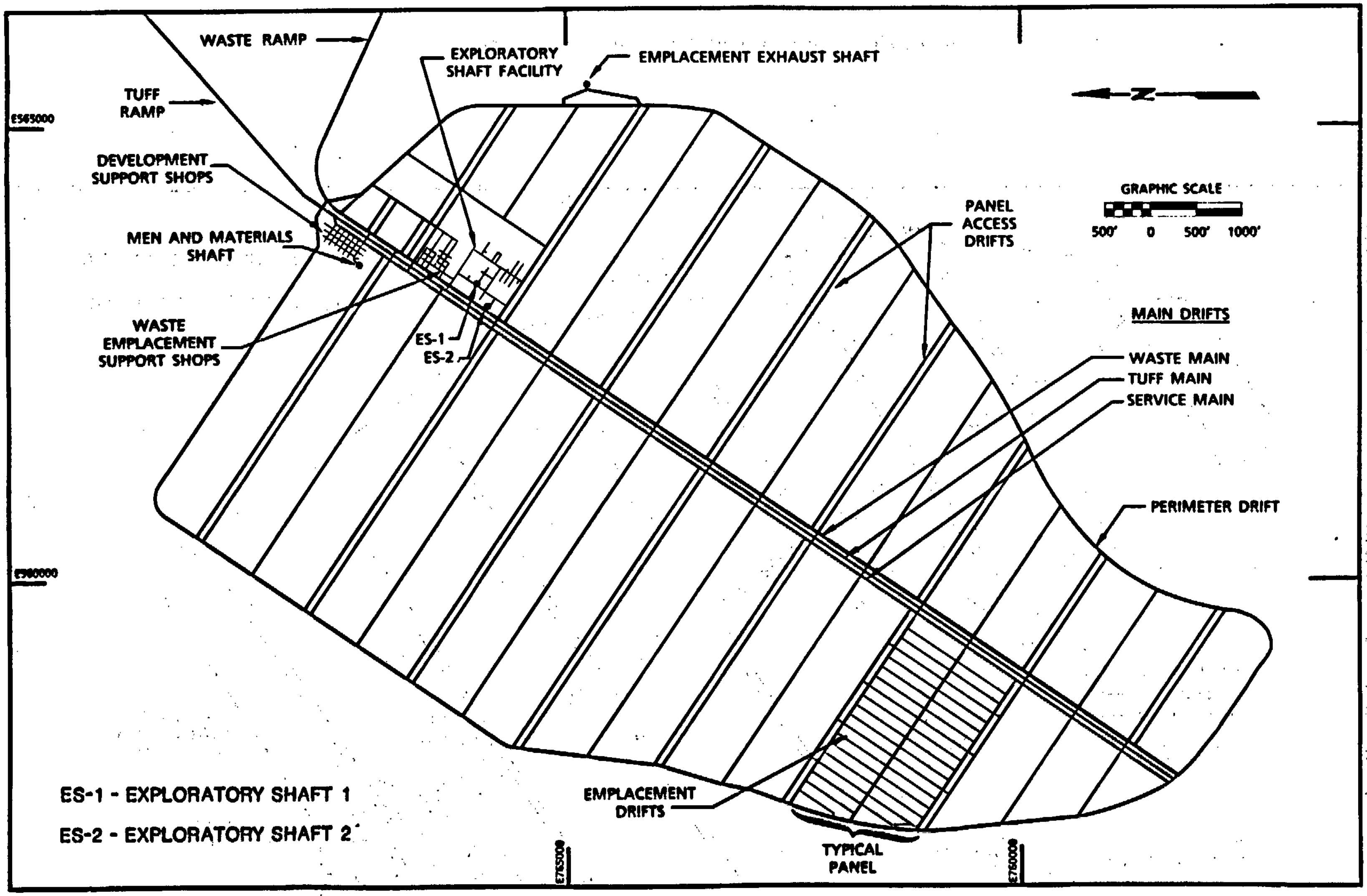


Figure 6-13. Vertical emplacement configuration.

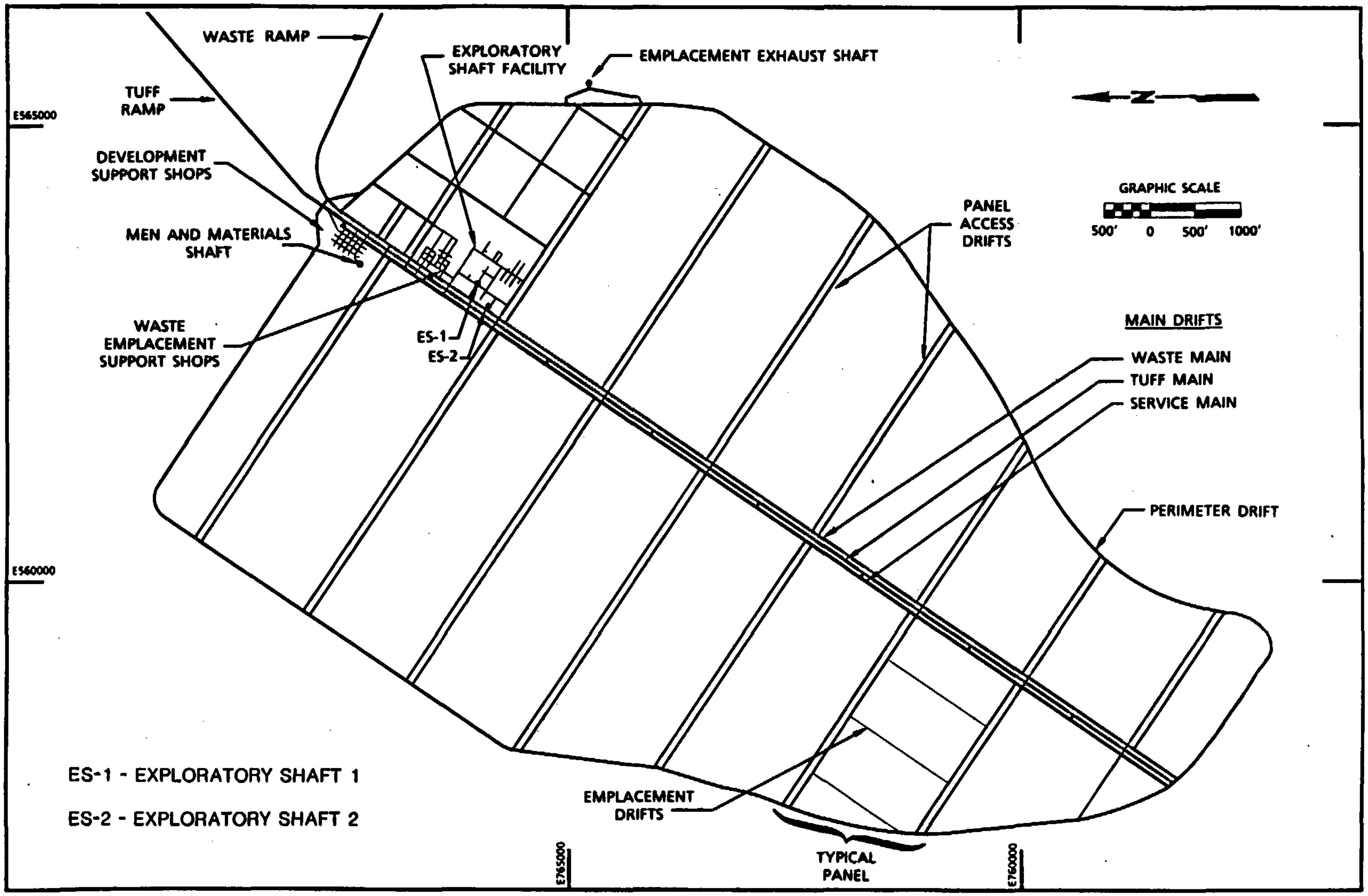


Figure 6-14. Horizontal emplacement configuration.

6.2.3 REPOSITORY OPERATIONS

This section briefly describes the principal operations that would be performed at a repository, including waste handling and disposal, waste retrieval, and support services. Chapters 3.1 and 4.5 of the SCP-CDR describe the operations, emplacement configurations, and equipment needed to perform these operations.

6.2.3.1 Waste handling and disposal operations

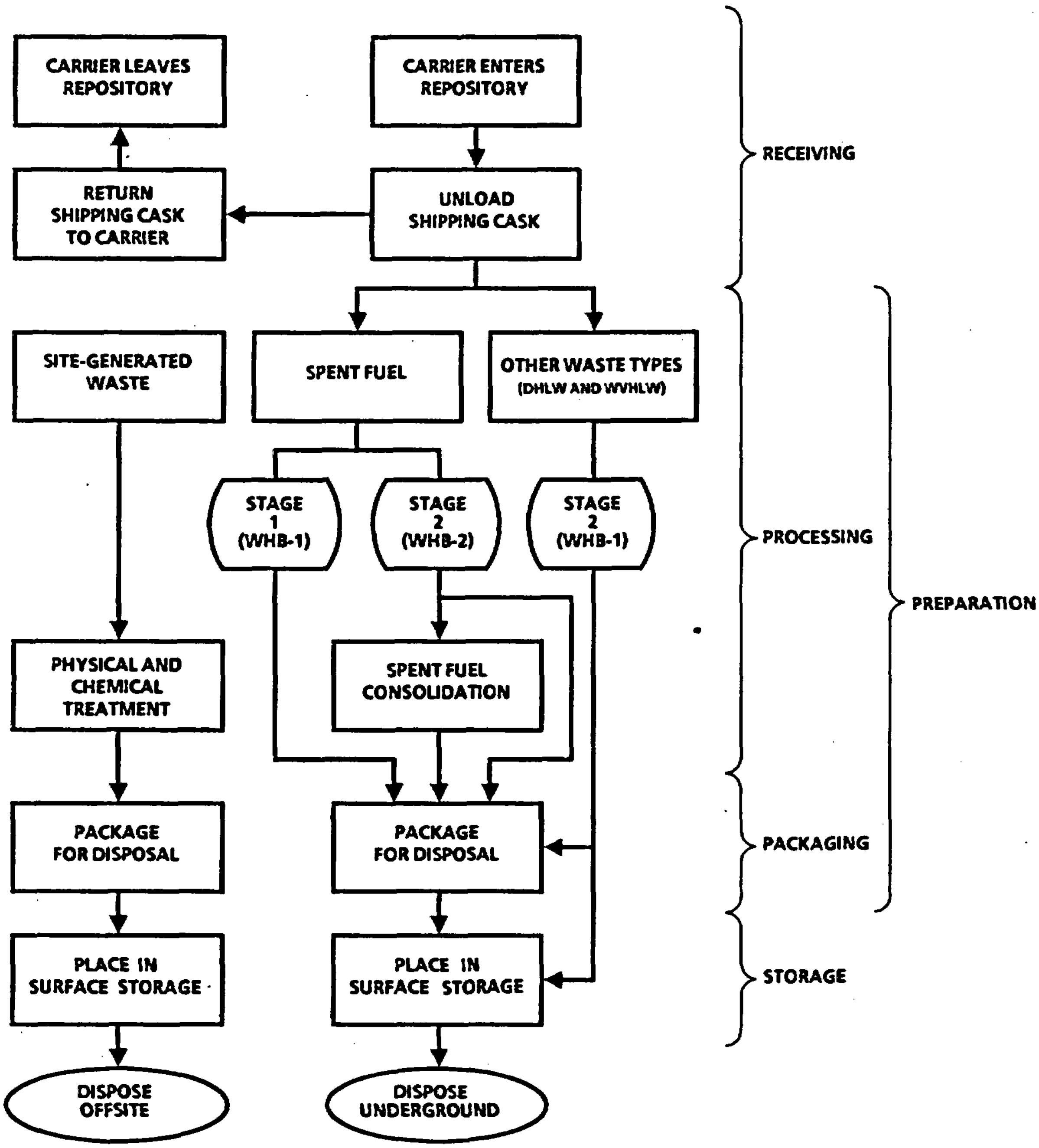
This section describes the current concepts for the waste receipt, and for preparation, storage, disposal, caretaker, and closure operations at the repository. This information is presented for spent fuel and other high-level waste. In addition, this section contains block-flow diagrams defining the principal operations, conceptual flow diagrams showing the equipment to be used in the operations, and lists of the major equipment illustrated in the conceptual flow diagrams. Surface and underground facility descriptions are provided in Sections 6.2.4, 6.2.5, and 6.2.6.

6.2.3.1.1 Waste handling operations

Figure 6-15 presents a block-flow diagram of the waste-handling operations. Waste shipped to the repository would be initially inspected at the gate to the waste-receiving area (Dennis et al., 1984b and 1984c). After this preliminary inspection, the waste in its shipping cask would be moved into the receiving area by the carrier. Complete radiological surveys and security-related inspections would be performed on the cask and carrier before moving them to the designated parking or waiting area near the waste-handling buildings. Figure 6-16 shows the steps that would be involved in transferring the waste to the waste-handling building and unloading the waste from the shipping cask.

The surface facilities at Yucca Mountain would be developed in two stages. During the Stage 1 operation, waste handling building 1 (WBH-1) would be used for the preparation of spent fuel for disposal (Figures 6-17, 6-18, and 6-19). During Stage 2, waste would be prepared in both WHB-1 and waste handling building 2 (WHB-2). WHB-2 is designed to have the capability of consolidating spent fuel assemblies (Figure 6-20). WHB-1 would be used during Stage 2 for preparing waste that would not require consolidation (i.e., defense high-level waste, West Valley high-level waste, and spent fuel consolidated at reactors or at an alternate facility). The waste would then be placed in a surface storage vault to await emplacement. Site-generated radioactive waste would be prepared in a separate building for offsite disposal, as shown in Figures 6-21 through 6-25. Offsite disposal of site-generated waste is a DOE design criteria (Stein, 1986).

Waste emplacement operations would begin with the removal of the waste packages from surface storage in the waste-handling buildings. Site-generated waste would be removed from the storage areas in the waste treatment building and loaded on trucks for disposal outside the repository (Figure 6-25).



DHLW - DEFENSE HIGH LEVEL WASTE

WVHLW - WEST VALLEY HIGH-LEVEL WASTE

WHB-1 - WASTE-HANDLING BUILDING 1

WHB-2 - WASTE-HANDLING BUILDING 2

Figure 6-15. Flow diagram of waste handling.

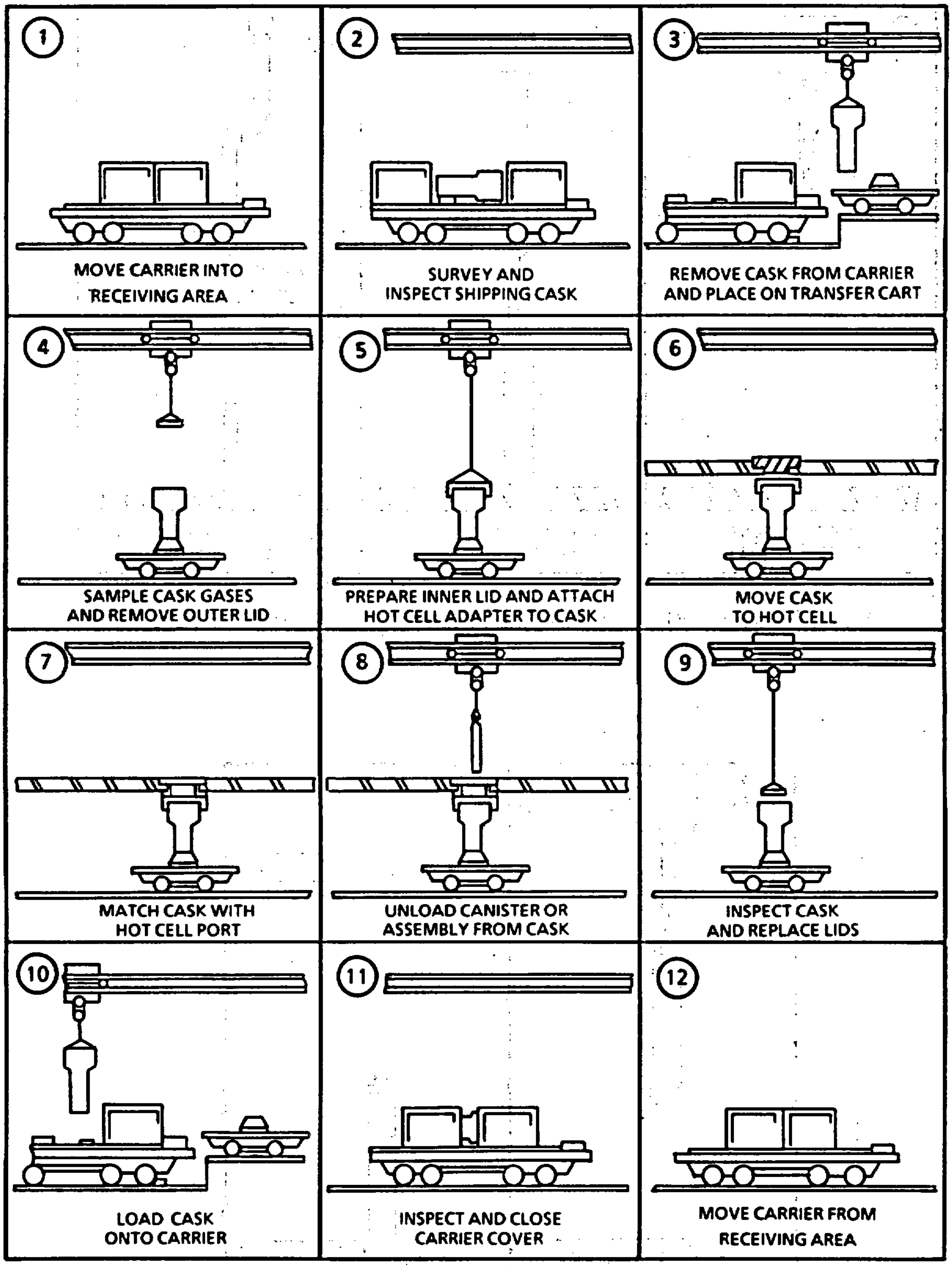


Figure 6-16. Steps involved in receiving the waste.

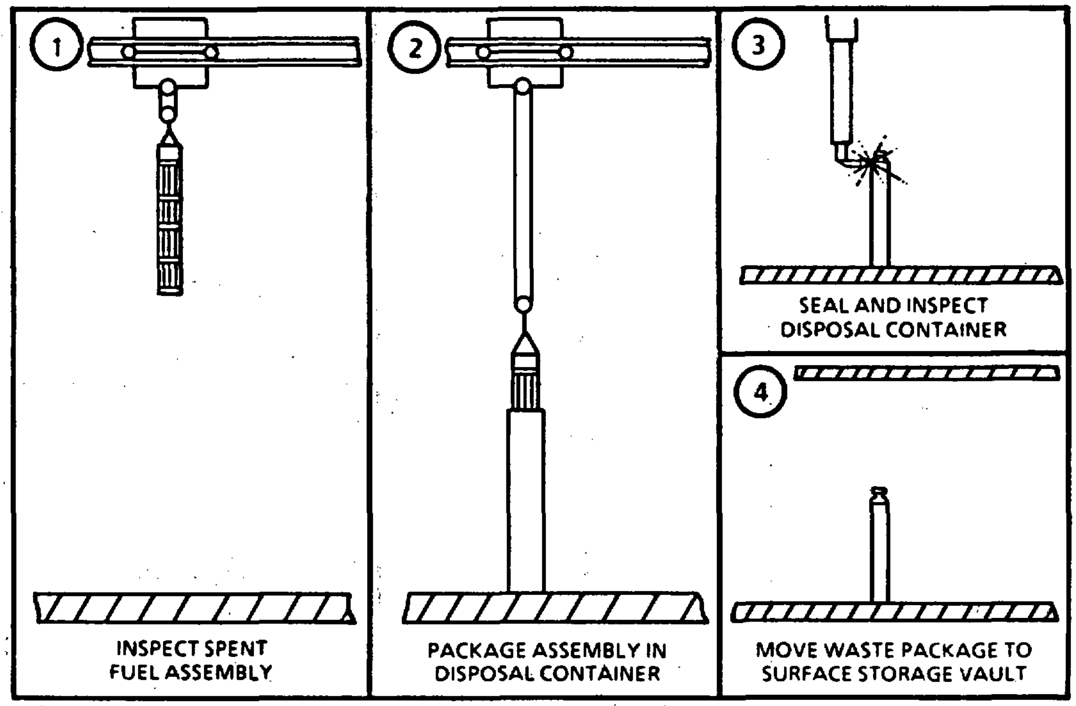


Figure 6-17. Inspection, packaging, and storage of a spent fuel assembly.

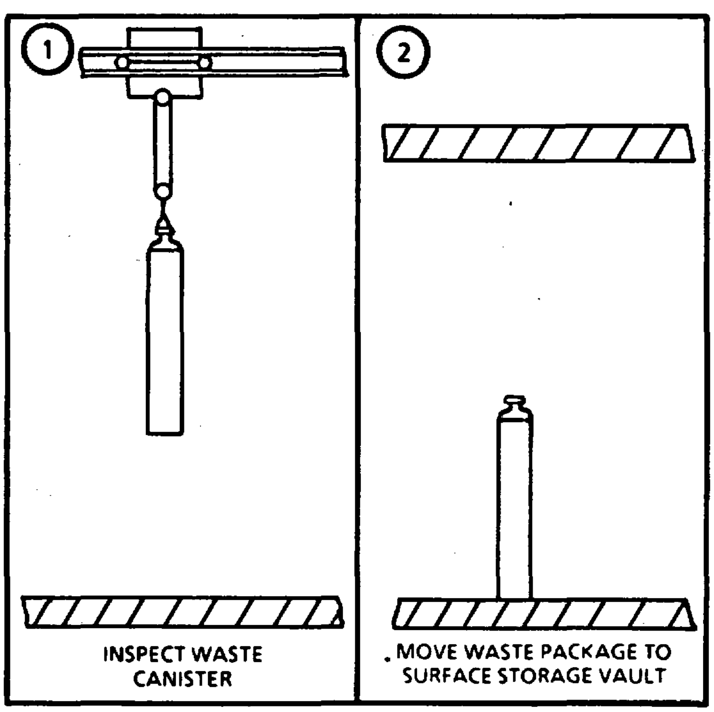


Figure 6-18. Inspection and storage of consolidated spent fuel and other high-level waste.

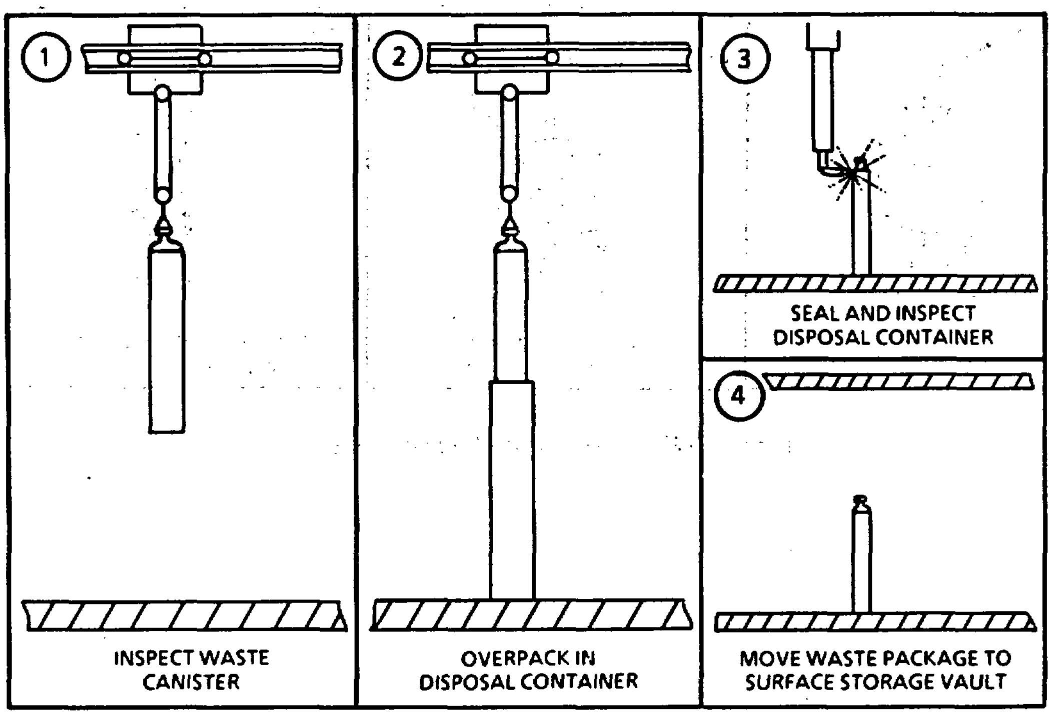


Figure 6-19. Inspection, overpacking, and storage of a canister.

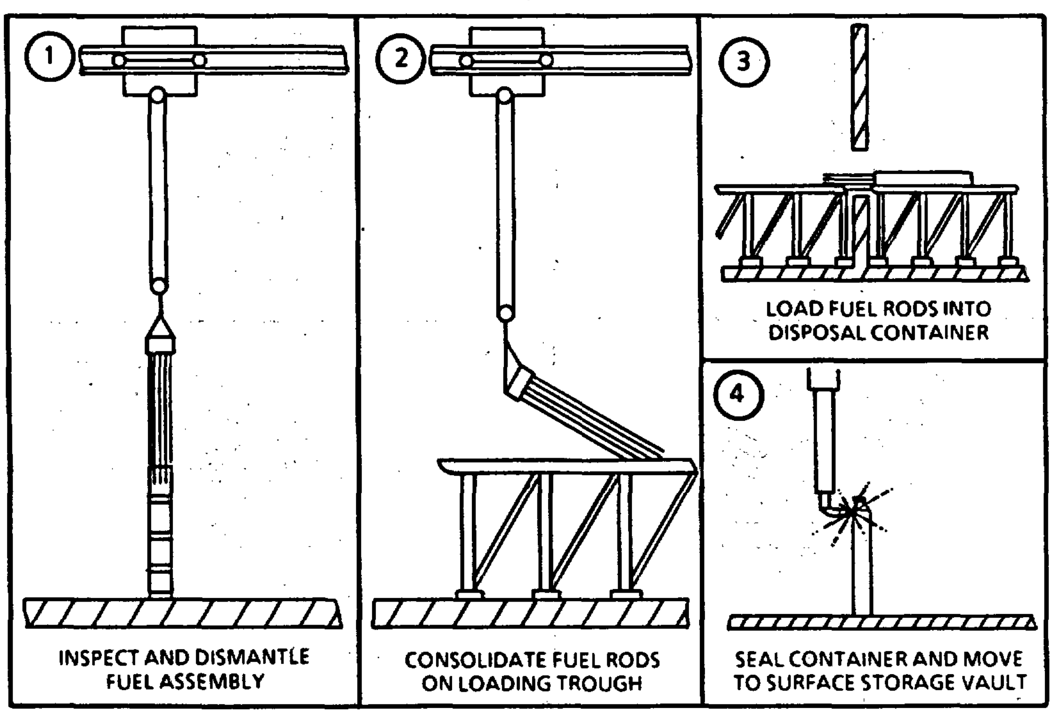


Figure 6-20. Consolidation of spent fuel assemblies in Stage 2.

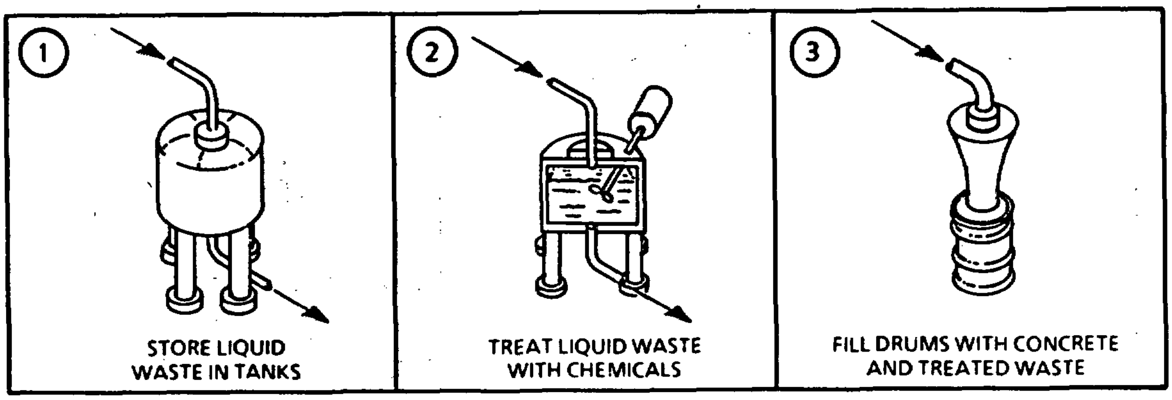


Figure 6-21. Treatment of liquid wastes.

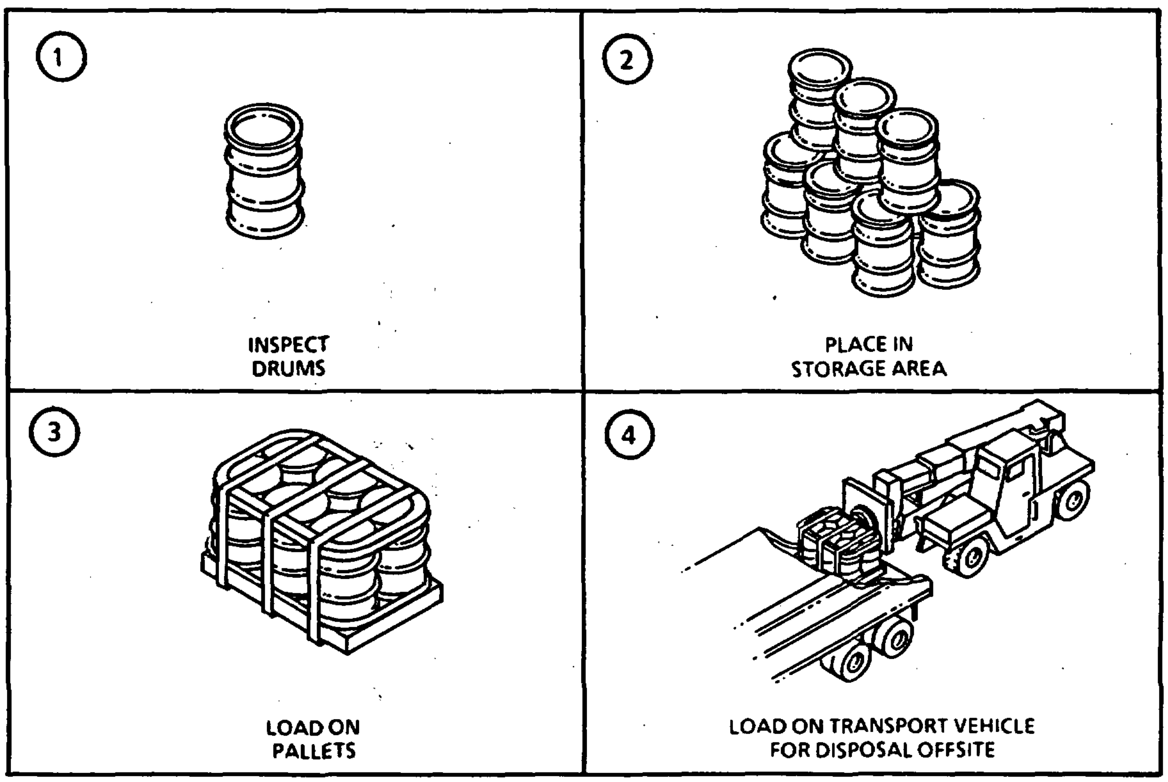


Figure 6-22. Storage and offsite shipment of solidified waste.

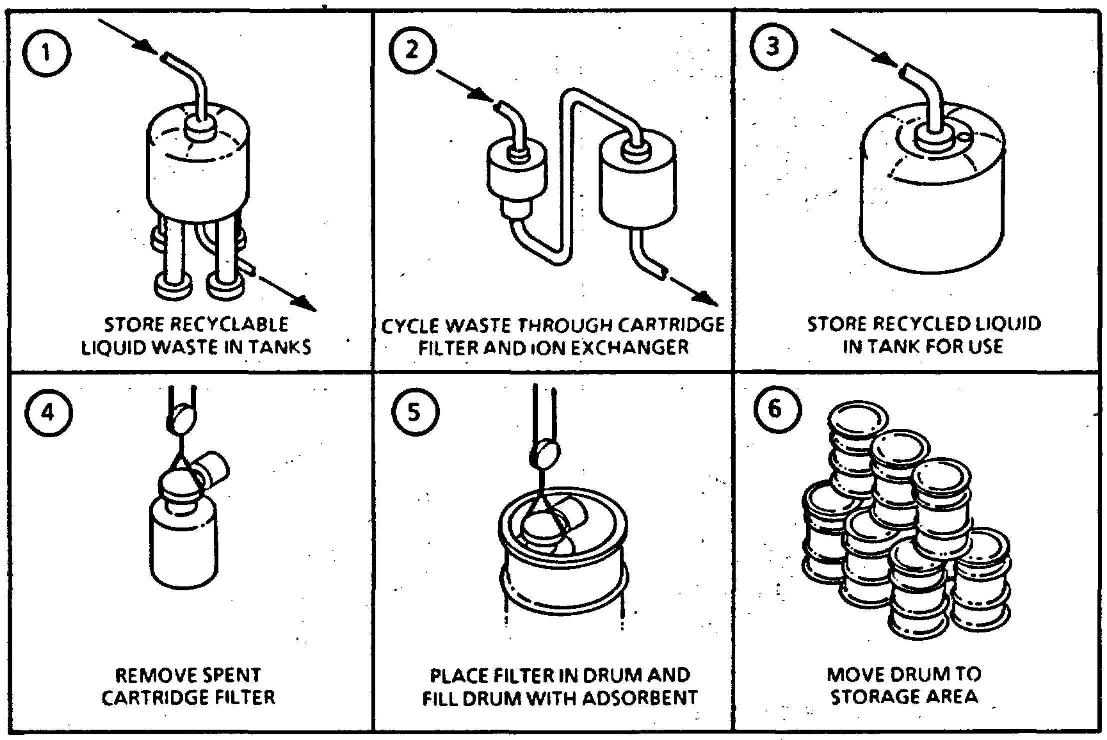


Figure 6-23. Packaging of spent cartridge filters.

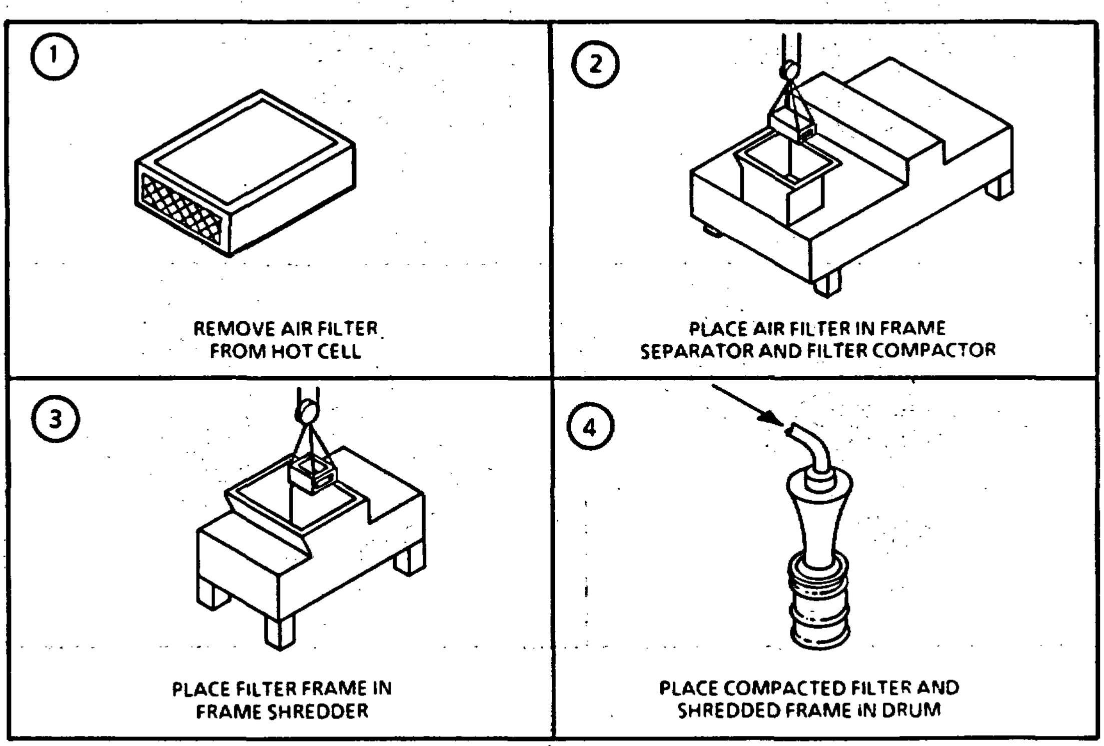


Figure 6-24. Packaging of air filters.

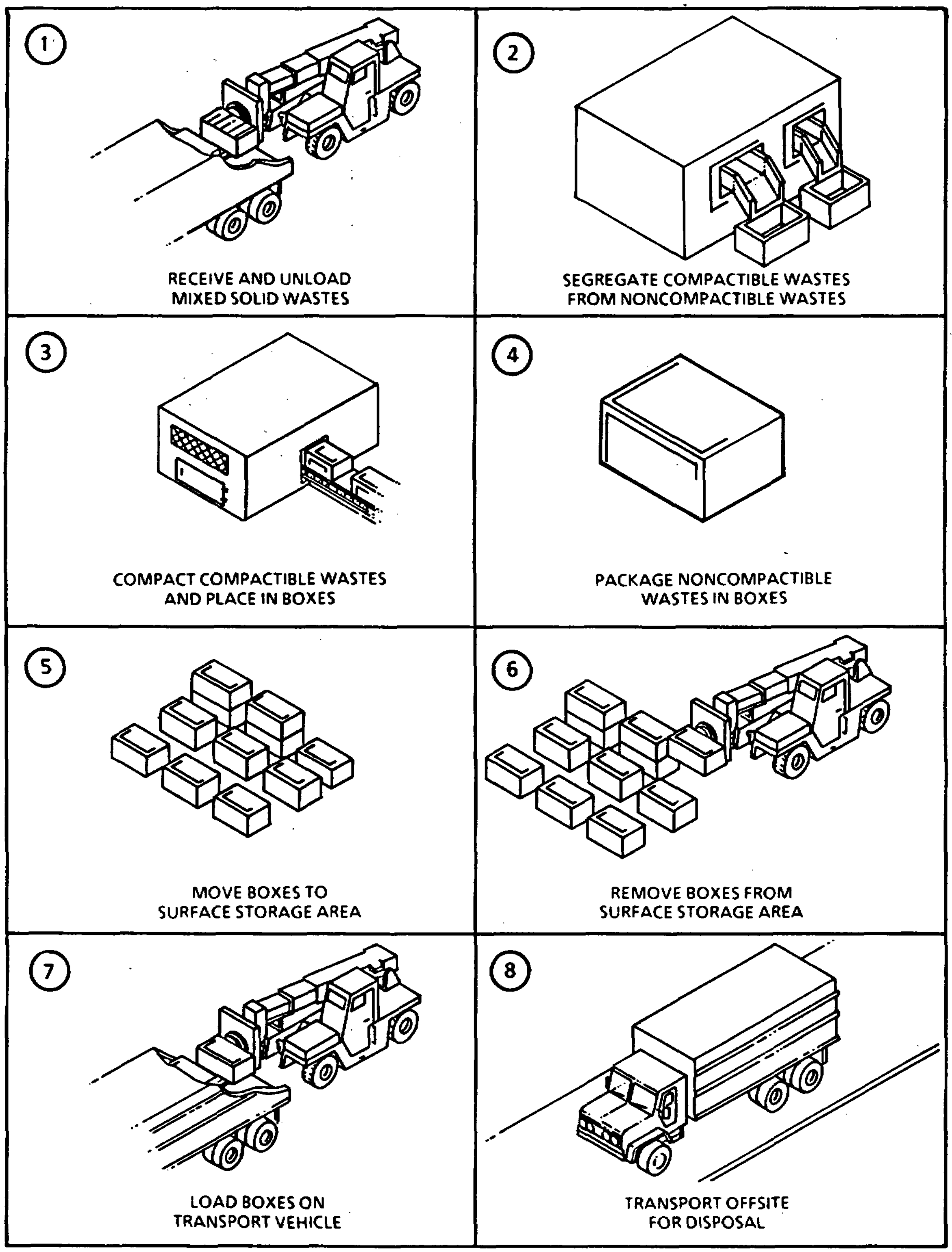


Figure 6-25. Preparation of offsite shipment of site-generated solid waste.

6.2.3.1.2 Waste disposal operations

Figure 6-26 presents a block-flow diagram of the waste-disposal operations for spent fuel and other high-level waste for both the reference vertical option and the horizontal option. Operations for both vertical and horizontal emplacement are presented as a comparison of the two configurations.

6.2.3.1.2.1 Vertical emplacement

The vertical emplacement configuration is the reference configuration for the NNWSI Project. The basic operations required for the vertical emplacement of a waste package include the following steps: (1) preparing the waste emplacement borehole, (2) transferring the waste to the emplacement area, (3) emplacing the waste container, and (4) closing the borehole. A description of these operations is provided by Stinebaugh and Frostenson (1986) and illustrated in Figures 6-27 through 6-30.

6.2.3.1.2.2 Horizontal emplacement

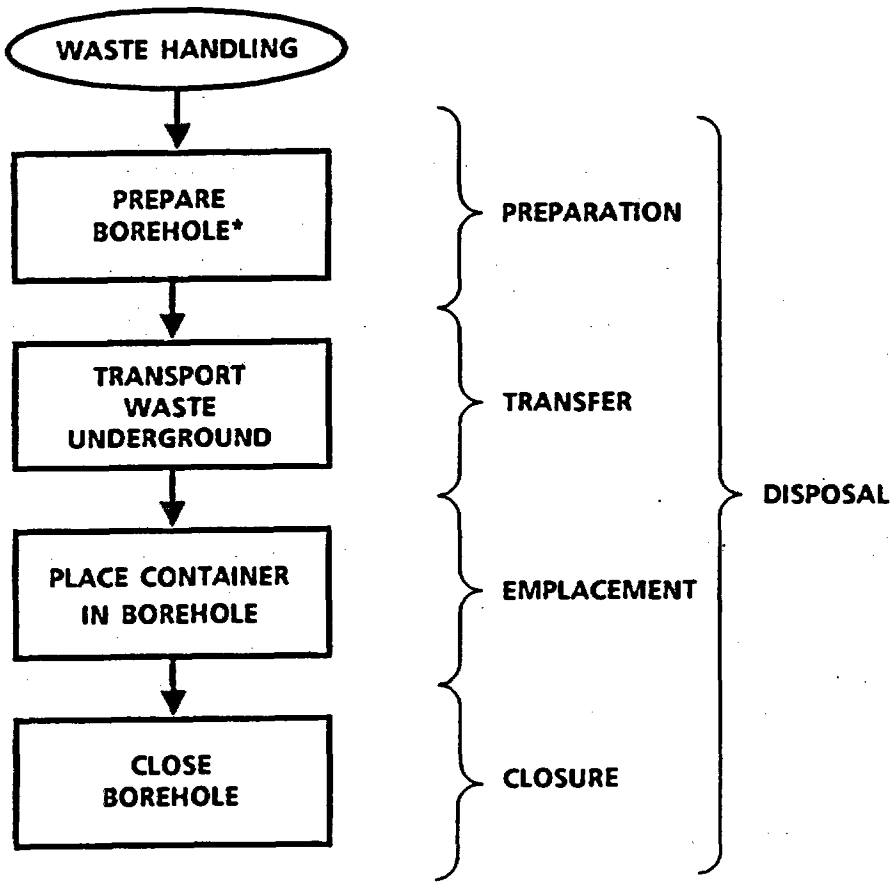
The basic operations required for the horizontal emplacement of a waste package include the following steps: (1) preparing a horizontal emplacement borehole, (2) transferring the waste to the emplacement area, (3) emplacing the waste container, and (4) closing the emplacement borehole. A description of these operations is provided by Stinebaugh et al. (1986) and illustrated in Figures 6-31 through 6-34.

6.2.3.1.2.3 Caretaker

Caretaker operations would be initiated after the last waste package had been emplaced and normal waste handling had been completed. These activities could include continued performance confirmation, radiological protection, security operations, and limited facility maintenance. Caretaker operations would continue until repository closure and decommissioning.

6.2.3.1.2.4 Closure and decommissioning

Permanent closure of the repository includes underground backfill and seals as described in Sections 6.2.7 and 6.2.8. Decommissioning activities could include decontamination and dismantling of the surface facilities and installation of facilities and equipment for a postclosure institutional barrier system (e.g., monuments).



* A VERTICAL OR HORIZONTAL BOREHOLE WILL BE PREPARED, DEPENDING ON THE EMPLACEMENT CONFIGURATION SELECTED

Figure 6-26. Flow diagram of waste disposal.

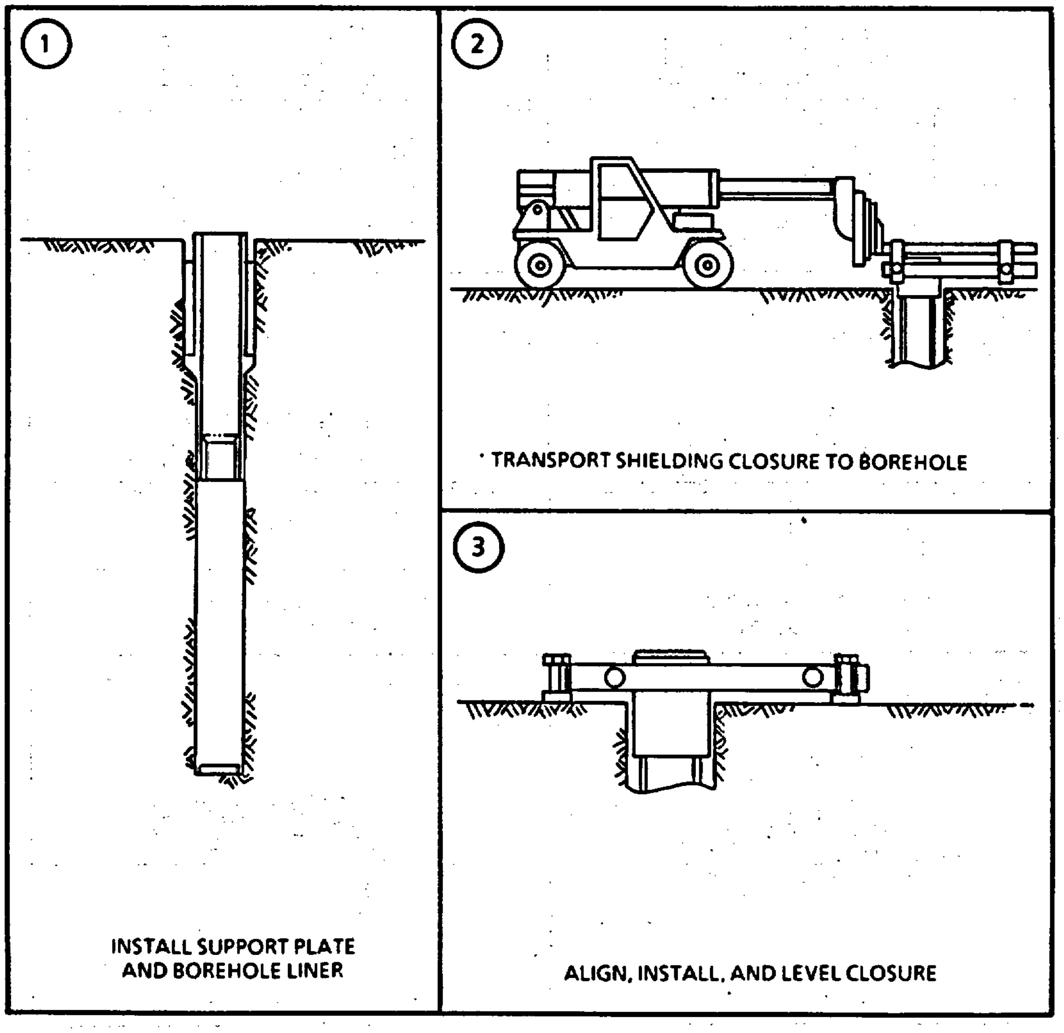


Figure 6-27. Preparation of a vertical emplacement borehole.

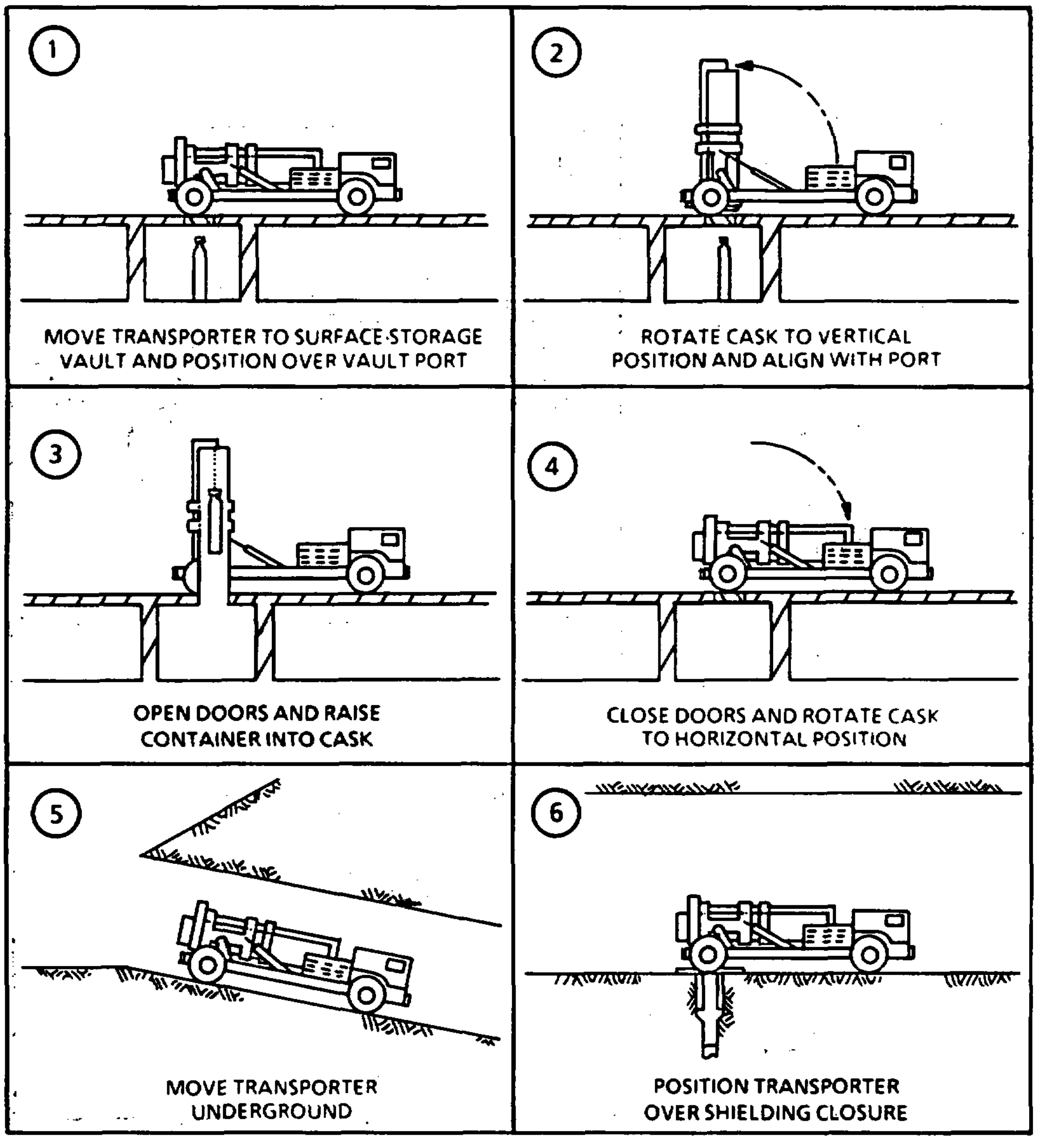


Figure 6-28. Transfer of a waste package to a vertical emplacement borehole.

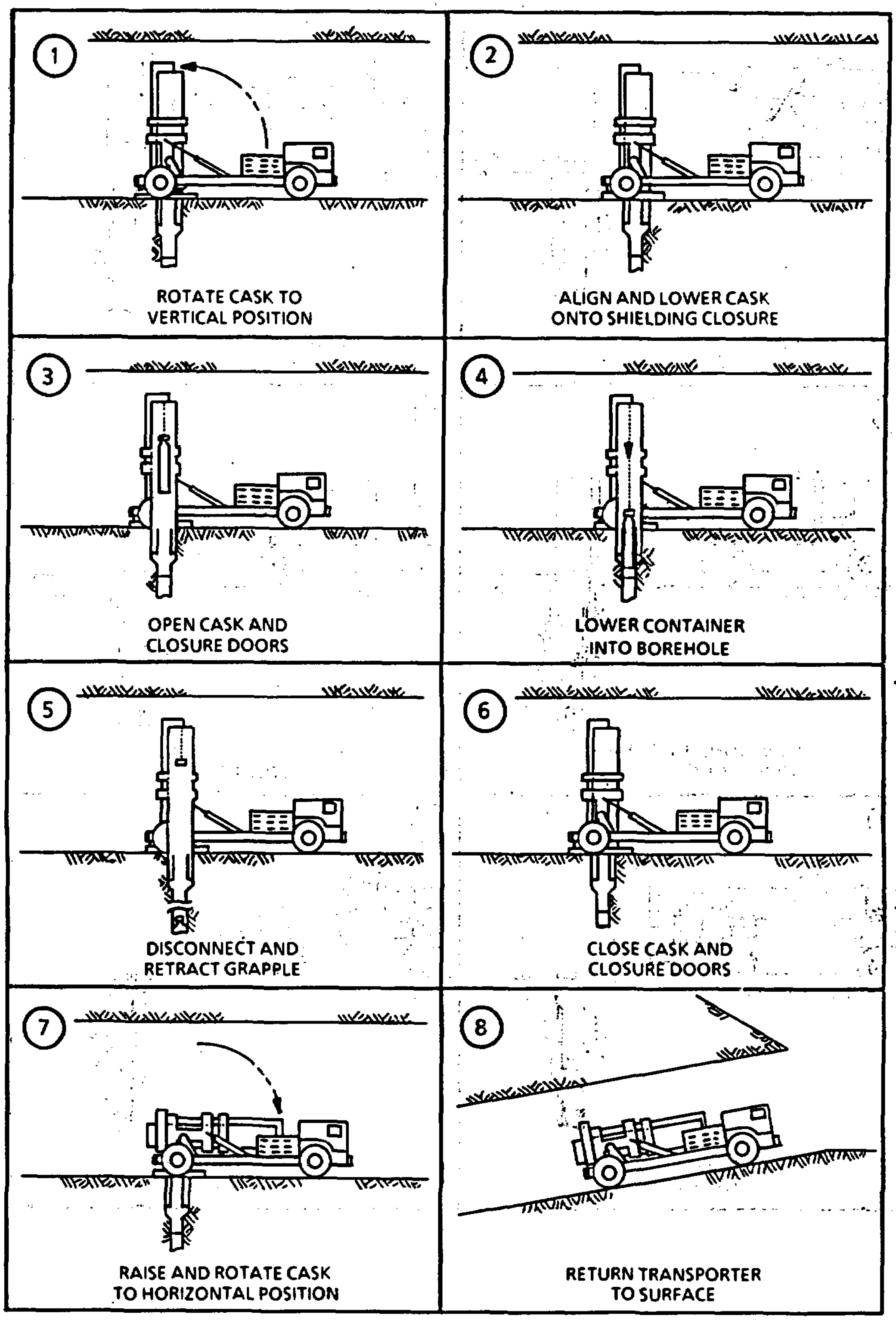


Figure 6-29. Emplacement of a waste package in a vertical borehole.

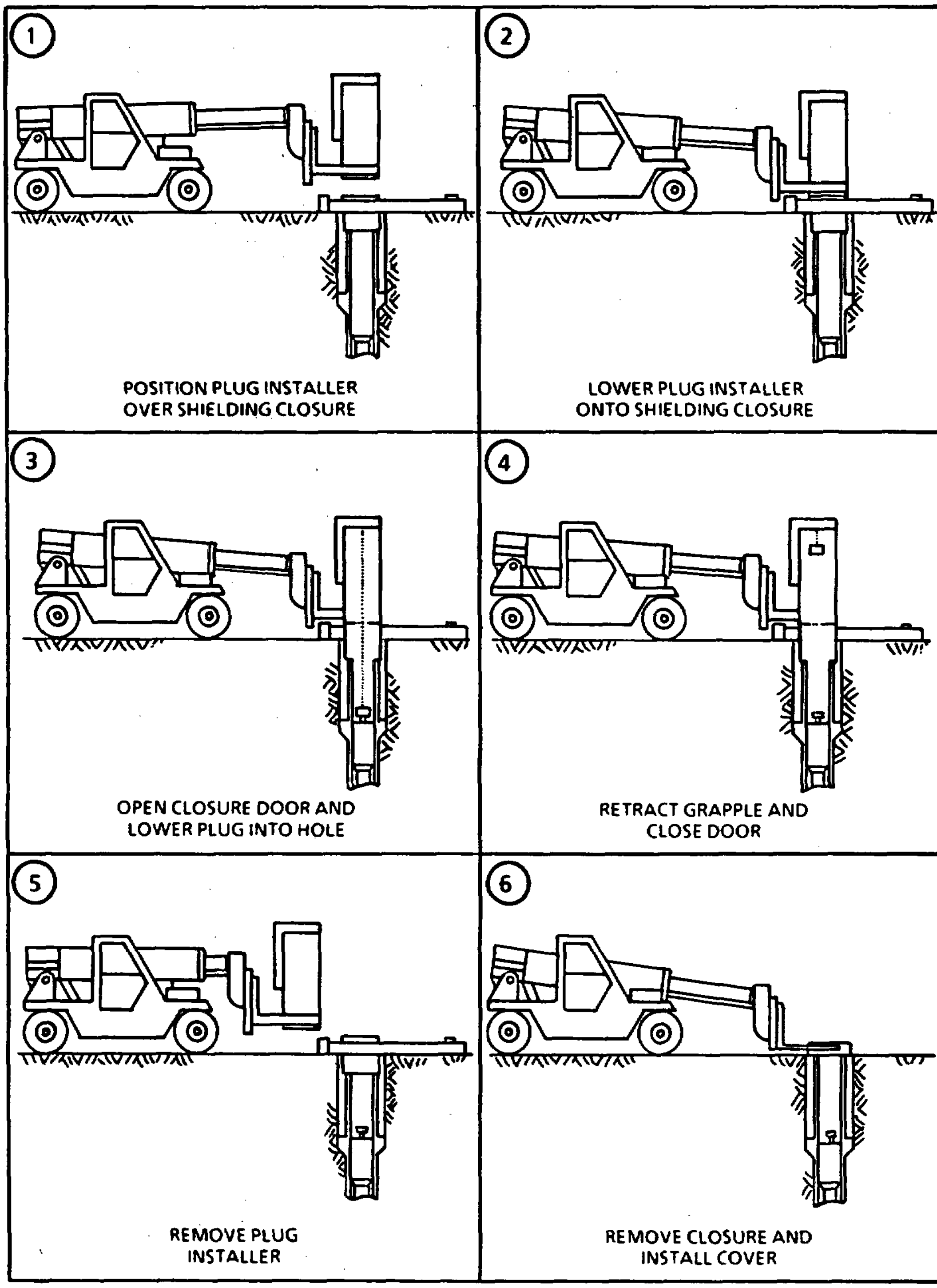


Figure 6-30. Closure of a vertical borehole after waste emplacement.

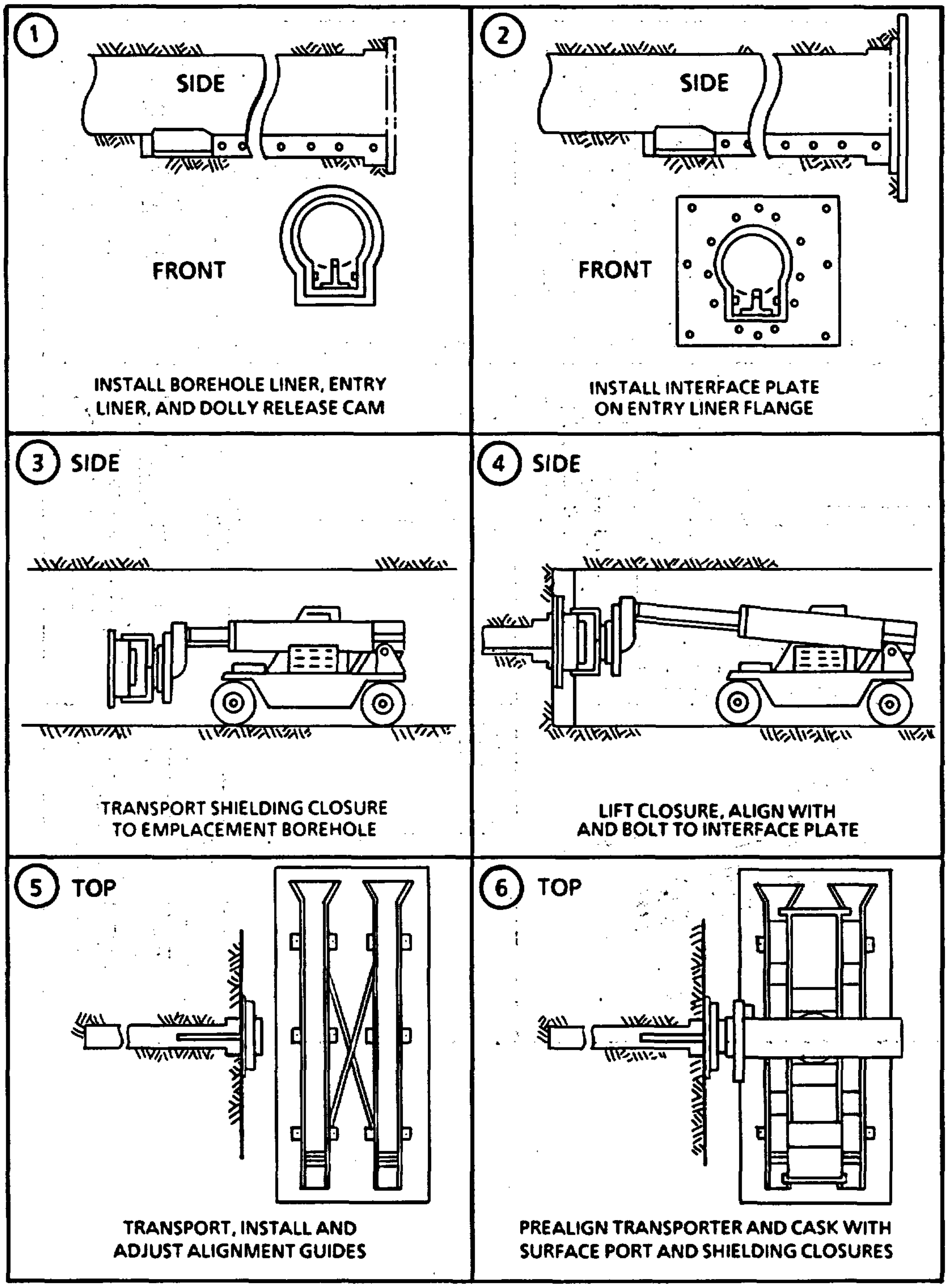


Figure 6-31. Preparation of a horizontal emplacement borehole.

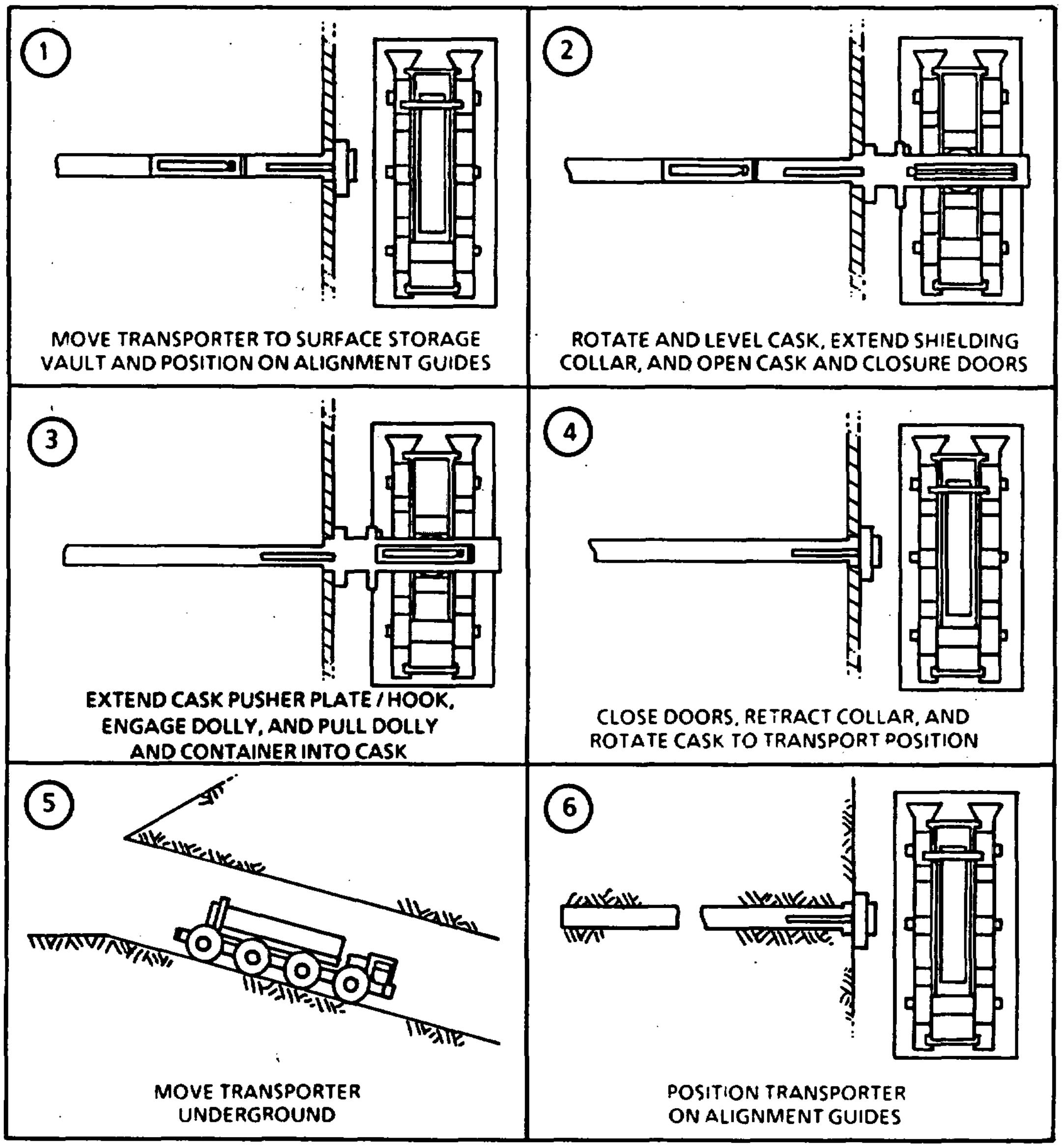


Figure 6-32. **Transfer of a waste package to a horizontal emplacement borehole.**

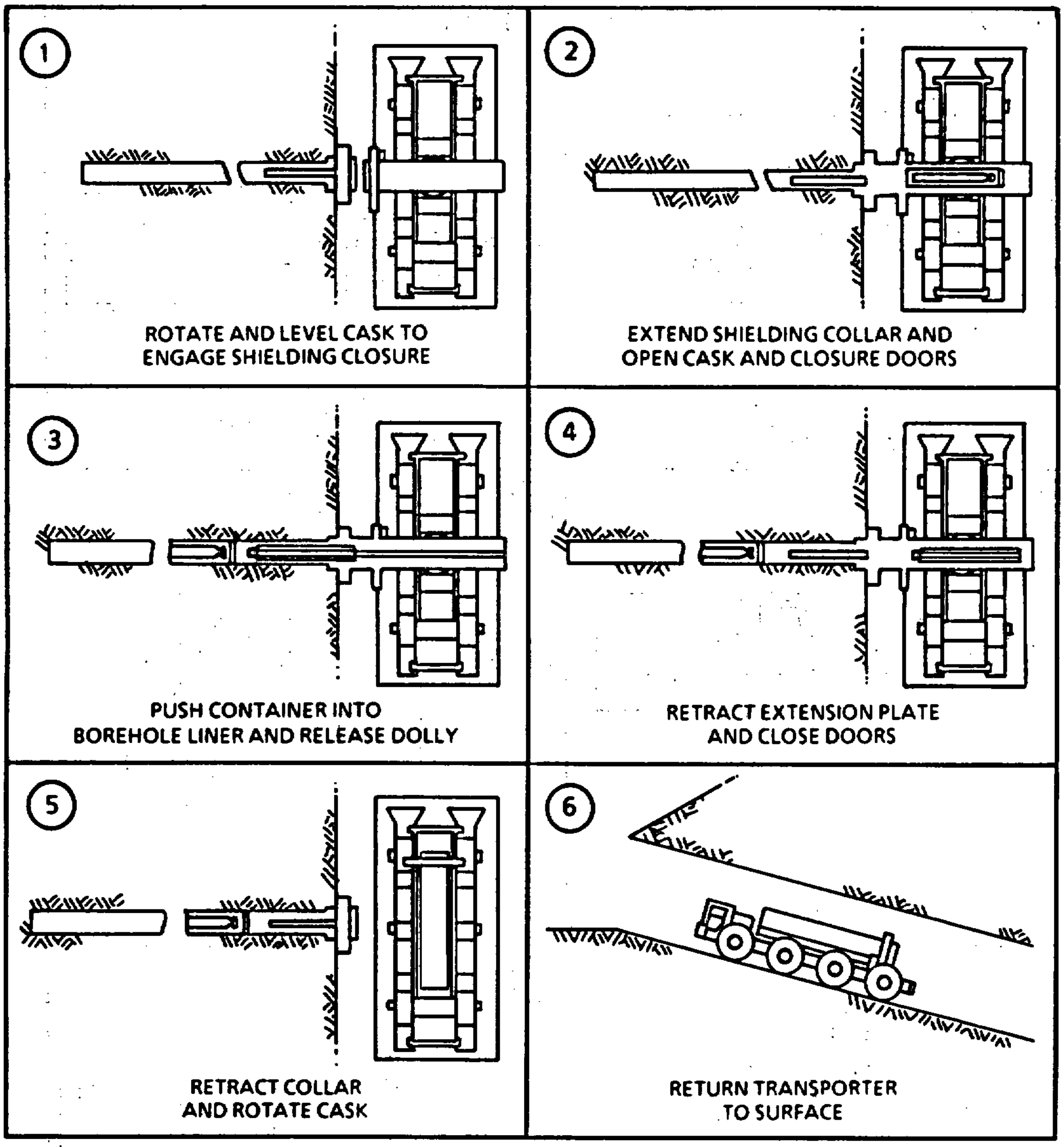


Figure 6-33. Emplacement of a waste package in a horizontal borehole.

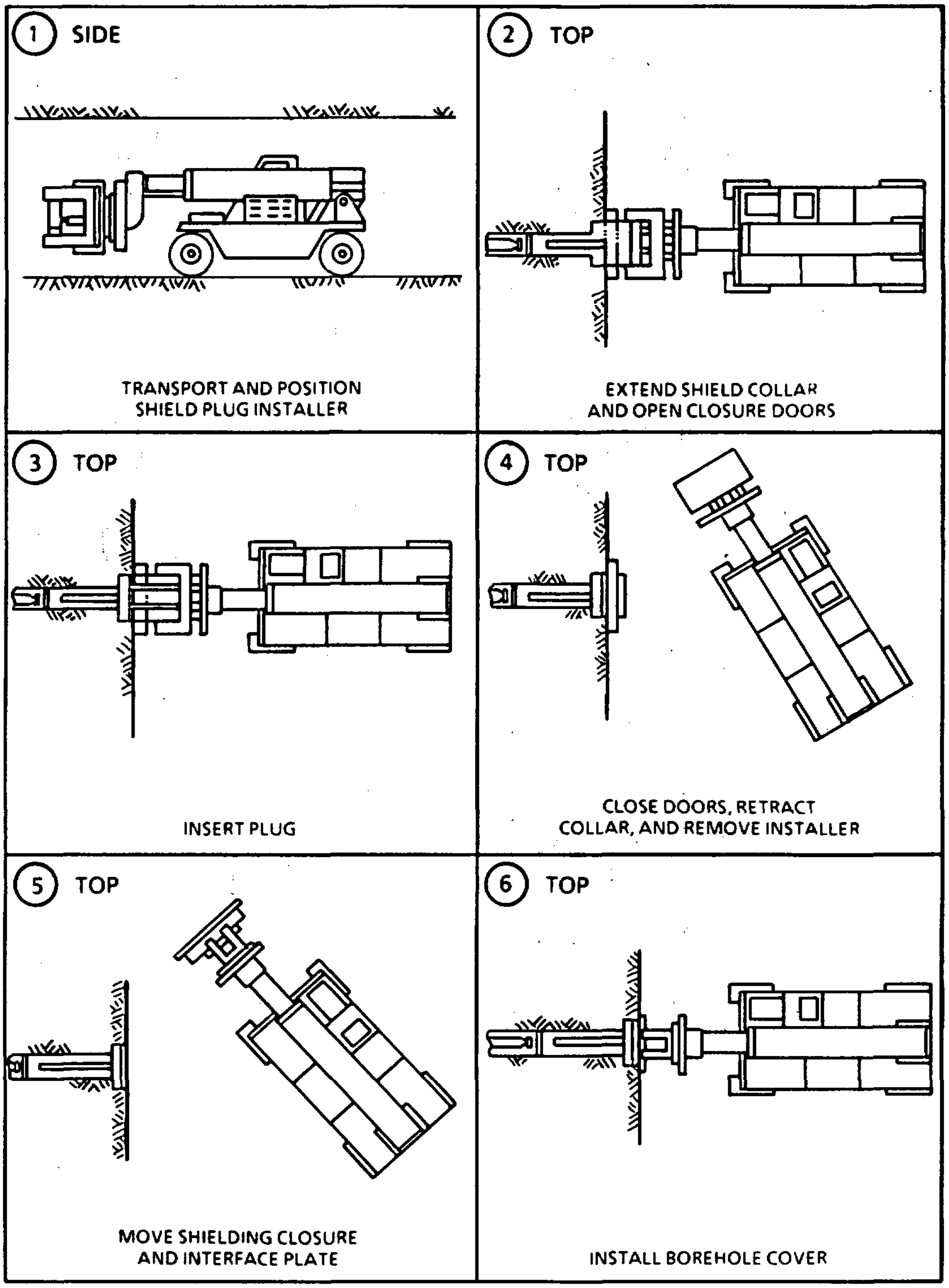


Figure 6-34. Closure of a horizontal borehole after waste emplacement.

6.2.3.1.3 Equipment

All equipment identified for waste emplacement is based on currently available technology. Conceptual designs have been developed for the equipment required for each emplacement concept. All emplacement equipment will require a detailed design, cost analysis, and development process to meet repository standards for feasibility, reliability, safety, and performance. Table 6-19 summarizes the equipment that would be used for vertical emplacement and its functions. The transporter for vertical emplacement is illustrated in Figure 6-35 (Stinebaugh and Frostenson, 1986). The equipment that will be used in horizontal emplacement is summarized in Table 6-20. The transporter for horizontal emplacement is illustrated in Figure 6-36. (Stinebaugh et al., 1986).

The drilling of vertical emplacement boreholes to contain a single waste package would be accomplished using existing mining equipment modified for this purpose. The capability for accurately drilling and lining horizontal boreholes will require the development and demonstration of prototype drilling equipment. Borehole drilling and lining is part of the subsurface excavation and development process discussed in Section 6.2.6.1.

6.2.3.2 Waste retrieval and shipping operations

This section describes the current concepts for the retrieval operations at the repository. In addition, this section contains a block-flow diagram defining the principal operations and conceptual flow diagrams showing the equipment to be used in the operations. The retrieval concept is discussed in Section 6.2.9.

6.2.3.2.1 Waste retrieval

Figure 6-37 is a block-flow diagram of the waste retrieval operations under normal conditions. Operations for both vertical and horizontal retrieval are presented for a comparison of the two systems. Waste retrieval is discussed in more detail in Section 6.2.9.

6.2.3.2.1.1 Vertical retrieval

The basic operations required for the removal of a vertically oriented waste container include the following steps: (1) preparing the vertical borehole, (2) removing the waste container, (3) transferring the waste to the surface, and (4) closing the borehole. A description of these operations under normal conditions is provided by Stinebaugh and Frostenson (1986) and illustrated in Figures 6-38 through 6-41. Off-normal events for retrieval are discussed in Section 6.2.9.2.2.

Table 6-19. Summary of vertical emplacement equipment and functions

Equipment	Function
WASTE CONTAINER, EMPLACEMENT ENVELOPE, AND SHIELDING HARDWARE	
Waste container	Waste containment
Borehole	Containment and support of waste container
Liner	Alignment of waste container and protection of borehole opening during emplacement and retrieval
Support plate	Centering and support of waste container
Plug	Radiation attenuation from borehole
Cover	Content identification and final closure of borehole
Instrumentation	Monitoring and preretrieval assessment
WASTE TRANSPORTER	
Transporter cab	Steering, controls, and monitoring
Running gear	Locomotion
Brake system	Braking
Hydraulic system	Cask support and positioning
Cask	Conveyance, handling, and shielding of waste container
MODIFIED FORKLIFT	
Forklift cab	Steering, controls, and monitoring
Running gear	Locomotion, transportation, and towing of equipment
Extending boom	Alignment, installation, and removal of shielding mechanism and equipment
SHIELDING MECHANISM AND EQUIPMENT	
Hoisting adapter	Handling of shielding closure
Shielding closure	Temporary shielding during installation and retrieval of borehole plug
PLUG INSTALLER AND REMOVER	
Housing	Radiation shielding during installation and removal of plug
Hoist	Raising and lowering of plug through shielding closure
Grapple	Attachment of hoist to pintle of plug

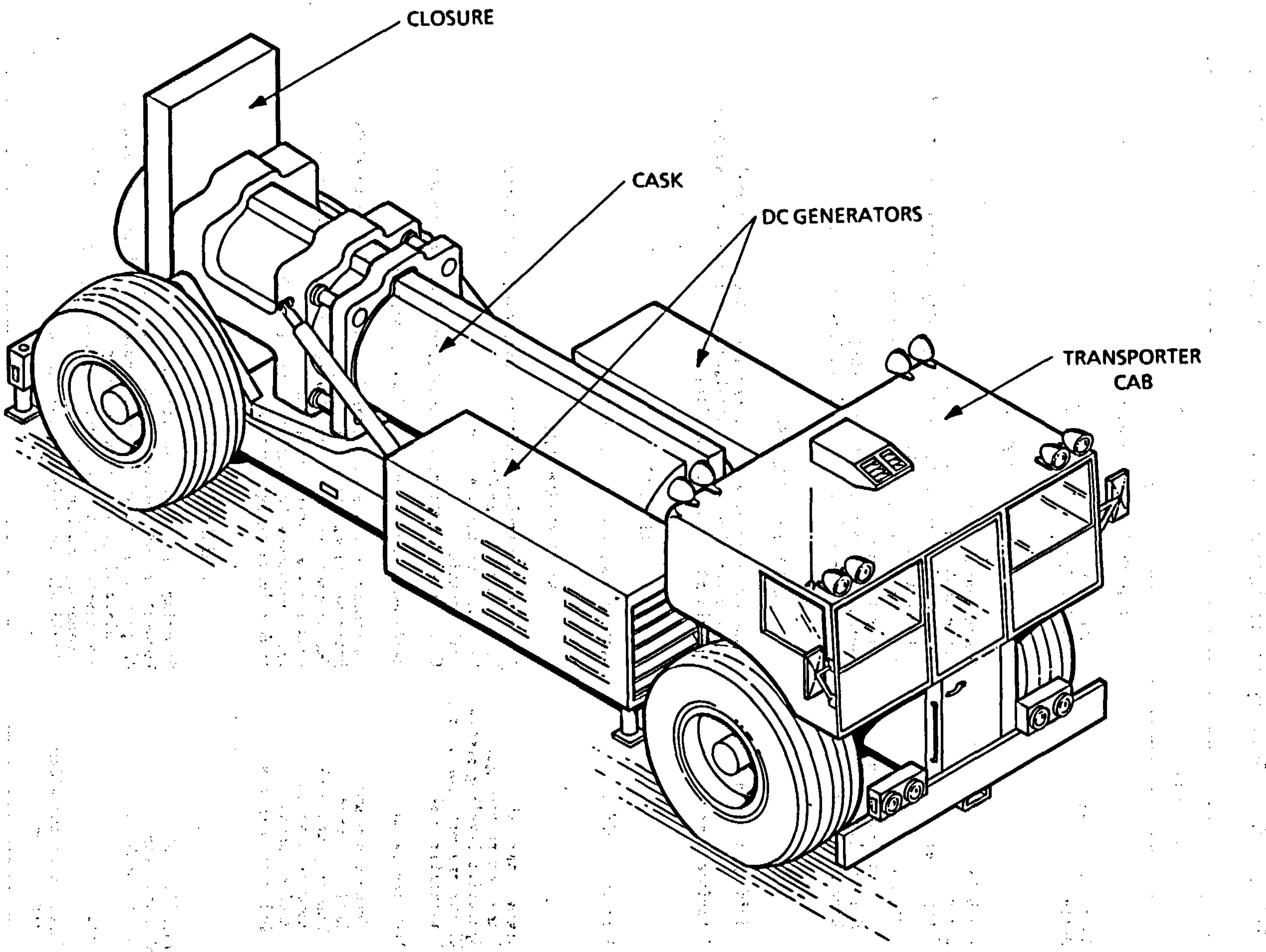


Figure 6-35. Transporter for vertical emplacement.

Table 6-20. Summary of horizontal emplacement equipment and functions

Equipment	Function
	WASTE CONTAINER AND DOLLY
Waste container	Waste containment
Dolly	Mobility for waste container
	EMPLACEMENT ENVELOPE
Borehole	Waste containment
Liner	Waste containment and support
Entry liner	Support of waste container during entry for emplacement and support for shield plug
Flange	Attachment for interface plate and borehole cover
Dolly release cam	Dolly release
Shield plug	Radiation attenuation from borehole
Borehole cover	Content identification and final borehole cover
	SHIELDING MECHANISM
Shielding closure	Temporary shielding during emplacement and retrieval of the waste container, and installation or removal of the plug
Interface plate	Attachment for shielding closure
	ALIGNMENT
Alignment guides	Waste transporter positioning
	WASTE TRANSPORTER
Transporter cab	Steering, controls, guidance, monitoring, and safety
Frame and running gear	Support and locomotion
Hydraulic leveling system	Cask support and leveling
Electrical rotation system	Cask rotation
Transporter cask	Conveyance, handling, and shielding of waste container
Cask mechanism	Emplacement and retrieval of waste container
Extension plate	Insertion of waste container in and removal from borehole
Ballscrew shaft	Drive mechanism for extension plate
Pusher plate/hook	Emplacement and retrieval of waste container and dolly
Hook release cam	Hook release during emplacement
Roller chains	Drive mechanism for pusher plate and hook
Dolly release cam	Hook release during retrieval
	MODIFIED FORKLIFT
Forklift cab	Steering controls and monitoring
Running gear	Locomotion and transportation of equipment
Extending boom	Alignment, installation, and removal of shielding, mechanism, shield plug, and borehole cover
Fork	Attachment of shielding closure, shield plug installer and remover, and borehole cover
Shield plug installer and remover	Shield plug installation and removal

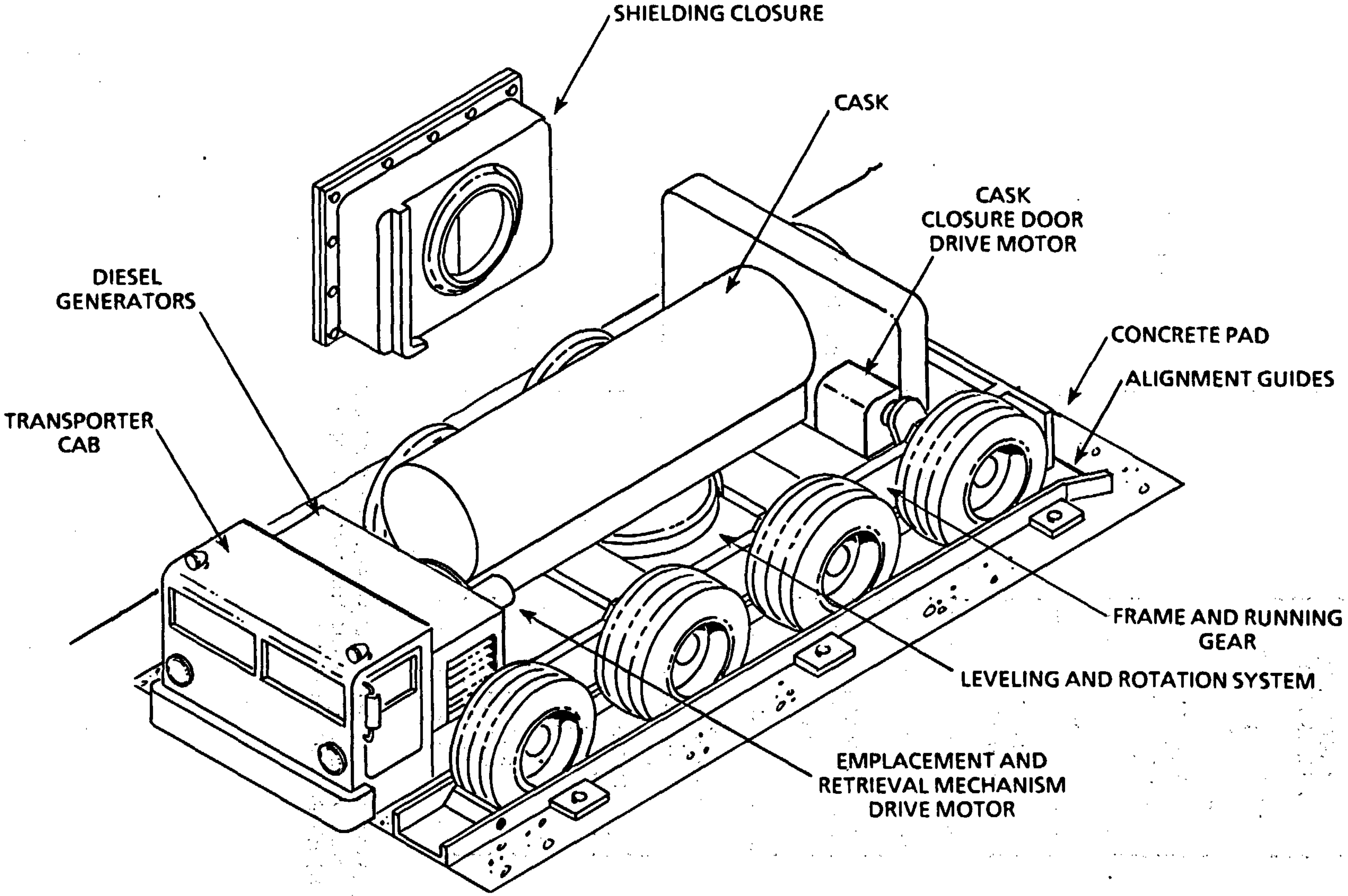


Figure 6-36. Transporter for horizontal emplacement.

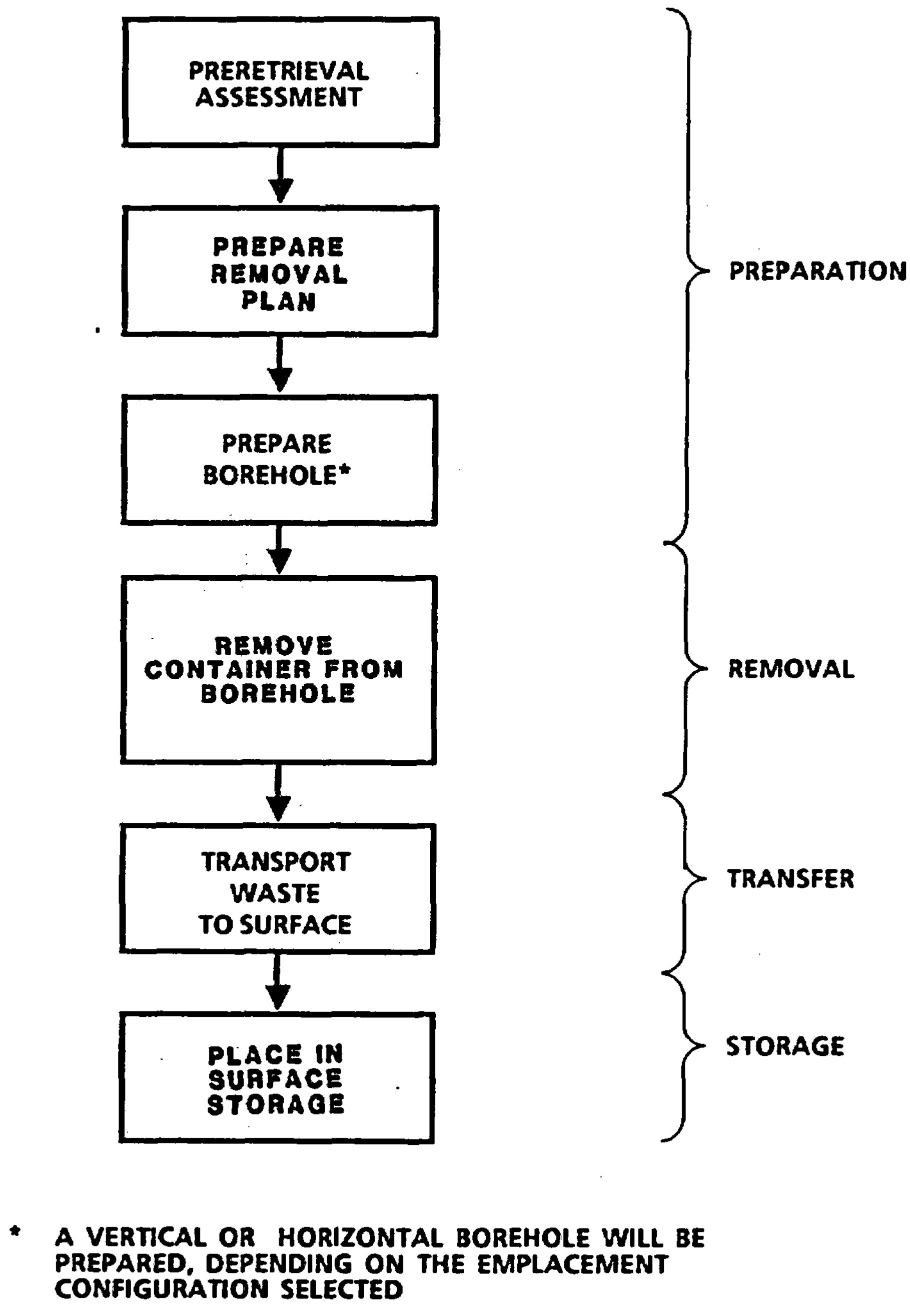


Figure 6-37. Flow diagram of waste retrieval.

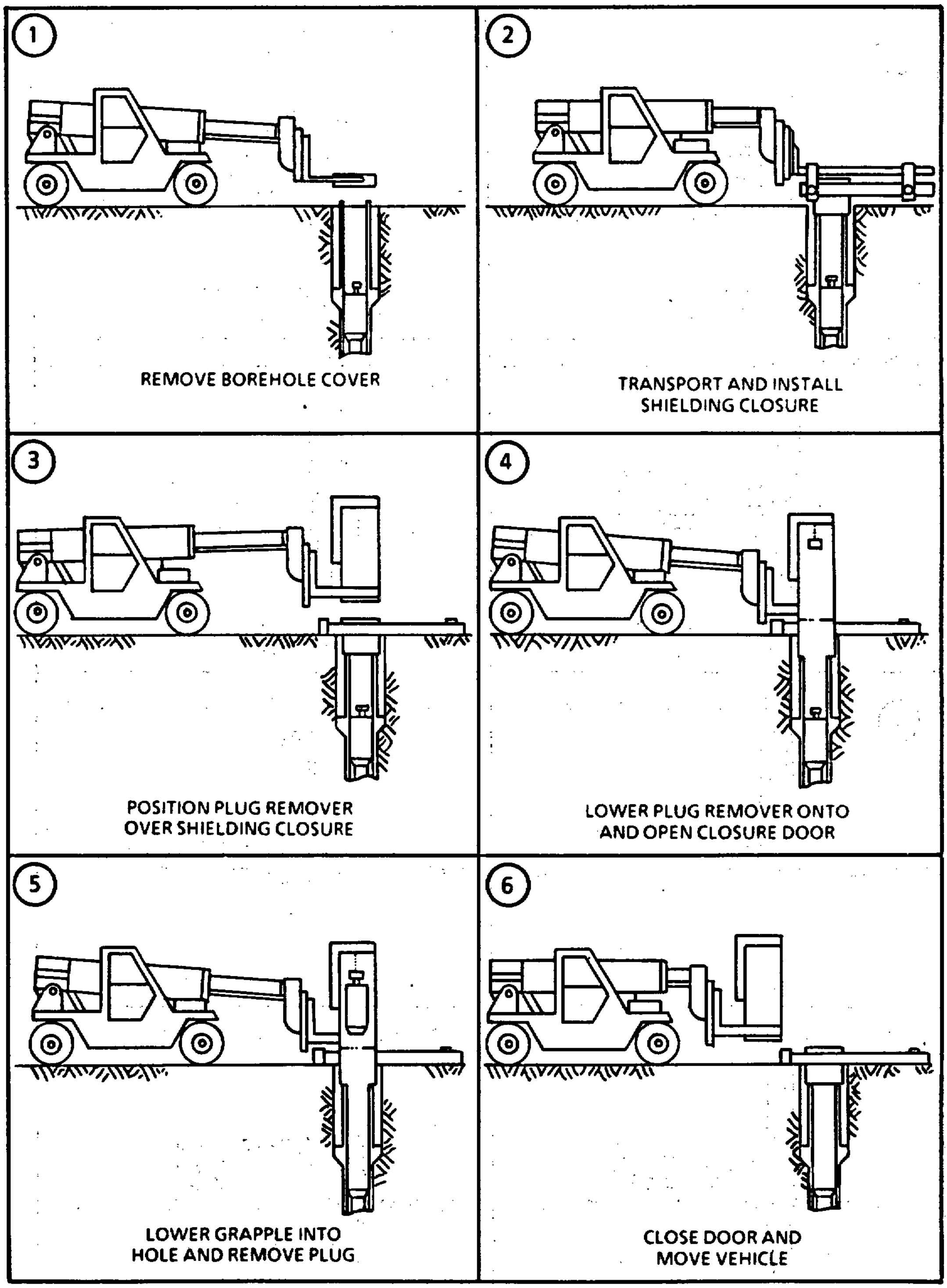


Figure 6-38. Preparation of a vertical borehole for waste package removal.

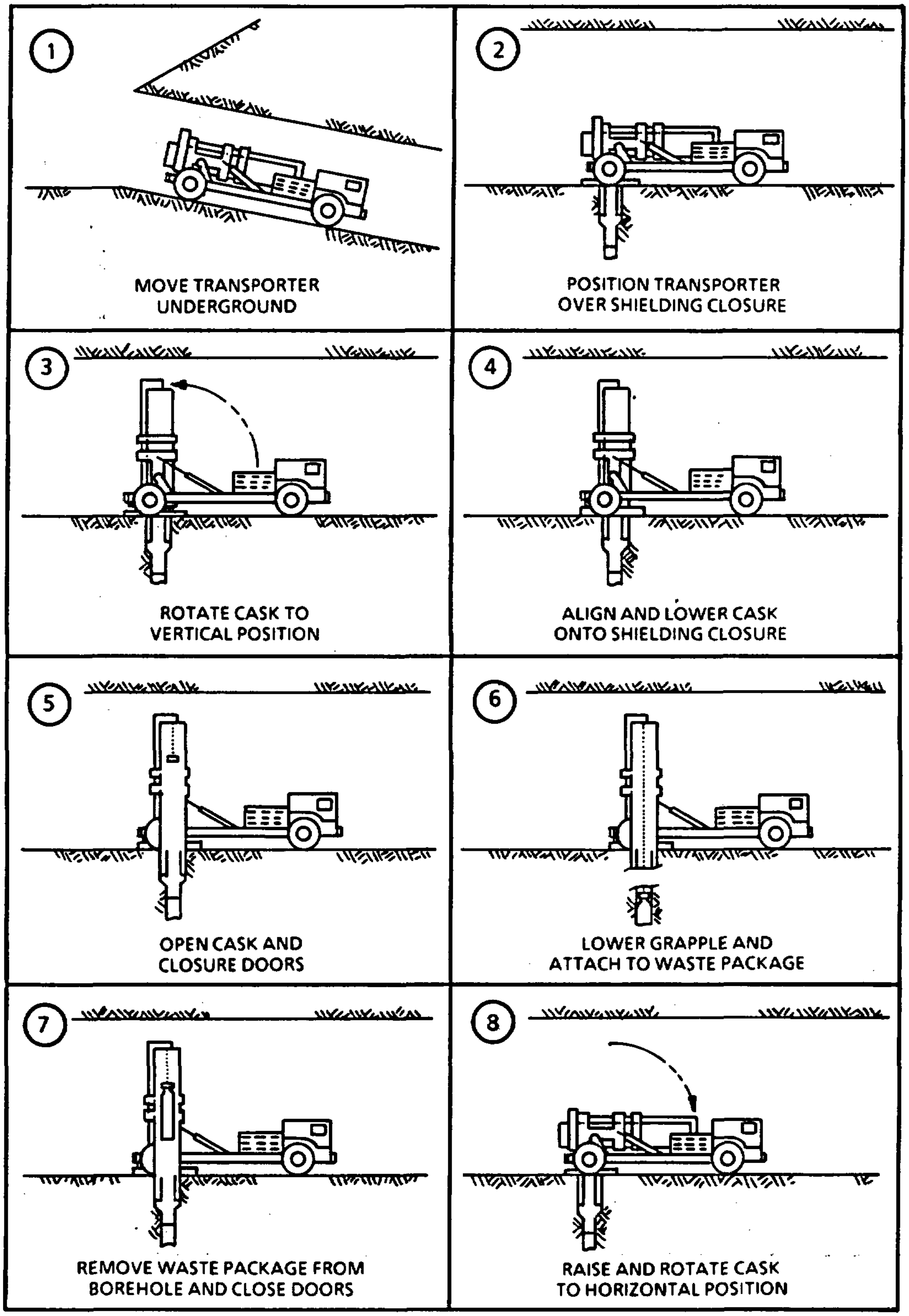


Figure 6-39. Removal of a waste package from a vertical borehole.

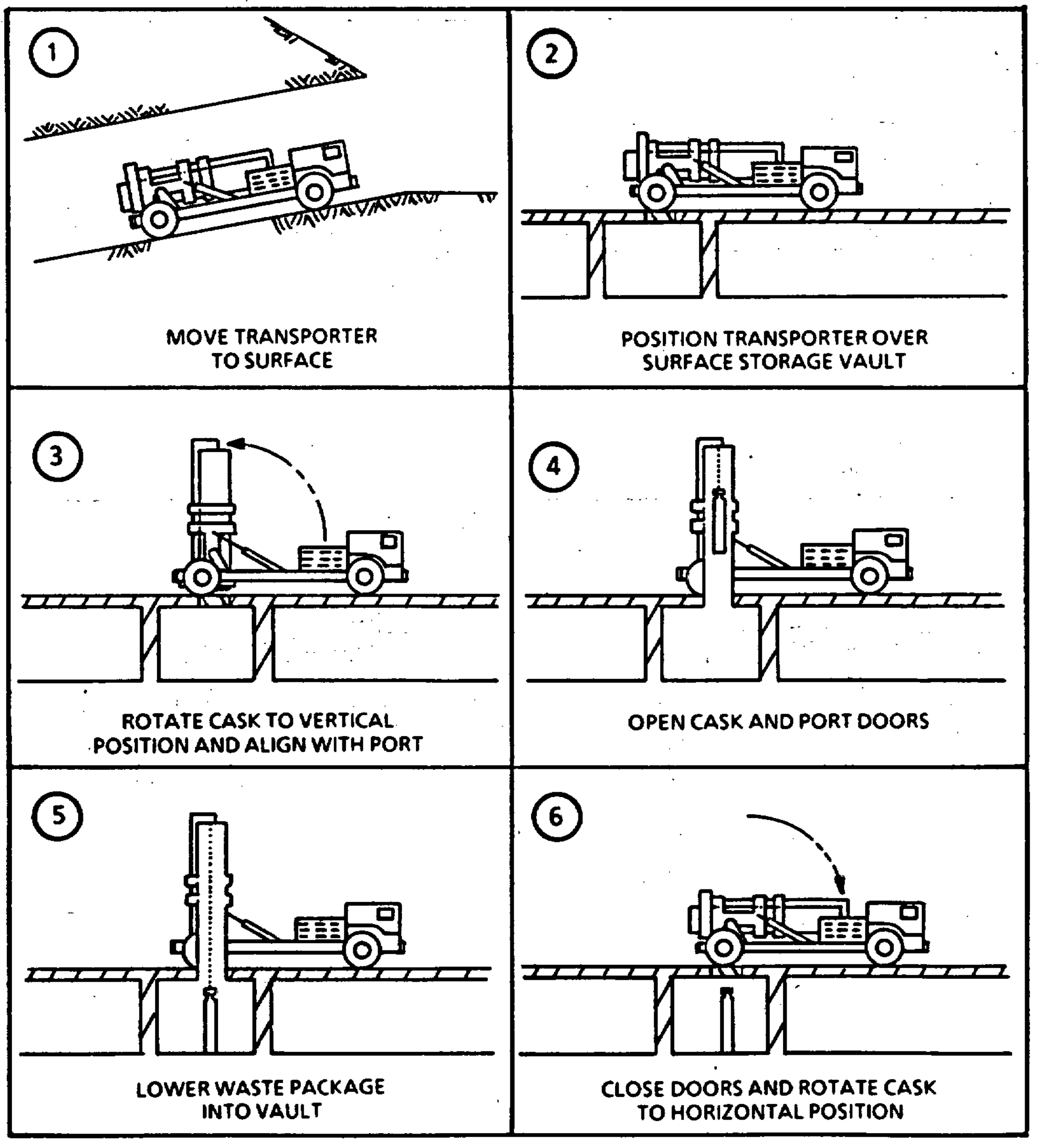


Figure 6-40. Transfer of a waste package from a vertical borehole to surface storage.

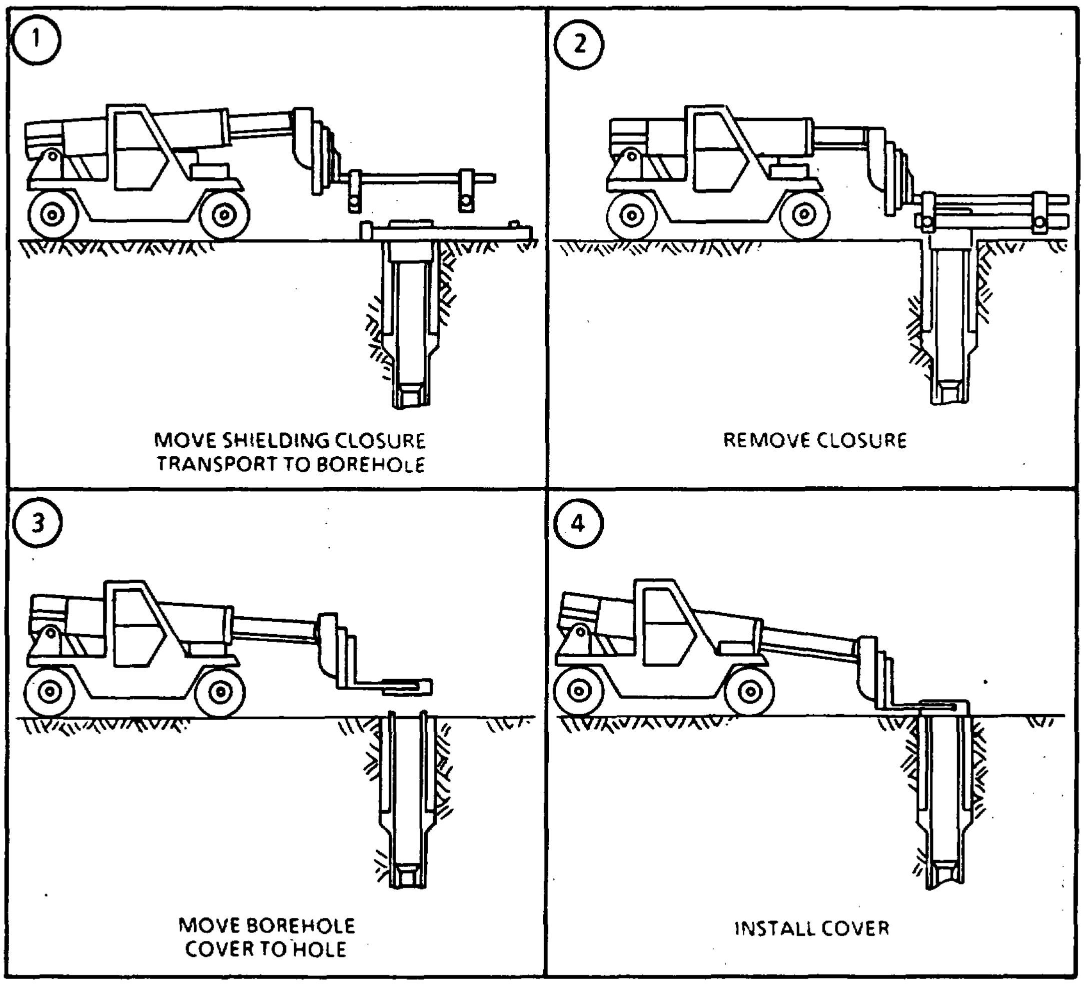


Figure 6-41. Closure of a vertical borehole after waste removal.

6.2.3.2.1.2 Horizontal retrieval

The basic operations required for the removal of a horizontally oriented waste container include the following steps: (1) preparing the horizontal borehole, (2) removing the waste container, (3) transferring the waste to the surface, and (4) closing the borehole. A description of these operations under normal conditions is provided by Stinebaugh et al. (1986) and illustrated in Figures 6-42 through 6-45. Off-normal events for retrieval are discussed in Section 6.2.9.2.2.

6.2.3.2.2 Waste shipping

Figure 6-46 presents a block-flow diagram of the planned waste shipping operations, and Figure 6-47 illustrates the shipping operations. Waste shipping operations would begin when the waste containers are removed from the surface storage vaults in the waste-handling buildings. Spent fuel and other high-level waste packages may require additional containment before loading in a shipping cask. If required, this would be done in the waste-handling building. Waste containers not requiring additional containment would be loaded directly into shipping casks, and the casks would be placed on carriers.

Radiological surveys and security-related inspections would be performed on the casks and trailers or railcars before onsite transportation vehicles would be used to move the loaded trailers or railcars to a designated shipping area. The carrier would receive a final inspection at the gate before leaving the repository.

6.2.3.3 Accident analyses

Anticipated off-normal conditions that could occur during repository operations will be assessed by the design process in accordance with the methodology discussed in Section 6.1.4. These events include maximum credible natural phenomena, mechanistic failures associated with waste-handling operations, and other man-caused events that could cause release of radioactive materials. Plans for conducting accident and safety analyses and assessments will be developed as the repository design progresses. These plans are discussed in Section 8.3.5.5.

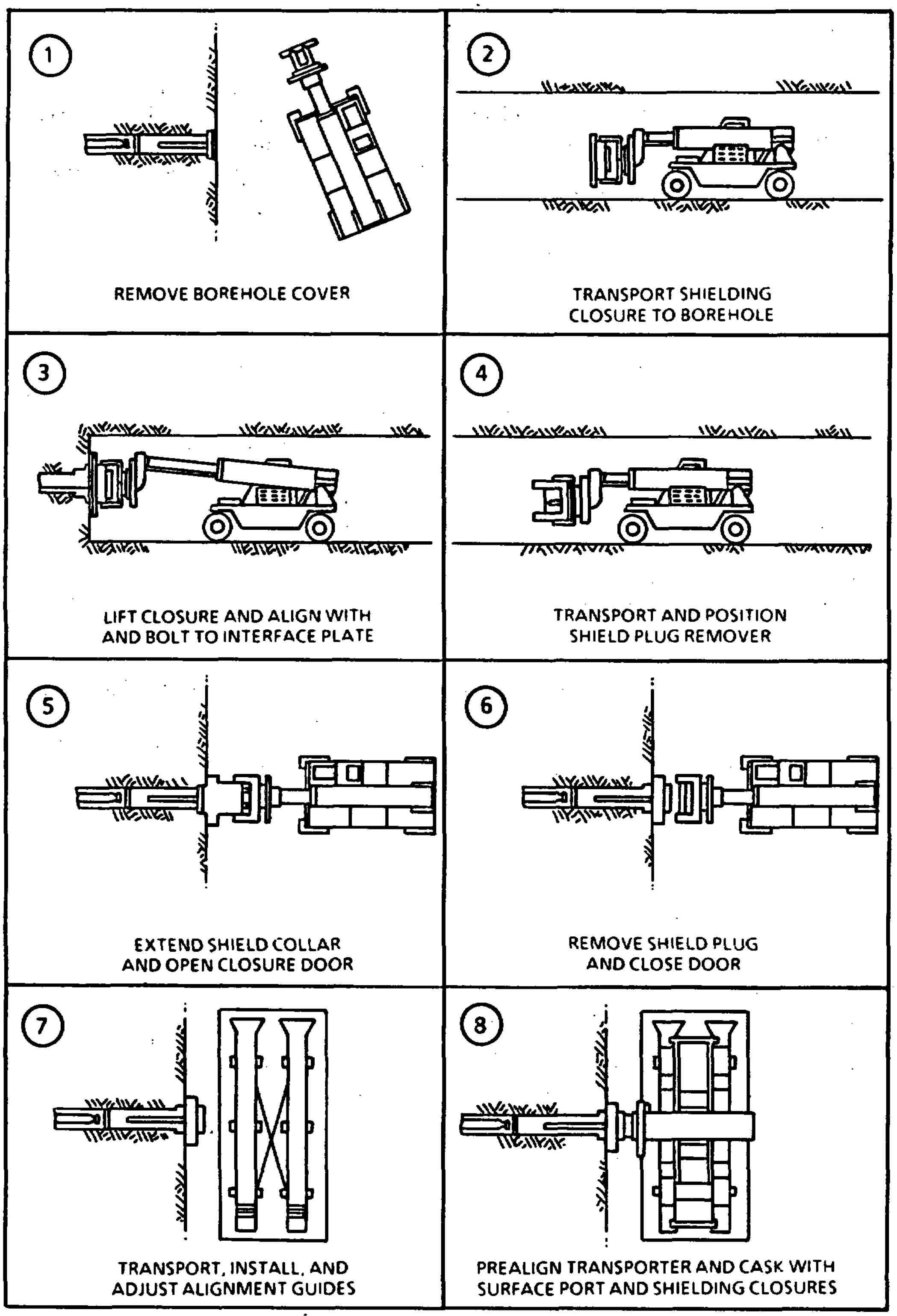


Figure 6-42. Preparation of a horizontal borehole for waste container removal.

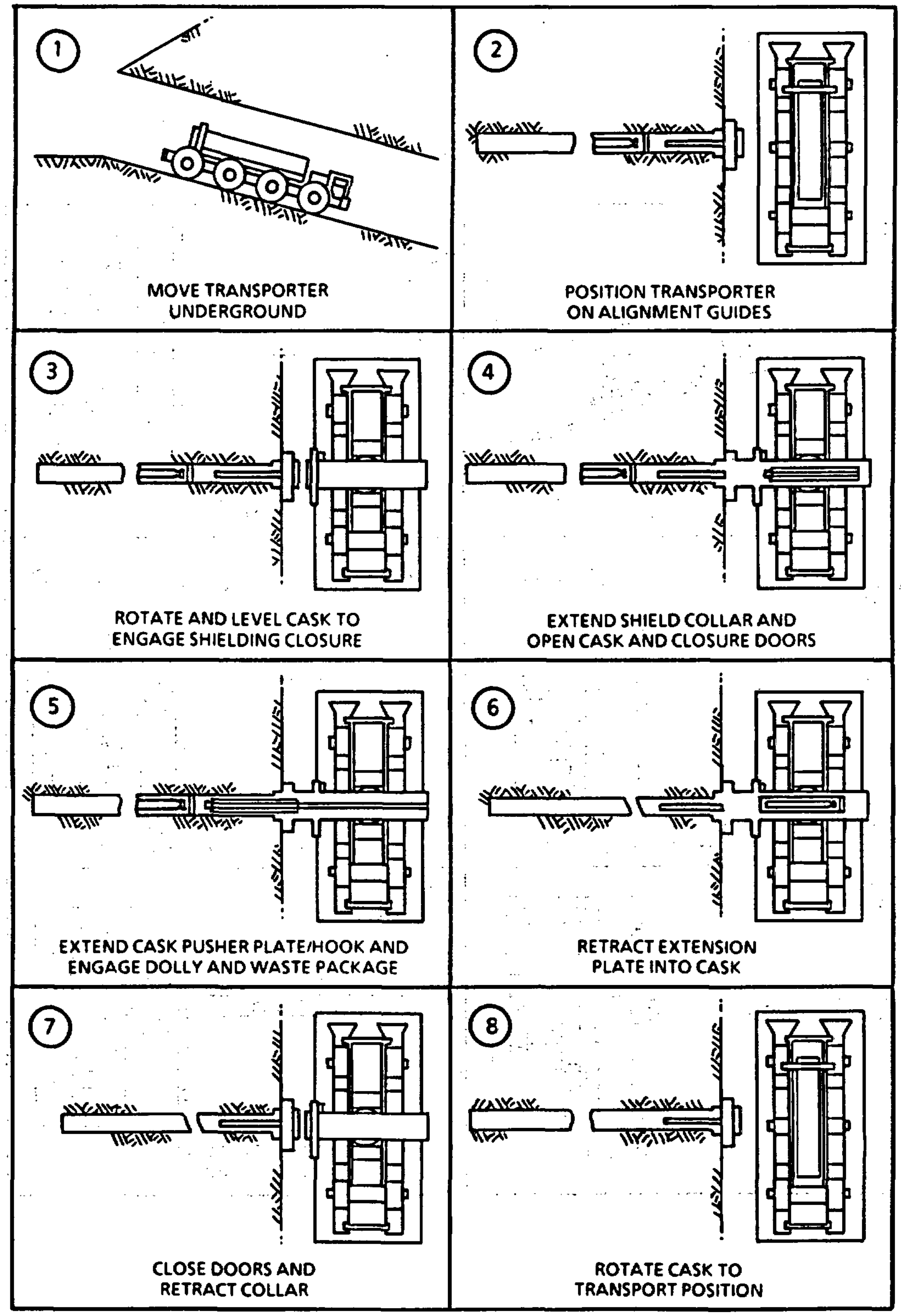


Figure 6-43. Removal of a waste container from a horizontal borehole.

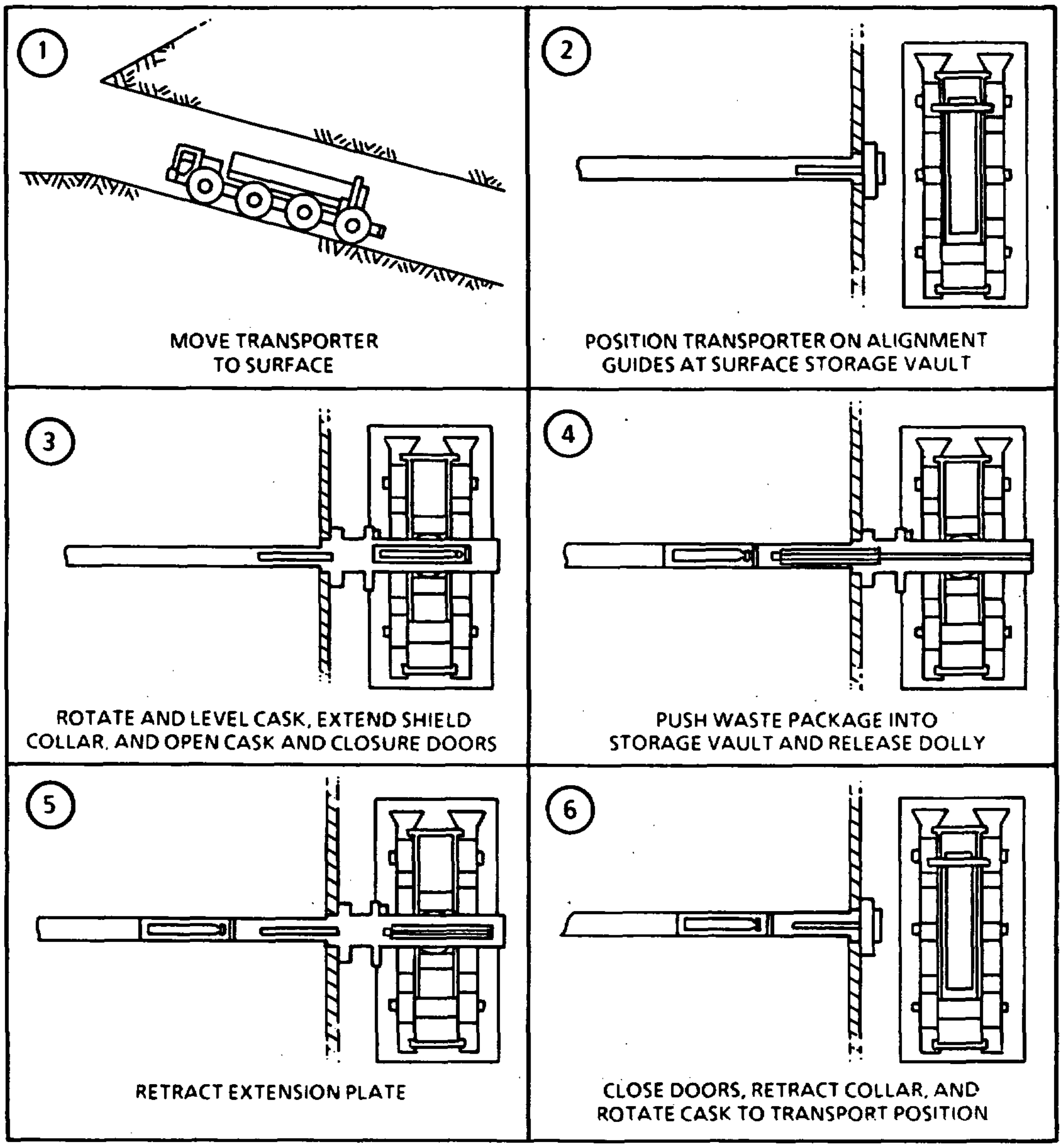


Figure 6-44. Transfer of a waste container from a horizontal borehole to surface storage.

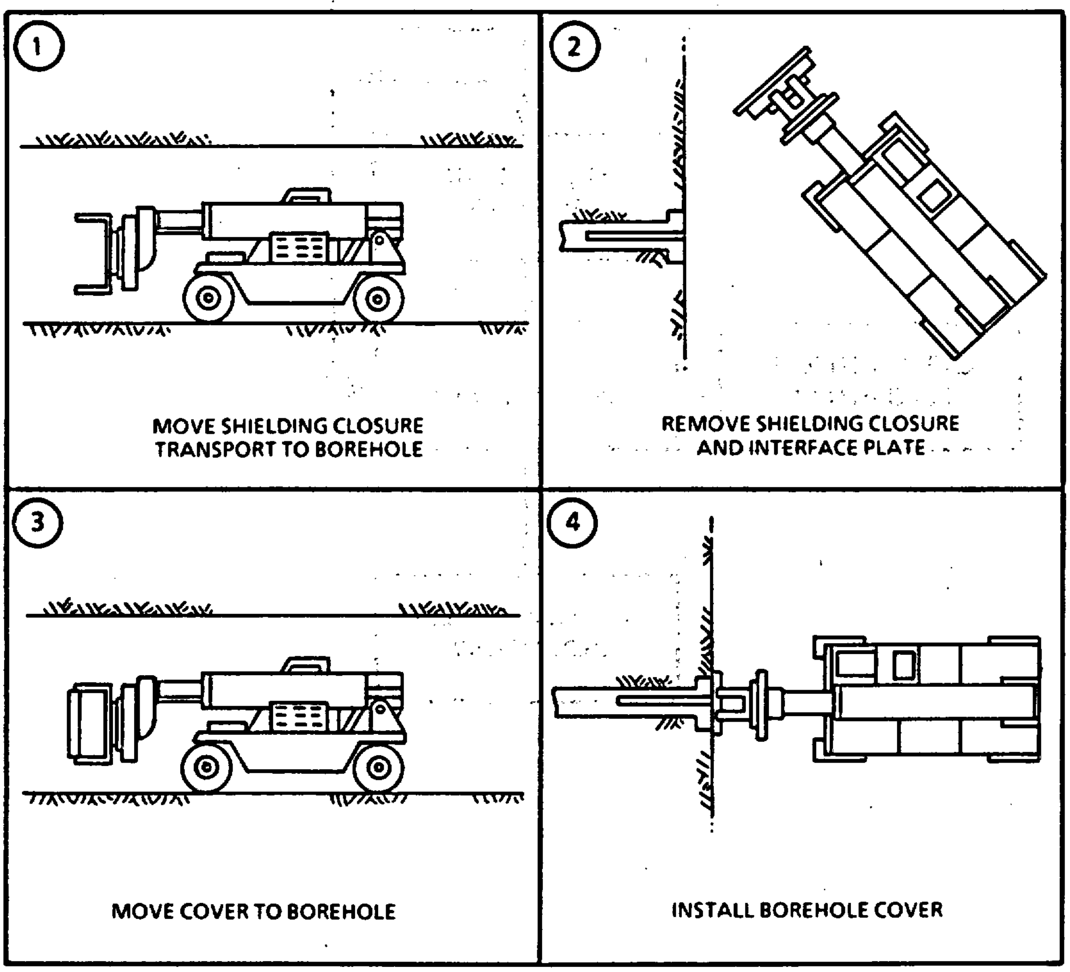


Figure 6-45. **Closure of a horizontal borehole after waste removal.**

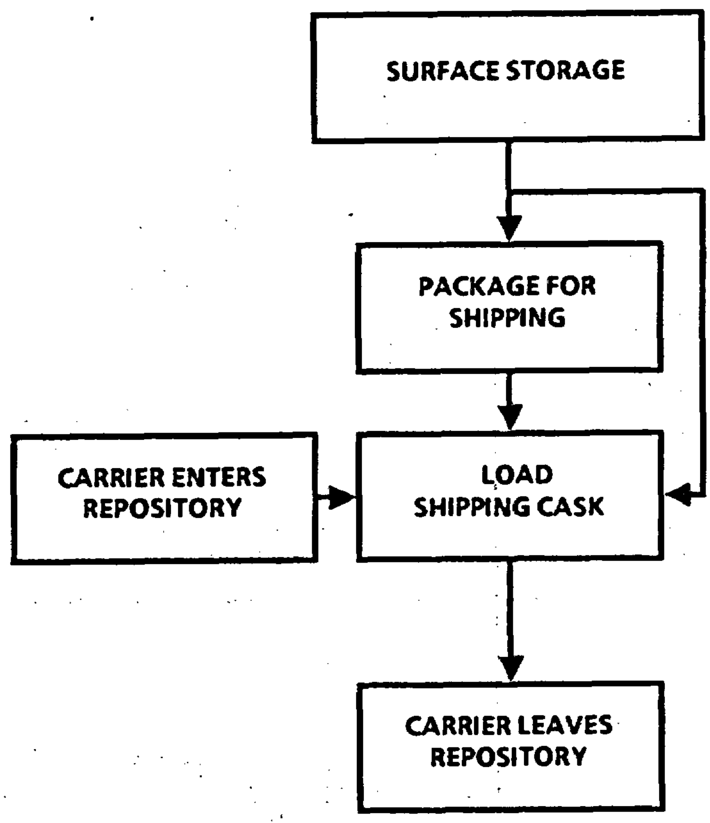


Figure 6-46. Flow diagram of waste shipping.

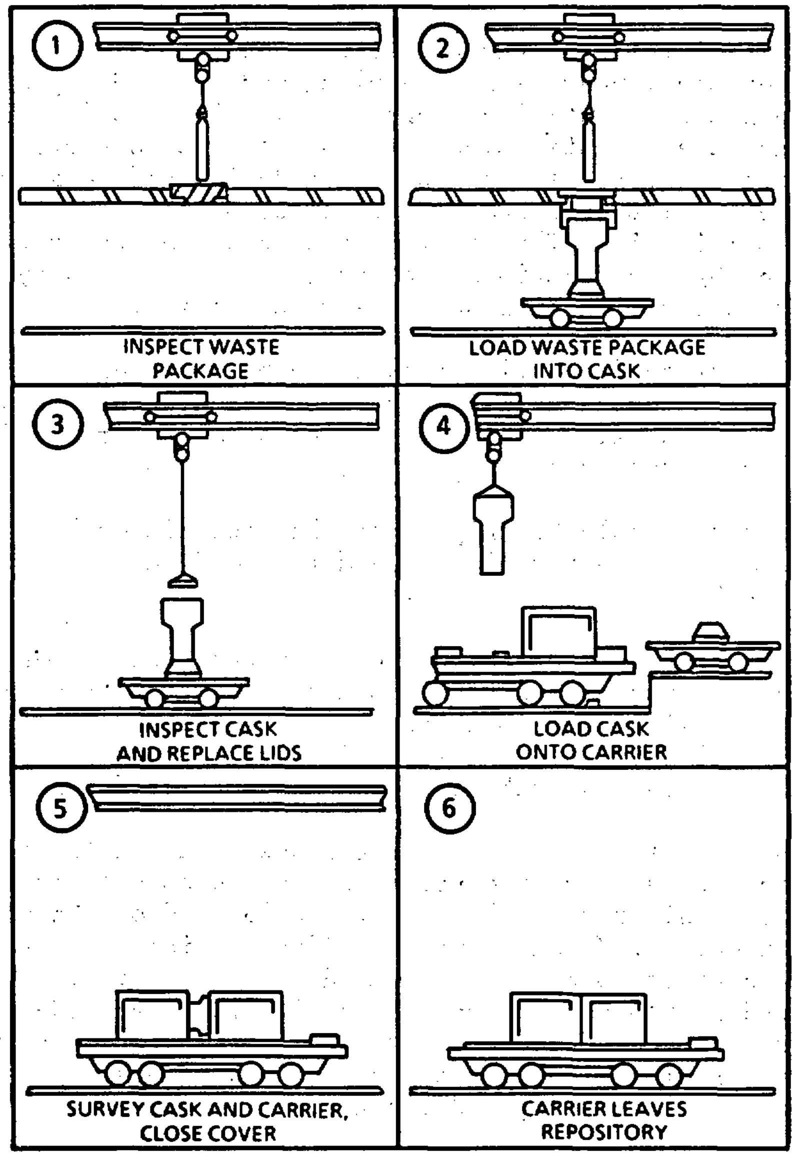


Figure 6-47. Waste shipping operations.

6.2.4 DESIGN OF SURFACE FACILITIES

The surface facilities at the repository have been designed to include a central surface facilities area, other onsite facilities that are not contiguous with the central facilities, and offsite transportation access as discussed in Section 4.2 of the SCP-CDR.

Surface facilities

The surface facilities at the repository would consist of a central surface facilities area, where waste handling and related support activities would occur, and numerous outlying support facilities and facilities that would provide access and ventilation for the underground portions of the repository (Figure 6-11, Section 6.2.2). The design and construction sequence of these facilities assumes development of the repository in two stages (Section 6.1.1.6.1). The location and layout of the surface facilities are governed by the functions they perform, by topography, and by requirements for integration with the subsurface facilities.

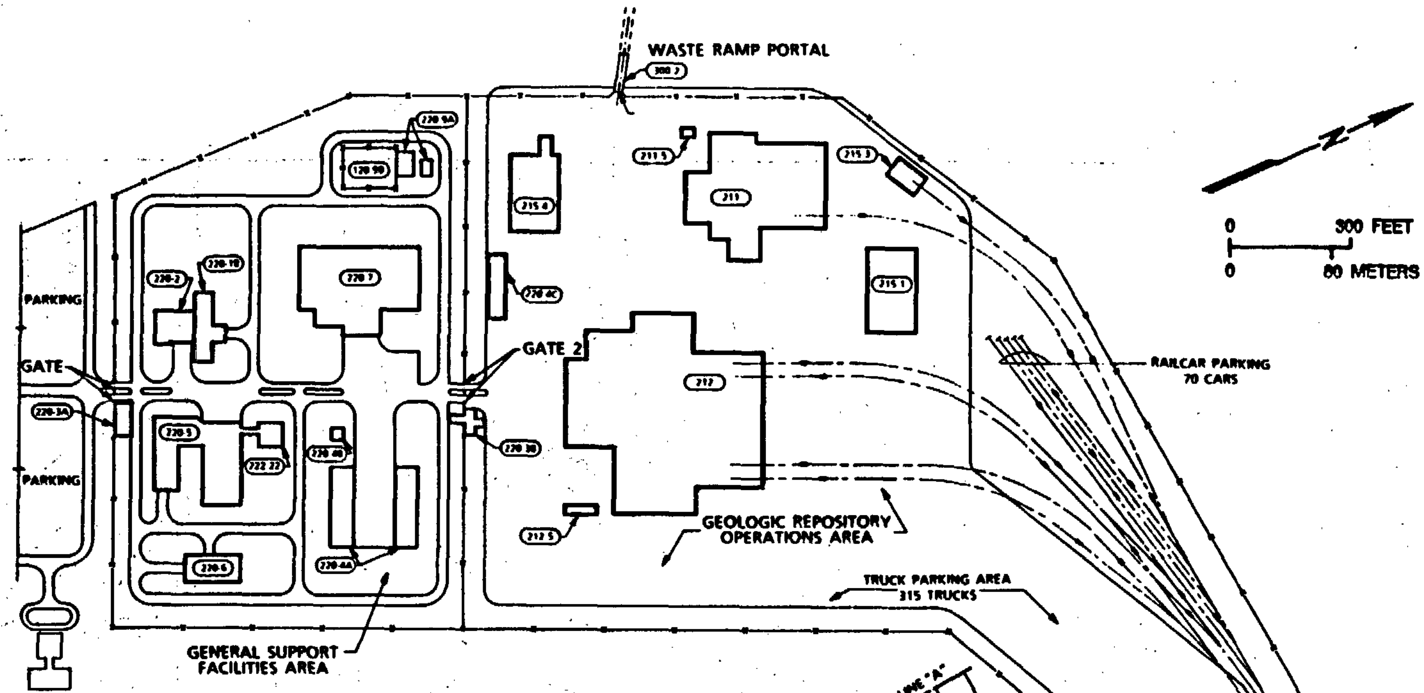
The central surface facilities area would be composed of three distinct functional areas--the waste-receiving and inspection area, the waste operations area, and the general support facilities area (Figure 6-48). Each area would be bounded by security fencing.

Radioactive waste would be shipped to the site either by rail or truck. The routes proposed for the new highway and railroad access to the site are shown in Figure 6-49.

In selecting locations for the proposed surface facilities, it was necessary to consider the siting requirements dictated by the layout and function of each facility, the location of related subsurface facilities, surface characteristics in the immediate vicinity of each facility, and general site characteristics such as access and surface drainage patterns.

A study was conducted to select a reference location for the central surface facilities to be used in developing the conceptual design (Neal, 1985). The areas considered in that study are located on the alluvial fans along the eastern base of Yucca Mountain. After an initial screening, the six areas shown in Figure 6-50 were selected for evaluation. The siting factors considered in the comparison of the six areas were identified based on the preclosure system and technical guidelines set forth in 10 CFR Part 960 for preclosure radiological safety, environmental quality, and ease and cost of construction, operation, and closure.

Numerical weighting and ranking methods were used to select the preferred site, an area east of Exile Hill (Figure 6-50). The primary advantages of this site are gentle slopes necessary for railroad construction, availability and contiguity of the area, protection from flash flooding, location adjacent to a rock outcrop suitable for constructing the waste ramp portal, and location near the northern edge of the repository, which allows flexibility for any necessary future expansion. Data obtained thus far (Neal, 1985) indicate that there are no conditions that would disqualify the area as a location for the waste-handling facilities. This is a preliminary



SURFACE FACILITIES

NO.	FACILITY NAME
120-9A	WATER STORAGE TANKS
120-9B	UTILITY ELEC. SUBSTATION
211	WASTE HANDLING BLDG. NO. 1
211-5	WATER CHILLER NO. 1
212	WASTE HANDLING BLDG. NO. 2
212-5	WATER CHILLER NO. 2
215-1	WASTE TREATMENT BUILDING
215-2	VEHICLE WASH FACILITY
215-3	DECONTAMINATION BLDG.
215-4	PERFORMANCE CONFIRM. BLDG.
220-1A	HEALTH PHYSICS STN. NO. 4
220-1B	MEDICAL CENTER
220-2	FIRE STATION
220-3A	SECURITY STATION NO. 1
220-3B	SECURITY STATION NO 2 / HEALTH PHYSICS STN NO. 3
220-3C	SECURITY STATION NO. 3
220-4A	SHOPS
220-4B	MOTOR POOL AND SERVICE STATION

SURFACE FACILITIES, CONTINUED

NO.	FACILITY NAME
220-4C	WASTE OPS. AREA GARAGE
220-5A	ADMINISTRATION BUILDING
220-5B	FOOD SERVICE FACILITY
220-5C	TRAINING AUDITORIUM
220-6	MOCK-UP BUILDING
220-7	CENTRAL WAREHOUSE
220-8	VISITOR'S CENTER (NOT SHOWN)
220-9A	MAIN SUBSTATION AND STANDBY GENERATOR BUILDING
221-19	SEWAGE TREATMENT LAGOONS
222-22	COMPUTER BUILDING

SHAFT AND RAMP FACILITIES

NO.	FACILITY NAME
300-1	MEN AND MATERIALS SHAFT
300-2	WASTE RAMP
300-3	TUFF RAMP
301	EXPLORATORY SHAFT
300-8	EMPLACEMENT EXHAUST SHAFT

Figure 6-48. Central surface facilities area.

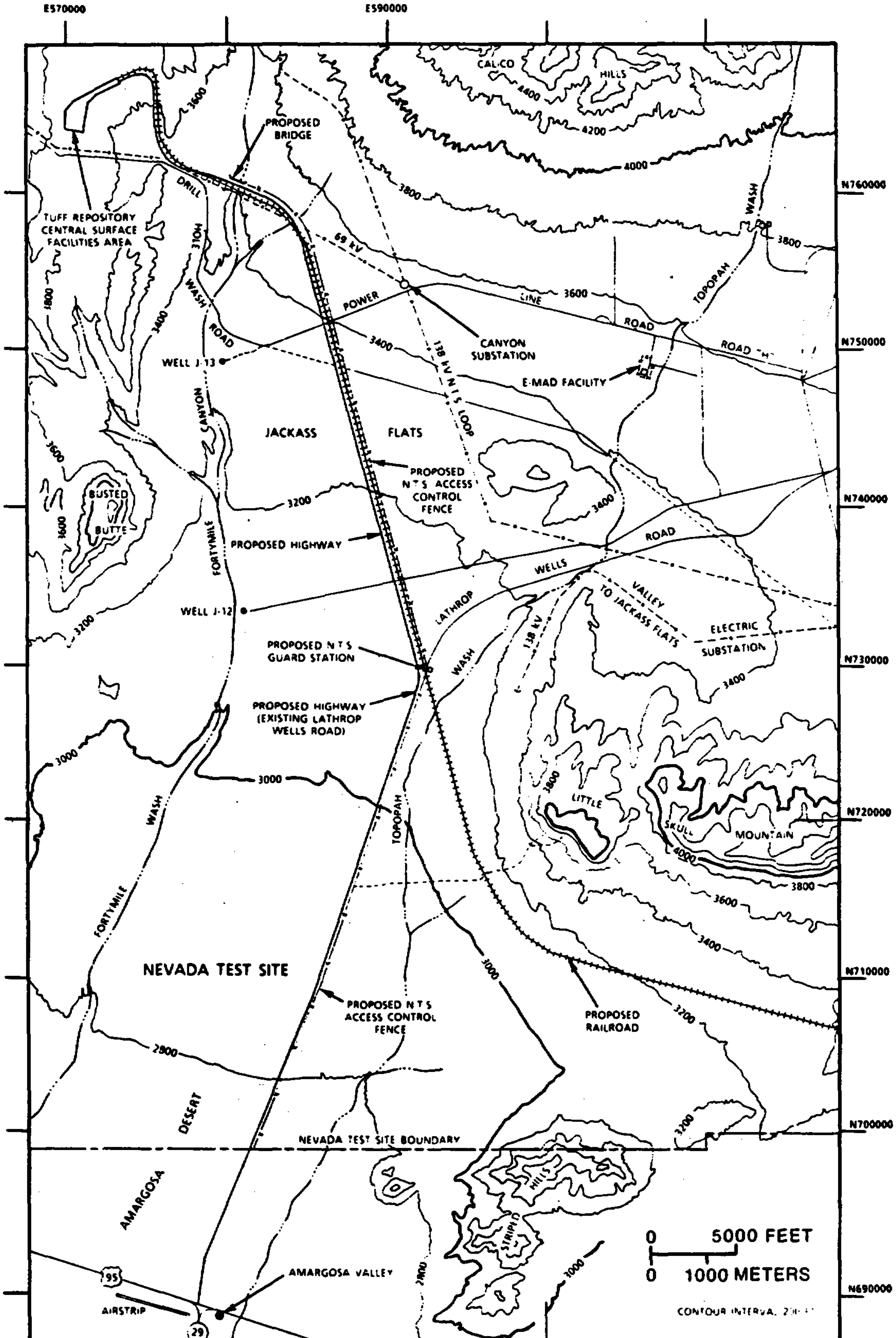


Figure 6-49. Route proposed for new highway and railroad access to the Yucca Mountain site.

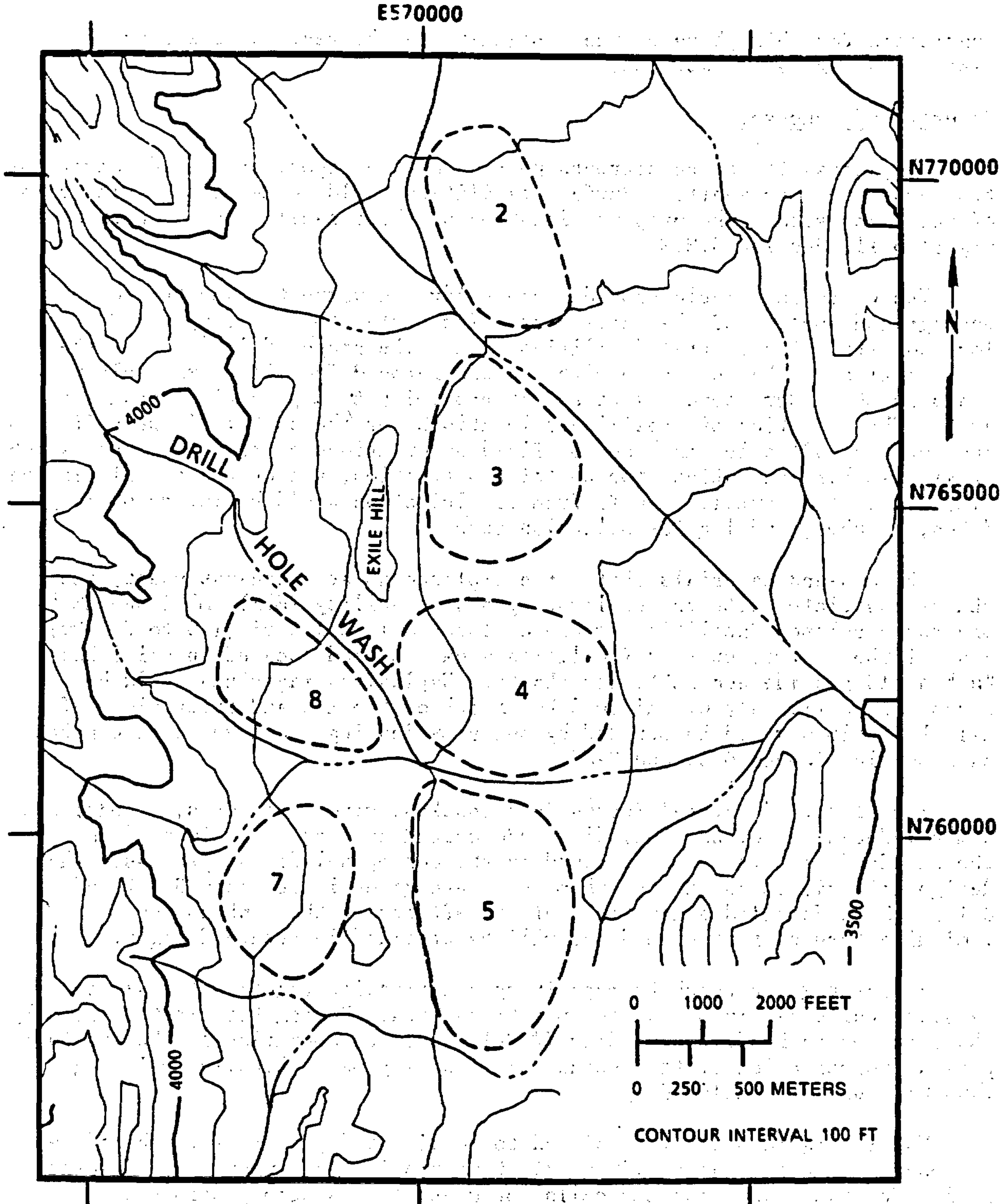


Figure 6-50. Locations of the six candidate areas for the surface facilities.

conclusion for this phase of the design and may be revised as a result of site characterization studies.

Underground accesses

The access to the underground portion of the repository would consist of two ramps and four shafts. Surface facilities would be associated with each of these accesses. The proposed location of these facilities is shown on Figure 6-11, Section 6.2.2.

The waste ramp would provide access for the waste transporter to the underground portion of the repository. The portal to that ramp would be located within the central facilities area. The proposed location of the intersection of the tuff ramp with the underground facilities was selected based on the underground layout and on proximity to a potential expansion area. The selection of preliminary locations for the portal of the tuff ramp and for the tuff pile was based on field observations of rock outcrops, which provide stable foundations for portal construction, and on the terrain in the vicinity of the portal. Runoff from precipitation would be intercepted by dikes, ditches, and liquid-collection sumps.

The men-and-materials shaft, the emplacement area exhaust shaft, the two shafts associated with the exploratory shaft facility (ESF), ES-1 and ES-2, and their related facilities, would be located 1 to 1.5 mi (1.6 to 7.4 km) west of the central surface facilities area. A road located in Drill Hole Wash would provide access to the shafts. Explosives magazines would be located approximately 0.5 mi (0.8 km) north of the men-and-materials shaft. All shaft sites would be bounded by security fencing and have level benches as shown in Figures 6-51 and 6-52.

The effect of natural forces (earthquakes, wind, tornadoes, floods) and human-induced phenomena, including underground nuclear explosions (UNEs) at the Nevada Test Site were addressed in the conceptual design process. The design criteria based on each phenomenon are given in Sections 6.1.1 and 6.1.2. More detailed evaluations of the effects of these phenomena, including more current site data, will be provided in future designs.

A two-stage approach to repository construction requires two waste-handling buildings in the waste operations area. During the first 3 yr, only the first waste-handling building (WHB-1) would be operational. During this period, construction of the second full-capacity waste-handling building (WHB-2) would be completed.

WHB-1, Figure 6-53, is designed to receive and prepare for subsurface disposal the equivalent of 400 metric tons uranium (MTU) per year of spent fuel. The two-stage approach calls for spent fuel assembly shipments to WHB-1 to be phased out when WHB-2 begins operating. WHB-1 would then handle only defense high-level waste and West Valley high-level waste and WHB-2 would be dedicated to handling spent fuel shipments. WHB-2, Figures 6-54 and 6-55, is designed to receive, consolidate, and prepare the equivalent of 3,000 MTU/yr of spent fuel for subsurface disposal and to package fuel assembly hardware generated during the consolidation process.

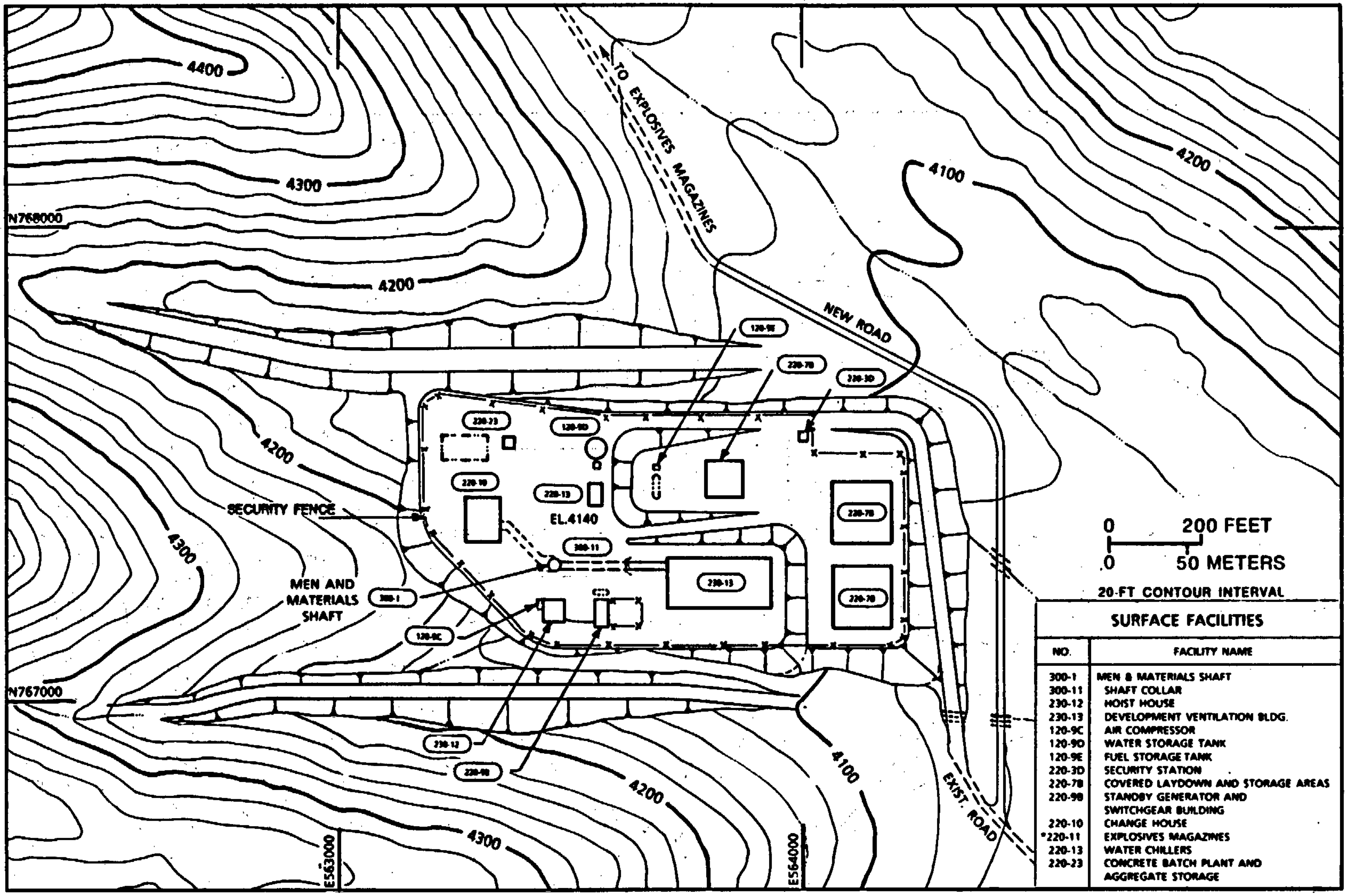


Figure 6-51. Surface facilities (large scale) of shaft sites.

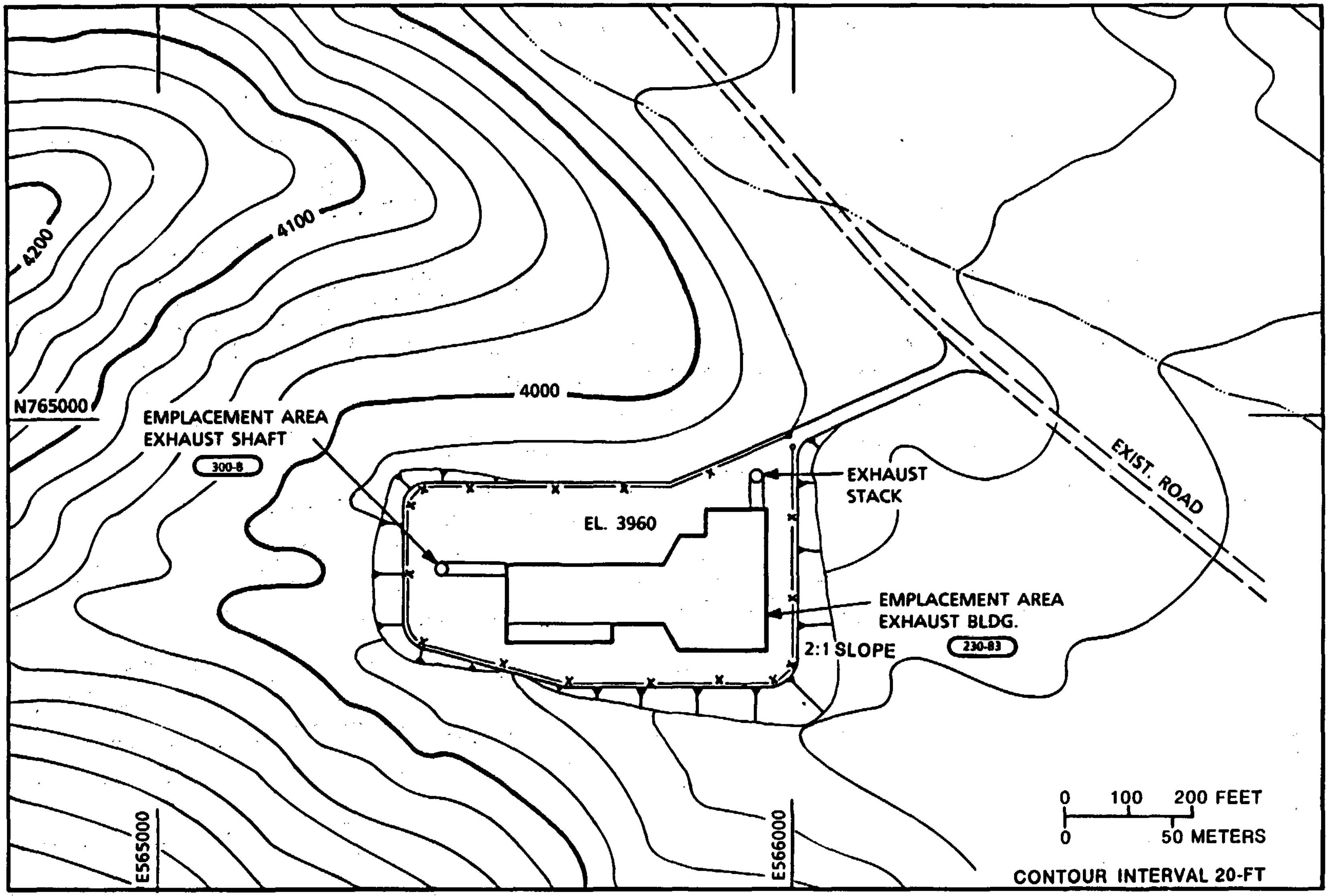
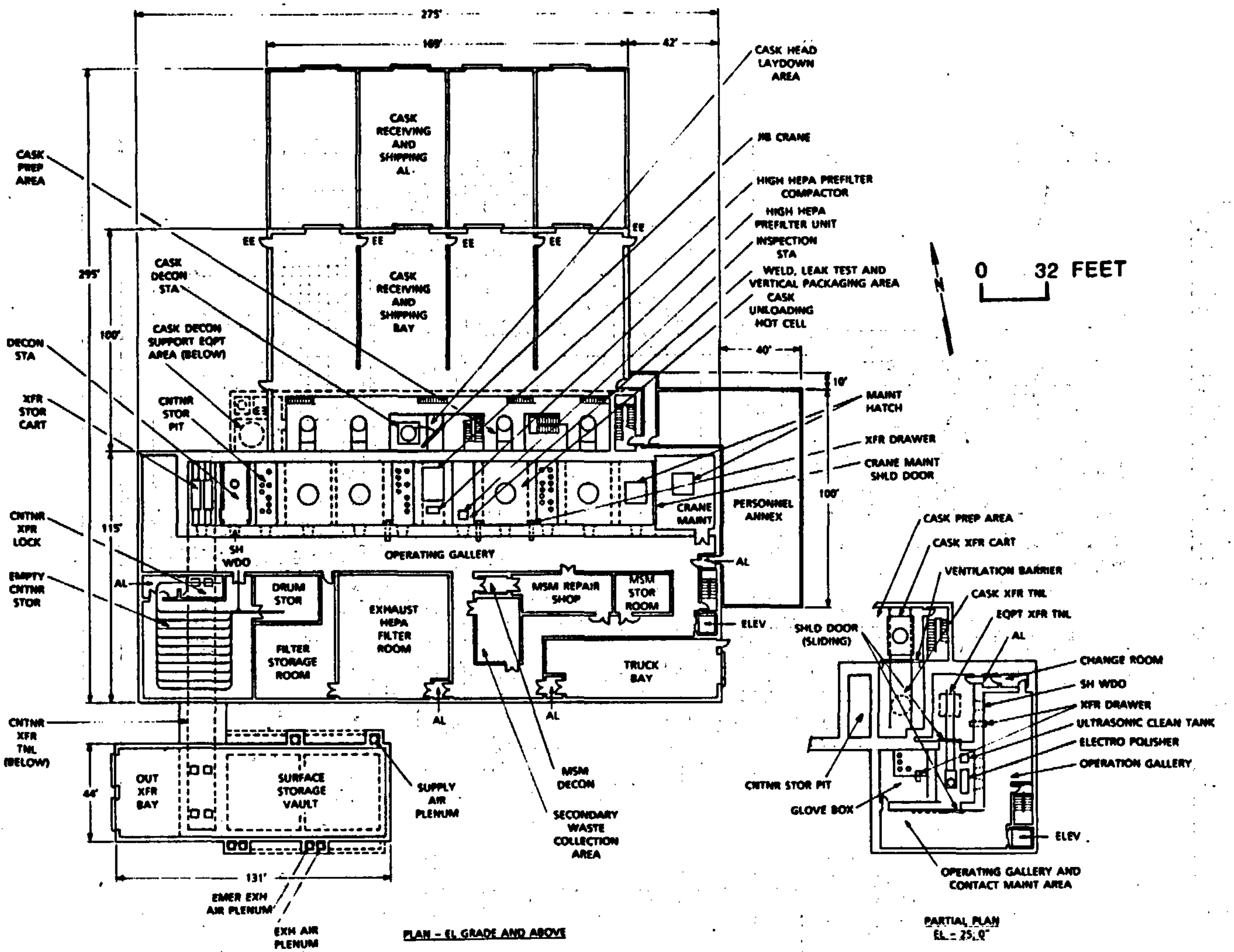


Figure 6-52. Surface facilities (small scale) of shaft sites.

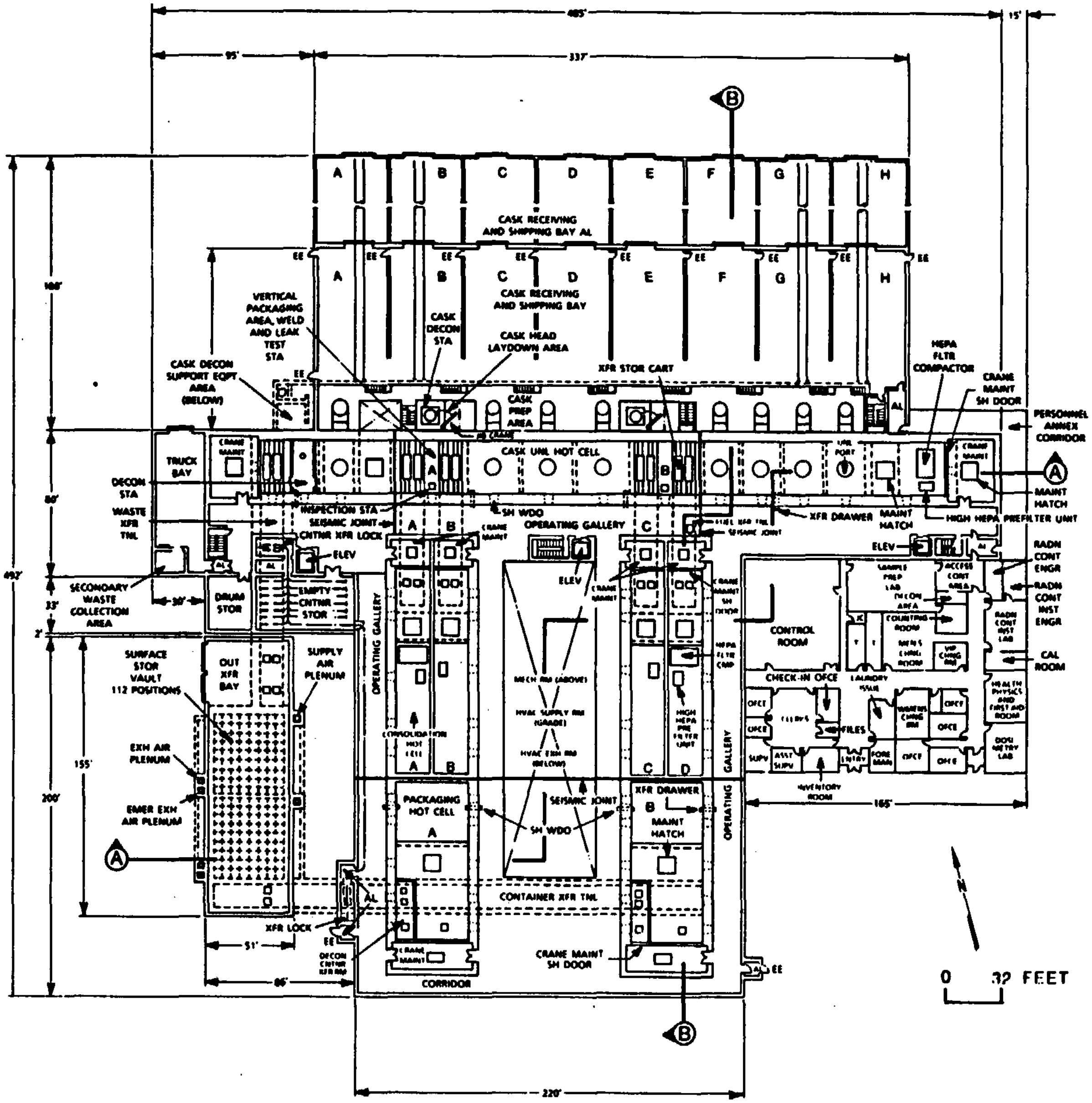


KEY TO ABBREVIATIONS

AL	-	AIRLOCK
ASST	-	ASSISTANT
BRDG	-	BRIDGE
CAL	-	CALIBRATION
CHNG	-	CHANGE
CNTNR	-	CONTAINER
CMP	-	COMPACTOR
CONT	-	CONTROL
DECON	-	DECONTAMINATION
EE	-	EMERGENCY EXIT
ELEV	-	ELEVATOR
ELEC	-	ELECTRIC
ELMCH	-	ELECTROMECHANICAL
EMER	-	EMERGENCY
ENGR	-	ENGINEER
EQPT	-	EQUIPMENT
EXH	-	EXHAUST
FLTR	-	FILTER
HEPA	-	HIGH EFFICIENCY PARTICULATE AIR
HVAC	-	HEATING, VENTILATING, AND AIR CONDITIONING
INSP	-	INSPECTION
INSTRM	-	INSTRUMENTATION
JC	-	JANITOR'S CLOSET
MACH	-	MACHINE
MAINT	-	MAINTENANCE
MECH	-	MECHANICAL
MSM	-	MASTER SLAVE MANIPULATOR
OFCE	-	OFFICE
PREP	-	PREPARATION
RADN	-	RADIATION
RM	-	ROOM
RMT	-	REMOTE
SH	-	SHIELD
SHLD	-	SHIELDING
STA	-	STATION
STOR	-	STORAGE
SUPV	-	SUPERVISOR
T	-	TOILET
TNL	-	TUNNEL
UNL	-	UNLOADING
WDO	-	WINDOW
XFR	-	TRANSFER

Figure 6-53. Waste handling building 1. general arrangement.

CONSULTATION DRAFT



KEY TO ABBREVIATIONS

AL	-	AIRLOCK
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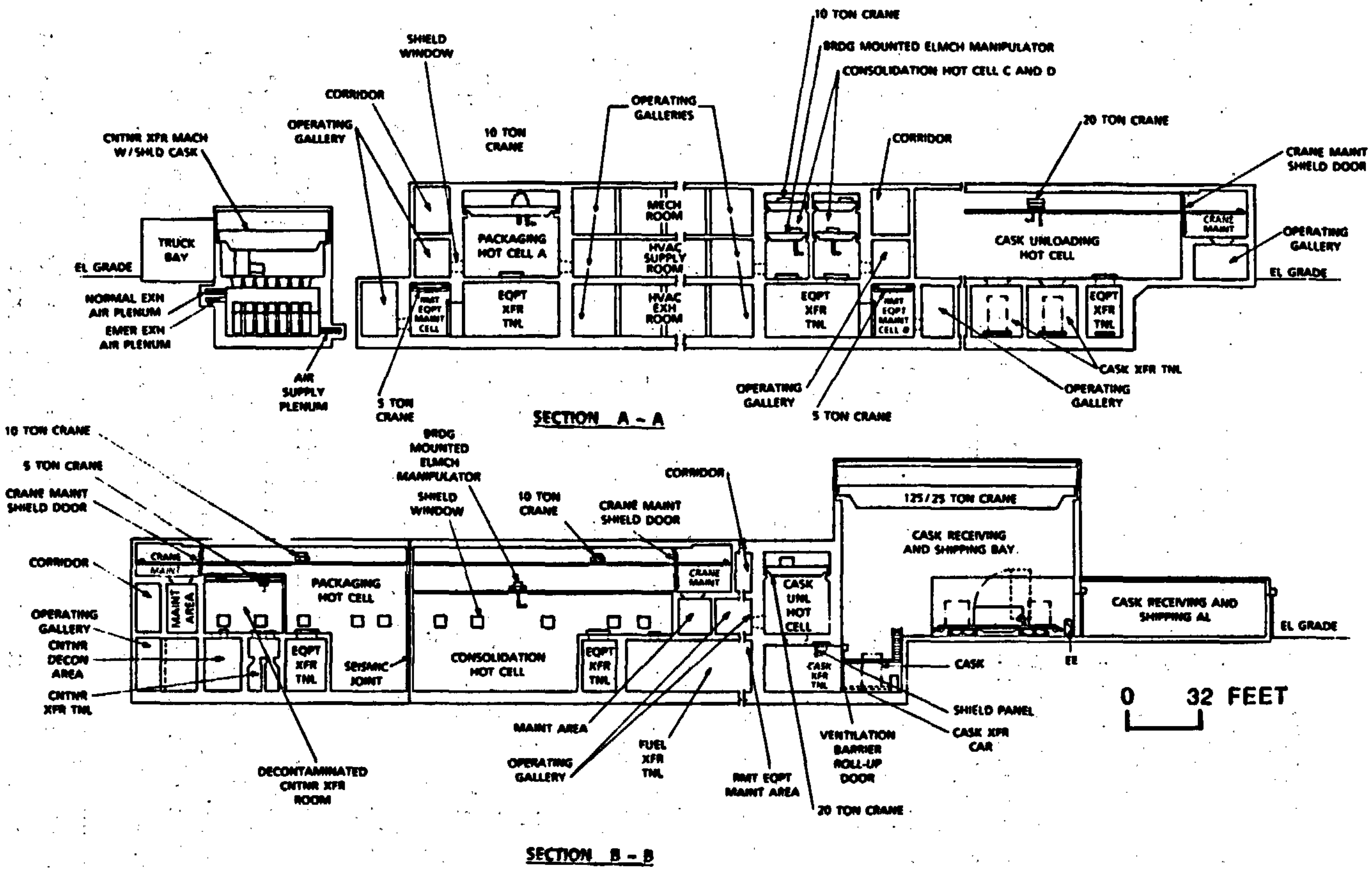
CONT	-	CONTROL
DECON	-	DECONTAMINATION
EE	-	EMERGENCY EXIT
ELEV	-	ELEVATOR
ELEC	-	ELECTRIC
ELMCH	-	ELECTROMECHANICAL
EMER	-	EMERGENCY
ENGR	-	ENGINEER
EQPT	-	EQUIPMENT
EXH	-	EXHAUST
FLTR	-	FILTER
HEPA	-	HIGH EFFICIENCY PARTICULATE AIR
HVAC	-	HEATING, VENTILATING, AND AIR CONDITIONING
INSP	-	INSPECTION
INSTRM	-	INSTRUMENTATION
JC	-	JANITOR'S CLOSET
MACH	-	MACHINE
MAINT	-	MAINTENANCE
MECH	-	MECHANICAL
MSM	-	MASTER SLAVE MANIPULATOR
OFCE	-	OFFICE
PREP	-	PREPARATION
RADN	-	RADIATION
RM	-	ROOM
RMT	-	REMOTE
SH	-	SHIELD
SHLD	-	SHIELDING
STA	-	STATION
STOR	-	STORAGE
SUPV	-	SUPERVISOR
T	-	TOILET
TNL	-	TUNNEL
UNL	-	UNLOADING
WDO	-	WINDOW
XFR	-	TRANSFER

Figure 6-54. Waste handling building 2, preliminary general arrangement.



KEY TO ABBREVIATIONS

AL	-	AIRLOCK
ASST	-	ASSISTANT
BRDG	-	BRIDGE
CAL	-	CALIBRATION
CHNG	-	CHANGE
CNTNR	-	CONTAINER
CMP	-	COMPACTOR
CONT	-	CONTROL
DECON	-	DECONTAMINATION
EE	-	EMERGENCY EXIT
ELEV	-	ELEVATOR
ELEC	-	ELECTRIC
ELMCH	-	ELECTROMECHANICAL
EMER	-	EMERGENCY
ENGR	-	ENGINEER
EQPT	-	EQUIPMENT
EXH	-	EXHAUST
FLTR	-	FILTER
HEPA	-	HIGH EFFICIENCY PARTICULATE AIR
HVAC	-	HEATING, VENTILATING, AND AIR CONDITIONING
INSP	-	INSPECTION
INSTRM	-	INSTRUMENTATION
JC	-	JANITOR'S CLOSET
MACH	-	MACHINE
MAINT	-	MAINTENANCE
MECH	-	MECHANICAL
MSM	-	MASTER SLAVE MANIPULATOR
OFCE	-	OFFICE
PREP	-	PREPARATION
RADN	-	RADIATION
RM	-	ROOM
RMT	-	REMOTE
SH	-	SHIELD
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SUPV	-	SUPERVISOR
T	-	TOILET
TNL	-	TUNNEL
UNL	-	UNLOADING
WDO	-	WINDOW
XFR	-	TRANSFER

Figure 6-55. Waste handling building 2 - sections, preliminary general arrangement.

Approximate water consumption at the repository during the first 7 yr (including the construction period) is estimated to be 112,500,000 gal/yr (425,800 m^3/yr) and is expected to remain at this level for the next 25 yr. The average water demand for the following 23 yr of operation is estimated to be 2,500,000 gal/yr (9,460 m^3/yr). Present plans call for the construction of new water wells and storage provisions to be located at the proposed central surface facilities. The SCP-CD is based on the use of water, in the interim, from the existing well, J-13, located approximately 5 mi (8 km) southeast of the central surface facilities.

6.2.4.1 Foundation considerations

Foundations for the major surface buildings would be located in alluvial soil, except for some buildings adjacent to the shafts. The alluvial soil is a light tan to gray, silty to sandy gravel, with numerous blocky cobbles and boulders. These rock particles consist mostly of welded or partly welded volcanic ash-flow tuffs, derived from nearby bedrock sources.

Limited preliminary investigations of several exploratory borings and test pits were done between January and July 1984 in the six potential site areas for surface facilities, as shown in Figure 6-50.

Preliminary stratigraphic information has been developed from the exploratory boreholes and pits (Neal, 1985). The total depth of the alluvial soil at the proposed location of the central surface complex is about 90 ft (27 m); however, because the bedrock surface is sloping, the thickness of alluvium may be greater or less than this value, depending on the final location of surface structures.

The test pits were excavated in May 1984, to a depth of about 12 ft (3.7 m) below ground surface, and the soil conditions logged and sampled to obtain general physical and engineering characteristics and to estimate the possible variability among sites. Preliminary measurements of soil properties have been made on samples from the test pits. The surficial soil has been significantly modified by well-defined horizon development. The top 1 or 2 ft (0.3 or 0.6 m) (A and B horizons) of soil are loose and fine-grained; this soil would be removed during construction. The underlying material typically is partly cemented with calcite (caliche) to a depth of about 8 ft (2.4 m). Below that depth, the soil is not appreciably cemented or may be cemented only locally.

The foundations for principal surface buildings are expected to extend substantially below grade; the zone that included appreciable calcite cementation is probably too shallow to be considered for major foundations. Moreover, the degree of cementation and thickness of this zone is expected to be quite variable. Therefore, the conceptual foundation design is based on the strength and properties of the underlying uncemented material.

Preliminary measurements were taken on samples of the underlying uncemented soil from the test pits. The samples were taken at depths of 12 ft (3.7 m) or less. These measurements can be considered conservative estimates for properties of the deeper foundation soils, because soil strength normally increases with confining pressure, which increases with depth.

No direct measurements or tests of engineering properties of the proposed site soils have been completed; however, conservative estimates can be based on results of the index property tests and knowledge of the general behavior of the identified soils. The engineering properties given in Table 6-9 (Section 6.1.2.1.2) apply to uncemented soils below the zone of loose topsoil. Additional soils properties will be obtained, as described in Section 8.3.1.14 (surface characteristics) for use in surface facilities design described in Section 8.3.2.5 (preclosure design and technical feasibility).

6.2.4.2 Flood protection

Because of the rugged terrain and meteorological conditions at the Yucca Mountain site, brief, but intense localized precipitation occurs infrequently.

Flood protection was a consideration in choosing the proposed locations for surface facilities and shafts in the conceptual design. U.S. Geological Survey (USGS) topographic maps, with 20-ft contour intervals on a 1:24,000 scale, were used to choose the site. However, these maps do not provide the detail necessary for a final design based on probable maximum flood levels.

The flood history and potential are described in Section 3.2.1. In the analyses performed thus far, maximum flood flows, except for the men-and-materials shaft area described below, are derived from Crippen and Bue (1977), which contains graphs of peak discharges versus drainage areas of measured historical floods, with envelope curves above the plotted floods. The envelope curves represent the maximum potential flood for a given drainage area. The graph used for estimating maximum flows at the site is based on a region covering all or parts of Nevada, California, Utah, Arizona, and New Mexico. This methodology provides estimates of the flood discharges at the site suitable for conceptual design.

Future surface area design will be based on probable maximum flood (PMF) flows and levels, determined in accordance with ANSI/ANS 2.8 (1981). In general, the underground entries and surface facilities will be protected by providing channels and dikes to divert the surface runoff and by setting grades above the adjacent PMF levels (Section 6.1.2.6). This design effort will be finalized when definitive topographic maps and other data become available (Sections 6.3.7, 8.3.2.5, and 8.3.1.14).

A preliminary analysis of the PMF has been performed for the men-and-materials shaft area. This preliminary analysis was to evaluate the feasibility of locating the shaft and its supporting surface complex in this area. In the analysis, the PMF flows and levels were estimated, and flooding protection provisions were incorporated in the design. The men-and-materials shaft area would be benched, with the shaft entrance designed to be above the PMF levels in the diversion channels, located on the north and south sides, as well as the PMF level in Drill Hole Wash. From this preliminary analysis, it was concluded that the men-and-materials shaft may be adequately protected from PMF levels at the proposed location.

6.2.5 SHAFT AND RAMP DESIGN

Access between the surface facilities and the underground facility would be provided by shafts and ramps. The major functions of the shafts and ramps would be as follows:

1. Transfer of waste packages to the emplacement area.
2. Transfer of mining equipment to and from the underground facility.
3. Removal of mined tuff.
4. Transfer of construction materials and supplies and backfill materials to the underground facility.
5. Transfer of general supplies and test equipment.
6. Transfer of explosives.
7. Transfer of personnel.
8. Intake and exhaust of ventilation air.
9. Routing for utilities.

In determining the number, type, size, and location of the accesses needed at the Yucca Mountain repository, the following factors were considered for the conceptual design:

1. Personnel and operational safety.
2. Efficiency and effectiveness of operations, including transportation and ventilation functions.
3. Geology and natural phenomena.
4. Capital and operational costs.
5. Schedule.
6. Security.
7. Structural considerations for ramp and shaft collars.
8. Interaction between surface and subsurface facilities.

The proposed location of these accesses and their interrelationship with the underground facility are illustrated in Figure 6-56, and the number,

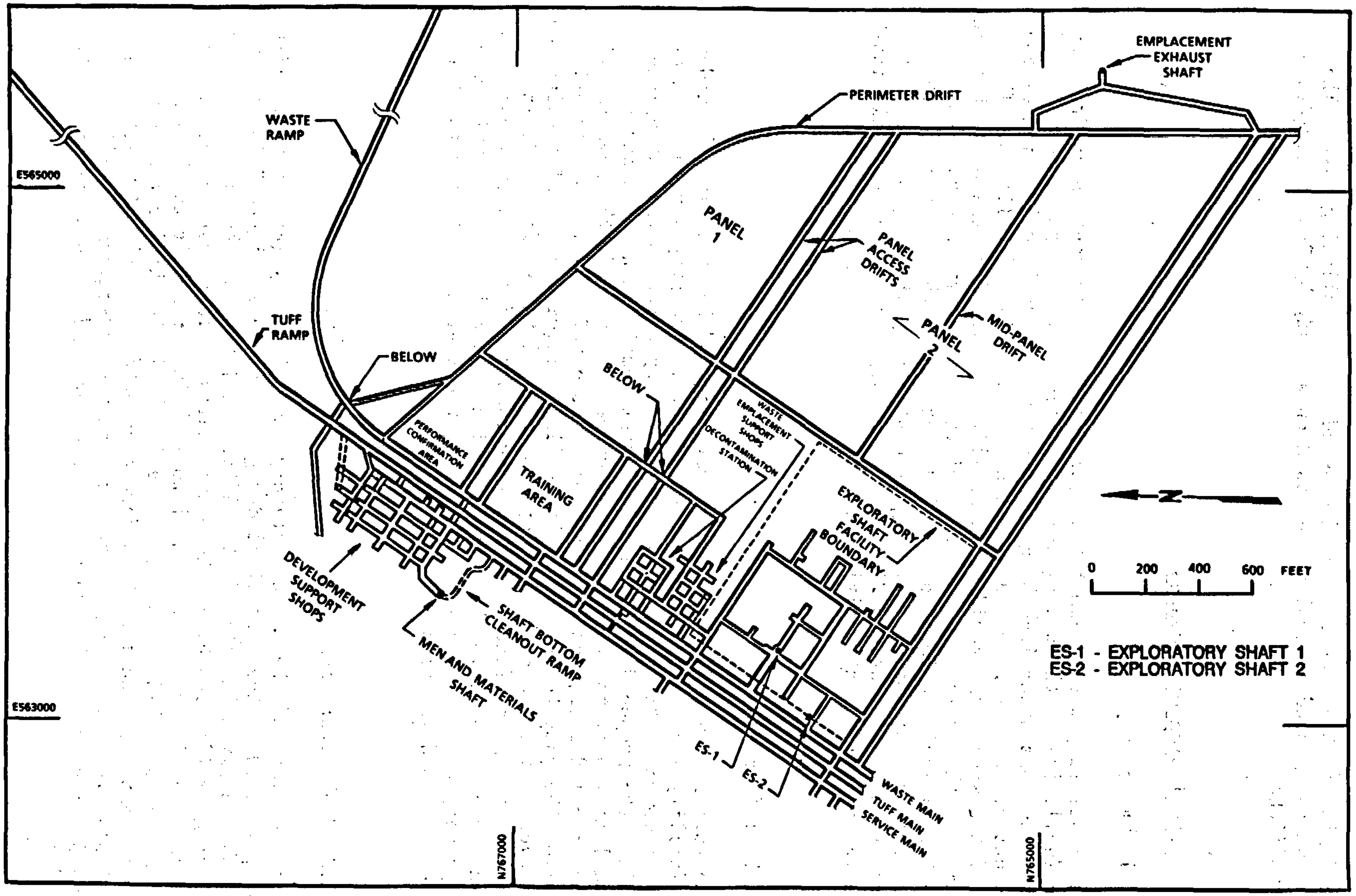


Figure 6-56. Location of shafts and ramps.

type, and size of the accesses are discussed in the following text. The types of accesses used in design are based on a study by Dennis and Dravo Engineers (1985).

6.2.5.1 Description of accesses

6.2.5.1.1 Waste ramp

The waste ramp would permit transport of the waste containers from the surface facilities to the underground facilities. The proposed location of the waste ramp was determined by grade limitations, desired location of the surface entry, and the proposed location of the surface facilities. The portal of the waste ramp would be physically separate from the waste-handling facilities on the surface. The portal of the waste ramp (Figure 6-48, Section 6.2.4) would be located in solid rock inside the boundary of the central surface facilities area. Significant data pertaining to the waste ramp are presented in Table 6-21. The waste ramp would be a fresh air intake for the waste emplacement activities.

6.2.5.1.2 Tuff ramp

The tuff ramp would be used for excavating and constructing the underground facility and for removing excavated tuff. The proposed location of the tuff ramp was determined by the desired entry point to the subsurface facilities, the proposed location of the waste emplacement area and the proposed location of the tuff pile. As currently located, the ramp portal would be in solid rock, easily accessible to the tuff pile. This location would allow the ramp to be a straight decline, minimizing transfer points on the conveyor belt between the development area and the surface. During operation of the subsurface facility, this ramp would have minimal usage for equipment transportation. The current design also calls for the tuff ramp to be the primary exhaust airway for the development area. Data for the tuff ramp are presented in Table 6-21.

6.2.5.1.3 Exploratory shafts

The locations of the two exploratory-shaft facility (ESF) shafts, ES-1 and ES-2, as used in the conceptual design are shown in Figure 6-56; their dimensions are given in Table 6-21. After completion of the site characterization program (Section 8.4), these two shafts would be used as air intakes for the waste emplacement area. ES-1 would bring fresh air to the waste emplacement area. ES-2 would serve as a fresh air intake for the shops in the emplacement area and for the underground decontamination facility; ES-2 would also serve as an emergency egress from the underground facility. Figure 6-57 illustrates the general arrangements and cross sections of all the shafts.

Table 6-21. Data for ramps and shafts

Opening	Elevation at collar (ft)	Elevation at collar (m)	Length or depth (ft)	Length or depth (m)	Slope (%)	Diameter (ft)[a] Horizontal emplacement configuration (ft)	Horizontal emplacement configuration (m)	Vertical emplacement configuration (ft)	Vertical emplacement configuration (m)
Waste ramp	3,687	1,124	6,603[b]	2,013	8.9	21	6.4	23[e]	7
Tuff ramp	3,914	1,193	4,627[b]	1,410	17.9	21	6.4	25[e]	7.6
Exploratory Shaft 1	4,160[c]	1,268	1,480	451	(d)	12	3.7	12	3.7
Exploratory Shaft 2	4,160[c]	1,268	1,020	311	(d)	6	1.8	6	1.8
Men-and-materials shaft	4,140[c]	1,260	1,090	332	(d)	20[f]	6	20[f]	6
Emplacement area exhaust shaft	3,960[c]	1,207	1,030	314	(d)	20[f]	6	20[f]	6

[a]The dimensions of the ramps are excavated dimensions; those of the shafts are inside finished dimensions.

[b]Includes length of portal.

[c]Final construction grade elevation.

[d]All shafts are vertical.

[e]The diameter of the ramps is larger in the vertical configuration because ventilation airflow needed in this configuration is greater than that in the horizontal configuration.

[f]The diameters of the shafts are controlled by operational requirements rather than ventilation airflows.

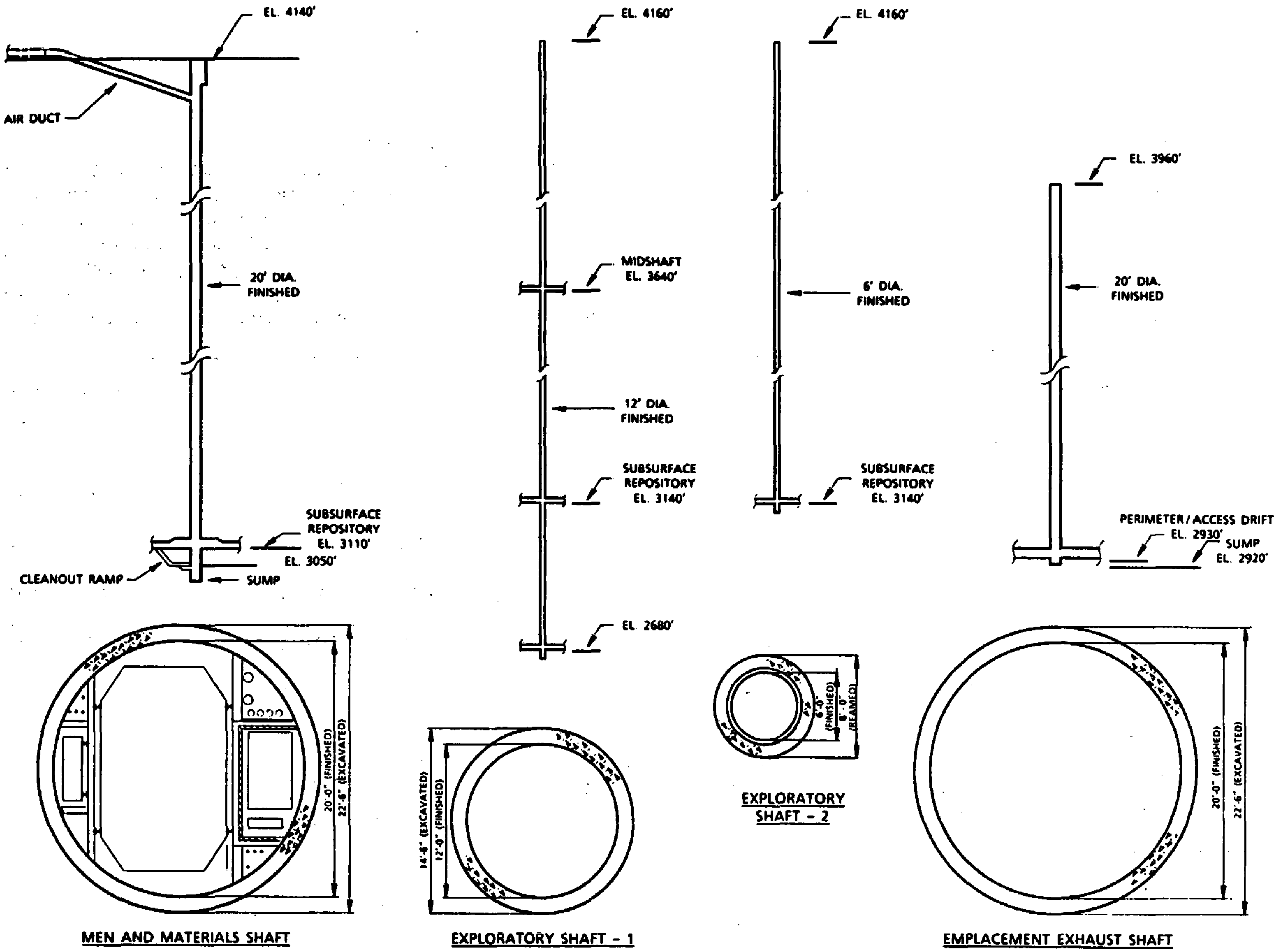


Figure 6-57. Shaft elevations and cross sections.

6.2.5.1.4 Men-and-materials shaft

The men-and-materials shaft (Figure 6-58) would provide access for men and materials and serve as an air intake for the development area. The proposed location of the shaft would provide convenient access to the development shops as well as to the remainder of the subsurface facilities. The proposed location of the surface opening of this shaft is shown in Figure 6-12 (Section 6.2.2). This shaft would be equipped with a men-and-materials cage, a service elevator, and would serve as an access for utilities. As shown on Table 6-20, the shaft is designed to have a finished diameter of 20 ft (6 m) and a total depth of 1,090 ft (330 m).

6.2.5.1.5 Emplacement area exhaust shaft

The exhaust shaft for the waste emplacement area would be located near the first panel just east of the perimeter drift, which would optimize its use as an exhaust pathway. The proposed surface location (Figure 6-12, Section 6.2.2) would provide a suitable location for the repository exhaust filtration equipment. The shaft is designed to have a finished diameter of 20 ft (6 m) and a vertical depth of 1,030 ft (314 m), Table 6-19, Section 6.2.5.1.1).

6.2.5.2 <u>Construction and ground support</u>

6.2.5.2.1 Sequence and methods of construction

6.2.5.2.1.1 <u>Ramps</u>

It is currently planned that the waste and tuff ramps will be excavated with a tunnel boring machine (TBM), which is a cost-effective method for ramp construction. After the TBM has progressed approximately two machine lengths down the ramp, the first portion of a conveyor would be installed. The conveyor would transport mined tuff from the TBM to the surface. This conveyor would be a temporary installation and would be removed after completion of the ramp. The excavated tuff would be transported to the tuff pile from the waste ramp portal by trucks and from the tuff ramp by conveyor belt. As the TBM progresses down the ramp, the conveyor would be extended, and the ground support and the ramp floor would be installed. Current ground support concepts for ramps are discussed in Section 6.2.6.1.4.

6.2.5.2.1.2 <u>Shafts</u>

The current design calls for the ES-1, the men-and-materials shaft, and the emplacement area exhaust shaft to be constructed using drilling and

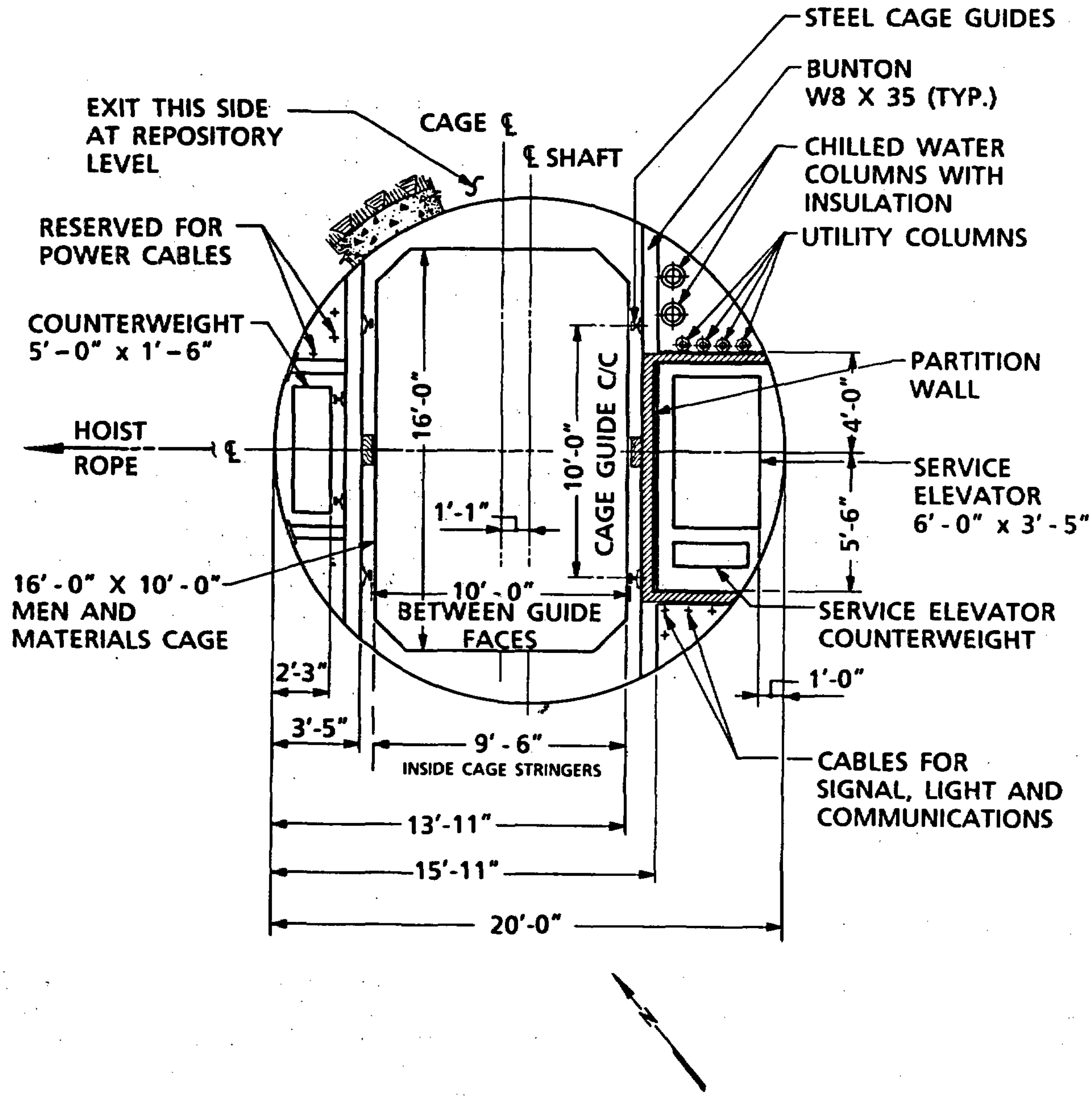


Figure 6-58. Cross-section of men and materials shaft.

blasting techniques. ES-2 would probably be constructed by raise-boring techniques. The proposed general arrangement of all shafts and current shaft lining concepts is illustrated in Figure 6-57 (Section 6.2.5.1.3).

6.2.6 SUBSURFACE DESIGN

The SCP-CDR (SNL, 1987) provides complete details about the underground repository design. The underground facility area for repository conceptual design is shown in Figure 6-59.

The conceptual design of the underground facility considered two waste emplacement orientations, vertical (the reference case) and horizontal. In the vertical orientation, a single waste container would be placed in a vertical borehole drilled in the drift floor. In the horizontal orientation, up to 14 spent fuel waste containers or up to 18 defense high-level waste containers can be emplaced in a long, horizontal borehole. The facilities for both orientations are summarized in this section and detailed in Section 4.4 of the SCP-CDR.

Description of the underground layout

The design of the underground layout is based on waste characteristics (Section 2.1 of SNL, 1987), geologic and other site characteristics (Section 6.1.2), and the requirements for total repository capacity and throughput (Section 6.2.3). A description of excavation and other development activities is presented in Section 6.2.6.1.

The proposed location for the underground facilities is within the Topopah Spring Member of the Paintbrush Tuff, specifically unit TSw2. Selection of this unit was based on hydrologic, geotechnical, and thermal criteria (Johnstone et al., 1984). The principal geologic structure considered in the conceptual design is shown in Figures 1-19 and 1-20. A primary area for the facilities was selected within the Topopah Spring Member, based on structural considerations. The boundaries for the primary area are illustrated in Figure 6-12 (Section 6.2.2). Any contiguous zones that meet regulatory, geologic, structural, engineering, and performance assessment requirements also may be used. However, the primary area contains sufficient thickness and area to accommodate the equivalent of 70,000 metric tons of uranium (MTU) waste.

The general underground facility layouts for the vertical and horizontal emplacement orientations are very similar. Figure 6-13 (Section 6.2.2) shows the underground facility layout for the vertical emplacement method, and Figure 6-14 (Section 6.2.2) shows the underground layout for the horizontal emplacement method. The emplacement panel is the primary component of the underground layout. Access to the panels would be provided by shafts, ramps, the main entry drifts, a perimeter drift, and panel access drifts. The perimeter drift, which would serve as an exhaust airway for the waste emplacement area, surrounds the entire underground facility. Shop areas areas would be provided in both the development and waste emplacement areas. The locations of the shafts and ramps are discussed in Section 6.2.5 and shown in Figure 6-56 (Section 6.2.5.1.3). The design life for all

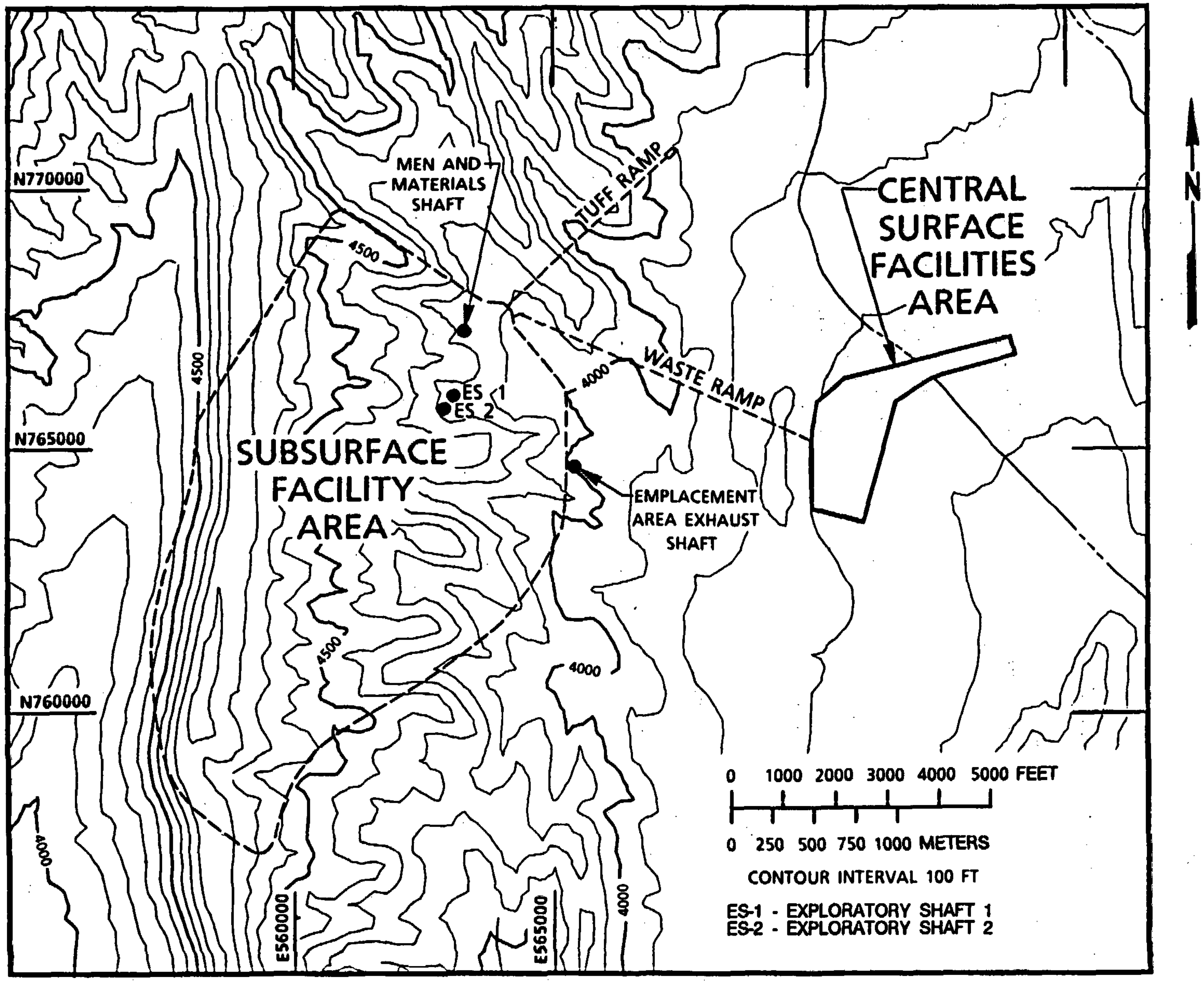


Figure 6-59. Underground facility area for the SCP-CD.

underground openings is 84 yr. The dimensions for all underground openings are shown in Figures 6-60 and 6-61, and the lining concepts for the shafts are shown in Figure 6-57 (Section 6.2.5.1.3).

Main entry drifts

Three parallel main entry drifts are planned to extend southwest through the underground facility to provide access to the emplacement panels during both the development and emplacement phases. Cross sections of these drifts are shown in Figures 6-60 and 6-61.

The waste main would be dedicated to transporting waste, the tuff main dedicated to transporting tuff and bulk materials, and the service main dedicated to ventilation. Space for electrical distribution systems would be provided in the service main. The layout and spacing of the main drifts allow separation of the development-area ventilation air from that of the waste emplacement area as detailed in Section 6.2.6.3.1. Table 6-22 presents the configurations for mains and for the perimeter drift for both vertical and horizontal emplacement options.

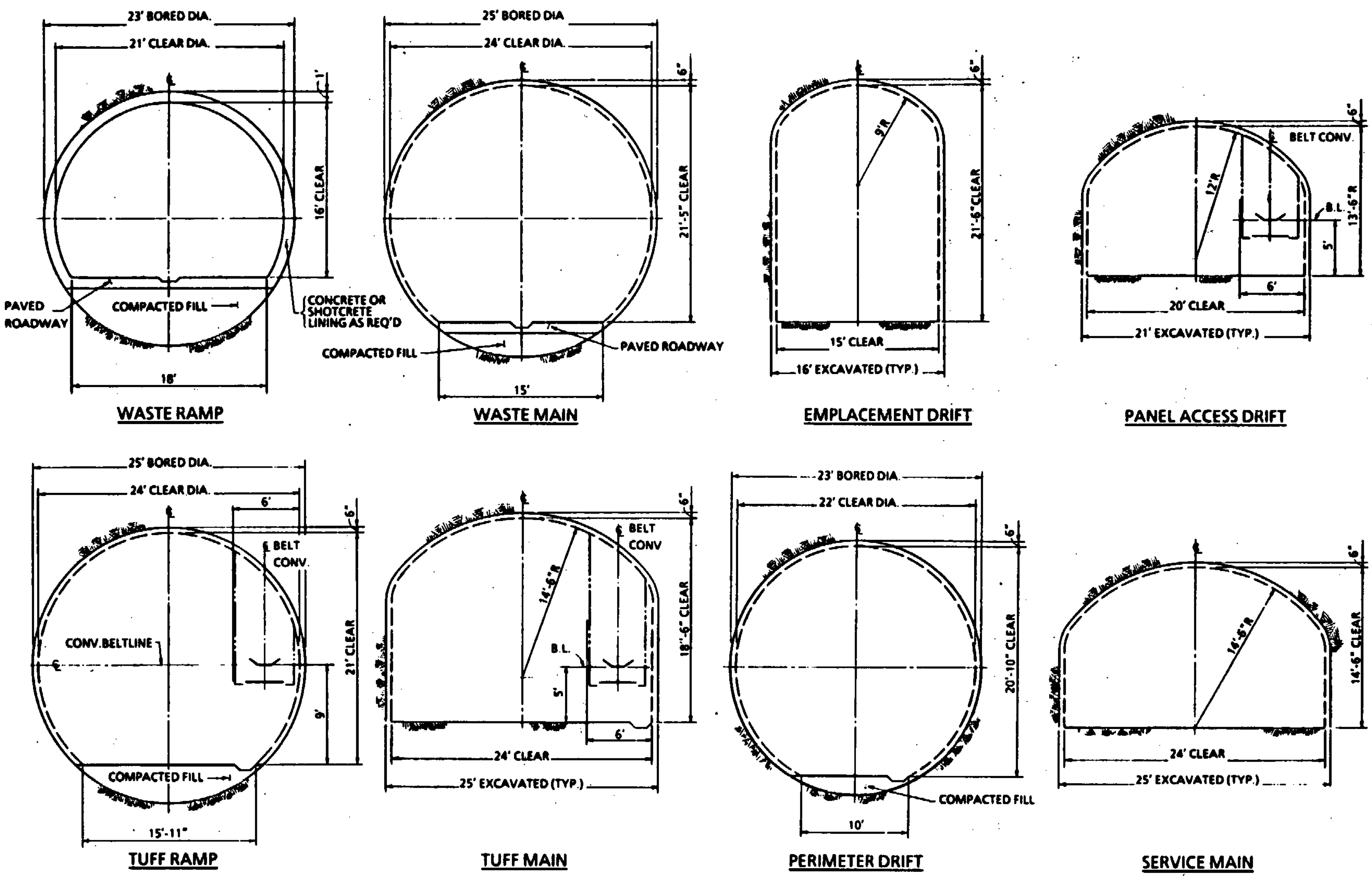
Table 6-22. Data for main and perimeter drifts

Opening	Vertical emplacement (ft)	Vertical emplacement (m)	Horizontal emplacement (ft)	Horizontal emplacement (m)
Waste main, diameter	25	8	21	6
Tuff main, width x height	25 x 19	8 x 6	25 x 19	8 x 6
Service main, width x height	25 x 15	8 x 5	25 x 15	8 x 5
Perimeter drift, diameter	23	7	23	7

The slope of the drifts was established using cross sections through the emplacement horizon. The slope of each drift was constrained by the upper and lower boundaries of the emplacement horizon and by the elevation at drift intersections.

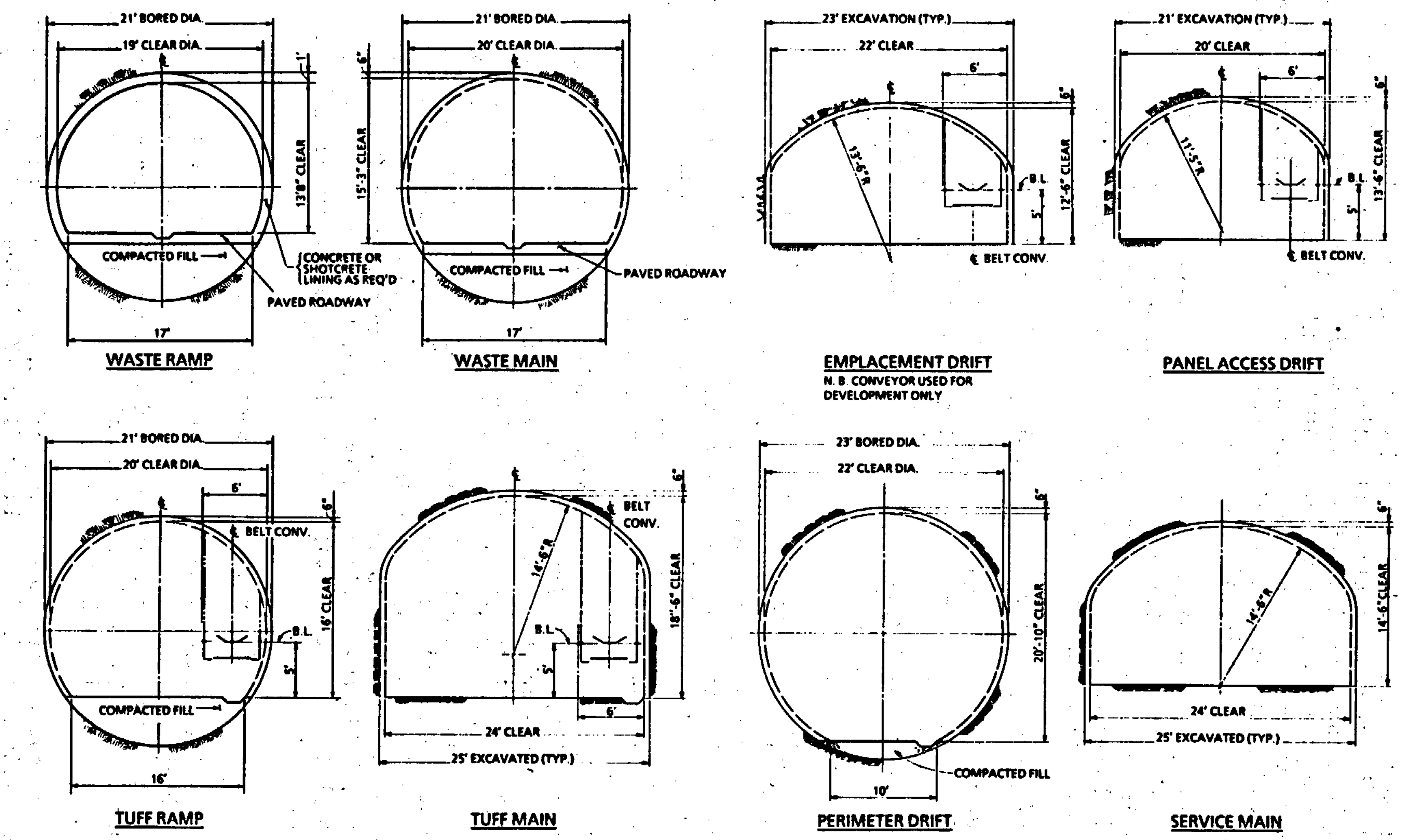
Emplacement panels

The general repository layout is divided into panel segments. The emplacement panels are planned to be approximately 1,400 ft (427 m) wide, parallel to the main drifts, and 1,500 to 3,200 ft (457 to 975 m) long, perpendicular to the main drifts, for both the vertical and horizontal configurations. A typical panel would have an approximately rectangular shape.



DIA. - DIAMETER
TYP. - TYPICAL
CONV. - CONVEYOR

Figure 6-60. Drift and ramp cross sections for vertical emplacement.



DIA. - DIAMETER
TYP. - TYPICAL
CONV. - CONVEYOR
B.L. - BELT LINE

Figure 6-61. Drift and ramp cross sections for horizontal emplacement.

The methodology used to design the layout of each panel is similar in the vertical and horizontal emplacement methods. The layout for both the vertical and horizontal configurations consists of a sequence of emplacement panels. To accommodate the equivalent of 70,000 MTU of waste, the preliminary design of the panel layouts for both the vertical and horizontal waste emplacement configurations consists of 18 panels. These layouts reflect the use of an areal power density of 57 kW/acre.

Development of the panels would begin in the northeast corner and progress sequentially in a clockwise direction. Waste emplacement operations would follow in the same order. Waste emplacement would not begin until two full panels had been completely developed, providing separation between development and emplacement operations.

Description of the general layout for vertical emplacement

Figure 6-62 illustrates the details of a typical panel layout for the vertical emplacement. The panel width of 1,400 ft (457 m) was selected based on reasonable haulage distances for mined tuff removed. The design is based on an initial heat load of 3.03 kW per waste package (O'Brien, 1985). Flexibility in the methodology of the design allows for adjustments of the panel width.

A midpanel drift would serve as an airway for ventilation during development of the panel and for cooling during retrieval. Emplacement drifts (Figure 6-63) would connect the panel access drifts and would be spaced within the panel at intervals determined by the number of waste containers, borehole spacing, and standoff distances necessary to satisfy heat load criteria. The waste packages would be emplaced in 25 ft (8 m) vertical boreholes located in the floor of the emplacement drifts.

Standoffs, the distance from the access drifts to the first borehole in the emplacement drift, result from a design criterion to minimize temperatures in panel access drifts, the main entry drifts, and perimeter drifts. The current design provides for a minimum standoff of 85 ft (26 m). The access drift is currently designed to be 14 ft (4 m) high. The height of the emplacement drift is dictated by the dimensions of the equipment used for drilling the boreholes and emplacing the waste. To accommodate the transporter in the emplacement mode, the height of the emplacement drift would gradually increase from 14 ft to 22 ft (4 to 8 m) in the 85-ft (26-m) standoff distance. In the vertical configuration, the emplacement boreholes for defense high-level waste (DHLW) would typically be alternated with those for spent fuel.

Description of the general layout for horizontal emplacement

Figure 6-64 illustrates a typical panel layout for horizontal emplacement. In the horizontal waste emplacement configuration, waste packages would be in long horizontal boreholes drilled in the wall of the emplacement drifts (Figure 6-65). Up to 14 containers of spent fuel or 18 containers of DHLW could be emplaced in each borehole.

In the horizontal emplacement configuration, the panels would be 427 m wide, and the emplacement drifts would be 23 ft (7 m) wide by 13 ft (4 m)

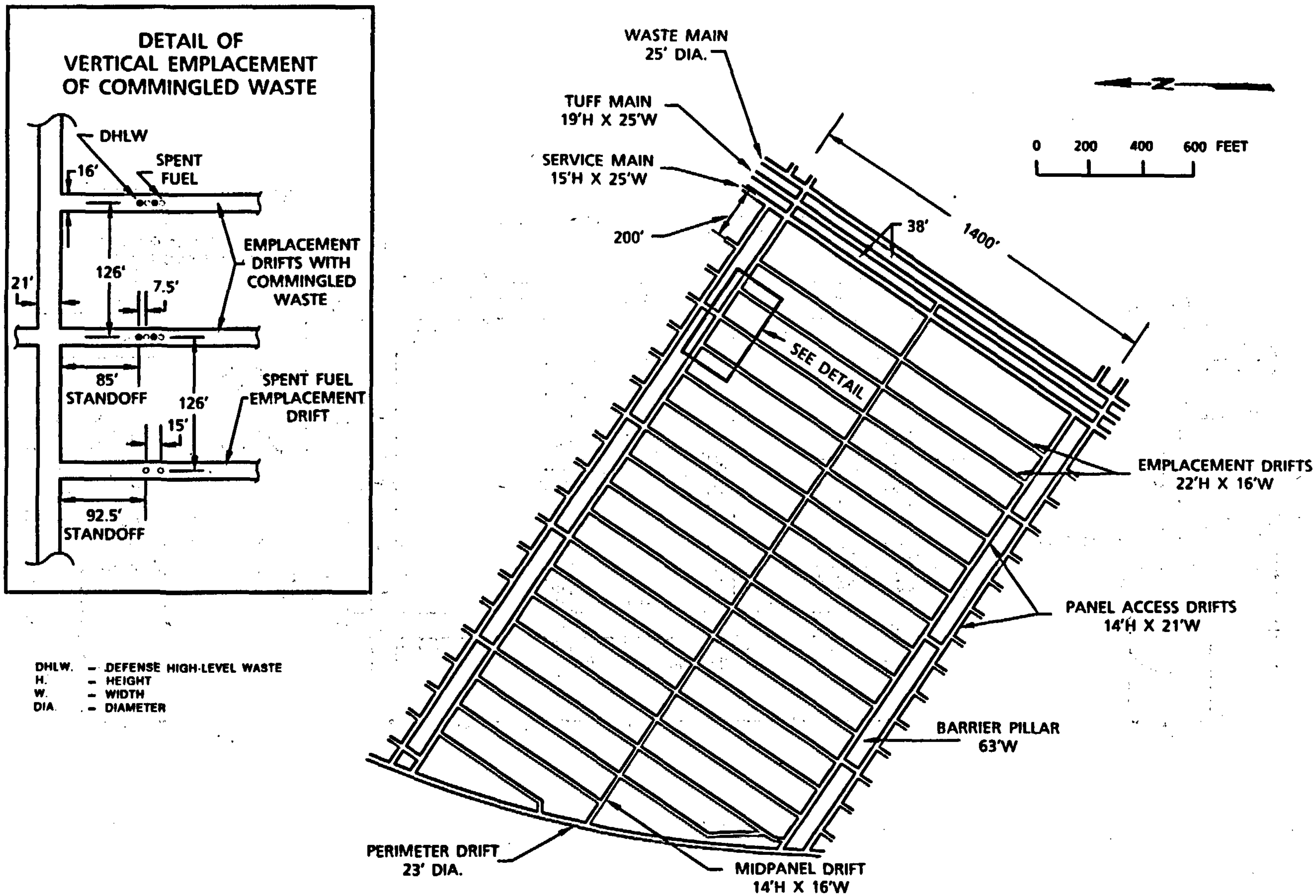


Figure 6-62. Typical panel layout for vertical emplacement.

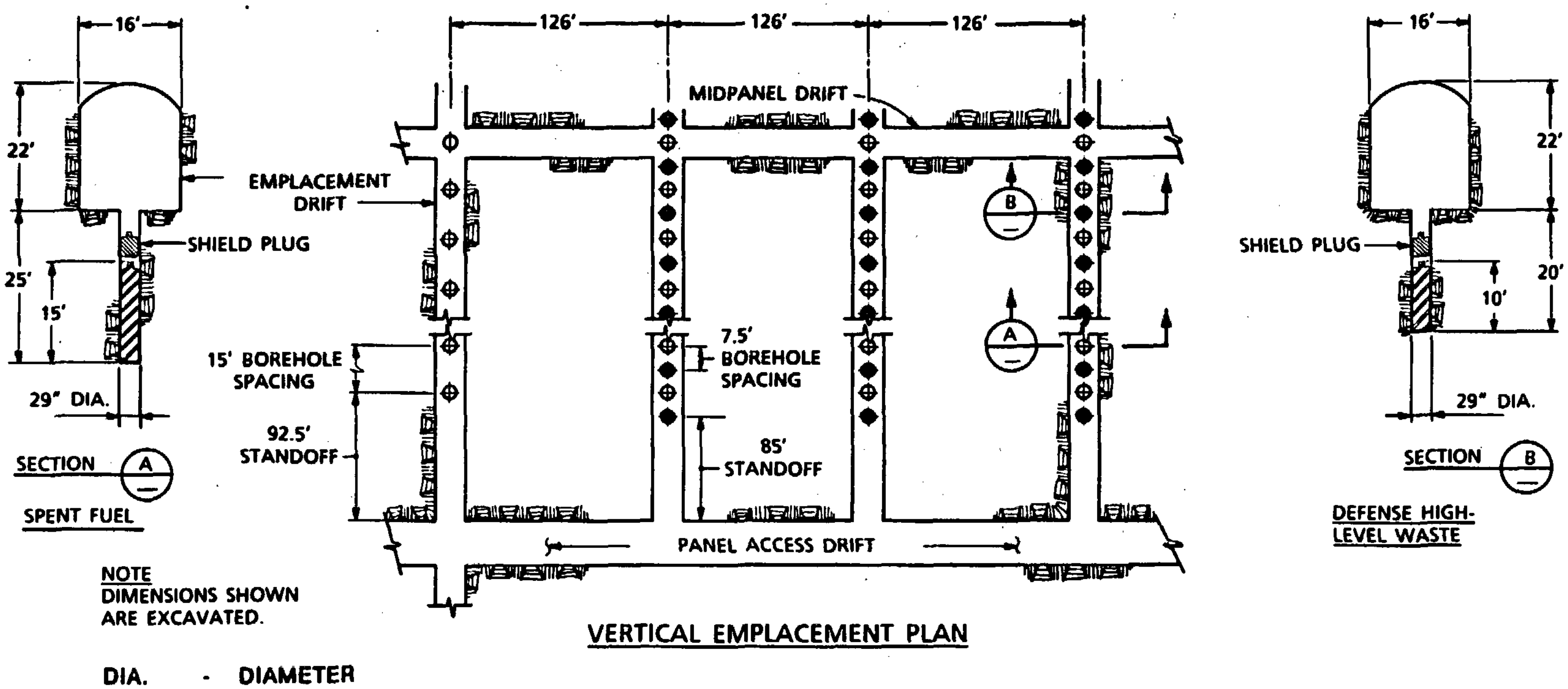


Figure 6-63. Panel details for vertical emplacement.

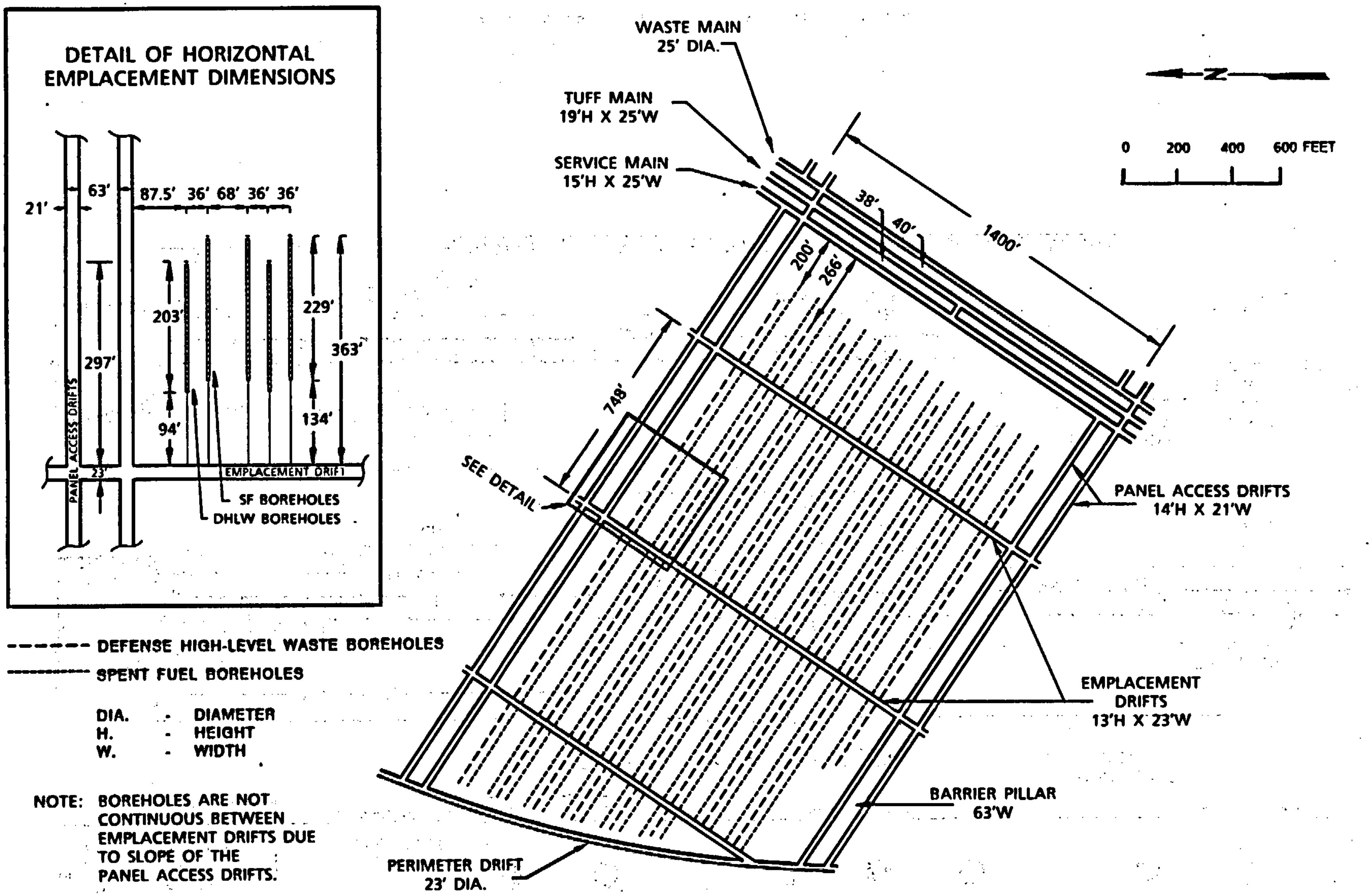


Figure 6-64. Typical panel layout for horizontal emplacement.

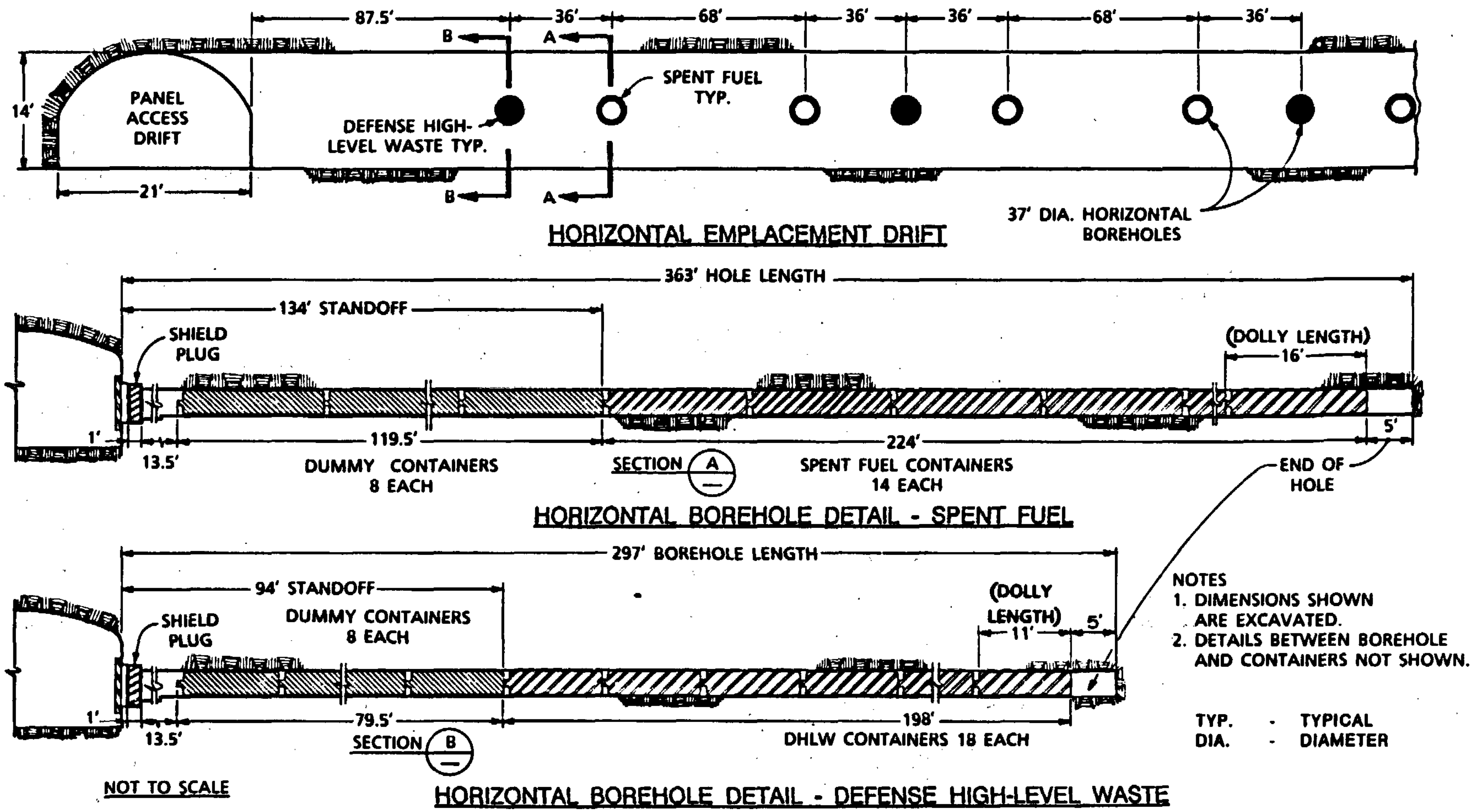


Figure 6-65. Panel details for horizontal emplacement.

high. The panel access drifts in the vertical configuration would be 21 ft (6 m) wide by 14 ft (4 m) high. No midpanel drifts are included in the design because the standoff distance between the waste containers and the drift in the horizontal configuration would reduce the temperatures in the emplacement and access drifts. Boreholes would be spaced within the panel at intervals determined by the number of waste containers and standoff distances necessary to satisfy heat load criteria. When required, the emplacement boreholes for DHLW would be alternated with the emplacement boreholes for spent fuel. The emplacement holes for DHLW and spent fuel would have the same dimension and lining.

Maintenance Shops and Service Areas

The current design calls for the shops in the development and emplacement areas to be located at the base of the waste ramp. These are shown on Figures 6-66 and 6-67. The underground service facilities would be equipped so that most preventive maintenance and minor repair functions could be performed underground. Sufficient spare parts and components for use in preventive maintenance would be stocked underground so that most repairs could be performed in a timely manner. Major rebuilding and overhauling would be performed in the maintenance facility on the surface.

An underground service area, to be located at the men-and-materials shaft, would contain a control room that houses the communications, ventilation, water, electrical, and ground-control monitoring systems. The control room would be the subsurface location for all repository monitoring and control systems. The main monitoring console for these systems would be on the surface.

Other facilities proposed to be located in the underground service areas are maintenance shops, space for equipment parking, bulk materials storage, supplies, service equipment, and space for administrative functions. Maintenance facilities, comparable to those in the underground service area, would be provided in the waste emplacement area.

Explosives would not be stored in the underground warehouse and shop area but would be stored on the surface where delivery would be controlled by warehousing personnel. Shortly before use, explosives would be brought underground and stored near the areas where they are planned to be used. Storage and transportation of explosives will follow the procedures described in 30 CFR Part 57.

6.2.6.1 Excavation, development, and ground support

Several types of openings to and within the underground portion of the repository are proposed to provide for development and waste emplacement activities. These proposed openings include two ramps, various types of drifts, four shafts, and the boreholes in which the waste containers would be placed. The proposed openings are identified as follows:

1. The waste ramp would link the central surface facilities with the subsurface facility. All waste to be emplaced in the repository

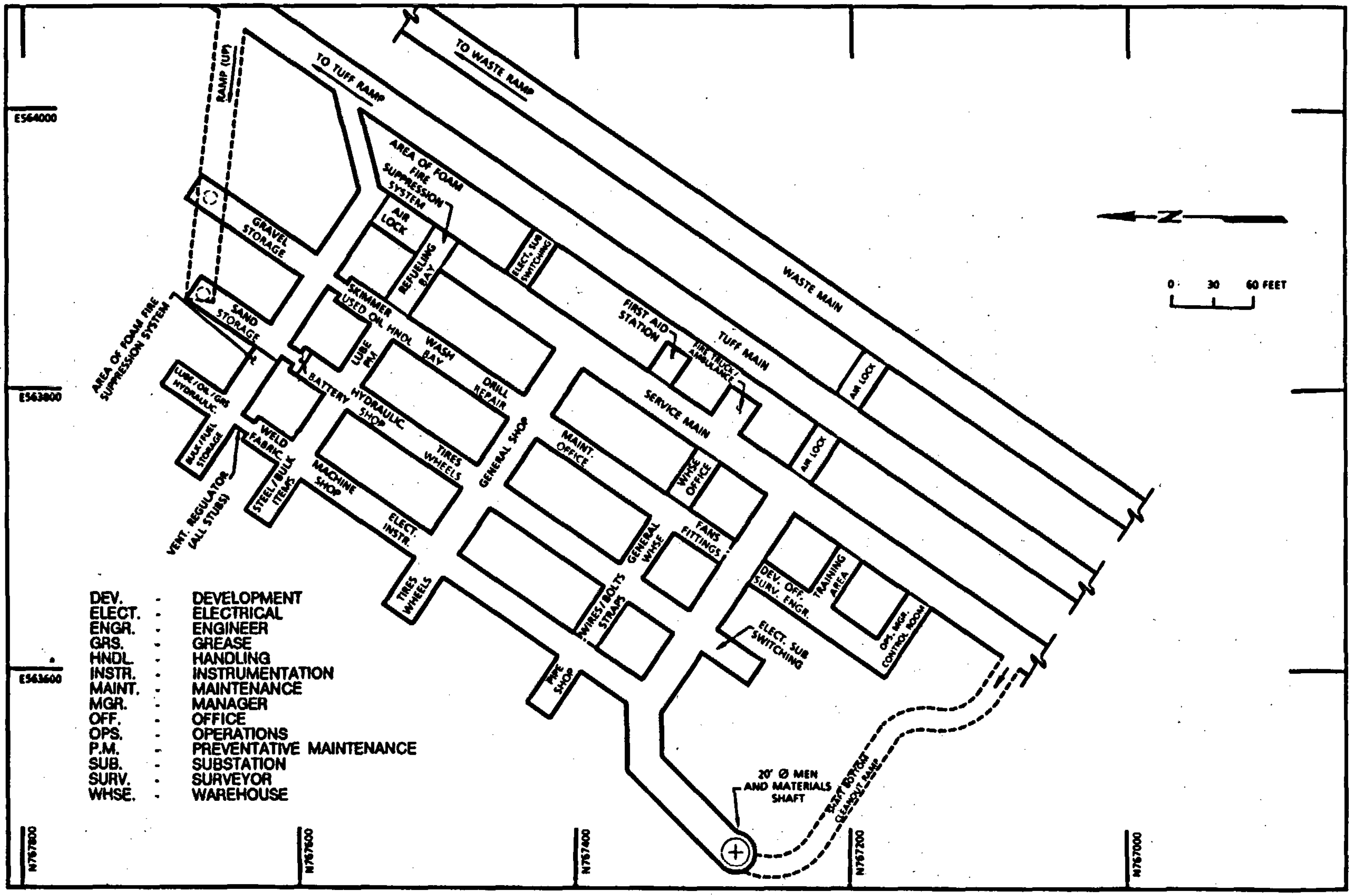


Figure 6-66. Development shops and warehousing.

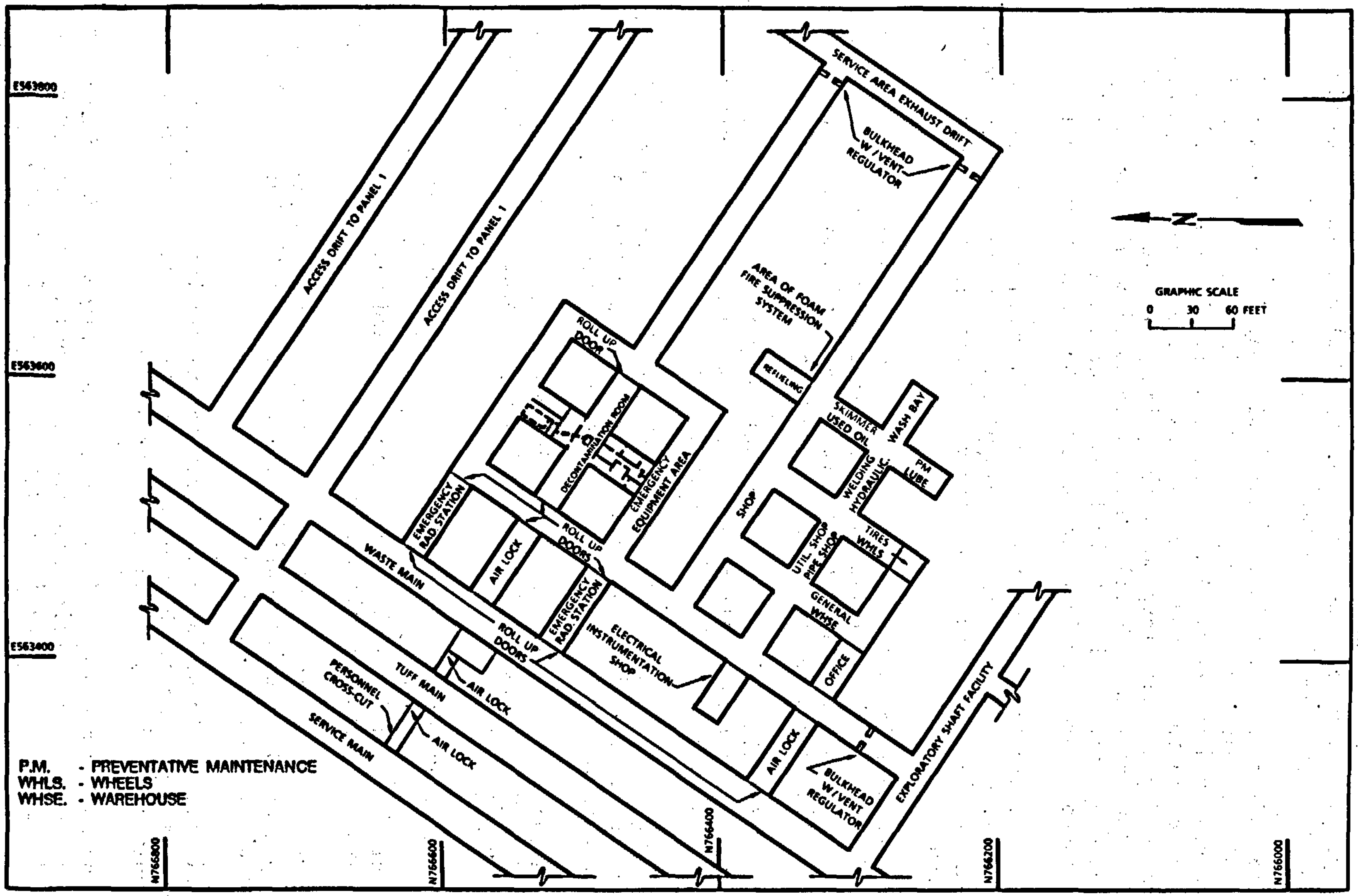


Figure 6-67. Emplacement shops, warehousing, and decontamination areas.

would be transferred from the surface to the underground facility through this ramp. The waste ramp would also serve as the air intake that supports waste emplacement.

2. The tuff ramp, which is the main haulageway for excavated tuff, would contain a belt conveyor and the main electrical feeder for the underground facility. A redundant electrical feeder would be located in the men-and-materials shaft. The current design also calls for the tuff ramp to be the primary exhaust airway for the development area. Traffic on the ramp would consist primarily of vehicles that service the belt and may occasionally be used to transport large machinery to and from the emplacement level.

3. The primary function of the service main would be to provide access for all development personnel, supplies, and machinery. The service main would also be used to carry ventilation air to the development area.

4. The waste main would connect the waste ramp with the access drifts and serve as the ventilation intake for the air circuit in the waste emplacement area. Together the waste ramp and waste main would form the sole access for the waste transporter.

5. The tuff main would be the main haulageway for excavated tuff at the emplacement level. All exhaust air from the development circuit would be exhausted through the tuff main.

6. The perimeter drift would be the exhaust airway for the air circuit in the waste emplacement area. Traffic through the perimeter drift would be restricted to inspection and maintenance vehicles.

7. The panel layout for vertical emplacement is shown in Figures 6-61 and 6-62. The layout for horizontal emplacement is shown in Figures 6-63 and 6-64.

8. Panel access drifts run perpendicular to the mains and provide access to the emplacement drifts. During development, the drifts would be used for haulage and ventilation and must accommodate mining vehicles and belt conveyors.

9. Emplacement drifts are planned to be the disposal areas, from which emplacement boreholes would be drilled, in both the horizontal and vertical emplacement modes.

10. Midpanel drifts would be used only in the vertical emplacement mode. The main purpose of these drifts is to carry exhaust air from the emplacement drifts to the perimeter drift.

11. Four shafts are proposed to lead to the underground facilities. The men-and-materials shaft would provide access for men and materials and air intake for the development area. The first exploratory shaft (ES-1) would provide intake of air for the waste emplacement area. The emplacement exhaust shaft would discharge the air from the waste emplacement area. The second exploratory shaft (ES-2)

would provide secondary intake of air for the waste emplacement area.

Boreholes would be used for the emplacement of waste containers. The vertical boreholes are designed to hold a single waste container while the horizontal boreholes are designed to accommodate up to 14 spent fuel waste containers or up to 18 DHLW waste containers.

6.2.6.1.1 Development sequence

The construction and emplacement operation of the underground repository is proposed to take place in two steps. The first step precedes waste emplacement and would consist of initial construction of accesses and underground drifts. In the second step, construction of the new emplacement drifts and emplacement of waste in previously constructed drifts would occur simultaneously.

Initial construction

In this first step of the development sequence, the entry points to the emplacement level would be constructed.

In this conceptual design, the shafts in the exploratory shaft facility (ESF) are proposed to be converted to ventilation air intakes. The 12-ft (4-m) diameter shaft, ES-1, would be stripped of all steel and internal fixtures, leaving only the concrete lining. The headframe, hoist house, and other surface facilities would also be removed, and the surface exhaust fan would be removed from the 6-ft (2-m) diameter shaft, ES-2. ES-1 would serve as the primary source of air for the waste emplacement area. ES-2 would be a secondary source of air for the waste emplacement area and the main source of the air for the shops in the waste emplacement area.

Two 20-ft (6-m) diameter finished shafts are planned. One shaft would be outfitted for use as a men-and-materials shaft; the other would be used to exhaust air from the waste emplacement area.

Current plans for initial underground development do not call for the use of the exploratory shafts, ES-1 and ES-2. However, the conceptual design does not preclude future use of ES-1 and ES-2 for underground development, if advantageous.

Concurrent development and emplacement

After completion of initial construction, the three main drifts and the perimeter drift would be developed to a point approximately two panel widths away from the point at which the first waste is planned to be emplaced. Development and emplacement is planned to begin in the northeast quadrant of the repository and proceed in a clockwise direction.

The planned operation involves concurrent activities in three panels; while one panel is being developed, one panel has been developed and is ready to receive waste, and a third panel is receiving waste. The emplacement panels would be developed by first constructing the access drifts (for vertical orientation), or emplacement drifts (for horizontal orientation) from the main drifts. The panel would be developed from the access or emplacement drift and a series of boreholes would be drilled in the required configuration and prepared to receive the waste. Liners would be placed in the horizontal boreholes during development and partial liners are planned for use in vertical boreholes. Vertical and horizontal boreholes are illustrated in Figures 6-68 and 6-69.

6.2.6.1.2 Mining methods

The excavation method for each underground opening will depend on the shape and dimensions of the opening and the properties of the rock surrounding the opening. Descriptions of the planned excavation methods for the ramps, shafts, drifts, and boreholes are provided in the following paragraphs.

Drill-and-blast methods are planned to be used to excavate most shafts. Shafts with smaller diameters, such as the 6-ft (2-m) diameter shaft in the ESF, may be raise bored.

The waste and tuff ramps are both of sufficient size and length to favor the use of tunnel-boring machines (TBMs). The ramps would be driven at a constant slope.

Long-drive drifts, the waste main and the perimeter drift, are similar to ramps in shape and dimensions. The TBM method is similarly proposed for excavating the mains. Drill-and-blast methods are proposed for excavating the remaining, shorter drifts.

Boreholes for the vertical emplacement method would be drilled using existing methods and equipment. The equipment is being developed to demonstrate the capability to accurately drill and line horizontal boreholes of the lengths proposed in the SCP-CD.

The methods proposed for excavation of each type of opening are summarized in Table 6-23.

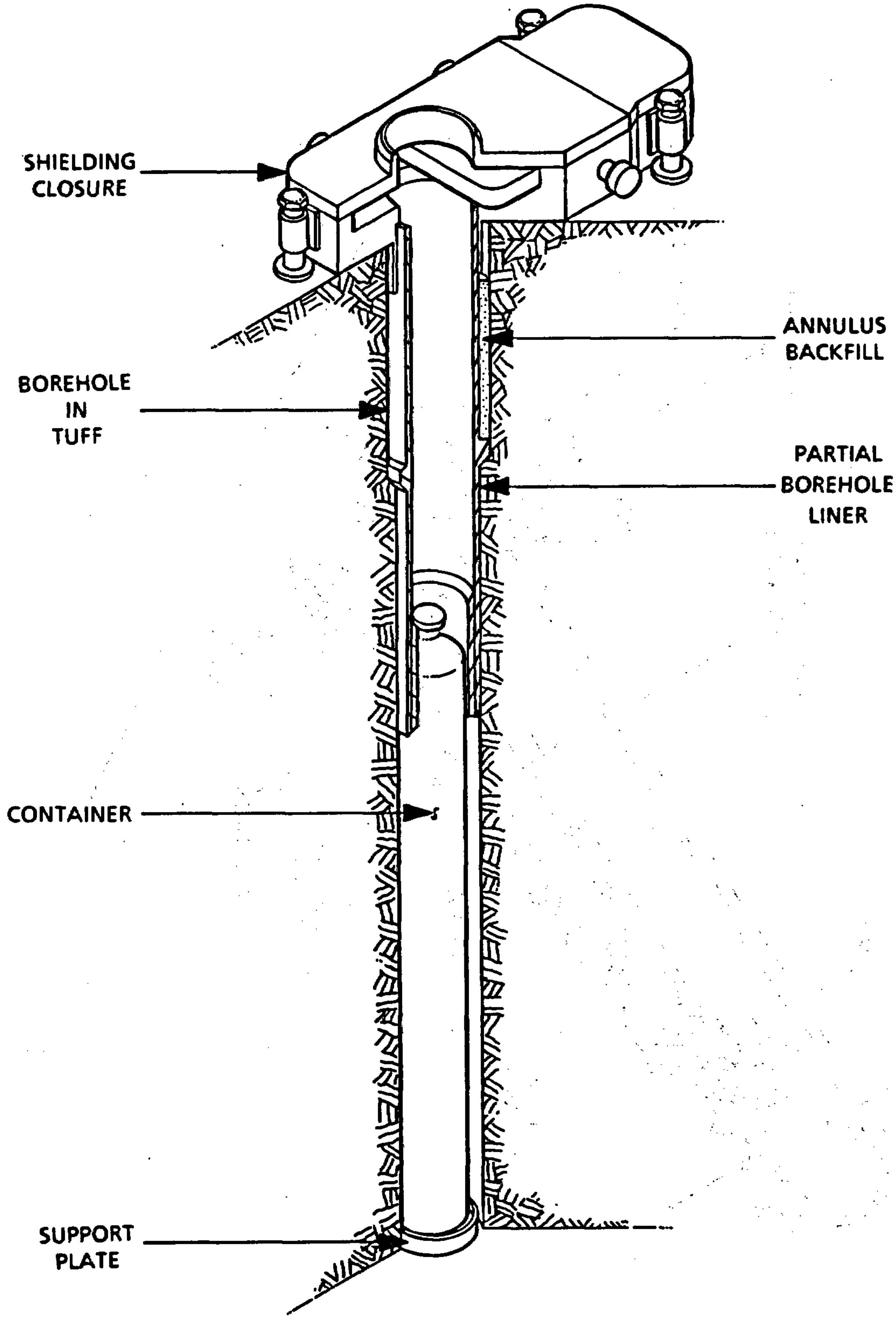


Figure 6-68. Vertical borehole.

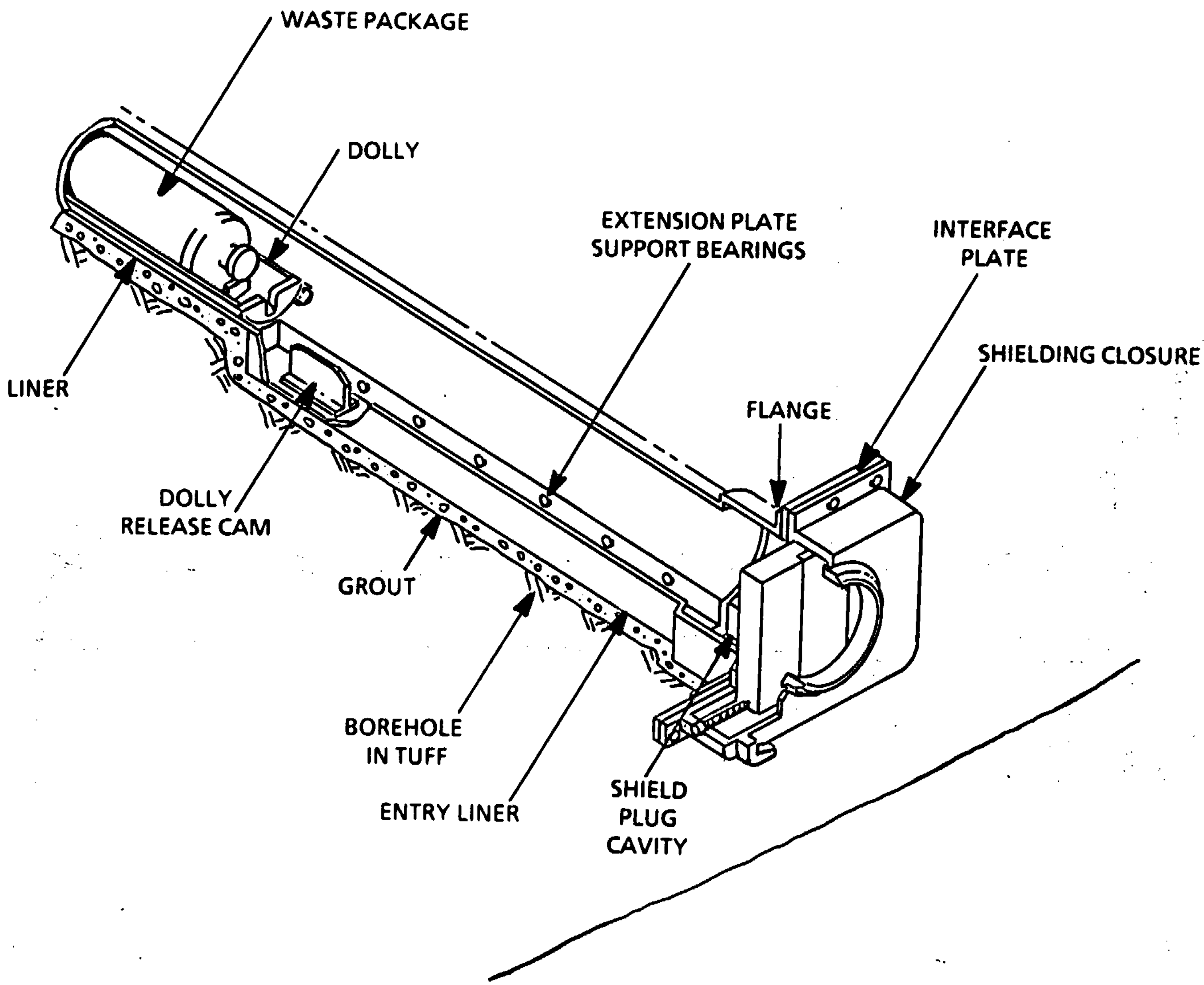


Figure 6-69. Horizontal borehole.

Table 6-23. Mining methods

Opening	Proposed mining method
Shafts	
Small diameter	Drilling, raise boring
Large diameter	Drill and blast
Waste ramp	Tunnel-boring machine
Tuff ramp	Tunnel-boring machine
Waste main	Tunnel-boring machine
Tuff main	Drill and blast
Service main	Drill and blast
Perimeter drift	Tunnel-boring machine
Emplacement drifts	Drill and blast
Panel drifts	Drill and blast
Midpanel drifts	Drill and blast
Emplacement boreholes	Drilling

6.2.6.1.3 Handling of excavated tuff

In the current conceptual design, excavated tuff would be transported from the working face to a feeder-breaker by load-haul-dump units. The feeder-breaker would crush the tuff into pieces smaller than 8 in. (20 cm) and place the crushed tuff on a conveyor belt for transportation to the surface. The conveyor series would, at its longest, be approximately 13,600 ft (4,145 m) long. At the portal of the tuff ramp, the excavated tuff would be transferred to a surface conveyor for transport to the tuff pile.

All conveyors would be controlled at the underground control center and powered by the main power distribution system. The separate units of the conveyor system would have sequential startup and shutdown for control and economy of operations. Each unit of the system would be equipped with a manually operated emergency shutdown system.

6.2.6.1.4 Ground support

This section summarizes the ground support systems proposed for all drifts and ramps at Yucca Mountain. A brief description of the design method is presented, along with a discussion of the site-specific factors that affect the choice of ground-support methods. Section 6.1.1 identifies the design requirements for opening stability, as prescribed by 10 CFR Part 60.

Ground support options

A number of ground support systems currently used in mining and civil tunneling projects are well suited for use in a repository. Although specific tunneling experience in welded tuff is rather limited, the range of expected conditions is well within the limits of historical experience. Due to the strength of the rock, depth of the openings, and ground support that is planned, no surface subsidence is anticipated. The following ground support options are candidates for use at the repository:

1. No support.

2. Friction bolts (Swellex, split-set).

3. Point-anchor bolts.

4. Resin-grouted dowels.

5. Cement-grouted dowels (pretensioned, posttensioned, and untensioned).

6. Cement-grouted cable anchors.

7. Chain-link fence materials.

8. Welded wire mesh.

9. Shotcrete with steel fiber, microsilica, and accelerators.

10. Structural-steel sets.

11. Lattice girders.

12. Yieldable steel arches.

13. Cast-in-place concrete lining.

14. Prefabricated, segmented linings.

The ground support systems selected should include the following features:

1. Compatibility with excavation methods and sequence of construction.

2. Relative flexibility to conform with thermally and seismically induced deformations.

3. Minimal site-specific prefabrication.

4. Installation methods or upgrading as needed to deal with anomalous conditions.

5. Installation that minimizes work in unsupported openings.

6. Adaptability to accommodate varying shapes of openings and intersections.

7. Durability to withstand elevated temperatures and the possible presence of water for 100 yr.

8. Cost-effectiveness for the support obtained.

9. Chemical components that are compatible with waste package isolation and containment strategies.

These containment and isolation strategies are discussed in Section 8.3.

Ground support recommendations

The empirical rock-mass classifications discussed by Langkopf and Gnirk (1986) and Dravo Engineers, Inc. (1984) recommend the use of a combination of rock bolts, grouted dowels, wire mesh, and shotcrete in varying degrees to conform with local conditions. Figure 6-70 shows typical sections of the ground support systems in the conceptual design for both bored and conventionally mined drifts. The site characterization program will provide a more detailed description of the in situ rock characteristics in the emplacement horizon. These data will provide insight into the variability of the rock characteristics encountered in a few thousand feet of drifting. Even with these data it will not be advisable or necessary to assign final ground-support designs to individual drifts. Observations and measurements made during repository construction will support the final determination of the ground support at any given location, in accordance with predetermined standards.

6.2.6.1.5 Underground development equipment

The equipment that would be used for underground development is shown on Figures 6-71 and 6-72. Except for the drill for the horizontal borehole, the equipment is currently available. Feasibility studies and conceptual designs for drilling and lining horizontal boreholes have been completed (Robbins Company, 1984a, 1984b, 1985). The design process, which is currently in the detailed design phase, will be followed by construction of demonstration equipment to be used in proof-of-concept demonstrations (SNL, 1987, Sections 6.3.2.1 and 6.3.2.2).

6.2.6.2 Ground-water control

Exploratory drilling performed to date indicates the proposed repository horizon, the Topopah Spring Member of the Paintbrush Tuff, lies within the unsaturated zone above the water table. No perched water zones have been identified within the proposed horizon, although the potential for a perched water table exists at the interface between the Topopah Spring and the less

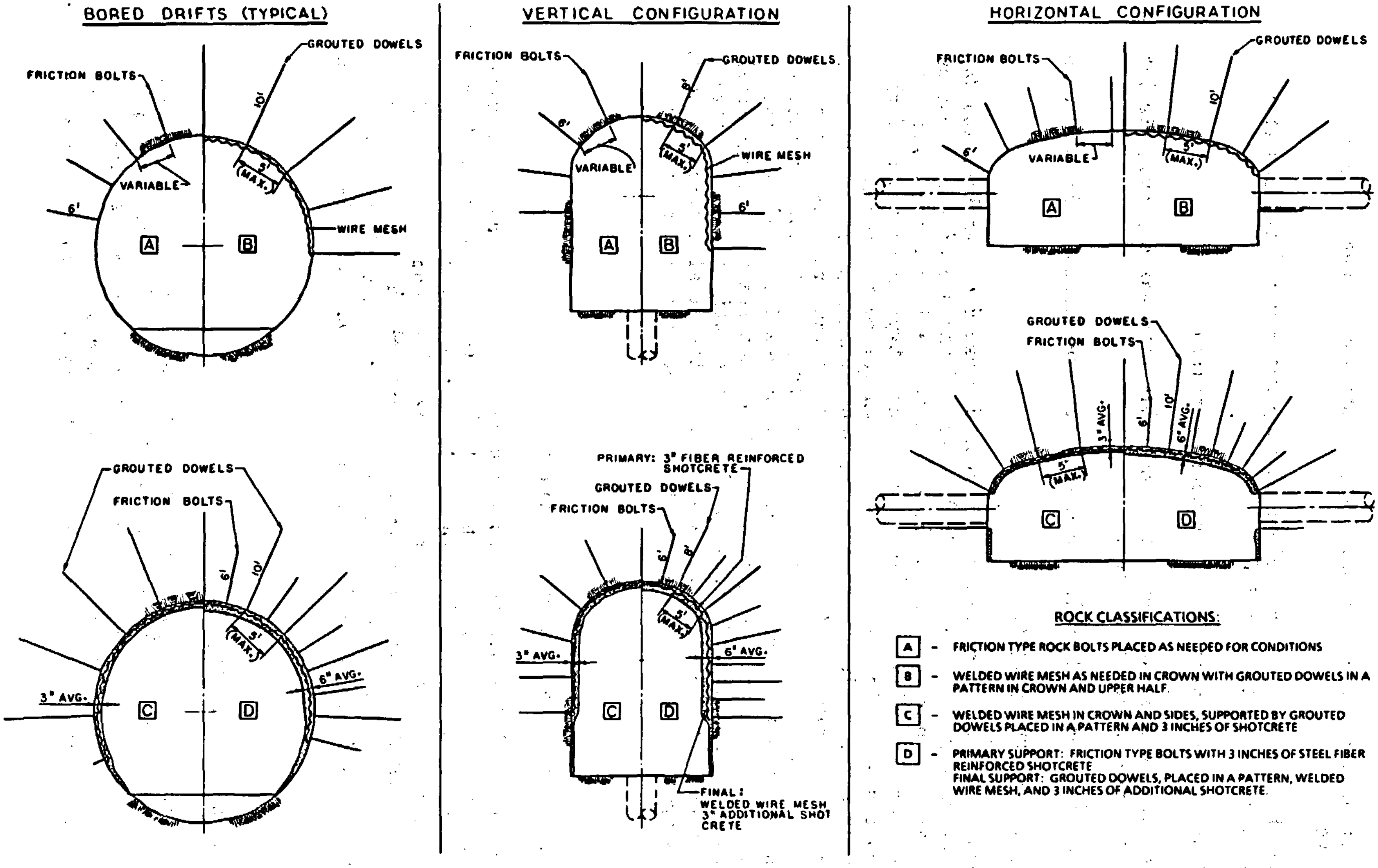


Figure 6-70. Typical ground support cross sections.

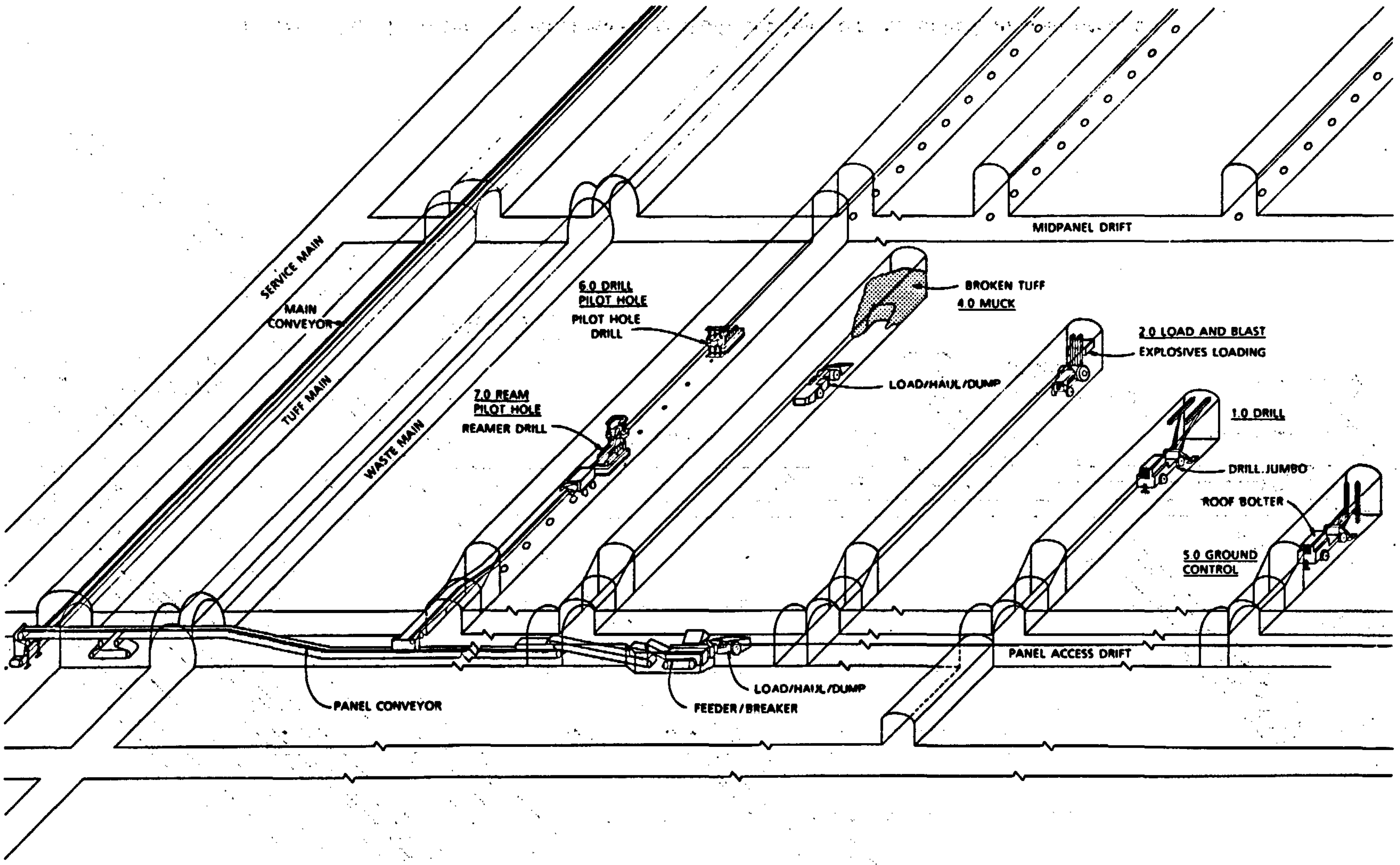


Figure 6-71. Isometric diagram of mining methods and sequence for vertical emplacement.

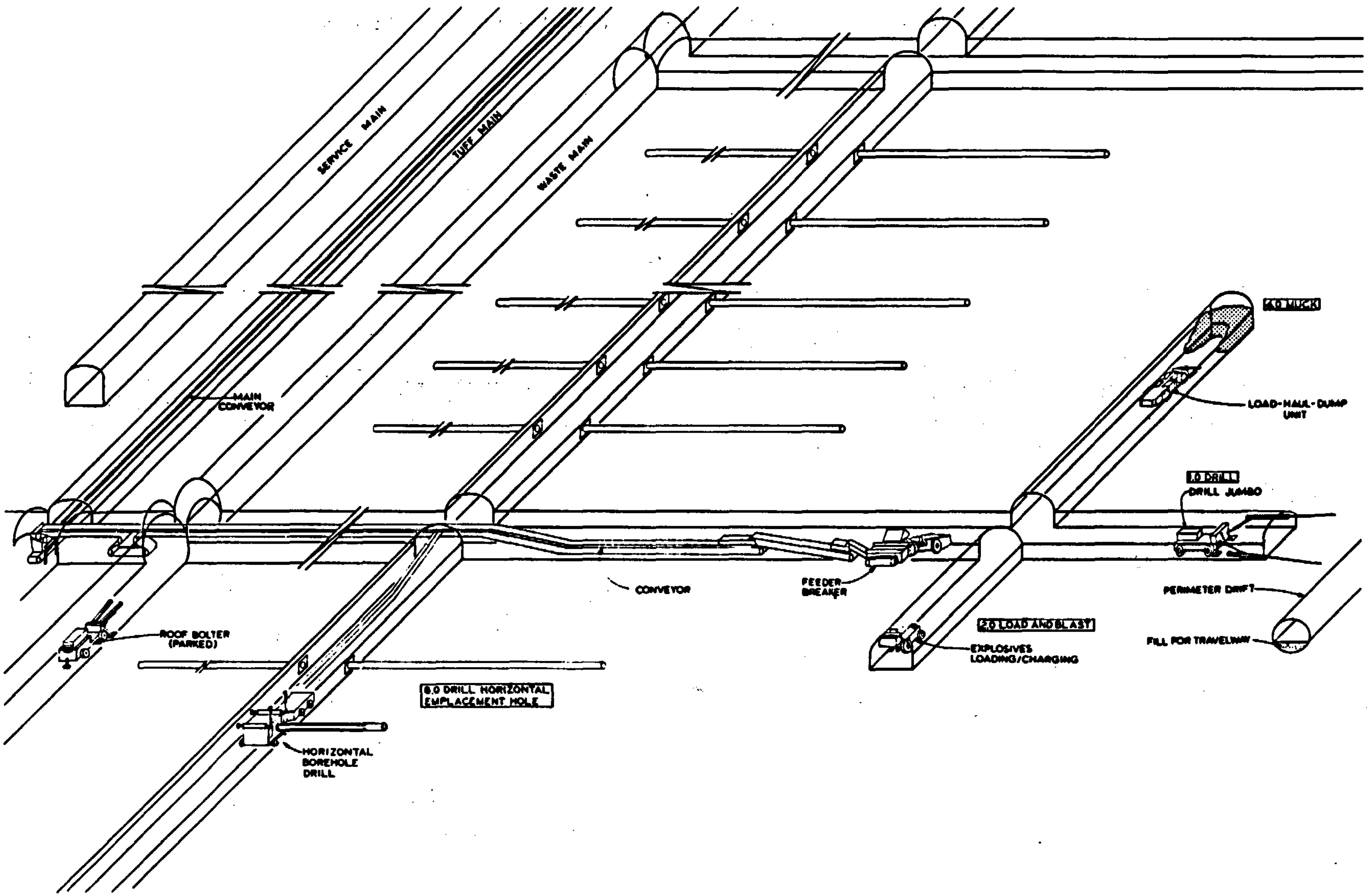


Figure 6-72. Isometric diagram of mining methods and emplacement for horizontal emplacement.

permeable Calico Hills zeolitized tuff. However, the conceptual repository layout is situated above this interface, and relatively dry conditions are anticipated throughout the repository.

Inflow of ground water is not anticipated in significant quantities, however, the drifts are designed so that any water, whether from ground water or from operations within the underground facilities, would be diverted away from the waste emplacement locations (Figure 6-73). All areas would drain in the direction of a sump located in the bottom of the emplacement area exhaust shaft, the lowest point in the underground facility. From this location, the water would be pumped to the surface through the emplacement area exhaust shaft. Backup pumps would be available to ensure adequate pumping capacity.

6.2.6.3 Ventilation

The following section describes the general ventilation system. Sections 6.2.6.3.2 and 6.2.6.3.3 describe the ventilation systems for the vertical and horizontal emplacement configurations, respectively.

6.2.6.3.1 General overview and description of the system

Two independent ventilation systems are planned to serve the underground facilities. One system would provide air for the development of the repository while the other would provide air for waste emplacement operations. Connections between the two ventilation systems would be sealed with bulkheads or air-locks. Redundancy in the ventilation fans on each side is planned. A complete description of the ventilation systems is given in Section 3.4 of the SCP-CDR.

The development and emplacement areas would be ventilated by a system with two independent air circuits. Interaction and leakage between air circuits is inevitable. To ensure that leakage would occur from the development air circuit to the emplacement air circuit, pressure differentials are established between the air circuits. A forcing or positive pressure system would be employed for the development air circuit. This positive pressure system would use forcing fans located at the collar of the men-and-materials shaft. An exhausting or negative pressure system would be used for the emplacement air circuit. This negative pressure system would use exhaust fans located at the collar of the emplacement area exhaust ventilation shaft. The conceptual design does not provide the capability for reversal of the underground ventilation, because reversal would cause leakage from the emplacement air circuit to the development air circuit. The question of reversal of underground ventilation will be addressed further as part of the advanced conceptual design studies.

The performance of the repository ventilation systems would be monitored continuously at surface and underground control centers. The goal of the planned monitoring system is threefold: (1) to maintain an immediate measure of the working environment within the repository; (2) to provide immediate notice of accidents, including fire and incidents involving radioactive

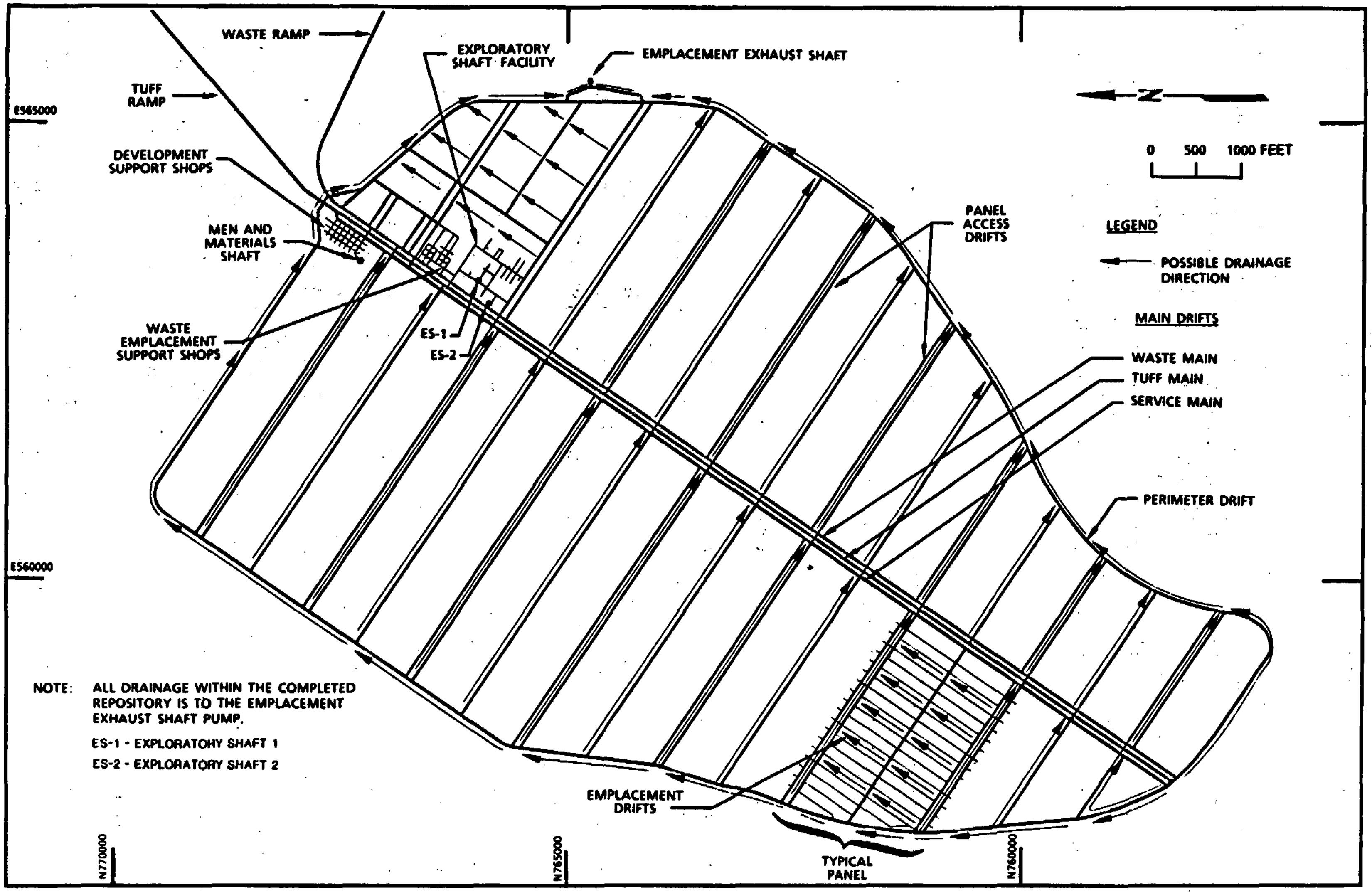


Figure 6-73. General underground facility layout showing drainage directions for vertical emplacement.

material; and (3) to activate appropriate measures, such as evacuation of personnel, redirection of waste emplacement exhaust air through filters, and dispatch of emergency crews.

During normal operations, return air from the waste emplacement ventilation system would be exhausted directly to the atmosphere. However, should the monitors detect a radiation release, the return air would be routed through a set of filters, including high-efficiency particulate air filters, before discharge.

The underground ventilation concepts are based on the proposed repository layout and development sequences presented in Section 6.2.6.1. The basic ventilation layout consists of the following: (1) four shafts, (2) two ramps, (3) three main airways, (4) emplacement areas on either side of the main airways, and (5) a perimeter airway that encircles the repository (Figure 6-74).

The main components of the planned development area ventilation system are as follows:

1. Men-and-materials shaft for air intake from surface.
2. Service main for air intake to development areas.
3. Tuff main as return for air from development areas.
4. Tuff ramp as return for air to surface.

The main components of the planned waste emplacement area ventilation system are as follows:

1. Exploratory shafts and waste ramp for air intake from surface.

2. Waste main for air intake for waste emplacement, emplacement room cooling, or caretaking operations.

3. Perimeter drift as return for air from waste emplacement area.

4. Emplacement area exhaust shaft as return for air to surface.

The waste emplacement area ventilation system is designed to ensure safe working conditions during waste transport, emplacement, or retrieval operations. Both spent fuel and defense high-level waste may be emplaced in the same drift.

For the most part, the required airflows for both ventilation systems were derived from considerations of diluting diesel exhaust fumes, minimum statutory requirements for airflow, and shop demands. Computed airflow velocities at various underground locations were compared to the maximum velocity constraints shown in Table 6-24. The velocity constraints were determined from dust abatement and comfort considerations (National Materials Advisory Board, 1980).

Cooling of an emplaced drift for inspection, maintenance, or retrieval is expected to be necessary because the containers will heat the rock mass around the emplacement hole, which, in turn, will transfer heat to the

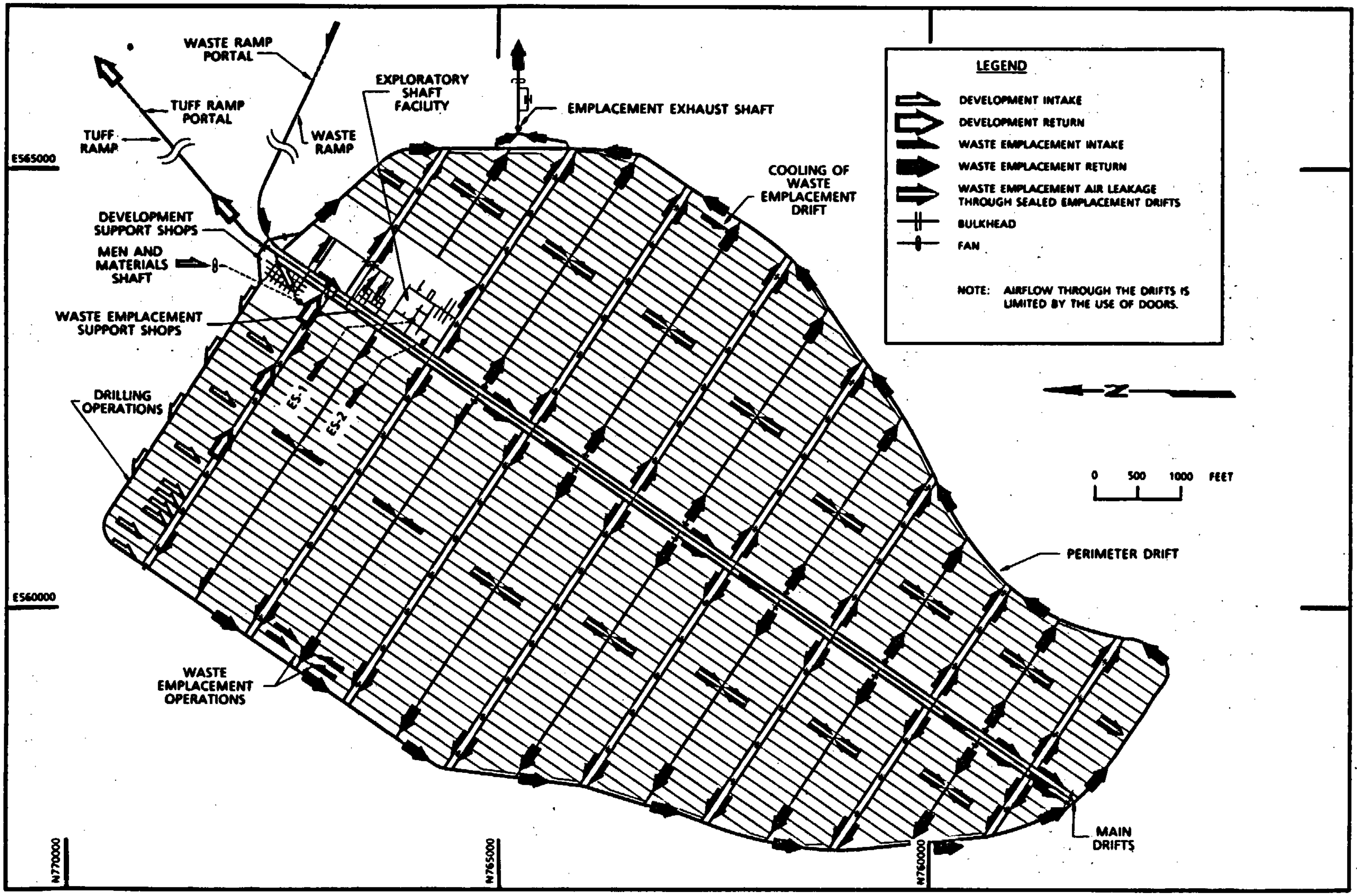


Figure 6-74. Maximum development of ventilation requirements for vertical emplacement.

Table 6-24. Maximum velocity constraints

Area	Maximum velocity[a] ft/min	m/min
Intake shafts (unobstructed)	4,000[b]	1219
Return shafts (unobstructed)	4,000[b]	1219
Waste transport ramp	1,500	457
Tuff ramp or shaft	1,500	457
Men-and-materials shaft	2,300	701
Perimeter airway	2,000	610
Main entry drifts	1,500	457
Main return drifts	1,500	457
Haulage airways (no conveyor)	1,200[b]	362
Haulage airways (conveyor)	1,000[b]	305
Emplacement drifts	1,500	457
Development areas (drilling, etc.)	600	183

[a]Maximum shaft velocities assume that the shafts are dry and unobstructed.
[b]National Materials Advisory Board (1980).

emplacement drift airflow. Because the pre-waste-emplacement rock temperature is expected to be low at Yucca Mountain, no air cooling is expected to be required in the development ventilation system.

6.2.6.3.2 Vertical (reference) emplacement configuration

Vertical development area

Figure 6-74 shows the main air intake and return flow directions and quantities, the temperature distribution, location of main fans, main fan pressures, and ventilation controls throughout the vertical emplacement configuration at the maximum development airflow demand. The main fan requirements for this layout are shown in Table 6-25.

Vertical emplacement area

The maximum airflow demand on the ventilation system for the waste emplacement area would occur when the repository is nearly fully developed and when emplacement and inspection or maintenance are occurring simultaneously. At this time, vertical borehole drilling would be the only operation in the development area. This set of conditions would require the largest waste emplacement fan capacities because the air exiting the panel in which

Table 6-25. Maximum airflow requirements for the development area in the vertical emplacement configuration

Ventilation system	Main fan requirements	
	Pressure (in. w.g.)[a]	Airflow (cfm)[b]
Development	9.0	411,800
Waste Emplacement	3.25[c]	481,300

[a]Inches water gauge.
[b]Based on standard air density, cubic feet per minute.
[c]Pressure required at the collar of waste emplacement area exhaust shaft.

waste is being emplaced would have to travel a great distance around the repository in the perimeter drift to the waste emplacement area exhaust shaft.

Figure 6-75 shows the expected distribution of the airflow and air temperature, as well as the proposed main fan locations throughout the repository. Nearly 40 percent of the intake air for the waste emplacement area would enter through the waste ramp. The remaining intake air would enter through the two exploratory shafts. The basic ventilation system shown for the waste emplacement area would give acceptable airflows throughout the repository. Table 6-26 identifies the fan requirements for this layout time phase.

Table 6-26. Maximum airflow requirements in the waste emplacement area in the vertical emplacement configuration

Ventilation system	Main fan requirements	
	Pressure (in. w.g.)[a]	Airflow (cfm)[b]
Development	1.50	209,400
Waste emplacement	13.75[c]	837,200

[a]Inches water gauge.
[b]Based on standard air density.
[c]Pressure required at the collar of waste emplacement area exhaust shaft

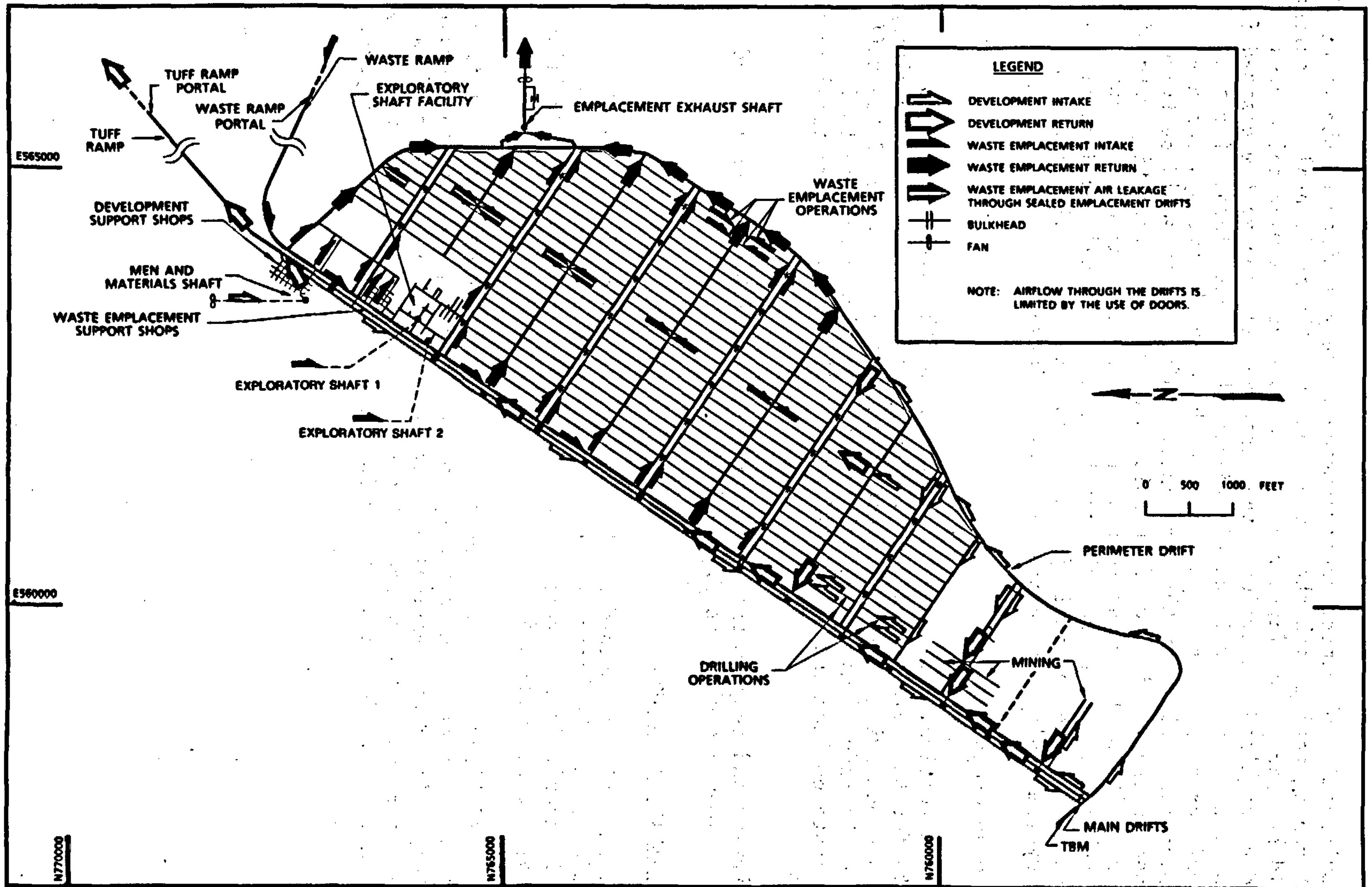


Figure 6-75. Maximum airflow directions, quantities, and temperatures for the waste emplacement area for vertical emplacement.

6.2.6.3.3 Horizontal emplacement configuration

The horizontal emplacement configuration is very similar to the vertical emplacement configuration with the exceptions that the horizontal emplacement drifts would be spaced much farther apart and no vertical midpanel access drift would be required. Therefore, the basic ventilation system planned for the horizontal configuration is nearly identical to that planned for the vertical configuration. The key differences between the two systems are (1) the emplacement drifts in the horizontal configuration would be twice as long as those in the vertical configuration and (2) the alternating sets of panel access drifts would act as returns for the horizontal emplacement drifts on each side. Therefore, the ventilation of a panel would be similar to that planned for the vertical system except that the panels in the horizontal system would be effectively twice as large.

<u>Horizontal development area</u>

As in the vertical emplacement configuration, the maximum airflow requirements for the development ventilation system are expected when mining operations are occurring at the greatest distance from the base of the tuff ramp. Given the reduced mining activities, the airflow requirements for horizontal waste emplacement also would be less than those for vertical waste emplacement.

The airflow and temperature distributions, ventilation controls, and main fan locations are shown on Figure 6-76.

<u>Horizontal emplacement area</u>

The maximum airflow demand on the ventilation system for the waste emplacement area for the horizontal configuration would occur when the repository is nearly fully developed and only emplacement borehole drilling operations are being conducted.

Figure 6-77 illustrates the expected airflow directions and quantities, air temperatures, ventilation controls, and main fan requirements throughout the repository. As in the vertical emplacement configuration, a significant amount of air for the waste emplacement area would enter the facility through the waste ramp. Table 6-27 shows the main fan requirements for the layout.

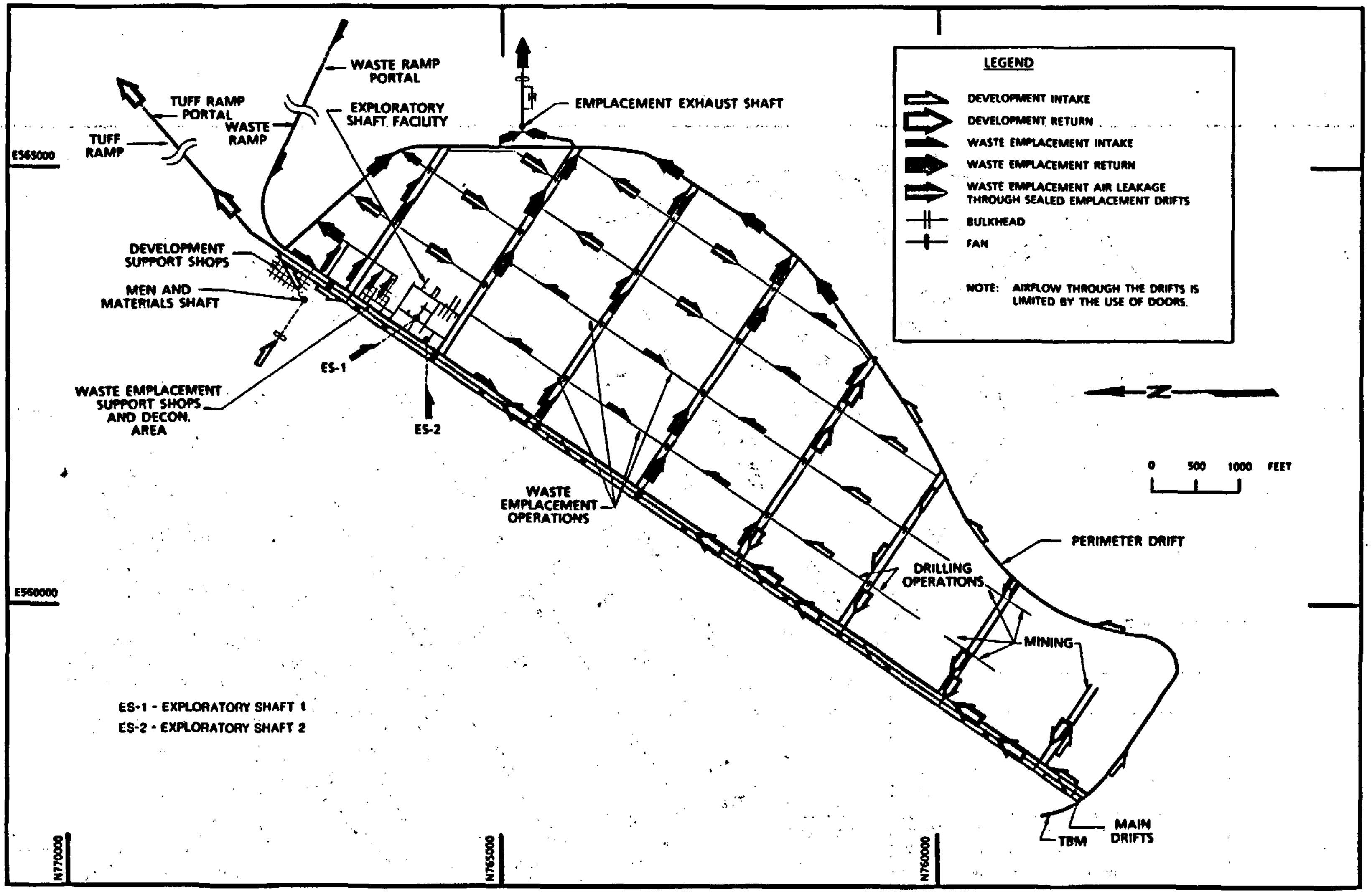


Figure 6-76. Maximum airflow directions, quantities, and temperatures for the development area for horizontal emplacement.

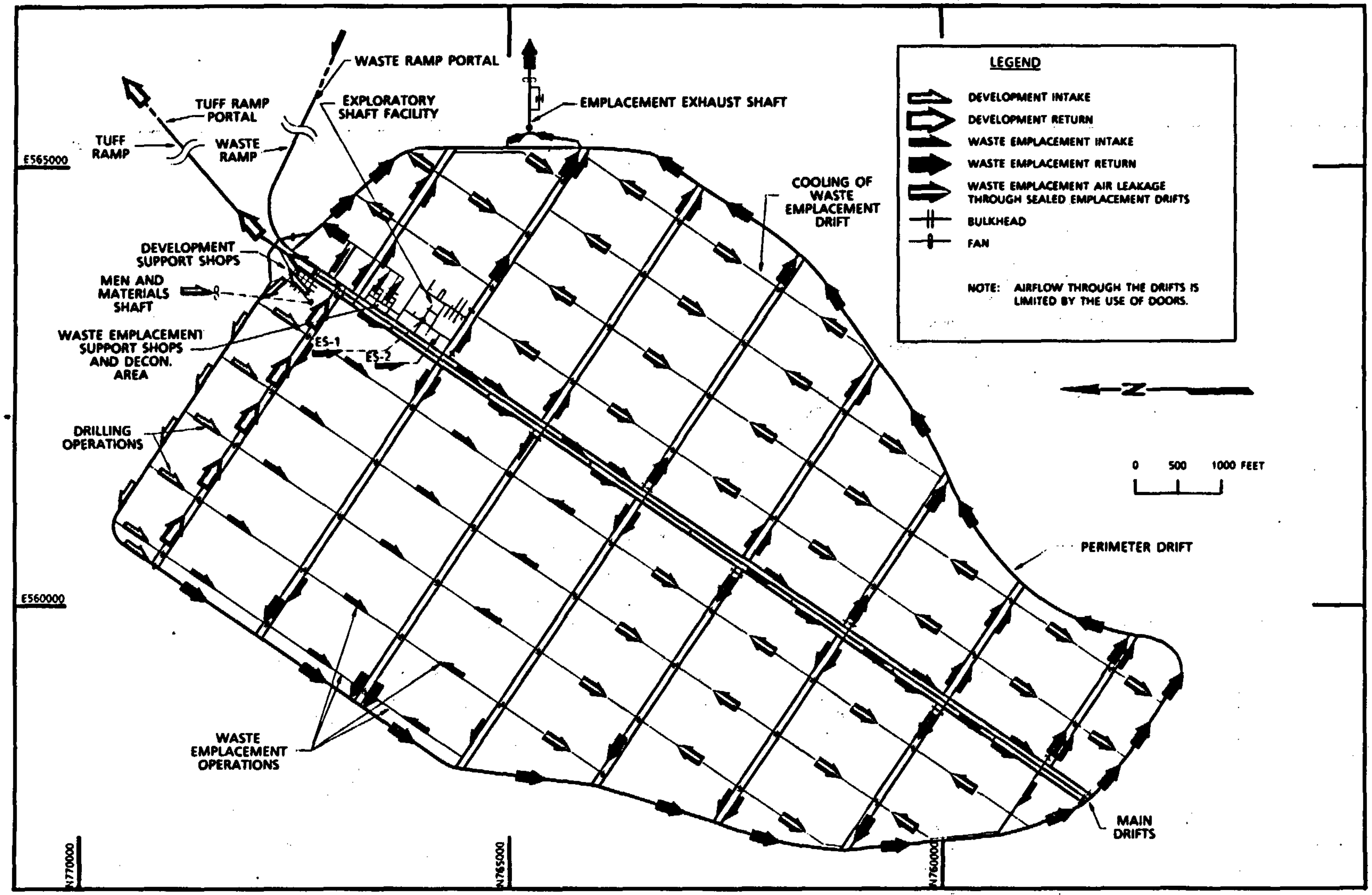


Figure 6-77. Maximum airflow directions, quantities, and temperatures for the waste emplacement area for horizontal emplacement.

Table 6-27. Maximum airflow requirements in the waste emplacement area in the horizontal emplacement configuration

Ventilation system	Main fan requirements: Pressure (in. w.g.)[a]	Airflow (cfm)[b]
Development	1.00	117,200
Waste emplacement	5.00[c]	517,200

[a]Inches water gauge.
[b]Based on standard air density, cubic feet per minute.
[c]Pressure required at the collar of waste emplacement area exhaust shaft.

6.2.7 BACKFILL OF UNDERGROUND OPENINGS

Section 60.133(h) of 10 CFR Part 60 states, "Engineered barriers shall be designed to assist the geologic setting in meeting the performance objectives for the period following permanent closure." Backfill is considered part of the underground facility, which is part of the engineered-barrier system.

Backfilling following emplacement and backfilling at closure are the two options considered. The need for backfill must be assessed based on the stability analyses of the underground openings and the analyses of the hydrologic conditions within the repository.

In addition, the need for backfilling following emplacement must not preclude retrieval of emplaced waste. If backfill is shown to enhance the performance of the overall repository system, requirements for backfilling will be developed. The properties of the backfill material, emplacement concepts, and specifications for backfilling will be established on the basis of these requirements.

6.2.7.1 Backfilling following emplacement

In the current conceptual design, backfilling of mined openings is not planned immediately following emplacement. The reasons for this position are that backfill is not required for structural support before closure and backfilling following emplacement would unnecessarily complicate potential retrieval operations.

Design calculations have been performed evaluating the stability of the rock mass at the underground horizon. These calculations are discussed in

Section 6.4.8.2.4. Because these calculations did not take into consideration backfill, it can be concluded that backfilling is not necessary to ensure mechanical stability throughout the retrievability period. Stability through the retrievability period is planned to be further enhanced through the use of ground support, such as rock bolts and wire mesh. More details of these calculations are reported in the SCP-CDR.

6.2.7.2 Backfilling at closure

Hydrologic calculations were performed to determine whether backfill could assist the geologic setting in meeting the performance objectives. These calculations evaluated the water flow in the vicinity of a vertically emplaced waste package located in the unsaturated zone of Yucca Mountain (Fernandez and Freshley, 1984; Freshley et al., 1985a).

The objective of these hydrologic calculations was to determine whether the selection of a drift backfill could influence the flow of water past waste packages and, thus, potentially influence the release of radionuclides. The calculations focused on determining the type of materials that might be useful as backfill. Coarse materials such as moderately to lightly crushed tuff or fine-grained backfill consisting of highly crushed tuff could be used. Sand and clay were the materials simulated in the calculations. These materials hydrologically represent a broad range of potential backfill material.

The basic approach to the modeling just described was to assume a continuum approach to water flow in the matrix of the fractured tuff of Yucca Mountain. The flux in the rock media was assumed to be less than the saturated hydraulic conductivity of the matrix. Hence, it is reasonable to assume the fractures do not transmit water, and they were not explicitly included in the analysis.

Conclusions from these hydrologic analyses indicate that from a hydrologic perspective, by approximating an open drift with coarse sand in numerical simulations, backfill in the drifts is not likely to influence flow significantly around waste packages. The results of the numerical simulations indicate that a coarse material will perform more satisfactorily as a capillary barrier to matrix water flow through drifts than will a fine material. The excavated tuff removed during development of the underground facility would be a source for coarse backfill. This material is planned to be stored in stockpiles on the surface and could be transported to the underground facility. Because of a bulking effect, only a fraction of the rock that was originally removed could be replaced as backfill.

The basis for current planning is that the underground facility will be backfilled at closure using the tuff that was excavated during development.

Water used during backfilling operations to control dust, improve compaction, or both will be introduced in limited quantities. Excess water will be removed in the same way as water introduced during development activities.

6.2.8 SEALS

Sealing refers to all activities associated with the permanent closure of the shafts, ramps, exploratory boreholes, and underground facility. Sealing includes emplacing backfill and sealing elements in shafts, ramps, drifts, emplacement holes, and exploratory boreholes (Fernandez and Freshley, 1984).

According to 10 CFR 60.134, the seals for shafts and boreholes shall be designed so that following permanent closure they do not become pathways that compromise the geologic repository's ability to meet the performance objectives for the period following permanent closure. Materials and placement methods for seals shall be selected to reduce, to the extent practicable (1) the potential for creating a preferential pathway for ground water or (2) radioactive waste migration through existing pathways.

The four functional requirements (Fernandez and Freshley, 1984) for sealing were developed based upon physical processes involving radionuclide transport through the geologic system to the accessible environment by ground-water flow. If ground-water flow near the waste packages can be inhibited or controlled, the potential for radionuclide transport can be reduced.

The first requirement (containment and isolation) addresses this concern. It is the intent of requirement 1 to preclude ground water from reaching the waste package as follows: (1) by preventing water from entering the underground facility through vertical shafts, ramps, or other vertical or horizontal penetrations; and, (2) if water does enter into the vicinity of the waste package, by diverting the ground water around the waste package. If radionuclides should enter the ground-water system, it would be desirable to retain radionuclides in the geologic system by retarding flow and absorbing radionuclides downgradient from the waste container. However, with the predominant vertical gradient in the unsaturated zone, it is not anticipated that radionuclides contained in ground water could reenter drifts.

The second requirement (human intrusion) addresses limiting radionuclide release as a result of either deliberate or inadvertent human intrusion. This objective can be achieved by closing all large openings, shafts, and ramps in a manner that would deter reentry. Small openings, such as exploratory boreholes, are not expected to present a safety hazard because seals acceptable by today's standards sufficiently deter reentry of the wells.

The third requirement (longevity of components) addresses the concern that sealing components must perform acceptably and with a sufficient degree of confidence over a required period. Their long-term performance may include a progressive but acceptable deterioration with time. An increase in confidence can be achieved in the following three ways: (1) by properly designing sealing components to static and dynamic loadings, (2) by reducing the uncertainties associated with material properties and emplacement techniques, and (3) by selecting different materials and designs serving the same or overlapping functions. The need for redundancy in seal functions will be determined through engineering analyses.

The fourth requirement (cost) also must be considered for investigating seal materials and their emplacement. When possible, complex designs and materials should be avoided because increased design, emplacement, and performance verification efforts may be required. Implicit in the verification requirements is the possibility for additional laboratory and field testing for more complex designs.

The sealing concepts proposed for the proposed repository in the unsaturated tuff of Yucca Mountain were developed by Fernandez and Freshley (1984) and provide the basis for continuing NNWSI Project repository sealing activities (Fernandez, 1985). These concepts were developed considering the hydrology of Yucca Mountain, the functional requirements discussed previously, preliminary repository concepts, federal and state regulations, preliminary performance criteria for sealing, and hydrologic calculations. The concepts are briefly described in Section 6.2.8.1 and are described in more detail in the SCP-CDR.

6.2.8.1 Shaft and ramp seal characteristics

6.2.8.1.1 Shaft seals

Four shafts and two ramps are proposed to penetrate the underground horizon at Yucca Mountain. Only the exploratory shaft is planned to extend below the repository horizon into the zeolitized tuff of the Calico Hills.

Sealing concepts for shafts, shown in Figure 6-78, can include a surface barrier, shaft fill, settlement plugs, and station plugs. Beneath the surface barrier, appropriately graded and unreactive fill, such as crushed tuff, settlement plugs, and station plugs, are proposed for the lower portion of the shaft. The surface barrier is proposed to consist of a shaft cover, a collar core, and an anchor-to-bedrock plug-seal.

The lower shaft sealing components are planned to consist of shaft fill and settlement plugs. The shaft fill can be permeable to allow water entering the shaft to drain to the bottom of the shaft where the water can infiltrate the surrounding rock below the underground horizon. Settlement plugs also can be designed to support the shaft fill and prevent the development of a surface depression, that could lead to ponding of surface water or create a safety hazard. The station plug, to be emplaced at the intersection of the shaft and the drifts within the repository horizon, can be designed to resist the lateral forces exerted by the shaft fill and, thus, control settlement of the shaft fill.

6.2.8.1.2 Ramp seals

The concepts for sealing a ramp (Figure 6-79) are similar to those for sealing a shaft (Fernandez and Freshley, 1984). The major differences in the ramp seal concepts are proposed periodic installation of dams designed to

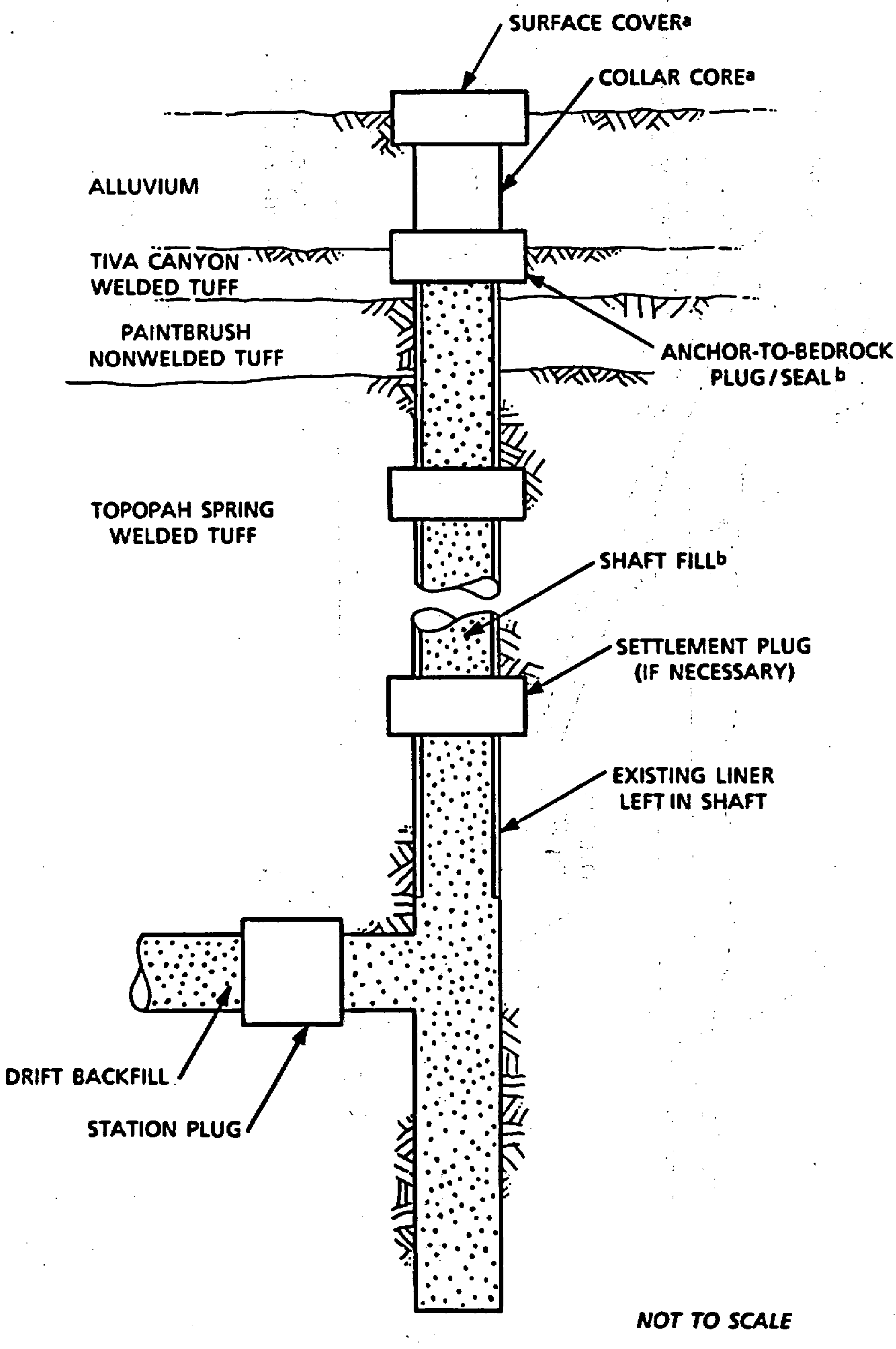


Figure 6-78. General arrangement for shaft seals.

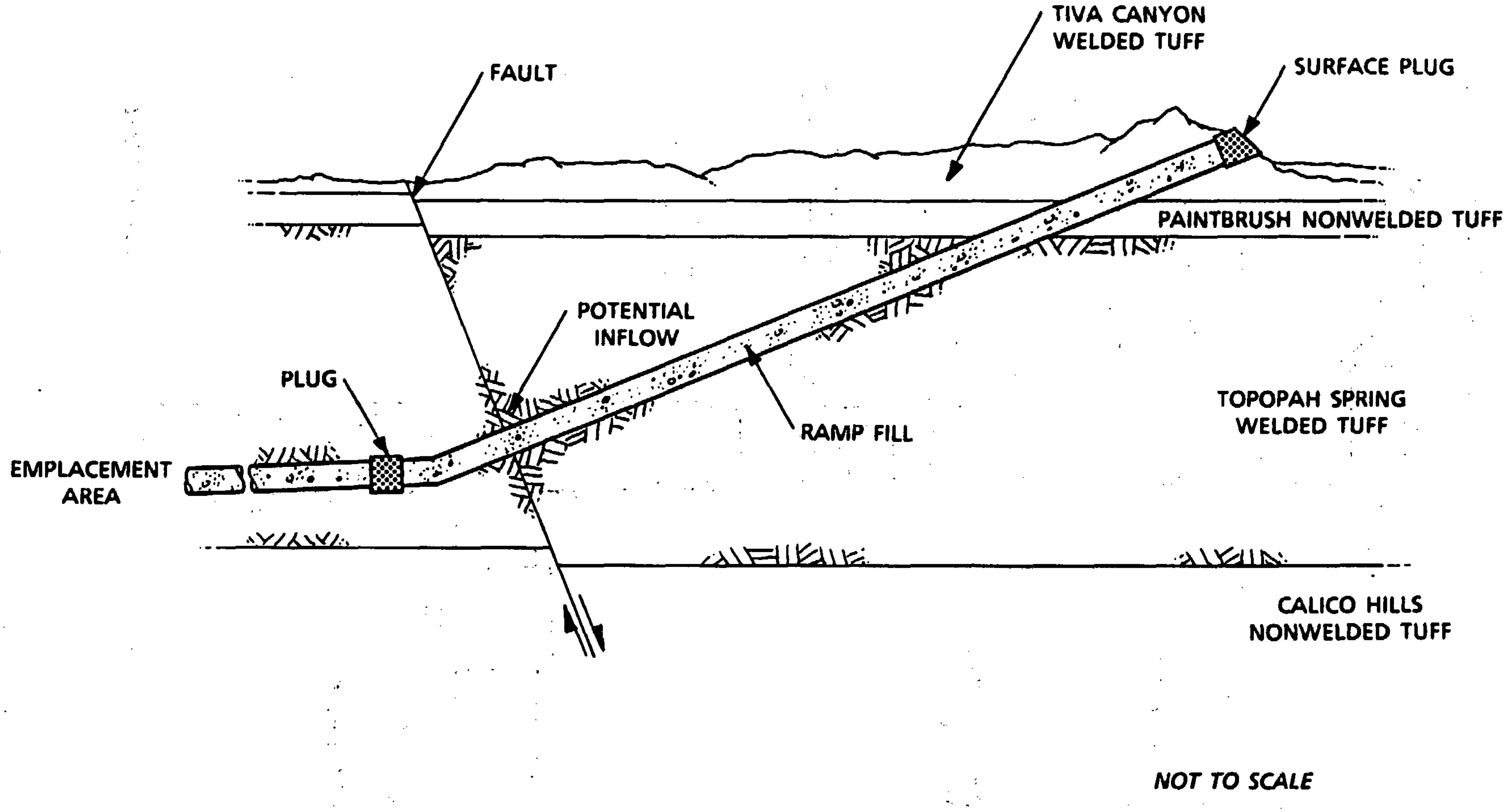


Figure 6-79. General arrangement for ramp seals.

encourage downward flow of water through the tuff rather than allowing flow down the ramp. The frequency of and necessity for dams depend on the water flow into and down the ramp. This flow is expected to be negligible. If these dams are needed, they should have a permeability that is less than the effective permeability of the undisturbed rock.

If a discrete fault or fracture zone that provides a continuous supply of water is encountered in a ramp, one of the concepts for sealing faults (Section 6.2.8.6) can be installed. If extensive concrete or grout is placed on the floor or ribs of the inclined ramp, it can be removed or perforated, partially or totally, to enhance the ramp's drainage capability. Concrete or grout at the roof of the ramp may act as a diversion shield for water and, therefore, need not be removed.

6.2.8.2 <u>Shaft and ramp seal emplacement</u>

Before emplacing the shaft fill, it may be necessary to remove all shaft outfitting steel that is anchored to the concrete liner. Steel left in the shaft could hamper backfilling operations. At the bottom of the shafts, below the repository station, the concrete liner may be removed or perforated to permit drainage through the walls of the shaft. The shaft should then be backfilled. The backfill, as determined by the preliminary calculations (Fernandez and Freshley, 1984), could be a coarse, well-graded, unreactive material (e.g., crushed tuff), to reduce settlement and to permit the drainage of water. Further analysis and testing are required to define the grading as described in Section 8.3.3.2.

Settlement may be further reduced by selecting the proper emplacement technique, installing settlement plugs, and allowing settlement to occur before abandoning the shaft. If it is necessary to control settlement and if settlement plugs are selected, it may be desirable for each plug to have a high permeability or be designed to drain water that may collect above it. This could be accomplished by placing tubes through the plug or emplacing a no-fines concrete. The strength, spacing, and placement of the plugs require knowledge of the load exerted on each plug and the competency of the rock into which it is placed. The plugs may be keyed into the shaft for additional support. This would require removal of the liner and excavation of additional rock.

The design of shaft and ramp seals is not well enough defined at this stage of design to permit discussion of construction details. Hence, the construction method and the general construction sequence for each component of the shaft seal are not addressed. If shaft or ramp seals are incorporated into the repository design, the construction details will be provided by the advanced conceptual design and license application design. Section 8.3.3.2 provides details on establishing the need for seal components.

6.2.8.3 Borehole seal characteristics

The primary purpose of borehole seals is to ensure that the boreholes do not become preferential pathways to the accessible environment. This function applies particularly to the following:

1. Any exploratory borehole within the perimeter of the underground facility that penetrates the water table.

2. Boreholes that penetrate to the water table down-dip from the emplacement horizon and inside the boundary of the accessible environment; these boreholes could provide a preferred pathway for contaminated ground water that drains vertically from the emplacement area through the rock mass and then flows down-dip along a capillary or permeability barrier to intersect the boreholes.

The existing boreholes that will be considered for sealing are discussed in Section 8.3.3. Exploratory boreholes drilled as part of site characterization will be added to this list.

The objectives of sealing boreholes are to (1) control preferential water movement through the tuffaceous beds of the Calico Hills and (2) dissipate into the densely welded, highly fractured tuff any water entering the boreholes.

For those boreholes that could potentially act as a preferential path for any radionuclide release to the accessible environment, emplacement of a seal in the zone penetrating the tuffaceous beds of Calico Hills is suggested. A schematic drawing of the borehole sealing concept is presented in Figure 6-80. Holes may be sealed by conventional cement plugging and emplacement of a granular material.

More details for borehole sealing (i.e., boreholes that require special sealing methods, seal properties, and the types of seals important to repository performance) will be established as the conceptual design progresses. These details will be provided in the advanced conceptual design and license application design.

Information necessary to describe the key features, types of seal materials, seal material properties, and properties of the rock and ground water surrounding the boreholes that are relevant to borehole seal design is not currently available. Plans to obtain this information are presented in Section 8.3.3.2.

6.2.8.4 Borehole seal emplacement

Commercially available technology will be used to install borehole sealing components. Alternative concepts consist of grouting the entire borehole, as described previously, or grouting only in the critical zones (i.e., the Calico Hills nonwelded tuff) with granular material placed in other zones (Fernandez and Freshley, 1984).

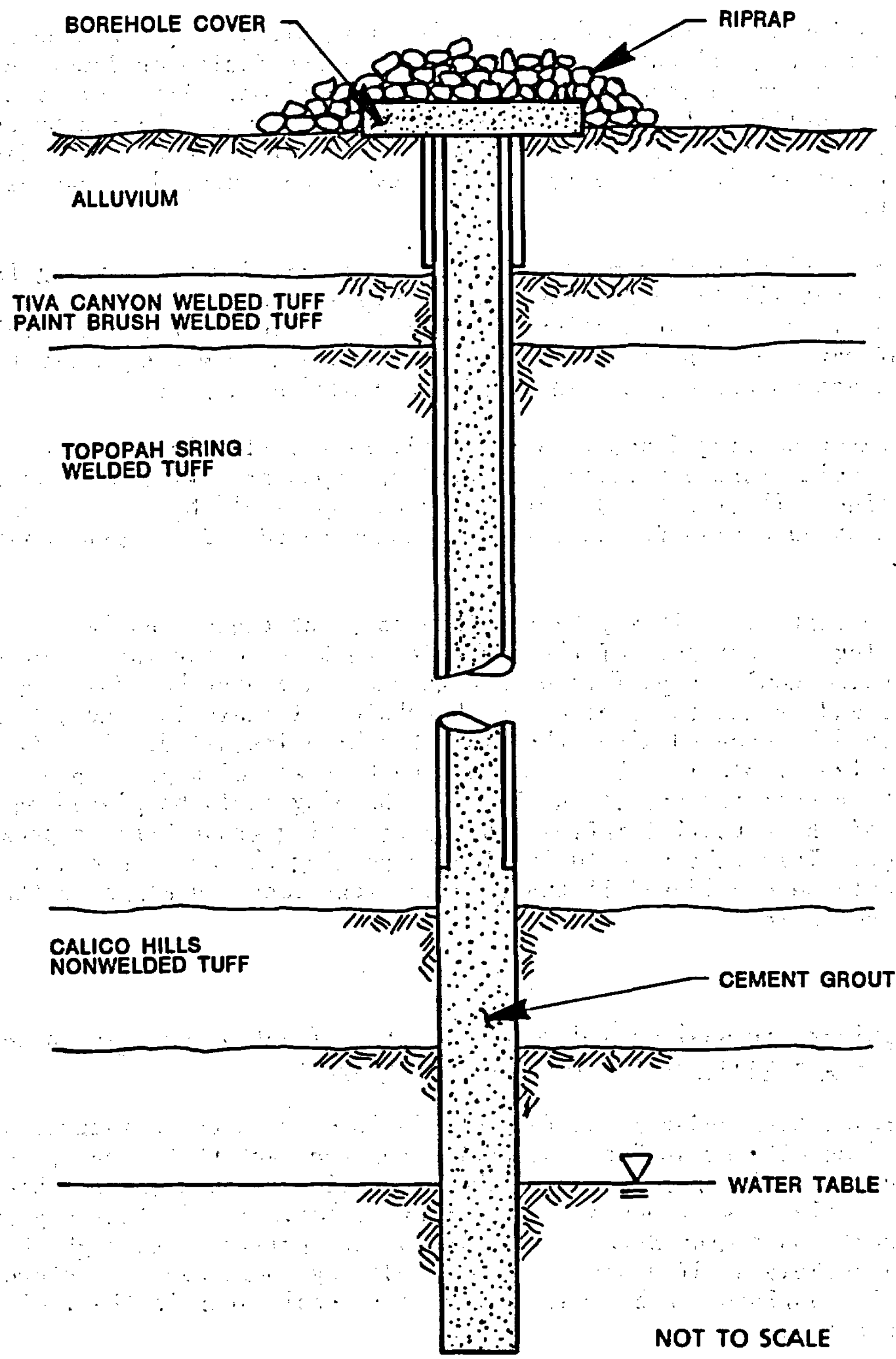


Figure 6-80. Borehole sealing concepts.

6.2.8.5 Sealing in the vicinity of waste package

Information available to date from investigations at Yucca Mountain suggests that a significant number of water-bearing faults or fractures are not likely to be encountered at the repository horizon. This information is not, however, sufficient to rule out the presence of water in fractures. Accordingly, concepts have been developed as part of the conceptual design to deal with water-bearing fractures should they be encountered in repository development.

In the vertical emplacement mode, the presence of water-bearing fractures would most likely be detected during emplacement drift development. In the horizontal emplacement configuration, information about the possible presence of water bearing fractures will be obtained as mining activities develop the access and emplacement drifts surrounding a panel.

If a water-bearing fracture with significant inflow is encountered using horizontal emplacement activities, several concepts are available for contingency planning. The first and most likely concept would be to abandon any borehole in which a significant inflow is encountered before waste emplacement.

In some instances, it may be possible to grout the permeable zone and to install a plug so that some of the borehole can be used for waste emplacement. Grouting could be performed through small-diameter boreholes drilled parallel to and around the emplacement borehole. In this instance, the borehole would be grouted after the liner had been installed. An alternative concept involves isolating the fracture zone by means of a grout plug emplaced at or near the end of the liner. The plug would be placed on the drift side of the potential inflow zone by injecting grout between packers or bridge plugs. This scheme would involve abandoning the hole beyond the plug and would only be considered if the fracture zone occurred close to the far end of the borehole.

6.2.8.6 Options for sealing a discrete fault or fracture zone in an access or emplacement drift--vertical emplacement

The prospective underground facility is located in the unsaturated zone. The semiarid conditions at Yucca Mountain, and the fact that much of the rainfall occurs in intense events of short duration, should ensure that relatively little water reaches the emplacement horizon. Preliminary information suggests that ground-water flux is low and primarily through the matrix. Nevertheless, if discrete water-producing zones are encountered several design options can be implemented to control water in the vicinity of the waste packages.

Water-producing zones in drifts can be isolated by drains or dams (Figures 6-81 and 6-82) to increase the drainage of the drift floor and to control the lateral migration of water in the drift. The drifts also can be isolated by grouting the rock above the drift (Figure 6-83) or by employing massive bulkheads to isolate large flows, if encountered.

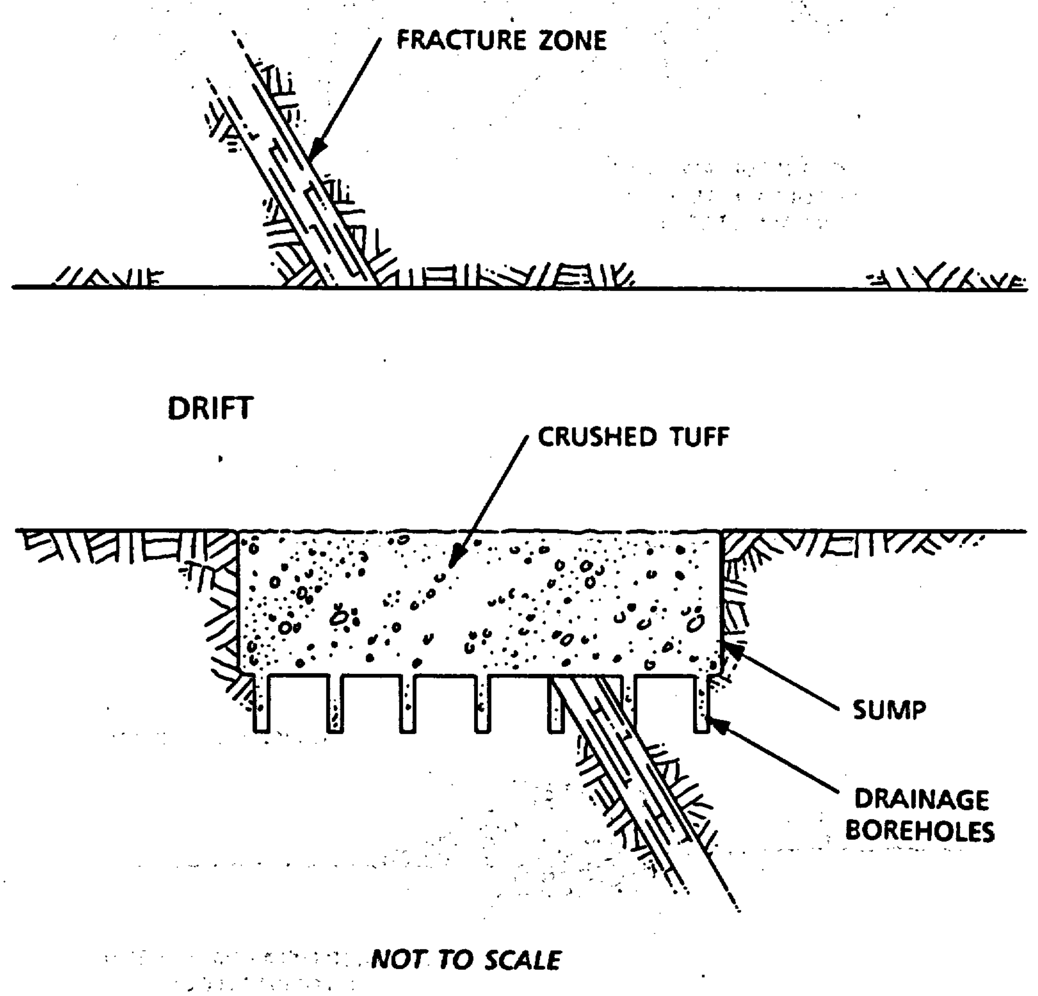


Figure 6-81. Concept for impounding and diverting water inflow using sumps and drains.

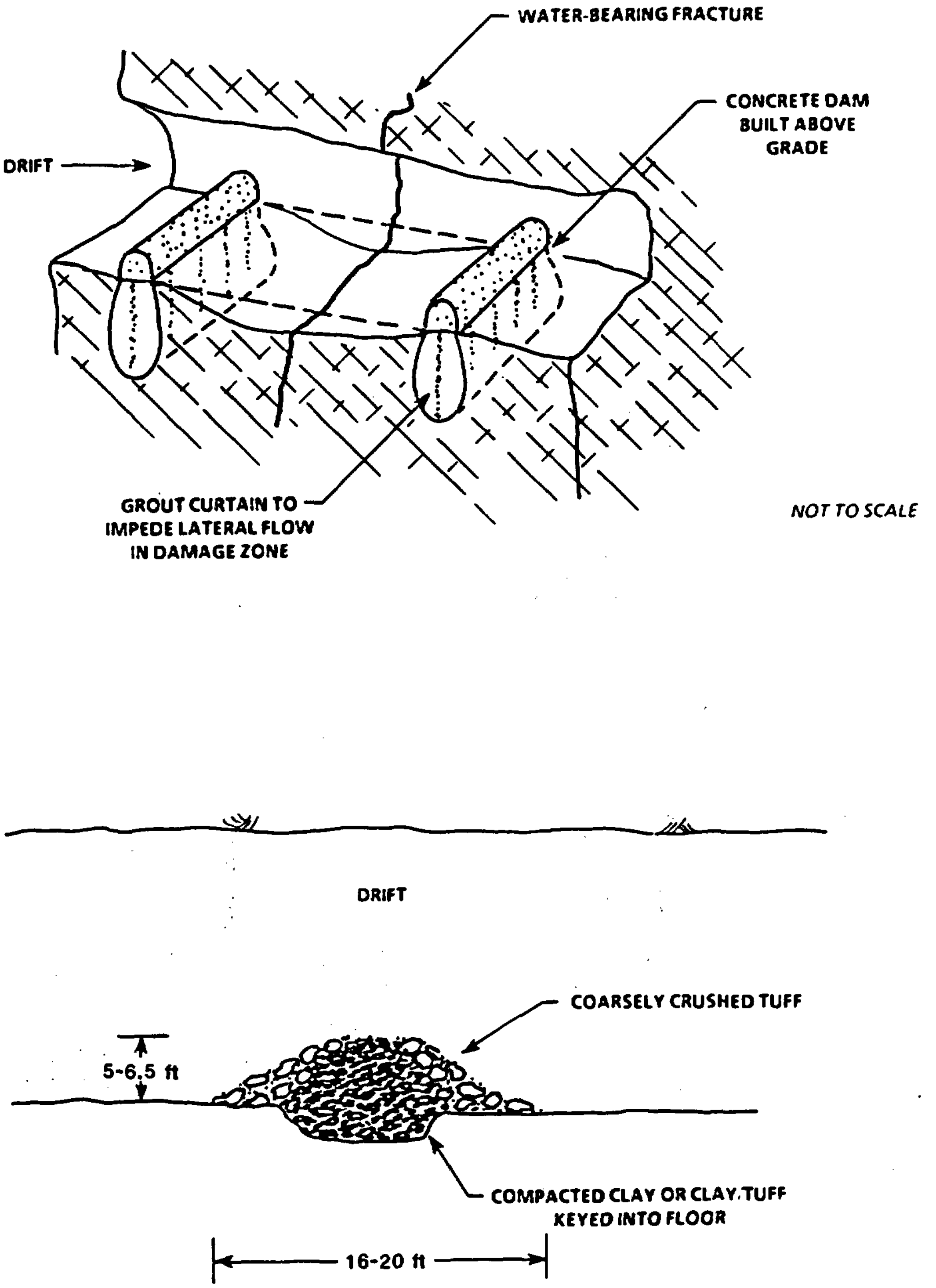


Figure 6-82. Concept for controlling water inflow with small dams.

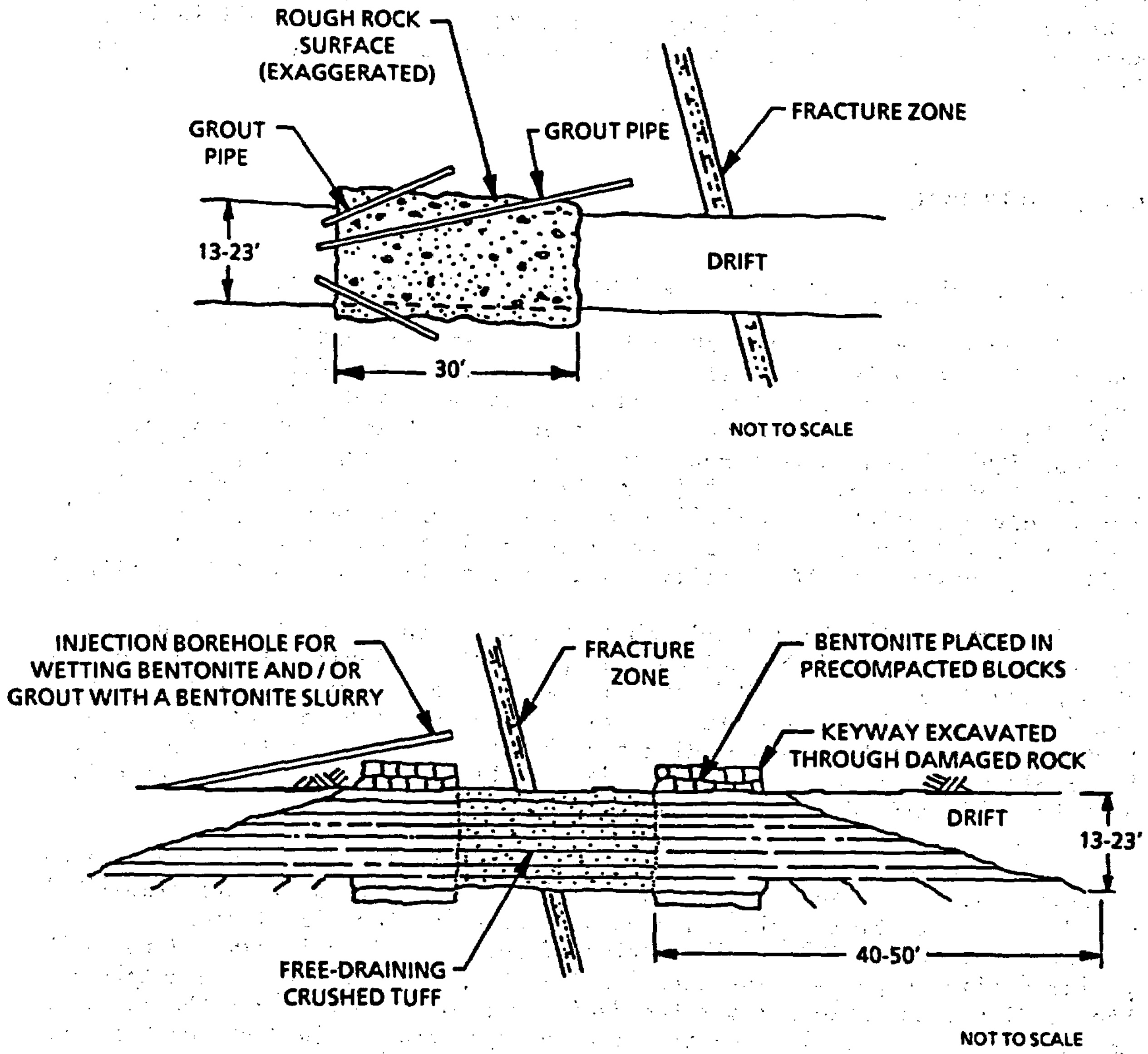


Figure 6-83. Concepts for isolating major inflows with grouting or drift bulkheads.

These options are more appropriately considered for vertically emplaced waste packages than for horizontally emplaced packages. In the latter case, the emplacement boreholes would be located at the midheight of the drift walls so that water entering from one hole could not enter other holes. The choice between the options will be determined by the expected inflow volume. Options 1 and 2 (drains and dams) are more appropriate for small inflows, whereas options 3 and 4 (grouting and bulkheads) are more appropriate for large inflows.

6.2.9 RETRIEVAL

6.2.9.1 Retrieval requirements and planning-basis time periods

The preservation of the ability to retrieve emplaced high-level radioactive waste is a federally mandated requirement. This is stated as follows: "any repository constructed on a site approved under this subtitle shall be designed and constructed to permit the retrieval of any spent nuclear fuel placed in such repository, during an appropriate period of operation of the facility ..." (NWPA, 1983, Section 122); and the geologic repository operations area shall be designed to preserve the option of waste retrieval...." for up to 50 yr after waste emplacement operations are initiated, unless the NRC specifies a different time (10 CFR Part 60.111(b)).

To comply with these retrievability requirements, the Yucca Mountain repository is designed to include the option of retrieving the emplaced waste as a planned contingency (DOE, 1986a). Inclusion of the retrieval option in the design is to be done so that it will not compromise the safety of the repository, nor will it compromise the ability of the repository to isolate the emplaced waste (Flores, 1986). Retrievability-related design criteria have been identified in Section 6.1.1.7.

The time periods used in the current conceptual design that are related to retrieval are shown in Figure 6-84. The terms "period of retrievability" and "actual retrieval period" are used to describe the time periods related to retrieval (DOE, 1986a). The period of retrievability is assumed to be 50 yr for design purposes. The actual retrieval period, the time to complete the retrieval operations after the decision is made to retrieve the waste, is assumed to be 34 yr. The construction and operating periods proposed in the Generic Requirements document (GR) (Appendix B of DOE, 1986d) are 6 yr and 28 yr, respectively.

For purposes of design the time period for which the emplaced waste must remain retrievable is the sum of the period of retrievabilty and the actual retrieval period. By combining the 50-yr period of retrievability and the 34-yr actual retrieval period, the maximum time period for design purposes from emplacement of the first waste to complete retrieval of waste is 84 yr.

In this chapter the term off-normal is used to identify conditions that are anticipated to occur infrequently. In future documents the term off-normal will be replaced with the term abnormal.

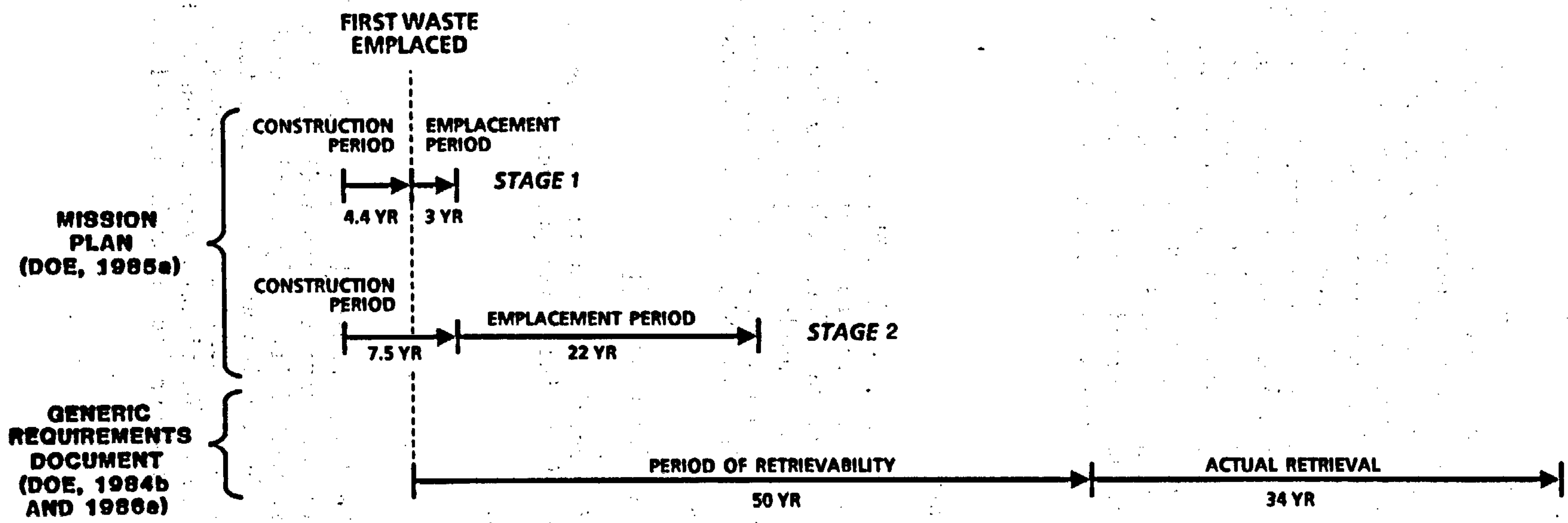


Figure 6-84. Retrieval time frame for design purposes.

6.2.9.2 Retrieval conditions

In the design work completed to date, waste retrieval conditions and, hence, operations and equipment, have been divided into two categories: normal and off-normal. Normal conditions are considered to be those conditions under which the retrieval process can be performed using standard equipment and procedures. In this discussion, standard equipment is considered to be essentially the same equipment used for waste emplacement. Minor maintenance and cleanup may be required (Flores, 1986). Off-normal conditions are considered to be those conditions under which the retrieval process must be performed using nonstandard equipment or procedures. It is important to note that the existence of an off-normal condition does not mean that the retrieval process will be particularly difficult or hazardous; in general it means that modified equipment and procedures may be used. For example, if excessive temperatures are encountered in an emplacement drift, a decision may be made to extend the cooldown period, perform the retrieval using additional thermal protection for workers, or to use a combination of these alternatives.

6.2.9.2.1 Normal retrieval conditions

The performance allocation process described in SCP Section 8.3.5.2 identifies repository system elements whose performance and, as a result, condition could affect the ability to retrieve. These elements include accesses and drifts, emplacement boreholes, ventilation system, waste-handling building, retrieval equipment, and the waste container. The normal conditions for these elements are summarized in this section; more detail is provided in Appendix J of the SCP-CDR.

Normal condition of accesses and drifts for retrieval

The normal conditions expected for retrieval operations in the accesses and drifts are characterized in terms of the following parameters:

1. Rock temperatures in the drifts.
2. Condition of the openings.
3. Radiation environment.
4. Air quality.

The normal conditions are based on the design basis that the drifts will not be backfilled until closure. Furthermore, current plans indicate that ventilation will be provided to emplacement drifts only until the emplacement process for that drift is completed. Ventilation would be reinstated for periodic inspection, maintenance, performance confirmation purposes, or retrieval until closure of the repository. Continuous ventilation of the waste emplacement ramp, access drifts, and service areas is planned until repository closure.

The surface rock temperature in the drifts is an important consideration in establishing the retrieval environment because it not only influences the ventilation requirements but also affects opening stability and retrieval equipment design. It is expected that the temperature in access drifts for vertical emplacement (emplacement drifts in horizontal) will not exceed 50°C before the end of the period of retrievability. With only brief ventilation, these drifts can be cooled to less than 40°C (the design basis temperature used for planning retrieval operations). For vertical emplacement, the emplacement drift floor temperature rises very quickly (94°C at 5 yr). The maximum temperature predicted for the floor (during the period of retrievability) is about 130°C (Section 6.4.8). Therefore, within a short period of time after waste emplacement, extensive ventilation cooling would be required to return the surface rock temperature to the environment required for retrieval.

Under normal conditions, the ramps, ventilation shafts and drifts are expected to remain stable and usable with only minor maintenance required before initiating retrieval operations. The basis for this expectation is threefold. First of all, periodic maintenance of the openings is planned throughout the period of retrievability. This implies that if areas require major maintenance, this need would have been identified and repairs made prior to the start of retrieval. Second, numerous sets of thermomechanical calculations have been performed that predict that the drifts will be stable throughout the period of retrievability (Section 6.4.8). Finally, observations and experience in the miles of drifts affected by underground testing of nuclear weapons provide indications that drifts in bedded tuffs can be maintained. It is recognized that these tuffs differ from the Topopah Spring tuff, but the experience is considered a preliminary indication of feasibility.

Under normal conditions, the radiation environment for retrieval is considered to be essentially the same as that considered for emplacement. This implies that both naturally occurring radon- and waste-related effects will be considered. The air quality requirements for retrievability operations will be the same as those for the emplacement operations.

Since the requirements for air quality are the same for retrieval and emplacement, it is expected that the actual environment (in the accesses and drifts) will be similar. Possibly the most notable exception will be related to the increased air temperature. However, precooling of the drifts before retrieval is planned so that significant differences are not likely to exist.

<u>Normal condition of emplacement boreholes for retrieval</u>

The normal conditions expected for retrieval operations in the boreholes are characterized in terms of the following:

1. Rock temperature.
2. Condition of the boreholes.
3. Condition of the borehole liner.
4. Radiation.

The predicted temperatures in the emplacement boreholes are presented in Figure 6-85. As shown in the figure, the maximum predicted temperatures for the wall in the vertical and horizontal emplacement boreholes are approximately 227 and 214°C, respectively. In addition, the temperature of the borehole wall is expected to remain above 140°C for 100 yr after waste emplacement. Additional detail is given in Appendix J of the SCP-CDR.

In the vertical emplacement concept, the boreholes are expected to be stable and the amounts of loose rock in the boreholes are expected to be negligible. Similar conditions are expected for the horizontal borehole. The status of supporting thermo/mechanical analyses is discussed in Section 6.4.10.

The liner is expected to remain intact and provide acceptable access to the emplaced waste containers throughout the design-basis, 84-yr period. Both corrosion rates and rockfall-induced loading are predicted to be small (Appendix J of SNL, 1987).

Normal condition of ventilation system for retrieval

The entire ventilation is planned to be maintained in fully operational condition throughout the caretaker period; hence the system will be available for use if retrieval operations are necessary.

Normal condition of waste-handling building for retrieval

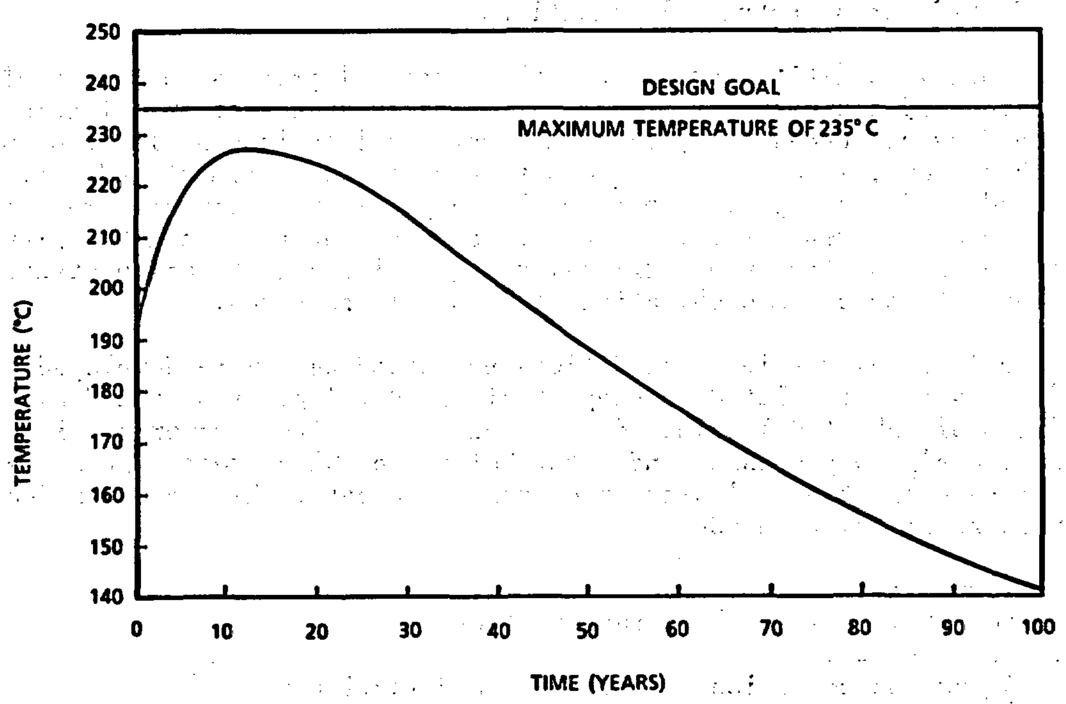
If waste emplacement operations are in progress, the waste-handling building is expected to be in operable condition. However, the current planning basis is that the building will not be constructed for reverse operations for full retrieval and, therefore, extensive modifications and additional construction would be necessary to accomplish full retrieval. In the current plan, the equipment located in the waste-handling building will not be maintained in an operational state during the caretaker period. It is planned that maintenance and repair will have been performed to maintain the structure during this period.

Normal condition of equipment for retrieval

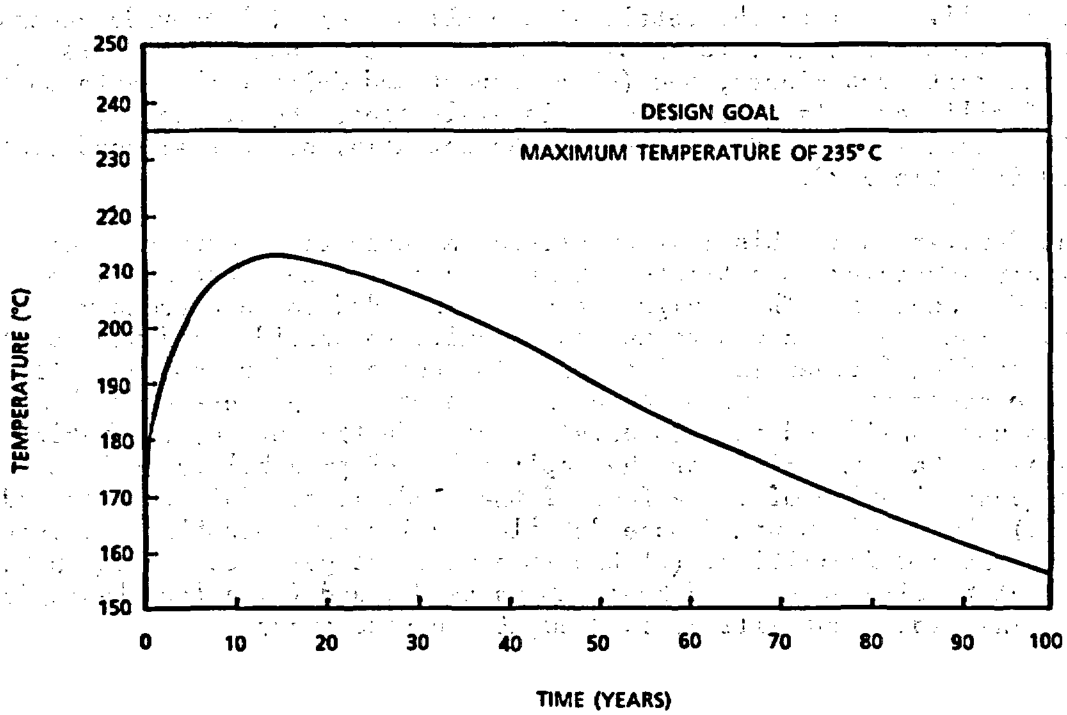
If waste emplacement operations are in progress, the equipment required for waste removal under normal conditions will be in operational condition because the current design basis includes using the same equipment (transporter, auxiliary equipment, and shield collar) for both emplacement and retrieval operations. During the caretaker phase, two sets of equipment are planned to remain operational and two other sets would require maintenance and possibly repair before starting to retrieve waste.

Normal condition of waste container for retrieval

Under normal conditions, the waste container is expected to remain intact up to and during the retrieval process. This expectation is based on the low corrosion rate and the low loading expected on the container.



BOREHOLE WALL TEMPERATURE – VERTICAL EMPLACEMENT



BOREHOLE WALL TEMPERATURE – HORIZONTAL EMPLACEMENT

Figure 6-85. Predicted temperatures for emplacement boreholes.

6.2.9.2.2 Off-normal retrieval conditions

Off-normal conditions exist when the retrieval process must be performed with nonstandard equipment or procedures. The existence of an off-normal condition does not necessarily mean that retrieval is impossible or particularly hazardous; in general it means that modified equipment and procedures may be used. For example, if higher than expected temperatures are encountered in an emplacement drift, a decision may be made to extend the planned cooldown period, perform the retrieval using additional thermal protection for workers, or to use a combination of these alternatives.

The off-normal retrieval conditions presented here were developed as part of evaluation completed in support of the development of the SCP-CDR (Appendix L of SNL, 1987). This development began with a comprehensive list of approximately 75 processes and events of potential concern. From the initial screening, the following processes and events, which could affect the ability to retrieve, were identified:

1. Tectonics.
2. Variability in rock characteristics.
3. Human error.
4. Aging and corrosion of equipment and facilities.
5. Radiolysis.

With the use of engineering judgment, these events and processes were evaluated relative to the SCP-CD. The four functions that must be performed to successfully complete the retrieval operation are: (1) provide access to the emplacement boreholes, (2) provide access to the waste containers, (3) remove the waste containers, and (4) transport and deliver the waste to the surface facilities. As a result of this evaluation, the off-normal conditions were identified. A list of the potential off-normal conditions is provided in Table 6-28.

The derivation of this list of off-normal conditions consisted of a preliminary screening to estimate the frequency of occurrence of various events and processes. The analysis was not intended to be extremely detailed. The intention was to use the results to provide guidance relative to areas needing further investigation. The potential for combined effects (i.e., the occurrence of two or more of the events or processes at the same time) was not considered in this development. In the future, the table will be used as a starting point for the application of probability evaluations and for quantification of the effect of the conditions. This is intended to aid in (1) the development of more detailed design and operational criteria for equipment and facilities, (2) the more accurate guidance for equipment development requirements and demonstration needs, and (3) a firm basis for deciding what equipment will be on hand at the repository.

Table 6-28. Potential off-normal conditons for retrieval (page 1 of 4)

Cause of condition	Component	Postulated result
Tectonics--seismic (0.45 to 0.60 g event)	Ramp	Localized rockfall within ramp
	Ventilation system	Malfunction of ventilation system surface damage of ventilation equipment
	Transmission line	Loss of offsite power
	Waste container--vertical orientation	Rockfall around waste container in vertical emplacement borehole
	Waste container--horizontal orientation	Lateral movement of waste container on the order of a few centimeters
	Waste container--vertical orientation	Movement (tilt) of waste container within borehole
	Shield plug	Jamming of shield plug resulting from borehole distortion
	Transporter cask and emplacement collar	Binding of transporter cask and emplacement collar during removal operation
Tectonics--faulting	Ramp	Localized rockfall within ramp
	Drift	Localized rockfall within drift
	Borehole and liner-horizontal orientation	Excessive liner deflection. Shearing of borehole and liner (although the probability of occurence for a shear of the borehole and liner is extremely low, it is included because of the potential consequences

Table 6-28. Potential off-normal conditons for retrieval (page 2 of 4)

Cause of condition	Component	Postulated result
Variability of rock (area of reduced mechanical strength characteristics)	Ramp	Localized rockfall within ramp
	Drift	Localized rockfall within drift
	Borehole--vertical orientation	Rockfall in borehole around vertically emplaced waste container as a result of reduced mechanical strength
Human error during fabrication	Heating, ventilating, and air conditioning (HVAC) system	Failure of ventilation system
	Liner	Excessive deflection of liner
	Collar	Malfunction of collar
	Auxiliary equipment	Malfunction of auxiliary equipment
	Shield plug	Jamming of shield plug
	Dolly - horizontal orientation only	Failure of dolly
Human error during maintenance	Ramp	Rockfall within ramp
	Drift	Rockfall within drift
	HVAC system	Malfunction of HVAC system
	Collar and collar attachment	Malfunction of collar or collar attachment
	Transporter (removal)	Malfunction of transporter during waste removal

Table 6-28. Potential off-normal conditons for retrieval (page 3 of 4)

Cause of condition	Component	Postulated result
Human error during maintenance (continued)	Transporter (transport)	Malfunction of transporter during waste transport
	Transporter (unloading)	Malfunction of transporter during waste unloading
	Surface facility interface	Malfunction of surface facility interface during unloading of waste
Human error during operation	Transporter	Collison of transporter with ramp while transporter is moving up or down the ramp
	Transporter	Collision of transporter with auxiliary equipment
	Transporter	Collision of transporter with another transporter
	Transporter cask-borehole collar	Alignment error between transporter cask and borehole collar
	Waste container	Excessive thermal loading of waste container resulting from incorrect determination of thermal output of waste container
	Waste container	Incorrect emplacement of waste container in borehole

Table 6-28. Potential off-normal conditons for retrieval (page 4 of 4)

Cause of condition	Component	Postulated result
Human error during operation (continued)	Waste container	Alignment error during removal of waste container
	Transporter cask-surface facility loading port	Alignment error during alignment of transporter cask and surface facility loading port
	Waste container	Unloading error at surface faciilty
Agining or corrosion of equipment of facilities	Rockbolt	Failure of rockbolt resulting from corrosion
	Dolly (horizontal emplacement)	Failure of waste container dolly resulting from corrosion
Radiolysis	Liner	Corrosion rates of liner above expected levels
	Dolly (horizontal orientation only)	Corrosion rates of dolly above expected levels
	Waste container	Corrosion rates of waste container above expected levels

6.2.9.3 Equipment development

In early design stages, the feasibility of developing the equipment necessary to perform the retrieval operations is an important consideration in evaluating the ability to perform the operations. As more detailed designs are developed, proof-of-principle testing can be planned for completion before license application. At present, design concepts exist for the retrieval equipment being considered for both the vertical and horizontal emplacement options. Operations under both normal and off-normal conditions have been considered in these concepts.

The design discussions presented in this chapter focus on the design aspects that are most related to the site. Therefore, the development to date regarding retrieval-related equipment proposed for use in a repository will be only briefly summarized here. Substantially more detail is provided in Sections 3.2, 4.5, 6.3, and related appendices of the SCP-CDR.

Lists and estimated quantities of equipment needed to perform the retrieval operations for both emplacement operations (under normal and off-normal conditions) are provided in Section 3.2 of the SCP-CDR. Additional information is provided to indicate whether the equipment is either currently available or may require some development for its intended use in the NNWSI Project. Both baseline and alternative concepts are described and operations are identified that will enhance maintaining the ability to retrieve the waste. Operations that could be carried out to facilitate retrieval under off-normal conditions are described considering both access to the emplacement boreholes and waste removal from the holes. Conditions affecting access or removal are identified and then procedures for overcoming the conditions are described.

The equipment intended for use in the operations are described in Section 4.5 of the SCP-CDR for both emplacement options. These descriptions reflect conceptual designs for the equipment planned for use under normal conditions and design concepts being considered for selected off-normal conditions. It is important to note that many of the operational features of equipment planned for use in handling of the waste have been demonstrated at the Climax facility on the Nevada Test Site (Patrick, 1985) for the vertical emplacement option. Some aspects of the equipment planned for use in the vertical emplacement option will need to be developed further and may require some demonstration. For the horizontal emplacement option, essentially no field demonstrations have been completed. A one-twelfth scale model has been developed (White et al., 1986) as part of ongoing evaluations of the feasibility of horizontal emplacement and retrieval. If the horizontal emplacement option is selected for use in the proposed repository, more equipment development and demonstration would be required than would be necessary for the vertical option.

6.3 ASSESSMENT OF DESIGN INFORMATION NEEDS

6.3.1 INTRODUCTION

To ensure the completeness of the site characterization program for the Yucca Mountain mined geologic disposal system (MGDS), the DOE has chosen to develop this program around an issues hierarchy. The bases for this issues hierarchy are the four key issues identified in the DOE Mission Plan (DOE, 1985a). Each of the four key issues is divided into two components: (1) system performance issues, and (2) facility design issues. Summaries of the strategies for resolving each of these issues are presented in Section 8.2. The complete issue resolution strategy (IRS) for each issue that requires site characterization information is presented in Section 8.3.

The purpose of Section 6.3 is to provide a bridge between the topics identified in Chapter 6 of the NRC Regulatory Guide 4.17 (NRC, 1987) and the issues that address these topics. In each instance where a NRC Regulatory Guide 4.17 topic is identified, the subsection headings of 4.17 are used as the subsection headings for this section. In addition the following information is provided:

1. Identification of the subsection of Section 8.3 that (a) identifies the concern in the context of the resolution of the associated issue and (b) presents the data requirements, including the current and needed confidence.

2. Identification of the subsection of Section 6.4 that (a) summarizes the analytical work completed, and (b) presents plans for future analytical work.

This method of presentation was selected to provide a perspective for the treatment of the individual NRC Regulatory Guide 4.17 (NRC, 1987) topics within the context of the DOE issue resolution strategies.

6.3.2 DESIGN OF UNDERGROUND OPENINGS

6.3.2.1 <u>Exploratory shaft facility</u>

The exploratory shaft facility (ESF) will be located near the eastern edge of the MGDS underground facilities as shown in Figures 6-13 and 6-14 (Section 6.2.2). The ESF will consist of a surface facility that provides office, shop, and warehouse space; a 4-m- (12-ft-) diameter shaft; a 2-m- (6-ft-) diameter shaft; and the underground drift complex. Further discussion of the ESF is provided in Section 8.4 of this document. The general arrangement of the shafts is shown in Figure 6-57 (Section 6.2.5).

The relationships of the ESF to the MGDS underground facilities, shafts, and ramps are shown in Figure 6-56 (Section 6.2.5). The known or inferred geologic and hydrologic conditions at the site, as determined from preliminary site investigations, are discussed in Chapters 1, 2, and 3. The associated design parameters are summarized in Section 6.1.2 (reference design data base). For design purposes, the geologic and hydrologic properties at the ESF location are expected to be representative of those obtained during preliminary site investigations.

6.3.2.2 Layout of the mined geologic disposal system underground facilities

The proposed layouts of the underground facilities for both the vertical and horizontal configurations are discussed in Section 6.2.6 (subsurface design), and are shown in Figures 6-59 through 6-64 in Section 6.2.6.

The design criteria for the MGDS underground facilities have been developed under the relevant performance and design issues. The following list provides the section in Chapter 8 where the issue resolution strategy and data requirements for each issue are discussed and the section in Chapter 6 where the completed work, future work, and the data needs are presented:

Issue	Subject	Chapter 8 section	Chapter 6 section
1.11	Configuration of underground facilities (postclosure)	8.3.2.2	6.4.2
2.1	Public radiological exposures --normal conditions	8.3.5.3	6.4.4
2.2	Worker radiological safety --normal conditions	8.3.5.4	6.4.5
2.3	Accidental radiological releases	8.3.5.5	6.4.6
2.4	Waste retrievability	8.3.5.2	6.4.8
2.7	Repository design criteria for radiological safety	8.3.2.3	6.4.7
4.2	Nonradiological health and safety	8.3.2.4	6.4.9

The initial layouts for the underground facility were developed based on the additional design criteria for the underground facility--10 CFR 60.133a (1) and (2), and on the criteria for thermal loads--10 CFR 60.133(i). The following factors control these initial layouts:

1. Waste quantities.
2. Waste container thermal output.
3. Maximum waste container temperature.

4. Near-field thermal and mechanical constraints.
5. Far-field thermal and mechanical constraints.
6. Separation of waste emplacement and mine development areas.

6.3.2.3 Shafts, ramps, drifts, and waste emplacement boreholes

The design concepts for the shafts and ramps are presented in Section 6.2.5 (shaft and ramp design). The general arrangements of the shafts and ramps are shown in Figures 6-56 through 6-60 of Section 6.2.5. The data for the shafts and ramps are summarized in Table 6-19 (Section 6.2.5).

The design concepts for the drifts and waste emplacement boreholes, both vertical and horizontal, are presented in Section 6.2.6 (subsurface design). Typical waste emplacement drift and ramp cross-sections for the vertical waste emplacement configuration are shown in Figure 6-60. Similarly, typical waste emplacement drift and ramp cross-sections for the horizontal waste emplacement configuration are shown in Figure 6-61. Typical emplacement drift cross-sections with alternative ground support systems are shown in Figure 6-70. The mining methods for the drifts are summarized in Table 6-23. The underground development equipment is shown in Figures 6-71 and 6-72. All these figures and Table 6-23 are in Section 6.2.6.

The following basic criteria govern the design of the underground openings:

1. Equipment clearances.

2. Utility clearances.

3. Ventilation flows that were used to establish the minimum requirements for the cross-sectional area of the shafts, ramps, and drifts.

4. Opening stability.

5. Maximum duration required for access to the underground.

6. Drainage and material property constraints.

The discussion of completed and future work, and the identification of data needs is presented in Section 6.4.10 for Issue 4.4--(preclosure design and technical feasibility). The discussion of data requirements is in Section 8.3.2.5.

6.3.2.4 Worker safety

The following table provides the section in Chapter 8 where the data needs for each worker safety issue are discussed and the section in Chapter 6 where the completed and future work and the data needs are presented.

Issue	Subject	Chapter 8 section	Chapter 6 section
2.2	Worker radiological safety --normal conditions	8.3.5.4	6.4.5
2.3	Accidental radiological releases	8.3.5.5	6.4.6
4.2	Nonradiological health and safety	8.3.2.4	6.4.9

Section 6.2.3.3 (accident analysis) identifies the design approach currently employed.

Air quality is the principal industrial health and safety concern for underground facilities. The function of the underground ventilation systems is to provide quality air to workers in the underground facilities. There are two separate ventilation systems, one for the waste emplacement area and one for the underground development area. These systems are described in Section 6.2.6.5 (ventilation).

6.3.3 BACKFILL

The backfilling of the MGDS drifts is discussed in Section 6.2.7 (backfill of underground openings). This discussion supports the DOE program position regarding backfill at the Yucca Mountain site as follows:

1. The option to backfill the repository drifts will be maintained throughout the retrievability period.

2. The reference case for planning the closure and decommissioning operations, cost, and schedule includes backfill.

Current planning calls for backfilling of the shafts and ramps during the closure and decommissioning of the mined geologic disposal system facilities. The discussion of backfilling shafts and ramps is included in Section 6.3.5 (seals).

Backfilling is being addressed under the issues in the following table. The table also gives the section in Chapter 8 where the data needs for each issue are discussed and the section in Chapter 6 where the completed and future work and the data needs are presented.

Issue	Subject	Chapter 8 section	Chapter 6 section
1.12	Seal characteristics	8.3.3.2	6.4.3
4.4	Preclosure design and technical feasibility	8.3.2.5	6.4.10

6.3.4 STRENGTH OF ROCK MASS

The test requirements necessary to supplement or confirm the preliminary design values used for the thermal and mechanical properties of rock are described in Section 8.3.1.4 (rock characteristics) and Section 8.3.1.15 (thermal and mechanical rock properties). The rock mass information presented in Section 6.1.2 (reference design data base) has been used in the development of the MGDS conceptual design. The site characterization information, which will be obtained during site characterization activities, will be recorded in the NNWSI Project Reference Information Base (RIB) as it is revised periodically (Appendix Q of SNL, 1987). The RIB is a controlled information base that will be used as a data source by the designers of the MGDS facilities during license application design activities.

The information needed to validate the analytical methods used to predict preclosure and postclosure MGDS performance relative to the relationship between intact rock properties and rock mass properties is identified in Issue 1.11 (configuration of the underground facilities) and Issue 4.4 (preclosure design and technical feasibility). The experiments that will be conducted in the exploratory shaft facility to obtain information relative to the relationship between intact rock properties and rock mass properties are identified in Section 8.3.1.4 and Section 8.3.1.15. In particular, discussions include data needs and experiments that address the following: (1) elastic and inelastic behavior of rock mass, (2) thermomechanical behavior of rock mass, and (3) mechanical behavior of rock discontinuities. The effects of radiation on thermal and mechanical rock properties have been identified as needed information in Issue 4.4.

The issues covering strength of rock mass and the corresponding Chapters 8 and 6 sections are summarized in the following table.

Issue	Subject	Chapter 8 section	Chapter 6 section
1.11	Configuration of underground facilities (postclosure)	8.3.2.2	6.4.2
4.4	Preclosure design and technical feasibility	8.3.2.5	6.4.10
	Rock characteristics (postclosure)	8.3.1.4	6.1.2

Issue	Subject	Chapter 8 section	Chapter 6 section
	Thermal and mechanical rock properties	8.3.1.15	6.1.2

The reader is directed to the discussions of future work and the identification of data needs in Section 6.4.2 for Issue 1.11 and in Section 6.4.10 for Issue 4.4. The experiments that will be conducted to obtain this information are identified in Section 8.3.1.4 and Section 8.3.1.15.

6.3.5 SEALING OF SHAFTS, EXPLORATORY BOREHOLES, AND UNDERGROUND OPENINGS

The conceptual design for sealing of shafts, ramps, exploratory boreholes, discrete faults, and fracture zones are discussed in Section 6.2.8 and are addressed under Issue 1.12 (seal characteristics). Design concepts reflect the fact that the underground facilities are located above the static water table (Figures 6-78 through 6-80 in Section 6.2.8).

The discussion of the completed and future work, and the identification of data needs is provided in Section 6.4.3 for Issue 1.12, and the discussion of data requirements is in Section 8.3.3.2.

6.3.6 CONSTRUCTION

The construction sequence and excavation methods are described in Section 6.2.6.1 (excavation, development, and ground support), and the construction of the facility is addressed under Issue 4.4 (preclosure design and technical feasibility).

The exploratory shaft facility (ESF) will be incorporated into the underground facilities and will become an integral part of the underground facility during the first phase of underground facility construction. Thus, the ESF facilities, the 4-m (12-ft) shaft, the 2-m (6-ft) shaft, and those drifts that directly tie the shafts to the underground facilities will be considered as part of the facilities. The following actions are planned:

1. Impose a quality assurance program on the design and construction of the ESF compatible with licensing requirements.

2. Impose a quality assurance program, compatible with licensing requirements, on all construction and maintenance activities conducted in the ESF before incorporation into the facilities.

3. If required at the time of license application, incorporate plans in the final procurement and construction design (FPCD) to rework the ESF design to meet licensing needs.

These actions will be taken to ensure that site integrity is maintained during the initial period when the ESF is incorporated into the MGDS underground facilities.

The construction methods being considered for development of the underground facilities are identified and discussed in Section 6.2.6.1.2 (mining methods). Preliminary site investigations indicate that site conditions are favorable for underground development and that drill-and-blast mining techniques can be used. No known or inferred site conditions that would require specialized construction techniques have been identified. However, tunnel boring machines are planned to be used to construct the waste ramp, the tuff ramp, the waste main, and the perimeter drifts to minimize the damage zone associated with the development.

Ground support methods are discussed in Section 6.2.6.1.4. Only conventional ground support methods are planned. Reinforced concrete liners are planned to be used in the shafts, and friction-type bolts, grouted dowels, and wire mesh are the principal support components in the balance of the underground facilities.

The control, collection, and disposal of ground water are discussed in Section 6.2.6.4 (ground-water control). The facilities are proposed to be located in the unsaturated zone above the static water table. The preliminary site investigation has not identified any perched water within the horizon selected for the underground facilities. Therefore, control, collection, and disposal of ground water are not expected to pose any significant problems at the Yucca Mountain site.

The construction plans for the facilities will be reevaluated after information is available from the ESF and after the advanced conceptual design, the license application design, and the FPCD are completed.

The reader is directed to the discussion of completed and future work, and the identification of data needs in Section 6.4.10 for Issue 4.4 (preclosure design and technical feasibility) and to the discussion of data requirements in Section 8.3.2.5.

6.3.7 DESIGN OF SURFACE FACILITIES

The design of surface facilities is described in Section 6.2.4 (design of surface facilities) and under Issue 4.4 (preclosure design and technical feasibility). The discussion presented in this document is limited to general information and directed toward those design features requiring information that will be obtained during the site characterization activities. A more detailed description of the surface facilities is contained in the SCP-CDR.

The site characterization activities for surface facility design are principally directed toward obtaining parameters that relate to the following:

1. Surface materials and soil characterization.

2. Surface flooding potential.
3. Surface topography.
4. Sources of water.
5. Seismic design parameters.
6. Characteristics of mined tuff.

The reader is directed to the discussion of completed and future work, and the identification of data needs in Section 6.4.10 for Issue 4.4 and to the discussion of data requirements in Section 8.3.2.5.

6.3.8 MINED GEOLOGIC DISPOSAL SYSTEM COMPONENT PERFORMANCE REQUIREMENTS

Wherever possible preliminary numerical values for the performance goals have been established and these values are stated in Section 8.3. In some instances (e.g., the use of reasonably available technology), numerical goals have not been and cannot be established. The reader is reminded that early assignment of numerical goals for systems and components cannot be accomplished with a high degree of accuracy and that revisions of these numerical values will occur as the design of the mined geologic disposal system (MGDS) matures.

The reader is directed to the discussion of the performance goals contained in Section 8.3 and in particular to the following sections:

SCP section	Subject	Issue
8.3.2.2	Configuration of underground facilities (postclosure)	Issue 1.11
8.3.2.3	Repository design criteria for radiological safety	Issue 2.7
8.3.2.4	Nonradiological health and safety	Issue 4.2
8.3.2.5	Preclosure design and technical feasibility	Issue 4.4
8.3.3.2	Seal characteristics	Issue 1.12
8.3.5.2	Waste retrievability	Issue 2.4
8.3.5.3	Public radiological exposures --normal conditions	Issue 2.1
8.3.5.4	Worker radiological safety --normal conditions	Issue 2.2
8.3.5.5	Accidental radiological releases	Issue 2.3

6.4 SUMMARY OF DESIGN ISSUES AND DATA NEEDS

6.4.1 PURPOSE AND ORGANIZATION

The purpose of Section 6.4 is to (1) describe the current status of the studies and analyses that have been completed as part of the facility design activities and (2) summarize the future studies and analyses necessary to complete the design activities and the additional site data needed to support these studies and analyses. The organization of Section 6.4 is based on the design-related issues that are part of the NNWSI Project issues hierarchy.

The NNWSI Project issues hierarchy is described in detail in Section 8.2 of this document and summarized by shortened titles in Figure 6-86. Briefly, the highest level of the hierarchy consists of four key issues, which were first defined in the DOE Mission Plan (DOE, 1985a). Issues form the second level of the hierarchy and are grouped as performance assessment and design issues under each key issue. Regulatory and functional requirements imposed on the MGDS are embodied in the issues.

The third level consists of information needs. Information needs are convenient groupings of activities and data needs appropriate to the resolution of an issue. Examples include such activities as determining detailed characteristics of the site, designing the engineered subsystems and components, analyzing performance of the natural and engineered subsystems and components, as necessary for the resolution of each issue.

Section 8.1 describes the generic strategy for resolving design and performance issues. Briefly, the issue resolution strategy for design and performance issues uses the following five-step procedure:

1. Identify the system elements of the Yucca Mountain MGDS that participate in meeting the regulatory (performance) requirements addressed by the issue. Performance allocation will be applied to these system elements and to the functions and processes applicable to these system elements, as identified in the following steps. The hierarchy of system elements for the Yucca Mountain MGDS is given in Section 8.2.1.

2. For each system element, identify the function(s) that the element must perform for the MGDS to meet the specified requirement(s). Note that in several design issues, it was found to be more convenient to define the functions in step 1, and then identify the numerous system elements that participate in performing each function. In those issues where this alternative approach is taken, the reader is appropriately alerted.

3. For each function, the processes used to perform the function are identified.

4. For each process, performance measures are defined. A performance measure is an indicator that will be used to evaluate the performance of a process.

KEY ISSUE 1 POSTCLOSURE PERFORMANCE

PERFORMANCE ISSUES
- 1.1 TOTAL SYSTEM PERFORMANCE
- 1.2 INDIVIDUAL PROTECTION
- 1.3 PROTECTION OF GROUND WATER
- 1.4 CONTAINMENT BY WASTE PACKAGE
- 1.5 ENGINEERED BARRIER SYSTEM RELEASE RATES
- 1.6 GROUND-WATER TRAVEL TIME
- 1.7 PERFORMANCE CONFIRMATION
- 1.8 NRC SITING CRITERIA
- 1.9 HIGHER LEVEL FINDINGS - POSTCLOSURE

DESIGN ISSUES
- 1.10 WASTE PACKAGE CHARACTERISTICS (POSTCLOSURE)
- 1.11 CONFIGURATION OF UNDERGROUND FACILITIES (POSTCLOSURE)
- 1.12 SEAL CHARACTERISTICS

KEY ISSUE 2 PRECLOSURE RADIOLOGICAL SAFETY

PERFORMANCE ISSUES
- 2.1 PUBLIC RADIOLOGICAL EXPOSURES -- NORMAL CONDITIONS
- 2.2 WORKER RADIOLOGICAL SAFETY -- NORMAL CONDITIONS
- 2.3 ACCIDENTAL RADIOLOGICAL RELEASES
- 2.4 WASTE RETRIEVABILITY
- 2.5 HIGHER LEVEL FINDINGS -- PRECLOSURE RADIOLOGICAL SAFETY

DESIGN ISSUES
- 2.6 WASTE PACKAGE CHARACTERISTICS (PRECLOSURE)
- 2.7 REPOSITORY DESIGN CRITERIA FOR RADIOLOGICAL SAFETY

KEY ISSUE 3 HEALTH, SAFETY, ENVIRONMENT, SOCIOECONOMIC, TRANSPORTATION

KEY ISSUE 4 PRECLOSURE PERFORMANCE

PERFORMANCE ISSUE
- 4.1 HIGHER LEVEL FINDINGS - EASE AND COST OF CONSTRUCTION

DESIGN ISSUES
- 4.2 NONRADIOLOGICAL HEALTH AND SAFETY
- 4.3 WASTE PACKAGE PRODUCTION TECHNOLOGIES
- 4.4 PRECLOSURE DESIGN AND TECHNICAL FEASIBILITY
- 4.5 REPOSITORY SYSTEM COST EFFECTIVENESS

Figure 6-86. Nevada Nuclear Waste Storage Investigations (NNWSI) Project issues hierarchy.

5. For each performance measure, performance goals and associated current and needed confidence levels are assigned. Performance goals reflect the regulatory or functional requirements as allocated to the system elements, functions, and processes. The confidence is either a numerical level or nonnumerical level, such as high, medium, or low, that indicates the importance (from an issue resolution standpoint) of an individual performance measure meeting its assigned goal.

Using this generic approach, Sections 8.3.2 through 8.3.5 describe the specific strategies and plans for resolving each issue requiring information about site characteristics. The details of the above five-step process are described at the issue level for each design and performance issue in Section 8.3. The discussions of the information needs for each issue describe how each information need is related to the processes or functions of that issue and how the activities undertaken to satisfy the information need contribute to the resolution of the issue.

Several of the issues found in Section 8.3.2, Repository program, 8.3.3 Seals Program, and Section 8.3.5, Performance assessment program, are directly related to the design of the surface and subsurface MGDS facilities, the subject of Chapter 6. While Section 8.3 gives the specific plans for resolving each of these issues, Sections 6.4.2 through 6.4.11 give the status of work already completed relative to these issues. This relationship is shown in the following table.

SCP section 6.4	Issue number	Short title of the issue	Related 8.3 section
6.4.2	1.11	Configuration of underground facilities (postclosure)	8.3.2.2
6.4.3	1.12	Seal characteristics	8.3.3.2
6.4.4	2.1	Public radiological exposures --normal conditions	8.3.5.3
6.4.5	2.2	Worker radiological safety --normal conditions	8.3.5.4
6.4.6	2.3	Accidental radiological releases	8.3.5.5
6.4.7	2.7	Repository design criteria for radiological safety	8.3.2.3
6.4.8	2.4	Waste retrievability	8.3.5.2
6.4.9	4.2	Nonradiological health and safety	8.3.2.4
6.4.10	4.4	Preclosure design and technical feasibility	8.3.2.5
6.4.11	4.5	Repository system cost effectiveness	8.2.2.3.2.4

6.4.2 ISSUE 1.11: CONFIGURATION OF UNDERGROUND FACILITIES (POSTCLOSURE)

6.4.2.1 Introduction

The question asked by Issue 1.11 is

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

The regulatory requirements addressed by this issue contained in 10 CFR 60.133 are the parts that address postclosure performance. The other parts of 10 CFR 60.133 that regulate preclosure performance are addressed by other issues. The specific parts of 10 CFR Part 60 addressed by this issue are as follows:

133(a)(1) General criteria for the underground facility.

> The orientation, geometry, layout, and depth of the underground facility, and the design of any engineered barriers that are part of the underground facility shall contribute to the containment and isolation of radionuclides.

133(b) Flexibility of design.

> The underground facility shall be designed with sufficient flexibility to allow adjustment where necessary to accommodate specific site conditions identified during in situ monitoring, testing, or excavation.

133(e)(2) Underground openings.

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

133(f) Rock excavation.

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

133(h) Engineered barriers.

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

133(i) Thermal loads.

> The underground facility shall be designed so that the performance objectives will be met taking into account the predicted thermal

and thermomechanical response of the host rock, and surrounding strata, groundwater system.

The proposed strategy for resolution of this issue is presented in Section 8.3.2.2. In that section, the issue resolution strategy for Issue 1.11 is presented and interrelationships between Issue 1.11 and other issues are addressed. Readers unfamiliar with the issue resolution strategy for this issue should review the contents of Section 8.3.2.2 before continuing. In this section, the current status of resolution of the issue is reported.

Summary information describing the computer codes used in the analyses supporting the work completed is contained in Table 6-29.

The postclosure design criteria of 10 CFR 60.133 addressed by this issue require that the underground facility and engineered barrier system be designed to

1. Contribute to containment and isolation.

2. Assist the geologic setting in meeting performance objectives and limit the potential for deleterious rock movement or preferred pathways.

3. Account for the thermal and thermomechanical response of the host rock and the need for sufficient flexibility of design to accommodate site-specific conditions.

The underground facility, as referred to in this issue, includes the underground structure, drifts and emplacement boreholes including all materials used in construction of these openings. The underground structure includes the volume of rock adjacent to the excavation that sustains the load of the surrounding rock. Drift seals are part of the underground facility; however, they are explicitly addressed by Issue 1.12, and, thus, are considered to be an interface to this issue.

The postclosure design issue provides the mechanism for identification of repository design characteristics and configurations important to the resolution of Key Issue 1 (postclosure containment and isolation), quantification of how these characteristics and configurations are in compliance with 10 CFR 60.133, and incorporation of postclosure performance concerns into the design.

The characteristics and configurations important to containment and isolation on the scale of the whole underground facility are best understood by considering the information needs for this issue and their associated products. Listed in the following pages are the information needs and their associated products. The section of Chapter 8 is identified in which the information need is discussed in detail. In each instance, the name and number of the product is stated and the product is briefly described. The products are numbered in a manner that corresponds to the numbering used in Section 8.3.2.2. For example, product 1.11.1-2 is the second product identified under the first information need in Issue 1.11.

Table 6-29. Codes used to support work completed for Information Need 1.11.6 of Issue 1.11 (page 1 of 4)

Product number	Code name	Author	Ownership[a]	Design parameter	Analysis description
1	ADINAT	K.J. Bathe	MIT	Areal power density. Determine if thermal loading meets near- and far-field constraints.	A finite-element heat transfer program. 2-D, 3-D; for automatic dynamic nonlinear heat conduction; convective and adiabetic boundaries; constant or decaying heat source.
1	ADINA	K.J. Bathe	MIT	Areal power density. Determine if thermal-induced stresses meet near- and far-field constraints.	A finite element, stress analysis program, 2-D, 3-D; elastic, elastic/plastic ubiquitous joint model; accepts precalculated temperature history.
1	SPECTROM-41	D.K. Svalstad, RE/SPEC Albuquerque, NM	RE/SPEC	Areal power density. Determine if thermal loading meets near- and far-field constraints.	Finite element, heat transfer program. Nonlinear heat conduction; convection and adiabetic boundaries; constant or decaying heat sources.

Table 6-29. Codes used to support work completed for Information Need 1.11.6 of Issue 1.11 (page 2 of 4)

Product number	Code name	Author	Ownership[a]	Design parameter	Analysis description
1	SPECTROM-11	RE/SPEC Albuquerque	RE/SPEC No documentation available	Areal power density. Determine if thermal-induced stresses meet near- and far-field constraints.	Finite-element stress analysis program. Elastic, elastic/plastic ubiquitous joint model; accepts precalculated temperature history.
1	SPECTROM-349	D.K. Svalstad RE/SPEC Albuquerque, NM	RE/SPEC	Far-field temperature distribution, design of underground facility.	A linear superposition program. For three-dimensional heat conduction solutions for constant or decaying heat source from parallelopiped in a semi-infinite homogeneous medium.
1	ARRAYF	R.D. Klett	SNL	Borehole spacing strategy. Determine if thermal loading meets near-field constraints	A linear superposition program. For three dimensional heat conduction solutions for constant or decaying cylindrical heat source.

Table 6-29. Codes used to support work completed for Information Need 1.11.6 of Issue 1.11 (page 3 of 4)

Product number	Code name	Author	Ownership[a]	Design parameter	Analysis description
2	SIM	Ahmad Badie	Raymond Kaiser Engineering, Parsons Brinckerhoff, San Francisco, CA	Borehole spacing strategy. Determine if thermal loading meets near-field constraints	A linear superposition for three dimensional heat conduction solutions with constant or decaying line heat sources.
2	HEFF	B.H.G Brady, University of Minnesota	Public domain	Stresses around a borehole, emplacement drift, or repository	A boundary-element stress analysis program. 2-D, thermoelastic analysis of constant or decaying thermal load.
2	STRES3D	C. St. John M. Christianson University of Minnesota	Public domain	Stresses around a borehole, emplacement drift, or repository	Computer program for determining temperatures, stresses, and displacements around single or arrays of constant or decaying heat sources. Based on closed form solution.

Table 6-29. Codes used to support work completed for Information Need 1.11.6 of Issue 1.11 (page 4 of 4)

Product number	Code name	Author	Ownership[a]	Design parameter	Analysis description
2	DOT	Polivka, Wilson	University of California	Temperature distribution around a borehole, or emplacement drift.	A general purpose heat transfer program. Linear and nonlinear steady-state or transient-heat transfer. Input for VISCOT.
2	VISCOT	ONWI/OWID	Public domain	Stresses around a borehole, or emplacement drift.	Finite-element stress analysis or program. Thermovisco-elastic, thermo-viscoplastic; accepts precalculated temperature history.

[a]MIT = Massachussetts Institute of Technology; SNL = Sandia National Laboratories.

Information Need 1.11.1 Site characterization information needed for design (Section 8.3.2.2.1).

Number	Description
1.11.1-1	The data requirements list identifies the site data needed from site characterization to (1) support the postclosure design of the MGDS underground facility and (2) determine the contribution of the MGDS underground facility to containment and isolation.
1.11.1-2	The reference thermal/mechanical stratigraphy of Yucca Mountain is described.
1.11.1-3	The reference thermomechanical rock properties document will describe the conversion of measured rock properties data to reference rock properties for thermomechanical units other than the Topopah Spring Member. Reference rock properties will be recommended for incorporation in the NNWSI Project Reference Information Base (RIB) (Appendix Q of SNL, 1987).

Information Need 1.11.2 Characteristics of the waste package needed for design of the underground facility (Section 8.3.2.2.2).

Number	Description
1.11.2-1	The waste package characteristics for design of the underground facility will be obtained from Issue 1.10 (waste package characteristics--postclosure) and are recorded in the subsystems design requirements (SDR) document (Appendix P of SNL, 1987).

The characteristics of the waste package needed for design of the underground facility are identified in Section 8.3.2.2.2. The waste package characteristics used during the development of the conceptual design of the surface and subsurface facilities are presented in SCP-CDR Section 2.2, SCP-CDR Appendix G, and the SDR (Appendix P of SCP-CDR, SNL, 1987).

Information Need 1.11.3 Design concepts for orientation, geometry, layout, and depth of the underground facility that contribute to waste containment and isolation, including flexibility to accommodate site-specific conditions (Section 8.3.2.2.3).

Number	Description
1.11.3-1	The area-needed determination will establish the required area for the underground portion of the MGDS at the Yucca Mountain site.

Number	Description
1.11.3-2	The usable area and flexibility evaluation will (1) establish the boundaries of the area available for the MGDS underground facility at the Yucca Mountain site and (2) evaluate the flexibility of the site based on a comparison of the design for the MGDS underground facility layout and the area available for these facilities as determined by using a 3-D graphics model of the geologic structure of Yucca Mountain.
1.11.3-3	The vertical or horizontal emplacement orientation decision will document the decision and supporting logic for either (1) emplacing a single waste container in vertical boreholes in the floor of the drifts (current reference emplacement orientation) or (2) emplacing one or more waste containers in horizontal boreholes in the walls of the drifts.
1.11.3-4	The drainage and moisture control plan will present a plan for limiting the amount of water in contact with the containers to provide a favorable containment and isolation environment by promoting the migration of water away from the waste containers.
1.11.3-5	The criteria for contingency plan will provide (1) the criteria that can be used to identify underground emplacement areas that have geologic and hydrologic characteristics, conditions, or both within the ranges anticipated in licensing, and (2) criteria for modification of the MGDS underground facility baseline design based on the geologic characteristics encountered.

<u>Information Need 1.11.4</u> Design constraints to limit water usage and potential chemical changes (Section 8.3.2.2.4).

Number	Description
1.11.4-1	The material inventory criteria will provide criteria for the inventory of materials (type and quantity) proposed for use in the subsurface facility.
1.11.4-2	The water usage criteria will establish criteria relating to the use of water during the construction and operation of the MGDS underground facilities.

<u>Information Need 1.11.5</u> Design constraints to limit excavation-induced changes in rock mass permeability (Section 8.3.2.2.5).

Number	Description
1.11.5-1	The excavation methods criteria will (1) establish criteria for the allowable size and extent of the damage caused by excavation of the boreholes and drifts, (2) establish criteria for the allowable amount of alteration of in situ rock properties (e.g., permeability), and (3) establish criteria for excavation methods.
1.11.5-2	The long-term subsidence control strategy will provide design guidance to ensure that the design of the MGDS underground facilities will limit the potential for (1) subsidence and (2) creating preferential pathways for radionuclide migration.

Information Need 1.11.6 Repository thermal loading and predicted thermal and thermomechanical response of the host rock (Section 8.3.2.2.6).

Number	Description
1.11.6-1	The allowable areal power density chosen as a criteria on the layout of the MGDS underground facility and the logic supporting this choice will be documented.
1.11.6-2	The borehole spacing strategy will establish a plan for how to distribute the waste containers so that the allowable areal power density constraint and temperature criteria are met, considering the thermal characteristics of the waste.
1.11.6-3	The sensitivity studies will evaluate and document the effects of uncertainty in the description of the waste type and the geologic setting on the MGDS underground facility design and the thermal and thermomechanical response of the host rock.
1.11.6-4	The strategy for containment enhancement will document work done to evaluate alternative ways of distributing the waste containers so as to increase the number of containers that remain dry and the time the containers remain dry.
1.11.6-5	The reference calculations will (1) predict thermal and thermomechanical responses of the host rock on a container, drift, and far-field scale and (2) document the results of these calculations for use by other issues.

Information Need 1.11.7 Reference postclosure repository design (Section 8.3.2.2.7).

Number	Description
1.11.7-1	The reference postclosure design will document the reference design of the repository will form the basis for postclosure performance assessment of the MGDS facilities.

Number	Description
1.11.7-2	The documentation of compliance will document the compliance of the postclosure design with the requirements of 10 CFR 60.133.

The approach to resolution of Issue 1.11 (1) emphasizes ensuring that the postclosure waste disposal system element performs the functions identified in Section 8.3.2.2, and (2) includes developing a reference postclosure design of the repository.

The functions were derived directly from 10 CFR 60.133. The proposed strategy for resolution of Issue 1.11 used the three-step process identified in Section 8.3.2.2 (processes, performance measures, and performance goals and confidence) as a means of establishing that the functions are performed. The process step describes how the function will be accomplished. The performance measure step identifies the measure that will allow a determination of whether the process is being performed as required by the function. Each performance measure has an associated goal and confidence step. The goal is the value for the performance measure that will be adequate for the issue to be favorably resolved, and the current and needed confidence provides an indication of the importance assigned to meeting the goal.

The reference postclosure design will be discussed in future major design documents and will be documented in the Reference Information Base for use in future postclosure performance assessments.

Preliminary assessments and design concepts are contained in this chapter. Current goals are given in Chapter 8, Section 8.3.2.2. Updating of this information will continue through the advanced conceptual design and the license application design.

6.4.2.2 Work completed

Twenty products have been identified in Section 8.3.2.2 as important to the resolution of Issue 1.11 (see Section 6.4.2.1 for a complete listing of the products). Significant results have been reported to date for the following six products:

1.11.1-2 Reference thermal/mechanical stratigraphy

1.11.1-3 Reference thermomechanical rock properties document

1.11.3-1 Area-needed determination

1.11.3-2 Usable area and flexibility evaluation

1.11.6-1 Allowable areal power density

1.11.6-2 Borehole spacing strategy

The approach and data used and the results obtained for the six products are summarized in the following discussions.

1.11.1-2 Reference thermal/mechanical stratigraphy

The reference thermal/mechanical stratigraphy documents the three-dimensional thermal/mechanical stratigraphy of Yucca Mountain as contained in the Interactive Graphics Information System (IGIS) as the reference basis for design and performance assessment.

Analytical approach

The documented thermal/mechanical stratigraphy (Ortiz et al., 1985) provides a geometric representation of the rock units at Yucca Mountain. This representation, with associated material properties for each of the units, is being used as the reference stratigraphy in the design and performance assessment of the underground facility. This reference stratigraphy provides a consistent reference representation of the stratigraphy, thus addressing the use of conflicting stratigraphic descriptions through a change control process. The reference stratigraphy will be updated as information is provided from the site characterization. Final performance assessment will be based on the reference stratigraphy.

An IGIS was used to develop and display a three-dimensional model of Yucca Mountain. The model is a collection of smooth three-dimensional surfaces based on interpolation between sparse and irregularly spaced data points. Each of the smooth three-dimensional surfaces represents the base of a thermal/mechanical and hydrological reference unit. Faulting of the units is incorporated in the model. A complete description of the approach has been published (Ortiz et al., 1985).

Data

The reference thermal/mechanical stratigraphy is a compilation of site data, including surface mapping data and data obtained from boreholes drilled at the site. Current reference data and measured site data (raw data) used to establish the reference data are documented in Ortiz et al. (1985).

Specification of the accuracy of the model is difficult. However, within the primary area, the surfaces are sufficiently accurate to perform the needed conceptual design (see Section 8.3.2.2) for current accuracy, required accuracy, and additional site data needed). Confidence in the model inside the primary area is high. Additional data collected during site characterization will be used to improve the confidence in the geometric model outside the primary area.

Results

The thermal/mechanical stratigraphy (Ortiz et al., 1985) is in contrast to the previous geologic stratigraphy (Nimick and Williams, 1984) in that the geologic division of stratigraphic units does not lend itself readily to describing material properties. This is because a stratigraphic unit may contain more than one type of rock. Indeed, most stratigraphic units at Yucca Mountain include at least two different types of rock--welded ash-flow tuffs and bedded tuffs.

Field information and laboratory data were used in the development of the three-dimensional model. These data, concerning the nature and distribution of rock units at Yucca Mountain, are limited to surface geologic maps and drillhole logs. A method of analytically interpolating between sparse and irregularly spaced data source locations is used to generate a continuous analytical surface from a collection of three-dimensional coordinates.

Faulting effects are handled interactively on a case-by-case basis. The removal of fault movement from input data or its reinsertion into calculated surfaces has not been automated, because surface mapping of faults does not provide a comprehensive three-dimensional description of the area-wide fault system.

Referenceable products of the thermal and mechanical stratigraphy include cross sections (including faulting), isopach maps, contour maps, thickness or distance between features, and surface features (topography, outcropping, and faulting).

1.11.1-3 Reference thermomechanical rock properties document

This work will describe the conversion of measured rock properties data to reference rock properties for all thermomechanical units other than the Topopah Spring Member. Reference rock properties will be recommended for incorporation in the NNWSI Project RIB.

<u>Analytical approach</u>

Rocks are composed of crystals and grains in a fabric that frequently includes cracks and fissures. The selection of laboratory-sized specimens for testing excludes larger cracks and fractures that exist in the rock mass. Loads in the rock mass will be transmitted across these larger cracks and fractures. Laboratory strength tests on smaller specimens usually provide values greater than the actual strength of the rock mass. Thus, rock properties are dependent on sample size. Rock mass properties that are representative of a volume or mass of rock will be determined from measured data. The rock mass properties for the Topopah Spring Member are determined as part of preclosure analysis under Issue 4.4. A description of how the reference rock mass properties were determined from measured properties has been published with the recommended properties (Appendix O of SNL, 1987). Additional information also is given in Chapter 2.

<u>Data</u>

Rock properties are derived from laboratory measurements of thermal and mechanical rock properties. Current rock mass properties are given in

Section 6.1.2. (reference design data base). These data are derived from the site data given in Chapter 2, (Geoengineering).

Results

A consistent set of reference properties (physical, mechanical, and thermal properties and in situ conditions) for the thermal and mechanical stratigraphy at the Yucca Mountain site has been established. These reference properties have been derived from analyses of laboratory and field data (i.e., both intact rock data and rock mass data) currently existing for the site. These reference properties are contained in Section 6.1.2, in Chapter 2 and are included in the NNWSI Project Reference Information Base (Appendix Q of SNL, 1987). References for the sources of the laboratory and field data are cited in Chapter 2 and Section 6.1.2.

Analyses of the data have resulted in the derivation of methods to better understand and extrapolate both field and laboratory data. For example, a method for relating porosity to mechanical and strength data has been derived (Price and Bauer, 1985). Zimmerman et al.(1986a) show the relationship between laboratory and field determinations of the thermal, mechanical, and thermomechanical response of rock.

1.11.3-1 Area-needed determination

The area-needed determination will establish the required area for the underground facility at Yucca Mountain.

Analytical approach

Mansure (1985) gives a complete description of how the area needed was determined. Basically, the area for high-heat-producing waste has been determined by dividing the thermal output of the waste by the design basis areal power density (APD). The area for low-heat-producing waste was determined on the basis of operational and safety constraints. The area needed for the shops and other support facilities has been added to the areas needed for waste emplacement. The area needed is an important input into the usable area and flexibility evaluation discussed for the next product (1.11.3-2).

Data

The area-needed determination depends on the allowable APD. The APD, in turn, depends on site data. For the site data related to APD, refer to the discussion of that product in 1.11.6-1. The nonsite-related data required to determine the area needed include (1) the waste inventory, (2) the space for shops and support facilities, and (3) the size and spacing of the drifts.

Results

A preliminary determination of the area needed for a 70,000 metric tons uranium (MTU) underground facility has been completed. The results of this study have been used for (1) the planning of the site characterization program and (2) the preliminary evaluation of compliance with 10 CFR Part 960 as given in the environmental assessment (DOE, 1986c). Both of these uses of the area needed depend on comparing the area needed to the thickness and lateral extent of the host rock. The current value of the area needed is based on the layout of the underground facility presented in Section 6.2.

The current layout occupies 1,420 acres (Section 6.2). This is based on an inventory of 62,000 MTU of spent fuel and 8,000 MTU of defense high-level waste (DHLW) and West Valley high level waste (WVHLW), of an APD of 57 kW/acre. This is less than the area-needed given in the Environmental Assessment because the acreage reported there was for an all-spent-fuel repository. The uncertainty in the area-needed is judged to be ± 210 acres, based on uncertainty in the final basis APD of 40 to 80 kW/acre (Appendix M of SNL, 1987).

The analyses to determine the area-needed assume that the waste is emplaced at the equivalent energy density of the design basis APD. These analyses (Mansure, 1985) have resulted in two significant conclusions: (1) commingling (the placement of DHLW and WVHLW with spent fuel in the same emplacement panel) will not significantly (less than 10 percent difference) change the area needed, and (2) horizontal and vertical waste emplacement options do not require significantly different areas (less than 50 acres difference).

1.11.3-2 Usable area and flexibility evaluation

The usable area and flexibility evaluation will (1) establish the boundaries of the area available for the underground facility and (2) evaluate the flexibility of the site by comparing the layout with the area available for these facilities.

Analytical approach

The usable area and flexibility evaluation began with the selection of the primary and adjacent areas. Once these areas were selected, the preferred horizon for waste emplacement was chosen. A computer graphics model (CAD/CAM-like system) was used to display a three-dimensional picture of Yucca Mountain and compare underground facility location to constraints (required overburden, etc.). This approach is described in reports by Nimick and Williams (1984) and Mansure and Ortiz (1984).

Data

The data base used by the IGIS for this study was reported by Ortiz et al. (1985). The three-dimensional model of Yucca Mountain is based on geologic data from surface mapping of outcrops and faults and from unit contacts determined using core and cuttings taken from wells drilled at the site.

Results

Screening of the Nevada Research and Development Area of the Nevada Test Site and nearby areas for favorable locations for the permanent disposal of radioactive waste in a mined geologic disposal system (MGDS) resulted in the selection of Yucca Mountain as the primary area for location of the underground facility (Sinnock and Fernandez, 1982). Four geologic units at Yucca Mountain were compared--the Topopah Spring Member, the tuffaceous beds of Calico Hills, the Bullfrog Member, and the Tram Member. The portion of the Topopah Spring Member containing relatively few lithophysae was recommended (Johnstone et al., 1984). Subsequent evaluations of usable area and flexibility have been limited to the relatively low lithophysae portion of the Topopah Spring Member. Although the preferred horizon is expected to have low lithophysae content, this does not imply that the underground facility must be placed in low lithophysae host rock but only that host rock with lower lithophysae content may be preferable (Section 6.3.3.2.3 of DOE, 1986c).

Analysis (Mansure and Ortiz, 1984) of the output from a three-dimensional computer graphics model of Yucca Mountain prepared by Nimick and Williams (1984) indicates that Area 1, identified as the primary area and shown in Figure 6-87, contains approximately 2,200 acres. Approximately 1,850 acres of Area 1 are potentially usable on the basis of the disqualifying condition for erosion, which requires a 200-m overburden (DOE, 1986c).

Area 1 contains relatively few faults and rare fault breccias (Scott and Bonk, 1984). The surface and subsurface geologic exploration of Yucca Mountain has concentrated in this area and in the immediately surrounding area that has a relatively low fault density. Available site data indicate that rock with acceptable characteristics may be present within areas 2 through 6, and perhaps even outside these areas (Mansure and Ortiz, 1984; Sinnock and Fernandez, 1982).

If one considers only the primary area, the usable area (1,850 ± 140 acres) is more than the area-needed (1,420 ± 210 acres). Because of the irregularities of the shapes and the uncertainty in the size of the area needed and the area available, there is limited lateral flexibility. The other areas identified outside the primary area may contain over 5,000 acres (areas 2 to 6 on Figure 6-87); however, at this time, there are insufficient data to qualify most of these areas. Current understanding of design concepts and conclusions about offsets from site features suggest that there may be a need for as much as 300 additional acres to ensure adequate flexibility (Appendix M, SNL, 1987). Figure 6-88 shows two proposed expansions to the reduced primary area: (1) 2 EA and 2 EB and (2) SE. These areas could add at least an additional 750 acres. Note that the narrow, southern portion of the primary area, Area 1 (Figure 6-87), is not included in the revised, usable portion of the primary area shown in Figure 6-88 because it cannot be efficiently developed as part of the underground facility. The proposed site characterization program (Sections 8.3.2.2.1 and 8.3.2.2.3) includes plans to gather the data necessary to qualify these expansions.

Basic requirements for the thickness of the potential host rock are (1) the presence of sufficient overburden to ensure a low probability of uncovering the waste by erosion and (2) sufficient thickness of suitable host rock to provide the volume of rock required for construction of the underground facility. Mansure and Ortiz (1984) show that the approximate thickness of the preferred host rock is about 100 to 175 m within the primary area

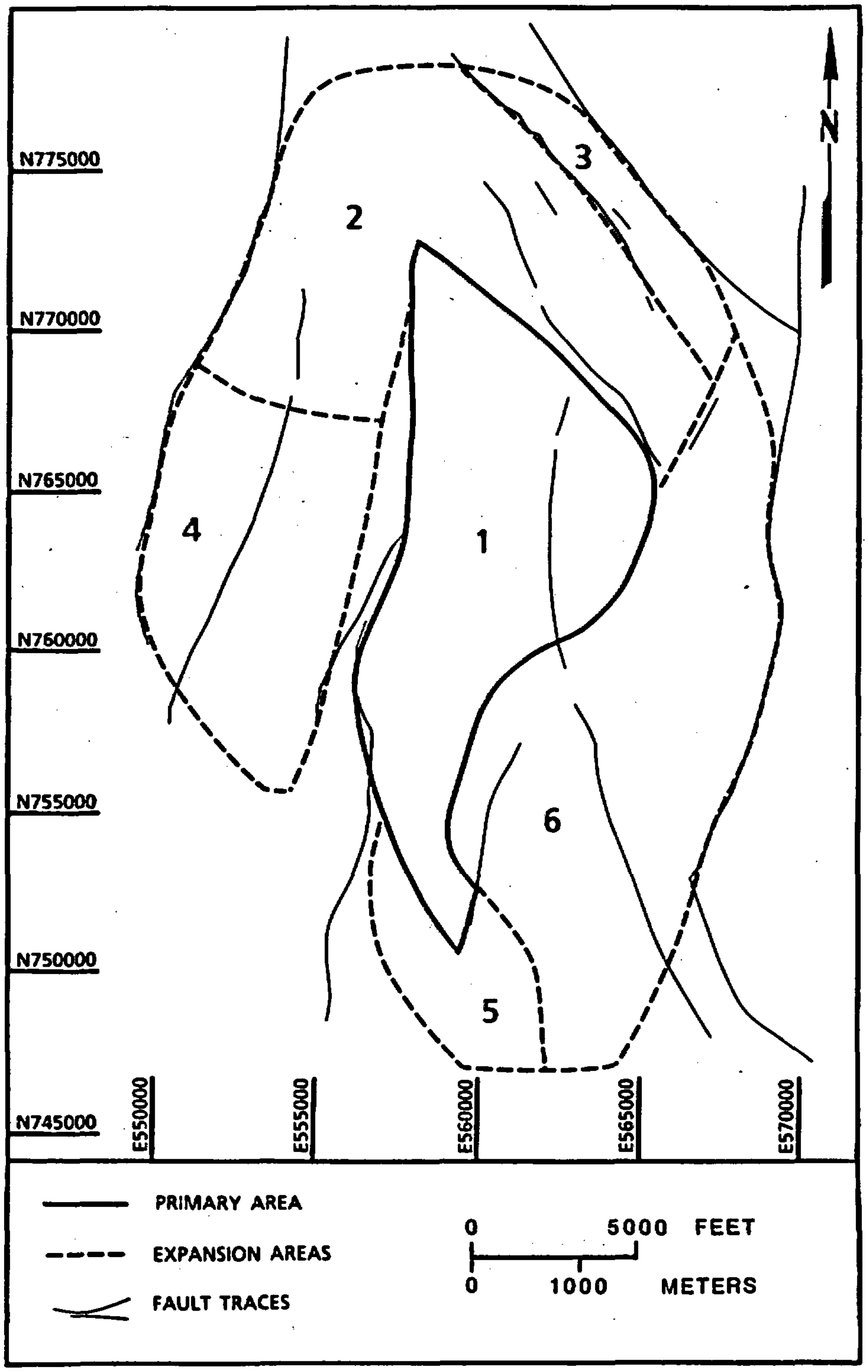


Figure 6-87. Primary area (area 1) for the underground repository and potential expansion areas (areas 2 through 6).

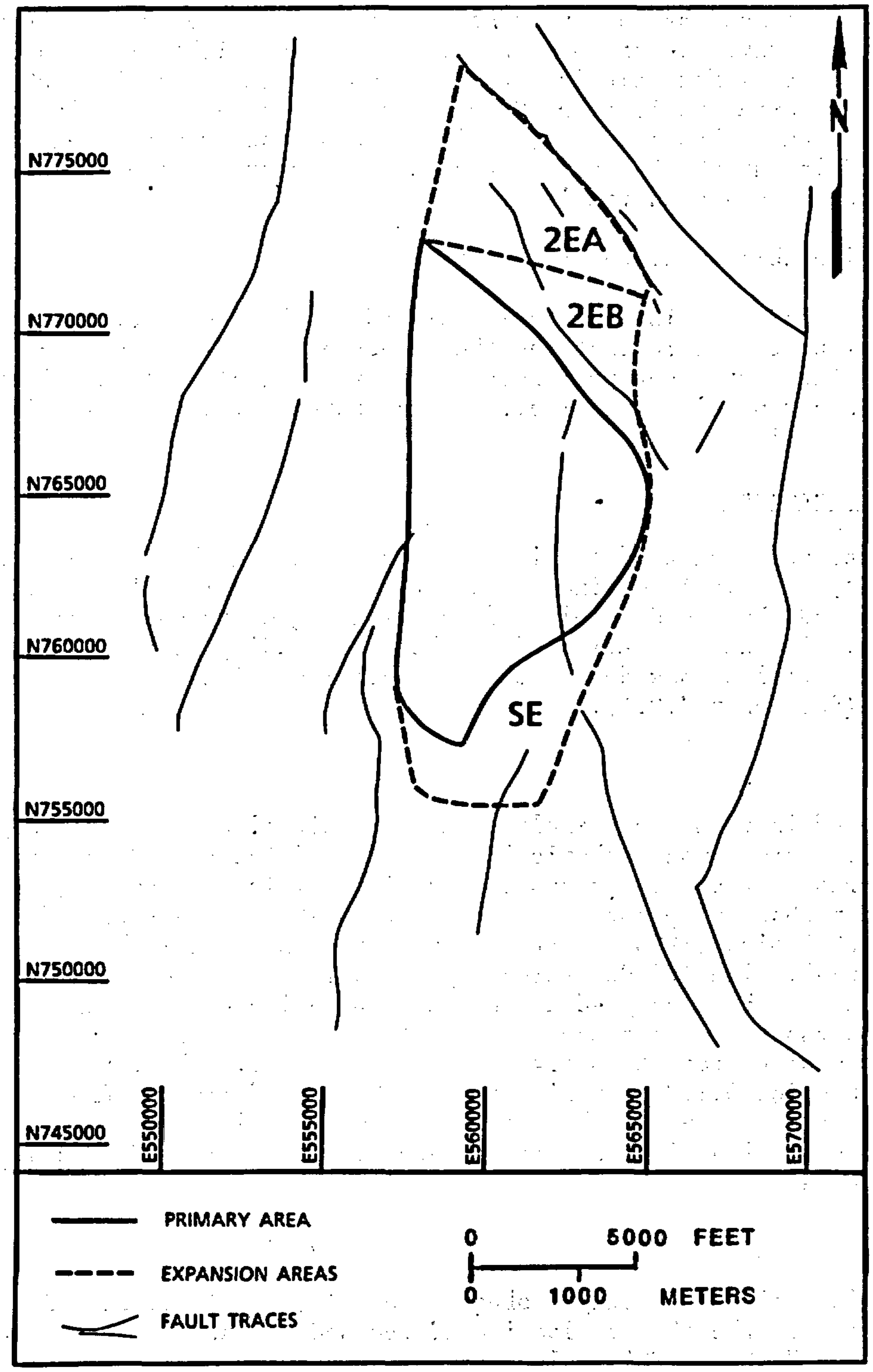


Figure 6-88. Revised usable portion of the primary area and expansion areas.

or about three times the thickness of the 45-m slab assumed for the underground facility envelope or more than 15 times the height of the drifts. The overburden at Yucca Mountain is more than 300 m thick over about 50 percent of the primary area and is over 200 m everywhere above the usable portion of the primary area. Thus, to date, exploration of the primary area has revealed sufficient thickness of potential host rock for flexibility in design of the underground facility.

1.11.6-1 Allowable areal power density

The APD (kW/acre) is a criterion placed on the design of the underground facility layout to ensure that the thermomechanical effects of the heat released by the waste meet performance allocation goals. This criterion is applied on a per panel basis (i.e., average output of a panel is divided by size of the panel).

Analytical approach

The approach used to determine the current design basis APD (Johnstone et al., 1984) was first to find the APD that resulted in a 100°C floor temperature and then to determine if that loading meets near- and far-field constraints. The determination of whether the loading meets near- and far-field constraints was done with the thermomechanical codes given in Table 6-29 (Section 6.4.2.1).

Data

Data used in this study include in situ initial conditions (temperature and stress), thermal and mechanical properties of the rock, the stratigraphy, and the thermal output of the waste. The initial in situ conditions and rock thermal and mechanical properties used in this study were reported by Tillerson and Nimick (1984). Stratigraphy used is given in Nimick and Williams (1984). The APD determined by the unit evaluation study (Johnstone et al., 1984) has been adopted as the current design basis. That study considered a range of parameter values sufficient to include the expected values of the site properties given in Section 6.1.2. The reference design data base, Section 6.1.2, contains values that are different from those used by Johnstone et al. (1984). The design basis APD will be revised before the advanced conceptual design and license application design to be consistent with the RIB data.

Results

The unit evaluation study (Johnstone et al., 1984) determined the value of 57 kW/acre for the thermal loading of the underground facility in the Topopah Spring Member. This value was computed using average waste age and burnup characteristics. This value has been the design basis used for developing the layouts reported in Section 6.2 and in Chapter 4 of the SCP-CDR. As noted in the analytical approach section previously, this loading was based on a maximum floor temperature for vertical emplacement of 100°C (Johnstone et al., 1984). This is a constraint that was assumed in the evaluation studies. Changes in ventilation system concepts have resulted in the issue resolution process replacing this constraint with a design goal of

50°C at 50 years (see Section 8.3.2.5, for an explanation of where and how the 50/50 constraint is applied). With the change to this constraint, the allowable thermal loading could increase above the current design basis of 57 kW/acre.

In establishing the allowable APD for the advanced conceptual design, a tradeoff study will be performed and an allowable APD higher than the current design basis may be adopted if it meets all criteria. Note that higher loadings are not necessarily detrimental to performance. A higher APD may make it possible to keep the waste containers dry for a longer period of time and, thus, assist in meeting the requirements of Issue 1.10, Waste package characteristics (postclosure). A higher APD also will reduce the area needed for the underground facility and, thus, increase lateral flexibility. On the other hand, a higher APD may have undesirable performance effects such as higher stresses and temperatures.

A procedure has been developed (Appendix G of SNL, 1987) based on the equivalent energy density concept (O'Brien and Shirley, 1984) to apply the design basis loading (57 kW/acre) to other than average waste ages and burnups. This procedure allows the design of the underground facility to accommodate the variability in thermal output of wastes of different ages and burnup rates.

1.11.6-2 Borehole spacing strategy

The borehole spacing strategy will establish a plan to distribute the waste containers such that the allowable APD constraint and temperature criteria are met, considering the thermal characteristics of the waste.

Analytical approach

The typical panel design, reported in Section 6.2 and in Chapter 4 of the SCP-CDR, distributes the waste to meet thermal constraints given in Section 8.3.2.2.6 (thermomechanical effects). This typical panel design is the first step in developing a borehole spacing strategy. The approach was to use actual drift and borehole dimensions to establish the standoff distances, which are used to control drift temperatures. Then, the borehole (and drift for vertical emplacement) spacings were varied to simulate emplacement of the waste at the design basis (57 kW/acre) loading, while limiting the extraction ratio to no more than 30 percent and meeting the temperature constraints (SNL, 1987; SCP Section 6.4.2). Various typical panel layouts were analyzed using the heat conduction code SIM (Table 6-29, Section 6.4.2.1). Professional judgment was used to pick the most practical panel layout.

Data

Data for these calculations were taken from reference properties (Appendix O of SNL, 1987). These data are consistent with the design data given in Section 6.1.2. Data required included rock thermal and mechanical properties and initial in situ conditions.

Results

The typical panel design presented in Section 6.2 and in the SCP-CDR is the first step in the borehole spacing study. Future work will determine practical development strategies based on sensitivity studies that consider waste type, age, and burnup. The current typical panel design contributes to the development strategies by demonstrating the design steps necessary to ensure that all criteria and design goals are met. That is, calculational procedures were developed to lay out a typical panel that met constraints. Thus, the typical panel demonstrates that reasonable waste distributions exist that meet all criteria and design goals. The typical panel presented includes commingling of waste types and should be sufficiently flexible to incorporate expected variations and uncertainty in the waste characteristics, inventory, and receipts.

The process developed results in a typical panel, reported in Section 6.2 and in the SCP-CDR, that does the following:

1. Uses the design basis APD.

2. Incorporates standoffs of the waste packages from drift walls to control drift wall temperatures.

3. Uses drift dimensions consistent with equipment, ventilation, mining, operation, and retrieval system requirements.

4. Meets borehole and rock mass thermal constraints.

Further, the design of the typical panel considers the goal (Section 8.3.2.2.6, thermomechanical effects) of enhancing containment of the waste by maintaining the temperature around the container above the boiling point of water for 300 yr. Thus, in determining the waste distribution, peak temperatures were held below constraints on the temperature of the waste package while consideration was given to maintaining the temperature of the rock surrounding the waste container above the boiling point of water for as long as possible.

In addition to the above six products where significant progress has been documented in published reports, progress has been made on understanding several of the other products.

1.11.1-1 Data requirements list

The current data requirements list is given in Section 8.3.2.2.1 (site characteristics needed for design). The list will be updated based on additional studies, changes to waste package characteristics, changes in design or design basis, or any changes to the goals of Issue 1.11.

1.11.2-1 Waste package characteristics for design of the underground facility

The current waste package characteristics for design of the underground facility are given in section 8.3.2.2.2. Those characteristics will be updated based on additional studies, any changes in the goals of Issue 1.10 (Section 8.3.4.2), or changes in design or design basis.

1.11.3-3 Vertical or horizontal emplacement orientation decision

The initial evaluations of horizontal and vertical emplacement are given in SCP-CDR (Appendix E of SNL, 1987). Potential discriminating factors in the decision process are containment, waste isolation, retrievability, worker radiologic safety, hydrologic character, and underground facility cost. Preliminary results based on normal operations indicate that the preclosure performance of the two emplacement options will be essentially the same except for worker radiologic safety and underground facility cost. The horizontal emplacement option appears to offer both lower worker exposure to penetrating radiation and lower underground facility costs. More equipment development and demonstration for retrievability would be required prior to license application for the horizontal emplacement configuration. However, both emplacement options are judged to perform in an acceptable manner; further investigations will be conducted to assess the effects of off-normal conditions.

1.11.3-4 Drainage and moisture control plan

A plan for drainage control has been incorporated in the design presented in Section 6.2 and in the SCP-CDR. This plan precedes both performance allocation and establishing goals on drainage. Future work on drainage will include establishment of performance and sealing requirements to limit the amount of water reaching emplacement areas during the postclosure period.

1.11.3-5 Criteria for contingency plan

Detailed work on the contingency plan will be part of the advanced conceptual design activities. However, some concepts on how to accommodate site-specific conditions have been incorporated in the current design. Specifically, the current design provides for a different ground support system to accommodate changes in underground conditions (SNL, 1987). During development, unexpected conditions like small zones of perched water, localized heavily fractured zones, water recharge pathways, or localized lithophysae-rich zones may be encountered. The contingency plan will provide the means to accommodate such regions.

Development of the contingency plan will begin with the assumption that all of the target area will be considered acceptable (except for possible local regions identified during the site characterization phase as being unacceptable). If local conditions are not consistent with performance objectives and regulatory requirements using the baseline design, then design modifications would be required. The procedures for implementing such design modifications would be licensed as part of the contingency plan, implemented by the performance confirmation program, and reported to and reviewed with the NRC. These procedures might include the following:

1. Continued development with design revisions like increased ground support and reduced thermal loading.

2. Skipping and isolating an area unfavorable for development.

Section 8.3.2.2.3, Underground facility orientation and layout, has a more detailed discussion of contingency plan concepts.

1.11.5-1 Excavation methods criteria

The excavation method design bases are (1) for emplacement drifts, conventional mining with controlled blasting techniques and controlled water usage, and (2) for boreholes, drill with vacuum chip removal and incorporating moisture for dust control only. These methods are documented in Section 6.2, Section 6.4.3 of the SCP-CDR, the subsystem design requirements document (Appendix P of SNL, 1987), and Section 8.3.2.2.5 (excavation methods for construction). These methods should result in excavations that meet performance goals (Section 8.3.2.2). The conventional mining of welded tuff has been demonstrated with blast control in G-Tunnel at the NTS (Section 7.3.2 of SNL, 1987) as discussed in Zimmerman and Findley (1987). Demonstration of the drilling equipment for the emplacement boreholes is currently planned for G-Tunnel (Section 8.3.2.5, preclosure design and technical feasibility).

1.11.5-2 Long-term subsidence control strategy

The long-term subsidence control strategy is to limit the extraction ratio and thermal load. The extraction ratio is to be less than 10 percent for horizontal emplacement and less than 30 percent for vertical emplacement (Section 8.3.2.2.5). Current design (Section 6.2; Section 6.4.2 of SNL, 1987) falls within this guideline for the emplacement areas. Stability at the design basis thermal loading of 57 kW/acre has been demonstrated analytically by thermomechanical calculations (St. John, 1987d). The calculations performed to assess long-term drift stability did not indicate any potential for appreciable subsidence. The design basis presented in Section 6.2 calls for backfill to be installed in all openings at the end of the retrievability period.

1.11.6-3 Sensitivity studies

The far-field unit evaluation study (Johnstone et al., 1984) considered the Topopah Spring Member, the tuffaceous beds of Calico Hills, the Bullfrog Member, and the Tram Member. Each unit is at a different depth; two are saturated and two are unsaturated, three are welded tuffs and one is a nonwelded tuff. This evaluation addressed a range of values for almost all parameters except horizontal to vertical in situ stress ratio. Results of the unit evaluation study did not show significant differences in the system response to the parameter variations. As a result, it is expected that the postclosure design will not be very sensitive to uncertainties in site data. Additional work will be needed to confirm this conclusion if the in situ stress ratio is substantially different from that assumed in the analysis done by Johnstone et al (1984). This conclusion will be evaluated in future studies (Section 8.3.2.2, configuration of underground facilities--postclosure).

1.11.6-4 Strategy for containment enhancement

Issue 1.10, waste package design--postclosure, (Section 8.3.4.2) incorporates a goal to enhance containment by keeping the container dry. Issue 1.11 has established a design goal of maintaining the majority of the waste containers at temperatures above the boiling point of water for 300 yr. Calculations of how long the containers remain above this temperature (Appendix K of SNL, 1987) have shown the (1) need for using the explicit geometry of waste distribution including the effects of the finite size of the underground facility (i.e., boundary effects) and (2) difference between local area power density and areal power density. The time duration that the containers remain above this temperature was shown to be very sensitive to thermal loading and position within the underground facility.

1.11.7-1 Reference postclosure repository design

The postclosure aspects of the conceptual design are summarized in Section 6.1.1.8 and given in detail in the SCP-CDR. This conceptual design will be used to evaluate MGDS performance and site characterization plans. The future versions of the Reference Information Base will contain reference postclosure repository design information and will be updated periodically using NNWSI Project change control procedures.

Work has not begun yet on four of the products identified in Section 8.3.2.2 for Issue 1.11. These are 1.11.4-1 (material inventory criteria); 1.11.4-2 (water usage criteria); 1.11.6-5 (reference calculations--for postclosure design); and 1.11.7-2 (documentation of compliance).

6.4.2.3 <u>Future work</u>

6.4.2.3.1 Analysis needs

The logic used in identifying the analyses required to resolve Issue 1.11 is presented in Section 8.3.2.2 and Sections 8.3.2.2.3 through 8.3.2.2.6 (information needs corresponding to issue resolution functions). The analyses are the approaches or methods described in those sections that will be used to calculate or otherwise establish that the anticipated or actual performance will meet the performance goals stated in Section 8.3.2.2. In general, the analyses are organized into activities to produce the products of the issue. For more information about these products and the analysis needs, see Sections 8.3.2.2.3 through 8.3.2.2.6.

6.4.2.3.2 Development needs

The reader is referred to Section 8.3.2.2 for discussions of future work on the products. In general, development needs do not exist for the products of this issue except the following:

1.11.3-4 Drainage-moisture control plan
1.11.3-5 Criteria for contingency plan
1.11.6-5 Reference calculations

6.4.2.3.3 Site information needs

The logic used in identifying the data important to resolution of Issue 1.11 is presented in Sections 8.3.2.2.3 through 8.3.2.2.6 (information needs corresponding to issue resolution functions). Section 8.3.2.2.1 (Information Need 1.11.1) lists in detail the site data needed to resolve this issue. It also defines how well the data need to be known to resolve the issue, and provides the link to the site characterization issues under which the test plans for obtaining the data will be discussed. The data required include rock properties data, summarized in Section 8.3.2.2, the geologic data necessary to develop the three-dimensional graphics model of Yucca Mountain, and the effects of mining on the rock mass. However, for the reasons noted previously in the Section 6.4.2.3.2, Development needs, additional data may be required to support establishing standoffs from unfavorable areas and to quantify the amount of water in contact with the container.

6.4.3 ISSUE 1.12: SEAL CHARACTERISTICS

6.4.3.1 Introduction

The question asked by Issue 1.12 is

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

The regulatory basis for Issue 1.12, the postclosure design criteria of 10 CFR 60.134, requires that

1. Seals for the shafts and boreholes shall be designed so that following permanent closure, they do not become permanent pathways that compromise the geologic repository's ability to meet the performance objectives for the period following closure.

2. Materials and placement methods for seals shall be selected to reduce, to the extent practicable, the potential (1) for creating a preferential pathway for ground water to contact the waste packages, or (2) for radionuclide migration through existing pathways.

A brief summary of the plan for assessing the performance of the seal system is described in Section 8.3.5.11. The complete discussion of the proposed strategy for resolution of this issue is presented in Section 8.3.3 (seal systems). Readers unfamiliar with the issue resolution strategy for this issue should review the contents of Section 8.3.3 before continuing. Issue 1.12 has been subdivided into four information needs and the completed work has been identified under the associated information need. The completed work is numbered in a manner that corresponds with the information need numbering system. For example, 1.12.4-1 is the completed work identified under the fourth information need of Issue 1.12. The information needs are as follows:

Information Need 1.12.1 Site, waste package, and underground facility information needed for design of seals and their placement methods.

This information need consists of the review and compilation of information associated with the site, the waste package, and the underground facility design. This work is ongoing and is not completed. The site characterization information needed for seal design is identified in Section 8.3.3.2.1.

Information Need 1.12.2 Materials and characteristics for seals for shafts, drifts, and boreholes.

This information need consists of the review, compilation, and development of information associated with the material and characteristics of seals for shafts, drifts, and boreholes. This work is ongoing. The site characterization information needed for seal design is identified in Section 8.3.3.2.2.

Information Need 1.12.3 Placement methods for seals for shafts, drifts, and boreholes.

The development of placement methods for seals has not begun; this information need is discussed in Section 8.3.3.2.3.

Information Need 1.12.4 Reference design of seals for shafts, drifts, and boreholes.

Number	Description
1.12.4-1	In the repository sealing concepts (hydrologic analysis 1), the concepts for sealing a nuclear waste repository in unsaturated tuff are presented. These concepts provide the basis for all future design activities in the NNWSI Project repository sealing program. As part of the development of these concepts, shaft and drift drainage calculations are performed.
1.12.4-2	In the modification of rock mass permeability in the zone surrounding a shaft (hydrologic analysis 2), analyses were performed to assess how the rock mass permeability around a vertical shaft excavated in a densely welded, highly fractured tuff might change. The modification of the rock mass permeability is due to the effects of stress distribution and blasting. From these analyses, a modified permeability zone model is presented.
1.12.4-3	In the hydrologic calculations to evaluate backfill of shafts and drifts (hydrologic analysis 3), hydrologic calculations were performed to assess the need for and extent of sealing the drifts and shafts.

1.12.4-4 In the numerical analysis to evaluate backfilling repository drifts (hydrologic analysis 4), hydrologic calculations evaluating the influence of backfilled drifts on flow through the surrounding unsaturated tuff matrix are presented.

1.12.4-5 In the vadose water flow around a backfilled drift (hydrologic analysis 5), the magnitude and direction of the ground-water flow in the vicinity of a vertically emplaced waste container were calculated. The waste container was situated in an unsaturated tuff environment.

Additional information on Information Need 1.12.4 is presented in Section 8.3.3.2.4.

Summary information describing the computer codes used in the analyses supporting the completed work just identified is contained in Table 6-30.

Summary of status of issue resolution

A brief summary of the status of issue resolution for sealing is presented below. This will aid in establishing a perspective for how the results of the individual analyses and evaluations completed to date (Section 6.4.3.2) contribute to the definition of planned future activities.

Sealing of a potential repository at Yucca Mountain involves emplacement of sealing elements in the shafts, ramps, boreholes, and underground facility. Design development of sealing elements first required establishing sealing concepts. Sealing concepts were developed with an understanding of the hydrogeology at the site and selected numerical calculations.

The following site conditions guided the concept development as well as the types of calculations to be performed.

1. The repository would be located in the unsaturated zone, 200 to 400 m above the water table.

2. The repository would be located in the Topopah Spring Member, which is a highly fractured, welded tuff unit.

3. Water flow at the repository horizon could occur within the matrix or discrete, water-producing zones.

The NNWSI Project repository sealing program is currently using these concepts to develop more specific sealing designs. Because specific seal designs have not been identified, it can be concluded that additional work is necessary to resolve this issue. Additional work will fall into the following categories:

1. Develop a complete design for the sealing subsystem. Design includes not only selection of the appropriate geometries for seals but also selection of materials and development of an appropriate emplacement strategy. Currently, the efforts within the NNWSI Project repository sealing program are focused on establishing the need for sealing and the appropriate design requirements. Both of

Table 6-30. Codes used for analyses addressing Issue 1.12

Code name	Author	Code location(s)	Design parameter	Analysis Description
TRUST	A. E. Riesenauer K. T. Key T. N. Narasimhan R. W. Nelson (Reisenauer et al., 1982) NUREG/CR-2360	Pacific Northwest Laboratory, Battelle Memorial Institute	Shaft drainage potential-performance evaluation of sealing components.	Finite difference; determines fluid flow past sealing elements in variably saturated porous media.
SAGUARO	R. R. Eaton D. K. Gartling D. E. Larson (Eaton et al., 1983) SAND 82-2772	Sandia National Laboratories	Shaft drainage potential-performance evaluation of sealing components.	Finite difference; determines fluid flow past sealing elements in variably saturated porous media.

these efforts will help to establish the suitable characteristics of sealing elements in shafts, ramps, boreholes, and the underground facility. These characteristics then will support the development of the configuration of sealing elements. First, selection of the appropriate design option will be made as part of the advanced conceptual design.

2. Document the hydrologic conditions encountered while excavating the exploratory shaft and the exploratory shaft facility. This information is necessary because the sealing concepts are based on the current understanding of the hydrologic conditions. This information will be obtained by participants involved with the testing in the exploratory shaft facility.

3. Assess the performance of select sealing designs to confirm acceptable performance and to arrive at preferred designs through design tradeoff studies. These tradeoff analyses will include performance, cost, and environmental concerns.

The resolution of this issue is believed (based upon preliminary evaluations completed to date) to be possible because of the following:

1. Conceptual designs have been defined as presented in Section 6.2 and in Chapter 5 of the SCP-CDR (SNL, 1987). These conceptual designs were developed assuming reasonably available technology would be used to construct these designs. Further, these designs form the basis for the site data needed.

2. Performance goals have been developed (Section 8.3.3) that can be used to evaluate the suitability of seal designs.

3. Preliminary calculations indicate that even if more water than anticipated is encountered at the repository horizon, these waters can effectively be isolated and drained through the repository drift floors.

However, before demonstrating the resolution of this issue, a total seal system design will have to be proposed and its performance evaluated. This includes the effects of environmental conditions on the performance of sealing materials. Currently, the design requirements are being developed and potentially suitable materials are being selected. The information obtained from this effort will support development of the ACD.

6.4.3.2 Work completed

Significant results have been reported to date for the work under Information Need 1.12.4. The approach used, data utilized, and the results obtained are summarized in the following section.

1.12.4-1 Repository sealing concepts (hydrologic analysis 1)

Analytical approach

Calculations evaluating shaft and drift drainage were presented in Fernandez and Freshley (1984). The purpose of these calculations was to determine if water entering the shafts or drifts can be drained at those locations. The possibility of using a shaft for drainage below the underground facilities was investigated using methods proposed by the U.S. Bureau of Reclamation (USBR) for boreholes and was summarized and critiqued by Stephens and Neuman (1982a,b). Two of the steady-state methods summarized by Stephens and Neuman (i.e. the methods by Glover and by Nasberg-Terletskata) were used directly in evaluating the shaft drainage potential. Flow into a drift floor was evaluated to determine the extent of the floor used to dissipate water from a discrete fault or fracture zone. Flow was computed using the equation for parallel plate analogy for flow in fractures.

Data

Drainage through a highly fractured, welded tuff was computed in this analysis. Two locations of welded tuff were considered: drift floor and the base of shafts. To compute drainage, the effective hydraulic conductivity was required. Values for fracture aperture width, hydraulic conductivity of fractures, and fracture frequency were used to compute the effective hydraulic conductivity.

From Zimmerman and Vollendorf (1982), two sets of values were selected for hydraulic conductivity and aperture width. One set represented the lowest measured hydraulic conductivity with an associated aperture width. The second set represented an arithmetic mean of 12 hydraulic conductivities with an associated mean aperture width. A conservatively low value for fracture frequency was assumed based on information discussed by Scott et al. (1983). Fracture frequencies presented by Scott et al. (1983) represented fracture frequencies of cores and outcroppings of densely welded tuff in the vicinity of Yucca Mountain.

Results

The performance of two sealing system elements (Section 8.3.3.2) was evaluated in this hydrologic analysis. The sealing system elements evaluated were the unsaturated Topopah Spring Member (TSw2) at the base of shafts (shaft drainage analysis following) and the drift floor within the Topopah Spring Member to accommodate net flow from faults (drift drainage analysis below).

From the results of the shaft drainage analysis, it was concluded that an estimated inflow of approximately 100 to 150 m^3/yr can be effectively drained through the bottom of the shaft, even when considering conservative values of fracture spacing and permeability. A geologic unit having bulk rock hydraulic conductivity of 5 x 10^{-6} cm/s could potentially drain 150 m^3/yr for a 8-m (22-ft)-diameter shaft and 120 m^3/yr for a 4-m-diameter shaft. Both conditions assume a modest buildup of water (i.e., about 15 m) at the base of a shaft. Because of the conservative nature of the calculations presented for drainage at the base of shafts (Fernandez and

Freshley, 1984) and because the expected value for bulk rock hydraulic conductivity of welded tuff is likely to be higher than 5 x 10^{-6} cm/s, yearly inflows of water (100 to 150 m^3/yr) into shafts are expected to drain through the bottom of shafts.

From the drift drainage calculations, it was concluded that considering the possible effects of fracture permeability, an inflow of 2.8 m^3/wk into a drift can be drained through a 6-m length of drift floor.

The ability to achieve the performance goals for the underground facility will depend on the frequency of water occurrences in the underground facility and the design options available to reduce or control water flow into the waste disposal rooms. Tradeoff analyses performed as part of advanced conceptual design and license application design will be performed to select the preferred design option.

1.12.4-2 Modification of rock mass permeability in the zone surrounding a shaft (hydrologic analysis 2)

Analytical approach

An analysis was performed to determine the modification in rock mass permeability resulting from stress redistribution and blast damage around a vertical shaft excavated through fractured, welded tuff (Case and Kelsall, 1987). To assess the permeability changes due to stress redistribution, elastic and elastoplastic stress analyses were performed to estimate the stress distributions after excavations for a wide range of rock properties and in situ stress conditions. Changes in stress are related to changes in rock mass permeability using stress-permeability relations for fractures obtained from laboratory and field testing. Coupling the information from the stress analysis with the relationship established between stress and permeability, the permeability enhancement due to stress redistribution was calculated.

The second half of this analysis involved performing an assessment of the increased permeability due to blast damage adjacent to the wall of the shaft. Both case histories and theoretical relationships between explosive charge weight and the particle velocity required to produce fracturing were evaluated to determine the potential extent of damage. This assessment of blast damage together with the analysis of stress redistribution effects on permeability were combined to develop the modified permeability zone model.

Data

The purpose of this analysis was to determine the changes in permeability around a shaft excavated in fractured, welded tuff. These changes were caused by stress redistribution in the area surrounding the excavation and by damage to this area due to blasting. The result of this analysis was the development of a modified permeability zone model. The data used to develop the model included the following:

1. Compressive strength of welded tuff (Price, 1983).

2. Tensile strength of welded tuff (Nimick et al., 1984).

3. Rock mass rating values (Langkopf and Gnirk, 1986).

4. Laboratory investigations of the influence of effective confining stress on fracture permeability (Peters et al., 1984).

5. Field data associated with the G-tunnel heated block test, specifically, permeability versus effective normal stress from a single fracture (Zimmerman et al., 1985).

6. Theoretical relationship between the charge weight and particle velocity required to produce fracturing (Holmberg and Persson, 1979).

Results

The modified permeability zone model was developed so that the performance of the shafts and drifts, as excavated, could be evaluated. This model then could be used in addressing the need for sealing. If it is determined that sealing is needed or desired, this model could be used in developing specified designs to achieve a desired performance.

The assumptions and data used in this analysis were varied to address potentially varying field conditions. Because of this variation in input parameters, multiple results were obtained. Two models were developed: one for a 100-m depth location in welded tuff and the second for a 310-m depth location in welded tuff. Expected conditions and upper bound changes also were evaluated. Finally, three conditions concerning blast damage were evaluated: no blast damage, a 0.5-m blast damage zone, and a 1-m blast damage zone from the shaft wall.

To compare the relative changes in rock mass permeability, the permeability was averaged over an annulus 1 radius wide around a 4.4-m (14.5-ft) diameter shaft. By performing this averaging, it was shown that permeability changes could range from 15 to 80 times the undisturbed rock mass averaged over an annulus 1 radius wide from the shaft wall. This model will be used in future analyses to determine the performance of the overall sealing system.

1.12.4-3 Hydrologic calculations to evaluate backfill of shafts and drifts (hydrologic analysis 3)

Analytical approach

Hydrologic calculations were performed to assess the need for and extent of sealing shafts and drifts. Two geometries were evaluated using the computer code TRUST (Reisenauer et al., 1982):

1. A drift with vertical emplacement of waste packages to determine water flow near the waste package and through the drift.

2. A shaft penetrating a slightly inclined contact between welded and nonwelded tuff units to determine the water flow into the shaft.

TRUST (Reisenauer et al., 1982), an integrated, finite difference code for unsaturated ground-water flow, was used for the drift and shaft analyses. Indi-vidual subanalyses were evaluated for each geometry. For the drift geometry, four subanalyses were performed. All subanalyses assumed that a drift was located in a welded tuff unit. The drift backfill, either clay or sand, and the saturated permeability values for the welded tuff unit were varied. Five subanalyses were evaluated for the shaft analysis. All drift subanalyses assumed that the shaft penetrated an inclined, welded-nonwelded tuff contact. It was assumed that the shaft was backfilled with either a clay or a sand material. The relative positions of the nonwelded and welded tuff units were varied together with the saturated permeability values. Additional details of the subanalyses evaluated are given in Freshley et al. (1985a) and in Fernandez and Freshley (1984).

Data

As indicated under the approach section for this analysis, water flow under unsaturated conditions was evaluated for two geometries. The first geometry involved a drift located in an unsaturated, welded tuff. The second geometry involved a shaft penetrating unsaturated welded and nonwelded units. Both of these geometries assumed that the drift or shaft was backfilled with a sand or clay. To assess water flow in the vicinity of the shaft or drift, it was necessary to obtain hydrologic properties of the materials used in the analysis. The permeability versus pressure-head relationships for sand, clay, and the welded and nonwelded tuff units were of primary concern. Knowledge of porosity of the materials also was required. The hydrologic properties and porosity of sand (Crab Creek sand) and clay (Chino clay) were taken from Mualem (1976). The hydraulic properties of selected welded and nonwelded units were determined from core taken from well USW GU-3. Under some instances, the permeability versus pressure-head curves were scaled up or down to provide a broad range of input parameters. All the data used in this analysis are included in Freshley et al. (1985a). The only other datum used in this analysis was the assumed input flux of 0.4 cm/yr.

Results

This analysis addressed the performance of two sealing system elements, shaft fill and drift backfill. The function of the shaft fill and drift backfill is to reduce the amount of water entering the waste disposal rooms. The analysis goes further to determine if the type of backfill can significantly influence the flow past waste packages for the drift backfill portion of the analysis. The conclusions given below are taken from Fernandez and Freshley (1984) and Freshley et al. (1985a).

The following conclusions were derived from the drift analysis:

1. From a hydrologic perspective, backfilling of the repository drifts is not essential. This conclusion is based on the observation that varying the backfill in drifts does not significantly influence the flow rates in the vicinity of the waste packages.

2. Water flow past horizontally emplaced waste packages cannot be altered by varying drift backfill. The standoff zone (i.e., the zone between the drift and the first waste package) is sufficiently

large to negate the effect backfill materials have on ground-water flow past the waste packages.

3. If backfilling is necessary, coarse, rather than fine, materials are more satisfactory because of their capacity to drain and act as a capillary barrier.

4. Greater flow of water into drifts may occur when saturation in the surrounding rock formation is high (98 to 99 percent). However, this level of saturation is unlikely to occur in the horizon being considered for the repository (Topopah Spring Member).

The conclusions from the shaft analyses were

1. From a hydrologic viewpoint, assuming porous matrix flow, backfilling the shafts is not essential. This conclusion is based on the prediction that the amount of water entering the shafts will be insignificant.

2. If backfilling is required for other reasons, the shaft should be filled with a material that behaves hydrologically like a sand.

The conclusions from the drift analysis stated above suggest that where free-flowing water from discrete, water-producing zones is not encountered, backfilling is not essential. Therefore, if sealing is required in the underground facility, emphasis will be placed on controlling water that enters the underground facility. In the current conceptual design, drainage paths exist from the emplacement drifts to the access drifts, then into the mains and finally to the base of the emplacement exhaust shaft. The ability to achieve the performance goals established for the underground facility will be evaluated, considering the alternative sealing components that could be emplaced in the underground facility.

Based on the shaft backfilling evaluation, assuming porous matrix flow, it was concluded that backfilling is not essential for hydrologic reasons, however, for safety reasons, backfilling of shafts will occur. In determining how the performance goals for shaft sealing components can be met, shaft backfill, the modified permeability zone, and other shaft sealing components will be evaluated.

1.12.4-4 Numerical analysis to evaluate backfilling repository drifts (hydrologic analysis 4)

Analytical approach

Additional hydrologic calculations evaluating the influence of backfilled repository drifts in a welded tuff unit were performed following the completion of the hydrologic calculations described under: hydrologic analysis 3. The TRUST code (Reisenauer et al., 1982) was used in this analysis. Both fine- and coarse-grained materials were assumed as the backfill material in the drift. The primary difference between this calculation and the hydrologic analysis 3 was the selection of a different permeability versus pressure-head relationship for the welded tuff unit. Details are given in Freshley et al.(1985b).

Data

This analysis evaluated the water flow, under unsaturated conditions, in the vicinity of a drift that was backfilled with a sand or clay material. This analysis (Freshley et al., 1985b) differed from that presented in Freshley et al. (1985a), by the selection of the hydraulic properties of the welded tuff unit modeled and by the flux imposed at the upper boundary. This analysis used data on the hydraulic properties of welded tuff that were considered more representative of the Topopah Spring Member than that used by other analyses. The data used are included in Peters et al. (1984). The moisture retention characteristics and unsaturated permeabilities from sample G4-6 were used in this analysis. Data obtained from sample G4-6 were used because the porosity and permeability of sample G4-6 are lower than for sample S-19 presented by Freshley et al. (1985a), and are more representative of the prospective host rock than data from other samples. Further, sample G4-6 is a densely welded tuff from the Topopah Spring Member. The flux used in this analysis was 0.01 cm/yr.

Results

This analysis evaluated the role of drift backfill on flow past a vertically emplaced waste package. Two moisture retention characteristic curves for the host rock formation were selected to perform the analysis. This analysis differs from hydrologic analysis 3 in that a second sample characteristic curve (sample G4-6) was input into the model. This second characteristic curve was more representative of the host rock formation. The conclusions from this analysis were similar to the conclusions presented in the hydrologic analysis 3. Thus, the conclusions from hydrologic analysis 3 were substantiated.

1.12.4-5 Vadose water flow around a backfilled drift (hydrologic analysis 5)

Analytical approach

Hydrologic analyses (Mondy et al., 1985), similar to those described in hydrologic analyses 3 and 4, were performed using the computer code SAGUARO (Eaton et al., 1983). SAGUARO is a finite difference code developed to model the flow of vadose water. In this analysis, the magnitude and direction of flow were determined in the vicinity of a vertically emplaced waste package below a drift backfilled with various materials. Sand and clay, representing the potential backfilled materials, were selected because of their significantly different hydrologic properties.

Data

The data used in this analysis were identical to the data used to perform hydrologic analysis 3. The hydrologic properties and porosity for sand and clay were taken from Mualem (1976). The hydrologic properties of the welded tuff unit were taken from preliminary hydrologic analyses of selected welded tuff samples from USW G-3.

Results

The sealing system element evaluated in this analysis was the drift backfill associated with the underground facility. The purpose of this analysis was to evaluate the flow past vertically emplaced waste packages using the same geometry as used in hydrologic analysis 3. However, this analysis was performed using a different computer code than that used in analysis 3 (TRUST) (Reisenauer et al., 1982). In this sense, corroboration of the results obtained in hydrologic analysis 3 would be possible. The following conclusions are based on the study in Mondy et al. (1985).

1. With the drift simulated as being backfilled with clay, the predicted water flow past a waste package is not significantly different from that predicted in areas relatively far removed from the drifts. Similarly, the analysis in which the drift was simulated as being backfilled with sand predicted that the flow near the waste package would be reduced by only 10 percent compared to that predicted when simulating clay-filled drifts. Hence, the water flow past a vertically emplaced waste package is not very sensitive to the hydrologic properties of the backfill material for the conditions simulated in this preliminary analysis.

2. The vertical water flow is diverted only one to two drift widths to the side of the drift by the drift backfill. This limited diversion implies that the drift backfill would not influence flow past a horizontally emplaced waste package if a stand-off distance of more than two drift widths is included in the design.

The conclusions from this analysis suggest, as did hydrologic analyses 3 and 4, that if sealing is required in the underground facility, emphasis will be placed on designing sealing components that will control water from discrete, water-producing zones.

6.4.3.3 Future work

6.4.3.3.1 Analysis needs

Because of the structure of this report, the analysis needs are discussed here and in Sections 8.3.3.1.3 (seal design), 8.3.3.1.4 (seal modeling), 8.3.3.2.1 (information needed for seal design under Information Need 1.12.1) and 8.3.5.11 (plans to assess seal system performance). The intent of this section is to summarize these identified sections.

The strategy used in developing seal designs is (1) to establish the need for seals through the use of analytical solutions describing unsaturated and saturated flow and (2) to account for the thermal effects of waste emplacement on the environmental conditions expected in the underground facilities, shafts, and ramps. Depending on the extent of the data base, sensitivity studies will be performed to establish a broad range of responses. Analyses will be performed on sealing elements to determine if the assigned performance goals can be achieved. This analytical effort may include the use of simple analytical solutions or complex computer codes.

6.4.3.3.2 Developmental needs

Numerical codes may be used to assess performance of sealing components, and can be used to more accurately define response of sealing components or subsystems. Responses can include hydrologic and thermomechanical behavior.

No new flow codes will be developed as part of the sealing program. Only existing codes will be used to assess the performance of sealing designs. Validation of the codes will be performed as part of the testing program associated with the exploratory shaft facility, and the strategy for this validation is described in the discussion of the ground-water travel time issue (Issue 1.6, Section 8.3.5.12).

6.4.3.3.3 Site information needs

This section presents the site characterization parameter needs to resolve Issue 1.12 (seal characteristics). The information needed to confirm design assumptions is included in tables in Section 8.3.3.2.1. Information such as the saturated hydraulic conductivity, gravitational analyses, compressibility of shaft fill, borehole construction, and geologic logs associated with specific boreholes, will support the design process in the selection of the appropriate methods to emplace sealing components. Site information needed to validate analytical methods may include hydrologic characterization of the Topopah Spring Member (TSw2). Specific properties are unsaturated matrix properties and the drainage capacity of the TSw2 unit. The prevalence of water-producing zones, if any, and the hydrologic nature of the Ghost Dance fault, the area underlying Drill Hole Wash, and the rock matrix will all be important site information needs in selecting the most appropriate sealing designs.

6.4.4 ISSUE 2.1 PUBLIC RADIOLOGICAL EXPOSURES--NORMAL CONDITIONS

6.4.4.1 <u>Introduction</u>

The question asked by Issue 2.1 is

> During repository operation and closure, (a) will the expected average radiation dose to 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 Part 191 Subpart A, and 10 CFR Part 20?

The complete discussion of the proposed strategies for resolution of this issue is presented in Section 8.3.5.3 (public radiological exposures--normal conditions). Readers unfamiliar with the issue resolution strategy for this issue, should review the contents of Section 8.3.5.3 before continuing.

Issue 2.1 has been subdivided into three information needs, and the completed work has been identified under the associated information need. The completed work is numbered in a manner that corresponds with the information need numbering system. For example, Section 2.1.2-1 is the first completed work identified under the second information need of Issue 2.1. Work that is similar to that required by this issue is discussed in Section 6.4.5 (radiological safety of workers--normal conditions) and in Section 6.4.6 (accidental radiological releases).

The Issue 2.1 information needs are as follows:

Information Need 2.1.1 Site and design information needed to assess preclosure radiological safety.

This information need consists of the review and compilation of information associated with the site; waste forms; surface and subsurface facility design; waste receiving, preparation, storage, and emplacement procedures; waste retrieval, storage, preparation, and shipping procedures; site-generated waste handling, preparation, and shipping procedures, repository caretaking procedures; and repository closure procedures. This work is ongoing. The site characterization information needed for resolution of this issue is identified in Section 8.3.5.3.1.

Information Need 2.1.2 Determination of projected releases of radioactive material from the repository to restricted and unrestricted areas under normal conditions.

Number	Description
2.1.2-1	The radioactive releases during normal operations for the surface facilities under normal operating conditions were addressed and reported in Section 6.1 of the SCP-CDR.

Information Need 2.1.3 Determination that public radiation exposure resulting from the release of radioactive material from the repository combined with exposures from offsite installations and operations meets applicable requirements.

Methodology similar to that used to obtain projections of public radiation exposure, resulting from the release of radioactive material under accident conditions, Section 6.4.9, will be used to forecast public exposures under normal conditions.

6.4.4.2 Work completed

The following work has been completed for Issue 2.1.

2.1.2-1 Radioactive releases during normal operations

Section 6.1 of the SCP-CDR, Radioactive releases during normal operations, addresses the releases that are expected to occur as a result of the waste receiving, preparation, storage, and emplacement activities. Releases of naturally occurring radiation (e.g., radon-222 and radon daughters released as a result of mining activities or released from the mined materials stored on the surface) and radiation releases from sources other than the site (e.g., radiation releases from the Nevada Test Site) have not been addressed by Section 6.1 of the SCP-CDR. This section is separated into four subsections: (1) liquid effluents, (2) solid wastes, (3) gaseous secondary wastes, and (4) site monitoring. In the first three subsections, the design concepts and approaches for collecting, monitoring, treating, and disposing of liquid, solid, and gaseous wastes are discussed. These discussions include identification of the sources, types, quantities, method of treatment, and method of disposal of these wastes. The releases of radioactive materials from the repository to the restricted and unrestricted areas under normal conditions are estimated. The fourth subsection discusses the requirements and philosophy of the site monitoring program. The site monitoring program will ensure that radioactive releases to the restricted and unrestricted areas under normal conditions are within the limits established in the regulations addressed by this issue.

6.4.4.3 Future work

Preliminary investigations are planned as part of the advanced conceptual design activities and more detailed analyses are planned as part of the license application design and licensing activities for the mined geologic disposal system.

Some of the site characteristics which have been identified in Section 8.3.5.3 as site information that should be obtained by the site characterization program are:

1. Meteorology of the Yucca Mountain site and adjacent areas.

2. Radon-222 and radon daughter emanation rate from the host rock at ambient and elevated temperatures.

6.4.5 ISSUE 2.2 WORKER RADIOLOGICAL SAFETY--NORMAL CONDITIONS

6.4.5.1 Introduction

The question asked by Issue 2.2 is

> 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?

The regulatory requirement addressed by this issue is 10 CFR 60.111(a). The wording of 10 CFR 60.111(a) invokes 10 CFR Part 20.

The performance objective stated in 10 CFR 60.111(a) (performance of the geologic repository operations area through permanent closure) is as follows:

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

The complete discussion of the proposed strategies for resolution of this issue is presented in Section 8.3.5.4 (radiological safety of workers--normal conditions). Readers unfamiliar with the issue resolution strategy for this issue, should review the contents of Section 8.3.5.4 before continuing.

Issue 2.2 has been subdivided into two information needs, and the completed work has been identified under the associated information need. The completed work is numbered in a manner that corresponds to the information need numbering system. For example, 2.2.2-1 is the first completed work identified under the second information need of Issue 2.2. The information needs are as follows:

Information Need 2.2.1 Determination of radiation environment in surface and subsurface facilities due to natural radioactivity.

As part of the site characterization program, the natural radioactivity of the site will be characterized. The natural radioactivity of the site will be used in the determination of the expected annual and repository lifetime exposures of workers to natural radioactivity. No work on this information need, other than the identification of the required site characteristics, has been completed. This work, identification of site characteristics needed for determination of natural radiation environments, is described in Section 8.3.5.4.1.

Information Need 2.2.2 Determination that projected worker exposures and exposure conditions meet applicable requirements.

Number	Description
2.2.2-1	Worker exposures under normal operating conditions have been estimated and these estimates have been used in both the design and evaluation of the repository facilities.

6.4.5.2 Work completed

The completed work for Issue 2.3 is described in the following section.

2.2.2-1 Worker exposures under normal conditions

Two investigations have been conducted to forecast the expected exposures of workers to penetrating radiation during repository operations under normal operating conditions. The results of these investigations are reported in Dennis et al. (1984a) and in Stinebaugh and Frostenson (1987).

The reports by Dennis et al. (1984a) and Stinebaugh and Frostenson (1987) were prepared for use by the repository architect-engineer in the conceptual design of the waste-handling facilities and equipment. These reports list the repository operations and the estimated worker radiation exposures. All forecast annual exposures were below the 5 rem/yr permissible dose equivalent limit. However, eight worker positions were identified where the forecast exposures exceed the 1 rem/yr design objective (DOE, 1986b, Chapter 11). future design efforts will focus on reducing the exposure at these eight positions, as well as reducing general worker exposure to levels as low as reasonably achievable.

Stinebaugh and Frostenson (1987) was prepared after Dennis et al. (1984a) and it addresses the expected worker exposure under current SCP-CDR (Chapter 6-8 of SNL, 1987) expected conditions during the emplacement and retrieval of spent fuel when the vertical emplacement mode is used. Emplacement and retrieval operations and the estimated worker radiation exposures are listed. All worker exposures were found to be below the 5 rem/yr exposure limit. Only one worker position exceeded the DOE design objective of 1 rem/yr. Future design efforts will focus on reduction of exposure at this position, as well as reduction of general worker exposure to levels as low as reasonably achievable.

6.4.5.3 Future Work

6.4.5.3.1 Analysis Needs

Worker exposures resulting from the natural radioactivity of the host rock will be investigated as site information becomes available. During each subsequent design phase (advanced conceptual design, license application design, and final procurement and construction design), the expected exposure of workers under normal conditions will be forecast. The forecast will become more detailed as the supporting design, waste characterization, and site information become more detailed.

6.4.5.3.2 Site data needs

As discussed in Section 8.3.5.4 (radiological safety of workers--normal conditions), certain site data are needed to determine the radiation environment in the surface and subsurface facilities as a result of natural radioactivity. The main contribution to worker exposure from natural radioactivity is due to radon-222 and its daughter isotopes. There are other contributions from other naturally occurring radionuclides; however, these are not significant when compared with the contribution due to radon-222 and its daughters. Some of the site data needed to determine worker exposure as a result of natural radioactivity are as follows:

1. Radon-222 and radon daughter emission rates from the host rock.
2. Meteorological and environmental data.

Certain other site data are needed to estimate worker exposure from operations. These also are discussed in Section 8.3.5.4. These site data are the characteristics of the host rock required to determine the shielding properties of the host rock. Other than these site data, no further site data have been identified as necessary to determine the expected radiation exposure of the workers under normal repository conditions.

6.4.6 ISSUE 2.3: ACCIDENTAL RADIOLOGICAL RELEASES

6.4.6.1 Introduction

The question asked by Issue 2.3 is

> 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 of workers in the restricted area, in excess of applicable limiting values?

The complete discussion of the proposed strategy for resolution of this issue is presented in Section 8.3.5.5 (accidental radiological releases). Readers unfamiliar with the issue resolution strategy for this issue, should review Section 8.3.5.5 before continuing.

Under this issue a list of structures, systems, and components important to safety will be developed. This list and a list of structures, systems, and components important to waste isolation combine to form the Q list.

Issue 2.3 has been subdivided into the following four information needs:

Information Need 2.3.1 Determination of credible accidents applicable to the repository.

Information Need 2.3.2 Determination of projected releases of radioactive material from the repository to restricted areas under accident conditions.

Information Need 2.3.3 Determination that projected worker exposures and exposure conditions meet applicable requirements.

Information Need 2.3.4 Determination that projected public exposures and exposure conditions under accident conditions meet applicable requirements.

These four information needs indicate the various steps (accident definition, projected releases, and predicted exposures) conducted in completing safety analyses for accident conditions. These steps have been taken in the two preliminary safety analyses completed to date for the proposed Yucca Mountain repository. The discussion for resolving the status of this issue is organized to show the progression made in moving from the analysis based on preliminary repository design concepts (Jackson, 1984) to that based on the conceptual design documented in the SCP-CDR (SNL, 1987).

Table 6-31 contains summary information describing computer codes used in the analyses supporting the completed work discussed here.

6.4.6.2 Work completed

This section discusses the work that has been performed to date to support resolution of this issue. The work has been documented in three reports:

1. Jackson, J. L., H. F. Gram, K. J. Hong, H. S. Ng, and A. M. Pendergrass, "Preliminary Safety Assessment Study for the Conceptual Design of a Repository in Tuff at Yucca Mountain," SAND83-1504, Sandia National Laboratories, Albuquerque, NM, December 1984. (Jackson et al., 1984)

2. "Preliminary Preclosure Radiological Safety Analysis," prepared by Bechtel National, Inc., for Sandia National Laboratories, Albuquerque, New Mexico, Appendix F of the Site Characterization Plan-Conceptual Design Report (SNL, 1987).

3. "Items Important to Safety and Retrievability for the Yucca Mountain Repository," prepared by Bechtel National, Inc., for Sandia National Laboratories, Albuquerque, New Mexico, Appendix L of the Site Characterization Plan-Conceptual Design Report (SNL, 1987).

The first report by Jackson et al. (1984) is of a scoping nature and based on preliminary repository concepts. Nevertheless, this work represents a significant contribution to the resolution of this issue. The second and third reports are Appendices F and L of the SCP-CDR, respectively. The second report is based on a more advanced and more complete design (although still conceptual in nature) of the repository than the Jackson et al. (1984) study and, therefore, enhances and updates some of the results of that earlier report. Also, the Jackson et al. (1984) report presented preliminary estimates of worst-case radioactive releases resulting from postulated accidents, while Appendix F of the SCP-CDR estimates radioactive releases for accidents developed using a probabilistic risk assessment (PRA) approach. Appendix L of the SCP-CDR discusses the results of Appendix F and uses the results to make a preliminary identification of items important to safety. The Jackson et al. (1984) report is discussed first, followed by an integrated discussion of Appendices F and L of the SCP-CDR.

Table 6-31. Codes used in analyses addressing Issue 2.3

Code name	Author	Code location	Design parameter	Analysis description
AIRDOS-EPA	R.E. Moore C.F. Baes III L.M. McDowell-Boyer A.P. Watson F.O. Hoffman J.C. Pleasant C.W. Miller	U.S. Environmental Protection Agency	Accident scenario. Atmospheric transport of radioactive plume. First-year and 50-yr dose commitments to maximum individual and repository personnel calculated using ALLDOS dose conversion factors.	Radionuclide releases modeled as Gaussian distributed short-duration plumes dispersed during average climatic conditions.
ORIGEN 2	A.G. Croff	Oak Ridge National Laboratory	Radionuclide source terms and release fractions (Jackson et al., 1984) 83-1504. Dose rate map extrapolation.	Calculates the radionuclide inventories for the various waste forms.

Summary of the Jackson et al. (1984) report

As just mentioned above, the Jackson et al. (1984) report presented preliminary estimates of worst-case releases resulting from postulated accidents for the repository based on preliminary repository concepts. Following is a discussion of the approach used by the Jackson et al. (1984) report and the results of that report.

The potential causes of accidental releases from repository operations that would expose the general public and repository personnel were divided into three main categories: (1) natural phenomena, (2) external manmade events, and (3) operational accidents. Three accidents were developed for the natural phenomena category: (1) flooding, (2) tornado or high winds, and (3) earthquake. Aircraft crash and ground motion resulting from underground nuclear explosion (UNE) tests were the two manmade events developed. Finally, for the operational accidents category, five accidents were developed: (1) a fuel assembly drop in a hot cell, (2) a transportation accident and fire at the loading dock that involves spent fuel, (3) a transportation accident and fire at the loading dock that involves commercial high-level waste (CHLW), (4) a transportation accident and fire in the waste-handling ramp that leads from the surface facilities to the disposal horizon, and (5) a transportation accident and fire in a waste emplacement drift in the horizontal waste emplacement concept.

Source terms for each accident were derived from the radionuclide inventory involved, the waste form, and the postulated accident. Radionuclide inventories were based on spent fuel from pressurized water reactors that had been out of reactor for 10 years, on CHLW derived from reprocessing this spent fuel, and on West Valley high-level waste (WVHLW).

The principal exposure pathway in the scenarios analyzed was the atmospheric transport of a radioactive plume. Exposures resulted from (1) radiation reflected from the plume (cloud shine), (2) radiation from fallout on the ground (ground shine), (3) direct contact (air immersion), (4) inhalation of radionuclides from the plume, and (5) ingestion of food-stuffs contaminated by radioactive fallout. In the flooding scenario, direct contact with contaminated flood water was the exposure mechanism for repository personnel.

The source terms and pathways were used to calculate the 50-yr dose commitments to the general public and the first-yr and 50-yr dose commitments to the maximum individual and repository personnel in each of the 10 scenarios. Dose commitments to the public were calculated using the AIRDOS-EPA computer code. Releases were modeled as Gaussian-distributed, short-duration plumes dispersed during averaged climatic conditions. Dose commitments to the maximum individual and to repository personnel were calculated using the ALLDOS dose conversion factors. The release plume was postulated to pass directly over the maximum individual at average wind velocity.

Dose commitments reported in this study were made up of an acute dose and a chronic dose commitment. These doses were received via external and internal exposure pathways. The acute dose was received within hours or minutes following the accidental release and was a result of external exposure. The chronic doses were received as a result of continuous exposure to radionuclides incorporated in the body after inhalation or ingestion. The calculated dose commitments were converted to health effects (excess cancer deaths), in accordance with the methodology for determining dose and health-effect relationships described in the BEIR III report (BEIR, 1980).

The Jackson et al. (1984) report presents the results of the analysis in terms of (1) doses to the repository workers, (2) doses to the maximum individual, and (3) doses to the general public. The results of the report also included the identification of accident scenarios and estimates of the probabilities of these accidents.

The Jackson et al. (1984) report analyzed ten accident scenarios. These were divided into three categories: (1) natural phenomena, (2) manmade external events, and (3) operational accidents. The natural phenomena analyzed included a flood, a 0.4g horizontal acceleration earthquake, and a tornado. The probability of these events was estimated to be 1.0×10^{-2} per yr, less than 1.3×10^{-3} per yr, and less than 9.1×10^{-11} per yr, respectively. Because of the low probability of the tornado, this event might not be considered credible. Accidents involving underground nuclear explosion (UNE) test and aircraft impact were the two manmade events analyzed. The probability of the UNE causing a radioactive release was estimated to be less than 1.0×10^{-3} for any one event. There were no data to estimate the event frequency. The probability of an aircraft impact was estimated to be 2.0×10^{-10} per year. Again, because of the low probability of the aircraft impact, this event might not be considered credible. There were five operational accidents analyzed: (1) a fuel assembly drop in a hot cell, (2) two transportation accidents and fires at the loading dock involving two different waste types, (3) a transportation accident and fire in the waste-handling ramp, and (4) a transportation accident and fire in an emplacement drift. The probabilities of these events were estimated to be 1.0×10^{-7}/yr for the transportation accidents. The transportation accidents were on the edge of what might be considered credible, taking into account the uncer-tainties of the estimates. A transportation accident with a fire can be avoided by using electric transporters and eliminating the fuel for the fire. This possibility is being considered.

The calculated first-year commitments for repository workers are below the occupational exposure limits (there is no specific accident-related exposure limit for workers) set by the NRC in 10 CFR Part 20 of 5.0 rem/yr and 3.0 rem/qtr for all accidents except for the transportation accident and fire in an emplacement drift. The dose commitment for this accident is 6.8 rem to workers in the emplacement drift. This accident was identified as being nearly credible. A major contributing factor to the dose, however, was the volatization of radionuclides caused by the fire. Since as noted earlier, all-electric transporters would remove the fuel for the fire, this accident can be eliminated or at least the consequences reduced considerably. -

The calculated first-yr and 50-yr dose commitments for the maximum off-site individual were all less than the important-to-safety threshold established by the NRC (10 CFR 60.2) of 0.5 rem whole-body per accident. The greatest single first-year dose commitment for the maximum individual was calculated to be 0.055 rem and occurred in the aircraft impact scenario (recall this scenario has an extremely low probability). It should be noted that actual Air Force flight data were not used in the Jackson et al. (1984) report but are being factored into current evaluations. Similar results were calculated for the general public except that doses for the general public are always lower than for the maximum individual. The greatest single exposure to the population was calculated to be 110 man-rem (for a population of 19,908) and, again, occurred during the aircraft impact scenario. The results of this study are preliminary. Future work is expected to produce differing results based on new and more accurate data.

Summary of Appendices F and L of the SCP-CDR

The previous discussion of the Jackson et al. (1984) report presented results that were based on worst-case radioactive releases. The following discussion of Appendices F and L of the SCP-CDR presents a probabilistic-risk-assessment (PRA) approach to estimating radioactive releases from credible accidents. The methodology is related to determining items important to safety and is depicted in Figure 6-89. The complete reports are contained in Appendices F and L of the SCP-CDR while the methodology and results are summarized in the following. (This information was given earlier in Section 6.1.4.2 but is repeated here for reader convenience.)

The method used in (Appendix F of SNL, 1987) PRSA, basically follows the NRC methodology for a simplified and streamlined level 3 PRA described in the PRA Procedures Guide (NRC, 1983). The level of detail of the PRSA varies at each step, depending on the data and design information currently available. Since the primary objective of the PRSA was to provide a numerical basis for the development of a preliminary list of items important to safety, only accident scenarios resulting in public exposures were considered in detail.

After developing the facility and system model initiating events, both internal and external, were identified and screened by a panel of experienced design and safety analysis engineers. The basis for the screening was the potential of the events to contribute to a significant offsite release of radioactive materials. Using the event-tree technique, accident scenarios then were developed for those initiating events surviving the first screening process. Event trees are graphical depictions of the sequence of events that occur following an initiating event. The construction of an event tree is an inductive process in that one goes from the specific--the initiating event--to the general, all the possible results of the initiating event. The key factor for developing an event tree for each surviving initiating event was the selection and definition of the intermediate events. Event trees were constructed in detail appropriate to the level of design detail available and as necessary to adequately characterize the accident. Because of lack of data and design details, fault trees were not completely developed and analyzed; however, variations of conventional fault tree or fault diagrams were developed for most intermediate events. Fault trees are graphic depictions of the possible events that might lead to an intermediate event on an event tree. Constructing a fault tree is a deductive process in that one goes from the general--all possible ways for the intermediate event to come about--to the specific, the intermediate event. The use of fault diagrams provides important insight into the probabilities of intermediate events.

After event trees were developed, the probability of each initiating event and each intermediate event was evaluated, as were the consequences of accident scenarios. The probability and consequence analyses were performed in parallel. Both historical data and the judgment of a panel of engineers,

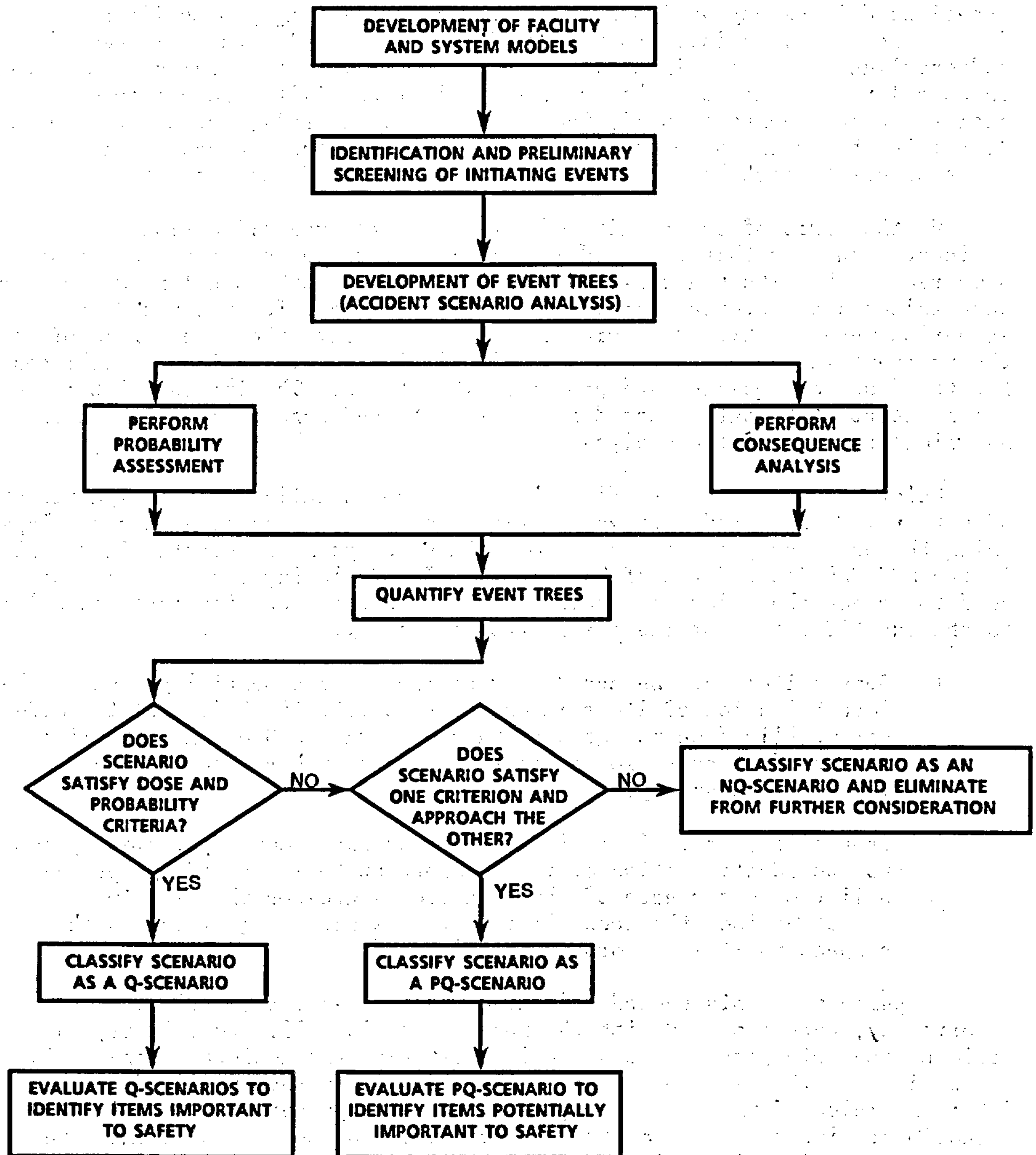


Figure 6-89. Q-list methodology for items important to safety.

experienced in safety analyses, were used in estimating probabilities. Consequence analyses involved the development of models and estimates of radionuclide releases, dispersion, and transport into the environment as well as calculation of doses. The results of the probability and consequence analyses were used to quantify the event trees. Briefly, the event trees are quantified by assigning probabilities to each intermediate event and consequences to each branch, or accident scenario, of the event tree.

On the basis of the results of the event tree quantifications, all accident scenarios that resulted in either dose consequences of more than 0.05 rem at the site boundary and probabilities of more than 1 x 10^{-9} per yr were selected as reference accident scenarios. The reference accident scenarios were identified by simplifying, or pruning, the event trees of all the accident scenarios that did not fall within the limitations established for the dose consequences and probability criteria. The initial list of items important to safety was derived from the reference scenarios and the numerical results of the analyses.

Reference accident scenarios that could potentially lead to significant offsite releases of radioactive material and dose consequences were developed using the previously described method. This analysis is reported in detail in the SCP-CDR (Appendix L of SNL, 1987). The following two criteria were used to screen the reference accident scenarios for scenarios that could lead to the identification of items important to safety.

1. Dose criterion: An accident scenario could potentially lead to the identification of items important to safety if the calculated off-site public dose was greater than or equal to 0.5 rem; otherwise, the accident scenario is not significant with respect to items important to safety.

2. Probability criterion: An accident scenario could potentially lead to the identification of items important to safety if the probability of occurrence of the scenario is greater than 1 x 10^{-5} per yr; otherwise, the scenario is not considered significant with respect to items important to safety.

In performing this second screening, the probability, including its uncertainty, were compared with the above criteria. If, and only if, an accident scenario passes both screening criteria, the accident scenario is classified as a Q scenario. Q scenarios then are further analyzed to determine which of the structures, systems, or components involved in the scenario are important to safety. Structures, systems, or components are important to safety if it is essential to either the prevention of the scenario or the mitigation of the scenario dose consequence.

Scenarios that are not significant with respect to items important to safety are classified as either a non-Q scenario (NQ scenario) or a potential-Q scenario (PQ scenario). All NQ scenarios are eliminated from further consideration in identifying items important to safety.

Any scenario not immediately identified as a Q scenario but which, as further study and design take place, is judged to have a reasonable potential to be upgraded to a PQ scenario is classified as a PQ scenario. Two criteria were used to decide between PQ and NQ. First, a scenario was classified as a PQ scenario even if no analyses had been performed if the item or scenario was sufficiently similar to others historically classified as PQ scenario or when practical consideration indicated that it could be a Q scenario. Second, if the analysis determined that either the consequences or probability exceeded the criteria and the other was sufficiently close that a change in assumptions or data could cause the criteria to be exceeded, the scenario was put on the PQ list. A variation of this second criteria was that when both consequence and probability were below the threshold but sufficiently close that a change in assumption or data could move both of them over, the scenario was classified as a PQ scenario.

Once a scenario is classified as a Q scenario or a PQ scenario, that scenario is further analyzed to determine which of the items involved in the scenario should be placed on the list of items important to safety or potentially important to safety. Further analysis of the scenario involves the evaluation of the systems, structures, and components involved in the scenario to determine what role the item plays in the scenario. Items that have a failure that causes the loss of consequence mitigation processes or have failure that directly causes the release of radioactive materials are classified as important to safety or potentially important to safety and placed on the Q list or PQ list, depending on which type of scenario is being evaluated. Current plans will make these items (PQ items), as well as items important to safety, subject to a QA level I program that satisfies the requirements of Title 10 CFR 60, Subpart G. A potentially-important-to-safety list is consistent with DOE guidance (DOE, 1987c).

The results to date have not identified any Q scenarios, or consequently, any Q-list items; however, this result is based on incomplete and preliminary data and design. For example, an airplane-crash event did not have available actual data and will have to be reexamined. Consequently, all items that have been classified as potential Q list will be treated as if they were Q list during future design, until the design detail and available data support a definitive analysis and conclusion. The preliminary list of potential items important to safety (PQ list), as developed in Appendix L of the SCP-CDR and through technical review of this appendix, is presented in Table 6-32.

In addition, as the design is developed, i.e., the reference configuration of the license application design and additional data become available, the complete sequence of the Q list method will be implemented again to refine, correct, and validate the initial results.

A detailed discussion of the methods used in determining items important to safety, is given in Appendix F of the SCP-CDR. A complete discussion of the results of the analysis to determine items important to safety, is given in Appendix L of the SCP-CDR.

Table 6-32. Potential Q-list for items important to safety at the Yucca Mountain Repository

Item	Location	Initiating event
Crane, shipping cask	Cask receiving and preparation area	Crane drops a shipping cask
Hot cell structure	Waste packaging hot cell	Earthquake causes hot cell structure failure
Crane	Unloading hot cell Consolidation hot cell Waste packaging hot cell	Earthquake causes crane to fall on fuel assemblies
Vehicle stop	Cask receiving and preparation area	Vehicle with cask falls in cask preparation pit (detailed analysis not performed)
Fire protection system	Waste-handling building	Fire involving radioactive material is a dispersion promoter (detailed analysis not yet performed)
Cask transfer mechanism	Surface storage vault	Cask transfer mechanism drops container with consolidated fuel rods
Transport Cask	Underground facility and ramp	Transporter coasts down the waste ramp and strikes the wall of the ramp or main access drift

6.4.6.3 <u>Analysis needs</u>

During each subsequent design phase (advanced conceptual design, license application design), the analyses described previously will be repeated. As site information becomes available and the repository design matures, the analyses will rely more on data and calculations and less on engineering judgement. The final set of analyses will be used to support the license application.

6.4.6.4 Site data needs

Immediate site data needs are meteorological data. These data include such items as wind and precipitation patterns, atmospheric-stability class, and site-boundary location. These data are used to calculate the transport of radionuclides in the atmosphere and are described in Section 8.3.1.12. Other data used by this issue are described in Sections 8.3.1.10, 8.3.1.11, and 8.3.1.13.

6.4.7 ISSUE 2.7: REPOSITORY DESIGN CRITERIA FOR RADIOLOGICAL SAFETY

6.4.7.1 Introduction

The question asked by Issue 2.7 is

> Have the characteristics and configurations of the repository been adequately established to (a) show compliance with the preclosure design criteria of 10 CFR 60.131 through 10 CFR 60.133, and (b) provide information for the resolution of the performance issues?

The general design criteria for the geologic repository operations area, (10 CFR 60.131); the additional design criteria for the surface facilities in the geologic repository operations area (10 CFR 60.132); and the additional design criteria for the underground facility (10 CFR 60.133) are presented in Table 6-33. The responsibility for meeting the criteria stated in 10 CFR 60.131 through 60.133 is divided among several issues. These issues and their associated responsibilities are identified in the table in Section 6.3.8.

To define the role and responsibilities currently assigned under this issue, an understanding of other issues is necessary. Issues 2.1 (public radiological exposures--normal conditions), 2.2 (worker radiological safety--normal conditions), and 2.3 (accidental radiological releases) address the compliance of the repository system with allowable releases of radioactive materials during preclosure. Under Issue 2.4 (waste retrievability) the retrieval option is maintained, and under Issue 1.11 (configuration of underground facilities--postclosure) the compliance with the postclosure design criteria of 10 CFR 60.133 is ensured with the exception of criteria related to sealing the repository that are addressed under the seal characteristics issue (Issue 1.12).

Issue 4.4 (preclosure design and technical feasibility) is the central or focusing issue that describes the development of the repository designs related to preclosure concerns.

With this understanding of the other issues, a detailed evaluation (Table 6-33) of the criteria specified in 10 CFR 60.131 through 10 CFR 60.133 reveals clearly the role of this issue (Issue 2.7). Under Issue 2.7 radiological-safety-related design criteria are developed and specified. The

Table 6-33. Design criteria for the geologic repository operations (page 1 of 8)

Design Criteria of 10 CFR Part 60	Issue that addresses the criterion	Are site data needed to address the criterion?
60.131 General design criteria for the geologic repository operations area.		
(a) Radiological protection. The geologic repository operations area shall be designed to maintain radiation doses, levels, and concentrations of radioactive material in air in restricted areas within the limits of specified in Part 20 of this chapter. Design shall include		
1. Means to limit concentrations of radioactive material in air;	2.7	Yes
2. Means to limit the time required to perform work in the vicinity of radioactive materials, including, as appropriate, designing equipment for ease of repair and replacement and providing adequate space for ease of operation;	2.7	No
3. Suitable shielding;	2.7	Yes
4. Means to monitor and control the dispersal of radioactive contamination;	2.7	Yes
5. Means to control access to high radiation areas or airborne radioactivity activity areas; and	2.7	No
6. A radiation alarm system to warn of significant increases in radiation levels, concentrations of radioactive material in air, and of increased radioactivity released in effluents. The alarm system shall be designed with provisions for calibration and for testing its operability.	2.7	Yes
(b) Structures, systems, and components important to safety.		
1. Protection against natural phenomena and environmental conditions.	2.7	Yes
The structures, systems, and components important to safety shall be designed so that natural phenomena and environmental conditions anticipated at the geologic repository operations area will not interfere with necessary safety functions.		

Design Criteria of 10 CFR Part 60	Issue that addresses the criterion	Are site data needed to address the criterion?
2. Protection against dynamic effects of equipment failure and similar events.	2.7	No
The structures, systems, and components important to safety shall be designed to withstand dynamic effects such as missile impacts, that could result from equipment failure, and similar events and conditions that could lead to loss of their safety functions.		
3. Protection against fires and explosions.		
(i). The structures, systems, and components important to safety shall be designed to perform their safety functions during and after credible fires or explosions in the geologic repository operations area.	2.7	Yes
(ii). To the extent practicable, the geologic repository operations area shall be designed to incorporate the use of non-combustible and heat resistant materials.	4.2	No
(iii). The geologic repository operations area shall be designed to include explosion and fire detection alarm systems and appropriate suppression systems with sufficient capacity and capability to reduce the adverse effects of fires and explosions on structures, systems, and components important to safety.	2.7	Yes
(iv). The geologic repository operations area shall be designed to include means to protect systems, structures, and components important to safety against the adverse effects of either the operation or failure of the fire suppression systems.	2.7	No
4. Emergency capability.		
(i). The structures, systems, and components important to safety shall be designed to maintain control of radioactive waste and radioactive effluents, and permit prompt termination of operations and evacuation of personnel during an emergency.	2.7	No

Table 6-33. Design criteria for the geologic repository operations (page 3 of 8)

Design Criteria of 10 CFR Part 60	Issue that addresses the criterion	Are site data needed to address the criterion?
(ii). The geologic repository operations area shall be designed to include onsite facilities and services that ensure a safe and timely response to emergency conditions and that facilitate the use of available offsite services (such as fire, police, medical, and ambulance service) that may aid in recovery from emergencies.	4.2	No
5. Utility services.		
(i). Each utility service system that is important to safety shall be designed so that essential safety functions can be performed under both normal and accident conditions.	2.7	Yes
(ii). The utility services important to safety shall include redundant systems to the extent necessary to maintain, with adequate capacity, the ability to perform their safety functions.	2.7	No
(iii). Provisions shall be made so that, if there is a loss of the primary electric power source or circuit, reliable and timely emergency power can be provided to instruments, utility service systems, and operating systems, including alarm systems, important to safety.	2.7	No
6. Inspection, testing, and maintenance.	2.7	Yes
The structures, systems, and components important to safety shall be designed to permit periodic inspection, testing, and maintenance, as necessary, to ensure their continued functioning and readiness.		
7. Criticality control.	2.7	Yes
All systems for processing, transporting, handling, storage, retrieval, emplacement, and isolation of radioactive waste shall be designed to ensure that a nuclear criticality accident is not possible unless at least two unlikely, independent, and concurrent or sequential changes have occurred in the conditions essential to nuclear criticality safety. Each system shall be designed for criticality safety under normal and accident conditions. The calculated effective multiplication factor (k_{eff}) must be sufficiently below unity to show at least a 5% margin, after allowance for the bias in the method of calculation and the uncertainty in the experiments used to validate the method of calculation.		

Table 6-33. Design criteria for the geologic repository operations (page 4 of 8)

Design Criteria of 10 CFR Part 60	Issue that addresses the criterion	Are site data needed to address the criterion?
8. Instrumentation and control systems.	2.7	No
The design shall include provisions for instrumentation and control systems to monitor and control the behavior of systems important to safety over anticipated ranges for normal operation and for accident conditions.		
9. Compliance with mining regulations.	2.7	No
To the extent that DOE is not subject to the Federal Mine Safety and Health Act of 1977, as to the construction and operation of the geologic repository operations area, the design of the geologic repository operations area shall nevertheless include such provisions for worker protection as may be necessary to provide reasonable assurance that all structures, systems, and components important to safety can perform their intended functions. Any deviation from relevant design requirements in 30 CFR, Chapter 1, Subchapters D, E, and N will give rise to a rebuttable presumption that this requirement has not been met.		
10. Shaft conveyances used in radioactive waste handling.	All waste will be transported underground in the ramp.[a]	
(i). Hoists important to safety shall be designed to preclude cage free fall.		
(ii). Hoists important to safety shall be designed with a reliable cage location system.		
(iii). Loading and unloading systems for hoists important to safety shall be designed with a reliable system of interlocks that will fail safely upon malfunction.		
(iv). Hoists important to safety shall be designed to include two independent indicators to indicate when waste packages are in place and ready for transfer.		

Table 6-33. Design criteria for the geologic repository operations (page 5 of 8)

Design Criteria of 10 CFR Part 60	Issue that addresses the criterion	Are site data needed to address the criterion?
60.132 Additional design criteria for surface facilities in the geologic repository operations area.		
(a) Facilities for receipt and retrieval of waste.	2.7	Yes
Surface facilities in the geologic repository operations area shall be designed to allow safe handling and storage of wastes at the geologic repository operations area, whether these wastes are on the surface before emplacement or as a result of retrieval from the underground facility.		
(b) Surface facility ventilation.	2.7	Yes
Surface facility ventilation systems supporting waste transfer, inspection, decontamination, processing, or packaging shall be designed to provide protection against radiation exposures and offsite releases as provided in 60.111(a).		
(c) Radiation control and monitoring.		
1. Effluent control.	2.7	Yes
The surface facilities shall be designed to control the release of radioactive materials in effluents during normal operations so as to meet the performance objectives of 60.111(a).		
2. Effluent monitoring.	2.7	No
The effluent monitoring systems shall be designed to measure the amount and concentration of radionuclides in any effluent with sufficient precision to determine whether releases conform to the design requirement for effluent control. The monitoring systems shall be designed to include alarms that can be periodically tested.		

Table 6-33. Design criteria for the geologic repository operations (page 6 of 8)

Design Criteria of 10 CFR Part 60	Issue that addresses the criterion	Are site data needed to address the criterion?
(d) Waste treatment.	2.7	No
Radioactive waste treatment facilities shall be designed to process any radioactive wastes generated at the geologic repository operations area into a form suitable to permit safe disposal at the geologic repository operations area or to permit safe transportation and conversion to a form suitable for disposal at an alternative site in accordance with any regulations that are applicable.		
(e) Consideration of decommissioning.	4.4	No
The surface facility shall be designed to facilitate decontamination or dismantlement to the same extent as would be required, under other parts of this chapter, with respect to equivalent activities licensed thereunder.		
60.133 Additional design criteria for the underground facility.		
(a) General criteria for the underground facility.		
1. The orientation, geometry, layout, and depth of the underground facility, and the design of any engineered barriers that are part of the underground facility shall contribute to the containment and isolation of radionuclides.	1.11	Yes
2. The underground facility shall be designed so that the effects of credible disruptive events during the period of operations, such as flooding, fires and explosions will not spread through the facility.	4.4	No
(b) Flexibility of design.		
The underground facility shall be designed with sufficient flexibility to allow adjustments where necessary to accommodate specific site conditions identified through in situ monitoring, testing, or excavation.	1.11	Yes
(c) Retrieval of waste.	2.4, 4.4	Yes

Table 6-33. Design criteria for the geologic repository operations (page 7 of 8)

Design Criteria of 10 CFR Part 60	Issue that addresses the criterion	Are site data needed to address the criterion?
The underground facility shall be designed to permit retrieval of waste in accordance with the performance objectives of 60.111.		
(d) Control of water and gas.	4.4	Yes
The design of the underground facility shall provide for control of water or gas intrusion.		
(e) Underground openings.		
(1). Openings in the underground facility shall be designed so that operations can be carried out safely and the retrievability option maintained.	2.4, 4.2, 4.4	Yes
(2). Openings in the underground facility shall be designed to reduce the potential for deleterious rock movement or fracturing of overlying or sur rounding rock.	1.11	Yes
(f) Rock excavation.	1.11	Yes
The design of the underground facility shall incorporate excavation methods that will limit the potential for creating a preferential pathway for ground water or radioactive waste migration to the accessible environment.		
(g) Underground facility ventilation.		
The ventilation system shall be designed to		
(1). Control the transport of radioactive particulates and gases within and releases from the underground facility in accordance with the performance objectives of 60.111(a).	2.7	Yes
(2). Assure continued function during normal operations and under accident conditions.	2.7, 4.2, 4.4	Yes
(3). Separate the ventilation of excavation and waste emplacement areas.	2.7,4.4	No

Table 6-33. Design criteria for the geologic repository operations (page 8 of 8)

Design Criteria of 10 CFR Part 60	Issue that addresses the criterion	Are site data needed to address the criterion?
(h) Engineered barriers.	1.11	Yes
Engineered barriers shall be designed to assist the geologic setting in meeting the performance objectives for the period following permanent closure.		
(i) Thermal loads.	1.11	Yes
The underground facility shall be designed so that the performance objectives will be met taking into account the predicted thermal and thermomechanical response of the host rock, and surrounding strata, ground-water system.		

[a]The repository design for the Yucca Mountain site uses a ramp (instead of a shaft and hoist) through which waste is transported underground by transportors.

related design work will be done in Issue 4.4 since other issues specify requirements that must be met by the system design, e.g., the ventilation system design must meet criteria related to radiological safety (Issue 2.7), retrievability (Issue 2.4), and nonradiological health and safety (Issue 4.2).

The proposed issue resolution strategy for this issue is presented in Section 8.3.2.3 (repository design criteria for radiological safety). Readers unfamiliar with the issue resolution strategy for this issue should review the contents of Section 8.3.2.3 before continuing.

The information needs for Issue 2.7 are as follows:

Information Need 2.7.1 Determination that the design criteria in 10 CFR 60.131 through 60.133 and any appropriate additional design objectives pertaining to radiological protection have been met.

Information Need 2.7.2 Determination that the design criteria in 10 CFR 60.131 through 60.133 and any appropriate additional design objectives pertaining to the design and protection of structures, systems, and components important to safety have been met.

Information Need 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.

Information Need 2.7.4 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.

Information Need 2.7.5 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.

The information needs indicate that the development of the design criteria applicable for radiological safety require (1) interfaces with site, waste package, and repository designs, (2) understanding potential conditions that may exist in surface and underground facilities, and (3) establishing means of controlling releases. The discussions below will focus on the work completed to date related to criteria development and to the means for controlling releases that are part of the current design.

6.4.7.2 Work completed

The work completed in support of this issue consists of design criteria established for the use in the conceptual design presented in the SCP-CDR and in criteria prepared to support the advanced conceptual design activities. Repository design guidelines were issued in advance of the SCP-CD. As part of the SCP-CD development these guidelines were expanded by establishing additional means of limiting exposures and by more clearly defining planned operations. These refinements are part of the Subsystem design requirements (Appendix P of SNL, 1987).

Design criteria have been obtained from both regulatory guidance and from DOE Orders. The regulatory guidance is principally from 10 CFR 60.131, 132, and 133 while the DOE guidance is principally from DOE Orders 5480.1B (DOE, 1986b), 6410.1 (DOE, 1983b), and 6430.1 (DOE, 1983a). This guidance is translated into several specific points of design philosophy for the NNWSI Project work. Some of the more important points are as follows:

1. Design basis will be 20 percent of allowable release.

2. No administrative controls will be used to meet worker dosage criteria.

3. Separate underground ventilation systems will be used for excavation and waste emplacement areas.

4. Redundancy of systems and equipment will be provided.

5. Systems for mitigating disruptive events will be provided.

6. Design will consider decommissioning requirements.

7. Maintainability will be considered in facilities and equipment design.

The development of the conceptual design has led to identifying numerous means of limiting releases. For the surface facilities, these include the compartmentalization of surface facility operations, design of hot cells for negative-pressure operation, shielding of selected operations, and development of zoned ventilation systems in the surface buildings. In addition, filtration systems for gaseous effluents, strippable wall coatings in selected areas, removable liners from selected equipment, and automated systems, where possible, are used in the current design. Placement of the waste-handling building and its effluent exhaust systems is influenced by the prevailing wind direction as a means of limiting contamination of other surface facilities. Access control is also provided for the surface facilities. Collection and treatment of site-generated waste is reflected in the current design, as are specified areas for decontamination activities.

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

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

6.4.7.3 Future work

As described in the previous paragraphs and reflected throughout the SCP-CDR applicable criteria have been identified as the basis for establishing means of controlling releases of radioactive materials from the repository.

The future work related to this issue consists primarily of identifying progressively more detailed design criteria for advanced conceptual design and license application design activities. This work is described in more detail in Section 8.3.2.3.

6.4.8 ISSUE 2.4: WASTE RETRIEVABILITY

6.4.8.1 Introduction

The question asked by Issue 2.4 is

> 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?

In general, 10 CFR 60.111(b)(1) requires that the emplaced waste must be retrievable on a reasonable schedule until the completion of the performance confirmation program and NRC review. In addition, Section 5-1(a)(3) of 10 CFR Part 960 includes a requirement that the repository siting, construction, operation, and closure will be demonstrated to be technically feasible on the basis of reasonably available technology. These regulatory requirements form the basis for Issue 2.4. The resolution of this issue follows the issue resolution strategy (IRS) presented in Section 8.3.5.2. Readers unfamiliar with the IRS for this issue should review Section 8.3.5.2 before continuing.

The object of this issue is to ensure that the repository preserves the option of waste retrieval. To ensure that the retrieval option is maintained, this issue

1. Establishes a strategy for resolution through performance allocation.

2. Defines retrievability-related design criteria.

3. Establishes normal and off-normal conditions anticipated for retrieval operations. [Note that in this section, the term off-normal is used to identify conditions which are anticipated to occur infrequently. In future documents, the term off-normal will be replaced with the term abnormal.]

4. Identifies information (analyses, demonstrations, etc.) required from other issues to ensure compliance with retrievability requirements.

5. Assesses compliance with the regulatory requirements for retrievability.

These responsibilities assigned under Issue 2.4 are depicted in Figure 6-90, which details the strategy to be used for retrievability evaluation. The significance of Issue 4.4, (preclosure design and technical feasibility), also is evident in the figure. Under Issue 4.4 the design for facilities and equipment is developed, analyses of the design are conducted, needed tests and demonstrations are conducted, and an operations plan is developed.

In developing the strategy for resolving this issue, it was determined that the ability to perform retrieval operations is based on the ability to perform the following four functions:

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

To ensure that the design will include the ability to perform these functions under normal and off-normal conditions, it will be necessary to document the following:

1. Retrieval strategy and planning.

2. Retrieval conditions.

3. Retrievability input to repository design requirements (RDR) document.

4. Facility and equipment designs, demonstrations and design analyses.

5. Retrievability compliance analyses.

The designs, demonstrations, and supporting analyses will be documented in reports produced under Issue 4.4 (Section 8.3.2.5). Hence, discussions of the status of the retrievability issue will be focused on documentation produced to date regarding items 1, 2, 3, and 5 of the previous list.

Section 6.4.8.2 presents the work completed to date. The future work to be performed on these products is summarized in Section 6.4.8.3.

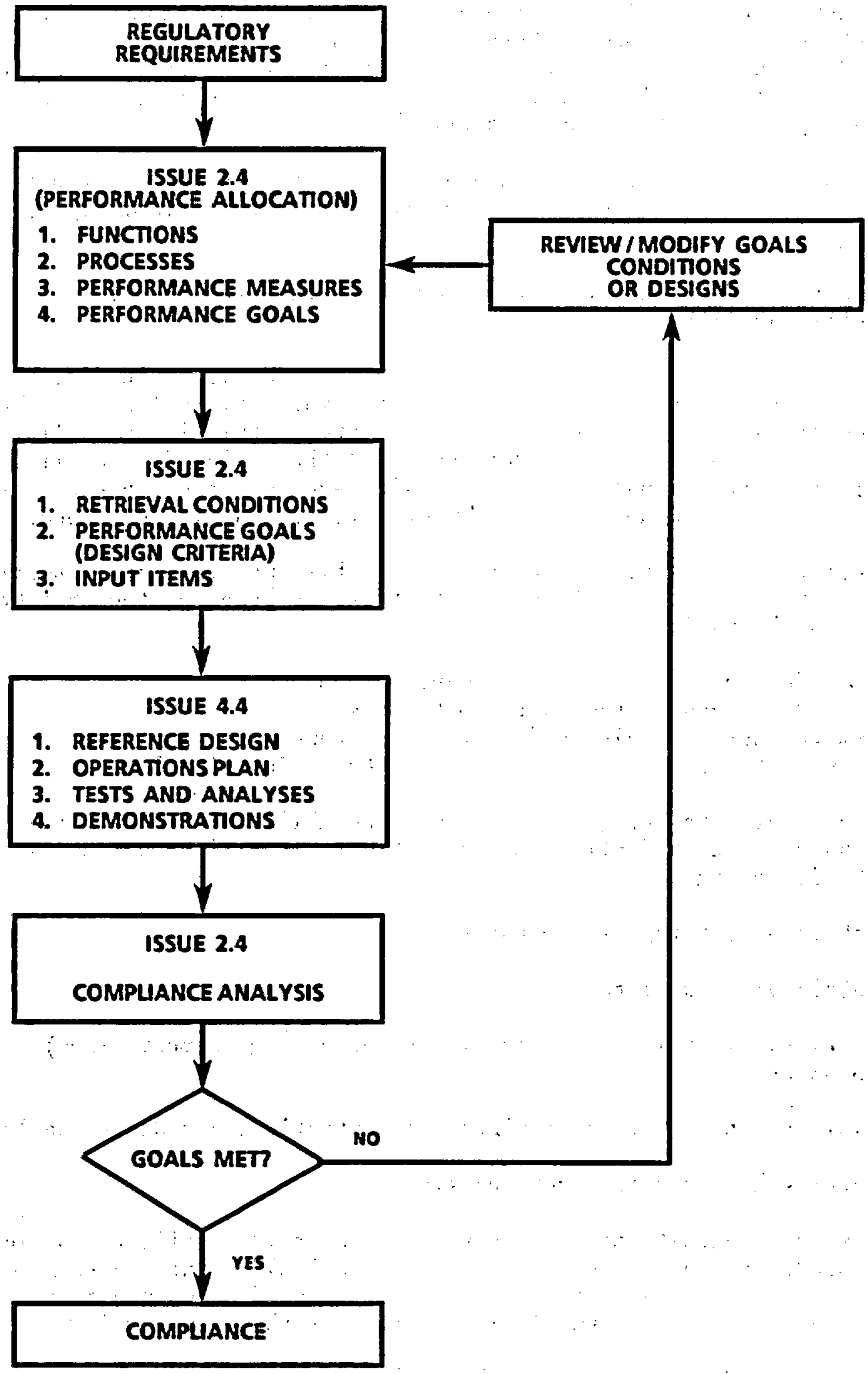


Figure 6-90. Strategy to be used for retrieval evaluation.

6.4.8.2 <u>Work completed</u>

6.4.8.2.1 Retrieval strategy and planning documents

The approach to development of a strategy for retrievability has been to develop a guidance paper to ensure consistency of planning assumptions concurrently with development of a strategy paper to adapt this guidance for NNWSI Project specific applications. The documents that address strategy and planning are as follows:

1. "Department of Energy Generic Requirements for a Mined Geologic Disposal Site," (DOE, 1986d).

2. "Retrievability: Strategy for Compliance Demonstration," SAND84-2242 (Flores, 1986).

The basis (or data) used to develop this strategy included the regulatory requirements, the Generic Requirements (GR) document (DOE, 1984b), and the Mission Plan (DOE, 1985a). These reports address (1) the identification and evaluation of the regulatory requirements for retrievability, (2) the establishment of a design basis for evaluating the ability to retrieve, (3) the identification of the expected repository conditions at the time of retrieval, (4) the development of the methodology for defining normal conditions and identifying off-normal conditions, and (5) the identification of the timing for design and demonstration activities that are needed to ensure that the ability to retrieve is maintained throughout the retrievability period.

These two reports will be used to form the basis for more detailed definition of the demonstrations, analyses, operations, equipment development, and anticipated conditions. Consistency in these detailed definitions requires an expansion of the strategy documented to date. This proposed strategy or approach is described in Appendix J of the SCP-CDR. This approach relies on the use of a probabilistic approach as a means for segregating conditions that require consideration from those that do not, Figure 6-91. A further segregation is identified to classify the conditions as normal and off-normal. This classification of conditions will form the basis for the segregation of items in the design approach, demonstration plans, and anticipated degree of readiness for various conditions. It is recognized that substantial engineering judgment will be necessary to implement this approach and that uncertainty will exist with regard to the exact probability of occurrence of many of the postulated conditions; nevertheless, it is planned to apply this, or a similar framework, in advanced conceptual design studies.

6.4.8.2.2 Retrieval conditions

Estimates of the repository conditions at the time of retrieval are important for use as input to the design basis and demonstration plans. The retrieval conditions are divided into two categories: normal and off-normal. Normal conditions are those conditions under which the retrieval process can

PROBABILITY	10-1		10-3	10-5
CONDITION CLASSIFICATION	NORMAL	EXPECTED OFF-NORMAL	CREDIBLE OFF-NORMAL	NOT CREDIBLE
DESIGN APPROACH	DESIGN BASIS		CONTINGENCY	NOT INCLUDED
DEGREE OF READINESS	ESTABLISHED EQUIPMENT ESTABLISHED OPERATIONS		EQUIPMENT CONCEPTS OPERATIONS CONCEPTS	DEVELOP CONDITION SPECIFIC PLAN
DEMONSTRATION PLANS	PROOF-OF-PRINCIPLE DEMONSTRATIONS PROTOTYPE DEMONSTRATIONS (AS NEEDED)		PROOF-OF-PRINCIPLE DEMONSTRATIONS (IF NEEDED)	NONE

Figure 6-91. Classification of retrieval conditions based upon probability.

be performed using standard (essentially, the emplacement equipment) equipment and procedures. Off-normal conditions exist when nonstandard equipment and procedures are required.

The basic approach to the development of the normal conditions involves the following: (1) the identification of the repository systems important to the performance of the retrieval process and (2) the prediction of the condition of those systems at the time of retrieval. The repository systems were identified by evaluating the ability to perform the four major functions for retrieval using the SCP-CD concepts as a basis. The prediction of the condition of these systems was accomplished using current design information, completed analyses, and engineering judgment.

The off-normal conditions were identified using the approach discussed in Appendix L of the SCP-CDR. As shown in Appendix L, a short list of potentially credible processes and events was developed by screening approximately 75 events and processes contained in the master list. To identify potential off-normal conditions, the short list of processes and events were evaluated relative to the ability to perform the four retrieval functions. The potential off-normal conditions were screened on a probability basis, resulting in the determination of potentially credible off-normal conditions.

The basis for the identification of normal and off-normal conditions was the regulatory requirements, results from technical analyses, results of literature reviews, the SCP-CD, and engineering judgment.

Normal retrieval conditions

As mentioned previously, normal conditions are those conditions under which the retrieval process can be performed using standard equipment and procedures. The system elements whose performance and, as a result, condition could affect the ability to retrieve include ramp and drifts, emplacement boreholes, ventilation system, including the shafts, waste-handling building, retrieval equipment, and the waste container. A complete discussion of current normal conditions for retrieval is presented in Appendix J of the SCP-CDR. In this section, a brief discussion on the normal conditions for these elements is presented.

Ramps and drifts

The normal conditions within the ramps and drifts are characterized in terms of (1) rock temperature in the drifts, (2) condition of the opening, (3) radiation levels, and (4) air quality.

The basis for retrievability planning is tied to the current conceptual design results as follows:

1. The anticipated temperatures for the floor of the emplacement drifts and the wall of the access drifts for vertical emplacement and for the emplacement drift floor for horizontal emplacement are addressed in Section 8.3.5.2. As shown in Appendix J of the SCP-CDR, the goal to limit the temperature to 50°C at 50 yr in the access drifts for

vertical emplacement and in the emplacement drifts for horizontal emplacement is met.

2. Under normal conditions, current design calculations suggest that the ramp and drifts are expected to remain stable. It is anticipated that small pieces of rock will fall through the holes in the wire mesh. This will be managed with light maintenance. It is also expected that in local, more highly fractured areas, more extensive and frequent maintenance may be required.

3. For normal conditions, personal radiation protection will be the same during retrieval as that required for emplacement operations (Dennis et al., 1984a). The radiological environments for worker safety are addressed under Issue 2.2 while the design for radiological safety is addressed under Issue 2.7.

4. Acceptable air quality will be maintained in all operational areas during retrieval operations. In the ramp, service areas, and access drifts, acceptable air quality will be maintained until repository closure, through the use of continuous ventilation. However, there are no plans to ventilate the emplacement drifts during the caretaker period. Therefore, ventilation will be reestablished to ensure that an acceptable air quality exists before reentry for initiation of retrieval operations will be allowed.

Emplacement boreholes

The conditions within the emplacement boreholes are characterized in terms of (1) rock temperature, (2) condition of the opening, (3) radiation levels, and (4) condition of the borehole liner.

The basis for retrievability planning under normal conditions is tied to the current conceptual design as follows:

1. The predicted temperature histories for the emplacement boreholes for the vertical and horizontal emplacement concepts are shown in Appendix J of the SCP-CDR. The temperature remains above 100°C throughout the retrievability period, therefore, a dry environment is expected.

2. For the vertical emplacement concept, the borehole will be stable with negligible amounts of rockfall into the emplacement borehole under normal conditions. For the horizontal concept, minor rockfall against the liner is anticipated. In addition, as noted previously, a dry environment, as a result of high temperatures, is expected.

3. At the time of emplacement, order-of-magnitude estimates of the waste container surface radiation dose rates for spent fuel are 10^5 rem/h for gamma and 10^2 rem/h for neutron radiation (O'Brien, 1985). These surface radiation levels are used as the worst-case levels for shielding design.

4. Under normal conditions, the liner will be intact and provide acceptable access to the emplaced waste containers throughout the design basis 84-yr period.

Ventilation system

The ventilation system equipment (fans, regulators, chillers, etc.) will continue providing ventilation to the ramp and access drifts throughout the caretaker period. In addition, the distribution and regulation system to the emplacement drifts will be used on a periodic basis for inspection and maintenance of the emplacement drifts. As a result, the emplacement ventilation system including the shafts and ramps will be maintained in a fully operational condition throughout the caretaker period.

Waste-handling building

If waste emplacement operations are in progress, it is expected that the waste-handling building, and the equipment contained within it, will be in operable condition. However, it is anticipated that extensive modifications and additional construction would be necessary to accommodate the retrieval operations. During the caretaker period, it is assumed that maintenance and repair will have been performed only to maintain the structure; therefore, repair and maintenance may be required to bring the waste handling equipment within the building to an operational state.

Retrieval equipment

If waste emplacement operations are in progress, the equipment required for waste removal under normal conditions (the emplacement equipment) will be in an operational condition. During the caretaker phase, it is anticipated that two sets of retrieval equipment will remain operational in support of the performance confirmation program. For full-repository retrieval initiated during the caretaker phase, it is anticipated that maintenance and repair will be required to achieve an operational condition for the other two sets of retrieval equipment, assuming the current design basis that four sets will be required. In addition, training of additional operators probably will be required.

For the horizontal concept, under normal conditions, the dolly and the dolly hook, described in Section 4.5 in the SCP-CDR, are not expected to fail during retrieval operations. The current planning basis for the dolly roller system under normal conditions is that it will be operable during retrieval operations; however, sliding friction, not rolling friction is assumed in establishing design loads for the emplacement or retrieval mechanism in the transporter.

Waste container condition

Under normal conditions, the waste container is expected to remain intact throughout the retrievability period and the removal process.

Off-normal retrieval conditions

As mentioned previously, off-normal conditions exist when the retrieval process must be performed using nonstandard equipment or procedures. The current development of off-normal retrieval conditions was part of the retrievability evaluation presented in Appendix L of the SCP-CDR. As shown in Figure 6-92, the first step was to develop a comprehensive list of processes and events that could potentially lead to a delay in retrieval operations. These events and processes were categorized as naturally occurring, human-induced, and repository-induced. Input for this master list was obtained from literature surveys, engineers involved in developing retrieval equipment and operations, working sessions with engineering professionals, and peer and management reviews of the master list. The resulting master list of approximately 75 events and processes is shown in Table 3-1 of Appendix L. This master list then was screened using the set of criteria shown in Table 3-2 of Appendix L to eliminate from further consideration those events and processes that, under current design concepts and understanding of site processes, either were not applicable to the Yucca Mountain site or obviously resulted in an insignificant time delay in retrieval operations. This screening resulted in the short list of processes and events that could potentially lead to a significant time delay in performing retrieval operations. The events and processes on the short list are as follows:

1. Tectonics.

2. Variability in rock characteristics.

3. Human error.

4. Aging and corrosion of equipment and facilities.

5. Radiolysis.

Consequences of these events and processes (e.g., waste package failure) are addressed in more detail of Appendix L of the SCP-CDR. The next step involved identifying retrieval conditions that result from the events and processes identified in the short list. These conditions were developed by examining the effects of these events and processes on the ability to perform the following four retrieval functions: (1) access to the emplacement boreholes, (2) access to the waste containers, (3) ability to remove waste containers, and (4) return waste containers to the surface. Using engineering judgment and the SCP-CD as a basis, a list of approximately 110 potential off-normal conditions was developed. These conditions are presented in Table 3-5 of Appendix L. These conditions were then assigned a probability of occurrence using engineering judgment. These estimates of probability were assigned using qualitative descriptions of high, medium, low, and negligible. Negligible was considered to be less than 10^{-5}/yr. Conditions that were judged to have a negligible probability of occurrence were removed from further consideration. Retrieval conditions judged to have a medium or low probability of occurrence were classified as off-normal. A list of the 43 identified off-normal conditions is contained in Table 3-1 of Appendix J of the SCP-CDR.

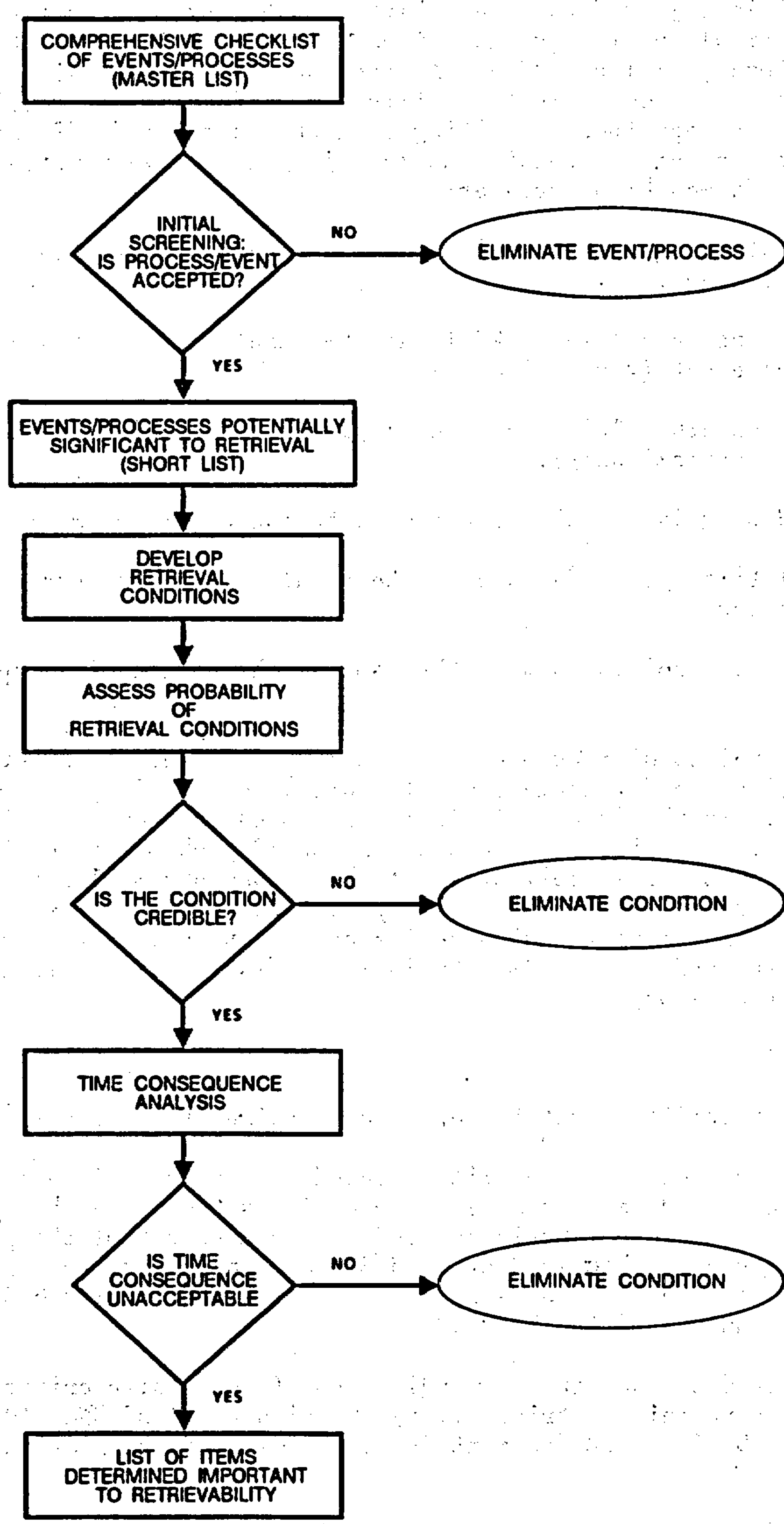


Figure 6-92. Methodology used to determine items important to retrievability.

Retrieval conditions judged to have a high probability of occurrence were classified as normal conditions and, if not already included in the design basis for retrieval, will be added. A time consequence analysis was performed to estimate the delay in total time for performing the retrieval operations for the repository resulting from the identified off-normal conditions. The following six conditions were judged to have a potential time consequence of six months or greater:

1. Ventilation equipment failure as the result of a tectonic (ground motion) event.

2. Emplacement borehole rockfall as the result of a tectonic (ground motion) event (vertical only).

3. Waste container "tilt" as the result of a tectonic (ground motion) event (vertical only).

4. Shield plug jam as the result of a tectonic (ground motion) event.

5. Ventilation system failure as the result of a human error related to maintenance.

6. Transporter collision with the ramp as the result of an operator error.

The off-normal conditions presented in Appendix J of the SCP-CDR have been used to guide the development of off-normal retrieval operations and equipment needs. In the future, Table 3-9 of Appendix L of the SCP-CDR will be used as a starting point for the application of probability evaluations shown in Figure 6-92. The application of these concepts will result in the development of more detailed design and operational criteria for equipment and facilities, more accurate guidance for equipment development requirements and demonstration needs, and a firm basis for deciding what equipment will be on hand at the repository.

6.4.8.2.3 Retrievability input to repository design requirements

The development of retrievability-related design criteria began during early design stages and has become more specific as the design has evolved. The current set of design criteria was refined as a result of the performance allocation process described in Section 8.3.5.2. In the future, this set of design criteria will be refined using the concept shown in Figure 6-91 and discussed in Appendix J of the SCP-CDR.

The basis or data used in the development of the design criteria include the regulations concerning retrievability (Section 2.6.1 of SNL, 1987), the SCP-CD, Appendix D of the GR document (DOE, 1986d), and the Mission Plan (DOE, 1985a).

The early designs that reflected the inclusion of retrievability-related design criteria were the Repository Design Concepts Report (Jackson, 1984) and the Two-Stage Repository Report (SNL, 1986).

6.4.8.2.4 Retrievability compliance analysis

Under Issue 2.4 the reference design and the results of analyses, tests, and demonstrations performed under Issue 4.4 are evaluated to determine if the goals for retrievability are met. This is accomplished during the compliance assessment activity shown in Figure 6-90. To effectively communicate between Issues 2.4 and 4.4, the concept of an input item is used. As shown in Figure 6-90, a list of input items is generated under Issue 2.4 to identify the information required from other issues to perform the retrievability compliance analysis. The current list of approximately 20 input items was developed in Section 8.3.5.2. For example, to ensure that the design will provide usable openings, a need is generated to provide opening and support system designs, perform analyses to predict their performance, develop contingency plans for off-normal conditions, and provide supporting evidence that the design will be satisfactory (i.e., the performance goals are met), which would be performed under Issue 4.4. A complete discussion of these input items is included in Sections 8.3.5.2.2 through 8.3.5.2.6.

Work toward providing these input items has been completed in the following areas: (1) underground opening design, (2) ventilation system design, (3) radiological protection, and (4) equipment development.

Underground opening design

Information on the stability of the underground openings is required both to perform the first retrieval function (i.e., to ensure that the access and drifts will be usable throughout the retrievability period) and to provide information concerning emplacement borehole stability for the second function--access to the waste container.

Evaluations of the thermal and mechanical effects on stability of shafts, ramps, drifts, and boreholes have been the focus of about 15 reports or studies synopsized in Section 6.4.10.2 and are not repeated here. These analyses have used a variety of numerical and empirical approaches as follows: (1) finite-element methods, (2) boundary-element methods, and (3) tunnel-indexing methods. Similarly, different constitutive models were used as follows: (1) elastic models, (2) ubiquitous-joint models, (3) compliant-joint models, and (4) elastic-plastic models. Other items that have been varied in some of the analyses include (1) opening sizes and shapes, (2) depths, (3) thermal and mechanical properties, and (4) fracture properties and in situ conditions. The common preliminary conclusions drawn from the approaches used to date are as follows:

1. Drifts, shafts, and ramps, as currently designed, are predicted to remain stable during preclosure.

2. Waste emplacement boreholes are predicted to remain stable during preclosure, although some potential exists for negligible amounts of rock to fall on the liner planned for use in horizontal emplacement holes.

3. Excavation-induced response of openings in Topopah Spring tuff should be expected to be similar to those in the Grouse Canyon tuff in G-Tunnel.

Ventilation system design

Evaluations of the ventilation system design are required to determine the feasibility of providing a safe working environment for retrieval operations. The status of these evaluations is presented in Section 3.4 of the SCP-CDR. Detailed analyses are documented in Appendix C of the SCP-CDR. The principal results related to retrievability are synopsized in the following text.

The design of the ventilation system has considered three different sets of operations conditions: (1) for construction and emplacement operations, (2) for reentry for inspection, and (3) for maintenance and retrieval operations. Preliminary ventilation system design analyses have been completed for both the vertical and horizontal emplacement orientations. For construction and emplacement operations, maximum velocity constraints are met and requirements to provide acceptable airflow to the ramp, drifts, and service areas are met using currently available equipment.

To ensure that continued access to the emplacement boreholes is maintained, reentry for inspection purposes is planned. The criteria for an acceptable inspection environment was defined as an air cooling power greater than 300 W/m^2 and a dry bulb temperature less than 45°C. As shown in Section 3 of the SCP-CDR, using ambient air, it would take 168 d and 14 d to cool the vertical and horizontal emplacement drifts, respectively. Using chillers, it would take 21 d and 5 d to cool the vertical and horizontal emplacement drifts, respectively. This is based on a 708-kW cooling load for vertical emplacement and a 490-kW cooling load for horizontal emplacement.

For reentry for maintenance or retrieval purposes, the criteria for an acceptable environment is defined as an air cooling power greater than 500 W/m^2 and a dry bulb temperature less than 40°C. As shown in Section 3 of the SCP-CDR, more than 560 d are required to cool the vertical emplacement drifts using ambient air. The horizontal emplacement drifts would require 70 d for cooling using ambient air. Assuming a 708-kW cooling load, the vertical emplacement drift can be cooled in approximately 37 d. For the horizontal concept, the emplacement drifts can be cooled within 11 d using a 490-kW cooling load.

The results of these preliminary analyses indicate that the requirements for providing adequate ventilation can be met for inspection and retrieval operations using currently available equipment. Future work will focus on refinement of these analyses with specific attention paid to the following items:

1. Particulates (burden and type).
2. Temperature.
3. Humidity.

4. Airborn radioactive contaminants.
5. Gaseous pollutants.

Radiologic protection

The basic approach to ensuring radiological protection is as follows: (1) identify radiation sources under normal and accident conditions, (2) establish the radiation levels for these sources, and (3) develop designs and operations plans that result in the ability to perform retrieval under an acceptable radiological environment.

The reports that address radiological concerns include the following:

1. "Reference Nuclear Waste Description for a Geologic Repository at Yucca Mountain, Nevada," SAND84-1848 (O'Brien, 1985).

2. "Preliminary Safety Assessment Study for the Conceptual Design of a Repository in Tuff at Yucca Mountain," SAND83-1504 (Jackson et al., 1984).

3. "NNWSI Repository Worker Exposure Volume I, Spent Fuel and High-Level Waste Operations in a Geologic Repository in Tuff," SAND83-7436/1 (Dennis et al., 1984a).

4. "Worker Radiation Dose During Vertical Emplacement and Retrieval of Spent Fuel at the Tuff Repository," SAND84-2275 (Stinebaugh and Frostenson, 1987).

5. "Preliminary Preclosure Radiological Safety Analysis," (Appendix F of SNL, 1987).

6. "Items Important to Safety and Retrievability at Yucca Mountain," (Appendix L of SNL, 1987).

Radiation sources in the repository are categorized as follows: (1) waste generated and (2) naturally occurring. Estimates of the source term for the waste containers are reported in O'Brien (1985). These estimates will be used as a basis for radiation shield designs for retrieval equipment. Worker dose estimates are contained in Jackson (1984), Dennis et al. (1984a), and Stinebaugh and Frostenson (1987). These studies indicate that radiation doses of less than 1 rem/yr are possible through modifications in operations or equipment. Preliminary results of studies to identify accidents during retrieval operations, which result in radioactive releases are discussed in Appendices F and L of the SCP-CDR.

Future work will include refinement of public and worker dose-rate estimates, detailed equipment shielding designs, and refinement of accident analyses. The principal concern for naturally occurring radiation sources is the potential contamination from radon-222 and radon daughters. No work in this area has yet been completed. Current work is focused on estimation of the emanation rate for radon-222 and its potential effect on repository operations. This work will include G-Tunnel tests and tests at the exploratory shaft facility (Section 8.3.1.15, rock characteristics program).

Equipment development

The development of equipment is achieved in the following phases:

1. Development of equipment concepts.
2. Conceptual design.
3. Interim design phases (proof-of-principle, prototype, etc.).
4. Final design.

Retrieval equipment development is performed under Issue 4.4 (preclosure design and technical feasibility). Work on equipment development is progressing in two areas: (1) the development of equipment for emplacement and retrieval of wastes and (2) the development of equipment to accurately drill and line long horizontal emplacement boreholes. The equipment related to drilling and lining horizontal emplacement boreholes is included here since the requirement to line the boreholes is principally related to ensuring access to the waste containers for possible retrieval. The concepts for equipment for emplacement and retrieval of waste have been developed and are presented in the following documents:

1. "Conceptual Engineering Studies and Design for Three Different Machines for Nuclear Waste Transporting, Emplacement, and Retrieval," SAND83-7089 (Fisk et al., 1985).

2. "Disposal of Radioactive Waste Packages in Vertical Boreholes--A Description of the Operations and Equipment for Emplacement and Retrieval," SAND84-1010, May 1986 (Stinebaugh and Frostenson, 1986).

3. "Disposal of Radioactive Waste Packages in Horizontal Boreholes--A Description of the Operations and Equipment for Emplacement and Retrieval," SAND84-2640, May 1986 (Stinebaugh et al., 1986).

4. "One-Twelfth-Scale Model of the Horizontal Emplacement and Retrieval Equipment for Radioactive Waste Containers at the Tuff Repository," SAND86-7135, 1987 (White et al., 1986).

Preliminary conceptual designs for retrieval equipment are presented in Stinebaugh and Frostenson (1986), Stinebaugh et al., (1986) and SCP-CDR, Appendix E. In addition, a one-twelfth-scale model of the waste emplacement and retrieval equipment for horizontal emplacement has been completed (White et al., 1986). This model is being used to gain perspective on design features that need modification. Future work will focus on developing design concepts that allow retrieval under off-normal conditions and completing conceptual designs of retrieval equipment for normal conditions during advanced conceptual design.

The work that has been completed on the development of drilling and lining equipment for the horizontal boreholes is presented in the following documents:

1. "Small Diameter Horizontal Hole Drilling---State of Technology," SAND84-7103 (Robbins Company, 1984b).

2. "Feasibility Studies and Conceptual Design for Placing Steel Liner in Long, Horizontal Boreholes for a Prospective Nuclear Waste Repository in Tuff," SAND84-7209 (Robbins Company, 1985).

3. "Installation of Steel Liner in Blind Hole Study," SAND85-7111 (Kenny Construction Company, 1987).

4. "Design of a Machine to Bore and Line a Long Horizontal Hole in Tuff," SAND86-7004 (Robbins Company, 1987).

A detailed design for the drill and lining system has been completed. Current work involves fabrication and testing of a prototype of the drill, which will be followed by additional testing in G-Tunnel at the Nevada Test Site. This work is being performed under Issue 4.4 (preclosure design and technical feasibility).

6.4.8.3 Future work

The future work that is planned under Issue 2.4 will focus on (1) further development of tactics and corresponding schedules that ensure that the work required to support resolution of Issue 2.4 is clearly identified and is completed on a schedule consistent with that for the NNWSI Project; (2) refinement of retrieval conditions, both normal and off-normal; (3) refinement of design criteria; (4) continued review of the results from Issue 4.4 for the defined input items to ensure that the established performance goals are met; and (5) development of a report that assesses compliance concerns relative to retrievability.

Retrieval planning and strategy documents

Before development of the advanced conceptual design, the strategy for meeting the regulatory requirements and for implementing the requirements contained in the DOE position on retrieval and retrievability, will be described in a future NNWSI retrieval strategy document.

During advanced conceptual design, the tactics for implementation of the retrieval philosophy outlined in Section 2.4.4 of the SCP-CDR (SNL, 1987)will be defined in more detail and presented in the retrieval implementation plan. This plan will address requirements for design development, equipment development, demonstrations, retrieval condition evaluation, and supportive studies.

Retrieval conditions

In the future, the classification of retrieval conditions will use the probability-based approach presented in Figure 6-91. Additional development of design detail for equipment, especially for off-normal operations, and additional evaluation of potential conditions is required during ACD. (In future documents, including the ACD report, the term off-normal will be replaced with the term abnormal.) This will allow classification of potential conditions as normal, abnormal (expected and credible), or not credible. The classification of these retrieval conditions will use an identification concept similar to the one used to date for identifying items important to retrievability (Appendix L of SNL, 1987). The results of future work will be presented in two reports describing retrieval conditions. The first report will be generated during advanced conceptual design; a second report is planned in support of the license application design.

Retrievability input to repository design requirements

The repository design requirement (RDR) report will be periodically updated as additional or modified requirements are developed. Most of the retrievability-related changes are expected to result from additional definition of equipment concepts and retrieval conditions. The resulting modifications to the retrievability-related design criteria will be forwarded to the RDR authors for review and publication in periodic updates.

Retrievability compliance analysis

A preliminary report addressing the status of compliance with the retrievability requirement will be issued at the completion of advanced conceptual design. An additional report on compliance will be completed as part of the license application design.

6.4.9 ISSUE 4.2: NONRADIOLOGICAL HEALTH AND SAFETY

6.4.9.1 Introduction

The question asked by Issue 4.2 is

> Are the repository design and operating procedures developed to ensure nonradiological health and safety of workers adequately established for the resolution of the performance issues?

The complete discussion of the proposed strategy for the resolution of this issue is presented in Section 8.3.2.4 (nonradiological health and safety). Readers unfamiliar with the issue resolution strategy for this issue, should review the contents of Section 8.3.2.4 before continuing.

Issue 4.2 has been subdivided into three information needs, and the completed work has been identified under the associated information need. The completed work is numbered in a manner that corresponds with the information need numbering system. For example, 4.2.3-1 is the first completed work identified under the third information need of Issue 4.2. The information needs are the following:

<u>Information Need 4.2.1</u> Site and performance information needed for design

This information need consists of (1) compiling the site characterization and performance assessment information identified in the other information needs under Issue 4.2 into a single integrated list and (2) reviewing the proposed site characterization program and performance assessment program to ensure that the actions required to obtain the site characterization information and to provide the required performance assessment information are incorporated in these programs. Work completed to date has focused on the safety aspects of excavation stability. The site characterization and performance assessment information needed for design is identified in Section 8.3.2.4.1.

<u>Information Need 4.2.2</u> Potential nonradiological hazards to personnel

The repository design and operating procedures will be reviewed to determine nonradiological hazards to personnel. The risk to personnel from a given nonradiological hazard then will be determined by (1) calculating the probability of occurrence of the event identified as a personnel hazard, (2) determining the consequences of the event, and (3) multiplying the probability of an event occurrence and the consequences of the event. If the risk is determined to be unacceptable, a change will be incorporated in the repository design and the repository operating procedures. The work completed to date for this information need has focused primarily on the identification of events that could have hazards associated with excavation stability.

<u>Information Need 4.2.3</u> Design measures for avoiding or mitigating hazards to personnel

Number	Description
4.2.3-1	The design analysis work describes the approach being used in the design of the underground openings and the underground ventilation system.
4.2.3-2	Other work describes the approach being used to develop design criteria that address worker nonradiological health and safety concerns.

Section 6.4.9.2 summarizes the completed work that is pertinent to the resolution of Issue 4.2. Section 6.4.9.3 identifies future work that will provide additional information for use in the enhancement of worker nonradiological health and safety.

6.4.9.2 <u>Work completed</u>

6.4.9.2.1 Design analysis work

Work has been completed in the following areas.

Underground openings

The concern in the design of the underground openings is that they are stable and usable for the life of the repository. For personnel safety, stability implies that (1) no localized rock fall of a size sufficient to cause serious personnel injuries will occur, and (2) no catastrophic failure of the openings that could block personnel access and egress will occur.

The analyses that are being made to ensure that the design results in underground openings that are stable and, thus, safe, is the same work that is done to support the conclusion that the openings can be designed, constructed, and used for the life of the repository using currently available technology. This work is presented in Sections 6.4.10.2, Technical feasibility - work completed and 8.3.2.5.7, Design analysis. The data required to do these calculations are specified in Section 8.3.2.5.1, Site Information needed for design. The conclusion drawn from this work is that the underground openings will be stable and usable for the life of the repository; this conclusion translates further into the conclusion that the drifts will be safe for repository workers. The results of these calculations are discussed in detail in Section 6.4.10.2.

Potential hazards to excavation workers

To evaluate the potential hazards to excavation workers at Yucca Mountain, excavation experience in the welded and nonwelded tuffs at the NTS that have been used for weapons-effect testing has been examined. The safety records show that in the past such excavations have been carried out with minimum adverse effects on worker safety. To assess the relative level of safety for tunneling operations at the NTS, the incidence rates for NTS operations can be compared with injury incidence rates for similar mining operations. Such a comparison was presented in Figure 6-27 of the environmental assessment for the Yucca Mountain site (DOE, 1986c). The industry category that is most similar to excavation conditions in the tuffs at NTS is the category of hard-rock metal mining. The data presented in the environmental assessment are based upon industry average data compiled by the National Safety Council and data for NTS operations compiled by Reynolds Electric and Engineering Co. (REECo), the DOE contractor for excavation operations. The data presented clearly indicate a significantly better safety record for NTS tunneling operations than is typical of industry practice. While the industry average incidence rate is lower now than it was 20 yr ago by a factor of about two, NTS operational safety record is still lower than the industry average by a factor of about three.

Specific excavation experience in G-Tunnel at the NTS is of interest because part of the G-Tunnel experience involves a welded tuff, the Grouse Canyon Member. Engineers and geologists familiar with excavation in the welded Grouse Canyon Member have expressed the opinion that the ground support that will be required in the Topopah Spring Member at Yucca Mountain is likely to be similar to that required in the welded Grouse Canyon Member. None of the accidents identified in a search of tunnel records could be considered to be caused by unstable ground, faulting, or other such geologically related conditions. This was observed to be consistent with the period between approximately 1965 and 1985 for NTS operational experience. The one accident that involved the falling of a piece of rock was the result of an oversight in barring down loose rock before support installation. The accident report in question indicates that this accident probably would not have occurred if the correct NTS mining practice had been followed (DOE, 1986c).

Faults and shear zones that could compromise the safety of repository personnel because of construction problems or water inflow are not expected in the primary repository area at Yucca Mountain. The design and layout of the underground facility is planned to minimize contact with portions of the host rock where minor faults and shear zones are identified. There is to date no indication that pressurized brine pockets, evidence of dissolution, or significant accumulations of water or toxic gases are present in the repository horizon.

Underground ventilation system

Other significant physical or chemical phenomena known to be associated with rock characteristics are related to ventilation-system design and worker safety. The temperature increases resulting from the emplaced waste are important in designing ventilation systems and in selecting the standoff distance between the drift and the emplaced waste. Excavations at the NTS show that explosive or other hazardous gases are not to be expected. Thus, the ventilation system will primarily control dust. Hazards associated with dust and hazards associated with naturally occurring radon released during rock excavation will be mitigated by supplying adequate flow volumes to meet safety requirements. Techniques already implemented in the uranium mining industry will be considered. The proper design and operation of a ventilation system based on current technology should readily mitigate dust and radiation concerns.

The results obtained from the analyses performed to verify that the ventilation of the underground repository facility could be accomplished using reasonably available technology are applicable in the resolution of Issue 4.2. These results are given in Section 6.4.10.2. The goal imposed on the design of the underground ventilation system is that adequate air must be supplied to the workers under the most extreme operational conditions. The analyses indicate that this goal can be achieved.

6.4.9.2.2 Other work supporting the conceptual design

The work, other than analyses, that has been completed consists primarily of identifying legislative and regulatory requirements governing worker safety. These requirements have been incorporated in the subsystems design requirements document (Appendix P of SNL, 1987), the design criteria for the repository. These requirements are summarized in Section 8.3.2.5.4 (repository design requirements). The operational plan, Section 8.3.2.5.3 (plan for repository operations), also is influenced by these legislative and regulatory requirements.

6.4.9.3 Future work

Underground opening stability

Basically, two things need to be done in relation to the design of the underground openings:

1. Further work needs to be done with the rock.mass classification methods. This work should be directed at obtaining additional data from comparable underground facilities to increase the data base on which projections of stability and the design of the support systems can be based.

2. Additional work needs to be done to verify the codes used to analyze the performance of the underground openings. This verification work can be accomplished in two ways: (a) by monitoring demonstration openings driven in the exploratory shaft facility, and (b) by applying the analyses techniques to previously driven openings and comparing the analytical results with the observed results.

Underground ventilation systems

Additional work needs to be done to quantify the potential radon gas burden on the ventilation system. The particulates generated during construction and operation need to be qualified and quantified.

The required efforts identified here are discussed in more detail in Section 6.4.10.3.1.

6.4.10 ISSUE 4.4 PRECLOSURE DESIGN AND TECHNICAL FEASIBILITY

6.4.10.1 Introduction

The question asked by issue 4.4 is

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

The complete discussion of the proposed strategy for resolution of this issue is presented in Section 8.3.2.5 (preclosure design and technical feasibility). Readers unfamiliar with the issue resolution strategy for this issue should review the contents of Section 8.3.2.5 before continuing.

Issue 4.4 has been subdivided into 10 information needs. Several of the information needs address the concept of reasonably available technology. Evaluations of whether satisfaction of an information need can be achieved using reasonably available technology will be based upon the 10 CFR Part 960 definition: Reasonably available technology means technology which exists and has been demonstrated or for which the results of any requisite development, demonstration, or confirmatory testing efforts will be available before license application.

The completed work has been identified under the associated information need. The completed work elements are numbered in a manner that corresponds with the information need numbering system. For example, 4.4.2-1 is the first completed work identified under the second information need of Issue 4.4. The information needs and completed work are the following:

Information Need 4.4.1 Site and performance assessment information needed for design.

This information need consists of (1) compilation of the site characterization and performance assessment information identified in the remaining Issue 4.4 information needs into a single integrated list and (2) the review of the proposed site characterization program and performance assessment program to ensure that the actions required to obtain the site characterization information and to provide the required performance assessment information are incorporated in these programs. This work has not been completed; the site characterization and performance assessment information needed for design is identified in Section 8.3.2.5.1.

Information Need 4.4.2 Characteristics and quantities of waste and waste packages needed for design.

Number	Description
4.4.2-1	The preliminary reference waste descriptions document (O'Brien, 1984) contains a description of the waste type and waste containers.
4.4.2-2	The reference nuclear waste descriptions document (O'Brien, 1985) contains a description of the waste being considered for disposal at the MGDS site.
4.4.2-3	Section 2.1 of the SCP-CDR (waste form and package) contains a summary description of the waste form and waste package used as a basis for conceptual design of surface and subsurface facilities.

Additional information on Information Need 4.4.2 is presented in Section 8.3.2.5.2.

Information Need 4.4.3 Plan for repository operations during construction, operations, closure, and decommissioning.

Number	Description
4.4.3-1	The operational procedures for receiving, packaging, emplacing, and retrieving waste describe these operations as they were understood at the beginning of the conceptual design phase.

Number	Description
4.4.3-2	Chapter 3 of the SCP-CDR (repository) provides an overview of the principal operations and functions that will be performed in the repository.

Additional information on Information Need 4.4.3 is presented in Section 8.3.2.5.3.

Information Need 4.4.4 Repository design requirements for construction, operations, closure, and decommissioning.

Number	Description
4.4.4-1	Chapter 2 of the SCP-CDR (bases for the SCP conceptual design) contains a documentation of the reference values and design assumptions used in the conceptual design of the MGDS facilities.

Additional information on Information Need 4.4.4 is presented in Section 8.3.2.5.4.

Information Need 4.4.5 Reference preclosure repository design.

Number	Description
4.4.5-1	The repository reference designs that formed the basis for the repository conceptual design are addressed.
4.4.5-2	Chapter 4 of the SCP-CDR (design description) presents a description and discussion of the conceptual design.

Additional information on Information Need 4.4.5 is presented in Section 8.3.2.5.5.

Information Need 4.4.6 Development and demonstration of required equipment.

Number	Description
4.4.6-1	The conceptual designs for the waste receiving and preparation equipment address the equipment necessary to receive the waste and prepare the waste for emplacement.
4.4.6-2	The conceptual designs for the waste emplacement and retrieval equipment address equipment necessary to transport the waste underground; emplace the waste; and, if directed, retrieve the waste.
4.4.6-3	The conceptual designs for the waste emplacement hole boring equipment are addressed.

Additional information on Information Need 4.4.6 is presented in Section 8.3.2.5.6.

Information Need 4.4.7 Design analyses, including those addressing impacts of surface conditions, rock characteristics, hydrology, and tectonic activity.

Number	Description
4.4.7-1	Structural, thermal, and thermomechanical analyses are addressed.
4.4.7-2	Ventilation analyses are addressed.
4.4.7-3	Hydrologic analyses are addressed.
4.4.7-4	Tectonic and seismic analyses are addressed.

Additional information on Information Need 4.4.7 is presented in Section 8.3.2.5.7.

Information Need 4.4.8 Identification of technologies for surface facility construction, operation, closure, and decommissioning.

This information need will review Information Needs 4.4.3 through 4.4.6 to determine if the technology used in the surface facilities design can be considered reasonably available technology.

Additional information on Information Need 4.4.8 is presented in Section 8.3.2.5.8.

Information Need 4.4.9 Identification of technologies for underground facility construction, operation, closure, and decommissioning.

This information need will review Information Needs 4.4.3 through 4.4.6 to determine if the technology used in the underground facilities design can be considered reasonably available technology.

Additional information on Information Need 4.4.9 is presented in Section 8.3.2.5.9.

Information Need 4.4.10 Identification of technologies for emplacement of seals for accesses, drifts, and boreholes.

This information need will review Information Needs 1.12.3 and 1.12.4 to determine if the technology used in the design and placement of seals can be considered reasonably available technology.

Additional information on Information Need 4.4.10 is presented in Section 8.3.2.5.10.

Summary information describing the computer codes used in the analyses supporting the completed work elements previously identified is contained in Table 6-34.

6.4.10.2 Work completed

The following sections summarize the completed work for Issue 4.4.

Table 6-34. Computer codes used in analyses for Issue 4.4[a] (page 1 of 4)

Code name	Author	Code location	Design parameter	Analysis description
VNETPC	J. McPherson	Mining Ventilation Services, Oakland, CA	Ambient mine ventilation requirements.	Simulates underground airflow distribution and calculates fan requirements and pressure loss.
CLIMSIM 2.0	J. McPherson	Mining Ventilation Services, Oakland, CA	Drift cooling requirements.	Given wet- and dry- bulb temperatures of inlet air, the code simulates the psychrometric and environmental conditions in the airways.
ASHSD	Ghosh, Wilson	University of California at Berkeley, CA	Seismic analysis of structure-soil system.	Finite element model.
PORFLOW-R	A.K. Runchal	ACRI, Los Angeles, CA	2-D analysis of vertical emplacement drift. Thermal modeling.	Finite-element heat transfer for 2-D nonlinear heat convection and conduction in a porous medium.
THERM 3D	A.K. Runchal	ACRI, Los Angeles, CA No documentation available	Thermal modeling and 3-D analysis of vertical emplacement drift.	Finite-element heat transfer for 3-D analysis.
TEMP 3D	M. Christianson University of Minnesota	Public domain	Thermal modeling and 3-D analysis of vertical emplacement drift.	Computer program for determining temperatures around single or arrays of constant or decaying heat sources. Based on closed form solution.
ABAQUS	Hibbit, Karlsson, and Sorenson, Inc.	Hibbit, Karlsson, and Sorenson, Inc.	Displacements and stresses around underground openings.	Finite-element program for linear and nonlinear structural analysis.
SANCHO	C.M. Stone R.D. Kreig Z.E Beisinger	Public domain	Displacements and stresses around underground openings.	Finite element program to compute quasistatic, large deformation, inelastic response of planar or axisymmetric solids.

Table 6-34. Computer codes used in analyses for Issue 4.4[a] (page 2 of 4)

Code name	Author	Code location	Design parameter	Analysis description
ADINAT	K.J. Bathe	MIT	Temperature surrounding underground openings, used in conjunction with ADINA.	Finite-element heat transfer program. 2-D, 3-D; for automatic dynamic nonlinear heat conduction; convective and adiabetic boundaries; constant or decaying heat source.
HEFF	B.G.H Brady University of Minnesota	Public domain	Effects of parameter uncertainty on drift stability.	Boundary-element stress analysis for 2-D thermoelastic analysis of a rock mass subject to constant or decaying thermal loading.
ADINA	K.J. Bathe	MIT	Displacements and stresses around underground openings.	Finite-element stress analysis program. 2-D, 3-D; elastic elastic/plastic ubiquitous joint model; accepts precalculated temperature history.
STRES3D	C. St John M. C. Christianson	University of Minnesota	Stress distribution for evaluation of usable emplacement area.	Computer program for determining temperatures, stresses, and displacements around single or arrays of constant or decaying heat sources.
LINED	C. St John J.F.T Agapito and associates.	Public domain	Liner integrity due to surrounding stress.	Static analysis of a tunnel with liner or damaged annulus.
BMINES	U.S. Bureau of Mines	Public domain	Rock bolt performance.	Computer program of analytic modeling of rock/structure interaction.
VISCOT	ONWI	Public domain	Displacements and stresses around underground openings.	Finite-element stress analysis program. Thermoviscoelastic, thermoviscoplastic; accepts precalculated temperature history.

Table 6-34. Computer codes used in analyses for Issue 4.4[a] (page 3 of 4)

Code name	Author	Code location	Design parameter	Analysis description
DOT	University of California	Public domain	Used in conjunction with VISCOT. Time/temperature history (input for other stress codes).	General purpose heat conduction code for both linear and nonlinear steady-state or transient heat analysis.
SPECTROM-11	RE/SPEC Albuquerque, NM	RE/SPEC No documentation available	Displacements and stresses around underground openings.	Finite-element stress analysis program. Elastic, elastic/plastic, ubiquitous joint model; accepts precalculated temperature history.
SIM	Parsons Brinckerhoff Quade & Douglas, San Francisco, CA	PBQ&D - Parsons Brinckerhoff Quade & Douglas,	Rock temperature around borehole for comparison with thermal limit of canister.	A linear superposition program for three dimensional heat conduction solutions with constant or decaying line heat sources.
COYOTE	D.K. Gartling Sandia National Laboratories	Public domain	Temperature around underground openings (input for other stress codes).	Finite element computer program for nonlinear heat conduction problems.
SPECTROM-41	D.K. Svalstad RE/SPEC for ONWI Albuquerque, NM	RE/SPEC	Temperature surrounding an underground opening.	Finite-element heat transfer program. Nonlinear heat conduction; convective and adiabetic boundaries; constant or decaying heat source.
SPECTROM-31	D.A. Labreche S.V. Petney RE/SPEC for SNL Albuquerque, NM	RE/SPEC	Displacements and stresses around underground openings	Finite-element stress analysis program. Large deformation, static and quasi-static response of planar and axisymmetric solids; thermo-elastic/plastic, ubiquitous joint model, compliant joint model; accepts precalculated temperature history.

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Table 6-34. Computer codes used in analyses for Issue 4.4[a] (page 4 of 4)

Code name	Author	Code location	Design parameter	Analysis description
JAC	J.H. Biffle Sandia National Laboratories	Public domain	Displacements and stresses around an underground opening.	Finite-element stress analysis program. Nonlinear quasi-static response of solids with the conjugate gradient method; elastic/plastic, ubiquitous joint model, compliant joint model; accepts precalculated temperature history.
FLUSH	J. Lysmer T. Udada C. Tsai H.B. Seed University of California at Berkeley, CA	J. Lysmer	Soil-structure interaction, license-application design.	2-D finite element soil/structure interaction program.
CLASSI	Luco and Wong University of California at San Diego, CA	Luco and Wong No documentation available	Soil-structure interaction, license-application design.	3-D soil/structure interaction analyses using frequency-dependent impedance functions.

[a]ACRI = analytic and computational Research, Inc.; MIT = Massachussetts Institute of Technology; ONWI = Office of Nuclear Waste Isolation.

6.4.10.2.1 Characteristics and quantities of waste and waste containers

4.4.2-1 Preliminary reference waste description

In the preliminary reference waste descriptions report, O'Brien (1984) describes the reference waste types and containers for the early stages of conceptual design of a radioactive waste repository being considered for location in the tuff formations at Yucca Mountain. An assessment of the effects of nonreference waste characteristics on repository design is included.

4.4.2-2 Reference nuclear waste description

In the reference nuclear waste description document, O'Brien (1985) describes the reference wastes to be used as a basis for the conceptual design of a geologic repository being considered for location in the tuff formations at Yucca Mountain. Waste characteristics and production rates are taken from a DOE guidance document (DOE, 1984b) and the SCP-CDR. This information is recast as waste receipt and emplacement schedules to be used in the design of repository facilities and equipment and as input to the timetable for repository development.

4.4.2-3 Characteristics and quantities of waste form and waste container

For the waste form and container, Section 2.1 of the SCP-CDR summarizes the characteristics and quantities of the wastes and waste packages that were used as a basis for the conceptual design of a geologic repository being considered for location in the tuff formations at Yucca Mountain.

6.4.10.2.2 Plans for repository operations

4.4.3-1 Operational procedures

For operational procedures for receiving, packaging, emplacing, and retrieving waste, Dennis et al. (1984c) was prepared for use by the designers of the surface and underground waste-handling facilities and equipment. The report describes the radioactive waste expected at the repository; the shipping casks and the facility casks; and the waste receiving, handling, packaging, transfer, and emplacement operations. Potential waste retrieval operations, also are discussed.

4.4.3-2 Principal operations and functions

Chapter 3 of the SCP-CDR provides an overview of the principal operations and functions that will be performed at the repository. These operations and functions include waste handling and emplacement, waste retrieval, mining, ventilation, and the equipment needed to perform these operations. Equipment and concepts requiring development are identified.

6.4.10.2.3 Repository design requirements

4.4.4-1 Reference values and design assumptions for conceptual design

Chapter 2 of the SCP-CDR documents the reference values and design assumptions used by the architect-engineer in the completion of the SCP-CD. Presented are the technical requirements and assumptions that are the bases for the repository design; the site constraints, assumptions, and data that affect the repository design or the approach to the design; and the reference geologic data used in the design.

6.4.10.2.4 Reference preclosure repository design

4.4.5-1 Repository reference designs forming basis of conceptual design

Repository reference designs are the basis for performance analyses, operational plans, costs estimates, and schedules. There have been three reference designs completed and documented for the proposed repository at Yucca Mountain:

1. Jackson, J. L., (compiler), 1984. "Nevada Nuclear Waste Storage Investigations Preliminary Repository Concepts Report," SAND83-1877, Sandia National Laboratories, Albuquerque, New Mexico.

2. SNL (Sandia National Laboratories), 1986. "Two-Stage Repository Development at Yucca Mountain: An Engineering Feasibility Study," SAND84-1351, H.R. MacDougall (compiler), Albuquerque, New Mexico.

3. SNL (Sandia National Laboratories), 1987. "Site Characterization Plan-Conceptual Design Report," SAND84-2641, H. R. MacDougall, L. W. Scully, and J. R. Tillerson (compilers), Albuquerque, New Mexico.

There is only one reference design for the repository at any one time. The current reference design for the proposed repository at Yucca Mountain is the SCP-CD. The other two designs just identified have been superceded by this design and are no longer used as a basis for supporting calculations, operational plans, or cost estimates. The two obsolete designs are identified here as a part of the chronological record of the design evolution for the repository. In addition, studies supporting these two designs are often referenced in the SCP-CDR. Additional information on the philosophy for reference repository designs is given in Section 8.3.2.5.5.

4.4.5-2 Conceptual design description

The design description is in Chapter 4 of the SCP-CDR, which describes the conceptual design of the repository, with emphasis on the excavations, facilities, systems, and equipment needed to perform the operations described in Chapter 3 of the SCP-CDR.

6.4.10.2.5 Development and demonstration of required equipment

4.4.6-1 Waste receiving and preparation equipment

For waste receiving and preparation, the equipment that must be developed is primarily the remote manipulation equipment required for unloading, packaging, welding, inspection, and decontamination. This equipment is not unique in that essentially all the required components have been built and demonstrated in other applications. The design task for the repository at Yucca Mountain is to (1) configure this equipment to perform the required tasks in a safe and effective manner and (2) determine that the resulting equipment set will be capable of accommodating the projected waste throughputs. The work completed to this time relative to the receiving and preparation activity is the development of conceptual designs and the analysis of worker environments. This work is documented in the following reports:

1. Dennis, A. W., 1983. "Design Considerations for Occupational Exposure for a Potential Repository at Yucca Mountain, High-Level Waste Handling Operations," SAND83-0247C, Sandia National Laboratories, Albuquerque, New Mexico.

2. Dennis, A. W., R. Mulkin, and J. C. Frostenson, 1984b. "Operational Procedures for Receiving, Packaging, Emplacing, and Retrieving High-Level and Transuranic Waste in a Geologic Repository in Tuff," SAND83-1982C, Sandia National Laboratories, Albuquerque, New Mexico.

3. Dennis, A. W., P. D. O'Brien, R. Mulkin, and J. C. Frostenson, 1984c. "NNWSI Repository Operational Procedures for Receiving, Packaging, Emplacing, and Retrieving High-Level and Transuranic Waste," SAND83-1166, Sandia National Laboratories, Albuquerque, New Mexico.

4. Dennis, A. W., J. C. Frostenson, and K. J. Hong, 1984a. "NNWSI Repository Worker Radiation Exposure, Volume 1, Spent Fuel and High-Level Waste Operations in a Geologic Repository in Tuff," SAND83-7436/1, Sandia National Laboratories, Albuquerque, New Mexico.

Current information supports a conclusion that the receiving and preparation tasks at the repository can be accomplished using reasonably available technology. The relevant considerations are the following:

1. The equipment design and operational procedures presented in the listed documents are based on commercially available equipment, such as manipulators, remote welders, and remote operated and programmable position cranes.

2. Operations are based on demonstrated procedures for handling of radioactive materials; such procedures include using shielding, placing operators in locations remote from the material being handled, and providing for remote replacement, repair, and maintenance of cell equipment.

3. The operations to be performed in receiving and preparing of the waste at the repository closely parallel the task of refueling nuclear power reactors; thus, the experience and the equipment developed to support refueling can be incorporated in the designs for receiving and preparation equipment.

4.4.6-2 Waste emplacement and retrieval equipment

For waste emplacement and retrieval, equipment is required for loading the waste at the surface facility, transporting the waste underground, emplacing the waste in the emplacement borehole, and retrieving the waste. The concepts for the equipment required to perform these activities are based on currently available technology (e.g., the waste transporter is based on the use of a commercially available mine haulage system that has been thoroughly tested in mining applications). Requirements imposed on the design of this equipment include the incorporation of backup actuators, provision for easy access to replace key components, and simplicity. These requirements are imposed to improve the reliability of the equipment for waste emplacement and retrieval and to minimize operational malfunctions from which recovery would be difficult and hazardous to personnel. The reports that document the work completed in support of the equipment development are as follows:

1. Stinebaugh, R. E., and J. C. Frostenson, 1987. "Worker Radiation Doses During Vertical Emplacement and Retrieval of Spent Fuel at the Tuff Repository," SAND84-2275, Sandia National Laboratories, Albuquerque, New Mexico.

2. Fisk, A. T., P. de Bakker, B. J. Doherty, J. P. Pokorski, and J. Spector, 1985. "Conceptual Engineering Studies and Design for Three Different Machines for Nuclear Waste Transporting, Emplacement, and Retrieval," SAND83-7089, prepared by Foster-Miller, Inc., Waltham, Massachusetts, for Sandia National Laboratories, Albuquerque, New Mexico.

3. Flores, R. J., 1986. "Retrievability: Strategy for Compliance Demonstration," SAND84-2242, Sandia National Laboratories, Albuquerque, New Mexico.

4. Stinebaugh, R. E., and J. C. Frostenson, 1986. "Disposal of Radioactive Waste Packages in Vertical Boreholes--A Description of the Operations and Equipment for Emplacement and Retrieval," SAND84-1010, Sandia National Laboratories, Albuquerque, New Mexico.

5. Stinebaugh, R. E., I. B. White, and J. C. Frostenson, 1986. "Disposal of Radioactive Waste Packages in Horizontal Boreholes--A Description of the Operations and Equipment for Emplacement and Retrieval," SAND84-2640, Sandia National Laboratories, Albuquerque, New Mexico.

The conclusion from the work completed to this point is that the equipment required to emplace and retrieve waste at the Yucca Mountain mined geologic repository can be designed and developed by integrating available technology. Development will be required to ensure that the integration of the available technology performs as required under the conditions for emplacement and retrieval.

4.4.6-3 Waste emplacement hole boring equipment

For waste emplacement and retrieval, the vertical emplacement boreholes can be bored using existing, commercially available drills with minor modifications. This conclusion is documented in a report by The Robbins Company (1984a). The boring of the holes for horizontal emplacement will require the development of a new drill. This drill, as it is currently designed, is based on technology used in tunnel boring machines (TBMs). The boreholes required for the horizontal emplacement concept are much smaller in diameter than the drifts produced by a TBM. Thus, it is necessary to scale down the components used for TBMs to build the waste emplacement hole drill. The horizontal emplacement hole drill, because of its smaller size and the desire to drill dry, has potentially unique problems such as cuttings removal, maintenance, and control. On the larger TBMs, personnel have direct access to the machine to correct problems occurring during boring.

The work that has been completed to this time in support of the design, development, fabrication, and testing of the horizontal hole drill is summarized by the following reports:

1. Robbins Company, 1984b. "Small Diameter Horizontal Hole Drilling--State of Technology," SAND84-7103, prepared for Sandia National Laboratories, Albuquerque, New Mexico.

2. Robbins Company, 1985. "Feasibility Studies and Conceptual Design for Placing Steel Liner in Long, Horizontal Boreholes for a Prospective Nuclear Waste Repository in Tuff," SAND84-7209, prepared for Sandia National Laboratories, Albuquerque, New Mexico.

3. Kenny Construction, Inc., 1987. "Installation of Steel Liner in Blind Hole Study," SAND85-7111, prepared for Sandia National Laboratories, Albuquerque, NM.

4. Robbins Company, 1987. "Design of a Machine to Bore and Line a Long Horizontal Hole in Tuff," SAND86-7004, prepared for Sandia National Laboratories, Albuquerque, New Mexico.

These reports document results of drill equipment market surveys, feasibility studies for liner installation methods, and preliminary retrieval techniques.

All work completed indicates that the drilling of the emplacement holes for waste at the Yucca Mountain repository can be performed with existing drilling systems or with adaptations of existing drill systems. The verification of this conclusion will require development tests in site-specific geology.

6.4.10.2.6 Design analysis

4.4.7-1 Structural, thermal, and mechanical analyses

The results from the structural, thermal, and thermomechanical analyses, that relate to evaluating the stability of underground openings and required ground support for the MGDS are synopsized in this section. The required ground support conditions identified by these analyses were determined to be well within the capabilities of available mine support systems. Results are presented from analyses using both computer codes and empirical approaches. The published reports that document the analyses discussed are the following:

1. Hustrulid, W., 1984a. "Lining Considerations for a Circular Vertical Shaft in Generic Tuff," SAND83-7068, Sandia National Laboratories, Albuquerque, New Mexico.

2. Hustrulid, W., 1984b. "Preliminary Stability Analysis for the Exploratory Shaft," SAND83-7069, Sandia National Laboratories, Albuquerque, New Mexico.

3. Hill, J., 1985. "Structural Analysis of the NNWSI Exploratory Shaft," SAND84-2354, Sandia National Laboratories, Albuquerque, New Mexico.

4. St. John, C. M., 1987a. "Interaction of Nuclear Waste Panels with Shafts and Ramps for a Potential Repository at Yucca Mountain," SAND84-7213, prepared by Agbabian Associates for Sandia National Laboratories, Albuquerque, New Mexico.

5. St. John, C. M., 1987b. "Investigative Study of the Underground Excavations for a Nuclear Waste Repository in Tuff," SAND83-7451, prepared by Agbabian Associates for Sandia National Laboratories, Albuquerque, New Mexico.

6. Johnson, R. L., 1981. "Thermo-Mechanical Scoping Calculations for a High Level Nuclear Waste Repository in Tuff," SAND81-0629, Sandia National Laboratories, Albuquerque, New Mexico.

7. Thomas, R. K., 1987. "Near Field Mechanical Calculations Using a Continuum Jointed Rock Model in the JAC Code," SAND83-0070, Sandia National Laboratories, Albuquerque, New Mexico.

8. Johnstone, J. K., R. R. Peters, and P. F. Gnirk, 1984. "Unit Evaluation at Yucca Mountain, Nevada Test Site: Summary Report and Recommendation," SAND83-0372, Sandia National Laboratories, Albuquerque, New Mexico.

9. Svalstad, D. K., and T. Brandshaug, 1983. "Forced Ventilation Analysis of a Commercial High-Level Nuclear Waste Repository in Tuff," SAND81-7206, Sandia National Laboratories, Albuquerque, New Mexico.

10. St. John, C. M., 1987d. "Thermomechanical Analysis of Underground Excavations in the Vicinity of a Nuclear Waste Isolation Panel," SAND84-7208, prepared by Agbabian Associates for Sandia National Laboratories, Albuquerque, New Mexico.

11. St. John, C. M., 1987c. "Reference Thermal and Thermal/Mechanical Analyses of Drifts for Vertical and Horizontal Emplacement of Nuclear Waste in a Repository in Tuff," SAND86-7005, prepared by J. F. T. Agapito and Associates, Inc., for Sandia National Laboratories, Albuquerque, New Mexico.

12. St. John, C. M. and S. J. Mitchell, 1987. "Investigation of Excavation Stability in a Finite Repository," SAND86-7011, prepared by J. F. T. Agapito and Associates, Inc., for Sandia National Laboratories, Albuquerque, New Mexico.

13. Ehgartner, B. L., 1987. "Sensitivity Analyses of Underground Drift Temperature, Stresses, and Safety Factors to Variation in the Rock Mass Properties of Tuff for a Nuclear Waste Repository Located at Yucca Mountain, Nevada," SAND86-1250, Sandia National Laboratories, Albuquerque, New Mexico.

14. Langkopf, B. S., and P. R. Gnirk, 1986. "Rock Mass Classification of Candidate Repository Units at Yucca Mountain, Nye County, Nevada," SAND82-2034, Sandia National Laboratories, Albuquerque, New Mexico.

15. Arulmoli, K., and C. M. St. John, 1987. "Analysis of Horizontal Waste Emplacement Boreholes of a Nuclear Waste Repository in Tuff," SAND86-7133, Sandia National Laboratories, Albuquerque, New Mexico.

16. St. John, C. M., 1985. "Thermal Analysis of Spent Fuel Disposal in Vertical Emplacement Boreholes in a Welded Tuff Repository," SAND84-7207, prepared by Agbabian Associates for Sandia National Laboratories, Albuquerque, New Mexico.

17. Dravo Engineers, Inc., 1984. "Effect of Variations in the Geologic Data Base on Mining at Yucca Mountain for NNWSI," SAND84-7125, Sandia National Laboratories, Albuquerque, New Mexico.

18. Zimmerman, R. M., M. L. Blanford, J. F. Holland, R. L. Schuch, and W. H. Barrett, 1986b. "Final Report G-Tunnel Small-Diameter Heater Experiments," SAND84-2621, Sandia National Laboratories, Albuquerque, New Mexico.

19. Zimmerman, R. M., R. L. Schuch, D. S. Mason, M. L. Wilson, M. E. Hall, M. P. Board, R. P. Bellman, and M. L. Blanford, 1986a. "Final Report: G-Tunnel Heated Block Experiment," SAND84-2620, Sandia National Laboratories, Albuquerque, New Mexico.

20. Zimmerman, R. M., 1983. "First Phase of Small Diameter Heater Experiments in Tuff," Proc. 24th U.S. Symposium on Rock Mechanics, College Station, Texas.

21. Zimmerman, R. M., M. L. Wilson, M. P. Board, M. E. Hall, and R. L. Schuch, 1985. "Thermal-Cycle Testing of the G-Tunnel Heated Block," Proc. 26th U.S. Symposium on Rock Mechanics, Rapid City, South Dakota.

22. Chen, E. P., 1987. "A Computational Model for Jointed Media with Orthogonal Sets of Joints," SAND86-1122, Sandia National Laboratories, Albuquerque, New Mexico.

23. Labreche, D. A., and S. V. Petney, 1987. "The SPECTROM-31 Compliant Joint Model: A Preliminary Description and Feasibility Study," SAND85-7100, Sandia National Laboratories, Albuquerque, New Mexico.

24. Bauer, S. J., R. K. Thomas, and L. M. Ford, 1985b. "Measurement and Calculation of the Mechanical Response of a Highly Fractured Rock," Proc. 26th U.S. Symposium on Rock Mechanics, Rapid City, South Dakota.

25. Labreche, D. A., 1985. "Calculation of Laboratory Stress-Strain Behavior Using a Compliant Joint Model," Proc. 26h U.S. Symposium on Rock Mechanics, Rapid City, South Dakota.

26. Thomas, R. K., 1982. "A Continuum Description for Jointed Media," SAND81-2615, Sandia National Laboratories, Albuquerque, New Mexico.

27. SNL (Sandia National Laboratories), 1987. "Site Characterization Plan Conceptual Design Report," SAND84-2641, H. R. MacDougall, L. W. Scully, and J. R. Tillerson (compilers) Sandia National Laboratories, Albuquerque, New Mexico.

Relevant information from these reports is summarized in the following paragraphs grouped according to structural features of repository.

Emplacement drifts

St. John (1987c) reports the results of two-dimensional finite- and boundary-element calculations for the emplacement drifts that include thermal effects out to 100 yr. The calculations are based on reference design information using currently available information about rock and site characteristics. The thermomechanical properties are presented in Chapter 2. The design basis is presented in Section 6.1.2 of the chapter. The thermal analyses were performed using the finite-element code DOT, and a second analysis used the boundary-element code HEFF. The HEFF code resulted in temperatures of within ±1°C of those predicted by DOT. Both codes used constant thermal and elastic properties. A mixture of 60 percent PWR and 40 percent BWR waste was modeled at an areal power density of 57 kW/acre. Because the analyses were two-dimensional with cross sections through the drifts, the heat sources (i.e., waste containers) were not explicitly represented along the axis of the drift. Rather, the heat sources were equivalently represented by a plane extending into and out of the modeled drift cross sections. Both vertical and horizontal emplacement drifts were analyzed using continuously ventilated and unventilated drift conditions. The intention was to bound the problem, realizing that actual effects of drift ventilation would fall somewhere between the two ventilation extremes modeled. Drift temperatures, although not directly related to drift stability, are important for assessing environmental conditions to which personnel may be subjected if cooling is not used. Maximum drift temperatures of 58 and 109°C resulted for the unventilated condition of the horizontal and vertical emplacement drifts, respectively. The maximum drift temperatures occurred at 100 yr after waste emplacement. The large difference in drift temperature for the unventilated horizontal and vertical emplacement is a result of the difference in standoff distance of the waste from the drift. The standoff distance for horizontal emplacement was simulated as 33 m. The standoff distance for vertical emplacement was simulated as 3.1 m. The ventilated condition placed the drift temperature at 30°C for both emplacement drifts analyzed over the 100-yr period. This is an estimate based on the 23°C in situ temperature and the likely inability of ventilation to maintain the drift at that temperature once the waste is emplaced. The actual drift temperature will likely fall within the broad range of the continuously ventilated and unventilated conditions.

Thermal results for two- and three-dimensional calculations of the vertical drift are documented by St. John (1985). The two-dimensional analyses were performed by the finite-element code PORFLOW, and the three-dimensional analyses were performed by the finite-element code THERM3D and the analytic solutions contained in the TEMP3D code. Nonlinear thermal effects were not modeled; the thermal decay of the waste was modeled and all other model input parameters were held constant throughout the 100-yr period analyzed. BWR containers at 3 kW each were spaced 4.0 m apart along the drift, 3.05 m below the floor. The analyses used a rectangular drift shape, and properties differed slightly from those of the reference information base. The temperatures resulting from the two-dimensional and three-dimensional codes differed little except in the immediate vicinity of the container, and the agreement between the analytic solutions and finite-element codes was excellent. Unventilated drift conditions resulted in a maximum temperature of 133°C at approximately 50 yr after waste emplacement. The drift temperature at 100 yr was only 4°C less than that at 50 yr. These results differ slightly from those presented by St. John (1987c). The differences are mainly because of differences in the decay characteristics of the waste used and the emplacement density along the drift. The initial source strength along the vertical emplacement drift in this analysis is 28 percent higher than that used in the analyses by St. John (1987c). The ventilated drift condition assumed the drift to be maintained at 30°C as did the St. John (1987c) analyses.

The thermal modeling discussed by Johnstone et al. (1984) for drift-scale analyses was used to establish the maximum areal power density (APD) for waste emplacement such that the drift floor temperature did not exceed 100°C for times up to 110 yr after waste emplacement. This criterion sets the maximum expected temperature and is used to design the cooling system necessary to prepare the drifts for reentry for purposes of inspection, repair, or retrieval. Note that this criterion has been superseded in the SCP-CD by temperature criteria established for access drift temperature in the vertical emplacement mode (Section 6.4.2). The analyses are based on the unventilated vertical emplacement drift. St. John (1987c) shows the unventilated drift exhibiting higher temperatures than the ventilated drift and the vertical emplacement drifts higher temperatures than the horizontal emplacement drifts. Therefore, the maximum temperature criteria, if applied to the horizontal emplacement of waste result, would result in a higher allowable APD. The nonlinear thermal analyses were performed using ADINAT and SPECTROM-41. The APD of the repository was established as 57 kW/acre for the Topopah Spring tuff.

The stress results reported in St. John (1987c) were obtained from the finite-element code VISCOT, using an elastic constitutive model. The stress analyses were performed at emplacement time and 100 yr later for the horizontal and vertical emplacement drifts, assuming both ventilated and unventilated drift conditions. The temperature results are reported in the previous paragraph. VISCOT uses the thermal field generated by DOT code analyses of temperature to calculate the induced thermal loading. The induced thermal stresses and in situ stresses are combined, and the stresses around the drift are computed. Knowledge of the stress state enabled the factors of safety against localized rock failure and activation of existing vertical joints to be assessed. The highest stresses were noted at the drift crown 100 yr after waste emplacement. The magnitudes of the principal stress in the drift crown ranged from 31 to 36 MPa for the horizontal emplacement drift, depending on the drift ventilation assumed. Higher stresses occurred for the unventilated drift condition. The vertical emplacement drift had crown stresses ranging from 13 to 54 MPa for the ventilated and unventilated conditions, respectively. The effect of ventilation is much more pronounced for the vertical emplacement option, where the waste packages are located much closer to the drift. The maximum stress magnitudes are well below the average unconfined compressive strength of 150.8 MPa measured in the laboratory. If a 50 percent reduction factor is applied to the average laboratory value of strength to account for scale effects (Appendix O of SNL, 1987), the minimum safety factor for the vertical emplacement drifts is 1.4. In this cluster analysis, the minimum safety factor calculated for the horizontal emplacement drift was 2.1. These safety factors are minimal because they are based on stresses at a point on the drift boundary. Stress magnitudes in this elastic analysis decrease for locations removed from the drift. This is illustrated in Figures 6-93 and 6-94, which plot the principal stress magnitudes and their directions for the vertical and horizontal waste emplacement drifts at excavation time and 100 yr later. The ventilated and unventilated drifts are shown in the figures. The safety factors corresponding to the stress levels plotted in Figures 6-93 and 6-94 are contoured in Figures 6-95 and 6-96 respectively. The safety factor contours show an increase in magnitude as distance from the drift crown increases. The mass of rock making up the crown area of the drift has an average safety factor much higher than the boundary values at the crown. The safety factor for the drift can be obtained by integrating or averaging the safety factor values over the crown region. The crown region is chosen because it has the lowest safety factor. Interpretation of Figures 6-97 and 6-98 result in an average safety factor for the crown region of the drifts which is greater than or equal to 3.0. This safety factor is considered conservative for the drift because the crown area will contain ground support such as rockbolts, a feature not modeled in the numerical analyses by St. John (1987c).

Johnstone et al. (1984) documents the results of inelastic vertical emplacement drift calculations using the ubiquitous-joint model for times out to 110 yr. These calculations are coupled to the thermal analyses performed by ADINAT and SPECTROM-41, as previously reported. No matrix fracturing

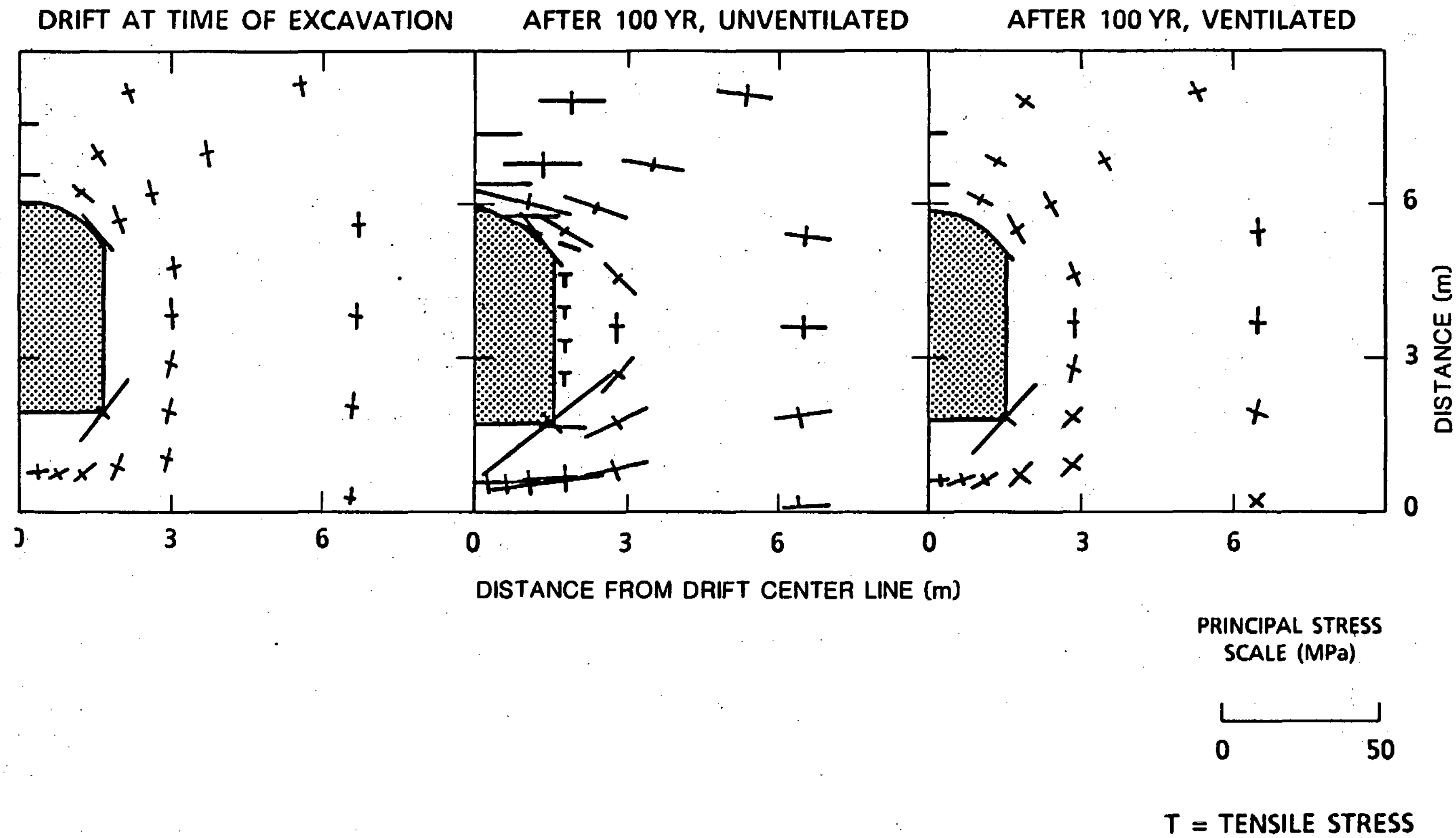

Figure 6-93. Finite-element predictions of the principal stresses in the vicinity of the vertical emplacement drift.

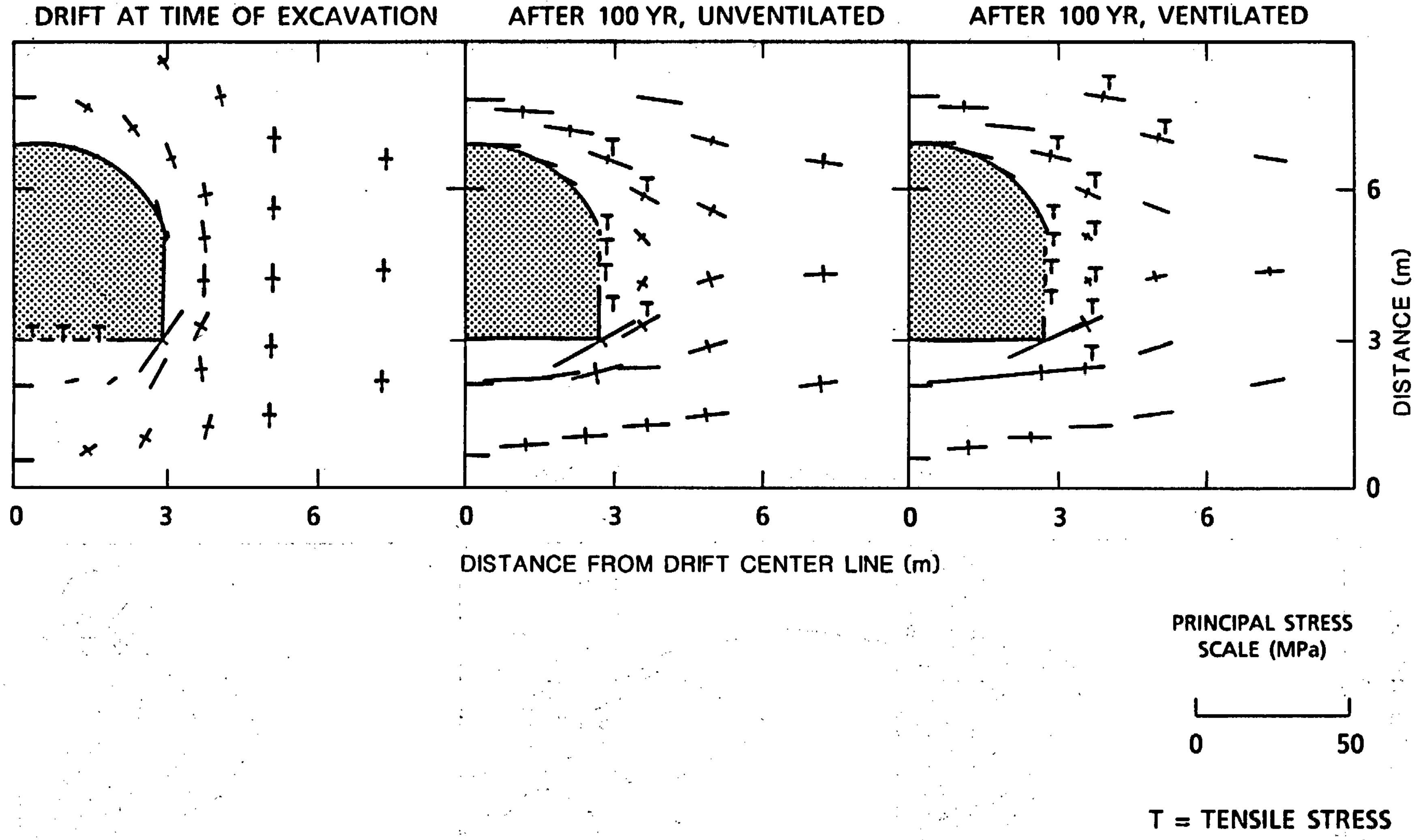

Figure 6-94. Finite-element predictions of the principal stresses in the vicinity of the horizontal emplacement drift.

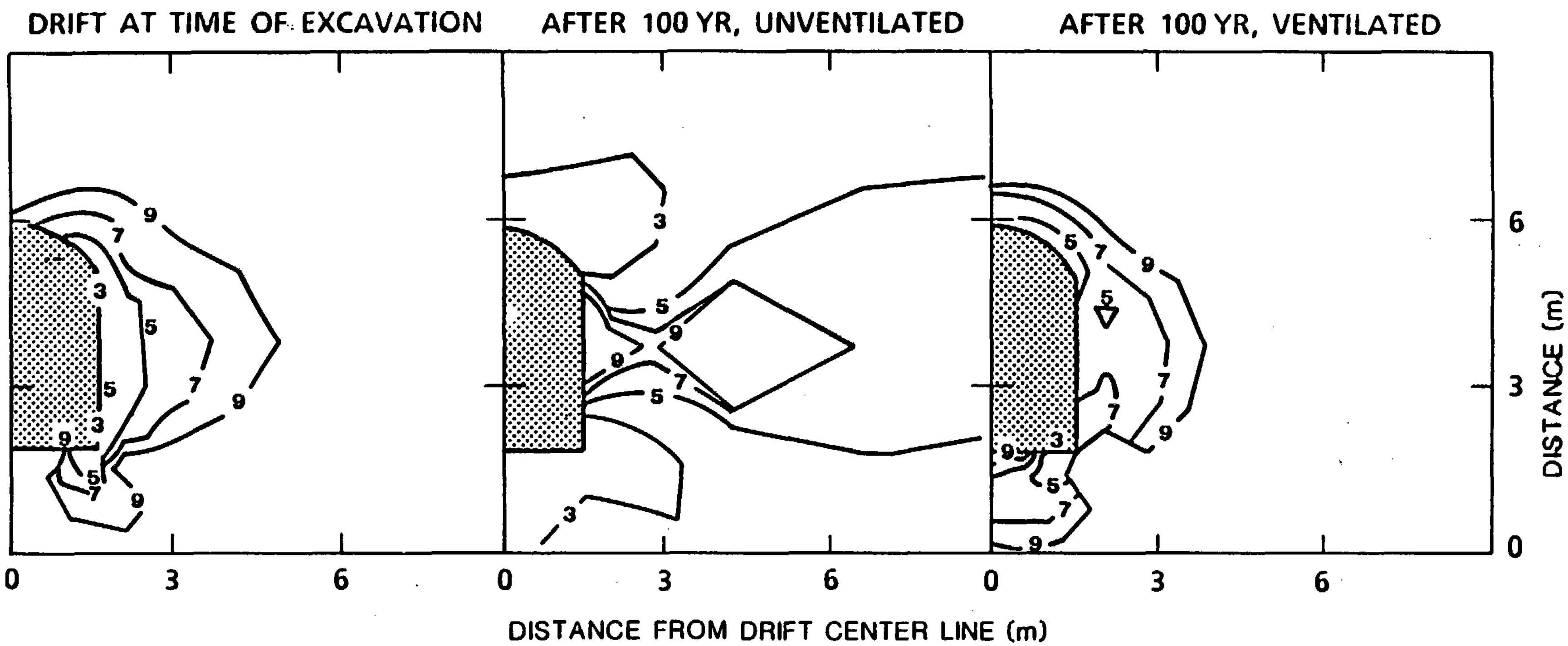

Figure 6-95. Finite element predictions of the ratio between matrix strength and stress around the vertical emplacement drift. The numbers on the plots are ratios.

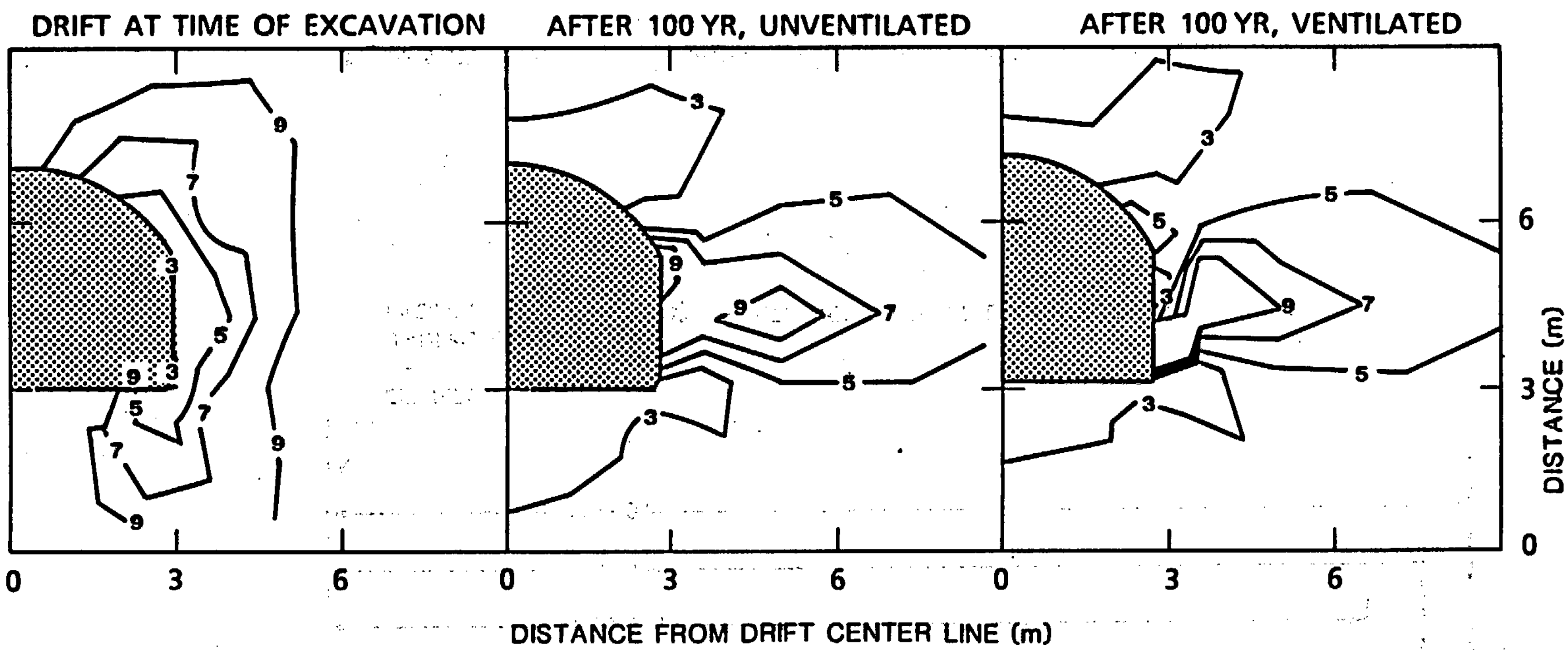

Figure 6-96. Finite-element predictions of the ratio between matrix strength and stress around the horizontal emplacement drift. The numbers on the plots are ratios.

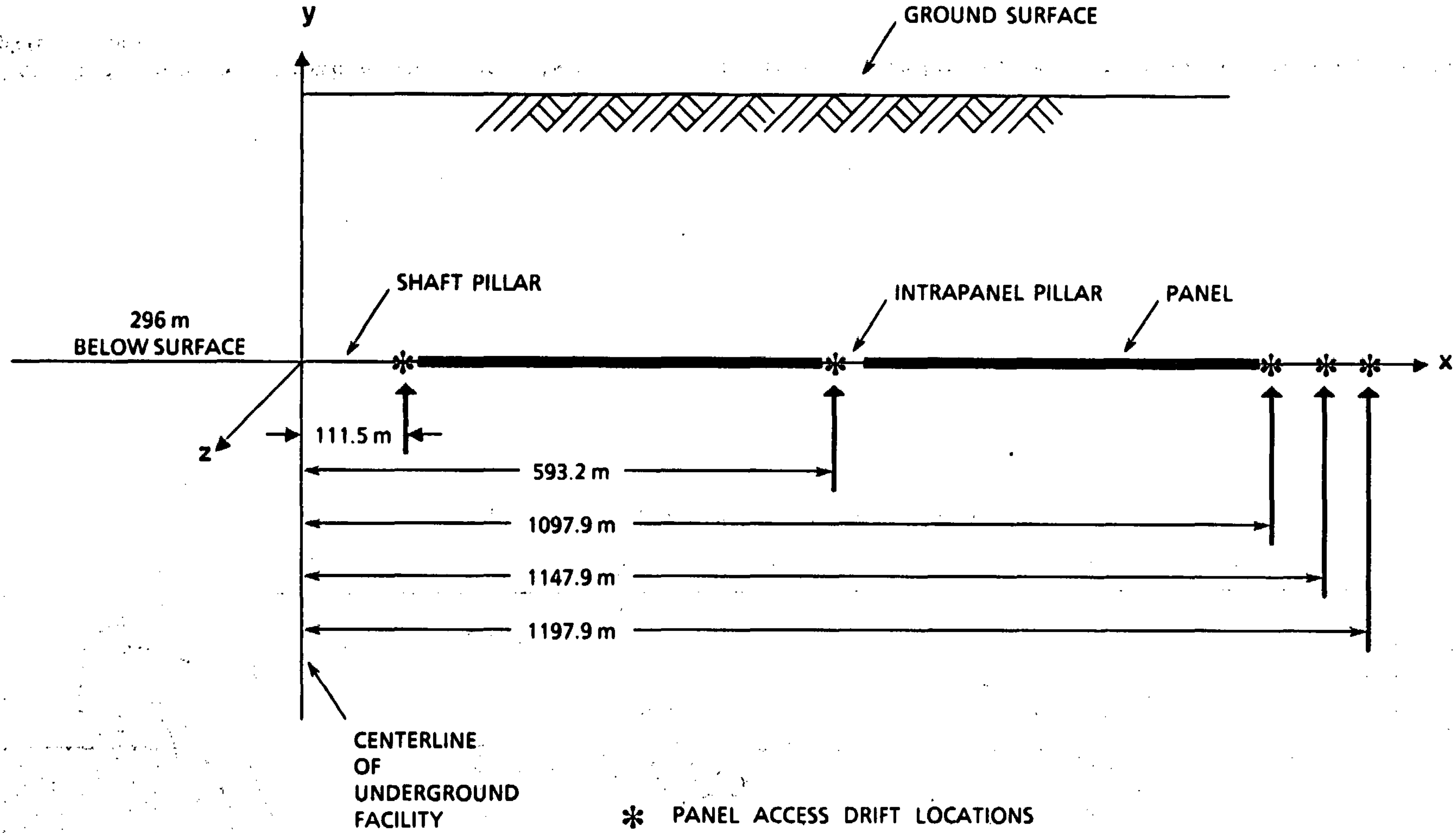

Figure 6-97. Repository cross section showing the access drift locations considered.

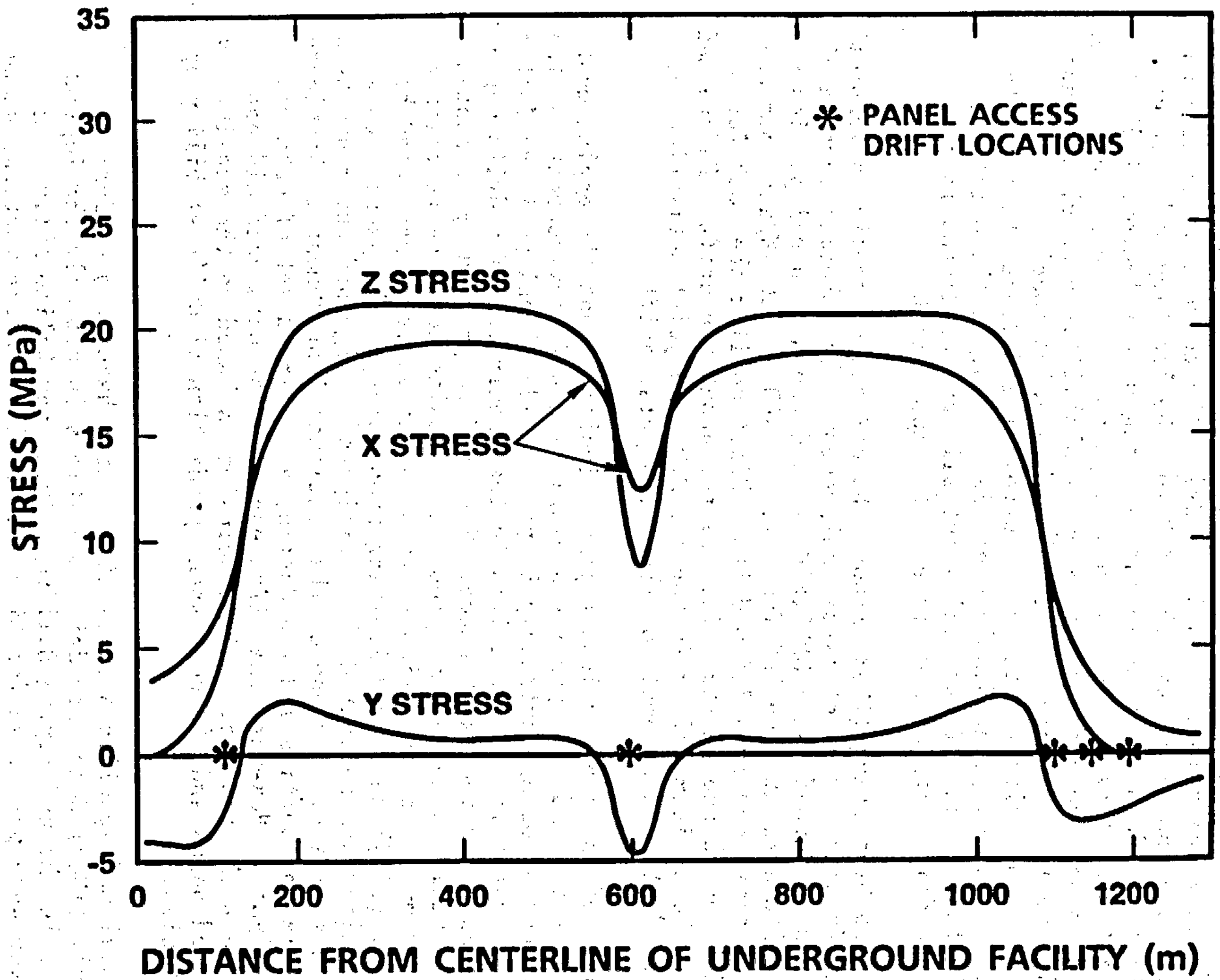

Figure 6-98. Induced stress profile on repository horizon 50 yr after waste emplacement.

occurred around the Topopah Spring drift for either the average or limiting property case. The limiting properties were taken as either plus or minus two standard deviations from average values, the sign being chosen on a worse-case basis. The elastic calculations presented by St. John (1987c) recognized the vertical emplacement drift as experiencing higher horizontal stresses than the horizontal emplacement drift for unventilated conditions. As such, the rock surrounding the horizontal drift should also remain intact when analyzed using the ubiquitous-joint model. The corresponding minimum safety factors were approximately 1.5 and 3 for the limiting and average case, respectively. Both the average and limiting safety factors indicate acceptable drift stability. Minor amounts of joint slip were noted; however, it is expected to have no consequence on drift stability--a conclusion supported by evidence from G-Tunnel. The ubiquitous-joint model predicts a slightly larger slip region for the rock surrounding G-Tunnel than for the repository drift, but no joint displacement is evident in the drifts of G-Tunnel. Limited amounts of vertical joint slip are predicted in the sidewalls of the drift both at and after waste emplacement.

Svalstad and Brandshaug (1983) report the effects of cooling a vertical emplacement drift after 39 yr of waste emplacement. The thermal portion of the analysis was performed using SPECTROM-41, and the mechanical portion used the elastic finite element code SPECTROM-11. An APD of 100 kW/acre was used to estimate the heat load in a 745-m drift. Blast cooling the rock for a year resulted in no change in the safety factor about the drift. Before and after cooling, the minimum safety factor was 2.0, and joint activation was limited to 2.0 m into the sidewall of the rectangular drift.

The results of the studies just reported indicate that the emplacement drifts will be stable and will provide a usable and safe environment for the retrievability period of approximately 84 yr. An additional positive factor in the long-term usability of the drifts is the requirement for drift support and periodic inspection and maintenance. The studies previously presented are based on thermal and mechanical properties considered to be representative of the rock mass (one exception to this is the analysis presented by Johnstone et al. (1984) that used limiting properties). The geometries and other model requirements reflected the anticipated design and environments at the time of the analyses. Because of the continual improvement in knowledge about the material properties and the design, an enlarged set of data was used in the analysis. However, the differences in the data used did not appreciably affect the results. This conclusion is based on the sensitivity studies presented below and the consistent prediction of drift stability by each of the studies.

Both general and specific sensitivity studies have been performed. Johnstone et al. (1984) documents drift conditions in not only the Topopah Spring but also in the underlying Bullfrog, Tram, and Calico Hills formations. Analyses were performed for times up to 100 yr after vertical waste emplacement for unventilated drift conditions. Thermomechanical properties for all the units differed. Johnstone et al. (1984) note that rock strength and modulus varied by a factor of three over the four units, but all units appear acceptable with regard to stability of the underground openings. Specific parameter sensitivities were investigated in Ehgartner (1987). The input parameters to the HEFF code were varied both individually and jointly to determine the effect on the horizontal emplacement drift at 50 yr. The results indicated that changes in rock strength and modulus affected the safety factors of the drift rock more than the other parameters that were varied, but in no case was the safety factor for the rock less than 1.0 over the probable range of input variables.

Ehgartner (1987) showed drift temperatures to be relatively insensitive to the thermal input variables. St. John (1987b) varied the shape of horizontal and vertical emplacement drifts over various in situ stress fields ranging from uniaxial to hydrostatic. The more rounded excavations had slightly lower stress concentrations. The elastic analyses used the boundary-element code HEFF and the elastic finite-element code, BMINES. BMINES enabled rock bolts to be included in the analyses. A damage region was modeled around the drift to simulate the impact of blasting during excavation, and rock bolts were inserted in the crown region. The calculated stresses in the rock bolts were approximately half the allowable strength of the rock bolts. The rock bolts had an insignificant impact on reducing drift closure or deformation, as compared to the unsupported drift analyses.

Johnson (1981) varied the APD for the vertical emplacement scheme to determine the effects on the drifts. The ADINAT and ADINA model incorporating ubiquitous jointing was used for analyses to 100 yr after waste emplacement. The two APDs of 75 and 100 kW/acre changed the maximum crown stress in the vertical emplacement drift by only 2 MPa. Drift temperatures were more affected by the APD change. The lower APD of 75 kW/acre resulted in a temperature of 98°C at the drift floor, whereas the 100 kW/acre APD increased the drift temperature to 107°C at 50 yr after waste emplacement. Johnstone et al. (1984) derived the maximum allowable APD for the Topopah Spring and the underlying Bullfrog, Tram, and Calico Hills units based on constraints for the vertical emplacement drift at 100 yr after waste emplacement. The APD determined for all the units including the Topopah Spring unit varied from 53 to 57 kW/acre.

In the previously mentioned sensitivity studies drift depth, shape, waste standoff, APD, and the thermomechanical properties were varied, and in each instance, it was concluded that drifts would remain stable. However, the stress ratio effects have not yet been examined.

Results of rock mass classification of the Topopah Spring tuff aid in estimating the ease or difficulty of constructing the drifts. Langkopf and Gnirk (1986) document the results of tunnel indexing or rock mass classification methods applied to the waste emplacement horizon of Yucca Mountain. Both the South African Council for Scientific and Industrial Research Classification System (CSIR) and Norwegian Geotechnical Institute Classification System (NGI) methods were applied. The CSIR gives an average standup time of 3 to 4 mo for an unsupported span of 6.1 m. The estimated standup times are based on a 6.1-m room or drift width, since this is typical in most mines. Drift widths for the vertical waste emplacement design vary from a minimum of 4.88 m (emplacement drift) to a maximum of 7.62 m for the mains. The horizontal waste emplacement design varies drift widths from a minimum of 6.40 m (access drift) to a maximum width of 7.62 m for the mains.

The NGI classification system estimates the maximum unsupported roof space from 2.3 to 9.9 m, the average being 6.0 m. The NGI system further qualifies the required support as ranging from grouted rockbolts on a 1-m spacing with chain-link mesh and shotcrete to a no-support requirement. The classification systems are based on the results of many diversified case studies, but a specific case to which anticipated repository excavation conditions can be related is found in G-Tunnel. The NGI and CSIR classifications systems both rank the welded Topopah Spring tuff and the nearby Grouse Canyon tuff almost exactly the same. This is because of the similarities in not only the geologic media but also in the in situ stress states. An underground facility (G-Tunnel complex) contains miles of drifts in a tuff unit known as Tunnel Bed 5 of the Grouse Canyon tuff; approximately 130 m of drifts in the Grouse Canyon tuff are in a welded tuff similar to the Topopah Spring unit. Drifts in this facility up to 9.2 m wide have been stable for periods up to 25 yr with a minimal amount of support.

The observations in G-Tunnel provide additional insight into the constructability and initial support requirements of the repository drifts. Even though faults and associated shear zones are expected to exist at Yucca Mountain, the preferred repository area is expected to be minable with standard equipment (Dravo Engineers, Inc., 1984). Rock with similar mechanical properties has been excavated at the G-Tunnel complex in Rainier Mesa using comparable methods of excavation and ground control.

The environmental assessment (DOE, 1986b) has documented tunneling experience in the welded Grouse Canyon Member at G-Tunnel. A nearly vertical fault with at least 1 m of vertical displacement was encountered during tunneling activities in the welded Grouse Canyon Member in G-Tunnel. No comments were noted by the mining inspector in his daily log; the lack of comments indicates that tunneling conditions had not varied appreciably. The fault zone was not noted until the tunnel had advanced about 6 m (18 ft) beyond the fault. The fault brought welded and nonwelded tuff together along a nearly vertical contact; no water influx was noted. The inspection record shows that the area of the tunnel with the fault was initially mined on November 19, 1981. Preliminary 2.5-m (8-ft) rock bolts were installed in the faulted area on November 20, 1981, and then on February 16, 1982, roughly 3 months later, 5-m (16-ft) resin-anchored hardening rock bolts were installed on a 1.3 by 1.3 m (4 by 4 foot) pattern across the back in the area adjacent to the fault. There was no record that the faulted area produced ground-support problems, and no special bolting was installed in the area of the fault. Crossing the nearly vertical fault with at least 1 m (3 feet) of vertical displacement did not result in the need for any special ground support in excess of the standard methods used in the drift where no faulting occurred. The observations at G-Tunnel and the results of rock mass classification apply to both emplacement drifts and access drifts. Panel access drifts are used between the repository mains and the emplacement drifts. The numerical analyses for the panel access drifts are discussed in the following paragraphs.

Panel access drifts

Results comparing panel access drift stability for various locations and standoff distances from the emplaced waste are documented by St. John and Mitchell (1987). The elastic two-dimensional calculations used the HEFF code for analyses of the horizontal emplacement scheme to 50 yr after waste emplacement at 57 kW/acre. Drifts were analyzed at locations in the central part and outer edges of the repository. The locations of the panel access drifts are shown in Figure 6-97. The hypothetical repository was configured of four panels, thus two of these are illustrated in the symmetric view presented in the figure. Interpanel locations also were considered. The thermally induced stresses (y stress) that correspond to Figure 6-97 are plotted in Figure 6-98. The induced stresses shown in Figure 6-98 are superimposed with the gravity induced stresses (x stress) to yield the total stress (z stress) to which the drifts are subjected. Analyses of the drifts indicated the results presented in Table 6-35 at 50 yr. A near hydrostatic in situ stress field was assumed. Although differences in results exist for the drifts at the various locations, no stability problems were identified at any of the potential locations.

The results of analyses on the intersection of the emplacement drift with a panel access drift are documented in St. John (1987d). The three-dimensional elastic calculations used STRES3D to generate the thermally induced stress field for the horizontal emplacement scheme and ADINA to elastically analyze the intersection. Stresses in the crown of the intersection reached approximately 23 MPa after 50 yr of waste emplacement. In this elastic analysis, tensile stresses approaching 9 MPa were predicted in the rib at the intersection. The tensile stresses dissipate 3 m into the rib. Note that the tensile stresses predicted in the elastic model will likely be reduced in the field because of the presence of existing horizontal fractures.

Table 6-35. Predicted stress, factor of safety, and temperatures of panel access drifts at different locations at 50 yr after emplacement

	Distance of drift from repository centerline (m)				
Parameter	115	606	1098	1148	1198
Crown stress (MPa)	36.0	48.6	34.0	24.1	19.1
Safety factor at crown	2.09	1.55	2.22	3.12	3.94
Drift temperature (°C)	56.7	71.3	55.8	28.5	23.6

Waste emplacement boreholes

The stability of waste emplacement boreholes must be evaluated to understand the loading that may be imposed on a waste package (or borehole liner) and to evaluate the environment anticipated for retrieval operations. The thermal and mechanical calculations and observations made in G-Tunnel testing related to small-scale heated borehole stability are discussed in a subsequent section on verification and validation results. The emphasis of that discussion is on model validation (i.e., the model represents the intended physical system or process). The emphasis here is to provide a synopsis of the calculations performed on the waste emplacement boreholes using configurations similar to those shown in Figure 6-97. In addition, the evaluations of potential loads on the emplacement borehole liner for the horizontal emplacement option are described briefly. The analysis results to date predict that the boreholes will be stable but that some uncertainty exists regarding whether there will be small (bounded by a few centimeters) regions where localized fracturing of the rock might occur.

Results of analyses on the horizontal waste emplacement borehole (Arulmoli and St. John, 1987) are discussed for (1) the elastic model, and (2) inelastic mechanical models. The thermal modeling used fixed thermal properties for the host rock. The calculations are based on conceptual design information and the expected rock and site characteristics. The two-dimensional finite-element calculations used boundary conditions that modeled an infinite series of boreholes of infinite length, and the thermal loading was imposed instantaneously. This approximation is considered appropriate since the focus is on very near-field effects and borehole loading rates would likely be a minor perturbation in the stresses imposed. The results reflect expected conditions in the central portion of the repository and are considered conservative near the outer regions of the repository.

The elastic horizontal borehole calculations were performed for times extending to 100 yr after waste emplacement using the DOT code with temperature constant properties and the VISCOT code with current thermomechanical properties and geometries. A maximum borehole wall temperature of 160°C occurred approximately 25 yr after the waste emplacement. Maximum borehole wall stresses ranged from 20 MPa at the sidewall to 50 MPa at the crown. Because of problem symmetry, the stresses are equivalent at the sidewalls and at the top (crown) and bottom of the borehole.

The inelastic horizontal borehole calculations used the JAC compliant-joint model, incorporating both single- and orthogonal-joint sets. The single-joint set was vertical with a strike parallel to the borehole axis. The orthogonal-joint set had both vertical and horizontal joints striking parallel to the borehole. The stresses predicted within a few centimeters of the borehole crown by the single-joint-set model were higher at the crown than those predicted by the elastic model. However, the sidewall stresses were lower for the joint model when compared to the elastic model results. The redistribution of stress is a result of joint slip in the sidewalls of the borehole and joint closure in the crown of the borehole. The joint closure is a result of increased horizontal stresses induced by the heat from the waste. The maximum borehole crown stress for the single vertical joint set was 96 MPa. This is nearly twice the magnitude of the elastic prediction of borehole crown stress.

An explanation of the difference in model predictions follows. The elastic analysis approximates the effects of joints through the use of a reduced elastic modulus meant to account for the deformation behavior of a jointed rock mass. The analyses using a compliant-joint model, on the other hand, use both the intact modulus for the rock matrix and a deformation modulus for the joints. Mechanically, as the vertical-joint set along the crown of the borehole closed, in the compliant-joint model the apparent modulus of the rock mass approached the modulus value of the intact rock.

The intact modulus used in the compliant-joint analysis was twice the rock mass value used in the elastic analysis. The thermally induced stresses are proportional to the modulus of the rock; higher crown stresses were predicted by the compliant-joint analyses. When the horizontal-joint set is included with the vertical-joint set, the horizontal joints along the crown slip, resulting in a stress redistribution and lowering the crown stress by approximately 20 MPa. The orthogonal-joint case is considered to be more representative of emplacement conditions; therefore, the higher stresses predicted by the JAC model using a single vertical joint set may be higher than would be expected to be observed underground.

In the analyses, the stress gradient is abrupt near the borehole crown. The result of this is a rapid decrease in the stress magnitude from the borehole boundary into the rock mass for all the calculations. At a distance several centimeters from the borehole boundary, the crown stresses predicted by the elastic model and those predicted by the compliant joint models are essentially the same. Thus, the higher stresses predicted by the joint models are considered a potential "skin effect." However, the localized high stresses predicted by the joint models exceed the rock mass strength. Little consequence of this small overstressed region in the crown of the borehole is expected because a liner that can withstand the loads potentially imposed by fallen pieces of rock is planned for use in all horizontal emplacement holes. Indeed, preliminary liner loading analyses indicate that such loading will not compromise the structural integrity of the horizontal borehole liner. Borehole liner loading analyses are documented in Appendix B of SNL (1987).

Shafts and ramps

St. John (1987a) contains analyses of a 6-m vertical repository access shaft at two different locations and an inclined repository access ramp. Elastic analyses of the 6-m shaft located it centrally in the repository within a central 200-m shaft pillar and alternatively at 100 m from the edge of the repository. The ramp was inclined at 10 degrees from the surface and intersected the repository at the edge of the 200-m shaft pillar. The analyses were time dependent, considering the thermally induced load up to 100 yr after waste emplacement. STRES3D generated a three-dimensional stress field of the repository superimposing both the in situ and thermally induced stresses. The stress field then was imposed on the circular shaft using LINED to calculate stresses for both the 0.5-m-thick concrete shaft liner and the rock mass surrounding it. The stress field also was used as input to the HEFF code to calculate stresses about the ramp. The alternative shaft locations at the center and edge of the repository showed slight differences, but in no instance was the rock mass surrounding it fractured because of the in situ or thermally induced loading. The concrete shaft liner was predicted to have approximately 3 MPa of tensile stress along its axis. The analysis assumed placement of the shaft in an elastic continuum, unreinforced concrete, and no expansion joints along the shaft. The transfer of the induced tensile stress from the rock mass to the liner will likely be moderate because of the presence of naturally occurring and excavation-induced joints in the rock mass surrounding the shaft liner. As shaft liner designs become more detailed, additional analyses are expected.

The ramp analyses contained in St. John (1987a) indicated no rock failure for the various cross sections analyzed along the length of the ramp from the surface to mid-repository. The minimum safety factor was 2.5, which corresponded to a maximum boundary stress of 31 MPa at 100 yr after waste emplacement.

Hustrulid (1984b) and Hill (1985) analyzed the structural stability of the exploratory shaft and facility, respectively. The analyses were time independent; therefore, the thermal effects of waste emplacement were not considered. The analyses showed safety factors greater than or equal to 3.0 for the underground facility. Both elastic three-dimensional and two-dimensional ubiquitous-jointing models were used in the ADINA code. Results were very similar between the two models. The shaft analyses implied no fracture potential for the rock at strengths corresponding to those of the Topopah Spring.

Hustrulid (1984a) considered rock units below the Topopah Spring--the Calico Hills, Bullfrog, and Tram units. Because the strength of the rock units underlying the Topopah Spring is generally lower, some rock failure was predicted but it was limited in extent. Concrete liner thickness of 0.41 and 0.30 m were recommended for the Calico Hills and Tram formations. The Bullfrog formation did not require a liner. Both elastic and plastic analyses were conducted, but no code was used. The analytic solutions are developed and applied in the text of the report.

These analyses indicate stability of both the ramps and shafts of the repository. Additional analyses are planned to evaluate seismic effects.

Verification and validation results

Finite-element methods. The finite-element method is planned to be the predominant method for license application design analyses. The status of work pertaining to qualification of models and codes in the context of verification (including benchmarking) and validation is that (1) a method of approach has been developed (Section 8.3.2.1.4, repository modeling) and (2) initial work in this area has been completed.

Part of code qualification includes the verification of the equation solver, which is the heart of a code. Two types of problems are used in verification. Problems with known analytical solutions are used to test the code's numerical solution methods. These numerical solution methods give an indication of the accuracy of the code and also may point out areas where the code may be in error. The second type of problems are hypothetical repository-type problems. These are used to determine whether the code can simulate interactions typical to the repository design. Frequently, verification of the equation solver is accomplished by comparing the computer-calculated response for a simple boundary value problem with closed-form analytic solutions. What follows is a compilation of the types of problems presented in the user's manuals for a selection of the computer codes being considered for use in design and performance assessment calculations. This compilation demonstrates the ability of the codes being considered to handle a wide field of analyses, including problems similar to those to be encountered in repository design and performance assessment.

ABAQUS is a general purpose finite-element computer program for linear and nonlinear structural analyses (Hibbitt, Karlson, and Sorenson, Inc., 1982). A theoretical development of the appropriate governing equations and a description of the numerical algorithms are presented along with a user's guide that includes several sample problems and the solutions. The sample problems, which include comparisons with closed-form analytic solutions, are briefly summarized as follows:

1. Analysis of a uniformly loaded, elastic-plastic plate is performed to serve two functions: to verify the coding of the rate-independent plasticity theory and to assess the accuracy of the time integration of this form of plasticity theory, especially in the form of nonproportional stressing.

2. Elastic analysis of the barrel-vault-roof problem is performed and is considered to be one of the standard shell-element convergence tests.

3. Elastic analysis of the pinched, open-ended circular-cylinder problem is performed and is considered to be one of the standard test cases used to evaluate the performance of shell-element formulations.

4. Elastic analysis of the cantilever beam to evaluate the accuracy of one of the beam elements in a single, large displacement case.

5. Analysis of the pressurization of a cylinder and a sphere are performed, with elastic and elastic-plastic material behavior. The structures are assumed to be quite thin, so that membrane analysis may be used to verify solutions obtained with the program. Further, the strains are quite large so that for the elastic-plastic cases, rigid-plastic analysis provides an accurate comparative result. The main purpose of the examples is to verify the capabilities of the axisymmetric shell elements at finite strains (Hibbitt, Karlson, and Sorenson, Inc., 1982).

SANCHO is a finite-element computer program designed to compute the quasi-static, large deformation, inelastic response of planar or axisymmetric solids (Stone et al., 1985). Finite-strain constitutive theories for plasticity, volumetric plasticity, and metallic creep behavior are included. A constant bulk strain, bilinear displacement isoparametric finite element is used for the spatial discretization. The solution strategy used to generate the sequence of equilibrium solutions is a self-adaptive, dynamic-relaxation scheme based on explicit central difference pseudo-time integration and artificial damping. A masterslave algorithm for sliding interfaces also is implemented. A theoretical development of the appropriate governing equations and a description of the numerical algorithms are presented along with a user's guide, which includes several sample problems and their solutions. The sample problems, which include comparisons with closed-form analytic solutions, are briefly summarized here:

1. The free thermal expansion of an infinite cylinder was included to demonstrate the input for a thermal stress problem and to demonstrate the ability of SANCHO to solve problems involving thermal loads.

2. The problem of an infinite cylinder loaded in the plastic range by an internal pressure serves as a good check of the elastic-plastic material model (Stone et al., 1985).

3. The stress relaxation of a single element is used to demonstrate the accuracy of the elastic creep model.

The last example problem is much more complex than the preceding examples and, therefore, relies on comparison with other finite-element programs for solution verification. The problem is a complex geotechnical analysis of an underground drift in a multilayered geologic medium, principally rock salt. It is characterized by creep and contains clay seams characterized with sliding interfaces and a friction coefficient of zero. Elastic anhydrite and polyhalite layers also are interspersed. The problem was specified as part of the Waste Isolation Pilot Plant (WIPP) Project code comparison activity called Benchmark II (Morgan et al., 1981). The problem involves determining the response of an infinitely long array of parallel drifts (Stone et al., 1985).

JAC is a finite-element computer program for solving large deformation, temperature-dependent quasi-static mechanics problems in two dimensions with the nonlinear conjugate gradient technique. Either plane strain or axisymmetric geometry assumptions may be used with material descriptions that include temperature-dependent elastic-plastic, temperature-dependent secondary creep and isothermal soil models. A four-node Lagrangian uniform-strain element is used with orthogonal hourglass viscosity control of the zero energy modes (Biffle, 1984). A theoretical development of the appropriate governing equations and a description of the numerical algorithms are presented along with a user's guide, which includes several sample problems and the solutions. The sample problems, which include comparisons with closed-form analytic solutions, are briefly summarized here:

1. The large deformation of an elastic cantilever beam is included since an analytical solution by Holden (1972) is available.

2. The plane strain crushing of a relatively thin tube in the diametrical direction by rigid platen represents a difficult elastic-plastic, large deformation and sliding surface problem for the finite-element technique.

3. The problem of the plane-strain extrusion of a plate (Biffle, 1984) is included to demonstrate a case where large amounts of sliding take place, along with elastic-plastic loading and unloading.

4. A laminated beam problem is used to demonstrate the behavior of multiple sets of slide lines. The problem is a simulation of the reaction of layers of material above a mine opening, as described by Sutherland et al. (1979).

5. A suddenly applied pressure is applied to the inside of a thick cylinder and the creep response is calculated (Biffle, 1984).

COYOTE is a finite-element program designed for the solution of two-dimensional, linear and nonlinear, steady- and transient-heat-conduction problems (Gartling, 1982). Available boundary conditions include constant temperature at a node, constant or time-dependent temperature along a side, adiabatic surface, forced convection, natural convection, and thermal radiation. Material properties (densities, specific heats, and conductivity tensors) may be dependent on temperature. A theoretical development of the appropriate governing equations and a description of the numerical algorithms are presented along with a user's guide, which includes several sample problems and their solutions. The sample problems, which include comparisons with closed-form analytic solutions, are briefly summarized here:

1. The problem of heat conduction in a steel bar (square cross section), with a circular hole that is subjected to prescribed temperature-boundary conditions, was performed.

2. To demonstrate the use of user subroutines for volumetric heating and generalized convection-radiation boundary conditions, a one-dimensional problem was considered. A cylindrical region of heat-generating material is encased by a thin layer of low-conductivity material and a thicker layer of material having a relatively high thermal conductivity. The outer surface of the cylinder loses heat to the surrounding environment by natural convection.

3. The finned tube radiator problem was chosen to illustrate the use of time-dependent boundary conditions.

4. Sensitivity analyses have been conducted using COYOTE and are reported by Branstetter (1983), Duffey (1980), and Gartling et al. (1981).

5. Duffey (1980) also reports the comparison of COYOTE's output with experimental results of a salt-block test. Good agreement was found for both the steady-state and transient conditions.

The SPECTROM codes solve for stresses around a repository using the finite-element method. Each of the codes can perform elastic and thermo-elastic analyses with loads due to a nodal temperature distribution, boundary stresses, and boundary displacement. A theoretical development of the appropriate governing equations and a description of the numerical algorithms are presented along with a user's guide that includes several sample problems and their solutions. The sample problems, which include comparison with closed-form analytic solutions, are briefly summarized here:

1. Analysis of a thin-walled cylinder subjected to a cooling of the interior and to an internal stress.

2. Analysis of an internally pressurized cylinder with Tresca yield criterion, compared with an analytic solution.

3. Analysis of a biaxially loaded plate with a central hole with Drucker-Prager yield criterion.

4. Analysis of a circular hole in a Mohr-Coulomb medium.

Another part of verification involves testing of components of specific material models and is often found in the detailed write-up of the material model. A general three-dimensional material model for regularly jointed media is presented by Thomas (1982). The model is composed of two parts: a continuum approximation based on average discontinuous displacements across jointing planes within a representative elementary volume, and a material constitutive description based on the linear behavior of the base material and nonlinear normal and shear behavior between jointing planes. The sample problems are briefly summarized here:

1. The dilatation response only was analyzed for a rock mass with a prescribed joint set (Thomas, 1982).

2. The shear response without coupled displacements was analyzed for a rock mass with a prescribed joint set (Thomas, 1982).

3. The shear response with coupled displacements was analyzed for a rock mass with a prescribed joint set (Thomas, 1982). The compliant-joint model was further verified through a comparison with a closed-form analytic solution and a similar compliant-joint model developed by RE/SPEC (Labreche and Petney, 1987). In the simulation, a rock joint specimen consisting of intact rock matrix and one set of joints spaced 5 m apart was inclined zero degrees from the horizontal. The excellent comparison of results is shown in Figure 6-99.

The compliant-joint model has been recently updated and modified to include a second set of joints (Chen, 1987). The sample problems, which include comparisons with closed-form analytic solutions, are briefly summarized:

1. The dilatation response only was analyzed for a rock mass with a prescribed joint set (Chen, 1987).

2. The shear response without coupled displacements was analyzed for a rock mass with a prescribed joint set (Chen, 1987).

3. The shear response with coupled displacements was analyzed for a rock mass with a prescribed joint set in an arbitrary orientation (Chen, 1987).

The results of these analyses were used to verify both the code (the equation solver) and the material model (numerical representation of the physics).

Another step in code qualification is the demonstration of the adequacy of the code and models through applications to problems in physical situations in rock. Examples follow of code-model applications to physical situations in real rock.

PROBLEM 1: 20 MPa CONFINING PRESSURE

	$G_s = 10^{10}$ MPa/m			$G_s = 10^7$ MPa/m		
θ	JAC	SPECTROM -31	ANALYTIC	JAC	SPECTROM -31	ANALYTIC
0°	0.166	0.166	0.166	0.166	NOT CALCULATED	0.166
30°	0.150	0.150	0.150	0.495	0.495	0.495
60°	0.122	0.122	0.122	0.467	0.466	0.467
90°	0.114	0.114	0.114	0.114	NOT CALCULATED	0.114

PROBLEM 2: LOW CONFINING PRESSURE

	$G_s = 10^{10}$ MPa/m			
	$\sigma_{cp} = 0$ MPa		$\sigma_{cp} = 1$ MPa	
θ	JAC	ANALYTIC	SPECTROM-31	ANALYTIC
0°	0.548	0.548	0.428	0.429

Figure 6-99. Compressive axial strain (%) at axial stress of 100 MPa (comparison of results of compliant-joint model (JAC). closed-form analytic solution, and a second compliant-joint model (SPECTROM-31)).

The ground support for the underground openings at the G-Tunnel underground facility are considered minimal (rock bolts and wire mesh) by rock mass classification ratings (Langkopf and Gnirk, 1986). The underground openings in welded and nonwelded tuff at G-Tunnel were the subject of finite-element analyses using the ubiquitous-joint model (Johnson and Bauer, 1987) and the compliant-joint model (Thomas, 1987). The models represent different approaches to modeling rock mass deformation. The details of accommodation of stresses and strains within the analyses performed by Johnson and Bauer (1987) and Thomas (1987) are different. Yet both models predicted stable openings at G-Tunnel, consistent with each other and with the observed physical situation at G-Tunnel. These calculation exercises provide a measure of credibility to the models-codes applied, which further justifies the concept that deformation of a rock mass may be represented by the combined deformation of the matrix plus fractures.

In a validation-type study, the mechanical response of thermally fractured granite was measured and calculated (Bauer et al., 1985b; Labreche, 1985). Analysis of the experimental results provides insight into the physical deformation of highly fractured rock, whereas the match between calculations and measurements (Figure 6-100) allows us to gauge the appropriateness of the numerical model and input parameters. In general, the calculated stress-strain behavior is in qualitative agreement with that measured. This agreement between measured and calculated response indicates a reasonable degree of validity in our modeling exercise for both the physical characterization and the numerical idealization.

Comparisons of measured and calculated thermal responses in welded and nonwelded tuff have been completed by Zimmerman (1983) and Blanford and Osnes (1987), respectively. As part of the experiment, observations were made of the borehole before and after the thermal cycling. No structural degradation was observed in the borehole. The comparison (Figure 6-101) of measured and calculated temperatures is rather good. This agreement between measured and calculated response indicates a reasonable degree of validity in the modeling exercise for both the physical characterization and the numerical idealization.

The models and codes proposed for use in thermal analyses (methods designed to model temperature-dependent heat conduction) have been subjected to numerous code qualification activities (Wart et al., 1984). Thus, the status of these codes is such that they are considered nearly ready for Level 1 analyses, pending a detailed review. The results of thermal analyses are used as input for thermomechanical analyses. Therefore, differences between results from thermal codes must be well understood.

Comparisons of measured and calculated thermomechanical response are in a preliminary ongoing phase. Initial results (Zimmerman et al., 1986a) of such a comparison are encouraging and further analyses currently are being pursued.

Calculations in support of site evaluation, repository design, and performance assessment require accurate estimates of the in situ stresses and the variability of the in situ stress state within Yucca Mountain. A modeling approach was developed to assist in understanding the in situ stress

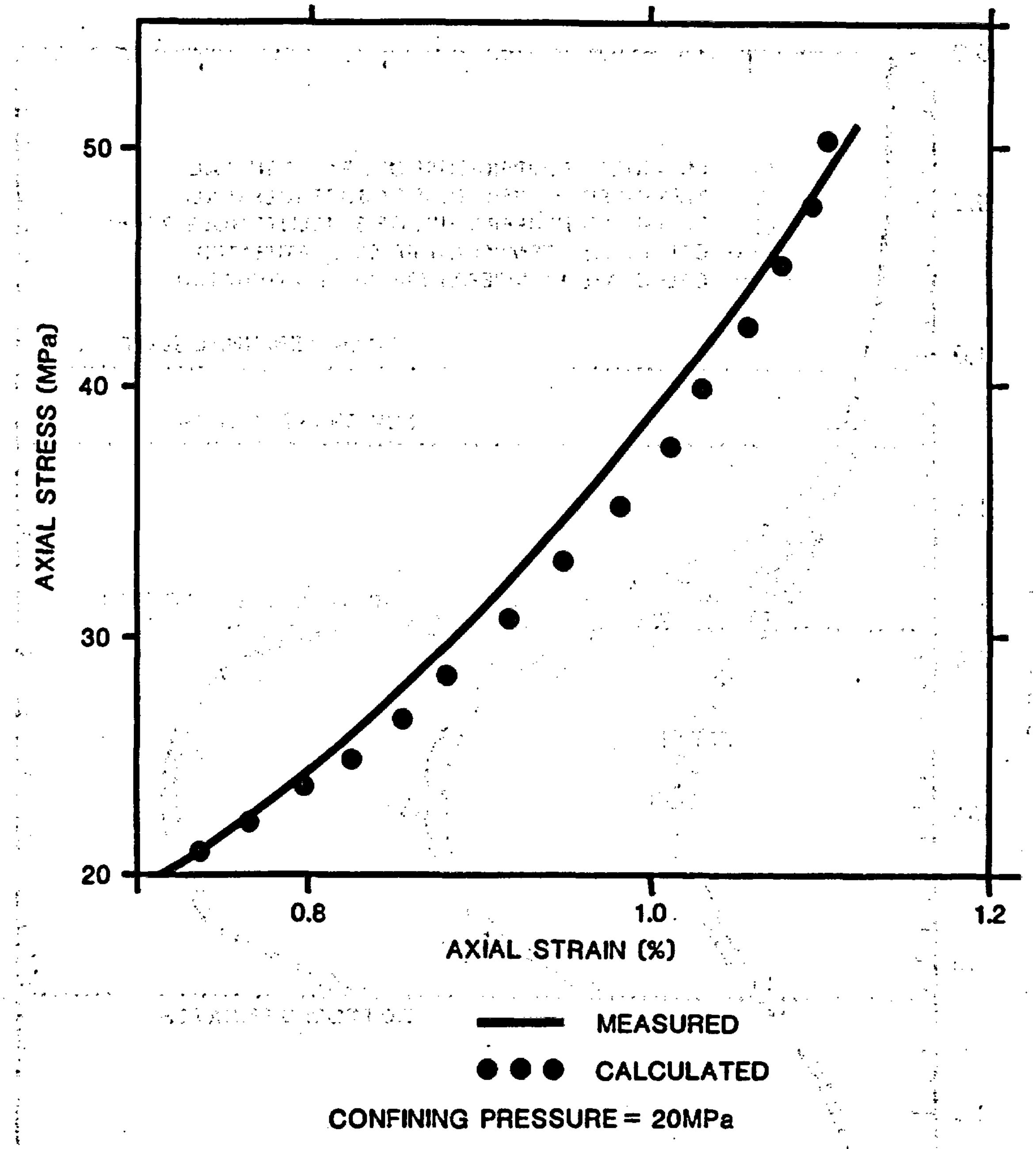

Figure 6-100. Measured versus calculated response for thermally cracked granite. Modified from Bauer et al. (1985b).

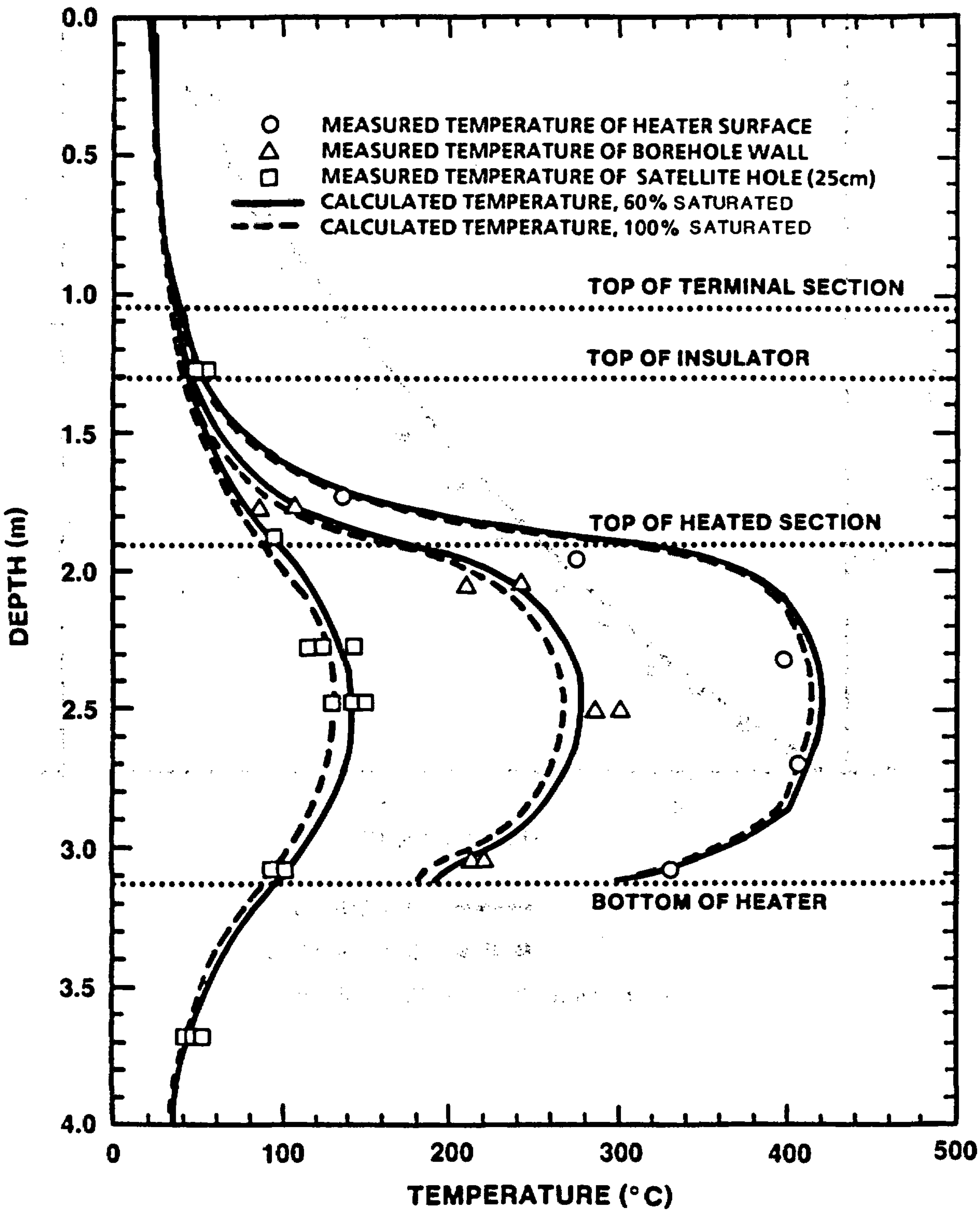

Figure 6-101. Comparison of measured and calculated temperature profiles for borehole subjected to thermal cycling. Modified from Blanford and Osnes (1987).

state at Yucca Mountain (Bauer et al., 1985a). The validation of this modeling approach is portrayed in the comparison of measured and calculated results. An analysis of the regional geologic studies that pertain to the stress state at the NTS, stress measurements in Yucca Mountain, and stress measurements in nearby Rainier Mesa was performed in conjunction with finite-element calculations to estimate the in situ stresses at Yucca Mountain (Bauer et al., 1985a).

Gravitational stress was the only loading mechanism modeled. Other assumptions used in the calculations were plane-strain conditions and linear-elastic material responses. The mechanical effects of pore pressure were not included except as pore water modifies the effective mass that induces gravitational loads. The validity of the approximations for estimating the in situ stress field were demonstrated through comparing the calculated stresses with carefully measured stresses at Rainier Mesa. Because of this favorable comparison, the same assumptions then were used for calculations that were compared with measured stresses at Yucca Mountain. The results indicate that topographic effects may result in spatial variations in the horizontal stress field at elevations of the proposed repository horizon. Also, by considering the vertical variation in mechanical properties (mechanical stratigraphy), deviations from a smooth increase in horizontal stress with depth are predicted. The combination of tectonic setting, measured values of in situ stress, and finite-element approximations of the stress state at Yucca Mountain provide a basis for estimating the lateral earth-stress coefficient that should be used in design and performance assessment calculations (Bauer et al., 1985a).

Boundary-element method. Boundary-element methods used here (e.g., Brady, 1980) are analysis methods for plane-strain thermoelastic analyses that may be applied to many problems posed by the emplacement of heat sources in a conductive stressed medium. The effects of excavation and heat may be included in the analysis. Rock strength and fracture slip may be used to interpret results. These methods allow for efficient parametric studies to be undertaken in which design tradeoffs and potential effects of parameter sensitivities to design can be evaluated through the predictions of deformations and stress at specific locations as a function of time. The usefulness of boundary-element methods will be qualified through comparison with closed-form analytic solutions, finite-element codes, and underground exploration because their applicability generally is limited to the preliminary phases of design.

Boundary-element methods are a relatively new geotechnical tool for thermal, mechanical, and thermomechanical analyses; yet the methods have been accepted for fairly wide use in underground stability analyses (Hoek and Brown, 1980).

The program HEFF is the FORTRAN code of an indirect formulation of the boundary-element method for plane-strain thermoelastic analysis. A theoretical development of the appropriate governing equations and a description of the numerical algorithms are presented in (Brady, 1980) along with a user's guide that includes several sample problems and their solutions. The sample problems, which includes comparisons with closed-form analytic solutions, are briefly summarized here:

1. Analysis of a circular hole in an elastic continuum, subject to plane strain, was performed and provides a convenient test of the segments of the code concerned only with solution of elastostatic problems.

2. Analysis was performed concerning the two-dimensional thermal stresses in an infinite medium subjected to an exponentially decaying line heat source perpendicular to the plane of analysis (Brady, 1980).

Tunnel index methods. Tunnel index methods (Barton et al. 1974a, b; Bieniawski, 1974) are empirical methods of classifying the rock mass through which ground support recommendations may be obtained. The tunnel indexing methods will be qualified through further studies of case histories specific to the repository in tuff, demonstrations in the exploratory-shaft facility, and checking against the implications of predictions made using boundary-element and finite-element analyses. The methods were each developed through an extensive study of case histories of underground openings in many types of rock, including tuff. The methods, Norwegian Geotechnical Institute Classification System (NGI) and the South African Council for Scientific and Industrial Research Classification System (CSIR) (Bieniawski, 1974), have been used to classify tuff rock masses at Yucca Mountain and G-Tunnel (Langkopf and Gnirk, 1986). These classifications have been used to recommend ground support for the repository openings (Dravo Engineers Inc., 1984). The methods were developed for a wide variety of rocks and currently do not incorporate the effects of heat in the considerations for their ground support recommendations.

4.4.7-2 Ventilation analyses

Results of the ventilation calculations completed to this time are discussed below. Both vertical and horizontal emplacement orientation have been analyzed. The SCP-CDR provides the basis for these discussions. Details are provided in Appendix C of the SCP-CDR.

Mine ventilation calculations for normal conditions

The approach to the design of an underground ventilation system starts with the determination of the required air quantities based on applicable regulations. For the repository, the selected regulation for compliance consists of the Mine Safety and Health Administration (MSHA) regulations (30 CFR Part 57) and the California Administrative Code. The ventilation criteria obtained from these documents are (1) from MSHA, the requirement to supply air for the dilution of diesel exhausts will be met by providing 125 cfm per brake horsepower of diesel equipment at a working location, and (2) from the California Administrative Code (Title 8, Division of Industrial Safety, Subchapter 17, Article 31) the minimum air velocity for work areas based on area cross section is 60 ft/min (18 m/min) and the minimum air supplied per worker is 200 cfm.

The typical emplacement drift for vertical emplacement is 16-ft (5m) wide and 21.5-ft (6.5 m) high, the maximum crew size in the drift during emplacement is 6 people, and the diesel-electric waste transporter is rated at 300 horsepower. Applying the requirements stated in the previous paragraph to the vertical emplacement system results in the following air quality requirements:

Air required to dilute diesel exhaust	37,500 cfm
Air required for 60 ft/min (18 m/min) velocity	20,640 cfm
Air required for crew (200 cfm per crew member)	1,200 cfm

The controlling requirement is the 37,500 cfm requirement for the dilution of exhausts. The design of the ventilation system is based on supplying 45,000 cfm to each active emplacement drift. The excess will provide the flexibility to compensate for changes in design requirements and philosophy and to provide for errors resulting from the estimates made for parameters, such as the roughness of mined surfaces and leakage.

The design accomplishes the goal of preferential leakage from the development (mining) side to the waste emplacement side of the repository by maintaining the pressures in the waste emplacement side lower than the development side. The pressure differential is accomplished by designing the waste emplacement ventilation system as a pull system with the suction fans located at the exhaust point and designing the development side ventilation system as a push system with the fans located at the air-intake point. The results of a point-by-point pressure calculation illustrate that this preferred pressure differential is maintained throughout the repository. These results are given in Section 3.4 of the SCP-CDR.

Table 6-36 presents the results of the normal mine ventilation calculations for horizontal and vertical emplacement under the two different scenarios. The results present the required fan airflow quantities and pressure heads to meet or exceed the criteria and boundary conditions of the problem, as described in the preceding approach and data sections. Because the mining and emplacement systems are separate, the fan quantities are given for each of these ventilation subsystems.

The quantities in Table 6-36 will be handled by the men-and-materials shaft as the intake and the tuff ramp as the exhaust for the mining ventilation system. The waste emplacement system uses the exploratory shaft and waste ramp as the intake and the waste ventilation exhaust shaft for exhaust. A more complete description of the ventilation system is provided in Section 6.2.6.3. The quantities required are presented in Table 6-36 to illustrate that the total air required is well within the capabilities of available mine ventilation equipment and is typical of the quantities required by conventional mines.

<u>Drift cooling calculations</u>

The required cooling times and loads calculated for the vertical and horizontal waste emplacement orientations are given in Table 6-37. Each orientation considers the alternatives of cooling the intake air or using ambient air. The results give the time required to achieve the conditions specified for the two different levels of activity (i.e., inspection and light maintenance, and heavy maintenance or retrieval). The calculations start with the conditions expected 50 yr after waste was emplaced.

Table 6-36. Maximum ventilation airflow requirements for two ventilation scenarios

Emplacement mode	Maximum development-side airflow scenario: Vertical	Maximum development-side airflow scenario: Horizontal	Maximum emplacement-side airflow scenario: Vertical	Maximum emplacement-side airflow scenario: Horizontal
Development side airflow (cfm)[a]	411,800	281,300	209,400	117,200
Emplacement side airflow (cfm)	481,300	446,400	837,200	517,200

[a]cfm = Cubic feet per minute.

Table 6-37. Cooling requirements for vertical and horizontal emplacement using ambient and conditioned air

Emplacement method	Inspection purposes (ACP[a]>300 w/m², T_{dry}<45°C)				Maintenance/partial retrieval (ACP>500 w/m², T_{dry}<40°C)			
	Ambient inlet temperature		Cooled inlet temperature		Ambient inlet temperature		Cooled inlet temperature	
	Time to cool (days)	Cooling load (kW)	Time to cool (days)	Cooling load (kW)	Time to cool (days)	Cooling load (kW)	Time to cool (days)	Cooling load (kW)
Vertical	168	0	21	708	>560	0	37	708
Horizontal	14	0	5	490	70	0	11	490

[a]ACP = Areal cooling power.

Table 6-37 shows that, for the vertical emplacement orientation, cooled inlet air will be required in all instances for the expedient cooling of the drifts in preparation for reentry. The table shows that ambient air can be used to cool the horizontal emplacement drifts for reentry to perform inspection, but for reentry to perform major maintenance or retrieval, cooled air also may be required if a cool-down time of 70 d is not acceptable.

4.4.7-3 Hydrologic analyses

The flood hazard for a 14-km (9-mi) reach of Fortymile Wash and its principal southwestern tributaries--Busted Butte, Drill Hole, and Yucca washes--were evaluated (Squires and Young, 1984). Data from 12 peak-flow gaging stations adjacent to the Nevada Test Site were used to develop regression relations that would permit an estimation of the magnitude of the 100- and 500-yr flood peaks.

Among seven cross sections on Fortymile Wash, the estimated maximum depths of the 100-yr, 500-yr, and regional maximum floods are 2,3, and 9 m (8, 11, and 29 ft), respectively. At these depths, flood water would remain within the deeply incised channel of the wash. Near flow velocities would be as great as 3, 4, and 9 m/s (9, 14, and 28 ft/s) for the three respective flood magnitudes.

The study shows that Busted Butte and Drill Hole washes (9 and 11 cross sections, respectively) would have water depths of up to at least 1 m (4 ft) and mean flow velocities of up to at least 2 m/s (8 ft/s) during a 100-yr flood. A 500-yr flood would exceed stream-channel capacities at several places, with depths of 10 ft and mean flow velocities at 3 m/s (11 ft/s). The regional maximum flood would inundate sizable areas in the central parts of the two watersheds.

At Yucca Wash (5 cross sections), the 100-yr, 500-yr, and regional maximum floods would remain within the stream channel. Maximum flood depths would be about 1.5, 3, and 7 m (5, 9, and 23 ft) and mean velocities about 3, 4, and 7 m/s (9, 12, and 22 ft/s), respectively, for the three floods.

The results of this study were considered in the siting of the surface facilities and in the conceptual design of the flood protection features. No explicit design calculations were performed to support the conceptual design of flood protection features. Where needed, the features (dikes, channels, etc.) were identified in the conceptual design. The final design of these features will be developed during the license application design phase and will be based on the site-specific probable maximum flood (PMF) analysis.

This flood hazard calculation is preliminary partly because the surface facility locations are conceptual and partly because some regional rather than site specific data had to be used in the supporting calculations. Regional data provides the most accurate flooding potential data that can be obtained in advance of acquisition of site-specific data through site characterization. The report documents preliminary calculations of discharge volumes as a function of time for four locations under thunderstorm and general storm conditions.

4.4.7-4 Tectonic and seismic analyses

Evaluation of ground motion at the Yucca Mountain site must address two types of events: (1) natural seismicity (earthquakes) and (2) underground nuclear explosions (UNEs), which are conducted periodically at the Nevada Test Site (NTS). The seismic design assumption for the SCP-CD is that 0.40g is the vibratory ground motion input. This value is based on information contained in current documents (USGS, 1984; DOE, 1986c; and URS/Blume, 1986) and seismologic and engineering judgment. This value may be revised as a result of ongoing studies, particularly the characterization of faults in the immediate vicinity of the site for use in future design analysis. The assumption does not account for any potential surface rupture on the faults in the site vicinity. A value of 0.40g for vibratory ground motion envelops the maximum ground acceleration expected from ground motion induced by a maximum yield UNE (700 kiltons) at the NTS, which is equal to 0.32g based on a mean value plus 3 standard deviations (Section 6.3.3.4, DOE, 1986c).

Two reports have been completed using probabilistic methods to estimate ground motion. In the first report (URS/Blume, 1986), seismogenic zones were delineated from regionalization of the southern Great Basin on the basis of historic seismicity, late Quaternary strain rates, and style of late Cenozoic deformation in order to predict the ground motion hazard at the site.

Further, an occurrence model for UNEs also was established in this study from historical data of NTS testing that occurred before the Threshold Test Ban Treaty. Any future testing was assumed to occur no closer than the Buckboard Mesa area, which is approximately 15 mi from the repository site and is closer than any of the locations on the NTS where testing actually occurs. A maximum yield of 700 kilotons was used for a UNE at Buckboard Mesa, based on the requirements for limiting offsite damage. The current testing limit of 150 kilotons, as limited by the Threshold Test Ban Treaty, produces negligible ground motion at the repository site. The ground motions calculated in URS/Blume (1986) are (1) an acceleration value of 0.4g with a return period of 2,000 yr as a result of natural seismicity and (2) an acceleration value of 0.15g based on a mean plus 2 standard deviations for UNEs.

The second study, which is in the process of completion, assumes faults in the vicinity of the site are active. Fault-specific, random-earthquake-occurrence models have been developed to predict the hazard caused by ground motion and fault displacements. The earthquake occurrence was determined from published fault length and slip rate information. The faults considered in the model include the Bow Ridge, Paintbrush, Ghost Dance, Midway Valley, and Severe Wash faults.

Preliminary evaluations indicate that several local faults range in length to 20 km or more. If the waste-handling facility were to be located in Midway Valley, the controlling earthquake source would appear to be the north-south-trending Paintbrush Canyon fault. This fault may be capable of producing a $M = 6.5$ earthquake, with an average return interval of several tens of thousands of years. Preliminary ground motion studies indicate that the most probable value for peak acceleration in close proximity to a $M = 6.5$ earthquake is about 0.5g. The probability of having a $M = 6.5$ earthquake or any significant surface offsets on the faults considered during the preclosure period is extremely small. Technology exists for designing surface facilities for the design accelerations much larger than those described above. Typical examples include Diablo Canyon Nuclear Power Plant and San Onofre Nuclear Power Plant. Published literature also shows that structures can be designed to resist moderate surface displacement before any catastrophic failure would occur (Reed et al., 1979). Plans for characterizing potential ground motion for design purposes are discussed in Section 8.3.1.17.

At the level of the underground facility, it is provisionally assumed that the peak accelerations are half those at the surface. This is based on an conservative estimate of attenuation of ground motion with depth available from UNE test data and other published information (URS/Blume, 1986; Carpenter and Chung, 1985) on earthquakes. Further investigation and data gathering during site characterization and the development of a satisfactory model for the surface and downhole data may result in revised estimates of peak accelerations. Carpenter and Chung (1985) indicate that up to surface shaking levels of 0.5g, no tunnel collapses as a result of shaking alone have been observed. Tunnels in poor soil and rock are more susceptible to damage than are tunnels deep in rock. Damages to all classes of deep tunnels consisted primarily of minor rockfalls and formation of new cracks except where active faults intersected tunnel bores. In these instances, localized severe damage was experienced. Hence, it can be seen that technology exists for designing underground facilities for the levels of accelerations described previously.

6.4.10.3 Future work

The planned future work is identified in Section 8.3.2.5.7. This work consists of (1) performing tradeoff and sensitivity studies to establish the design approach, the design configurations, and to select basic equipment types; (2) completing reference calculations; and (3) performing verification and validation of analysis codes.

For the underground facility, there are three specific things that need to be determined and assessed: (1) the potential for radon gas, (2) the impact of seismic events on the underground design, and (3) the radiation shielding characteristics of the formation.

The tunnel indexing methods will be qualified through further studies of case histories specific to the repository in tuff, demonstrations in the exploratory shaft facility (ESF), and checking against the implications of predictions made using boundary-element and finite-element analyses. The potential for studies of case histories may be limited because of the availability of underground openings in tuff. Demonstrations in the ESF will include evaluations of various ground support recommendations within the range of types of ground encountered. The boundary-element and finite-element techniques will be used to help qualify the tunnel indexing methods in at least two ways. In the first, the results of numerical analyses of openings without ground support for ambient temperature conditions will be compared with ground support recommendations using the tunnel indexing techniques to provide a second level of confidence to the initial ground support recommendations. Boundary-element and finite-element techniques (without ground support) will be applied next to determine the potential effects of heat on the opening stability. The results of these analyses will be studied to determine the potential for problems in the initial ground support design as a result of the heat. In this manner, analysis of these results will qualify the initial ground support recommendations.

Future work pertaining to method, model, and code qualification includes the following activities: (1) a review of existing methods, models, and codes; (2) verification; (3) benchmarking and parametric studies; and (4) validation. While it may appear that this work is to be completed sequentially, in reality, each progressive activity could lead to looping back through earlier ones. The following descriptions of activities apply to both boundary-element and finite-element models and codes.

At least three classes of material models (linear elastic and elastic-plastic, compliant joint, discrete discontinuities) are recommended for mechanical-structural calculations. A linear and nonlinear, steady- and transient-heat-conduction code is recommended for thermal calculations. A review of existing material models and codes will be performed to assess their applicability to repository performance, repository design, and site evaluation calculations. Selected material models and codes will be modified as necessary to satisfy requirements for analysis of repository performance and design.

Computer codes developed for engineering analysis will be verified to ensure that they correctly perform the operations specified in the numerical model. Verification will be accomplished by testing the model's numerical computations against closed-form analytic solutions. Part of the verification procedure for finite-element codes will be solutions comparisons with previously fully documented boundary-element codes.

Benchmarking is the comparison of the results on one item of software with the results of another item of software designed to solve a comparable problem to show that they produce similar results. Material models and codes will be benchmarked by cross-checking the numerical solutions to a series of well-defined thermal, mechanical, and thermomechanical boundary value problems. At least one benchmarking analysis will be run for each model for each problem scale to be encountered in repository design. Material properties, in situ conditions, boundary conditions, and loading conditions for these problems will be representative of those expected of the repository. The material models will be further evaluated through parametric studies in which input parameters are systematically varied to determine the relative significance of a parameter and to ensure that the variations impart the correct sense of change in material behavior.

It is currently planned to have models and codes qualified for Level I analyses by the end of final benchmarking activities. At that time only initial validation analyses will have been completed.

Validation is ensuring that the physical model, as embodied in software, is a correct representation of the intended physical system or process.

Validation will be accomplished by comparing the results of numerical computations with the results of field-, bench- and laboratory-scale experiments. Certain G-Tunnel, exploratory shaft, and laboratory experiments were developed for this purpose. The purpose of these physical models is to test the physics embodied in the material models. Analog material tests may be appropriate for this purpose. Validation analysis also may be conducted by comparing calculated results to experimental results available in the open literature. In general the validation process will be conducted using the following series of steps:

1. Experimental design analysis is performed to develop the experiment concept in a design that will address the phenomena of interest.

2. Site-specific data and material properties are collected for model calculations.

3. A pretest analysis is performed.

4. The experiment is conducted.

5. The pretest analysis is reevaluated in light of the actual experimental procedure.

6. A posttest comparison of experiment and analysis is conducted by a peer review panel.

Field experiments in the ESF are in the process of being designed specifically for validation of models used for thermal, mechanical, and thermomechanical analyses. The design of these experiments will include pretest analyses to optimize the experiment and analysis for the validation activity. For example, experiment location, orientation, loading conditions, and data collection arrays will be chosen such that analysis of the experiment (i.e., validation) will be facilitated.

6.4.11 ISSUE 4.5 REPOSITORY SYSTEM COST EFFECTIVENESS

6.4.11.1 Introduction

The question asked by Issue 4.5 is

> Are the costs of the waste package and repository adequately established for the resolution of the performance issues?

This section is concerned with the cost estimating activities related to establishing the cost bases necessary to perform the comparative analysis required by the performance issue under Key Issue 4. That performance issue addresses the higher level finding for the system guideline on ease and cost of construction operation, closure, and decommissioning of the mined geologic disposal system required by 10 CFR Part 960. The higher level finding is concerned, in part, with a comparative evaluation of the total system life cycle costs (TSLCC) for each of the repository siting options.

The work completed to date by the NNWSI Project has focused on the site specific aspects of the TSLCC. Specifically, cost estimates have been prepared for the construction, operation, and decommissioning phases for facilities and for waste packages. This information, which is tabulated in Table 6-38, is summed to produce the total repository life cycle cost (RLCC) estimate. The RLCC estimates are only a portion of the TSLCC; the resolution of this issue requires the consideration of nonsite specfic costs such as those associated with a monitored retrievable storage (MRS) facility, as well as transportation costs.

The discussion of the proposed strategy for resolution of this issue is presented in Section 8.2.2.3.1.1. Readers not familiar with the resolution strategy for this issue should review this section before continuing.

Issue 4.5 has been subdivided into three information needs. The text that follows briefly identifies each information need and discusses site specific work that has been completed to date for each of the information needs.

Information Need 4.5.1 Estimate the costs of the reference and alternative Waste packages

This information need consists of preparing and compiling the costs associated with the fabrication of the reference waste package, as well as alternative designs. The waste package includes the container and the materials within the container. Under the curent NNWSI Project design, the cost of the waste package is essentially the cost of the container. Waste container costs constitute a significant portion, about 9%, of the RLCC and are allocated entirely to the operations phase. They constitute over 12% of the operating phase costs (Table 6-38). There are several waste container design variables that affect these costs: size, material type, shell thickness, capacity, fabrication method, internal separator configuration, and quality assurance (QA). Cost analysis for alternative designs contributes to the TSLCC analysis and provides input for the selection of the final container design.

Information Need 4.5.2 Estimate the costs of the reference and alternative repository designs

This information need consists of preparing and compiling the costs associated with the construction, operation, and closure of the reference repository design, as well as alternative designs. Repository design costs allocated to the construction phase include the costs for the final design, construction, and inspection of surface and subsurface facilities, and for management and integration of these activities. The original construction and capital equipment cost estimate for the reference and alternative repository designs constitute approximately 21% of the RLCC or about $1.4 billion (Table 6-38). Repository life cycle costs for the construction phase are sensitive to the size and complexity of the physical plant required to support surface and subsurface operations.

Table 6-38. Repository Life Cycle Cost (RLCC) Comparison[a]

Cost Account Description	Construction Phase			Operations Phase			Decommissioning Phase			TOTAL RLCC	PERCENT RLCC
	Cost in $ Million	Percent Phase	Percent RLCC	Cost in $ Million	Percent Phase	Percent RLCC	Cost in $ Million	Percent Phase	Percent RLCC		
Management and integration	346	24.4	5.2	49	1.0	0.7	20	5.3	0.3	415	6.3
Architect/Engineer	217			0			14				
Construction Management	74			0			2				
Other	55			49			4				
Surface facilities	785	55.4	11.9	2,546	52.9	38.6	116	31.3	1.8	3,447	52.3
Site	167	11.8	2.5	114	2.4	1.7	38	10.2	0.6		
Waste-handling facilities	488	34.4	7.4	1,242	25.8	18.8	34	9.1	0.5		
Balance of plant	130	9.2	2.0	1,190	24.8	18.0	45	12.0	0.7		
Subsurface facilities	286	20.2	4.3	1,610	33.5	24.4	235	63.4	3.6	2,131	32.3
Shafts and ramps	62	4.4	0.9	28	0.6	0.4	3	.8	0.0		
Excavation and emplacement	136	9.6	2.1	838	17.5	12.7	101	27.1	1.5		
Service systems	88	6.2	1.3	744	15.5	11.3	132	35.5	2.0		
Waste packages	0	NA[b]	0.0	603	12.5	9.1	0	0.0	0.0	603	9.1
Spent fuel	0			351	7.3	5.3	0	0.0			
Defense High Level Waste	0			128	2.7	1.9	0	0.0			
Other	0			125	2.6	1.9	0	0.0			
Repository Life Cycle Cost	1,417		21.5	4,809		72.9	371		5.6	6,597	100.0

[a]Source: Gruer et al. (1987)
[b]NA = Not Applicable

Information Need 4.5.3 Estimate the life cycle costs of the reference and alternative total system designs

This information need consists of preparing and compiling the costs of the reference and alternative total system designs. The composite cost estimates for the reference and alternative total system designs cover all chronological phases and are referred to as the TSLCC. The TSLCC includes the costs of the waste package (Information Need 4.5.1) and the costs of the repository (Information Need 4.5.2). It also includes, however, costs for activities such as transportation and development of an MRS, which is relatively nonsite dependent. The NNWSI Project has prepared composite cost estimates for the reference and alternative waste package design, as well as the reference and alternative repository designs. These cost estimates cover only the site-specific portion of the TSLCC for three phases: construction, operation and decommissioning.

6.4.11.2 Work Completed

Information Need 4.5.1 Estimate the cost of the reference and alternative waste packages

Several preliminary waste container cost estimates have been performed for the two-stage repository study (SNL, 1986). The first preliminary cost estimate was based on a generic waste package. This design was revised to be more site-specific and the cost estimate was recalculated.

Approach

Cost estimates for the boiling water reactor (BWR) fuel rod and pressurized water reactor (PWR) fuel rod emplacement containers were determined by averaging several manufacturers' quotes. These quotes were obtained from manufacturers experienced in the fabrication of similar chemically resistant low-carbon stainless steel vessels. The technology for fabricating such stainless steel vessels is well established and is very similar to the fabrication process expected to be used for the emplacement containers.

Cost estimates for the alternative emplacement containers were determined by extrapolating the costs of the reference case containers. The similar physical parameters of the reference and alternative containers studied thus far have permitted plausible results. Shipping, handling, and quality assurance and quality control costs were also included.

Data

Data were obtained from manufacturer quotations for 2,000 units.

Results

Estimated emplacement container costs are identified specifically and included as data in RLCC reports and in the cost report by Gruer et al. (1987).

Information Need 4.5.2 Estimate the cost of the reference and alternative repository designs

Cost estimates are only approximations of value at a given time and are very sensitive to the degree of completeness of the design definition and available historical data. In the initial design stages, such as at SCP-CD, design details are not defined and large contingency factors were used to compensate for design uncertainty. As the design evolves through the conceptual phase, design options studies, development of the advanced conceptual design, and the later detailed design definition stages, the design information available upon which to base estimates becomes correspondingly more detailed, confidence increases, and contingency factors decrease.

Several traditional cost-estimating methods have been used to produce the direct (bare) labor and material costs because the amount of design detail available is not the same for each cost account considered (see Table 6-38). The design detail available for the particular category of cost account was the primary determining factor for the method used.

The subsurface cost-estimating methods were those traditionally used in the mining industry and included unit costs and itemized material takeoff. A detailed explanation of the method is described in the cost estimate for the SCP-CD (Gruer et al., 1987).

Cost markup factors were applied to the bare costs using conventional computer-oriented methods that use off-the-shelf personal computer spreadsheet and data base management software. Guidance for the format, methods, and cost account definitions was provided by the DOE/Weston cost guidelines (DOE, 1987d).

Data

Data sources include the architect-engineering (A/E) data bases, commercial cost-estimating references, and vendor's quotes. Data types include direct labor units and/or lot costs, equipment costs, and indirect labor and material costs.

Indirect labor and material factors were determined by the A/Es from their historical data bases. Other cost factors, such as engineering and contingency, were determined by professional judgment.

Results

Work completed includes nine capital cost estimates. Four cost estimates were produced for the two-stage repository report (SNL, 1986), which compared a single construction stage to a repository constructed in two stages, plus a vertical (reference) emplacement design and a horizontal emplacement design (for each construction stage). These same two emplacement configurations were reestimated for the SCP-CD. Construction costs are summarized in Table 6-38, which also shows the relative costs between the major cost accounts.

The results of the capital cost estimate are used for several purposes. During the conceptual design phase, the results are the basis for most of the input to the RLCC. This estimate is used as a factorable base from which other major project costs are derived, such as operations and maintenance, decommissioning, project management, equipment design and inspection, quality assurance, and contingency. These capital cost estimates are also used in the preparation of the project data sheets for project planning, funding, and management.

Information Need 4.5.3 Estimate the life-cycle costs of the reference and alternative total system designs

Approach

Total System Life Cycle Cost (TSLCC) estimates have been prepared to support the preliminary finding about the preclosure system guideline on ease and costs of construction (DOE, 1987e), as well as the annual assessment of waste fund fee adequacy (DOE, 1987d). The cost estimates prepared by the NNWSI Project under Information Needs 4.5.1 and 4.5.2 can be used to estimate the RLCC, which in turn is used to estimate the TSLCC. Different analytical approaches have been used to estimate the RLCC for each life-cycle phase, and several different approaches have been used within each phase. The costs for the construction phase are discussed under Information Need 4.5.2. The costs for waste packages, which are allocated to the operations phase, are discussed under Information Need 4.5.1. The operations phase, which lasts for 50 yr and accrues about 73% of the RLCC, is composed of two subphases: emplacement operations and caretaker operations. Preliminary estimates of the surface and subsurface facilities operations and maintenance cost were performed by the respective A/Es, based on preliminary information they had previously developed.

Emplacement phase operating labor, materials, and supply costs were estimated by using several methods. The labor force cost was estimated from a functional breakdown of site operations such as waste-handling equipment operation, hot cell operation, process maintenance, fire protection, training, health and safety, and quality assurance. Material and supply costs were factored as a percentage of the construction costs. Cost markup factors were determined by DOE guidance, historical data, and engineering judgment. The caretaker operations phase costs were estimated by the same method.

The final phase contains three distinct activities: closure, decommissioning, and site marking. All three costs were determined by examining plans for each activity and ascertaining sequences, material requirements, and costs, as well as labor requirements and associated costs.

Off-the-shelf personal computer spreadsheet and data base management software were used for the costs study (SNL, 1987). The cost matrix format, the cost account definitions, and the current RLCC methods were provided in the DOE/Weston cost guidelines (DOE, 1987d).

Data

The primary data sources included the A/E data bases, commercial cost-estimating references and vendor's quotes. Data types include direct labor units and/or lot costs, direct material units and/or lot costs, equipment costs, and indirect labor and material costs.

Results

The work completed for this information need includes nine RLCC estimates for various designs for a repository in tuff. An RLCC estimate was made for each of the four designs in the two-stage repository report, which are (1) a single-stage repository based on emplacement of single containers in short vertical boreholes, (2) a two-stage repository based on emplacement of single containers in short vertical boreholes, (3) a single-stage repository based on emplacement of multiple containers in long horizontal boreholes, and (4) a two-stage repository based on emplacement of multiple containers in long horizontal boreholes. The costs for current designs for a two-stage repository based on a single container in a short vertical borehole and multiple containers in a horizontal borehole were estimated for the SCP-CDR. Table 6-38 is excerpted from the SCP-CDR, and additional information may be found in Stinebaugh and Robb (1987).

The RLCC information is used primarily for project management purposes, including project funding, funding schedule, socioeconomic impact studies, and electric utility fee adequacy analysis.

6.4.11.3 Future work

Analysis Needs

Estimation of waste package costs is an ongoing activity that will support waste package design decisions during the advanced conceptual design (ACD), the license application design (LAD), and the final procurement and construction design (FPCD).

Identified future analysis needs include physical parameter sensitivity studies; reappraising quality assurance factors, especially with regards to NQA-1 criteria; and shipping and handling costs. Other specific future cost analysis needs have not yet been identified. Special NNWSI intraproject and DOE interproject studies will likely be identified as the design detail develops.

Cost needs include (1) new requests for quotation when the design, scope, or assumptions change; (2) regular reassessment of the appropriate cost factors, such as quality assurance and quality control, contingency, and engineering; and (3) the use of a consolidated data base management system to facilitate integration of new emplacement container costs in the RLCC.

Repository construction and TSLCC estimates will be updated at each design phase; the TSLCC for the ACD will form the basis for resolution of Issue 4.5 through a comparative evaluation of costs among siting options.

Alternative cost-analysis needs depend on the number of design considerations and the amount of design detail available. When more design detail is available, more detailed cost estimates with greater accuracy and smaller contingency are possible. Changes in economic conditions and labor policies that might impact the repository construction and operating costs will be considered in the analysis.

General cost-estimating analysis needs include analysis for staffing, quality assurance, operating and maintenance materials and supplies, decommissioning, site marking, and capital equipment.

Development needs

Internal to the cost-estimating process, there are no technical or process development needs. The RLCC data base will expand during the various design phases and become very site specific and detailed. Because of the large scope of this particular project, the only practical cost-estimating method requires the use of a computer.

Site information needs

There are no technical site characterization information needs related directly to the estimation of costs for resolution of this issue.

DOE/RW-0160

Nuclear Waste Policy Act
(Section 113)

Consultation Draft

Site Characterization Plan

Yucca Mountain Site, Nevada Research and Development Area, Nevada

Volume III

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DOCUMENT ORGANIZATION

DOCUMENT ORGANIZATION (continued)

TABLE OF CONTENTS

TABLE OF CONTENTS (continued)

TABLE OF CONTENTS (continued)

Page

TABLE OF CONTENTS (continued)

TABLE OF CONTENTS (continued)

TABLE OF CONTENTS (continued)

Page

TABLE OF CONTENTS (continued)

TABLE OF CONTENTS (continued)

Page

LIST OF FIGURES

LIST OF FIGURES (continued)

LIST OF FIGURES (continued)

LIST OF FIGURES (continued)

LIST OF FIGURES (continued)

LIST OF FIGURES (continued)

LIST OF FIGURES (continued)

LIST OF FIGURES (continued)

LIST OF FIGURES (continued)

LIST OF TABLES

LIST OF TABLES (continued)

LIST OF TABLES (continued)

LIST OF TABLES (continued)

DOE/RW-0160

Chapter 6

REFERENCES

Nuclear Waste Policy Act
(Section 113)

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