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Yucca Mountain Site Characterization Project

Retrieval Strategy Report for a Potential High-Level Nuclear Waste Repository

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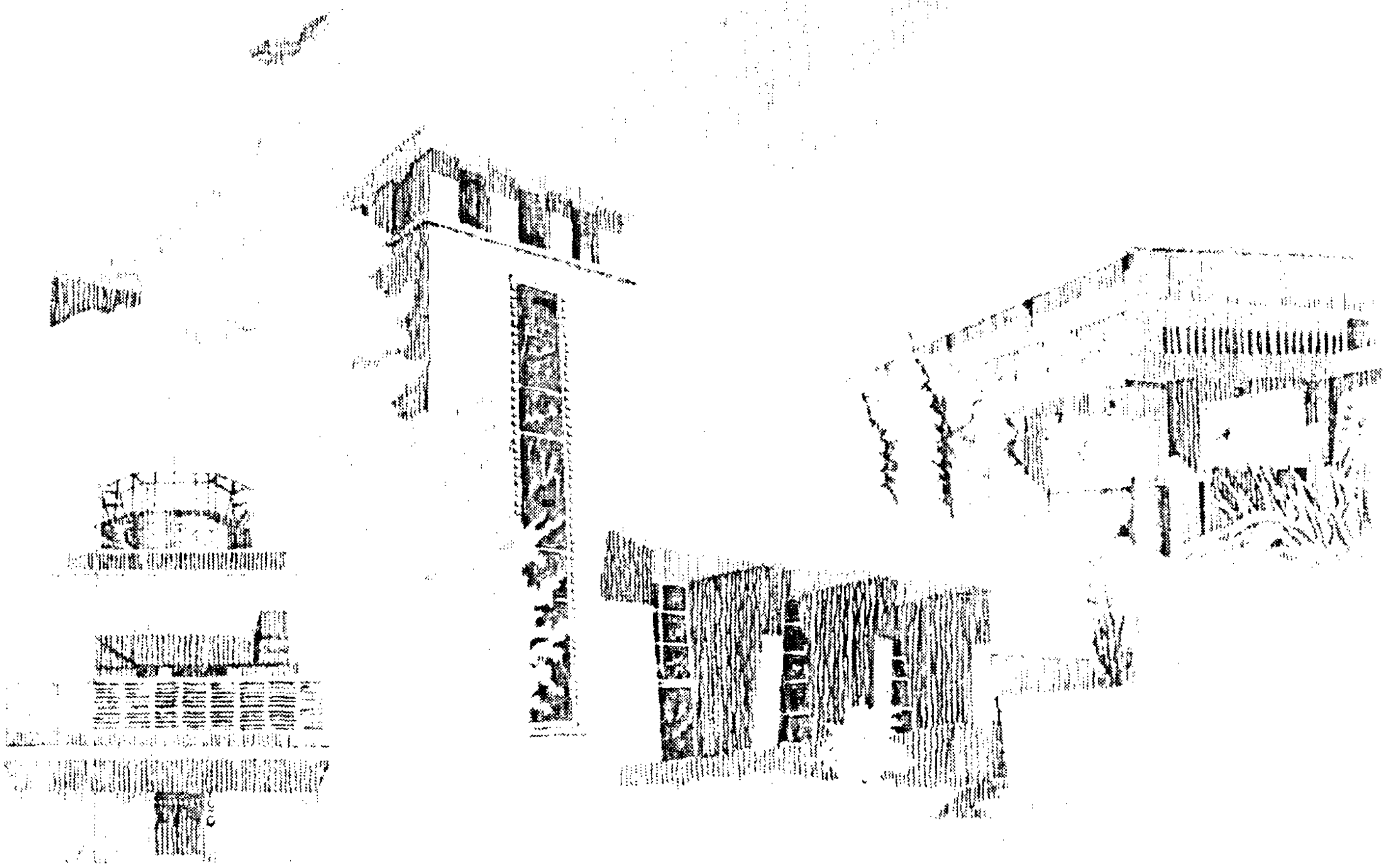

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RETRIEVAL STRATEGY REPORT FOR A POTENTIAL HIGH-LEVEL NUCLEAR WASTE REPOSITORY

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ABSTRACT

In federal laws, regulations, and departmental directives, the U.S. Congress, the Nuclear Regulatory Commission, and the U.S. Department of Energy have developed criteria for retrievability of waste emplaced in a geologic repository for high-level radioactive waste. In response to these criteria, the Yucca Mountain Project has included in the design of the potential repository at Yucca Mountain the option to retrieve emplaced waste as a planned contingency operation. This report presents a Project strategy for maintaining retrievability. It includes descriptions of repository and equipment designs; the operations during waste emplacement, post-emplacement, and retrieval; and expected repository conditions (normal and abnormal). Retrieval-related regulations and requirements are presented and discussed as a basis for evaluating the designs and operations plans. The report concludes with discussions of retrieval strategy implementation, which includes determining which equipment and operations demonstrations are necessary or required and plans for future work.

The report was worked on under the earlier WBS Element 1.2.1.4.3.3, but was completed under the current WBS 1.2.1.1.

FOREWORD

This report, SAND87-2777, describes a strategy developed in 1987 for retrieval of emplaced waste at the potential Yucca Mountain repository in Nevada. Clearly, changes to the repository design and program schedule have been ongoing, and such changes may bear on the final retrieval strategy. Nevertheless, it is felt that the document should be published in its present form because of the insightful technical evaluations and technical program definition information it contains.

EXECUTIVE SUMMARY

The Nuclear Waste Policy Act of 1982 and federal regulations that address the disposal of high-level radioactive waste in geologic repositories contain requirements for retrievability of emplaced waste. In response to these regulations, the U.S. Department of Energy (DOE) prepared their "Position on Retrievability and Retrieval for a Geologic Repository" (PRR) which provides a generic set of retrieval-related requirements and basic guidance. At the request of the DOE, Yucca Mountain Project staff at Sandia National Laboratories have prepared this Retrieval Strategy Report (RSR) to facilitate communication with the Nuclear Regulatory Commission and other interested parties on the subject of retrievability and retrieval.

The design information presented in this report was developed in 1987 based upon the "Site Characterization Plan Conceptual Design Report" (SCP-CDR). As the designs are refined, tests and analyses are completed, and schedules are revised, it is anticipated that this report will be updated.

This paper is organized into eight chapters and supporting appendices. A summary of each chapter follows.

Chapter 1--Introduction

This chapter provides background information on the radioactive waste repository program and an overview of how this report and the issue of retrievability fit into the potential Yucca Mountain repository program.

Chapter 2--Description of Emplacement System

Chapter 2 presents a description of the waste, the repository, the ventilation system, and emplacement operations. The conceptual design described in the SCP-CDR is used as a basis for this description.

Waste Description

The SCP-CDR design provides for the disposal of 70,000 metric tons uranium (MTU) of high-level waste including 62,000 MTU of spent fuel, 7,360 MTU of defense high-level waste (DHLW), and 640 MTU of West Valley high-level waste (WVHLW). Spent fuel hardware from fuel consolidation will also be emplaced at the repository. It is assumed for planning purposes that site-generated waste will be transferred to a commercial disposal site for low-level waste. Conceptual designs for containers have been completed by Lawrence Livermore National Laboratory for pressurized-water reactor (PWR) and boiling-water reactor (BWR) fuel for both the consolidated and unconsolidated cases. An alternative, hybrid container (for PWR and BWR fuel) is also described for the consolidated and unconsolidated cases.

Repository Description

The description of the repository includes descriptions of the surface facilities, the underground facility, and the waste transport and emplacement equipment. The design of the surface facilities assumes a two-stage development of the waste-handling buildings which accommodates an increase in the emplacement rate from 400 MTU the first year to 3,000 MTU the sixth and following years.

The underground facilities feature a ramp access for waste transporters and a perimeter drift for ventilation exhaust. The design includes configurations for vertical emplacement (reference case) and horizontal emplacement (alternate case). For the vertical emplacement configuration, spent fuel is emplaced in the floor of the emplacement drifts in 25-ft deep boreholes that are 15 ft apart. Between the spent fuel boreholes, DHLW and WVHLW are emplaced in 20-ft deep boreholes. For the horizontal emplacement configuration, 14 spent fuel containers are emplaced in the wall of the emplacement drift in 363-ft long boreholes, and 18 containers of DHLW or WVHLW are emplaced in 297-ft long boreholes located between every other spent fuel borehole. The distance between spent fuel boreholes is 68 ft. The distance between spent fuel and DHLW/WVHLW boreholes is 36 ft.

The equipment required to transport and emplace waste includes the transporter, modified forklift, borehole shielding closure, shield plug installer/remover, and the waste container dolly (for horizontal emplacement only). The transporter is the most complex piece of equipment needed and is the primary focus of development efforts.

Description of the Ventilation System

This section discusses the ventilation requirements for underground development and emplacement operations. The basic design incorporates standard concepts used in the mining industry. The ventilation system for the development area is a "push" system (fans located at the inlet); the ventilation system for the waste emplacement area is a "pull" system (fans located at the exhaust). This approach ensures that air leakage will be from the development area to the emplacement area and that contamination of the development area would be prevented in the event of a radiologic accident. In addition, high efficiency particulate air filters at the emplacement exhaust will be activated in case of a radiologic accident.

Ventilation analyses have been completed which indicate that acceptable air quality can be maintained in all working areas using standard ventilation techniques. The maximum airflow requirements are approximately 210,000 cfm for development and 840,000 cfm for emplacement (in the vertical emplacement configuration during emplacement operations). In addition, a cooling analysis has been performed which indicates that no cooling of ventilation air will be required during the emplacement period.

Description of Development and Emplacement Operations

Development begins with the construction of the ramps and shafts followed by the mining of the access drifts and waste emplacement panels. The repository design provides for simultaneous panel construction and waste emplacement operations. Shortly after a panel is completed, ventilation is converted from that for development to that for emplacement, and emplacement operations can begin.

Once development of a panel is complete, the borehole is prepared for emplacement by installing a shielding closure. The waste is transported to the borehole and emplaced. (In the horizontal emplacement configuration, multiple containers are emplaced in each borehole.) After the borehole is filled, it is closed by inserting a shield plug, removing the closure, and installing a cover.

Chapter 3--Retrieval Requirements and Design Criteria

In this chapter, retrieval-related design criteria are developed for the Yucca Mountain repository by evaluating the requirements contained in the PRR and applying these requirements to the potential Yucca Mountain site.

The PRR contains general, design, and operational requirements that must be met to ensure that the option for waste retrieval is maintained. Thirty-five specific retrieval-related requirements have been identified in the PRR. From these requirements, 24 site-specific design criteria have been generated. In the identification of the retrieval-related requirements, assumptions have been made in three areas: (1) the timing of major construction and modifications needed before retrieval starts, (2) the maintenance of retrieval-related equipment, and (3) the identification and classification of retrieval conditions.

Chapter 4--Post-Emplacement Operations

This chapter describes the repository operations that will be performed during the retrievability period. The SCP-CDR design assumes that backfill will not be emplaced during this period. However, as emplacement panels are filled with waste, ventilation to the panel will be reduced to "controlled leakage," and the panel will be classified as "closed." For all operational areas, ventilation will be maintained and the condition of the rock and the rock support system will be inspected to ensure that an acceptable working environment is maintained. The closed drifts will be inspected on an approximately 5-yr basis. Because of the waste-generated heat, prior cooling of the drift will be necessary (approximately 7 wk of cooling for the vertical emplacement configuration and 2 wk of cooling for the horizontal emplacement configuration). Four types of monitoring will be performed during post-emplacement operations: (1) performance confirmation, (2) ventilation (air quality), (3) geotechnical assessment, and (4) radiation and fire.

Chapter 5--Repository Conditions for Retrieval

Retrieval conditions are classified as normal or abnormal. The conditions described in Chapter 5 have been chosen to encompass extreme or "worst-case" conditions. None of the conditions are expected to compromise the capability to retrieve emplaced waste. Qualitatively, the conditions can be described as follows.

- The access ramp and all drifts will remain dry and stable throughout the retrievability period.
- Acceptable air quality will be maintained in the underground area.
- The ventilation system will be fully operational.
- Acceptable temperatures will either be maintained or be achievable by forced ventilation or cooling.
- Radiologic conditions will be acceptable.
- The emplacement envelope (borehole, liner, shield plug, and cover) will provide acceptable access to the waste containers.
- The waste containers will be intact.

A preliminary study to identify credible abnormal conditions has been completed. This study identified five processes, events, or conditions that could affect retrievability: (1) a tectonic event, (2) variability in rock characteristics, (3) human error, (4) aging/corrosion, and (5) radiolysis. By evaluating the effect of each of these processes, events, or conditions on the ability to retrieve waste, a list of 43 potential abnormal conditions were identified. None of the abnormal conditions that were deemed credible would prevent the waste from being retrievable.

Chapter 6--Retrieval Methods

Chapter 6 describes the methods planned for retrieval of waste containers from the repository at Yucca Mountain including all operations, necessary equipment, and contingencies to accomplish retrieval under abnormal conditions.

Retrieval Under Normal Conditions

Retrieval operations are performed in two phases: (1) preparation and (2) waste removal. Preparation activities include preparing surface facilities for support activities and receipt of waste, preparing the underground facility for waste removal, preparing retrieval equipment, and engineering and general support activities. The section discusses specifically all preparation activities and provides a schedule for these activities. It is estimated that preparation may take as long as 3 yr, depending on the time elapsed since emplacement operations ceased.

Waste removal activities include panel preparation (reestablishing ventilation in panels from which waste will be retrieved and inspecting and performing maintenance on emplacement drifts), borehole preparation, removal of waste from the borehole, transport and delivery of the waste to the surface, and closure of the borehole. This section includes flowcharts of the operations during the waste removal phase and the borehole-level operations for the vertical and horizontal waste configurations. Calculations of predicted radiologic exposures are presented in Appendixes F and G, and detailed studies of all necessary operations are presented in Appendix H.

Retrieval Under Abnormal Conditions

Retrieval of waste under abnormal conditions begins with an assessment of the conditions. This section describes efforts expected to be necessary for the following:

- correcting ramp or drift rockfall,
- correcting ventilation system malfunction,
- surmounting shielding closure malfunction,
- removing a bound shield plug,
- surmounting a liner collapse (in the horizontal emplacement configuration),
- surmounting retrieval equipment malfunction,
- surmounting a structural failure of the waste container,
- removing a bound waste container (in the vertical emplacement configuration),

- surmounting a transporter drive train malfunction, and
- mitigating the effect of a waste transporter collision.

Equipment Development

The final section in Chapter 6 addresses equipment development. Equipment designs for retrieval under normal conditions are based upon current technology and, where possible, use commercially available components. Preliminary concepts have been developed for equipment needed to retrieve waste under abnormal conditions. Development of equipment will be based on the probability of occurrence of the associated abnormal conditions.

Chapter 7--Retrieval Demonstrations

Chapter 7 discusses retrieval demonstrations, comprising proof-of-principle demonstrations and prototypical equipment development. It includes a discussion of the basis for deciding which equipment and systems will be demonstrated (systems and operations that have a significant degree of performance uncertainty), the environments in which the demonstrations must be made, and a schedule for equipment design, fabrication, testing, and documentation.

Chapter 8--Future Work

Chapter 8 describes future work that will support retrieval. In many instances the work is necessary for further development of the repository design, regardless of the requirement for retrievability. Work is planned in the following areas:

- site characterization,
- retrieval conditions (normal and abnormal),
- design (design criteria and repository and equipment design),
- retrieval operations,
- equipment tests,
- retrieval demonstrations (proof-of-principle demonstrations and prototype development), and
- retrieval compliance analysis.

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ACRONYMS

ACD	Advanced conceptual design
ACP	Air-cooling power
BWR	Boiling-water reactor
DB	Dry bulb temperature
DHLW	Defense high-level waste
DOE	U. S. Department of Energy
DOL	U. S. Department of Labor
EPA	Environmental Protection Agency
ES-1	Exploratory Shaft 1
ES-2	Exploratory Shaft 2
ESF	Exploratory shaft facility
HEPA	High efficiency particulate air (filter)
HVAC	Heating, ventilating, and air-conditioning
IN	Information need
MTU	Metric tons uranium
NRC	U. S. Nuclear Regulatory Commission
NTS	Nevada Test Site
NWPA	Nuclear Waste Policy Act
PRR	Position on Retrievability and Retrieval (document)
PWR	Pressurized-water reactor
SCP	Site Characterization Plan (document)
SCP-CDR	Site Characterization Plan Conceptual Design Report (document)
SNL	Sandia National Laboratories
WHB-1	Waste-handling Building 1
WHB-2	Waste-handling Building 2
WVHLW	West Valley high-level waste

1.0 INTRODUCTION

1.1 Background

The U.S. Congress passed the Nuclear Waste Policy Act of 1982 (NWPA) to provide the basic guidance, schedules, and source of funding for the development of geologic repositories for the disposal of radioactive waste in the United States (NWPA, 1983). This act was amended by Congress as the Nuclear Waste Policy Amendments Act (NWPAA, 1987). Under the direction of the U.S. Department of Energy (DOE), the Yucca Mountain Project staff are evaluating the feasibility of constructing a repository at Yucca Mountain, Nevada, which is located on and adjacent to the Nevada Test Site, approximately 160 km (99.4 miles) northwest of Las Vegas, Nevada (Figure 1-1). The target horizon for waste disposal is a formation of welded tuff located in the unsaturated zone at an average subsurface depth of approximately 300 m.

In accordance with the NWPA, federal agencies have developed regulations to ensure that radioactive waste disposal operations will not endanger public health and safety or the environment. Included in these regulations as an added measure of assurance is the requirement to maintain the option of retrieving emplaced waste. Consequently the potential Yucca Mountain repository design includes retrieval as a planned contingency.

To provide specific guidance for waste retrieval and retrievability, the DOE prepared "Position on Retrievability and Retrieval for a Geologic Repository" (PRR) which was published as an appendix to the "Department of Energy Generic Requirements for a Mined Geologic Disposal System" (DOE, 1986a).

Recognizing the importance of the retrieval option, the Yucca Mountain Project staff have completed numerous retrieval-related studies which are presented in the following documents.

- "Retrievability: Strategy for Compliance Demonstration" (Flores, 1986).

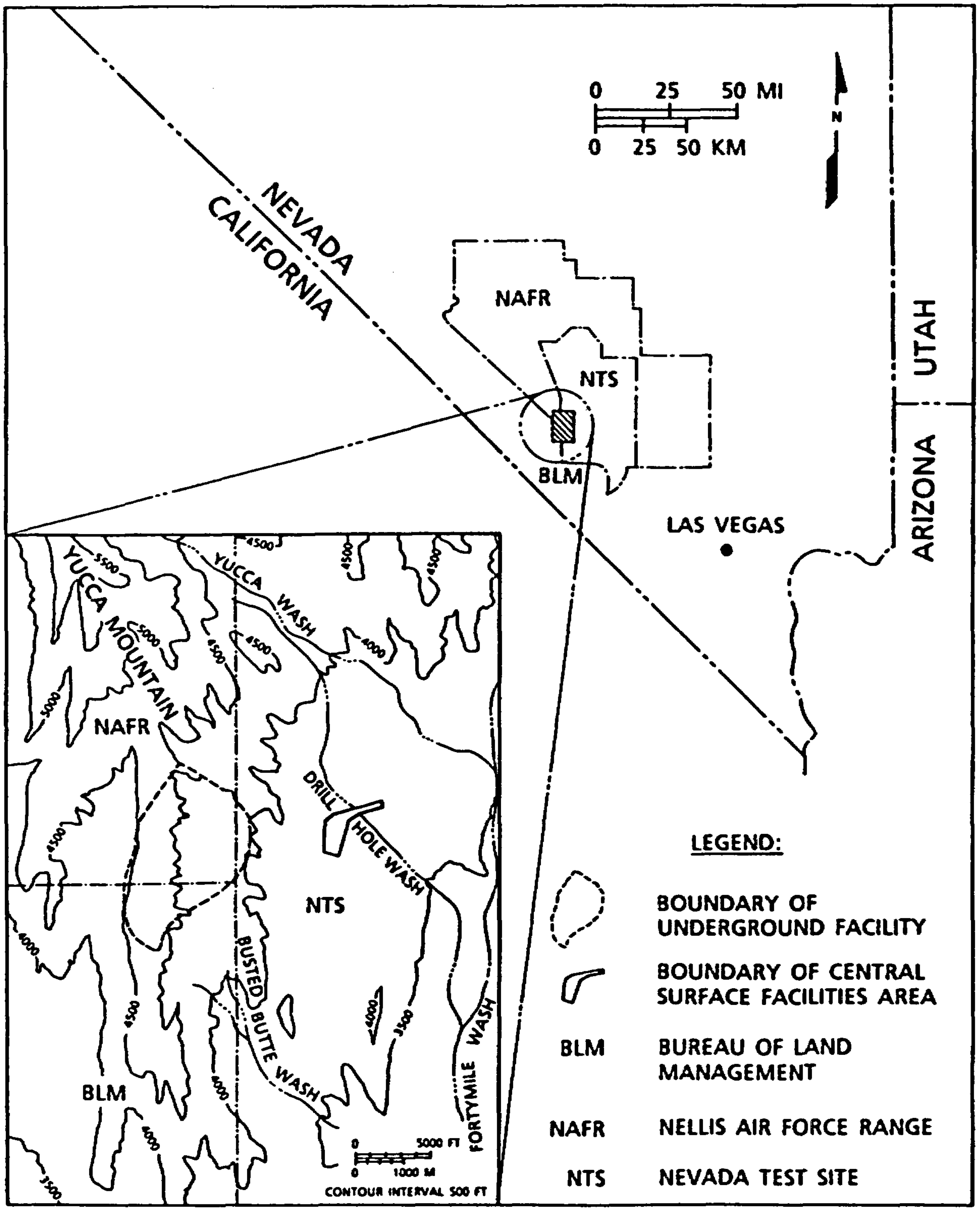


Figure 1-1. Location of the Yucca Mountain Site (from Figure ES-1, SCP-CDR)

- "Disposal of Radioactive Waste Packages in Vertical Boreholes--A Description of the Operations and Equipment for Emplacement and Retrieval" (Stinebaugh and Frostenson, 1986).

- "Disposal of Radioactive Waste Packages in Horizontal Boreholes--A Description of the Operations and Equipment for Emplacement and Retrieval" (Stinebaugh et al., 1986).

- "One-Twelfth-Scale Model of Horizontal Emplacement and Retrieval Equipment for Radioactive Waste Packages at the Proposed Repository in Tuff" (White et al., 1986).

- "Final Report of Core Drill Conceptual Design Study for Retrieval of Radioactive Waste Disposed in a Geologic Repository" (The Robbins Company, 1987).

- "Conceptual Engineering Studies and Design for Three Different Machines for Nuclear Waste Transporting, Emplacement, and Retrieval" (Fisk et al., 1985).

- "Preliminary Preclosure Radiological Safety Analysis" (SNL, 1987, Appendix F).

- "Items Important to Retrievability at the Yucca Mountain Repository" (SNL, 1987, Appendix L-2).

- "Preliminary Safety Assessment Study for the Conceptual Design of a Repository in Tuff at Yucca Mountain" (Jackson et al., 1984).

- "NNWSI Repository Worker Radiation Exposure, Volume I, Spent Fuel and High-Level Waste Operations in a Geologic Repository in Tuff" (Dennis et al., 1984).

- "Worker Radiation Doses During Vertical Emplacement and Retrieval of Spent Fuel at the Tuff Repository" (Stinebaugh and Frostenson, 1987).

- "Site Characterization Plan Conceptual Design Report" (SNL, 1987).

In 1986, the DOE recognized that a clear explanation of the retrieval strategy would facilitate communication with the U.S. Nuclear Regulatory Commission (NRC) and developed an annotated outline for a retrieval strategy report (Appendix A). This study represents the first version of the strategy document for the Yucca Mountain Project and is based upon the design presented in the "Site Characterization Plan Conceptual Design Report" (SCP-CDR) (SNL, 1987). The level of site data and design detail available for the SCP-CDR design imposes limitations on the ability to provide all of the information requested in the DOE annotated outline. A specific schedule is not included in this report because of program and schedule changes that have taken place since the early drafts of the report were prepared. Consequently, it is anticipated that this study will be revised during advanced conceptual design (ACD) to provide the level of detail requested by the DOE. Completion of an updated version of this strategy document is scheduled for the end of ACD.

1.2 Purpose and Scope

This study presents a Yucca Mountain Project strategy developed in 1987 for retrieval of emplaced waste. The purpose of this report is to facilitate communication among the DOE, the regulators, and Yucca Mountain Project staff on the subject of retrieval and retrievability.

This study presents the current status of and describes future work for all major activities needed to comply with the retrieval-related federal requirements and the PRR, including

- the development of retrieval-related design criteria,
- the identification of retrieval conditions,
- the development of retrieval-related equipment,
- the development of retrieval demonstrations,
- the development of retrieval operations, and
- the completion of a compliance analysis.

1.3 Relationship with Other Documents

The relationship of this strategy document with other DOE and Project documents is shown in Figure 1-2. As shown in the figure, the NWPA and federal regulations form the basis for the development of the program-level documents. The program-level documents and the state and local regulations potentially applicable to the Yucca Mountain site are used to generate the Project documents including the "Site Characterization Plan" (SCP), the SCP-CDR, the systems requirements document, and this retrieval strategy report. The requirements contained in these documents are used to generate the repository design requirements document, which provides designer-level design requirements.

1.4 Relationship with the Issues Hierarchy

As discussed in the "Mission Plan" (DOE, 1985), work being performed for the Yucca Mountain Project is organized according to the issues hieraracby presented in the "Issues Hierarchy for a Mined Geologic Disposal System" (DOE, 1986). The issues hierarchy consists of a three-level framework of key issues, issues, and information needs. At the highest level are four key issues which address the principal requirements contained in the federal regulations regarding geologic disposal of nuclear waste. The second level comprises a set of issues under each key issue. Each set of issues presents an expansion of all of the requirements addressed by the key issue. The third level of the issues hierarchy comprises a set of information needs for each issue. Each set of information needs identifies the information needed to resolve the corresponding issue. The issues hierarchy provides a mechanism for reducing broad questions pertaining to overall site performance and suitability to very specific questions about site characteristics, the design of the repository and the waste package, and the performance of the complete geologic disposal system.

Waste retrievability is included in the issues hierarchy as Issue 2.4, Retrievability. The issue is formally stated as follows:

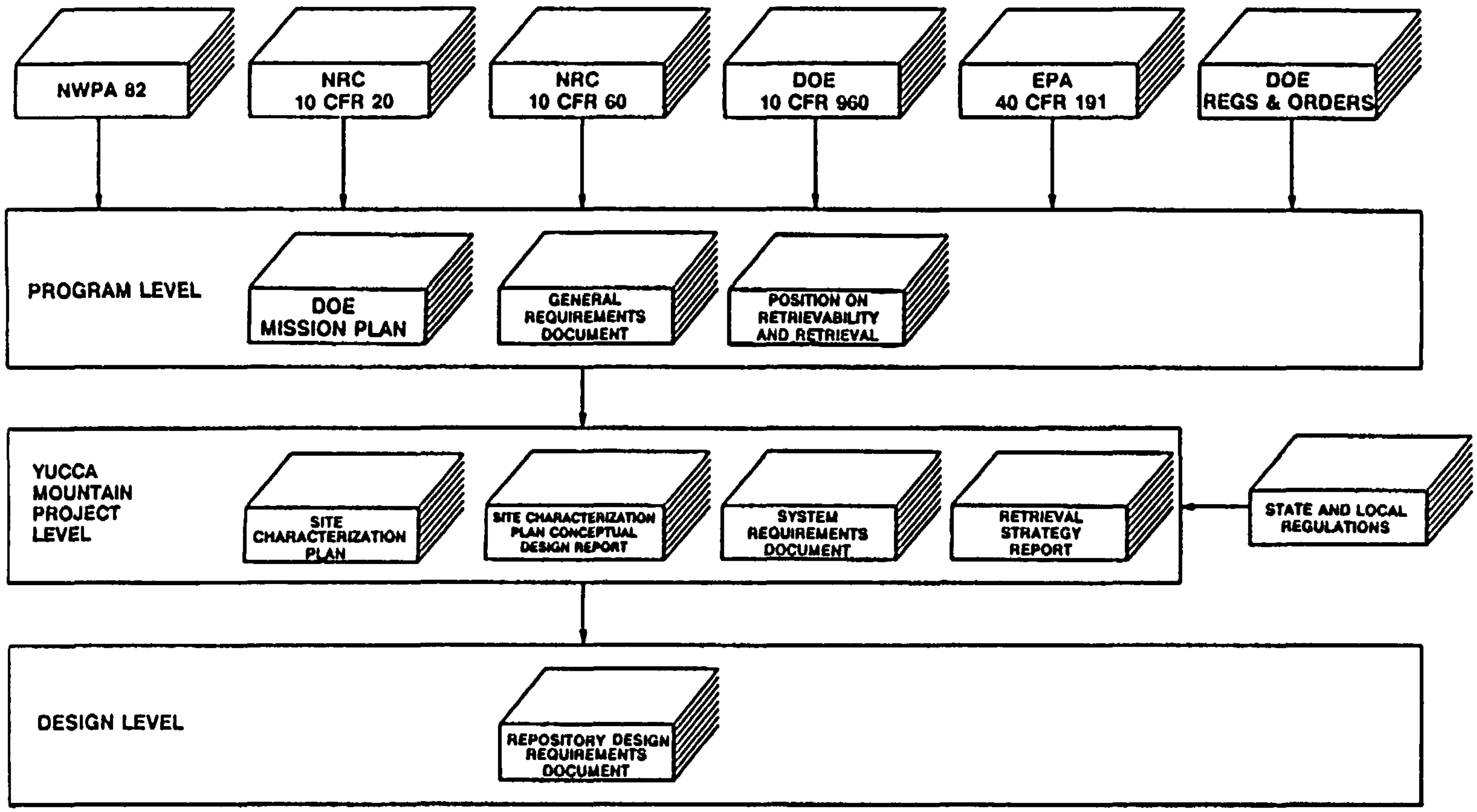


Figure 1-2. Relationship of Major Documents

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

The set of information needs (IN) associated with Issue 2.4 are as follows:

IN 2.4.1--Site and design data required to support retrieval.

IN 2.4.2--Determination that access to the waste emplacement boreholes can be provided throughout the period of retrievability and the actual retrieval period for normal and credible abnormal conditions.

IN 2.4.3--Determination that access to the waste packages can be provided throughout the period of retrievability and the actual retrieval period for normal and credible abnormal conditions.

IN 2.4.4--Determination that the waste can be removed from the emplacement boreholes for normal and credible abnormal conditions.

IN 2.4.5--Determination that the waste can be transported to the surface and delivered to the waste-handling surface facilities for normal and credible abnormal conditions.

IN 2.4.6--Determination that the retrieval requirements set forth in 10 CFR 60.111(b) are met using reasonably available technology.

A complete discussion of the resolution strategy for Issue 2.4 is contained in Section 8.3.5.2 of the SCP (DOE, 1988).

REFERENCES FOR CHAPTER 1

Dennis, A. W., J. C. Frostenson, and K. J. Hong, "NNWSI Repository Worker Radiation Exposure, Volume I, Spent Fuel and High-Level Waste Operations in a Geologic Repository in Tuff," SAND83-7436/1, prepared by Los Alamos Technical Associates, Inc., for Sandia National Laboratories, Albuquerque, NM, May 1984. (HQS.880517.2280)

DOE (U.S. Department of Energy), "Mission Plan for the Civilian Radioactive Waste Management Program," DOE/RW-0005, Office of Civilian Radioactive Waste Management, Washington, DC, June 1985. (HQP.870601.0271)

DOE (U.S. Department of Energy), "Generic Requirements for a Mined Geologic Disposal System," OGR/B-2, DOE RW-0090, Office of Civilian Radioactive Waste Management, Washington, DC, June 1986a. (NNA.870605.0001)

DOE (U.S. Department of Energy), "Issues Hierarchy for a Mined Geologic Disposal System," DOE/RW-0101, Office of Civilian Radioactive Waste Management, Washington, DC, September 1986b. (HQS.880517.0970)

DOE (U.S. Department of Energy), "Site Characterization Plan, Yucca Mountain Site, Nevada Research and Development Area, Nevada," DOE RW-0199, Office of Civilian Radioactive Waste Management, Washington, DC, December 1988. (HQO.881201.0002)

Fisk, A. T., P. Bakker, B. J. Doherty, J. P. Pokorski, and J. Spector, "Conceptual Engineering Studies and Design for Three Different Machines for Nuclear Waste Transporting, Emplacement, and Retrieval," SAND83-7089, prepared by Foster-Miller, Inc., for Sandia National Laboratories, Albuquerque, NM, March 1985. (HQS.880517.2289)

Flores, R. J., "Retrievability: Strategy for Compliance Demonstration," SAND84-2242, Sandia National Laboratories, Albuquerque, NM, January 1986. (HQS.880517.1627)

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. (HQS.880517.2307)

NWPA (Nuclear Waste Policy Act of 1982), Public Law 97-425, 96 Stat. 2201, 42 USC 10101, Washington, DC, January 1983. (NNA.890626.0312)

NWPAA (Nuclear Waste Policy Amendments Act of 1987), Public Law 100-203, 42 USC 10101, Washington, DC, December 22, 1987. (HQS.880517.3146)

SNL (Sandia National Laboratories), "Site Characterization Plan Conceptual Design Report," SAND84-2641, compiled by H. R. MacDougall, L. W. Scully, and J. R. Tillerson, Sandia National Laboratories, Albuquerque, NM, September 1987. (NNI.880902.0014-.0019)

REFERENCES FOR CHAPTER 1
(concluded)

Stinebaugh, R. E., and J. C. Frostenson, "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, NM, December 1986. (HQS.880517.2878)

Stinebaugh, R. E., and J. C. Frostenson, "Worker Radiation Doses During Vertical Emplacement and Retrieval of Spent Fuel at the Tuff Repository," SAND84-2275, Sandia National Laboratories, Albuquerque, NM, February 1987. (NNA.870513.0058)

Stinebaugh, R. E., I. B. White, and J. C. Frostenson, "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, NM, December 1986. (HQS.880517.2880)

The Robbins Company, "Final Report of Core Drill Conceptual Design Study for Retrieval of Radioactive Waste Disposed in a Geologic Repository," SAND84-7100, prepared for Sandia National Laboratories, Albuquerque, NM, September 1987. (NNA.870827.0084)

White, I. B., R. E. Graham, and J. C. Frostenson, "One-Twelfth-Scale Model of Horizontal Emplacement and Retrieval Equipment for Radioactive Waste Packages at the Proposed Repository in Tuff," SAND86-7135, prepared by Los Alamos Technical Associates, Inc., for Sandia National Laboratories, Albuquerque, NM, December 1986. (HQS.880517.2364)

2.0 DESCRIPTION OF EMPLACEMENT SYSTEM

This chapter provides an overview of the repository design presented in the "Site Characterization Plan Conceptual Design Report" (SCP-CDR) (SNL, 1987). This design does not consider the use of a monitored retrievable storage facility as an interim step between the power reactors and the repository. It is recognized that since that time several changes in guidance and in the respondent design concepts have occurred and additional design studies have been initiated (or completed). These changes will be reflected in future designs for the potential Yucca Mountain repository. 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 exploratory shaft facility design, extent, and construction methods.

2.1 Waste Types, Quantities, and Package

The waste to be received at the potential Yucca Mountain repository is described in detail in a report prepared by Sandia National Laboratories (SNL) (O'Brien, 1985). That report, which is based on the U.S. Department of Energy's (DOE) "Mission Plan" (DOE, 1985), provides the basis for the aspects of the repository design that depend on waste type, quantity, or characteristics. Sections 2.1.1 and 2.1.2 summarize the information regarding the waste used as a basis for design of the repository.

2.1.1 Waste Types

In the conceptual design, it is assumed that the following types of waste are received at the repository or generated during repository operations.

2.1.1.1 Spent Fuel

Both pressurized-water reactor (PWR) and boiling-water reactor (BWR) fuel are received at the repository. In the conceptual design, the quantities of PWR and BWR fuel received at the repository are equivalent to 37,200 and 24,800 metric tons uranium (MTU), respectively. For the design presented in the SCP-CDR, it is assumed that consolidation occurs at the repository. It is also assumed that up to 10% of all spent fuel received at the repository will not be suitable for consolidation and will therefore be emplaced in overpack containers instead of being consolidated. Radiological characteristics of the waste received are shown in Table 2-1.

There is a wide variety of PWR and BWR fuel rod and fuel assembly dimensions. Mechanical characteristics of spent fuel assemblies are shown in Table 2-2.

2.1.1.2 Spent Fuel Hardware

Fuel element hardware remains after the fuel has been consolidated. Typically, this hardware consists of grid spacers, plenum springs, tie plates, and fuel channels. The quantities of this waste are determined by the quantity of fuel consolidated at the repository.

2.1.1.3 Defense High-Level Waste

Defense high-level waste (DHLW) comes from facilities that process defense waste. In the current conceptual design, the quantity of DHLW received is assumed to be 7,360 MTU.

2.1.1.4 West Valley High-Level Waste

West Valley high-level waste (WVHLW) is solidified waste generated at the West Valley Demonstration Project in New York. Approximately 640 MTU of WVHLW is planned to be emplaced at the repository.

2.1.1.5 Site-Generated Waste

Site-generated waste results from decontamination activities in the cask-receiving area, from operations in the waste preparation and packaging hot cells, and from the laboratories used to assess samples

TABLE 2-1

TYPICAL RADIOLOGICAL CHARACTERISTICS OF WASTE AS RECEIVED[a]

Radiological Characteristics	PWR 5 yr out of reactor	BWR 5 yr out of reactor	PWR 10 yr out of reactor	BWR 10 yr out of reactor
Burnup (average conditions) MWd[b]/MTU	33,000	27,500	33,000	27,500
Actinides and daughters (Ci/MTU)	104,000	93,000	83,000	75,000
Fission products (Ci/MTU)	453,000	365,000	302,000	249,000
Decay heat (W/MTU)	1,800	1,400	1,100	900
Photon release (Photons/sec/MTU)	1.3×10^{16}	1.0×10^{16}	7.7×10^{15}	6.2×10^{15}
Photon energy release (Mev/sec/MTU)	4.8×10^{15}	3.6×10^{15}	2.6×10^{15}	2.0×10^{15}
Burnup (high condition) MWd/MTU	50,000		50,000	
Actinides and daughters	155,000		124,000	
Fission products (Ci/MTU)	640,000		442,000	
Decay heat (W/MTU)	2,800		1,800	
Photon release (Photons/sec/MTU)	1.9×10^{16}		1.1×10^{16}	
Photon energy release (Mev/sec/MTU)	7.3×10^{15}		3.8×10^{15}	

a. Modified from DOE (1984).
b. MWd = megawatt-days.

TABLE 2-2

MECHANICAL CHARACTERISTICS OF SPENT FUEL ASSEMBLIES*

Mechanical Characteristics	PWR	BWR
Overall length-range (in.)	149-186	84-179
Width (in.) (square)	8.1-8.5	4.3-6.5
Fuel rods/assembly	100-264	48-81
Fuel rod diameter (in.)	0.360-0.4440	0.483-0.570
Fuel rod length (in.)	91.5-171	80.5-165
Rod pitch (in.)	0.496-0.580	0.640-0.842
MTU/assembly	0.11-0.52	0.19-0.20
Assembly weight (lb)	1,280-1,450	600

*Modified from DOE (1984). Information from Table 7-3, SCP.

retrieved for the performance confirmation program. The quantities and characteristics of this waste have not yet been determined. However, the current repository design is based on the assumption that these wastes will be transferred to an offsite commercial disposal facility for low-level waste.

2.1.2 Waste Quantities

Table 2-3 shows the quantities of waste to be received annually at the repository.

2.1.3 Waste Container Design and Materials

The disposal container for spent reactor fuel currently planned for the repository in tuff has an outside diameter of 26 in., is 187.5 in. long, and has a wall thickness of 0.375 in. The top end of the container features a pintle to facilitate handling. Two alternative sets of partitions inside the container allow it to be used for either consolidated or unconsolidated (intact) PWR or BWR spent fuel. Figure 2-1 shows the disposal container for spent fuel loaded with (1) 6 consolidated PWR fuel

TABLE 2-3

WASTE RECEIPT RATES*

Year	MTU of WVHLW and DHLW This Year	MTU of WVHLW and DHLW Cumu-lative	MTU of Spent Fuel This Year	MTU of Spent Fuel Cumu-lative	Cumulative MTU of Spent Fuel and WVHLW/DHLW
1998	0	0	400	400	400
1999	0	0	400	800	800
2000	0	0	400	1,200	1,200
2001	0	0	900	2,100	2,100
2002	0	0	1,800	3,900	3,900
2003	400	400	3,000	6,900	7,300
2004	400	800	3,000	9,900	10,700
2005	400	1,200	3,000	12,900	14,100
2006	400	1,600	3,000	15,900	17,500
2007	400	2,000	3,000	18,900	20,900
2008	400	2,400	3,000	21,900	24,300
2009	400	2,800	3,000	24,900	27,700
2010	400	3,200	3,000	27,900	31,100
2011	400	3,600	3,000	30,900	34,500
2012	400	4,000	3,000	33,900	37,900
2013	400	4,400	3,000	36,900	41,300
2014	400	4,800	3,000	39,900	44,700
2015	400	5,200	3,000	42,900	48,100
2016	400	5,600	3,000	45,900	51,500
2017	400	6,000	3,000	48,900	54,900
2018	400	6,400	3,000	51,900	58,300
2019	400	6,800	3,000	54,900	61,700
2020	400	7,200	3,000	57,900	65,100
2021	400	7,600	3,000	60,900	68,500
2022	400	8,000	1,100	62,000	70,000

*DOE, 1985. Information from Table 2-1, SCP-CDR.

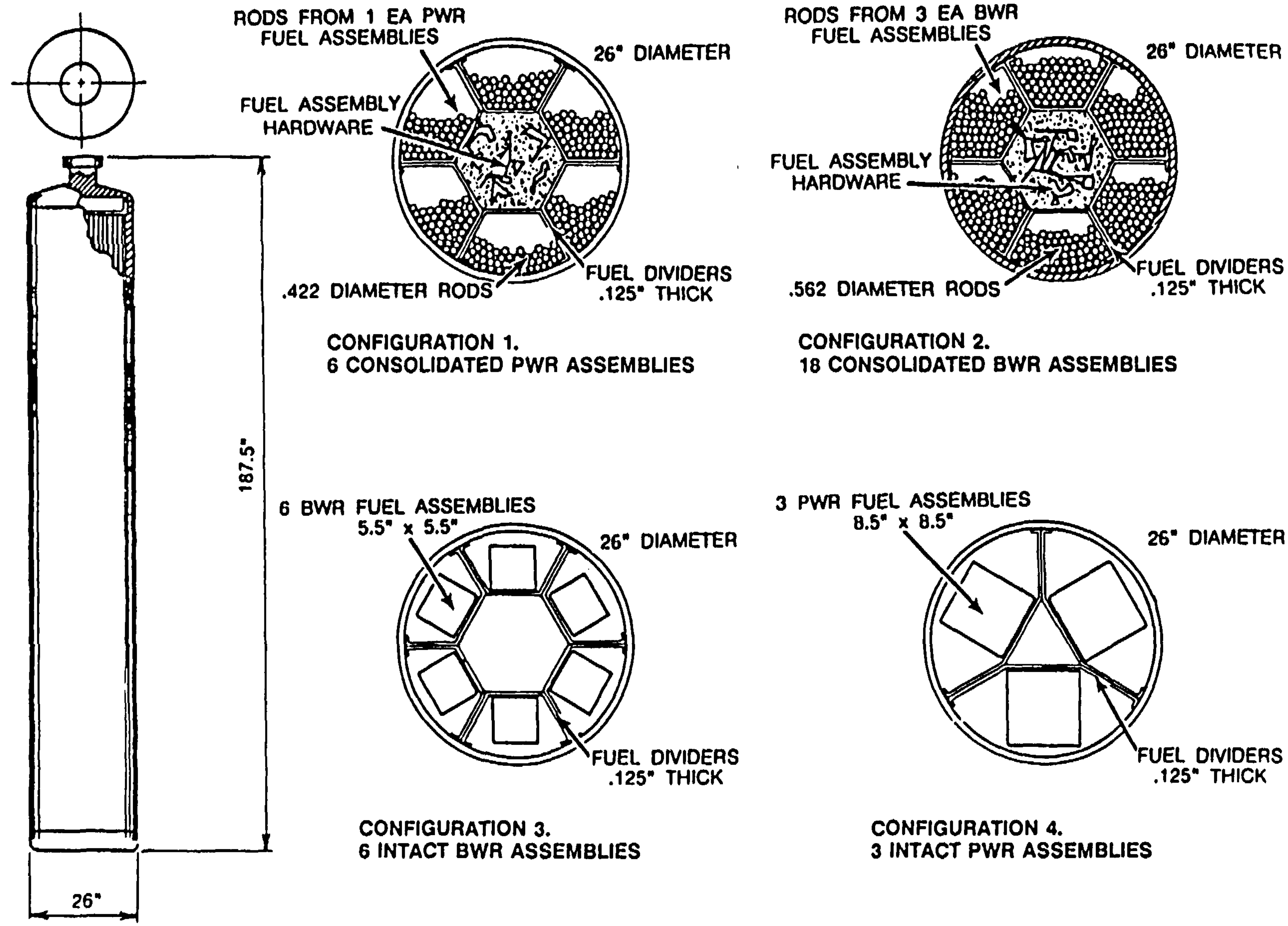


Figure 2-1. Yucca Mountain Project Reference Spent Fuel Container (Figure 7-2, SCP, supplied by Lawrence Livermore National Laboratory)

assemblies, (2) 18 consolidated BWR fuel assemblies, (3) 6 intact BWR fuel assemblies, and (4) 3 intact PWR fuel assemblies. The central compartment of the waste container accommodates fuel element hardware. For every six containers of BWR fuel assemblies, an additional container is needed to emplace the hardware from the consolidated BWR fuel assemblies. Alternate loading configurations for spent fuel are shown in Figure 2-2.

The pour canister for DHLW and WVHLW is overpacked with a disposal container at the repository (Figure 2-3). The completed waste package has a diameter of 26 in. and a length of 126 in.

The reference material for the waste package container in the SCP-CDR is AISI 304L stainless steel. The reference alloy system is the 300 series austenitic stainless steel and alloy 825, a high nickel, iron-based austenitic alloy. Candidate metals initially considered for the reference material include the following alloy groups: austenitic stainless steels, ferritic stainless steels, duplex stainless steels, high-nickel alloys, titanium alloys, zirconium alloys, copper-nickel alloys, low-carbon steels, and cast irons (Russell et al., 1983). Substantial additional efforts are being directed at evaluating materials most appropriate for waste package use.

2.2 Repository Description

The general layout of the repository is shown in Figure 2-4. A brief description of the surface facilities (covering, primarily, the waste-handling buildings shown in the figure) is followed by a discussion of the design of the underground facilities, waste transportation and emplacement equipment, the underground ventilation system, and the repository development and emplacement operations.

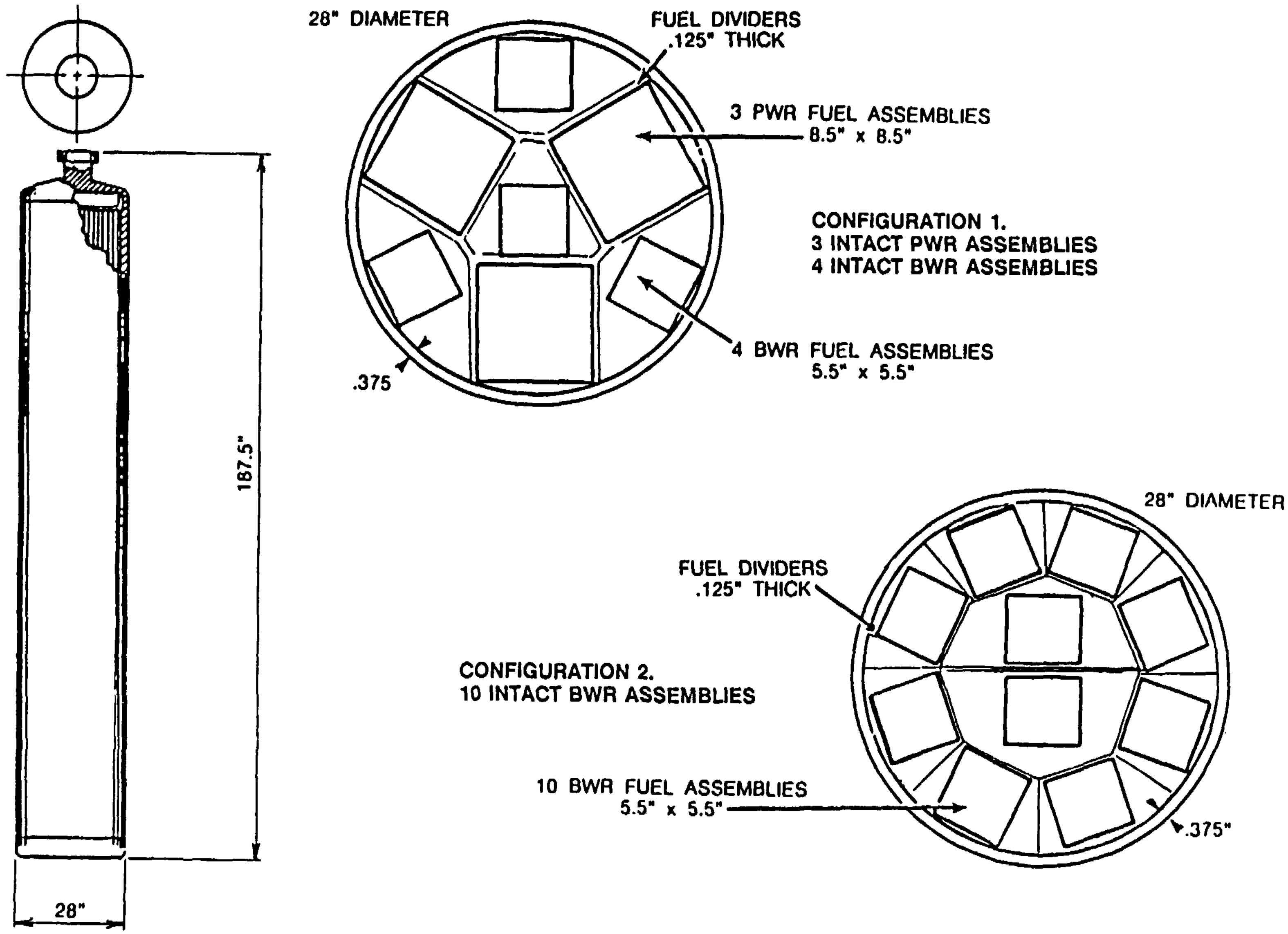


Figure 2-2. Yucca Mountain Project (modified from Figure 7-2, SCP supplied by Lawrence Livermore National Laboratory)

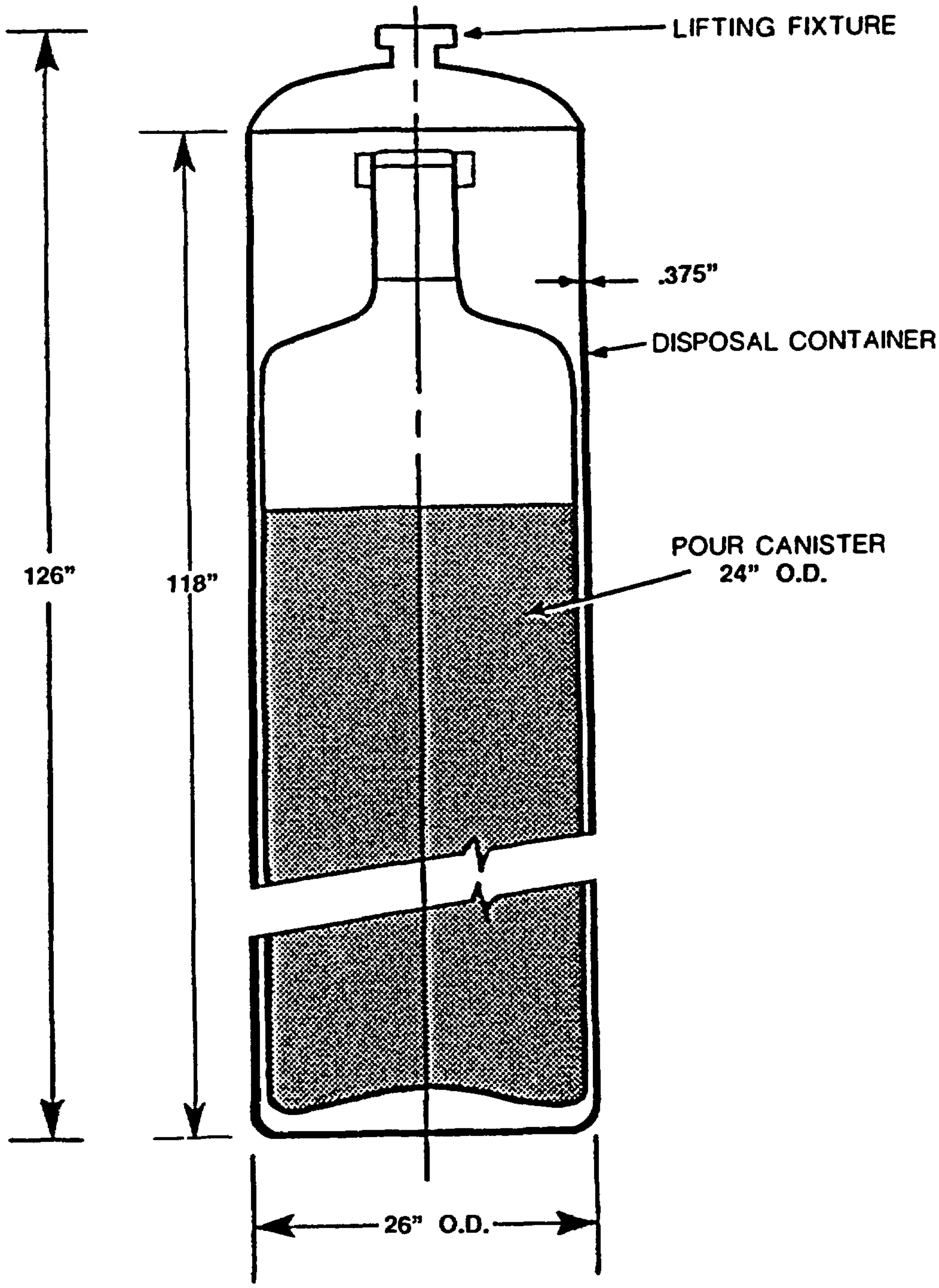


Figure 2-3. Reference West Valley/Defense High-Level Waste Container (from Figure 7-3, SCP, supplied by Lawrence Livermore National Laboratory)

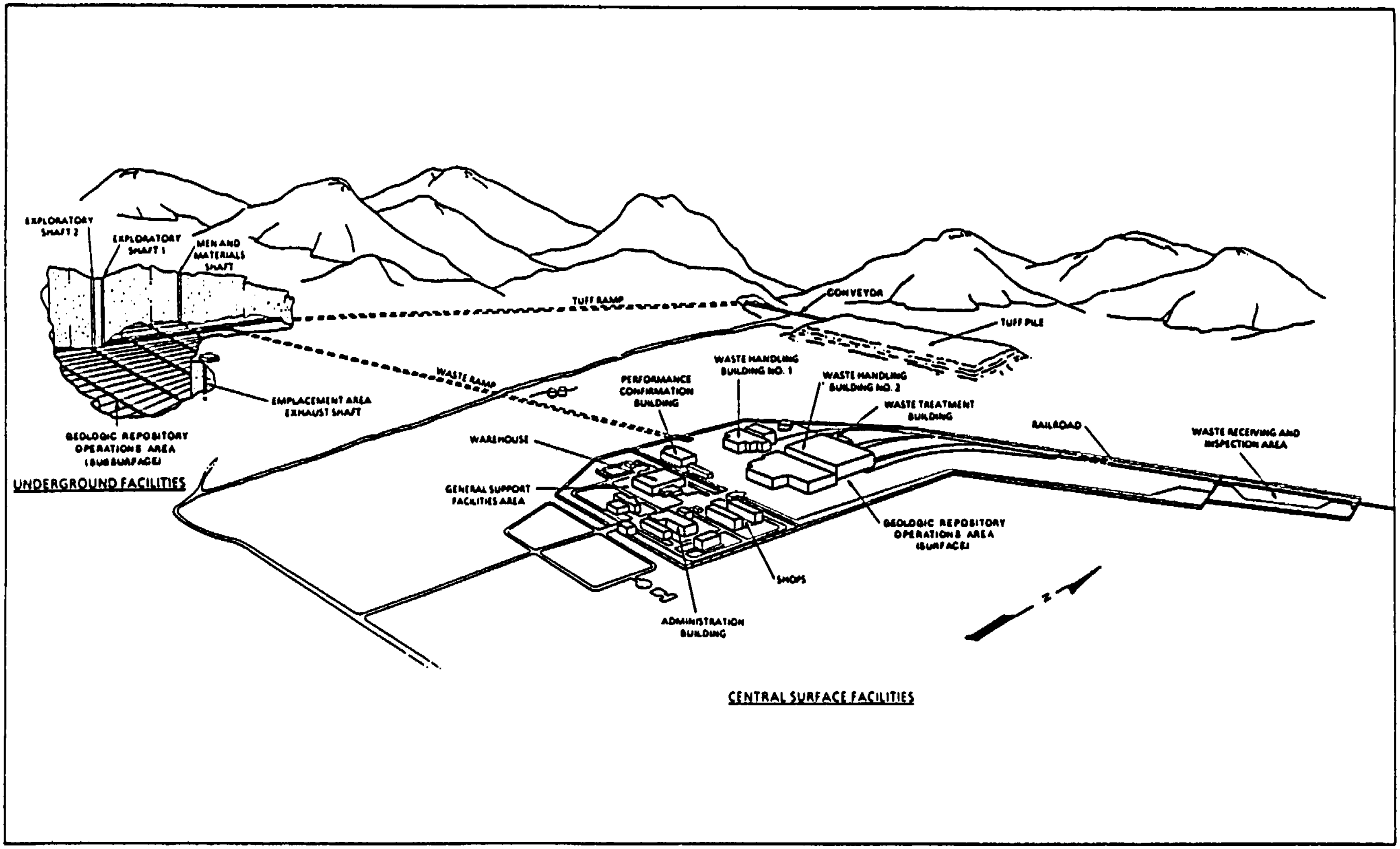


Figure 2-4. General Layout of the Repository (from Figure ES-3, SCP-CDR)

2.2.1 Surface Facilities

2.2.1.1 Central Surface Facilities

The central surface facilities are located on a leveled, 82-acre bench at an elevation of 3,665 ft. The central surface facilities are divided into three distinct functional areas--the waste-receiving and inspection area, the geologic repository operations area, and the general support facilities area. The waste-receiving and inspection area includes space for inspection of incoming shipments, railcar sidings, and a truck parking area. The surface portions of the geologic repository operations area include all surface facilities in which radioactive materials are handled or stored. The general support facilities area includes the facilities in the central surface facilities area that do not handle or treat radioactive materials.

2.2.1.2 Shaft and Ramp Areas

The exploratory shafts (ES-1 and ES-2), the men-and-materials shaft, the emplacement area exhaust shaft, and their related facilities are located 1-1.5 mi west of the central surface facilities area. During emplacement operations, the exploratory shafts are planned to be used as fresh air intakes for the emplacement area.

2.2.1.3 Waste-Handling Buildings

A two-stage approach to repository construction incorporates two waste-handling buildings in the surface portion of the geologic repository operations area. During the first 3 yr of operations, only Waste-Handling Building 1 (WHB-1) will operate while construction of a full-capacity waste-handling building, Waste-Handling Building 2 (WHB-2), is completed. A temporary fence will separate operations in WHB-1 from construction activities at WHB-2 during this period.

2.2.2 Underground Facility

The underground facility includes all subsurface excavations. This section describes the general layout of the facilities and explains various elements of the underground design.

The reference waste emplacement configuration for the Yucca Mountain Project is single-container emplacement in a vertical borehole. An alternate emplacement configuration is multiple-container emplacement in a horizontal borehole.

2.2.2.1 Design Methodology

All underground openings, for both the vertical and horizontal configurations, were designed considering the following:

- dimensions of the mining and waste transportation, emplacement, and retrieval equipment;
- ventilation requirements;
- other utility and support functions to be accommodated; and
- stability requirements.

The design of the drifts and panels considers

- the division of the usable area into approximately equal areas to facilitate staging of construction and waste-handling operations;
- drift orientation to minimize the average drift grade;
- frequency and direction of rock mass fractures;
- in situ stress, magnitude, and direction;
- heat transfer and temperature constraints;
- thermal stress and opening stability;
- ventilation operations;
- ground-water control; and
- locations of the accesses from the surface.

2.2.2.2 Underground Layout

Description of Common Features

The orientation and rather irregular shape of the emplacement area (Figure 2-5) are determined primarily by the geologic characteristics of the emplacement horizon. All facilities are located in the Topopah Spring Member (Mansure and Ortiz, 1984).

Table 2-4 lists the major elements of the underground facility and their corresponding functions. The arrangement of the main drifts, maintenance shops, offices, warehouses, and radiological facility is shown in Figure 2-6. The area indicated roughly approximates the extent of drifting required as part of the initial construction phase before the first waste is emplaced. Two special areas are set aside at the base of the waste ramp--one for performance confirmation testing and another for training of equipment operators. Figure 2-6 also shows the location of the exploratory shaft facility (ESF) with respect to the initial underground development.

The principal underground access is formed by three parallel main drifts extending from the base of the ramps to the southwest end of the emplacement area. Use of three main drifts allows complete separation of the ventilation air for the development area from the ventilation air for the waste emplacement area. The main drifts are designed and planned to be maintained and will remain operational throughout the construction, emplacement, and caretaker phases.

The perimeter drift forms the outer boundary of the underground layout and functions as the exhaust airway for the air passing through emplacement panels. The drift is sized to accommodate maximum ventilation requirements.

Vertical Emplacement Configuration

The overall underground facility layout for the vertical emplacement configuration is shown in Figure 2-5. The major elements of the

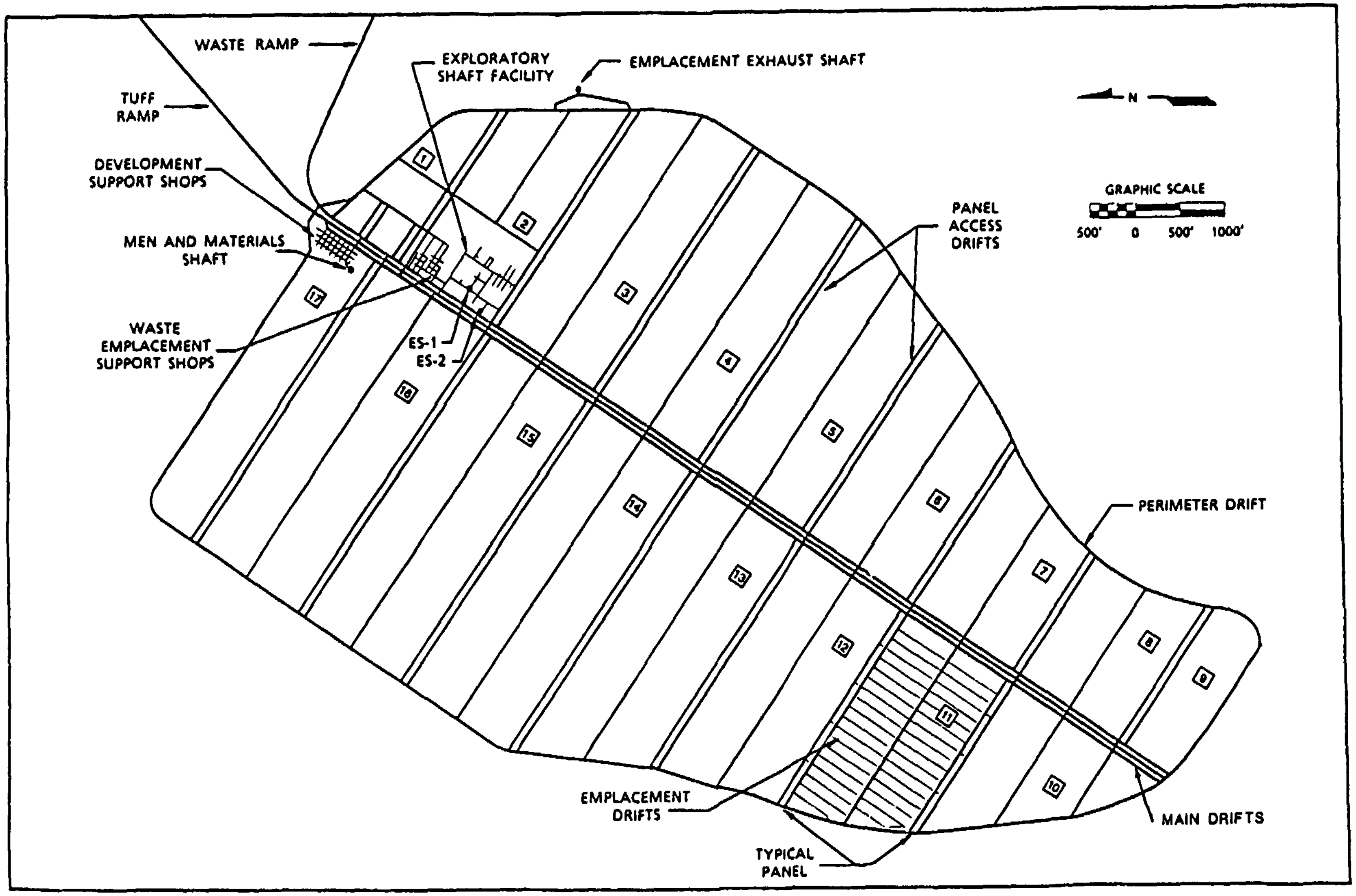


Figure 2-5. Underground Facility Layout, Vertical Emplacement (from Figure 3-20, SCP-CDR)

TABLE 2-4

MAJOR ELEMENTS OF THE UNDERGROUND FACILITY*

Element	Functions
Shafts and Ramps	
Waste Ramp	• Provides sole access for the waste transporter. • Serves as the ventilation intake for the waste emplacement areas.
Tuff Ramp	• Serves as the primary haulageway for excavated tuff. • Serves as the primary exhaust airway for the development area.
Men-and-Materials Shaft	• Provides transportation for personnel and materials. • Serves as the main utilities route. • Serves as the ventilation intake for the development area.
Emplacement Area Exhaust Shaft	• Carries exhaust air from the waste emplacement area.
Exploratory Shaft 1 (ES-1)	• Serves as the primary intake of ventilation air for the waste emplacement area.
Exploratory Shaft 2 (ES-2)	• Serves as the secondary intake of ventilation air for the waste emplacement area.
Access Mains	
Waste Main	• Connects waste ramp with access drifts. • Serves as sole access to the panels for the waste transporter. • Serves as ventilation intake for the waste emplacement area.
Tuff Main	• Serves as the main haulageway for excavated tuff. • Carries exhaust air from the development area.
Service Main	• Provides access from the men-and-materials shaft to the development area for personnel, supplies, and machinery. • Carries ventilation air to the development area.

TABLE 2-4

MAJOR ELEMENTS OF THE UNDERGROUND FACILITY
(concluded)

Element	Functions
Drifts	
Panel Access Drifts	• Provide access to the emplacement drifts.
Emplacement Drifts	• Contain emplacement boreholes.
Perimeter Drift	• Serves as an exhaust airway from the waste emplacement area to the waste emplacement area exhaust shaft.
Other Facilities	
Shops	
Development Area	• Supports development operations.
Waste Emplacement Area	• Supports waste emplacement operations.
Training Area	• Provides space in the waste emplacement area for training of personnel who perform emplacement and retrieval operations.
Performance Confirmation Area	• Consists of one or more areas that are highly instrumented and monitored to collect data for the performance confirmation program.
Exploratory Shaft Facility	• Is an area designated for obtaining data on site characteristics, mining, opening stability, and other information important to the design and to predicting repository performance.

*From Table 3-11, SCP-CDR.

underground facility, which are similar for the vertical and horizontal emplacement configurations, are shown in Figures 2-5 and 2-6 and are listed in Table 2-4. The shape and size of the major openings are shown in Figure 2-7.

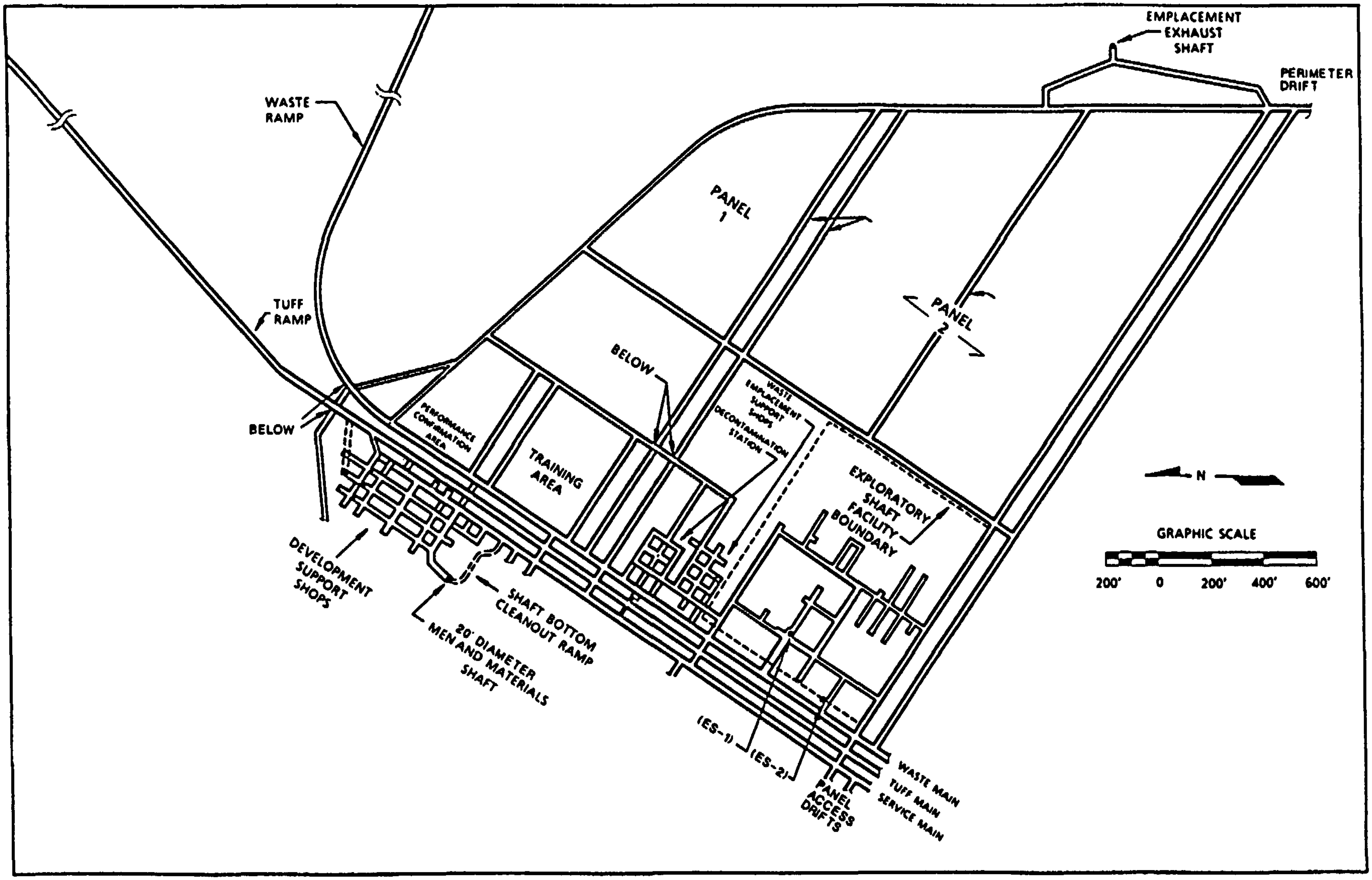


Figure 2-6. Exploratory Shaft Facility and Support Facilities, Vertical Emplacement (from Figure 4-34, SCP-CDR)

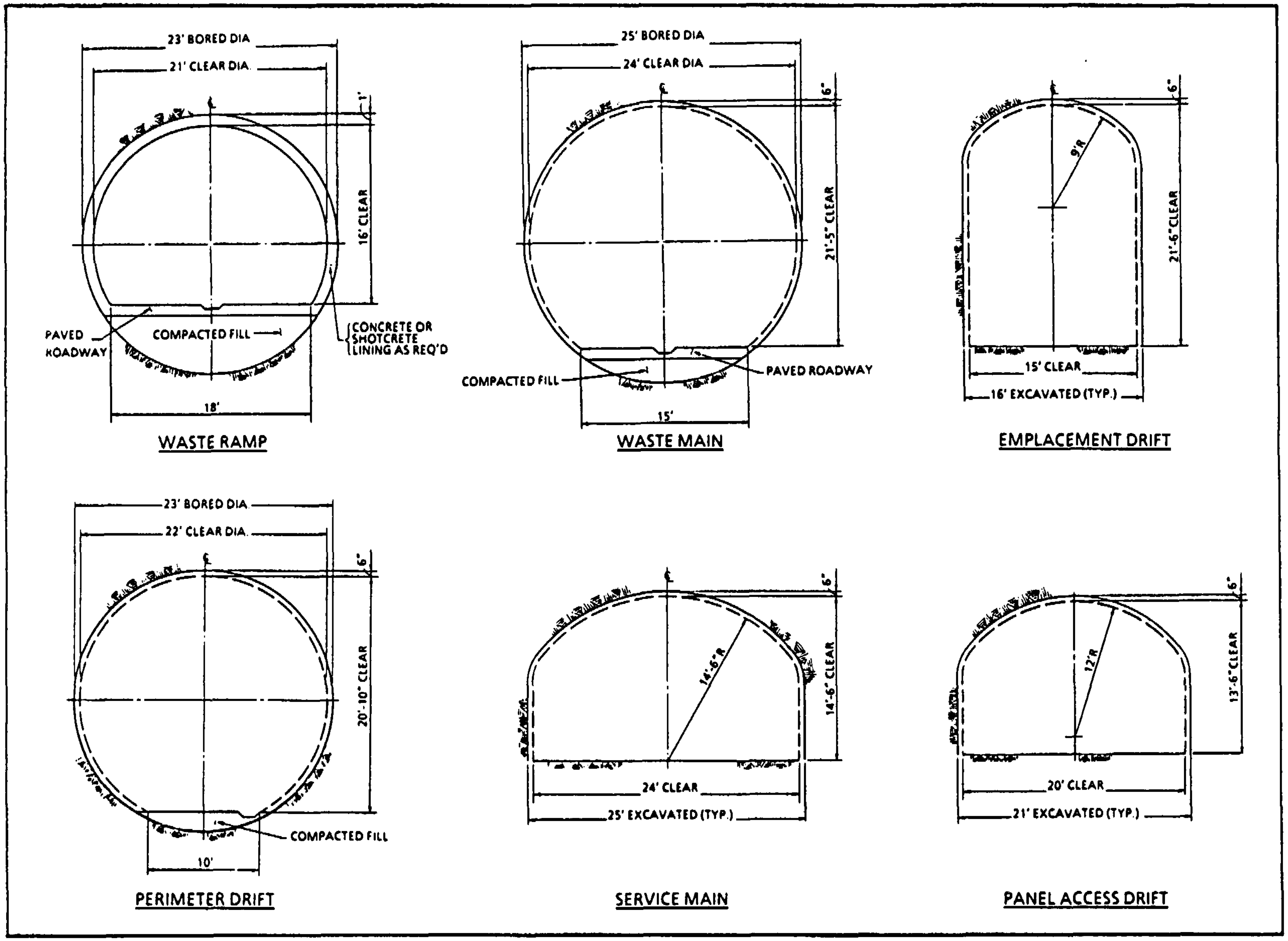


Figure 2-7. Drift and Ramp Cross Sections--Vertical Emplacement (from Figure 4-31, SCP-CDR)

Alternate Emplacement Case (Horizontal)

The overall underground facility layouts for the horizontal emplacement configuration is shown in Figure 2-8. The overall layout of the horizontal and vertical emplacement configurations is the same, although there are some differences in the emplacement panels. The shape and size of the major openings are shown in Figure 2-9.

2.2.2.3 Ground Support

Ground Support Options

Numerous ground support systems currently used in mining and civil tunneling projects are well suited for use in the repository. Tunneling experience applicable to welded tuff includes work conducted in the G-Tunnel complex at the Nevada Test Site (NTS) and in the Rivers Mountain Tunnel in Nevada (Sperry, 1969). The range of expected conditions for repository construction is well within the limits of historical experience. The following ground support options are some of those available for use at the repository:

- friction bolts (Swellex, split set);
- chain-link fence materials;
- welded wire mesh;
- point-anchor bolts;
- cement-grouted dowels (pre-, post-, and untensioned);
- cement-grouted cable anchors;
- shotcrete with steel fiber and/or accelerators;
- structural steel sets;
- yieldable steel arches;
- prefabricated, segmented linings; and
- cast-in-place concrete lining.

Ground Support Recommendations

For the purposes of the conceptual design, a rock-mass classification system has been proposed in which five ground support categories

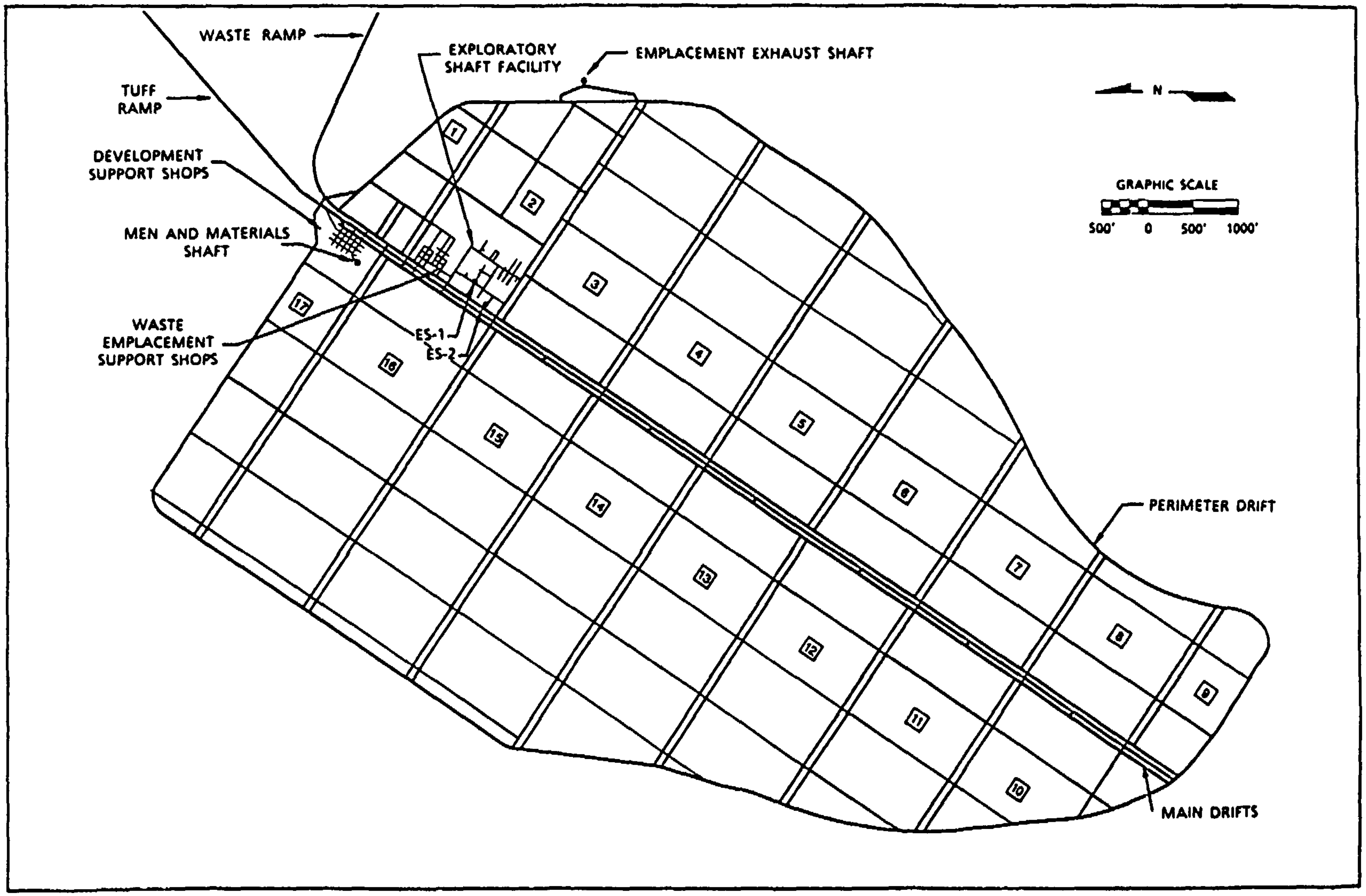


Figure 2-8. General Underground Facility Layout, Commingled Waste, Horizontal Emplacement (from Figure 4-30, SCP-CDR)

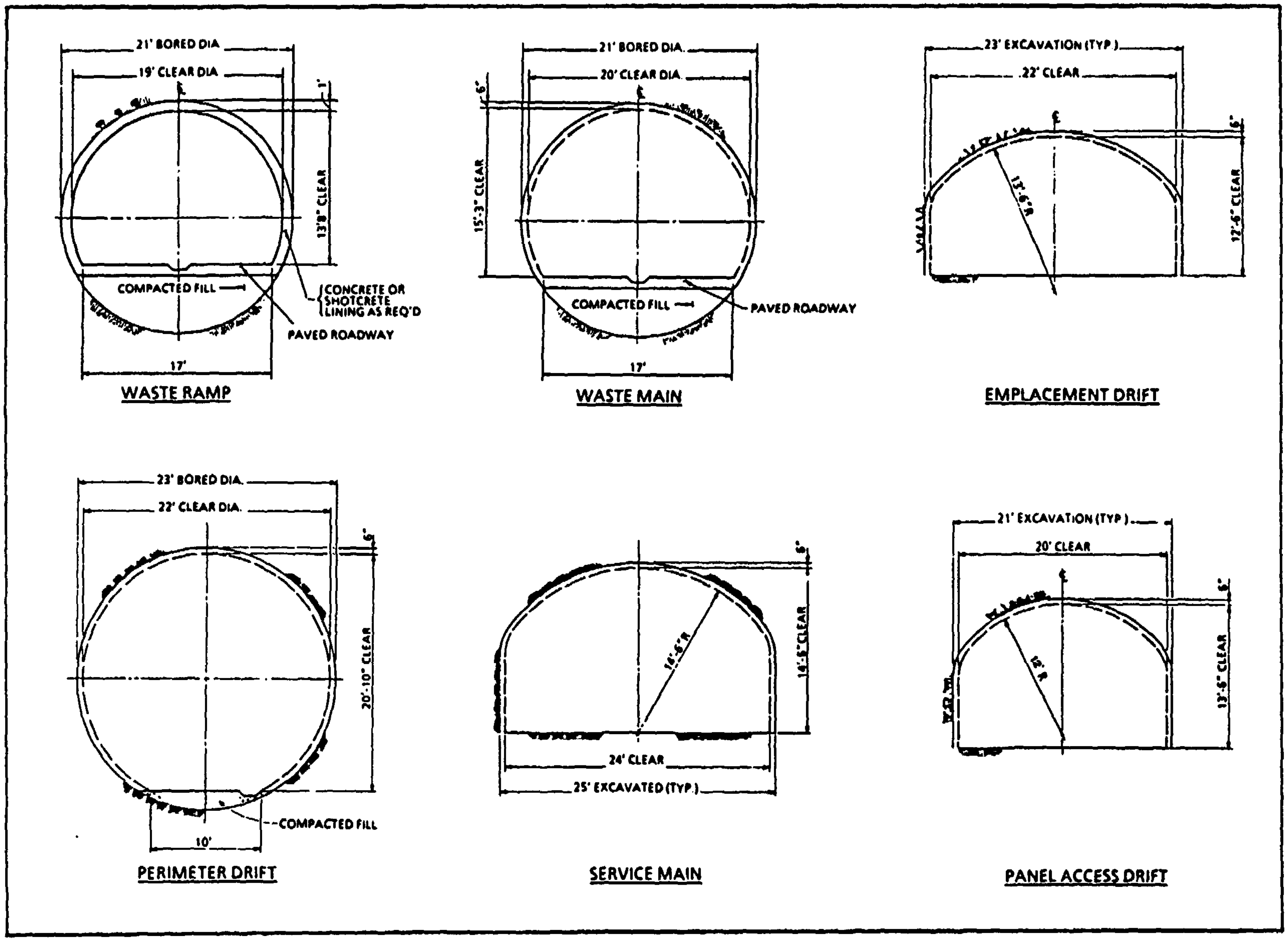


Figure 2-9. Drift and Ramp Cross Sections, Horizontal Emplacement (from Figure 4-32, SCP-CDR)

are defined for Yucca Mountain. The range of conditions spanned by the five assumed categories encompasses the full range of conditions reported by Langkopf and Gnirk (1986), Dravo Engineers, Inc. (1984), and Johnstone et al. (1984) in studies involving empirical rock-mass classifications of the Yucca Mountain tuffs.

Table 2-5 describes the five ground support categories in general geologic terms and presents a summary of the proposed ground support measures for each category. Figure 2-10 shows a typical section of the ground support systems for categories A through D for both bored and conventionally mined drifts. Observations and measurements made during excavation will ascertain the ground support needed at any given location in accordance with predetermined standards.

Ground Support Installation

Most of the underground area is expected to require ground support categories A through D. The design will be expected to accommodate these categories on a routine basis. The substantial ground support installation for Class E is expected to be needed only infrequently and should have only a slight impact on the rate of underground development.

Ground support will be installed very quickly after the ground has been opened up and before the next segment of drift is drilled and blasted so that the miners do not have to work under unsupported ground.

2.2.2.4 Description of Emplacement Panels

This section describes the waste emplacement panel designs for both the vertical and horizontal emplacement configurations. Typical panels for the vertical and horizontal configurations are shown in Figures 2-11 and 2-12, respectively. The panels in these two drawings have the following characteristics in common.

TABLE 2-5

GROUND SUPPORT RECOMMENDATIONS[a]

Ground Support Category	NGI[b] Ground Description	General Ground Condition Applicable to Yucca Mountain	Ground Support System Recommended for Conceptual Design
A	Very Good	Massive, welded tuff; little or no jointing; dry or slightly damp.	Untensioned, friction-type bolts on variable spacing as needed; typical grid spacing of 6.5 to 10 ft.
B	Good	Densely welded tuff with one to three joint sets; joints are tight with no alteration.	Untensioned grouted dowels on a 5- to 6.5-ft grid spacing with wire mesh or chain-link fabric on ribs and crown.
C	Fair	Densely welded tuff with multiple or random joint sets; little or no joint alteration.	Untensioned grouted dowels on a 5- to 6.5-ft spacing with welded wire mesh and 2 to 3 in. of shotcrete.
D	Poor	Heavily jointed, welded tuff; typical of conditions at transition within flow units.	Initial support; friction bolts on a 5-ft spacing with 2- to 3-in. fiber-reinforced shotcrete; final support: welded wire mesh, grouted dowels with 3 in. of additional shotcrete.
E	Very Poor	Fault zone; crushed tuff in a matrix of low-strength gouge; heavy alteration and possibly minor water.	Light steel ribs or lattice girders placed near face; fiber-reinforced shotcrete 3 to 4 in. followed by welded wire mesh, grouted dowels, and 2 in. of shotcrete.

[a]From Table 3-13, SCP-CDR.
[b]Norwegian Geotechnical Institute (Barton et al., 1974).

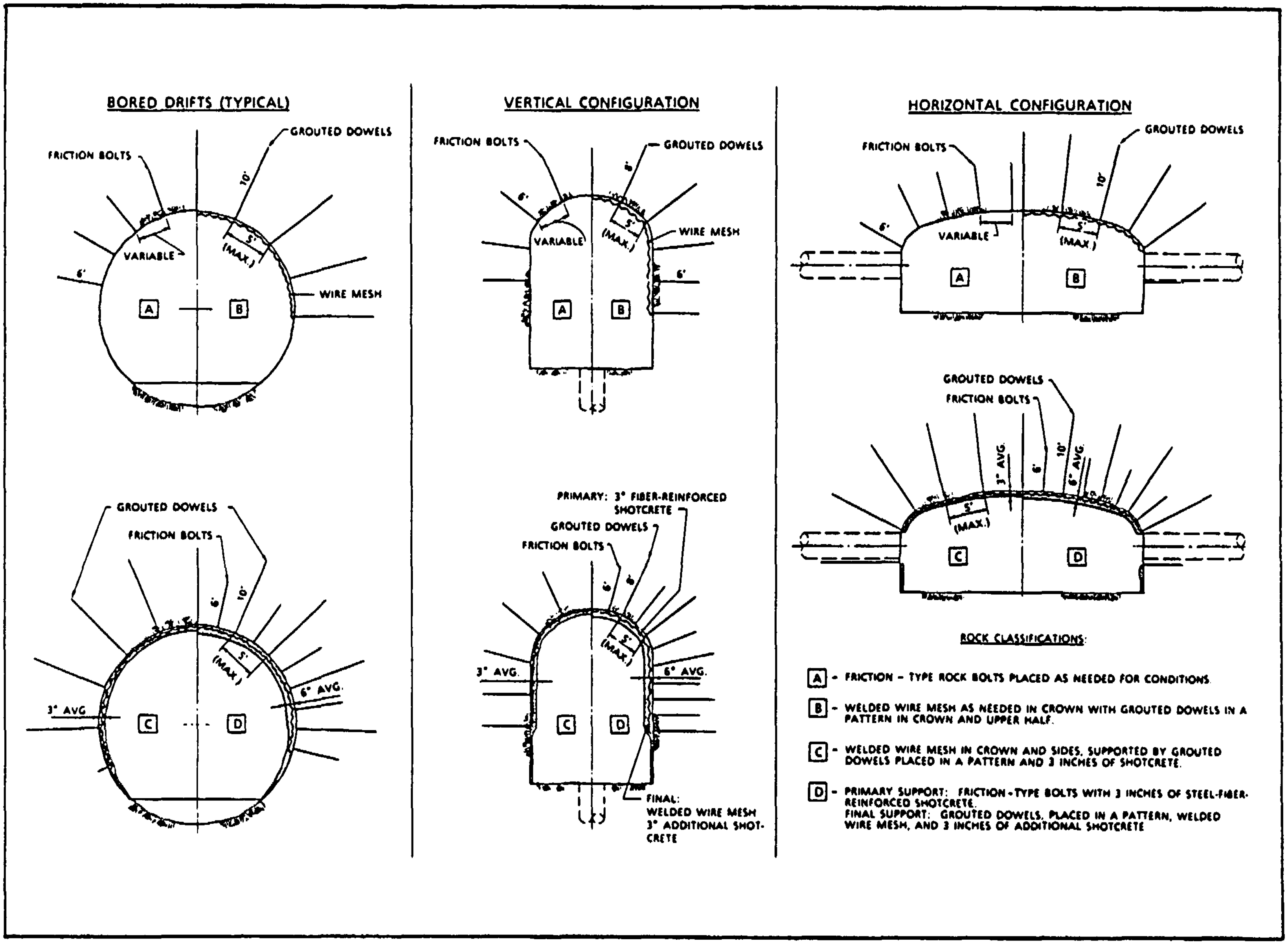


Figure 2-10. Ground Support Cross Sections (from Figure 3-25, SCP-CDR)

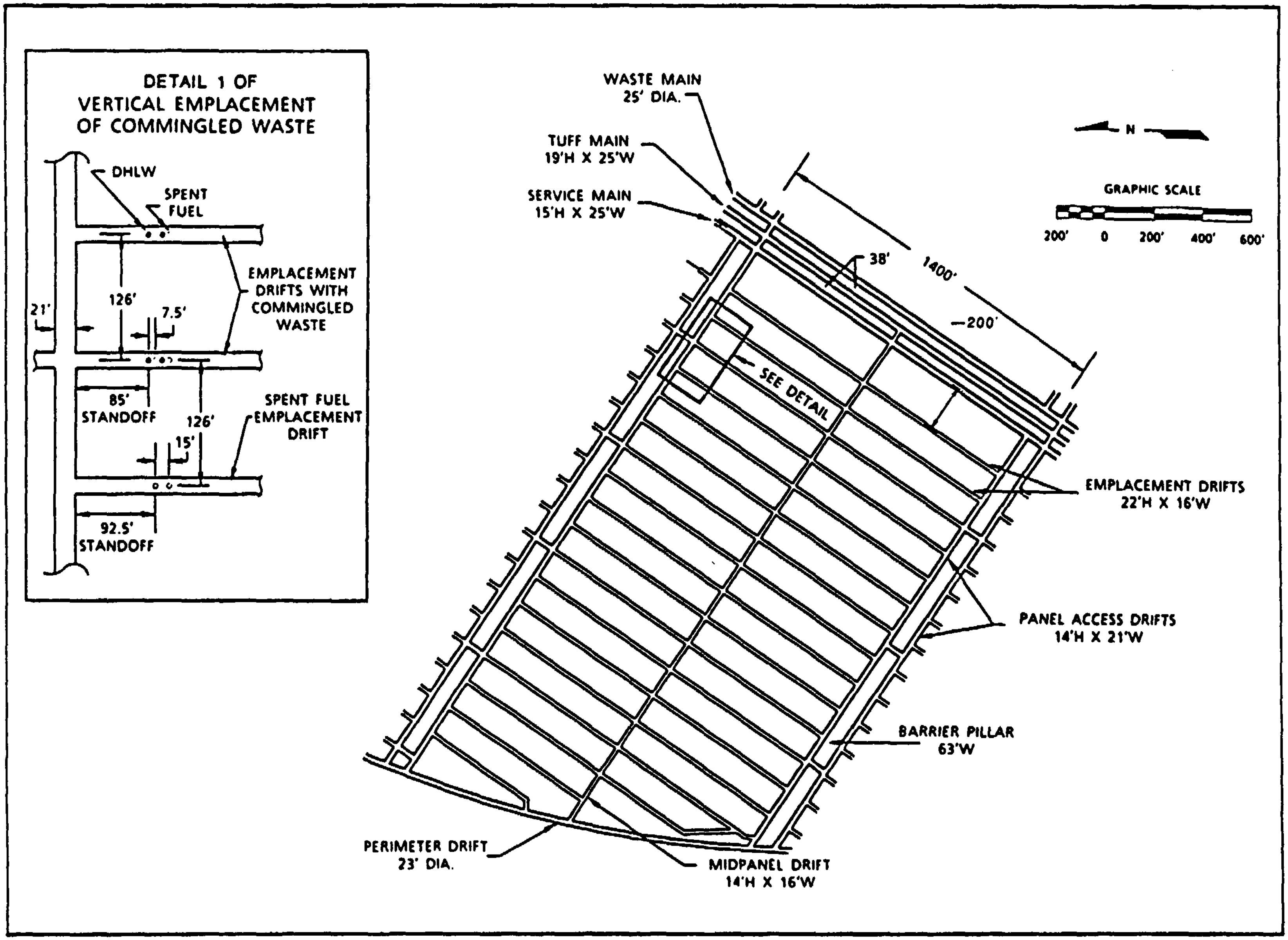


Figure 2-11. Panel Layout, Commingled Waste, Vertical Emplacement (from Figure 4-37, SCP-CDR)

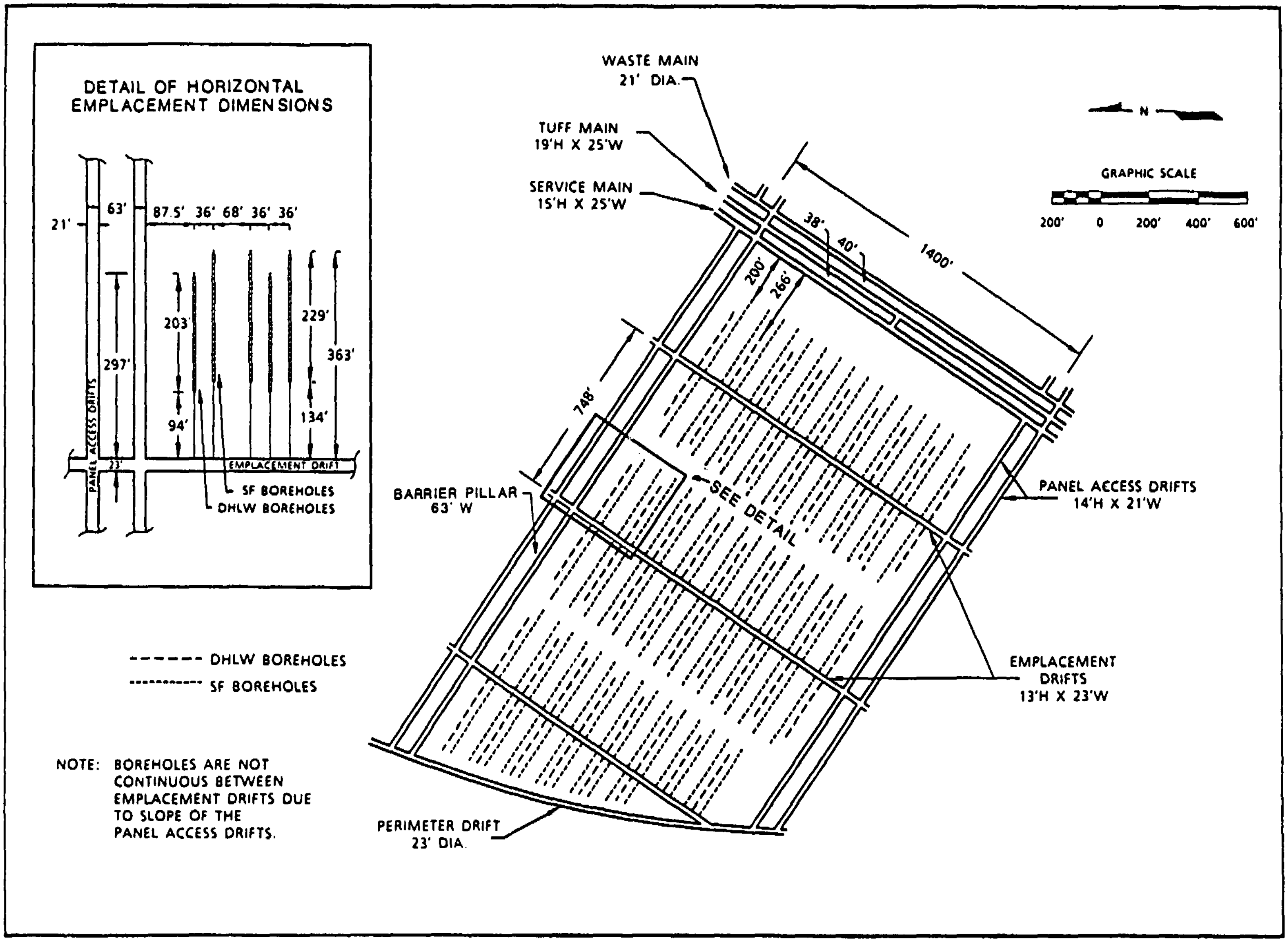


Figure 2-12. Panel Layout, Commingled Waste, Horizontal Emplacement (from Figure 4-38, SCP-CDR)

- The panels are identical in size. A panel width of 1,400 ft was selected based on reasonable haulage distances for tuff removal. Also, this panel width is compatible with development and emplacement schedules. Optimum panel widths for the two different configurations may vary slightly in future designs.

- Each configuration has dual sets of panel access drifts that extend the length of the panel to intersect the perimeter drift. Two panel access drifts are required to maintain separate ventilation systems between development and emplacement operations.

- The number of waste containers emplaced in the panels is essentially the same in both configurations. Only slight variations in the number of containers result from emplacement in the irregular areas at the perimeter drift.

- The standoff distance from the mains to the closest waste container in the panel is approximately 200 ft.

Design of drift spacing is based on thermal considerations described in Section 3.2.2.

Panel Layout for Vertical Emplacement

The emplacement panel in the vertical configuration (Figures 2-11 and 2-13) consists of a series of equally spaced emplacement drifts that run perpendicular to the panel access drifts and parallel to the mains. A midpanel drift, which runs parallel to the panel access drift, divides the panel into two 700-ft segments. The midpanel drift is used for ventilation control.

The dimensions of the various drifts that make up the vertical emplacement panel are shown in Figure 2-7. The opening of the panel access drift is controlled by the size of the mining equipment, the opening of the emplacement drift by the size of the waste transporter, and the size of the midpanel drift by ventilation flow requirements.

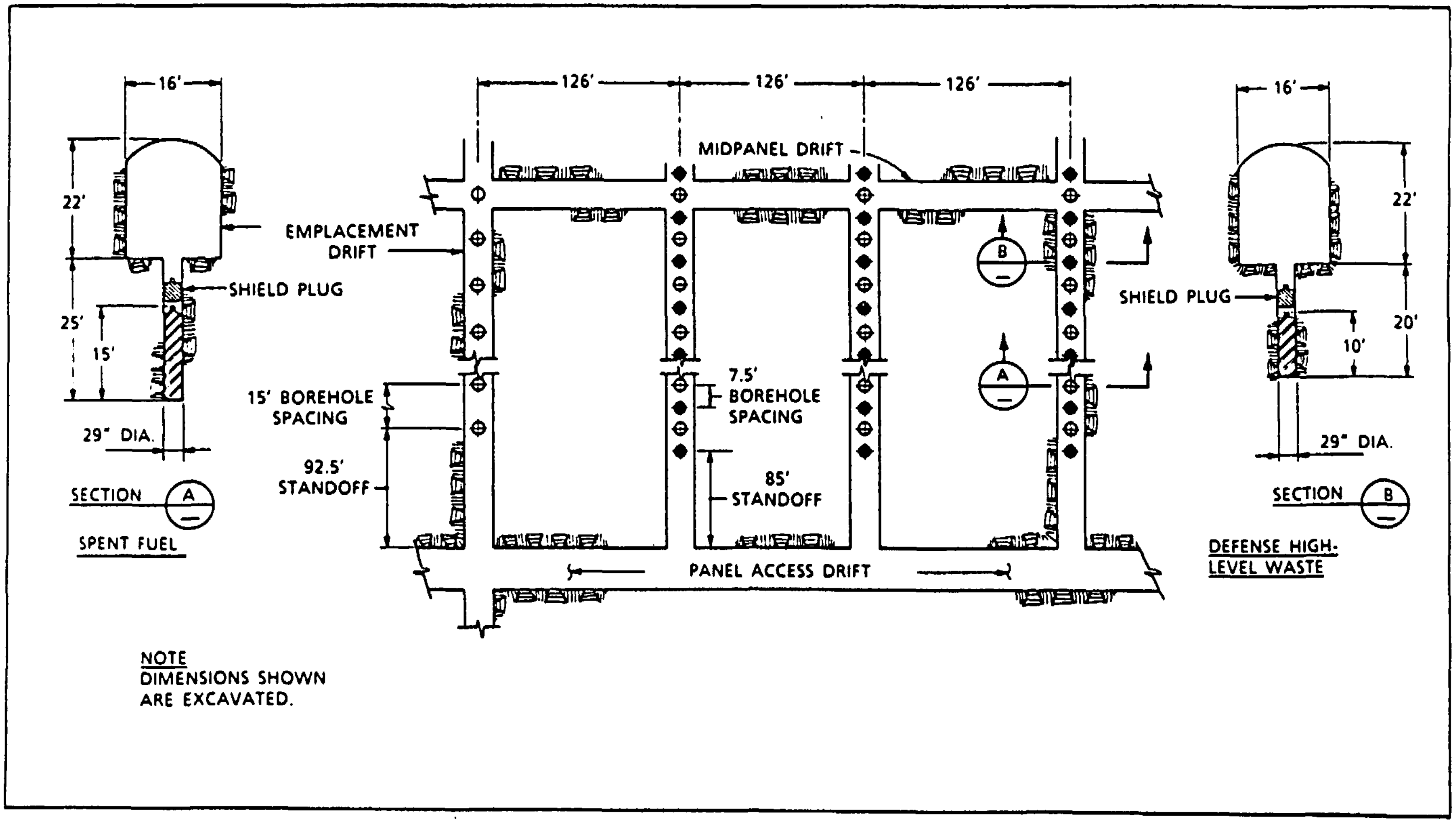


Figure 2-13. Panel Details for Commingled Waste, Vertical Emplacement (from Figure 4-34, SCP-CDR)

The layouts shown in Figures 2-11 and 2-13 were selected for the conceptual design. Each full-length drift in which waste is commingled has storage space for 75 spent fuel and 76 DHLW containers. The minimum spacing between spent fuel and DHLW boreholes is 7.5 ft. The end sections of the emplacement drifts adjacent to the panel access drift are left free of boreholes to allow for (1) transporter entry, (2) an air door, and (3) a zone in which drift height adjusts from 14 ft (in the panel access drift) to 22 ft (in the emplacement drift) (Figure 2-14). The reference value of the standoff distance between the first emplacement borehole and the access drift is 85 ft. As shown in Figure 2-14, the distance between spent fuel and DHLW boreholes is 7.5 ft and the distance between spent fuel boreholes is 15 ft. Borehole spacing in the emplacement drift is controlled by the maximum allowable temperature of the borehole wall, the strength and stability of the drift floor between adjacent boreholes, and equipment considerations. Spent fuel boreholes are 25 ft deep and DHLW boreholes are 20 ft deep so that a distance of 10 ft between the waste container and the drift floor can be provided to maintain adequate radiation shielding and thermal insulation.

The design receipt rate for DHLW and spent fuel containers dictates that commingling occur in three of every four emplacement drifts. The fourth drift can be used for additional containers, if necessary, because the spacing of spent fuel boreholes (15 ft) allows room for an additional borehole in between. Cooler DHLW containers are located at the ends of each drift in which both types of containers are emplaced. The spacing between emplacement drift centerlines is 126 ft.

<u>Panel Layout for Horizontal Emplacement</u>

The horizontal emplacement panel is made up of a series of widely spaced emplacement drifts into which 37-in.-diameter horizontal boreholes are drilled. Figure 2-12 shows a typical panel in the horizontal emplacement configuration.

Cross sections of the panel access drift and the emplacement drift are shown in Figure 2-9. The opening size of the panel access drift is

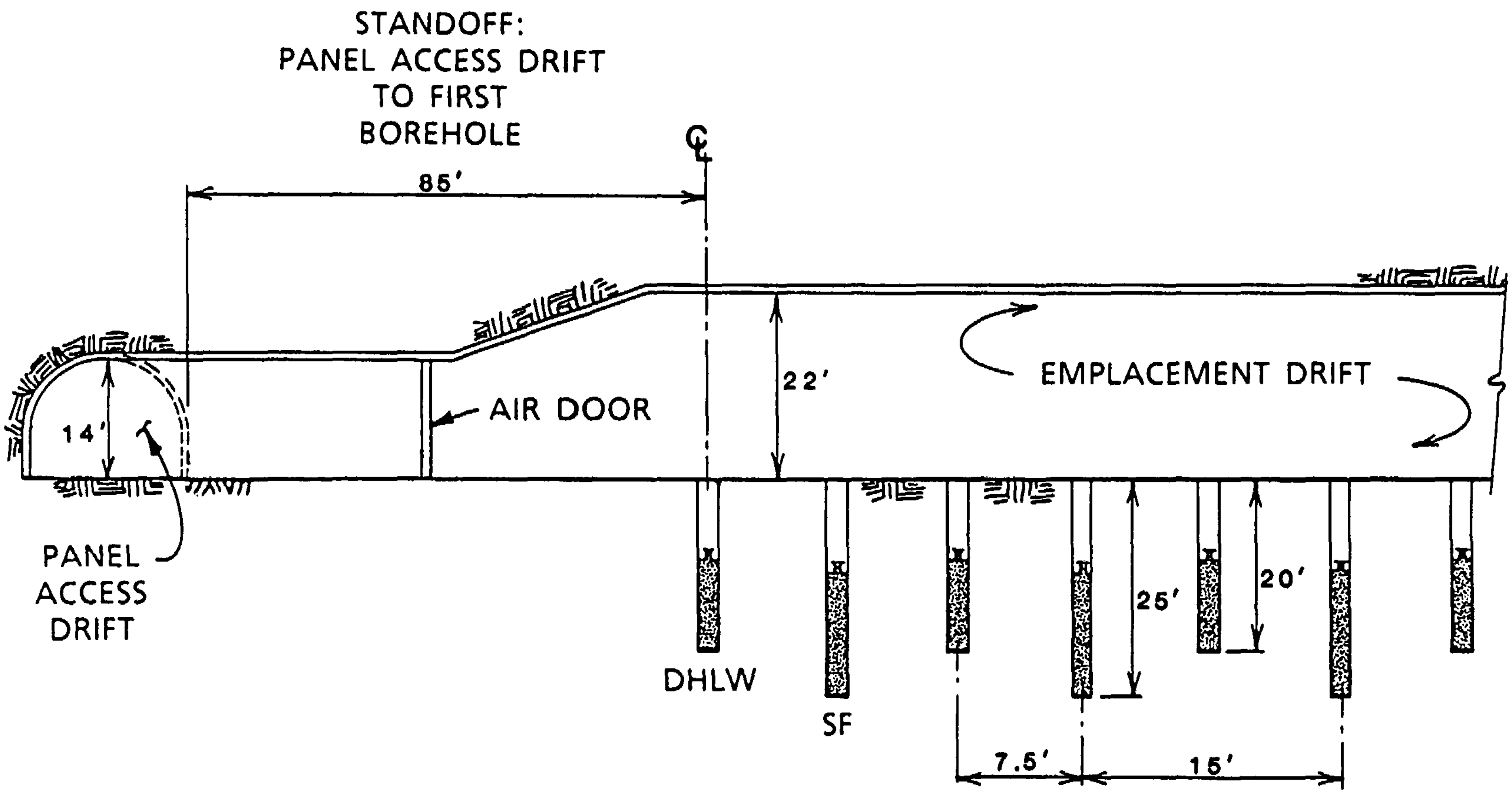


Figure 2-14. Side View of Standoff in a Vertical Emplacement Drift in Which Waste is Commingled (from Figure 4-40, SCP-CDR)

controlled by the size of the mining equipment, and the opening size of the emplacement drift is controlled by the dimensions of the transporter.

DHLW containers are commingled with spent fuel containers by placing 18 DHLW packages in boreholes between the spent fuel boreholes, in the pattern shown in Figure 2-15. The horizontal borehole for spent fuel used for the conceptual design holds 14 waste containers and is 363 ft long with a 134-ft standoff between the waste and the emplacement drift. The number of boreholes and containers per borehole is determined by the layout and the ratio of DHLW to spent fuel containers. The 68-ft spacing between adjacent spent fuel boreholes and the 36-ft spacing between spent fuel and DHLW boreholes is controlled by temperature constraints (Section 3.2.2) on the waste package and emplacement drift and borehole walls.

As shown in Figure 2-15, dummy containers are used in the SCP-CDR design to push the waste containers into the boreholes to create the necessary standoff. The standoff distances are controlled by the temperature constraints described in Section 3.2.2. To reduce costs, an effort will be made to eliminate the dummy containers in future designs.

The minimum allowable distance from the nearest spent fuel emplacement borehole to the panel access drift is determined by thermal analysis to be about 120 ft. A borehole containing cooler DHLW packages is placed nearest the access drift, permitting a standoff distance of 87.5 ft (Figure 2-15).

2.2.2.5 Vertical Emplacement Borehole and Borehole Hardware

A cross section of the vertical emplacement borehole for spent fuel is shown on Figure 2-16. The borehole has a 29-in. diameter and is drilled to a depth of 25 ft. The upper 6-ft section of the borehole is counterbored to a diameter of 34 in. to accommodate the beveled ring on the partial borehole liner.

The vertical borehole hardware consists of the borehole liner, the support plate, the shield plug, and the cover (Figure 2-16). The tubular-steel borehole liner extends approximately 12 ft into the 25-ft

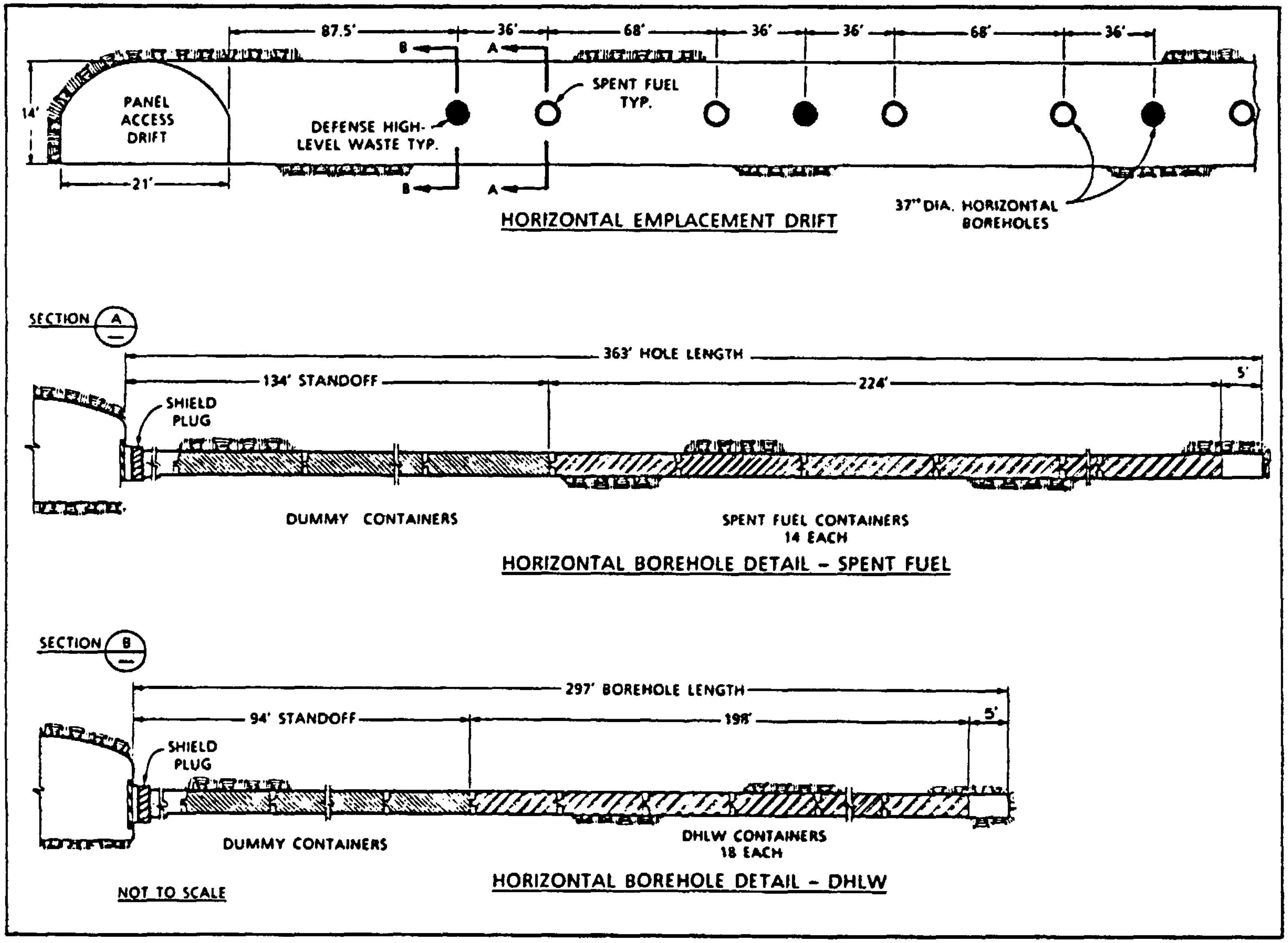


Figure 2-15. Panel Details for Commingled Waste, Horizontal Emplacement (from Figure 4-41, SCP-CDR)

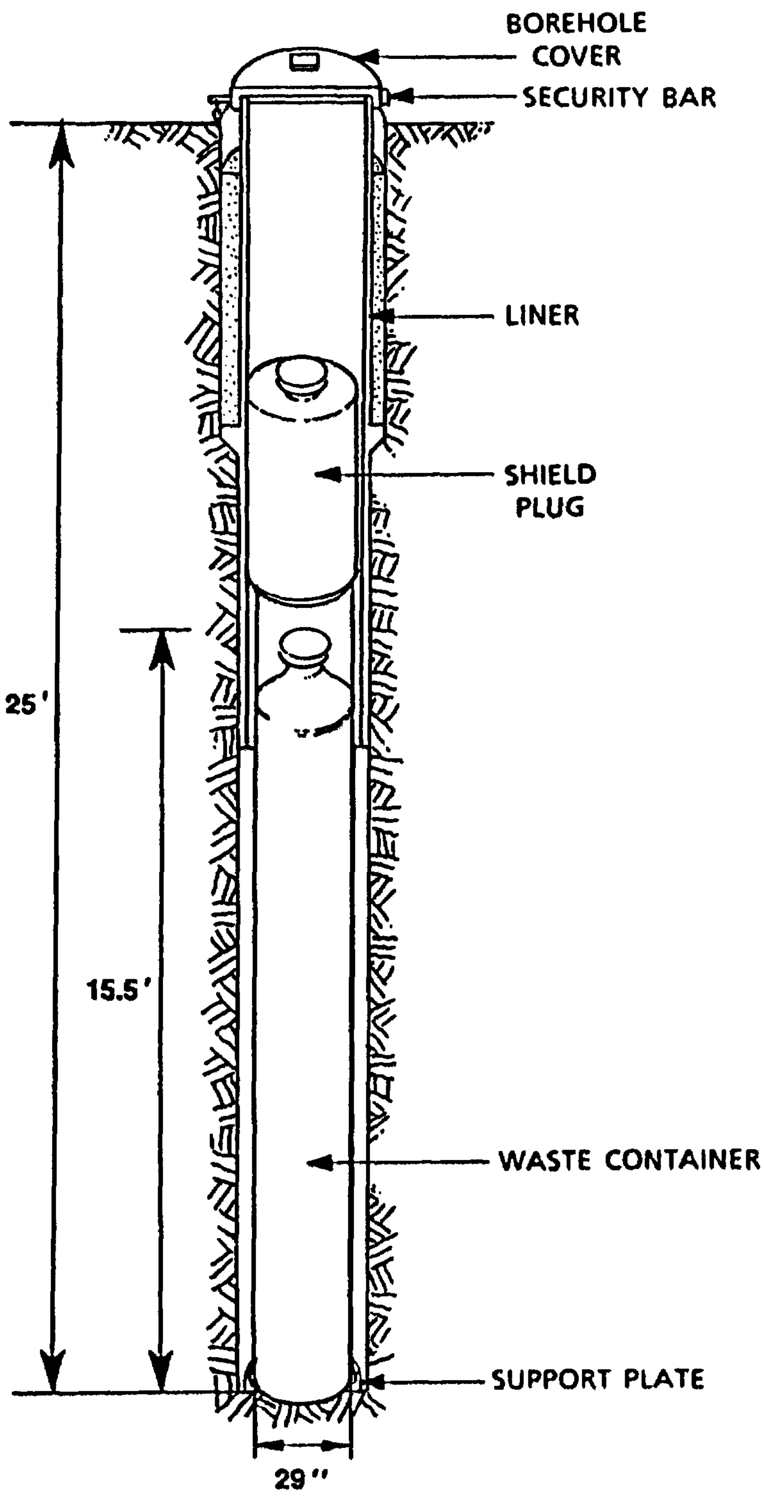


Figure 2-16. Design Configuration for Vertical Emplacement (from Figure D-3, Appendix D, SCP-CDR)

borehole to encompass the pintle and upper portion of the waste container. It provides structural stability for the upper borehole, protection for the mouth of the borehole, assistance in positioning emplacement and retrieval equipment, and a means for securing the borehole cover.

The support plate is placed at the bottom of the borehole. It centers the bottom of the waste container in the borehole, isolates the base of the waste container from the bottom of the borehole, and eliminates points of high stress by supporting the weight of the waste container evenly. Holes in the support plate permit drainage of moisture that might accumulate.

The shield plug will provide radiation shielding between the emplaced waste and workers in the repository. Material selection for the shield plug has not been completed; it is anticipated that a dense material (e.g., steel) will be needed for gamma photon shielding and a hydrogenated material (e.g., concrete) for neutron shielding.

A pintle, dimensionally identical to the pintle on the waste container, is located on the top of the plug so that a common grapple design can be used for both the waste package and plug. The borehole cover secures and identifies the borehole.

2.2.2.6 Horizontal Emplacement Borehole and Borehole Hardware

The horizontal borehole is illustrated in Figure 2-17. The borehole will be drilled horizontally to a constant 37-in. diameter, then counterbored near the borehole mouth to 46 in. to accommodate the larger-diameter entry liner. Techniques for drilling and lining the borehole have been investigated (The Robbins Company, 1984 and 1985; Friant and Dowden, 1987; Kenny Construction Company, 1987).

The borehole hardware includes the borehole liner, the shield plug, and the cover. The borehole liner extends the entire length of borehole and will keep pieces of rock from falling on the waste package and will provide support and guidance for the waste container and dolly.

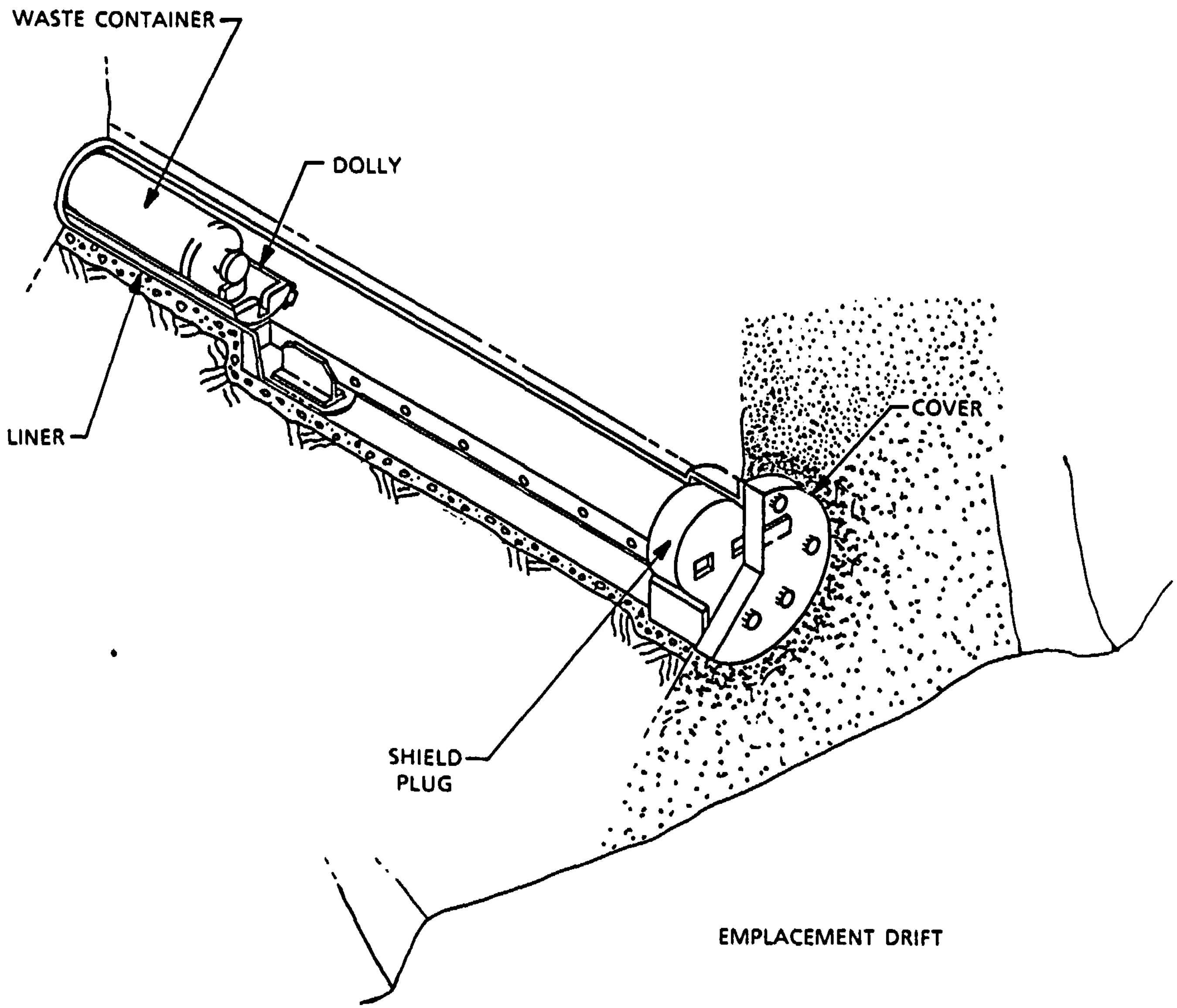


Figure 2-17. Design Configuration for Horizontal Emplacement (from Figure D-14, Appendix D, SCP-CDR)

The shield plug has attachment holes located on the front for installation and removal and is sized and keyhole-shaped to fit in the front of the entry liner. Material selection for the shield plug has not been completed; materials under consideration include those being considered for the vertical borehole plug.

After the shield plug is in place, a steel cover plate is bolted to the flange on the front of the entry liner to seal, secure, and identify the filled borehole.

2.2.3 Vertical Waste Transportation and Emplacement Equipment

The major equipment required for vertical waste emplacement includes the waste transporter, the modified forklift, the borehole shielding closure, and the shield plug installer/remover.

2.2.3.1 Waste Transporter

The transporter (Figures 2-18 and 2-19) is approximately 25 ft long, 10 ft wide, and 8 ft high and weighs approximately 120,000 lb. It has sufficient ground clearance to move over previously emplaced waste containers in covered boreholes. Either diesel or electric power will be used to drive the transporter.

The transporter has three main parts: the transporter cab, the running gear, and the cask.

Transporter Cab

The cab is partially sealed so that the pressure inside the cab is always greater than the pressure outside the cab. The inlet air is temperature-conditioned, filtered, and monitored by a continuous air monitor. The cab is designed to limit the radiologic dose for the operator to less than one-fifth the allowable dose of 5 rem/yr (NRC, 1986).

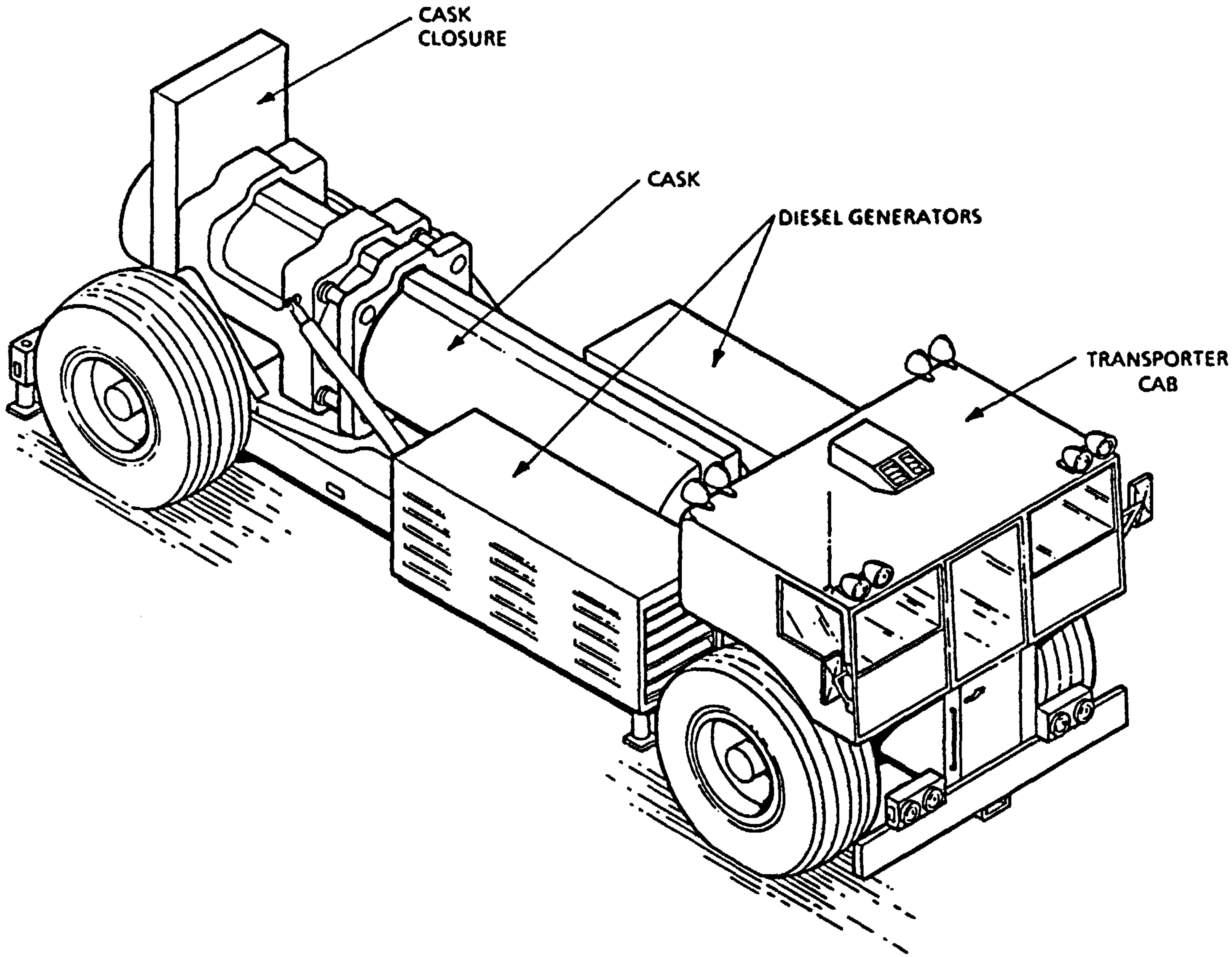


Figure 2-18. Waste Transporter in Transport Mode (Vertical Emplacement) (from Figure 4-46, SCP-CDR)

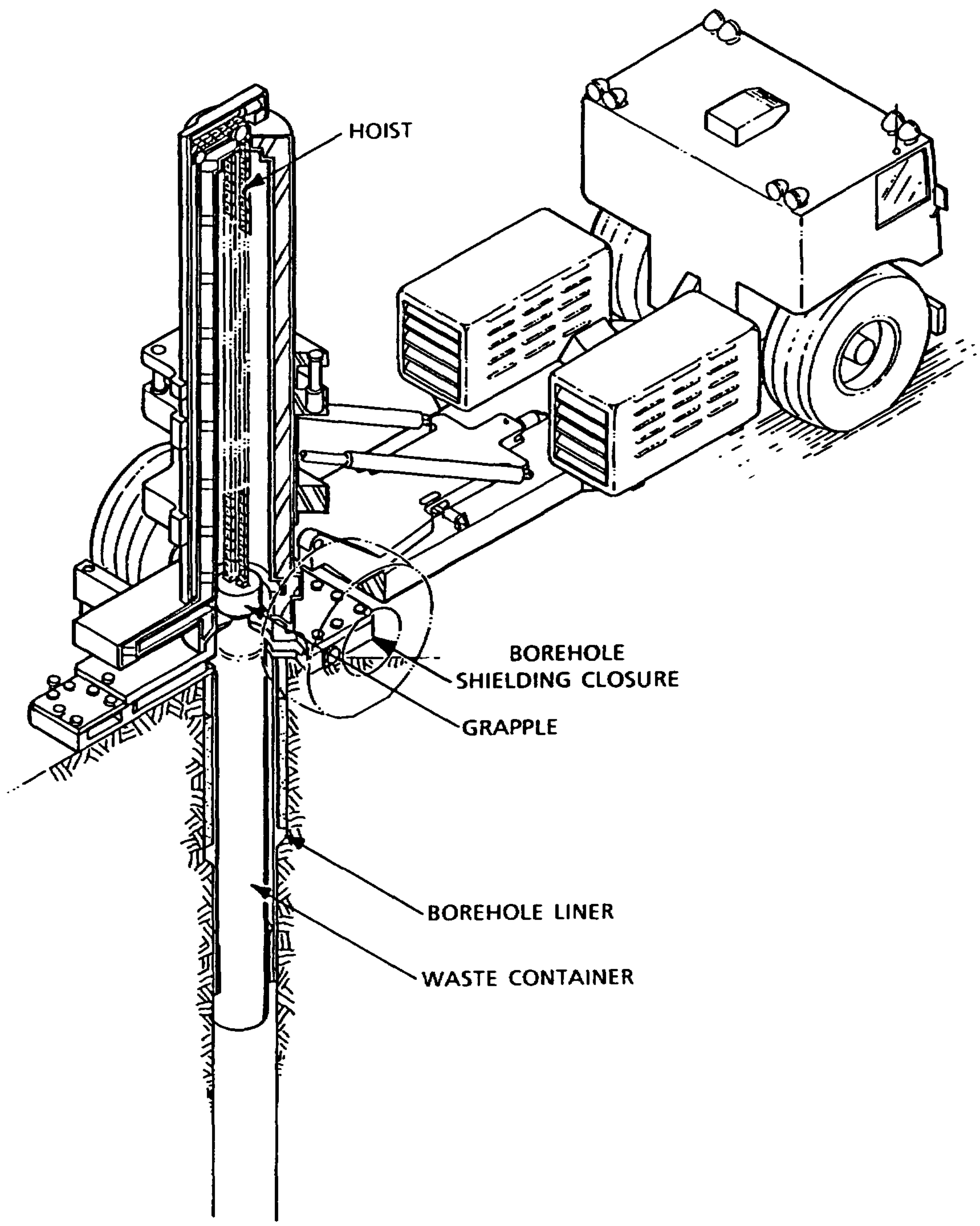


Figure 2-19. Waste Transporter in Emplacement Mode (Vertical Emplacement) (from Figure D-9, Appendix D, SCP-CDR)

The transporter cab (Figure 2-18) is designed to accommodate two occupants. The cab contains separate controls for the driving and the following emplacement equipment: the cask-positioning system, cask hoist, cask closure, and borehole shielding closure. The cab is also equipped with a radio communications system that enables the operator to maintain contact with other vehicles and various control stations in the repository.

Running Gear

The running gear is a rigid-framed, four-wheeled design with electric hub-mounted DC motors, powered by two diesel generators. The vehicle uses the front wheels for driving and steering and is designed to have a minimum 25-ft turning radius.

Cask

The cask (Figure 2-20) consists of a structural shell and radiologic shielding material, a waste container hoist, a waste package grapple, and a shielding closure. It is designed to accommodate the current 10,000-lb, 15-ft long, and 26-in. diameter waste package. The cask is approximately 18 ft long and 4 ft wide (O.D.). More details of the conceptual design of this equipment are contained in the SCP-CDR.

2.2.3.2 Modified Forklift

The modified forklift is used to transport, install, and tow various equipment used for waste emplacement and retrieval. The forklift (Figure 2-21) consists of a commercially available, extending-boom forklift modified for use in the repository. Modifications will include the addition of radiation shielding and a special fork that can be shifted laterally or rotated to align the temporary shielding equipment.

2.2.3.3 Borehole Shielding Closure

The borehole shielding closure (Figure 2-22) is designed to provide radiation shielding from an emplaced waste package during borehole closure

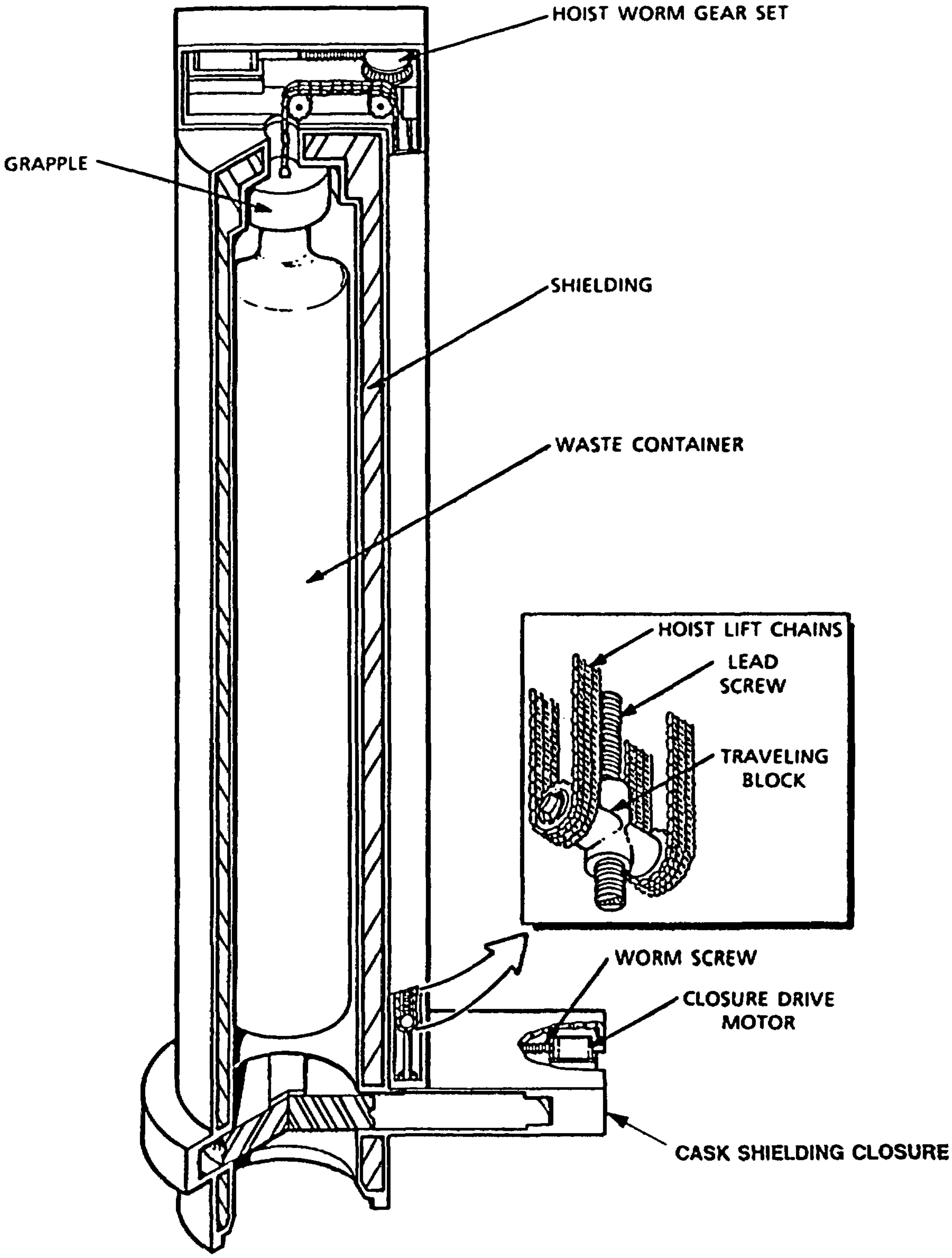


Figure 2-20. Transporter Cask (Vertical Emplacement) (from Figure D-9, Appendix D, SCP-CDR)

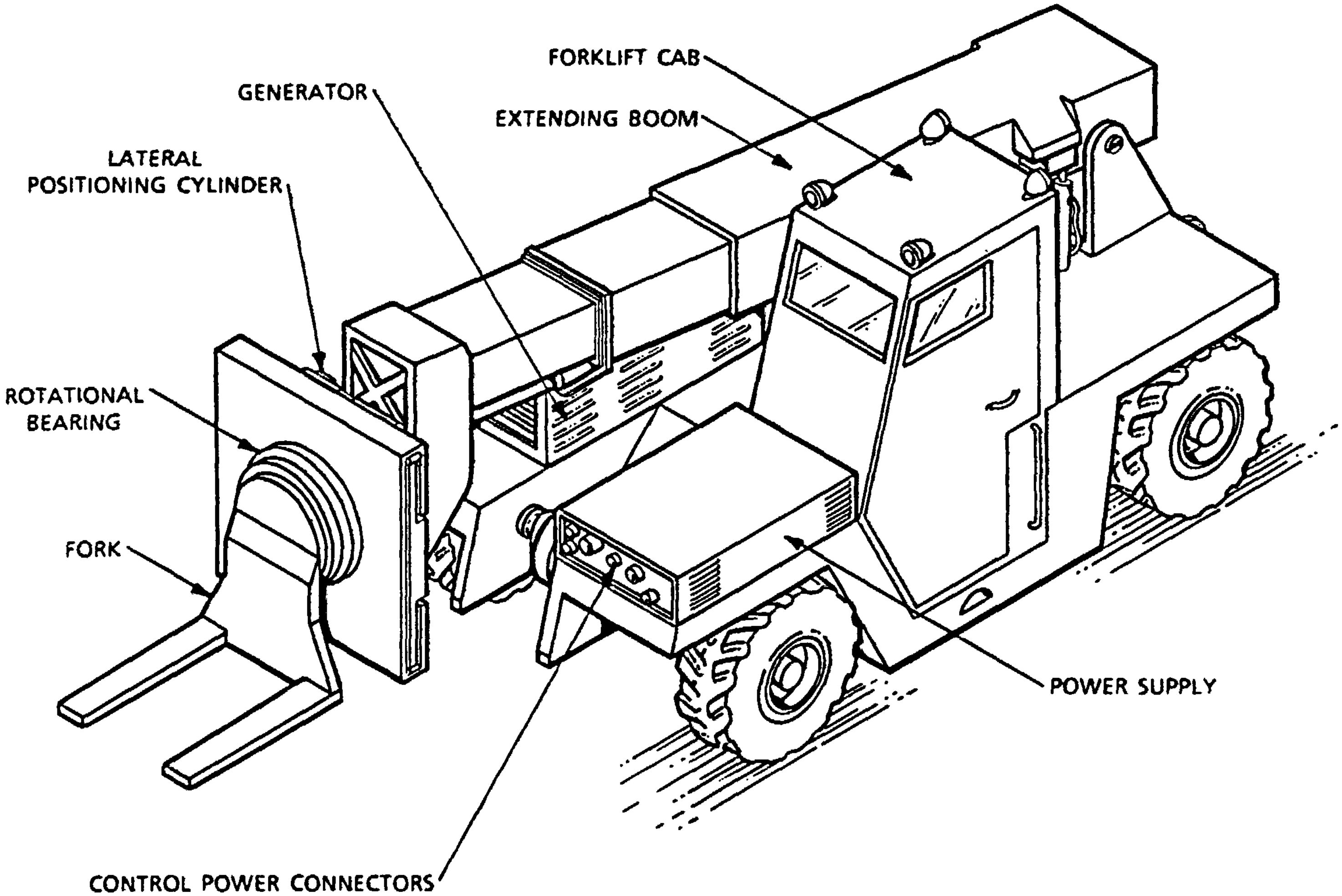


Figure 2-21. Modified Forklift (Vertical Emplacement) (from Figure D-11, Appendix D, SCP-CDR)

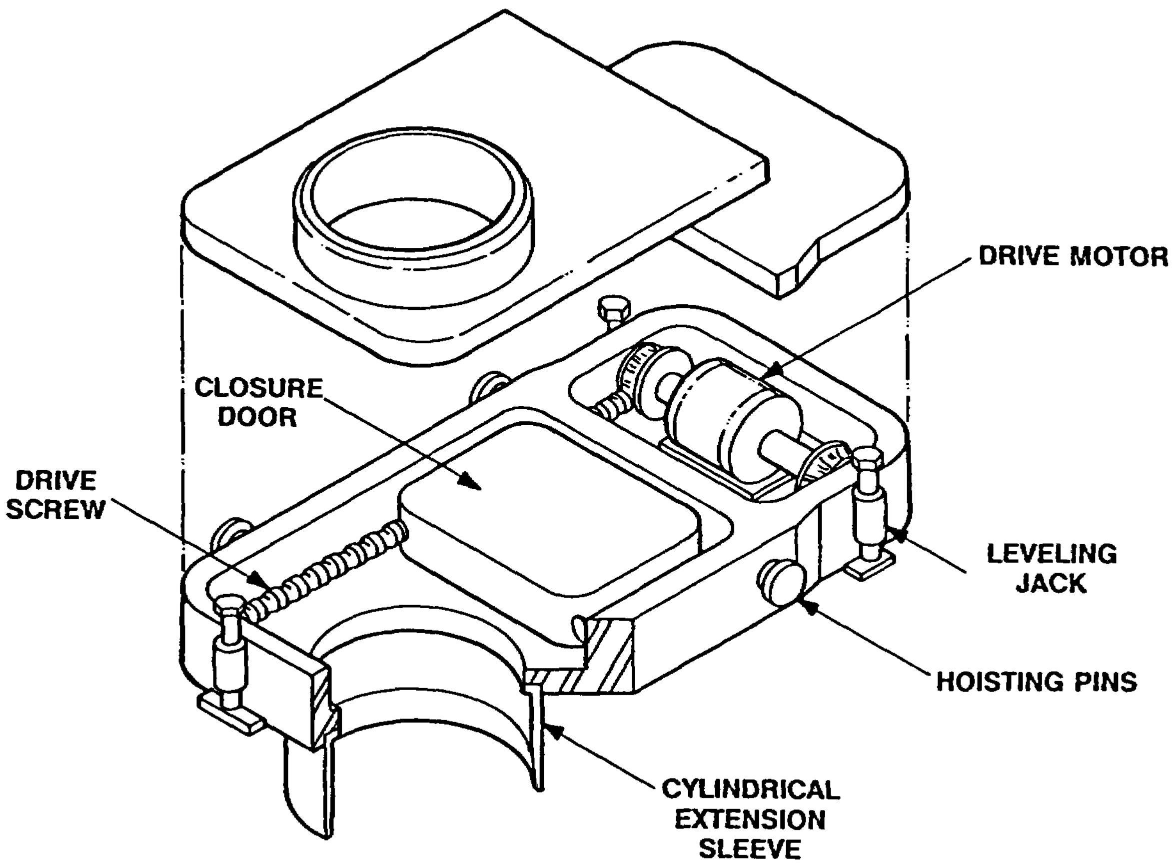


Figure 2-22. Vertical Borehole Shielding Closure (from Figure D-12, Appendix D, SCP-CDR)

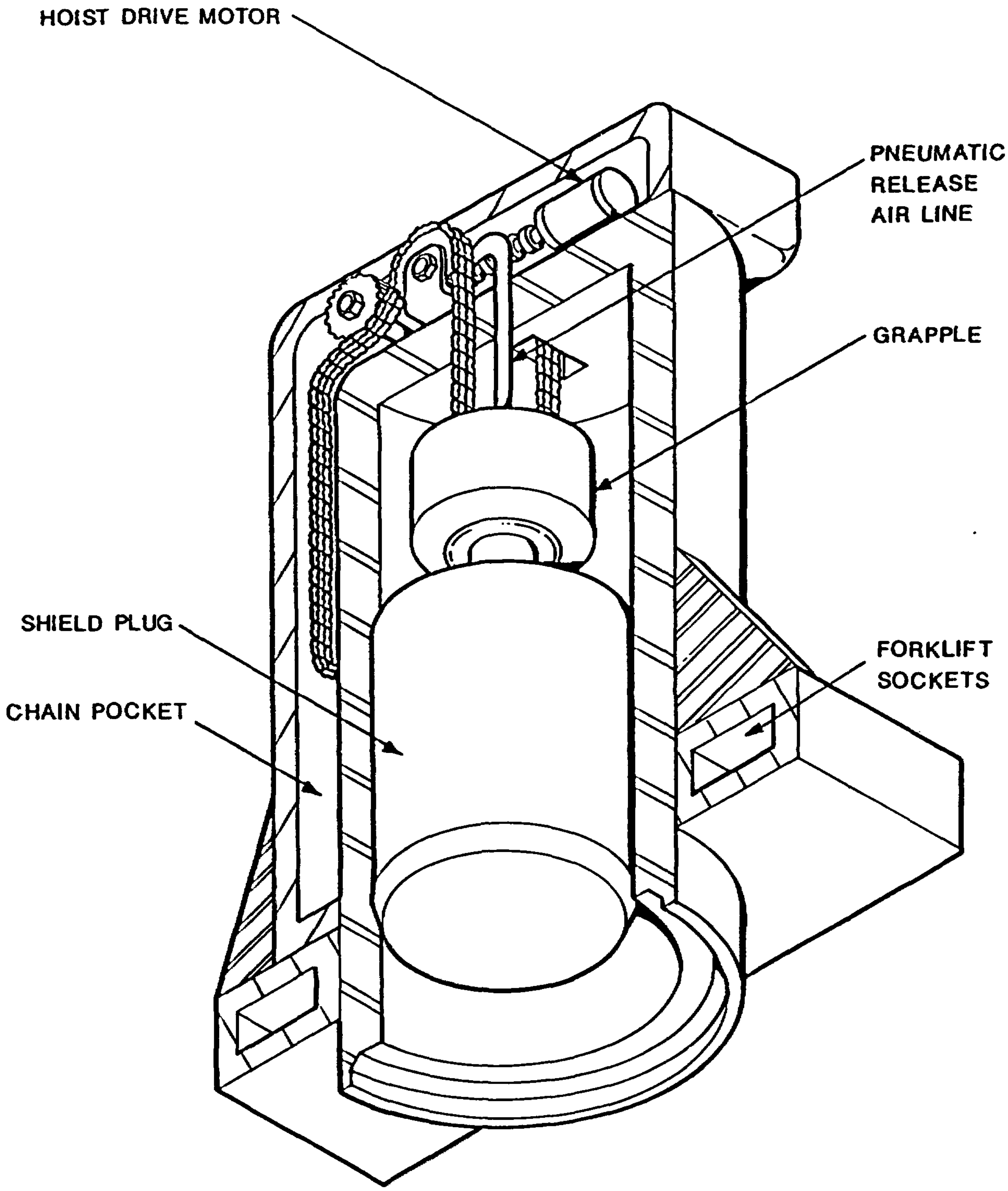


Figure 2-23. Shield Plug Installer/Remover (Vertical Emplacement) (from Figure D-13, Appendix D, SCP-CDR)

operations. A cylindrical sleeve on the housing of the closure fits over the borehole liner to ensure alignment and to provide shielding. The shielding closure is operated by an electric drive motor with mechanical back-up to open or close the shielding closure in case the motor fails. Mechanical jacks are installed on each corner of the closure housing to level and provide support for the closure.

2.2.3.4 Shield Plug Installer/Remover

The shield plug installer (Figure 2-23) attaches to the modified forklift and consists of three major elements: the housing, a hoist, and a grapple. The housing provides radiation shielding during installation and removal of the shield plug. The hoist is an electrically driven, roller chain hoist able to raise and lower a 2,500-lb plug. The grapple is similar to that used by the waste transporter.

2.2.4 Horizontal Waste Transportation and Emplacement Equipment

The major pieces of equipment required for horizontal waste emplacement are the waste container dolly, the waste transporter, the modified forklift, the borehole shielding closure, and the shield plug installer/remover.

2.2.4.1 Waste Container Dolly

The 15.5-ft waste container is mounted on a dolly which reduces loads or stress on the waste container during emplacement and retrieval operations. The dolly consists of a curved steel plate, cast iron or steel rollers attached to each side of the plate, a rear dolly hook, and a front steel plate that will accept both the cask pusher plate/hook and dolly hook. The hook and shackle allow a string of dollies to be attached for retrieval from the horizontal borehole. The waste container and dolly are illustrated in Figure 2-24.

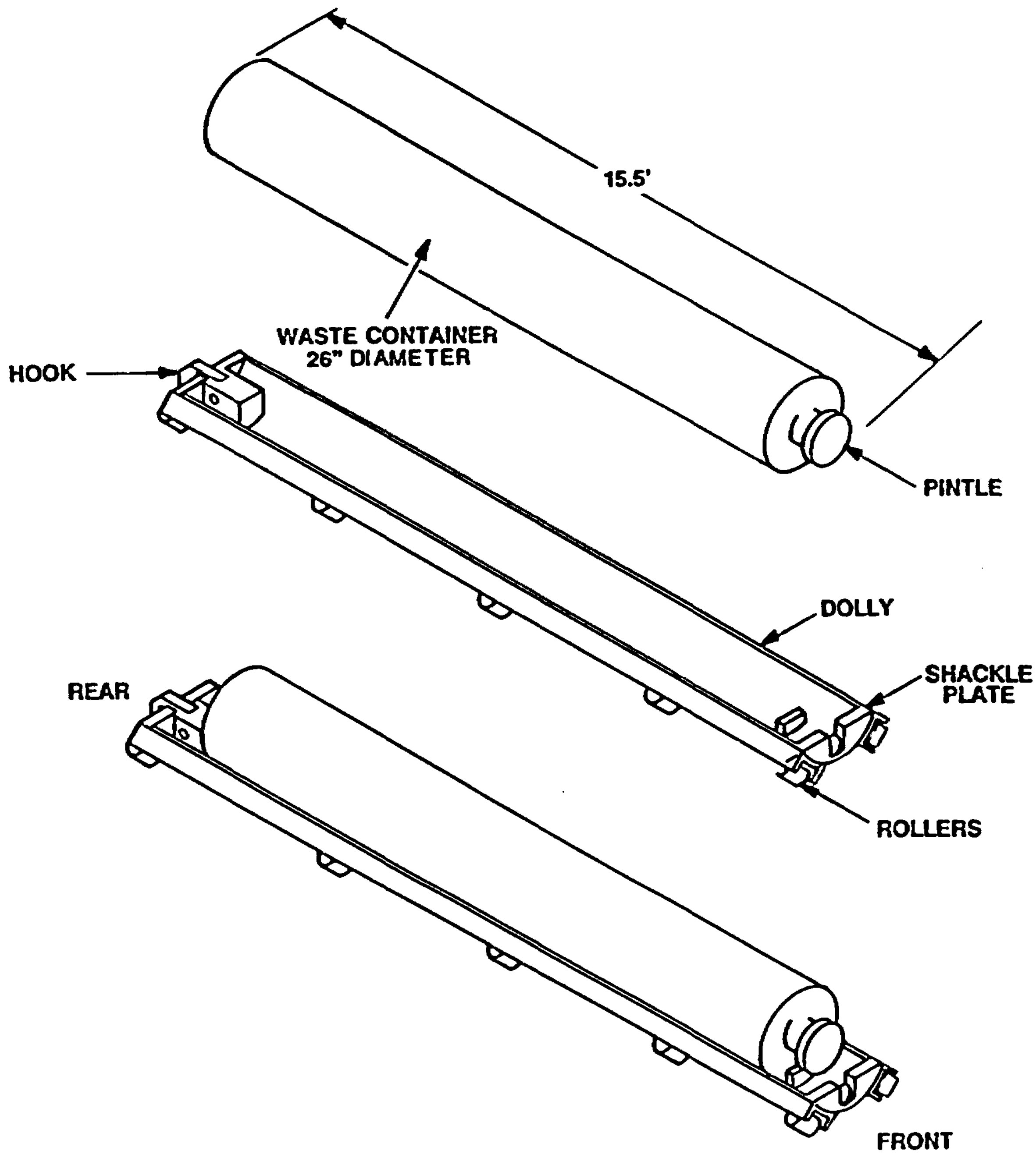


Figure 2-24. Waste Container and Dolly

2.2.4.2 Waste Transporter

The waste transporter, illustrated in Figures 2-25 and 2-26, has three main parts: the transporter cab, the frame and running gear, and the transporter cask. The design considerations for the transporter in the horizontal emplacement configuration are the same as those for the vertical. See Section 2.2.3.1 for the present transporter cab design details.

The cask (Figure 2-27) consists of a structural shell and radiologic shielding material, the emplacement/retrieval mechanism, and a shielding closure. More details of the current conceptual design of the transporter cask are contained in the SCP-CDR.

2.2.4.3 Modified Forklift

The design considerations for the modified forklift used in the horizontal emplacement configuration are the same as those for the vertical (Section 2.2.3.2).

2.2.4.4 Borehole Shielding Closure

The borehole shielding closure (Figure 2-28) consists of a solid housing that encloses and supports the two opposing, sliding closure doors and a cylindrical shield collar, which extends outward to engage and shield the cask closure mechanism. The closure doors are electrically driven by a motorized ballscrew mechanism, which also extends the collar using an integral linkage system. A manually operated mechanical back-up is provided to open or close the shield closure if the electrical motor fails.

2.2.4.5 Shield Plug Installer/Remover

The shield plug installer/remover (Figure 2-29) attaches to the special fork of the modified forklift and consists of two major elements, the housing and a pusher/remover plate. The housing that surrounds the shield plug will be compatible with the borehole shielding closure and

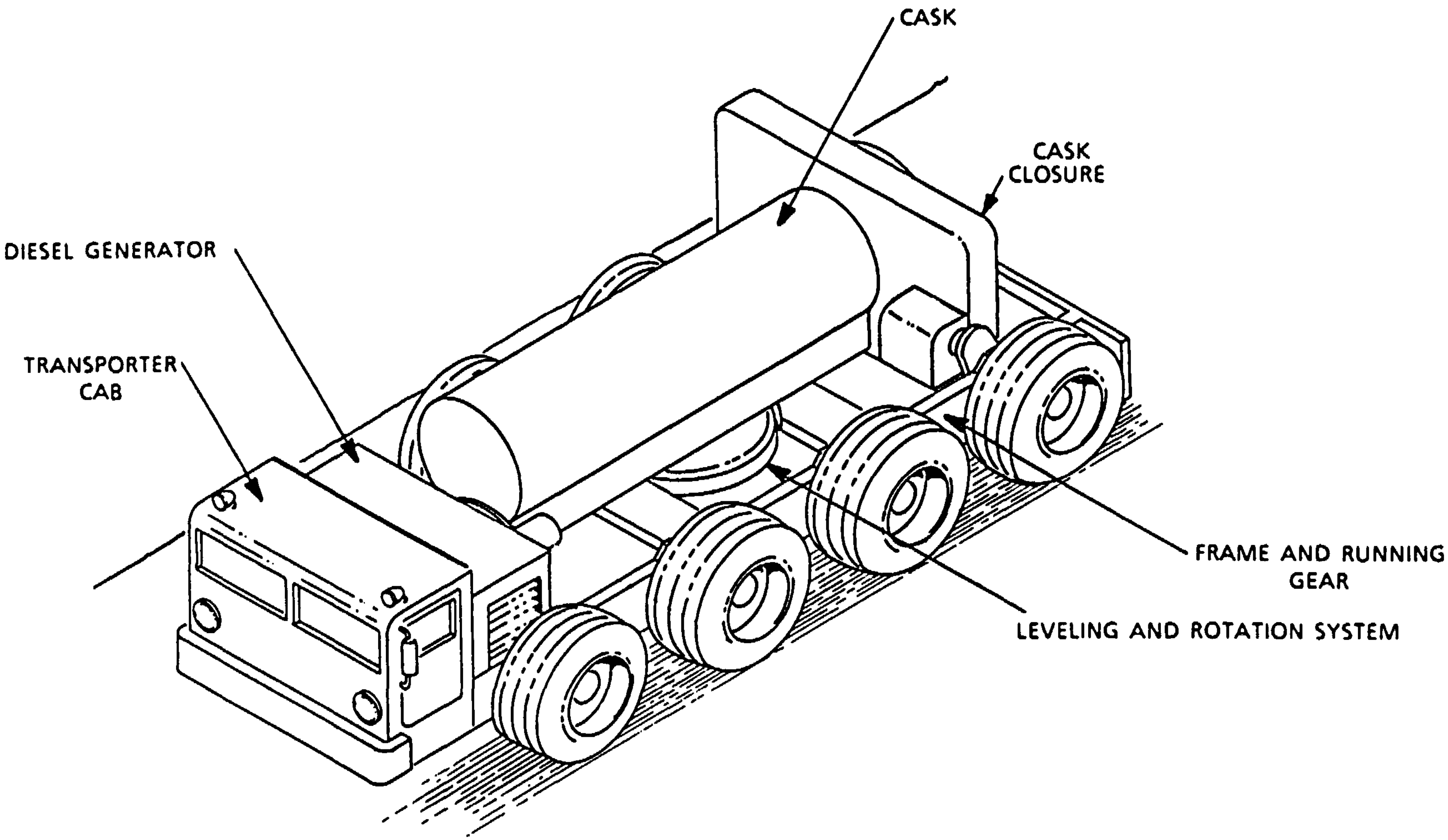


Figure 2-25. Waste Transporter in Transport Mode (Horizontal Emplacement) (from Figure 4-51, SCP-CDR)

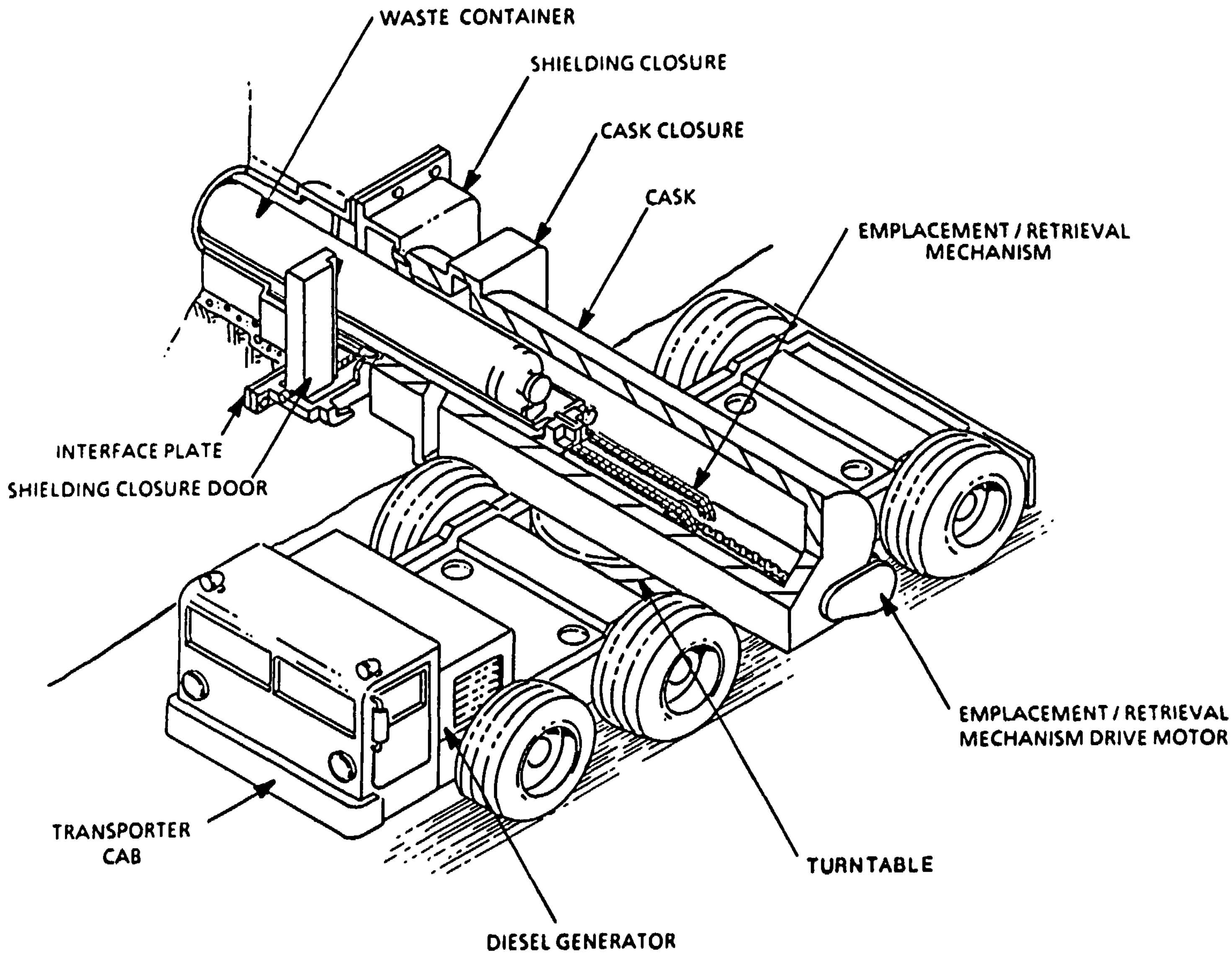


Figure 2-26. Waste Transporter in Emplacement/Retrieval Mode (Horizontal Emplacement) (from Figure 4-52, SCP-CDR)

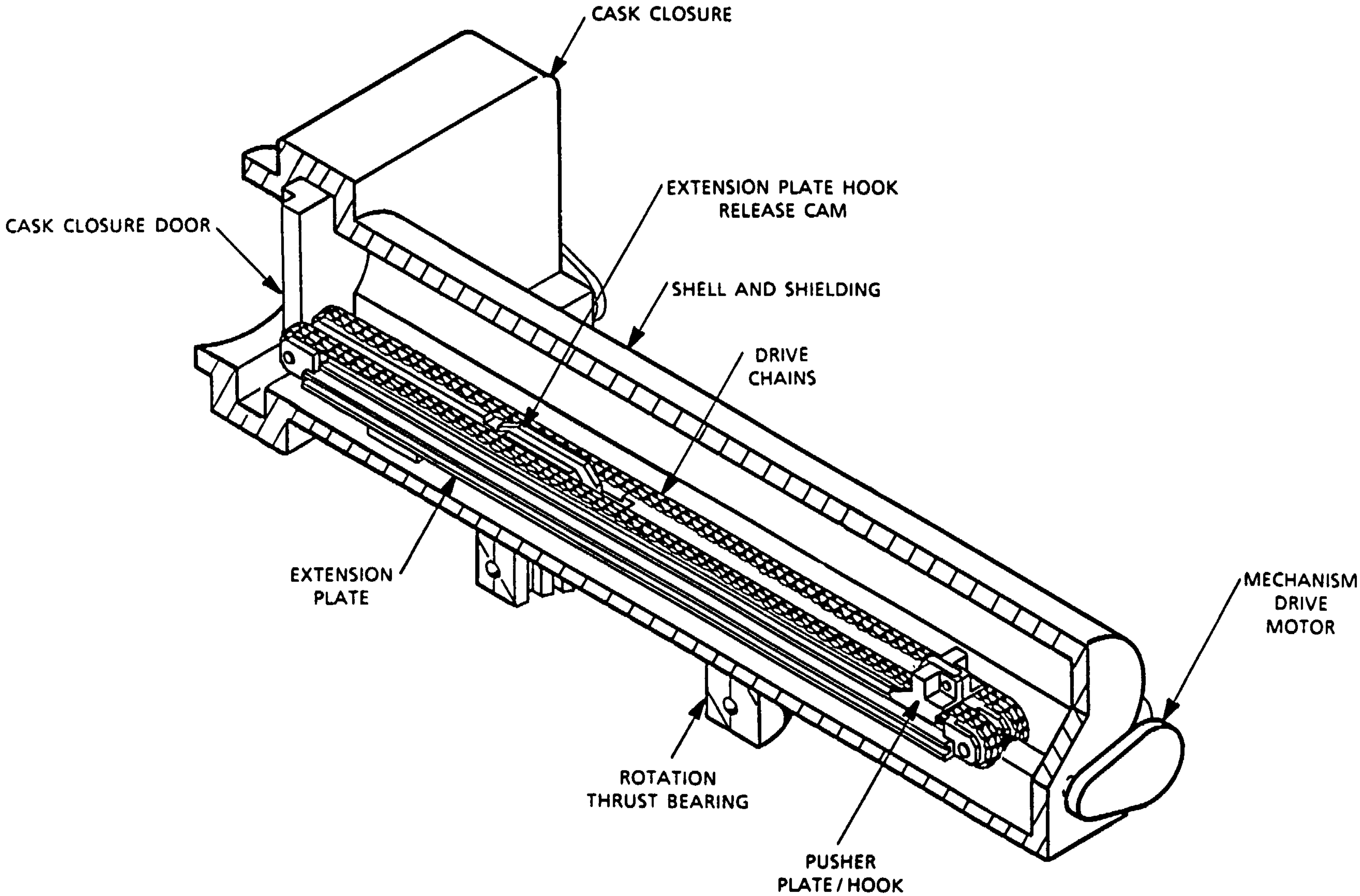


Figure 2-27. Transporter Cask (Horizontal Emplacement) (from Figure D-20, Appendix D, SCP-CDR)

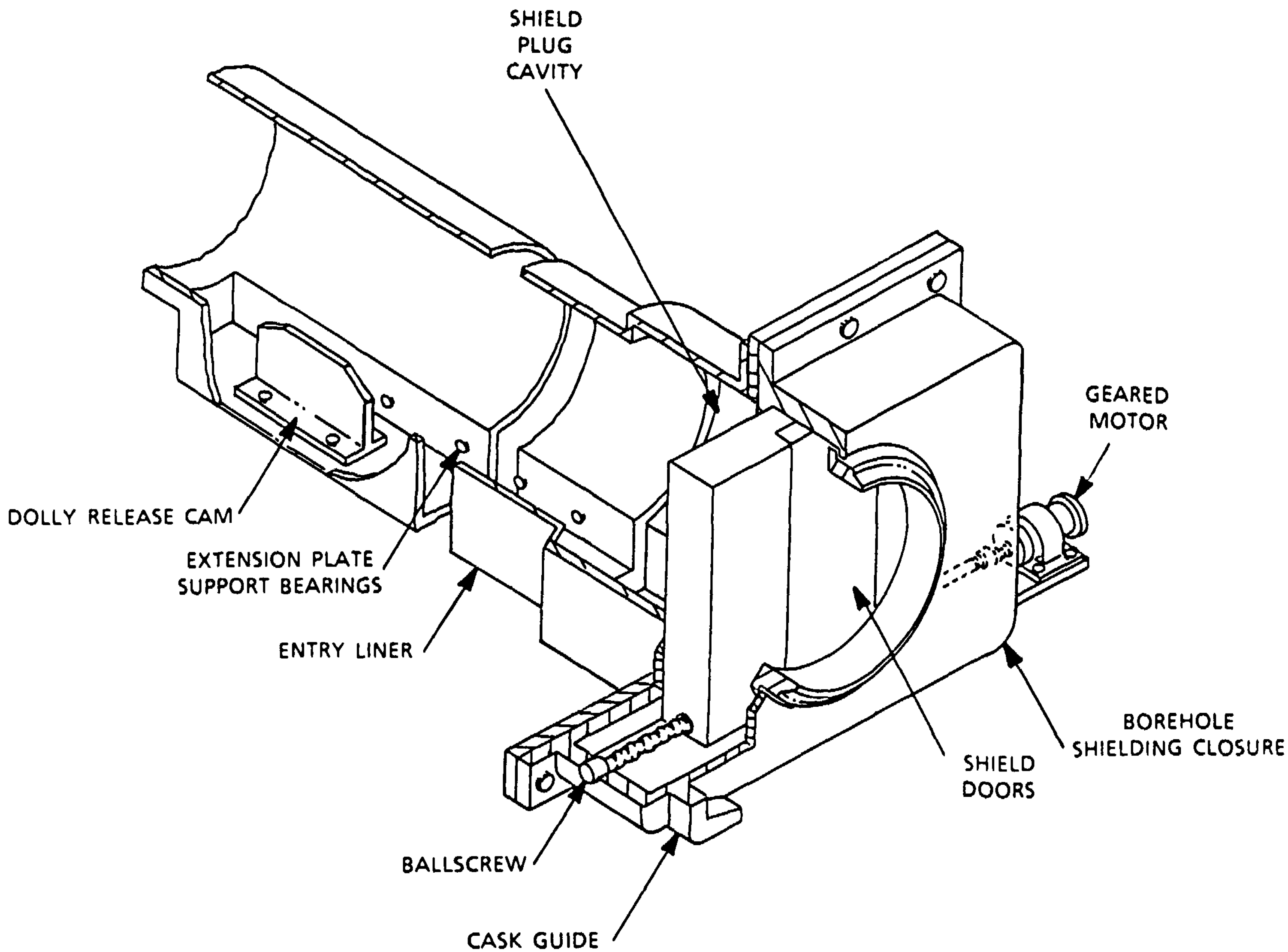


Figure 2-28. Horizontal Borehole Shielding Closure (from Figure D-25, Appendix D, SCP-CDR)

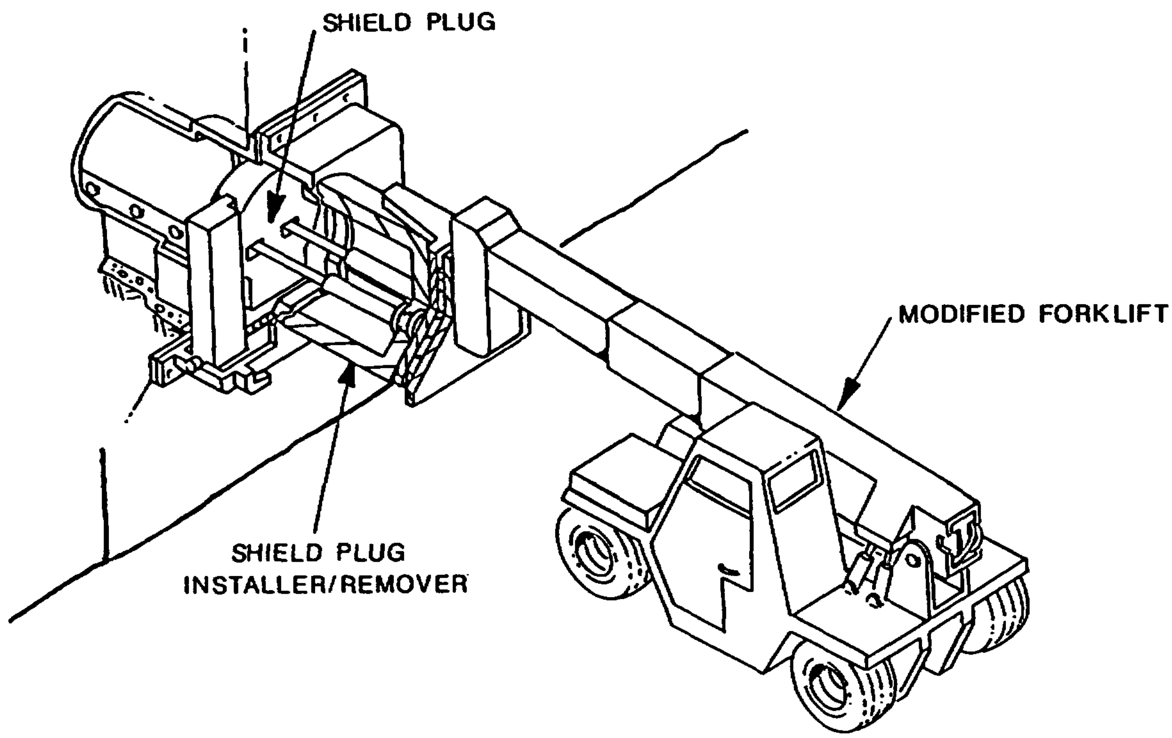


Figure 2-29. Shield Plug Installer/Remover (Horizontal Emplacement) (from Figure D-26, Appendix D, SCP-CDR)

will provide shielding during installation and removal of the shield plug. The hydraulically driven pusher/remover plate pushes the shield plug into the entry liner through the shield closure.

2.3 Ventilation

This section describes the ventilation system design for development and emplacement operations. Ventilation for caretaker and retrieval operations is described in Sections 4.2 and 6.1.

2.3.1 General Overview and Description of the System

Ventilation of the underground facilities is provided by two independent ventilation systems: the development system provides air for development activities, and the emplacement system provides air for waste emplacement operations. Connections between the two ventilation systems are sealed with bulkheads or double doors.

To ensure that the development area cannot be contaminated from a radiologic accident, ventilation leakage occurs only from the development (mining) area to the emplacement area. The current design accomplishes preferential leakage by maintaining lower pressures in the waste emplacement area than in the development area. The pressure differential is established by designing the development system as a "push" system with forcing fans located at the air-intake point (men-and-materials shaft) and designing the emplacement system as a "pull" system with suction fans located at the exhaust point (exhaust shaft).

The performance of the ventilation systems will be monitored continuously at surface and underground control centers. The monitoring system has three goals: (1) to maintain an accurate measure of the working environment in the emplacement and development areas; (2) to provide immediate notice of accidents, including fire and incidents involving radioactive material; and (3) to activate appropriate measures to any accidents, such as evacuation of personnel, redirection of exhaust air from the waste emplacement area through filters, and dispatch of emergency crews.

2.3.1.1 Development Area

The main components of the ventilation system in the development area are the men-and-materials shaft, which takes air from the surface to the service main from which it is distributed throughout the development area, and the tuff main, which carries air from the development area through the tuff ramp to be exhausted at the surface.

2.3.1.2 Emplacement Area

The main components of the intake ventilation system in the waste emplacement area are the exploratory shafts and the waste ramp. These passageways take air from the surface to the waste main, which carries the air to the waste emplacement area. Air from the waste emplacement area is carried through the perimeter drift to the emplacement area exhaust shaft, which exhausts the air at the surface.

The waste emplacement area ventilation system is designed to ensure safe working conditions during waste transport, emplacement, maintenance, and retrieval operations. In this system, air is continuously passed through the areas used for training, performance confirmation, the emplacement area shop, and the decontamination facility.

Spent fuel and DHLW are planned to be emplaced in the same drift in both emplacement configurations. To achieve the expected waste emplacement rate (Table 2-3), at least two emplacement drifts must be available for emplacement operations. However, for conservatism, four drifts will be ventilated for waste emplacement operations. The current strategy is to maintain at least two drifts at a minimum of 45,000 cfm and two standby drifts at 20,000 cfm. If a delay in emplacement were to occur in a drift, the airflow in that drift could be reduced to 20,000 cfm (because use of diesel equipment would be reduced), and a new emplacement drift could be ventilated at 45,000 cfm. Thus, if delays were to occur in activities in one or both of the two drifts ventilated at 45,000 cfm, ventilation could be increased to support the increase of activity in the third and fourth drifts, as necessary.

During normal operations, return air from the ventilation system in the emplacement area is exhausted directly to the atmosphere. However, if the monitors detect a radiation release, the return air would be routed through a set of filters, which includes high efficiency particulate air (HEPA) filters, before discharge to the atmosphere (Figure 2-30). Monitors for airborne radiation are located in the waste emplacement panels, thus permitting early detection of the airborne radiation and activation of the HEPA filter isolation dampers.

2.3.1.3 Design Criteria

The primary design criteria (Section 3.1.2) for the ventilation system are

- 125 cfm (minimum airflow) per brake horsepower of diesel equipment at a working location [30 CFR 57 (DOL, 1985)];

- 200 cfm (minimum airflow) per worker (California Administrative Code, 1981); and

- a minimum air velocity of 60 ft/min (California Administrative Code, 1981).

Assuming a 300-horsepower transporter and an emplacement crew of six, the transporter will require an airflow of 37,500 cfm, and each crew will require 1,200 cfm. The minimum airflow requirements used in the design for the underground facility are shown in Table 2-6. In addition, maximum air velocities for the underground openings were established based upon dust abatement needs, fan-operating costs, and comfort considerations (Table 2-7).

Acceptable environmental conditions are taken as an air-cooling power (Mitchell and Whillier, 1972) >500 W/m^2 and a dry-bulb temperature <40°C in areas where mining, drilling, maintenance, or retrieval of waste is occurring. Conditions that permit inspection of drifts containing emplaced waste are defined as an air-cooling power >300 W/m^2 and a dry-bulb temperature <45°C. Dry-bulb temperature is a governing

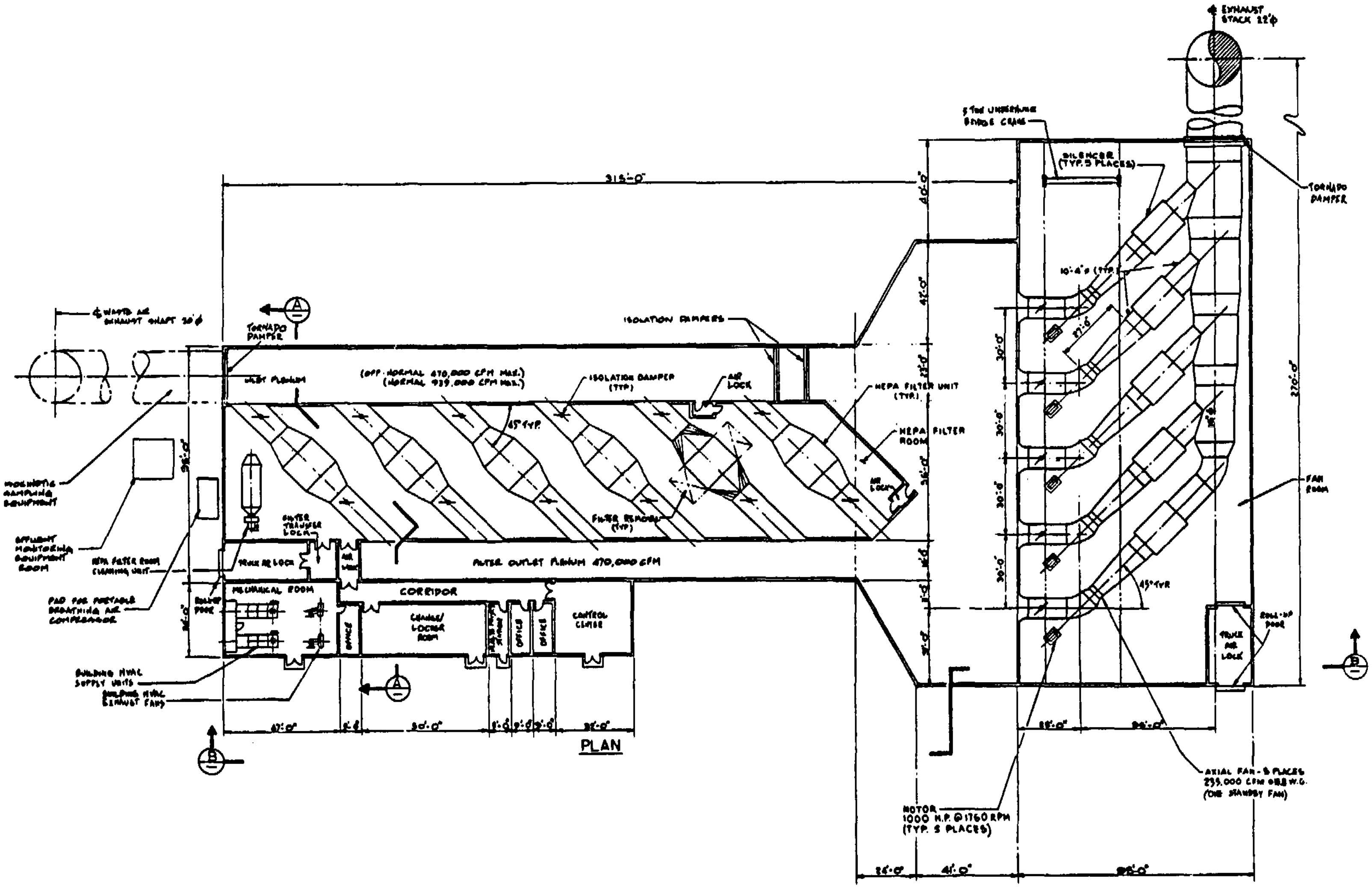


Figure 2-30. Emplacement Area Exhaust Building, Overall General Arrangement, Plan and Sections (from Figure 3-30, SCP-CDR)

TABLE 2-6

MINIMUM AIRFLOW REQUIREMENTS FOR THE UNDERGROUND FACILITY*

Area	Vertical (1,000 cfm)	Horizontal (1,000 cfm)
Development Shop	85	50
Drilling Operations	20	20
Perimeter Drift	40	40
Development Area	100	80
Access Drifts	50	50
Transporter Route	45	45
Training Area	45	45
Performance Configuration Area	25	25
Emplacement Area Shop	55	55
Emplacement Drift (Active)	45	45

*From Table 2-23, SCP-CDR.

TABLE 2-7

CONSTRAINTS ON MAXIMUM AIR VELOCITY[a]

Area	Maximum Velocities[b] (ft/min)
Intake Shafts (unobstructed)	4,000
Return Shafts (unobstructed)	4,000
Waste Ramp	1,500
Tuff Ramp	1,500
Men-and-Materials Shaft	2,300
Perimeter Drift	2,000
Main Entries	1,500
Main Return Drifts	1,500
Haulage Airways (no conveyor)	1,200
Haulage Airways (conveyor--homotropal)	1,000
Haulage Airways (conveyor--antitropal)	800
Emplacement Drifts	1,500
Development Areas	600

[a]From Table 3-23, SCP-CDR.
[b]Maximum air velocities in the shafts are based on the assumption that the shafts are dry and unobstructed.

criterion because of the dry atmospheric conditions expected at the repository site. The climate data used for this study are the mean summer conditions at the NTS (Eglinton and Dreicer, 1984).

The mean summer climatic conditions used for the cooling analyses are

- a dry-bulb temperature of 30.3°C,
- a wet-bulb temperature of 15.2°C, and
- an atmospheric pressure of 26.0 in. Hg (at an elevation of 3,924 ft above sea level).

2.3.1.4 Design Analysis

Two computer codes have been used to design the ventilation and cooling system: VNETPC (Ventilation Network Analysis), which simulates the underground airflow distribution and calculates the fan requirements, fan operating cost, and frictional pressure losses; and CLIMSIM (Climatic Simulation), which simulates the psychrometric and environmental conditions in the airways (Appendix D).

The design analyses consisted of determining the airflow distribution and fan requirements and the resulting climatic conditions throughout the underground facility at specific times during the life of the repository. Two ventilation scenarios were analyzed for each emplacement configuration. Scenario 1 (Figure 2-31) depicts the development of the repository at the greatest distance from the base of the tuff ramp, which is the time at which the demand on the ventilation system for the development area is expected to be the greatest. Scenario 2 (Figure 2-32) assumes that development is nearly completed while emplacement operations are occurring in the next-to-last panel and cooling operations are occurring in another panel. This scenario results in the maximum airflow required for the emplacement area (Table 2-8). Ventilation requirements for the waste emplacement area during caretaker or retrieval operations are not expected to exceed the requirements determined for these two scenarios (Sections 4.2 and 6.1).

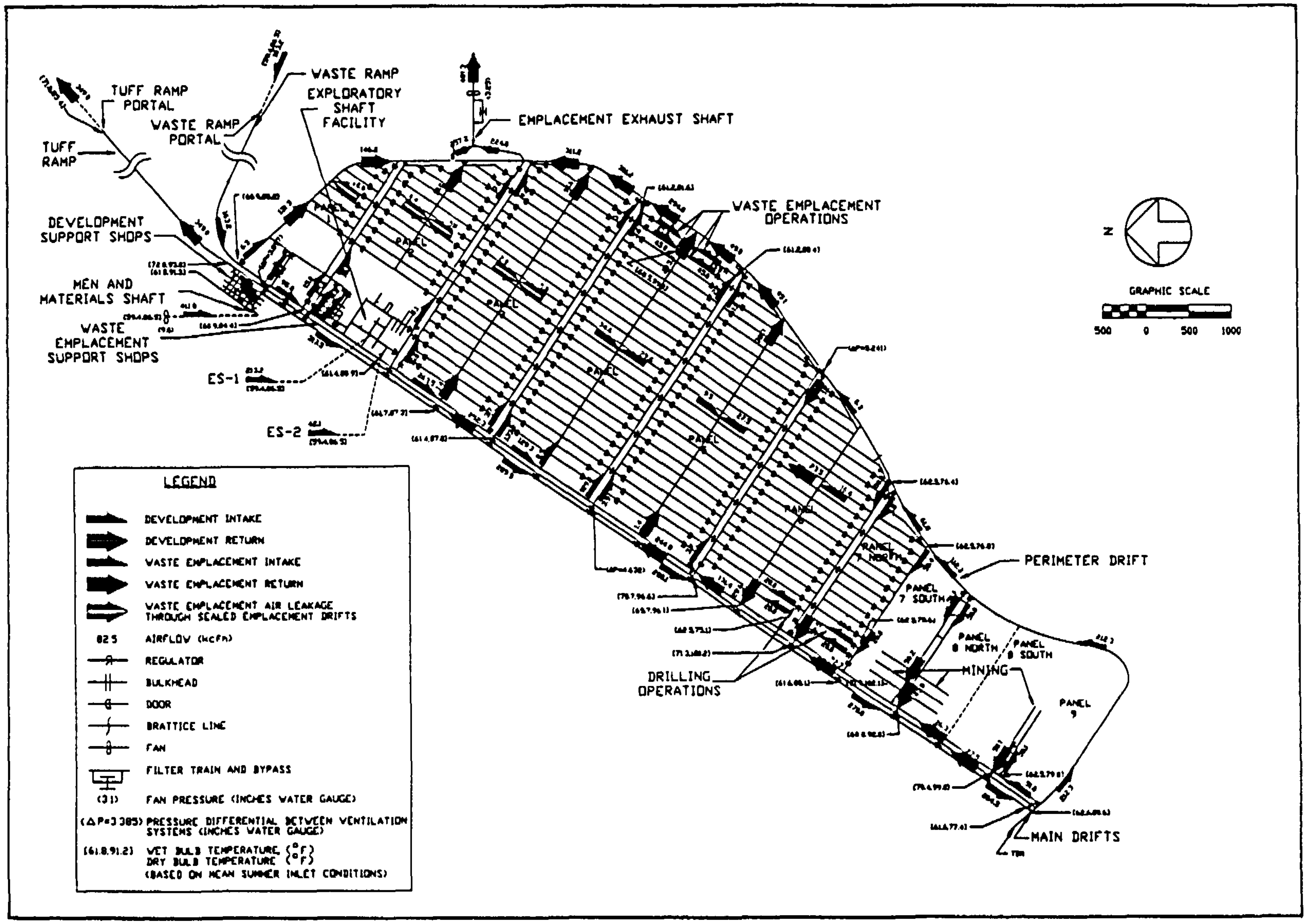


Figure 2-31. Maximum Ventilation Requirements for Development Operations, Vertical Emplacement (from Figure 3-31, SCP-CDR)

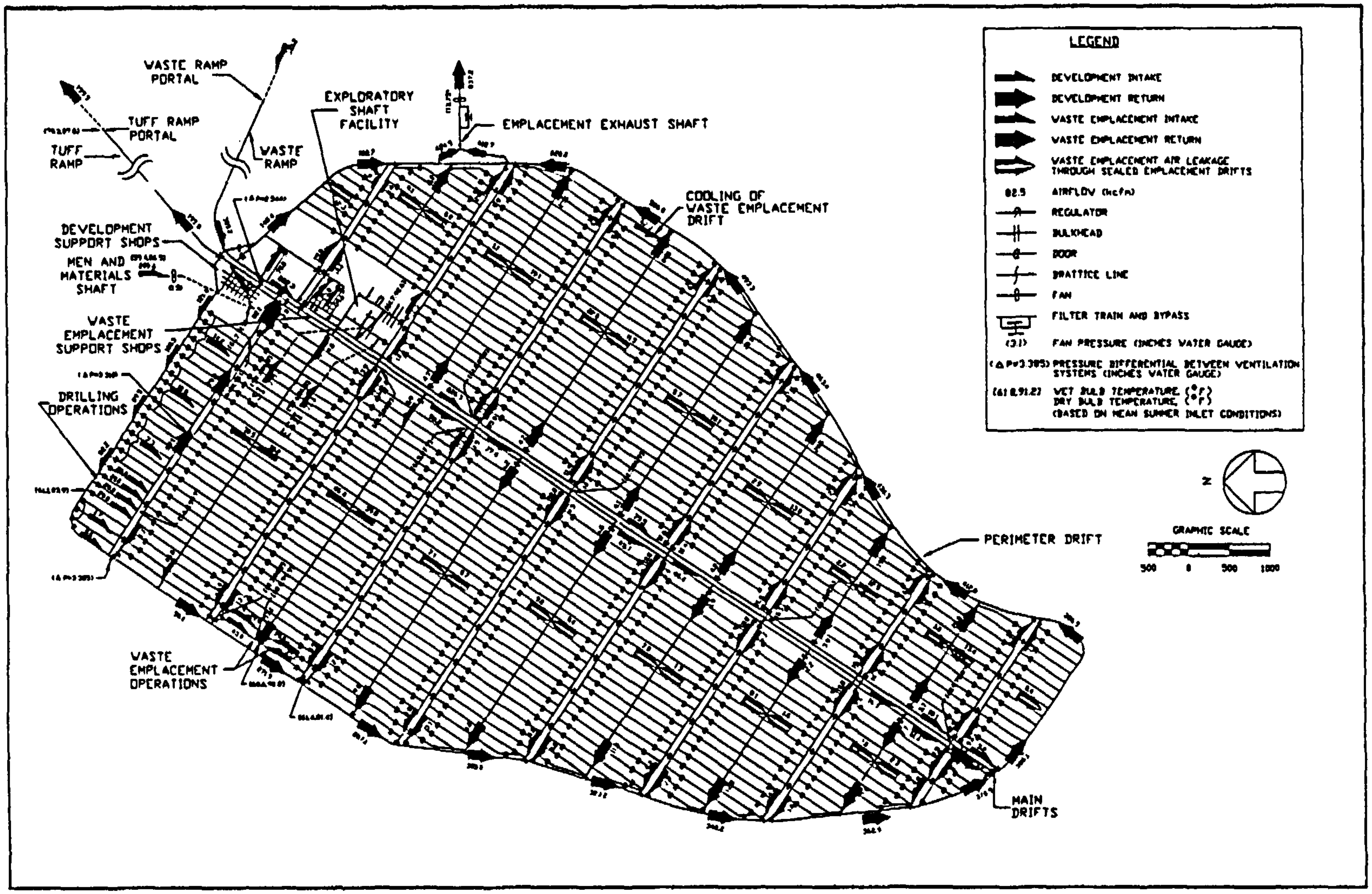


Figure 2-32. Maximum Ventilation Requirements for Emplacement Operations, Vertical Emplacement (from Figure 3-32, SCP-CDR)

TABLE 2-8

MAXIMUM FAN REQUIREMENTS FOR THE TWO VENTILATION SCENARIOS[a]

Emplacement Method	Repository Area	Maximum Fan Requirements for the Development Area Scenario 1 Airflow (cfm)[b]	Maximum Fan Requirements for the Development Area Scenario 1 Pressure (in w.g.)[c]	Maximum Fan Requirements for the Emplacement Area Scenario 2 Airflow (cfm)[b]	Maximum Fan Requirements for the Emplacement Area Scenario 2 Pressure (in w.g.)[c]
Vertical	Development	411,800	9.00	209,400	1.50
	Emplacement	481,300	3.25[d]	837,200	13.75[d]
Horizontal	Development	281,300	4.50	117,200	1.00
	Emplacement	446,400	4.00[d]	517,200	5.00[d]

a. Composite of Tables 3-17 through 3-20, SCP-CDR.
b. Based on standard air density (0.075 lb/ft^3).
c. Inches water gage.
d. Pressure required at the collar of the waste emplacement area exhaust shaft.

2.3.2 Vertical Emplacement Configuration

2.3.2.1 Maximum Ventilation Airflow Requirements for the Development Area

The maximum airflow demands on the ventilation system for the development area are expected to occur when mining operations are farthest from the base of the tuff ramp. At that time, development operations will consist of advancing the perimeter drift around the western panels, advancing two panel access drifts between Panels 8 and 9, mining six emplacement drifts from the two panel access drifts between Panels 7 and 8, and drilling vertical boreholes in four emplacement drifts--two in Panel 7 and two in Panel 6 (Figure 2-31). These areas are ventilated by coursing intake air for the development area from the end of the service main through the perimeter drift and back to the tuff main through the panel access drifts.

Air is supplied to the mining crews at the working face in the development area by an auxiliary fan and duct arrangement.

In panels on the emplacement area ventilation system, the air flows from the main drift, down the access drift, through the emplacement drift, into the midpanel drift, and to the perimeter drift. Air from the training, performance confirmation, decontamination, and shop areas is routed directly to the perimeter drift. When the emplacement of waste in a panel has been completed, the panel is sealed using a series of bulkheads and doors. A small amount of air is allowed to "leak" through the panel to reduce heat build-up. This leakage is controlled by a series of regulators (Section 4.2).

Figure 2-31 shows the airflow directions and quantities of intake and return air, the temperature distribution, the location of the fans for the development and emplacement areas, air pressures at the fans, pressure differentials between ventilation systems, and the ventilation controls throughout the vertical emplacement configuration at the time of maximum airflow demand in the development area. The fan requirements for this layout are listed in Table 2-8.

2.3.2.2 Maximum Ventilation Airflow Requirements for the Waste Emplacement Area

The maximum airflow demand on the ventilation system for the waste emplacement area occurs when the emplacement area is nearly fully developed and emplacement and inspection or maintenance are occurring simultaneously. At this time, borehole drilling is the only operation in the development area. This set of conditions places the largest demands on the fans in the waste emplacement area because the air leaving the panel in which waste is being emplaced must course a great distance around the emplacement area in the perimeter drift to the waste emplacement area exhaust shaft. Airflow through the ventilation system for the waste emplacement area is determined mainly by maintaining the airflow above 45,000 cfm in routes used by the waste transporters and by controlling air leakage in the panels that have been sealed.

As shown in Figure 2-32, air leaks from the mains to the perimeter drift through the panel access and midpanel access drifts, and between the access drifts through the sealed emplacement drifts. To design a system to control that leakage, a series of ventilation analyses was performed in which the controls on each drift were varied. The controls found to be the most effective were those that directed leakage as shown in Figure 2-32. This control is accomplished (1) by placing doors at the end of the panel access drifts adjacent to the perimeter drift, (2) by placing bulkheads at the end of the midpanel access drifts adjacent to the mains, and (3) by using a combination of doors and regulators at the end of the panel access drifts adjacent to the mains and regulators at the perimeter-drift end of the midpanel access drifts.

Each emplacement drift is equipped with a door on the panel access side of the airway. The ability to maintain the regulator at the end of the midpanel access drift is an operational concern because the only means of access is through the airflow downstream from the drifts in which spent fuel and high-level waste have been emplaced. Because air temperatures caused by the waste packages create unacceptable environmental conditions, it may be necessary to operate this regulator remotely and to design a specific maintenance program.

Figure 2-32 shows the distribution of airflow and temperature, as well as the locations of fans for the development and emplacement areas. It also illustrates the ventilation controls required to prevent excessive leakage. Nearly 40% of the intake air for the waste emplacement area enters through the waste ramp; the remaining air enters through ES-1 and ES-2. The basic ventilation system shown for the waste emplacement area provides adequate airflows throughout the underground facility, including the airflow required to ventilate four emplacement drifts simultaneously (two at 45,000 cfm and two at 20,000 cfm) and to permit inspection or maintenance operations in one emplacement drift (in which 85,000 cfm enters the panel and 42,000 cfm reaches the emplacement drift farthest from the mains). The remaining airflow is required for the shop, training, performance assessment, and decontamination areas, as well as for maintaining a pressure differential adequate to force leakage in the correct direction through each panel. Table 2-8 identifies the maximum ventilation requirements for the waste emplacement area in the vertical emplacement configuration.

2.3.3 Horizontal Emplacement Configuration

The basic ventilation system for the horizontal configuration is nearly identical to that for the vertical configuration. The key differences between the two systems are that the horizontal emplacement drifts are spaced much farther apart, no midpanel access drift is needed, and the emplacement drifts in the horizontal configuration are twice as long as those in the vertical configuration.

2.3.3.1 Maximum Ventilation Airflow Requirements for the Development Area

As in the vertical emplacement configuration, the maximum airflow requirements for the ventilation system in the development area are expected when mining operations are occurring at the greatest distance from the base of the tuff ramp. The mining requirements and ventilation techniques for the ventilation system in the development area in the horizontal configuration are identical to those for the vertical configuration, except that fewer emplacement drifts are mined along each panel access drift. Therefore, given the reduced mining activities, the airflow requirements in the horizontal configuration are less than those in the vertical configuration (Table 2-8).

The ventilation system for the waste emplacement area in this configuration is similar to that for the vertical configuration (Section 2.3.2). The main differences are that emplacement operations are occurring in Panels 3 and 4, and Panels 1 and 2 are sealed from continuous ventilation, except for the airflow required to maintain the correct leakage direction. As in the vertical configuration, one completed panel (ready for emplacement) separates operations in the development and emplacement areas. (Figure 2-8 gives the panel-numbering sequence.)

The airflow and temperature distributions, ventilation controls, locations of the main fans, and fan pressures are shown in Figure 2-33. The fan requirements for this layout are identified in Table 2-8.

2.3.3.2 Maximum Ventilation Airflow Requirements for the Waste Emplacement Area

The maximum airflow demand on the ventilation system of the waste emplacement area in the horizontal configuration occurs when the emplacement area is nearly fully developed and only borehole drilling operations are under way in the final panel. At this time, it is assumed that emplacement operations are in progress in Panel 16, and cooling operations are occurring in Panel 4.

In each panel, the air flows from the main drift, down the access drift, through the emplacement drift, into the access drift on the far side of the panel, and from there to the perimeter drift. Air from the training, performance confirmation, decontamination, and shop areas is routed directly to the perimeter drift. When the emplacement of waste in a panel has been completed, the panel is sealed using a series of bulkheads and doors. A small amount of air is allowed to leak through the panel to reduce heat build-up. This leakage is controlled by using a series of regulators (Section 4.2).

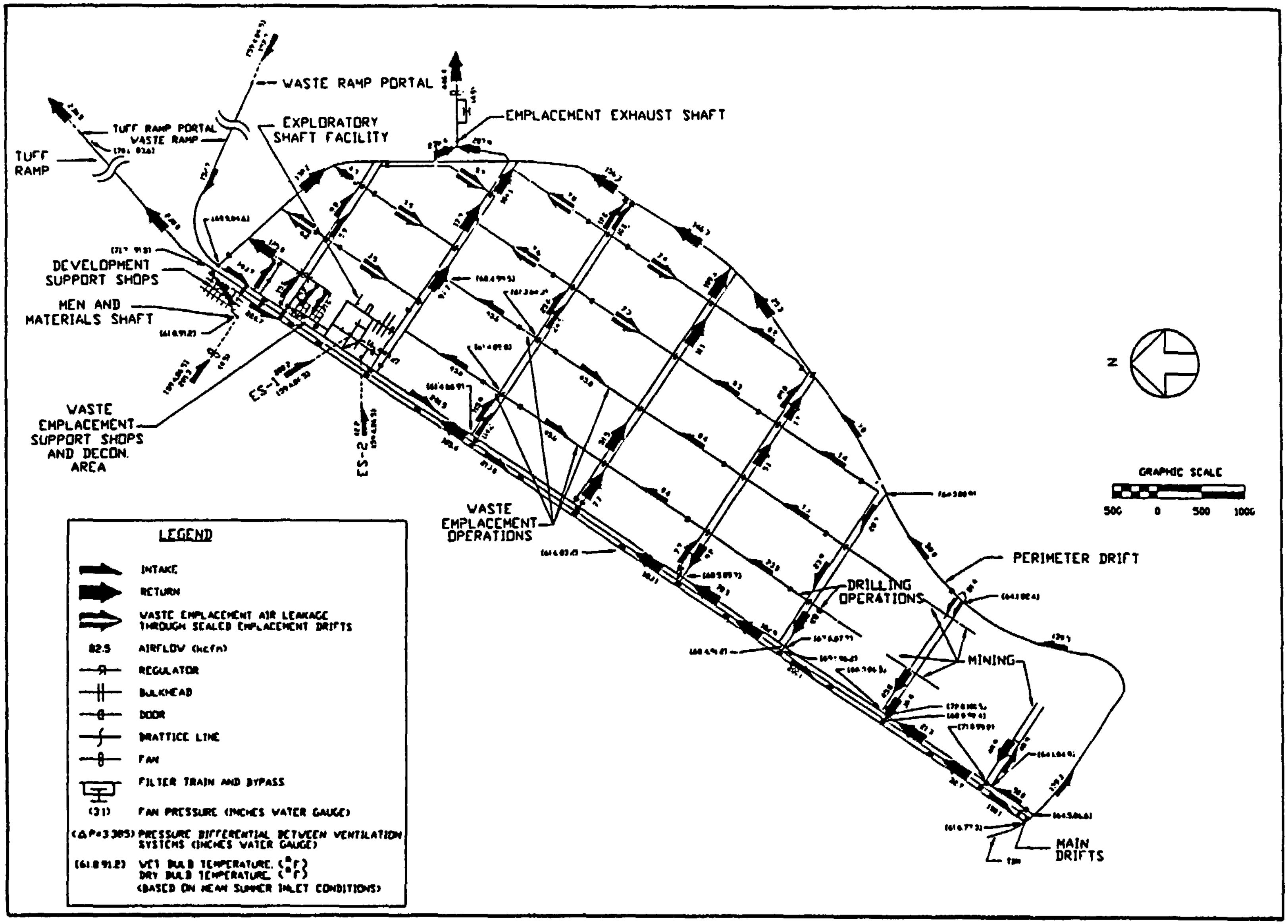


Figure 2-33. Maximum Ventilation Requirements for Development Operations, Horizontal Emplacement (from Figure 3-23, SCP-CDR)

The primary airflow requirements for the waste emplacement area are 45,000 cfm in the transporter routes, 20,000 cfm in the standby emplacement drifts, 45,000 cfm in the emplacement drift being cooled, sufficient airflow for the shops and other support areas, and pressure differentials adequate to force leakage through the panels in the correct direction.

Figure 2-34 illustrates the expected directions and quantities of airflow, air temperatures, ventilation controls, and fan requirements throughout the underground facility. As in the vertical configuration, a significant amount of air for the waste emplacement area enters the facility through the waste ramp.

2.3.4 Requirements for Cooling Air

Analysis of the underground climate (temperature and humidity) indicates that cooling the air for development and waste emplacement operations in both emplacement configurations is unnecessary. However, after a drift has been filled with waste for a period of time, it may be necessary to cool ventilation air to permit entrance to the drift within a reasonable period of time for inspection or maintenance. Cooling requirements for inspection, maintenance, or retrieval operations are discussed in Section 4.2.

2.4 Underground Repository Development and Emplacement Operations

The construction and operation of the repository take place in two phases: (1) construction, and (2) emplacement.

2.4.1 Construction Phase

The construction phase of the repository includes the construction of the ramps and shafts, excavation and construction of the common facilities in the shaft area, and initial development of the waste emplacement area.

The sequence of mining operations typical to both the vertical and horizontal emplacement configurations is illustrated in Figure 2-35.

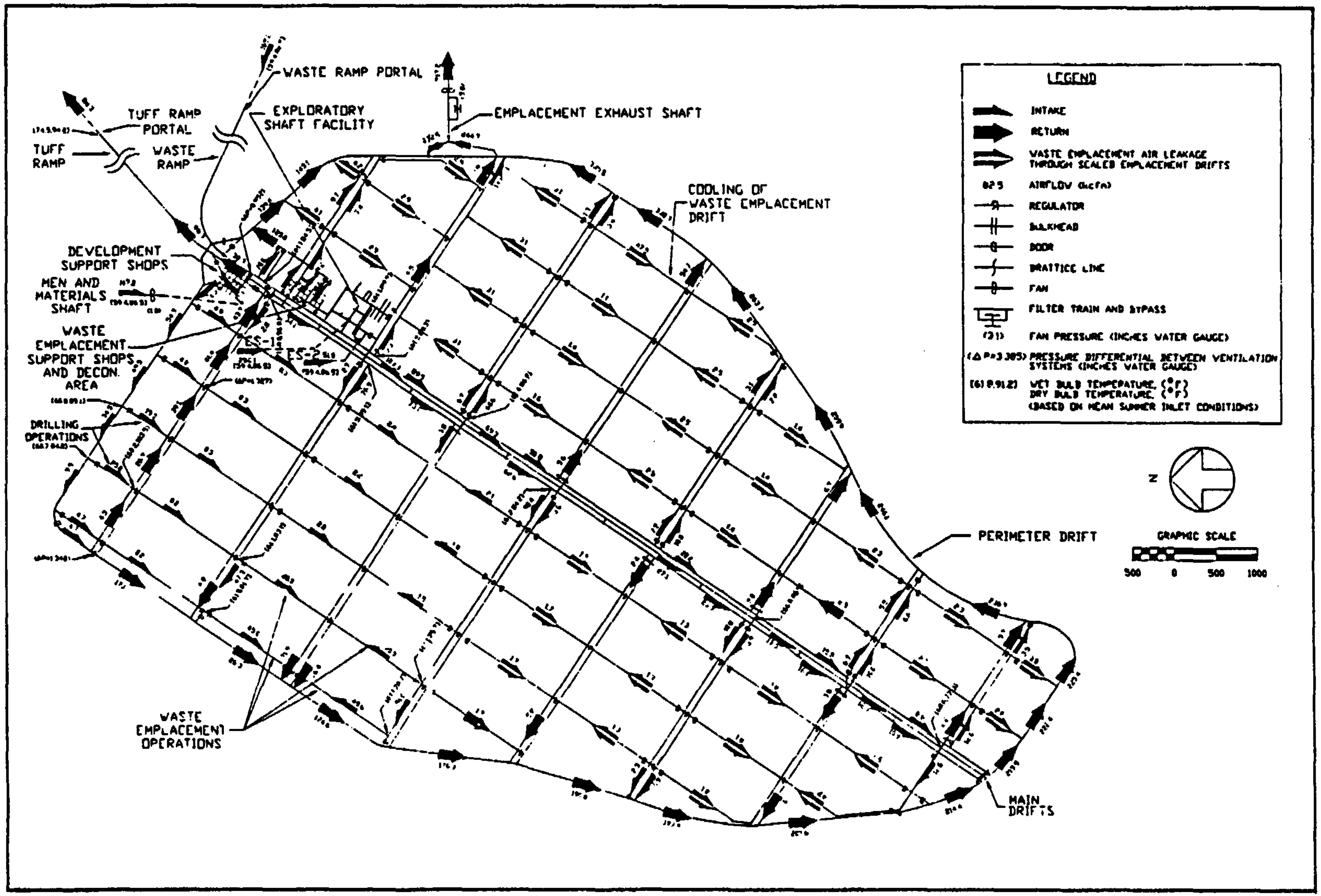


Figure 2-34. Maximum Ventilation Requirements for Emplacement Operations, Horizontal Emplacement (from Figure 3-34, SCP-CDR)

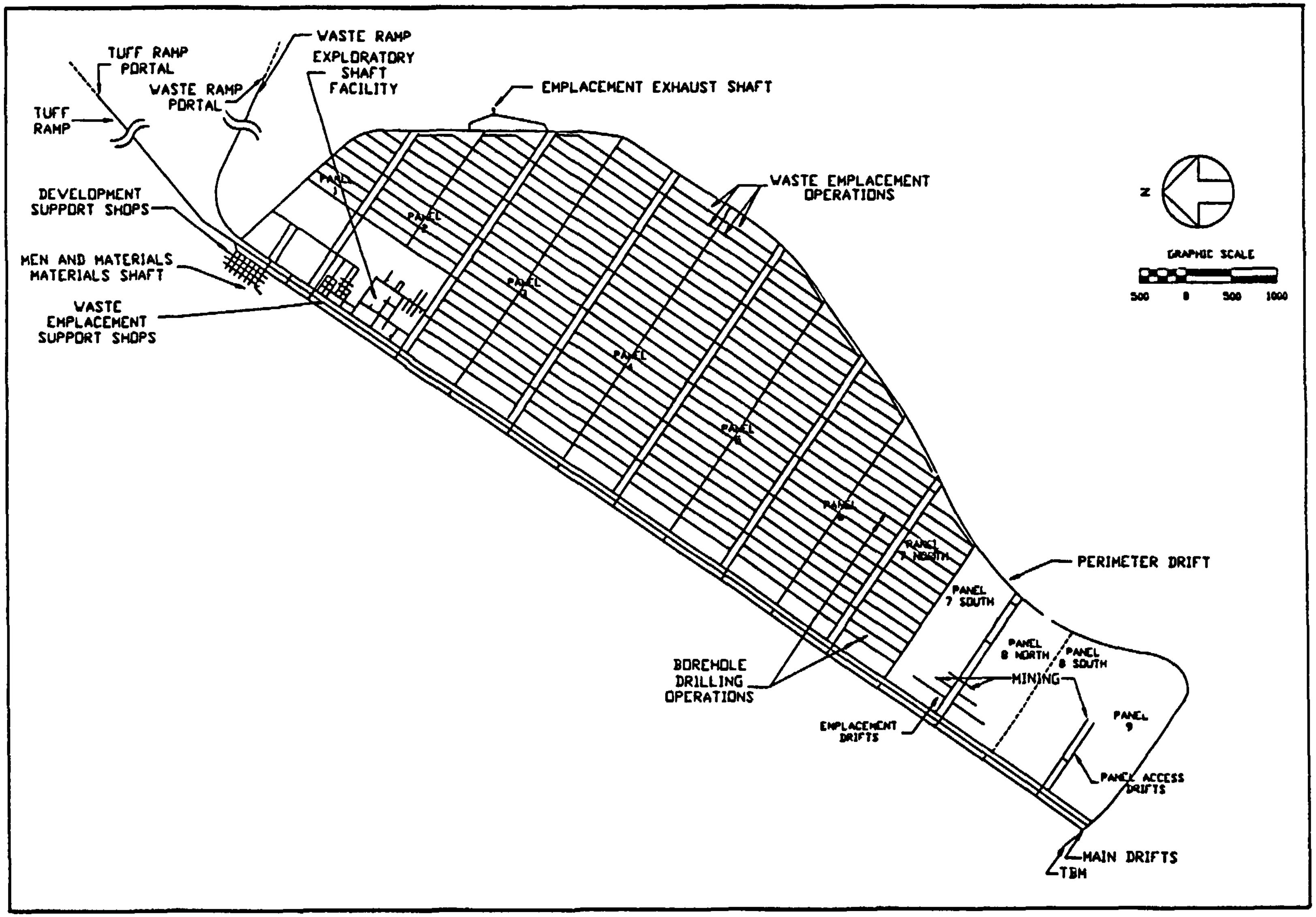


Figure 2-35. Typical Development Sequence, Vertical Emplacement (from Figure 3-26, SCP-CDR)

2.4.2 Emplacement Phase

2.4.2.1 Excavation and Preparation of Emplacement Panels

The excavation and preparation of the waste emplacement panels proceed until the entire emplacement area has been filled. Excavation of at least one full panel must be completed in advance of waste emplacement operations, to permit construction and maintenance of separate ventilation systems. Excavation of the emplacement area will be completed one or more years before waste emplacement is completed. Development and emplacement will commence in the northeast quadrant of the emplacement area and will proceed in a clockwise direction as indicated by the sequence of panel numbers in Figure 2-5.

The excavation sequence for a typical emplacement panel proceeds as follows. The three mains are developed to a point approximately two panel widths beyond the panel being developed. The panel access drifts are developed from the mains to the limit of the emplacement area boundary to confirm ground conditions. The perimeter drift is then advanced to intersect the panel access drifts, and a ventilation loop is established around a panel. The excavation of emplacement drifts then begins in the previous panel. This sequence is illustrated in Figure 2-35. In that example, the perimeter drift is completed to the southern end of the emplacement area before the emplacement drifts are excavated in the area that includes the southern half of Panel 7 and the northern half of Panel 8. Excavation of emplacement drifts may occur in one or two panels simultaneously.

The drilling and preparation of waste emplacement boreholes follows the completion of each 700-ft segment of emplacement drift. In the example given above, the drilling will be occurring in the northern half of Panel 7 when excavation of the emplacement drifts starts between Panels 7 and 8. Once drilling in the northern half of Panel 7 has been completed, drilling in the southern half of Panel 7 will begin.

When development of a full panel (both northern and southern halves) has been completed, the panel's ventilation system will be converted from the development area ventilation system to the ventilation system for the emplacement area by constructing or relocating various bulkheads (Section 2.3). This sequence of construction of the emplacement panels and conversion for active emplacement continues until the emplacement area has been completed.

2.4.2.2 Vertical Waste Emplacement Operations

Waste emplacement operations involve preparing individual boreholes for emplacement, transferring waste containers from the waste-handling buildings to the emplacement boreholes, and closing the boreholes.

Figure 2-36 is a schematic diagram showing the steps involved in preparing a vertical borehole for emplacement. A support plate is

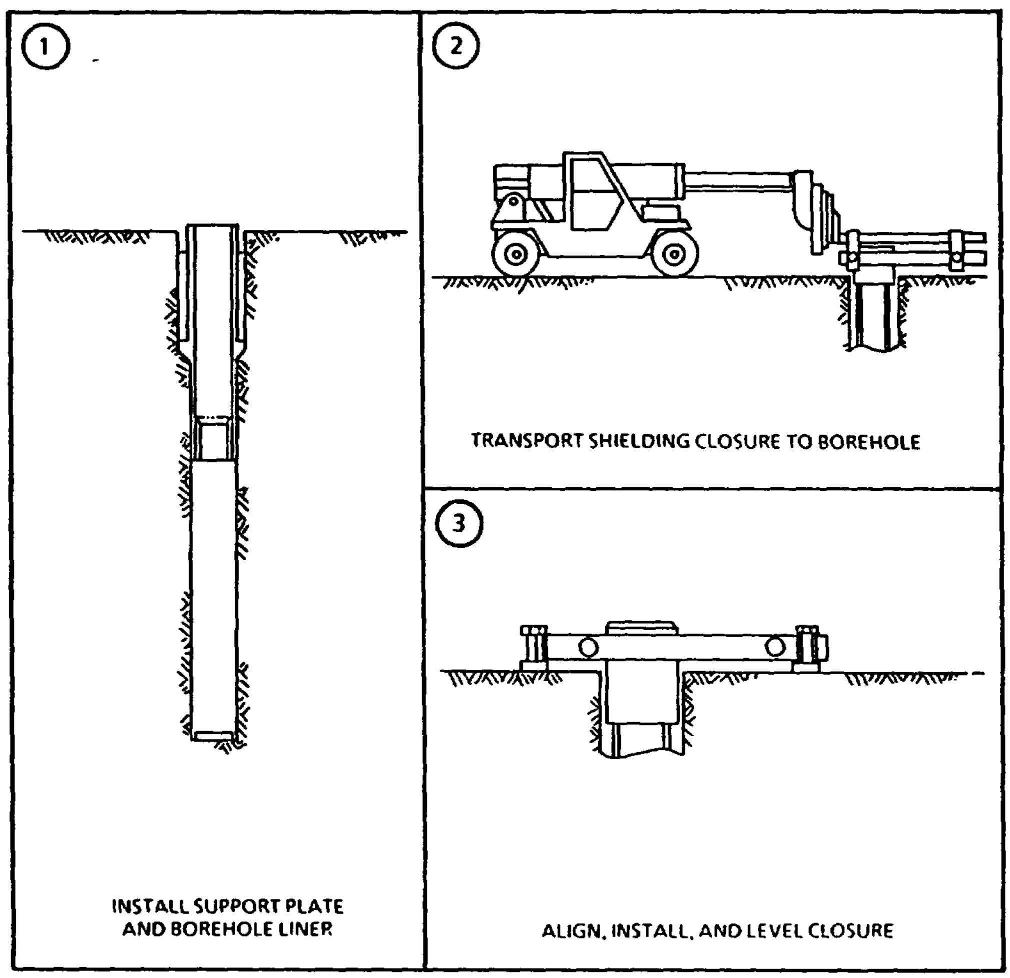


Figure 2-36. Preparation of Vertical Borehole for Emplacement (from Figure 4-43, SCP-CDR)

installed in the bottom of the borehole to support the waste container and to distribute the weight of the container over the bottom of the hole. A special forklift is used to transport a temporary borehole shielding closure to the borehole. The closure, which is used to provide shielding during emplacement operations, is then aligned, installed, and leveled.

Transfer of a single waste container from the surface facility to a vertical borehole is illustrated in Figure 2-37. After lifting the container from the surface storage vault into the transporter cask, the transporter is driven underground to the emplacement borehole and positioned over the temporary shielding closure. The cask, which carries the container and provides primary shielding for the transporter operators, is then rotated to a vertical position, and the shield doors are opened. The waste container is lowered into the borehole, and the grapple is disconnected from the pintle on the waste container and retracted into the cask. The shield doors are then closed, the cask is rotated to its transport position, and the transporter is returned to the surface facility.

Following waste emplacement, borehole closure is accomplished by replacing the temporary shielding closure with a shield plug and borehole cover, allowing the shielding closure to be used for waste emplacement operations at other boreholes (Figure 2-38).

2.4.2.3 Horizontal Waste Emplacement Operations

Preparation of the horizontal borehole involves installation of the shielding closure using the modified forklift.

Transfer of a single waste container from the surface facility to a horizontal borehole is illustrated in Figure 2-39. After transferring a single waste container and its dolly from the surface storage vault to the cask, the transporter is driven to the emplacement borehole and is positioned at a temporary shielding closure. The cask is then rotated 90°, and the shielding doors are opened. The waste container and dolly are pushed into the borehole using the emplacement and retrieval

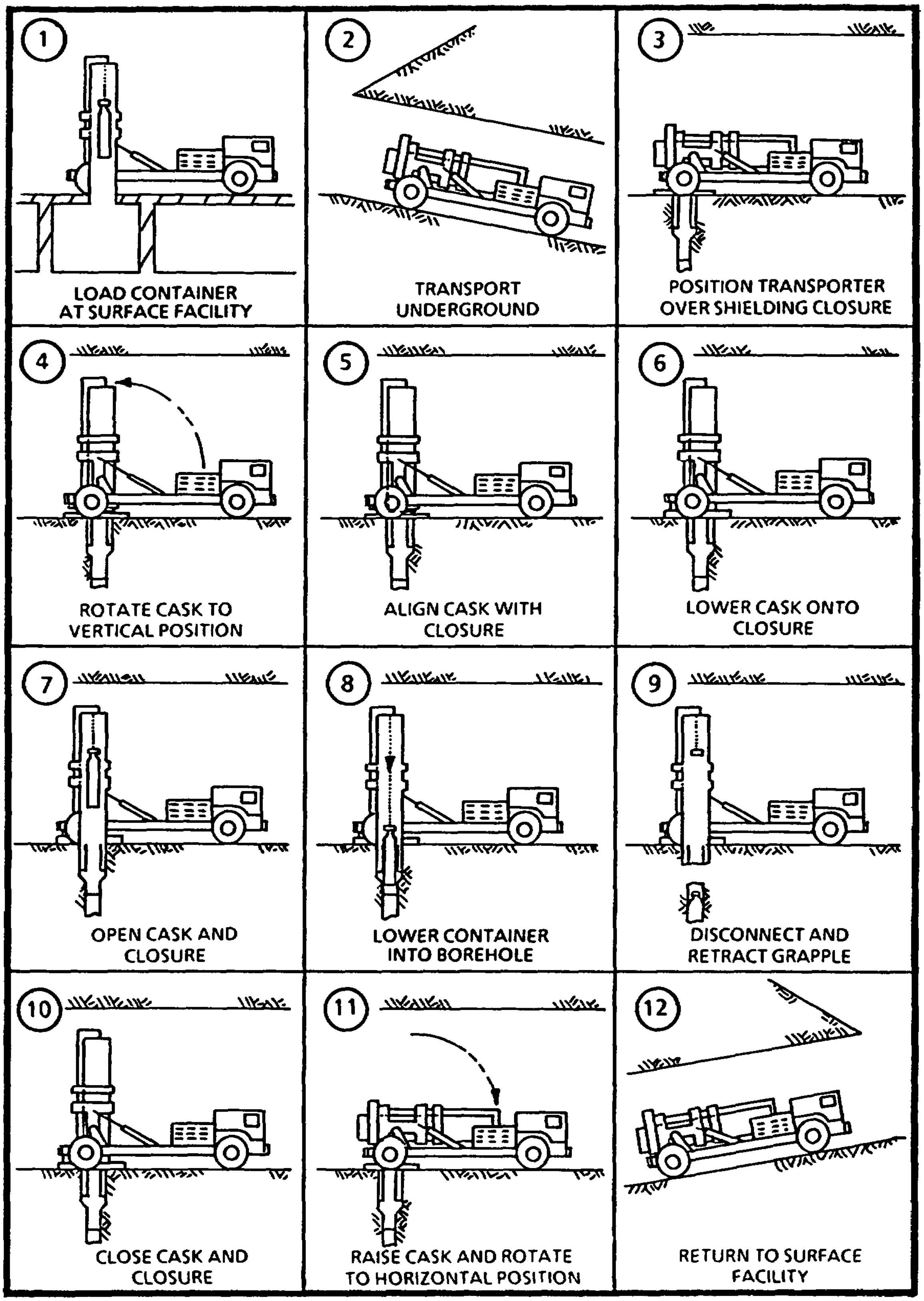


Figure 2-37. Vertical Emplacement of a Waste Container (from Figure 4-44, SCP-CDR)

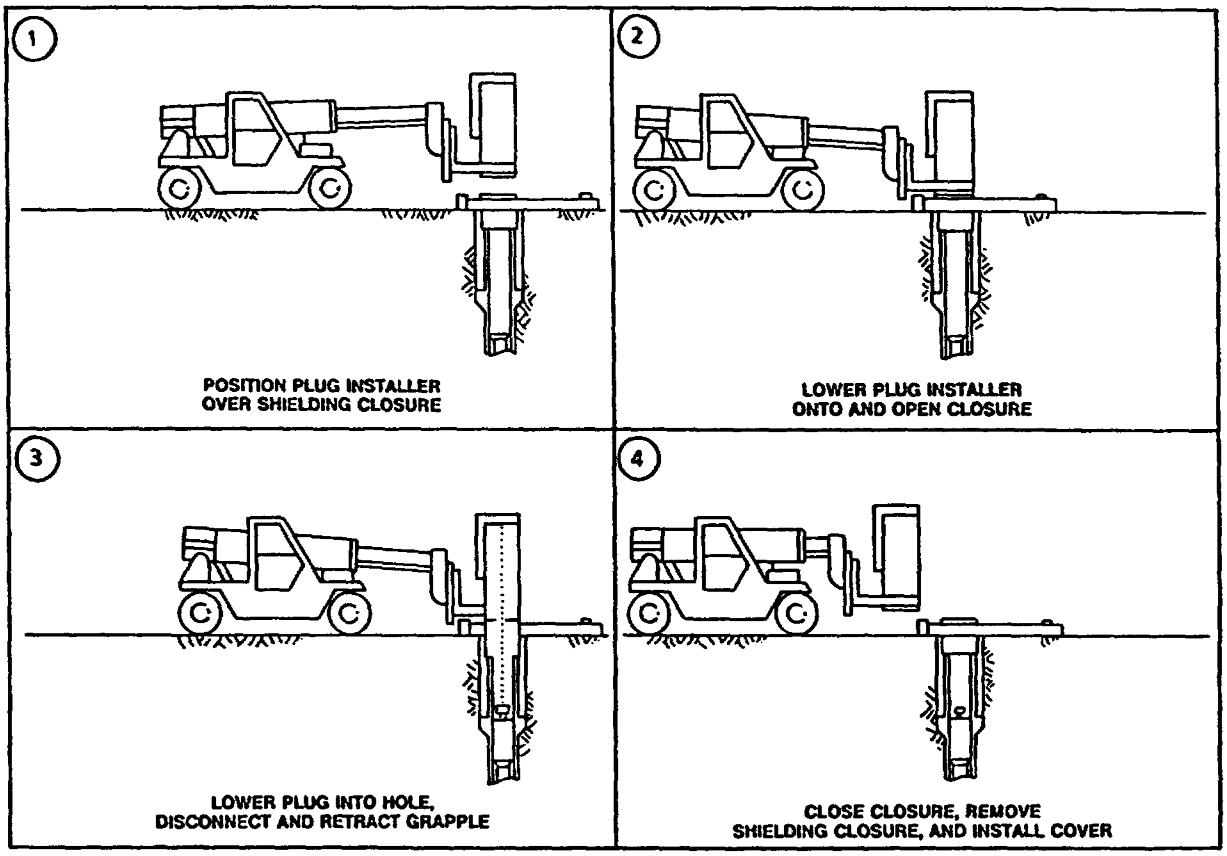


Figure 2-38. Closure of the Vertical Borehole (from Figure 4-45, SCP-CDR)

mechanism. The shielding doors are then closed, the cask is rotated to its transport position, and the transporter is returned to the surface facility. This procedure is repeated until the borehole has been filled to design capacity.

Achieving standoff between the last container emplaced and the emplacement drift can be accomplished in at least three ways. The first way (currently the reference for design purposes) is to use dummy containers or empty dollies, which are emplaced in the same manner as that used for a waste container. The second method is to use a pusher mechanism using hydraulic cylinders and coupled tubing to push the waste containers to the desired position. The third option entails using DHLW-filled containers (which have very low thermal output) as the last few containers emplaced in each borehole. Use of the third option would depend on whether commingling of DHLW and spent fuel in the same borehole is acceptable.

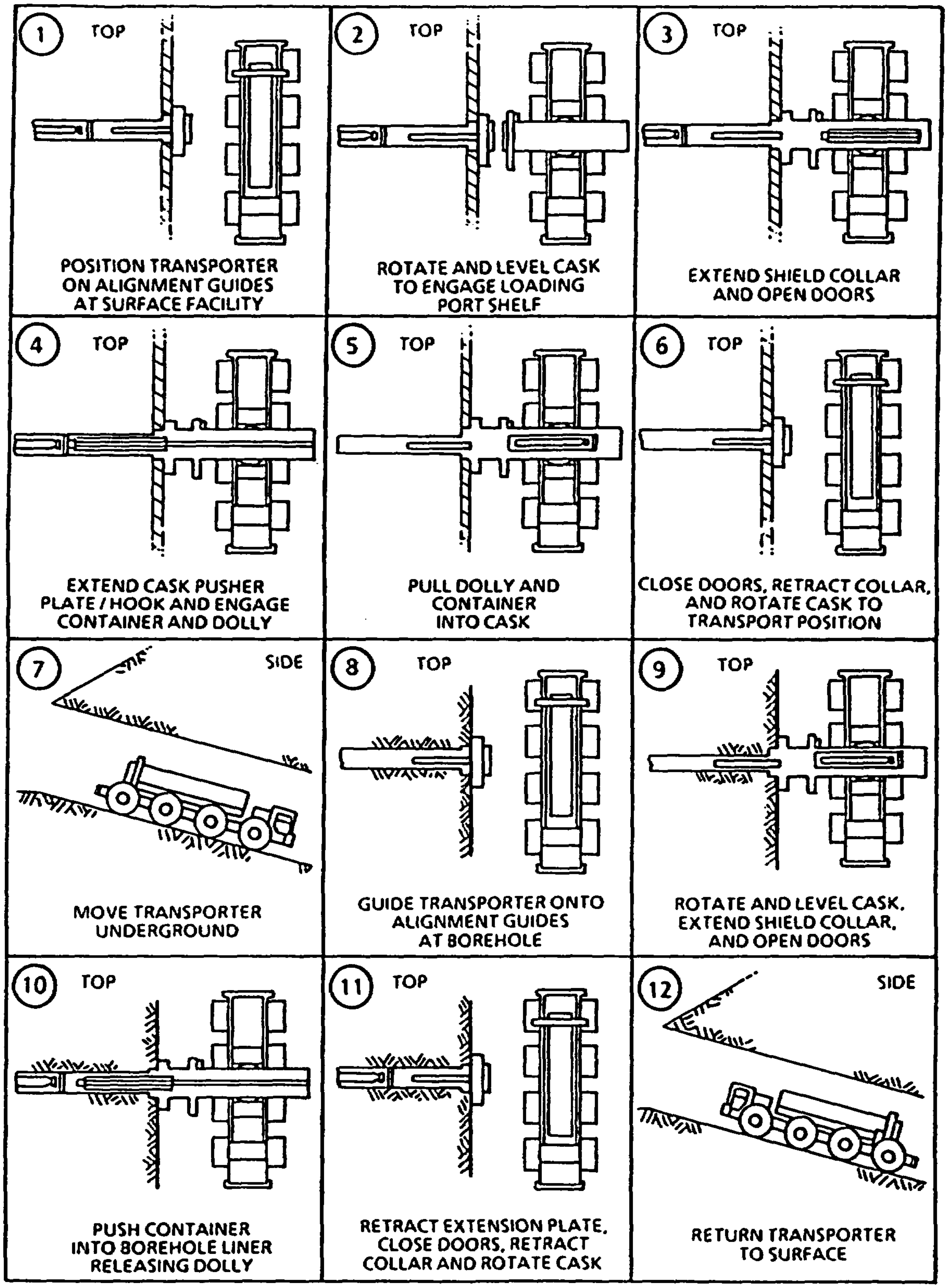


Figure 2-39. Horizontal Emplacement of a Waste Container (from Figure 4-49, SCP-CDR)

After all waste containers for a given borehole have been emplaced and standoff operations have been completed, final borehole closure is accomplished by replacing the temporary shielding enclosure with a shield plug and borehole cover, which allows the shielding closure to be used for waste emplacement operations at other boreholes (Figure 2-40).

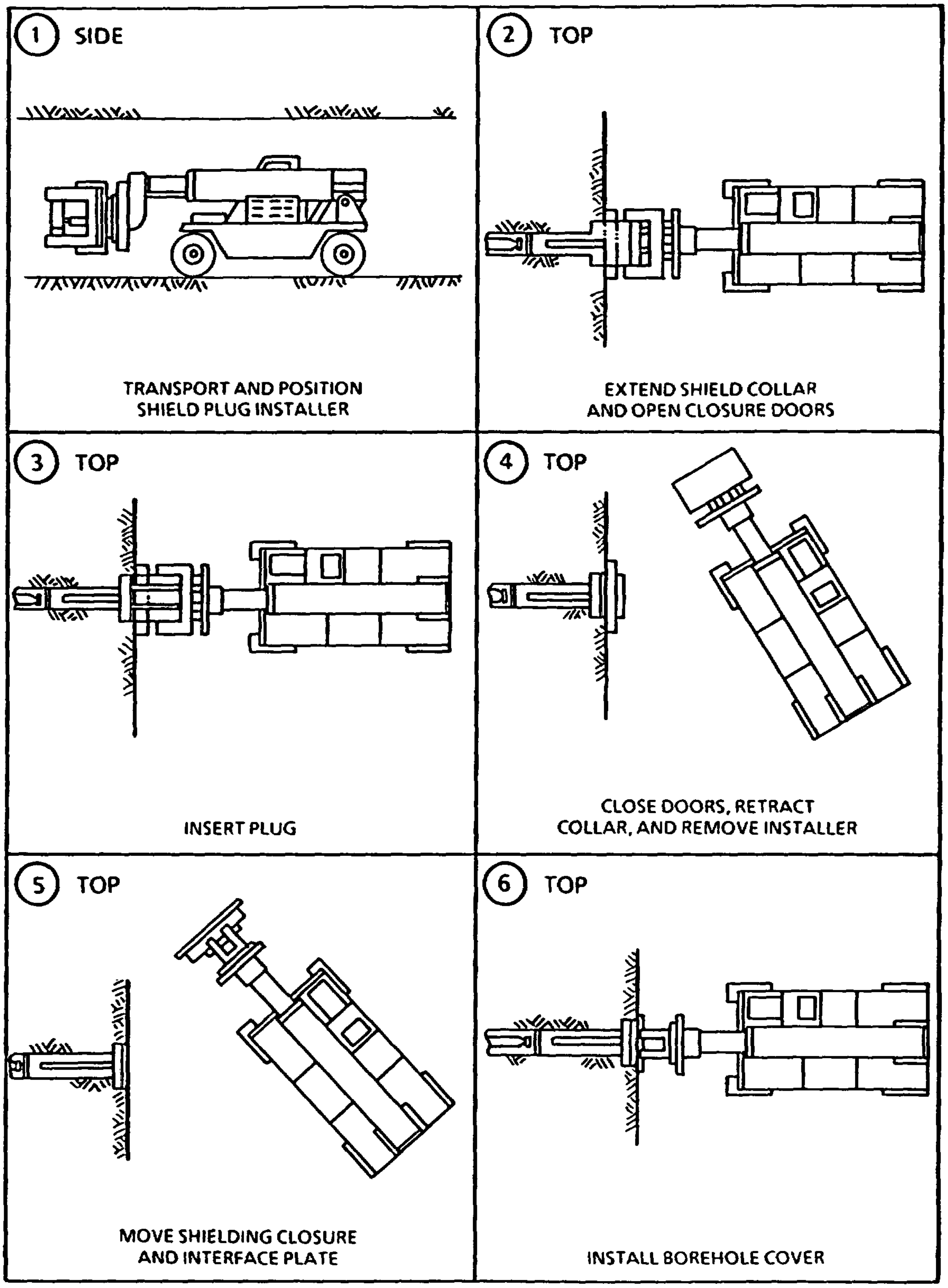


Figure 2-40. Closure of the Horizontal Borehole (from Figure 4-50, SCP-CDR)

REFERENCES FOR CHAPTER 2

Barton, N., R. Lien, and J. Lunde, "Engineering Classification of Rock Masses for the Design of Tunnel Support," Rock Mechanics, Vol. 6, No. 4, pp. 189-236, Springer-Verlag, New York, NY, 1974. (NNA.870406.0237)

California Administrative Code, Title 8, "Industrial Relations, "Part I, "Department of Industrial Relations," Chapter 4, "Division of Industrial Safety," July 1981. (NNA.900702.0009)

DOE (U.S. Department of Energy), "Generic Requirements for a Mined Geologic Disposal System," DOE/NE/44301-1, Office of Civilian Radioactive Waste Management, Washington, DC, September 1984. (NNA.870519.0102)

DOE (U.S. Department of Energy), "Mission Plan for the Civilian Radioactive Waste Management Program," DOE/RW-0005, Office of Civilian Radioac- tive Waste Management, Washington, DC, June 1985. (HQP.870601.0271)

DOL (U.S. Department of Labor), "Safety and Health Standards--Underground Metal and Nonmetal Mines," Code of Federal Regulations, Mineral Resources, Title 30, Part 57, Washington, DC, July 1985. (NNA.890411.0039)

Dravo Engineers, Inc., "Effect of Variations in the Geologic Data Base on Mining at Yucca Mountain for NNWSI," SAND84-7125, prepared for Sandia National Laboratories, Albuquerque, NM, December 1984. (HQS.880517.2283)

Eglinton, T. W., and R. J. Dreicer, "Meteorological Design Parameters for the Candidate Site of a Radioactive-Waste Repository at Yucca Mountain, Nevada," SAND84-0440/2, Sandia National Laboratories, Albuquerque, NM, December 1984. (NNA.870407.0048)

Friant, J. E., and P. B. Dowden, "Design of a Machine to Bore and Line a Long Horizontal Hole in Tuff," SAND86-7004, prepared by The Robbins Company for Sandia National Laboratories, Albuquerque, NM, September 1987. (HQS.880517.2292)

Johnstone, J. K., R. R. Peters, and P. F. Gnirk, "Unit Evaluation at Yucca Mountain, Nevada Test Site: Summary Report and Recommendation," SAND83-0372, Sandia National Laboratories, Albuquerque, NM, June 1984. (NNA.870519.0052)

Kenny Construction Company, "Installation of Steel Liner in Blind Hole Study," SAND85-7111, prepared for Sandia National Laboratories, Albuquerque, NM, September 1987. (HQS.880517.2310)

Langkopf, B. S., and P. F. Gnirk, "Rock-Mass Classification of Candidate Repository Units at Yucca Mountain, Nye County, Nevada," SAND82-2034, Sandia National Laboratories, Albuquerque, NM, February 1986. (HQS.880517.1662)

REFERENCES FOR CHAPTER 2
(concluded)

Mansure, A. J., and T. S. Ortiz, "Preliminary Evaluation of the Subsurface Area Available for a Potential Nuclear Waste Repository at Yucca Mountain," SAND84-0175, Sandia National Laboratories, Albuquerque, NM, December 1984. (NNA.870407.0047)

Mitchell, D., and A. Whillier, "Cooling Power of Underground Environments," Journal of the Mine Ventilation Society of South Africa, Vol. 25, No. 8, pp. 140-151, August 1972. (NNA.900702.0034)

NRC (U.S. Nuclear Regulatory Commission), "Standards for Protection Against Radiation," Code of Federal Regulations, Energy, Title 10, Part 20, Washington, DC, 1986. (NNA.890713.0151)

O'Brien, P. D., "Reference Nuclear Waste Descriptions for a Geologic Repository at Yucca Mountain, Nevada," SAND84-1848, Sandia National Laboratories, Albuquerque, NM, September 1985. (HQS.880517.2325)

Robbins Company, The, "Small Diameter Horizontal Hole Drilling--State of Technology," SAND84-7103, prepared for Sandia National Laboratories, Albuquerque, NM, November 1984. (HQS.880517.2332)

Robbins Company, The, "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, NM, July 1985. (HQS.880517.2333)

Russell, E. W., R. D. McCright, and W. C. O'Neal, "Containment Barrier Metals for High-Level Waste Packages in a Tuff Repository," UCRL-53449, Lawrence Livermore National Laboratory, Livermore, CA, October 1983. (NNA.891215.0013)

SNL (Sandia National Laboratories), "Site Characterization Plan Conceptual Design Report," SAND84-2641, compiled by H. R. MacDougall, L. W. Scully, and J. R. Tillerson, Sandia National Laboratories, Albuquerque, NM, September 1987. (NNI.880902.0014-.0019)

Sperry, P. E., "River Mountains Tunnel," Proc. of Second Symposium on Rapid Excavation, H. L. Hartman, ed., Sacramento, CA, October 1969. (NNA.900515.0012)

3.0 RETRIEVAL REQUIREMENTS AND DESIGN CRITERIA

Retrievability is required by the Nuclear Waste Policy Act (NWPA, 1983) (Section 122) and the Nuclear Waste Policy Amendments Act (NWPAA, 1987), and 10 CFR 60 (NRC, 1986b) [Section 111(b)]. Beyond those general requirements, 10 CFR 960 (DOE, 1986a) [Section 5-1(a)(3)] stipulates that the designs for construction and operation of the repository (which includes retrieval) use reasonably available technology. In response to these requirements, the U.S. Department of Energy (DOE) published the "Department of Energy Position on Retrievability and Retrieval for a Geologic Repository" (PRR) (Appendix B of this document). The PRR provides specific guidance for meeting the requirements for retrievability. This chapter discusses the requirements contained within the PRR, the resulting site-specific design criteria, and additional guidance needed from the DOE to ensure full compliance with the PRR.

3.1 Requirements Contained in the Position on Retrievability and Retrieval

The PRR contains three categories of requirements: (1) general, (2) design, and (3) operational. Figure 3-1 illustrates the organization of the requirements in the PRR; these requirements are discussed in the following sections. Although Section 5 of the PRR discusses performance confirmation, it does not contain any retrieval-related requirements and is not included on the figure. However, a discussion of the relationship between the performance confirmation program and the strategy for retrieval and retrievability is included here in Section 3.1.4.

3.1.1 General Requirements

Table 3-1 contains a synopsis of the general requirements contained in the PRR. Requirement 1.0(a) obligates the Yucca Mountain Project to include in the repository design and operations plan the retrievability requirements contained in the NWPA and 10 CFR 60, as well as those contained in the PRR. (See Appendix C for NWPA and 10 CFR 60 requirements.)

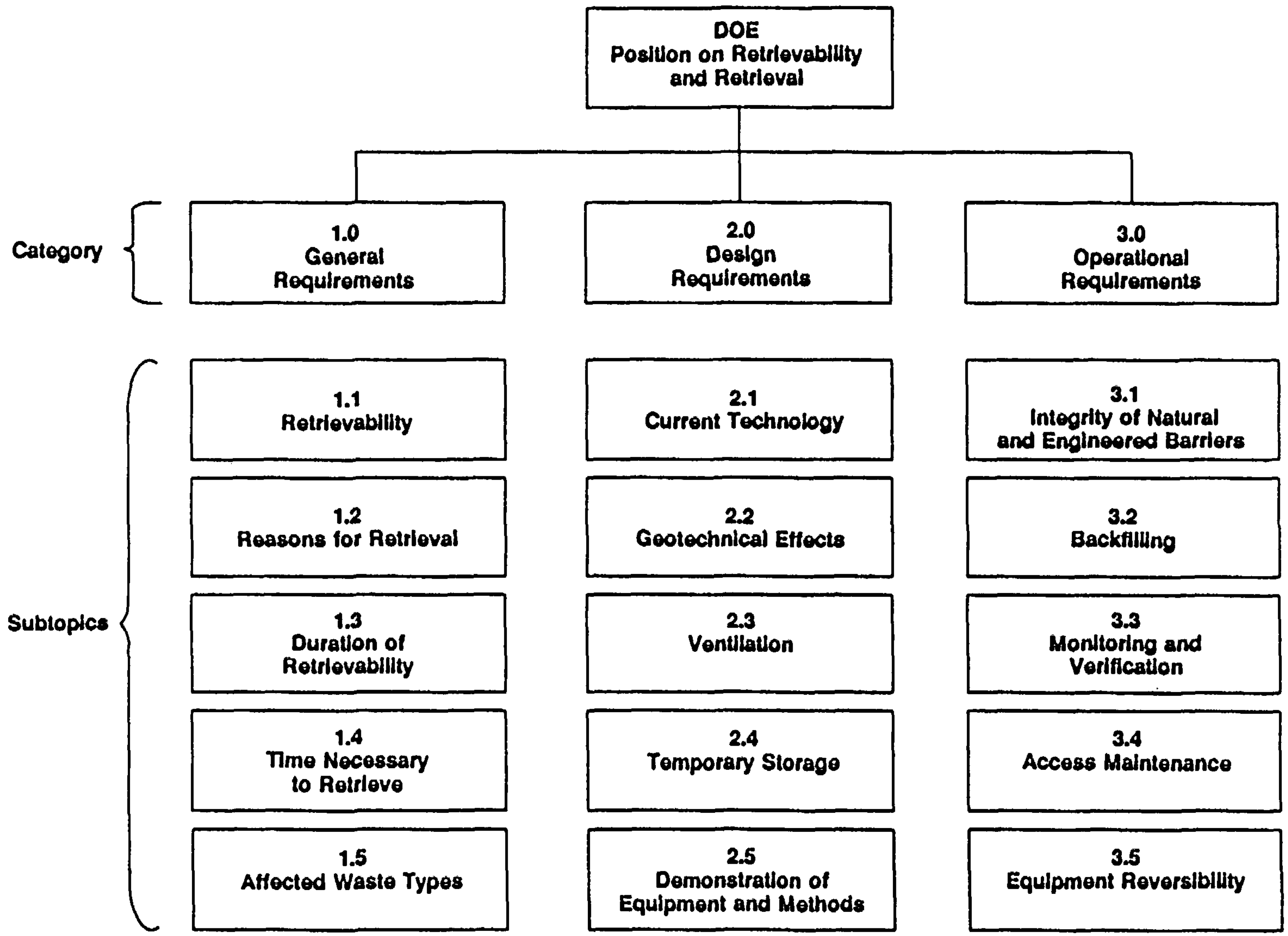


Figure 3-1. Organization of Retrievability Requirements Contained in the Position on Retrievability and Retrieval (from Table 2-19, SCP-CDR)

TABLE 3-1

SYNOPSIS OF GENERAL REQUIREMENTS FROM THE POSITION ON RETRIEVABILITY AND RETRIEVAL

Category or Subtopic	Requirement
1.0 General Requirements	1.0(a) The design of the waste retrieval capability must conform to the NWPA and 10 CFR 60.
1.1 Retrievability	1.1(a) The repository shall be designed, constructed, and operated with the capability to retrieve any or all of the emplaced waste within the time limits described under Subtopics 1.3 and 1.4.
	1.1(b) No act, whether by design or circumstance, shall preclude the capability of waste retrieval for the reasons identified in Subtopic 1.2.
	1.1(c) The act of waste retrieval is considered to be completed when the waste is brought back to the surface.
1.2 Reasons for Retrieval	1.2(a) There are two potential reasons for waste retrieval: (1) protection of public health and safety and the environment [ordered by the Nuclear Regulatory Commission (NRC)] and (2) recovery of resources (ordered by the DOE).
1.3 Retrievability Duration	1.3(a) The repository design shall assume that re trieval can start at any time for 50 yr after waste emplacement commences.
1.4 Time Necessary to Retrieve	1.4(a) For full repository retrieval, waste retrieval shall be performed as quickly as is safely practicable.
	1.4(b) To the extent it is feasible, retrieval should be accomplished on a reasonable schedule as defined in 10 CFR 60.111(b)(3).
	1.4(c) No specific time limit applies to retrieval for resource recovery as long as emplacement operations are scheduled to continue.
	1.4(d) If full or partial retrieval is ordered, all major operational and construction revisions will be completed before retrieval begins.
1.5 Affected Waste Types	1.5(a) All forms of spent fuel, defense high-level waste, and civilian high-level waste will be retrievable regardless of physical characteristics (e.g., weight and shape) and location within the repository.

3.1.1.1 Retrievability

Requirements 1.0(a) and 1.1(a) address the requirements for retrievability contained in 10 CFR 60.111(b)(1) and Section 122 of the NWPA. Requirement 1.1(b) requires review of designs and design modifications to ensure that potential effects on retrievability are considered. Initially, those reviews will consist of peer and management reviews. After submission of the license application, modifications that would make the emplaced waste irretrievable or substantially more difficult to retrieve would require license amendment [10 CFR 60.46(a)(1)].

Requirement 1.1(c) defines completion of retrieval activities. The PRR considers retrieval activities completed when the waste is placed in temporary storage at the surface (PRR, Section 2.1). Activities associated with the repackaging, transport offsite, and final disposition of waste are not part of retrieval and are not addressed in the PRR.

3.1.1.2 Reasons for Retrieval

Requirement 1.2(a) defines the PRR as specifically applicable to waste removal for protection of the public and the environment or for resource recovery. The DOE acknowledges that waste removal may be required for many other reasons, but that waste removal for any reasons other than those specified is not considered retrieval and is not governed by the requirements contained in the PRR. Waste removal activities not classified as retrieval are subject to applicable NRC regulations.

In Section 2.2 of the PRR, retrieval is described as an "extraordinary event" incurring great cost and effort, which is consistent with the requirements for licensing (NRC, 1982). Because the DOE will have had to provide reasonable assurance in the license application that the performance objectives pertaining to protection of the public and the environment will be met, it is extremely unlikely that the repository or the waste package will fail to meet the performance objectives, which would result in NRC-imposed retrieval. In addition, the DOE will not emplace spent fuel in the repository if reprocessing of spent fuel proves to be cost effective. Consequently, it is very unlikely that retrieval will be required for recovery of resources.

Because retrieval is an "extraordinary event," the capability for retrieval is included in the repository design only as a planned contingency. The substantial cost and level of effort needed for retrieval and all other consequences will be considered before making a decision to retrieve.

3.1.1.3 Retrievability Duration

Requirement 1.3(a) is derived from 10 CFR 60.111(b)(1), which requires that the geologic repository operations area must be designed so that retrieval operations could be initiated at any time during the 50-yr period that begins with the commencement of waste emplacement. In addition to Requirement 1.3(a), there are three other references in 10 CFR 60 and the PRR to the retrievability period.

- The design must include the option to retrieve any or all emplaced waste throughout waste emplacement, and thereafter, until completion of the performance confirmation program and NRC review [10 CFR 60.111(b)(1)].

- The DOE may desire to extend the retrievability period beyond 50 yr to facilitate resource recovery (PRR, Section 2.3).

- On a case-by-case basis, the NRC may approve or specify a different time period that is consistent with the emplacement schedule and the planned performance confirmation program [10 CFR 60.111(b)(1)].

The design basis for the Yucca Mountain repository includes a 50-yr retrievability period, but the design will not preclude the ability to extend the retrievability period, if required.

3.1.1.4 Time Necessary to Retrieve

Regulations regarding the retrieval period include PRR Requirement 1.4(a), which specifies that the health and safety of the public (including workers) are the primary considerations in defining the retrieval period, and 10 CFR 60.111(b)(1), in which the NRC requires that the geologic repository operations area be designed so that any or all of the emplaced waste could be retrieved on a reasonable schedule. In 10 CFR 60.111(b)(3), a reasonable schedule is defined as "one that would permit retrieval in about the same time as that devoted to construction of the geologic repository operations area and the emplacement of wastes" [Requirement 1.4(b)].

The design-basis retrieval schedule for the Yucca Mountain Project is presented in Figure 3-2. As shown in the figure, the design-basis retrieval period is 34 yr (6 yr for construction and 28 yr for

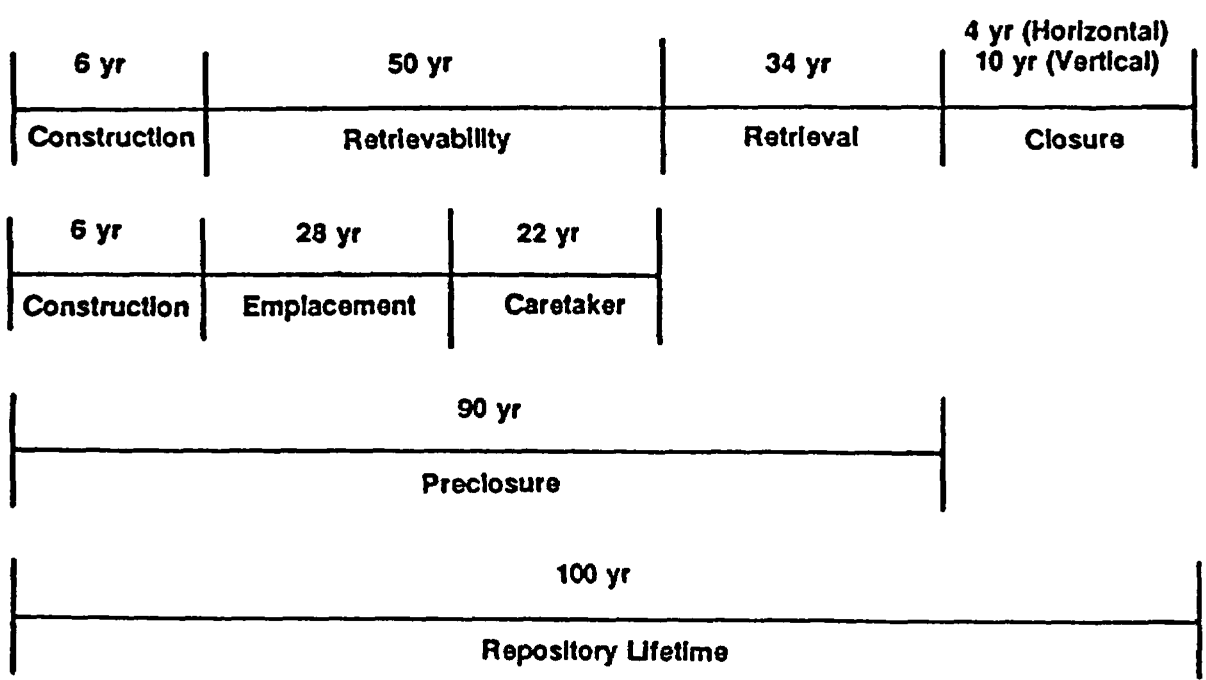


Figure 3-2. Design-Basis Retrieval Period (from Figure 3-1, SCP-CDR)

emplacement), which complies with 10 CFR 60. However, if retrieval is mandated, this period will be reevaluated to ensure the health and safety of the repository personnel and the public.

The time needed for closure is estimated to be 10 yr for vertical emplacement and 4 yr for horizontal emplacement (SNL, 1987). The 90-yr preclosure lifetime combined with the 10-yr closure period (vertical) results in a repository lifetime of 100 yr.

If partial retrieval for resource recovery is ordered during emplacement, no specific time limit for retrieval operations will be established [Requirement 1.4(c)]. If retrieval for this reason takes place after completion of emplacement operations, the waste will be removed as quickly as is safe and practicable [Requirement 1.4(a)].

The retrieval process begins with a period of preparation which includes modifications and/or procurement of equipment, modifications to the ventilation system and the waste-handling building, and construction of any additional temporary storage needed (Section 6.1). Requirement 1.4(d) states that these modifications must be completed before waste removal operations can commence.

There are two possible interpretations for Requirement 1.4(d): (1) as an operational restriction for the initiation of waste removal activities and (2) as a definition for the beginning of the retrieval period. The first interpretation poses a potential conflict with Requirement 1.4(a) which requires that retrieval be performed as quickly as is safely practicable. For health and safety or economic reasons, it may be advantageous to initiate waste removal before completion of construction and modification activities. The Yucca Mountain Project proposes that, in these instances and at the discretion of the DOE, waste-removal activities be initiated before completion of construction and modification activities. The second interpretation appears to conflict with PRR Section 2.4, which implies that the retrieval period will include a period of preparation (Appendix B). DOE review and clarification of Requirement 2.4 is requested in Section 3.3.

3.1.1.5 Affected Waste Types

In Requirement 1.5(a), the DOE limits the applicability of the PRR to all high-level waste in the current design basis for disposal at the Yucca Mountain repository. All other forms of radioactive waste potentially acceptable for disposal at the repository are not governed by the requirements contained in the PRR. Retrievability requirements for these types of waste will be addressed, if necessary, at a later time.

3.1.2 Design Requirements

Table 3-2 contains a synopsis of the PRR design requirements. Requirement 2.0(a) addresses the fact that the primary function of the repository is the containment and isolation of waste. The inclusion of the retrieval option in the repository design must not adversely affect the ability of the repository to meet the requirements for containment and isolation of waste specified in 10 CFR 60.112 and 10 CFR 60.113.

To avoid unnecessary complication of the design, design enhancements in support of retrieval are integrated into the design of the emplacement method. An example is the use of borehole liners. Included in the design to provide predictable access to the waste for retrieval purposes, they will also facilitate emplacement of waste by controlling rockfall in the emplacement boreholes.

In addressing Requirement 2.0(b), the Yucca Mountain Project has developed preliminary concepts for identifying credible malfunctions, accidents, processes, and events that might apply to the repository site. These concepts are described in Appendix L-2 of the "Site Characterization Plan Conceptual Design Report" (SCP-CDR) (SNL, 1987). The resulting retrieval conditions are described in Section 5.2 of this document. In the future, the concepts presented in Figure 3-3 will be used to integrate the classification of retrieval conditions with design, equipment, and demonstration requirements (Section 8.2). Further discussion of the concepts presented in Figure 3-3 is provided in Section 3.2.1.

TABLE 3-2

SYNOPSIS OF DESIGN REQUIREMENTS FROM THE POSITION ON RETRIEVABILITY AND RETRIEVAL

Category or Subtopic	Requirement
2.0 Design Requirements	2.0(a) The inclusion of the waste retrieval capability shall not affect or unnecessarily complicate the repository design such that the primary function of the repository, containment and isolation of waste, is compromised.
	2.0(b) The retrieval method shall anticipate both normal and abnormal conditions.
	2.0(c) The design of the waste container shall consider the potential need for waste retrieval.
	2.0(d) The design of the retrieval method shall minimize occupational health and safety hazards.
2.1 Current Technology	2.1(a) The design for waste retrieval capability shall employ levels of technology that are determined to be reasonably available at the time of license application.
2.2 Geotechnical Effects	2.2(a) The design for waste retrieval capability shall anticipate the potential for deterioration and degradation of geotechnical conditions.
2.3 Ventilation	2.3(a) Additional ventilation requirements for retrieval will be designed at the same time as the repository.
	2.3(b) Additional ventilation facilities and equipment required for retrieval need not be constructed at the time of repository construction.
2.4 Temporary Storage	2.4(a) The design of the repository operations area will not preclude the ability to construct temporary storage facilities at a later time if needed.
2.5 Demonstration of Equipment and Methods	2.5(a) Retrieval concepts, methods, and nonstandard equipment will be (1) designed and engineered before license application to function under both normal and abnormal conditions, (2) tested in mock-up environments during proof-of-principle demonstrations, and (3) further tested under selected repository conditions during prototypical equipment development (if needed).
	2.5(b) Proof-of-principle demonstrations will be completed and documented before submission of the license application to the NRC.
	2.5(c) Prototypical equipment development may continue, if needed, until the license to receive and possess is granted by the NRC.

PROBABILITY	10^{-1}	10^{-3}	10^{-5}
CONDITION CLASSIFICATION	NORMAL	ABNORMAL	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 AND (AS NEEDED) PROTOTYPE	PROOF-OF-PRINCIPLE (AS NEEDED)	NONE

Figure 3-3. Classification of Retrieval Conditions Based on Probability (from Figure 2-11, SCP-CDR)

The design of the waste container must consider the potential effects of retrieval [Requirement 2.0(c)]. Specifically, the container design must consider (1) the structural loads during retrieval, (2) degradation with time of the strength of the container, (3) any requirements resulting from the retrieval method, and (4) the effect of abnormal conditions on the waste container.

Requirement 2.0(d) emphasizes that the repository design must minimize radiologic and nonradiologic hazards for the repository workers and the general public. Federal requirements for radiologic and nonradiologic protection are contained in regulations and orders established by the DOE, the NRC, the U.S. Department of Labor (DOL), and the Environmental Protection Agency (EPA). A list of these regulations and orders is contained in Table 3-3.

3.1.2.1 Current Technology

Requirement 2.1(a) applies the 10 CFR 960 requirement for the use of reasonably available technology to retrieval. For Yucca Mountain, the current design of retrieval methods, equipment, and procedures use technology expected to be reasonably available by the time that submittal of the license application is scheduled. During design development, the DOE will define the acceptable limits of technology.

3.1.2.2 Geotechnical Effects on Rock Behavior

Requirement 2.2(a) acknowledges that deterioration of geotechnical conditions in the repository can occur with time and requires that it be considered in the design of the retrieval capability. The primary concern for Yucca Mountain is the effect of thermally induced stresses on the stability of drifts and emplacement boreholes. A discussion of this topic is contained in Section 5.1.2.

TABLE 3-3

FEDERAL REQUIREMENTS FOR RADIOLOGIC AND NONRADIOLOGIC PROTECTION*

NRC

"Standards for Protection Against Radiation," 10 CFR 20 (NRC, 1986a).

"Domestic Licensing of Production and Utilization Facilities," 10 CFR 50 (NRC, 1987a).

"Environmental Protection Regulations for Domestic Licensing and Related Regulatory Functions," 10 CFR 51 (NRC, 1987b).

"Disposal of High-Level Radioactive Wastes In Geologic Repositories; Licensing Procedures," 10 CFR 60 (NRC, 1986b).

EPA

"National Primary and Secondary Ambient Air Quality Standards," 40 CFR 50 (EPA, 1986a).

"EPA Administered Permit Programs: The National Pollutant Discharge Elimination System," 40 CFR 122 (EPA, 1986b).

"National Primary Drinking Water Regulations," 40 CFR 141 (EPA, 1986c).

"National Interim Primary Drinking Water Regulations Implementation," 40 CFR 142 (EPA, 1986d).

"National Secondary Drinking Water Regulations," 40 CFR 143 (EPA, 1986e).

"Regulations for the Enforcement of the Federal Insecticide, Fungicide, and Rodenticide Act," 40 CFR 162 (EPA, 1986f).

"Environmental Radiation Protection Standards for Nuclear Power Operations," 40 CFR 190 (EPA, 1986g).

"Environmental Radiation Protection Standards for Management and Disposal of Spent Nuclear Fuel, High-Level and Transuranic Radioactive Wastes," 40 CFR 191 (EPA, 1986h).

"Noise Emission Standards for Construction Equipment," 40 CFR 204 (EPA, 1986i).

"Toxic Substance Control Act," 40 CFR Chapter 1 (EPA, 1986j).

*Information from Table 2-23, SCP-CDR

TABLE 3-3

FEDERAL REQUIREMENTS FOR RADIOLOGIC AND NONRADIOLOGIC PROTECTION (concluded)

DOL

"Occupational Safety and Health Standards," 29 CFR 1910 (DOL, 1986a).

"Safety and Health Regulations for Construction," 29 CFR 1926 (DOL, 1986b).

"Safety and Health Standards--Underground Metal and Nonmetal Mines," 30 CFR 57 (DOL, 1985).

DOE

"General Guidelines for the Recommendation of Sites for Nuclear Waste Repositories," 10 CFR 960 (DOE, 1986a).

"Environment, Safety, and Health Program for Department of Energy Operations," DOE Order 5480.1B (DOE, 1986b).

"Environmental Protection, Safety, and Health Protection Standards," DOE Order 5480.4 (DOE, 1984).

"Safety Analysis and Review System," DOE Order 5481.1B. (DOE, 1986c).

"Environmental, Safety, and Health Appraisal Program," DOE Order 5482.1B (DOE, 1986d).

"Occupational Safety and Health Program for DOE Contractor Employees at Government-Owned Contractor-Operated Facilities," DOE Order 5483.1A (DOE, 1983a).

"Vital Records Protection Program," DOE Order 5500.1 (DOE, 1981a).

"Emergency Management System," DOE Order 5500.1A (DOE, 1987).

"Reactor and Non-Reactor Facility Emergency Planning, Preparedness, and Response Program for Department of Energy Operations," DOE Order 5500.3 (DOE, 1981b).

"General Design Criteria," DOE Order 6430.1 (DOE, 1983b).

3.1.2.3 Ventilation

Because of the increased temperature in the drift, ventilation requirements for retrieval could vary significantly from those for emplacement. Also, if the emplacement drifts are closed before the decision to retrieve is made, cooling will be necessary to provide an acceptable environment. Consequently, retrieval may require additional fan or exhaust capability, the addition of cooling capacity, or the modification of the distribution system.

The ventilation requirements for retrieval must be identified and included in the repository design basis [Requirement 2.3(a)]. The resulting design and construction criteria for ventilation system modifications will be submitted with the license application; these modifications need not be included in the initial construction [Requirement 2.3(b)]. However, the time needed to perform these modifications must be considered in establishing the actual retrieval period (Section 3.1.1.4).

3.1.2.4 Temporary Storage

The need for temporary storage will depend on the reason for retrieval, the extent of retrieval operations, and the details for final disposition of the retrieved waste. Because these variables are not clearly defined, flexibility in the design for temporary storage of retrieved waste is essential. Further, the DOE requires flexibility in the design to allow for the construction of temporary storage either underground or on the surface [Requirement 2.4(a)]. Storage constructed for emplacement operations can be used for retrieval. The current repository design includes lag storage for 210 waste containers. The time required to construct any additional storage facilities must be considered in determining the actual retrieval period (Section 3.1.1.4).

Because waste removal for performance confirmation purposes is not considered an act of retrieval, any storage of waste associated with performance confirmation is not subject to the requirements contained in the PRR.

3.1.2.5 Demonstration of Retrieval Equipment and Methods

Requirement 2.5(a) outlines the three activities that must be performed to demonstrate compliance with the performance objectives for retrievability contained in 10 CFR 60.111(b). The sequencing of these activities is shown in Figure 3-4.

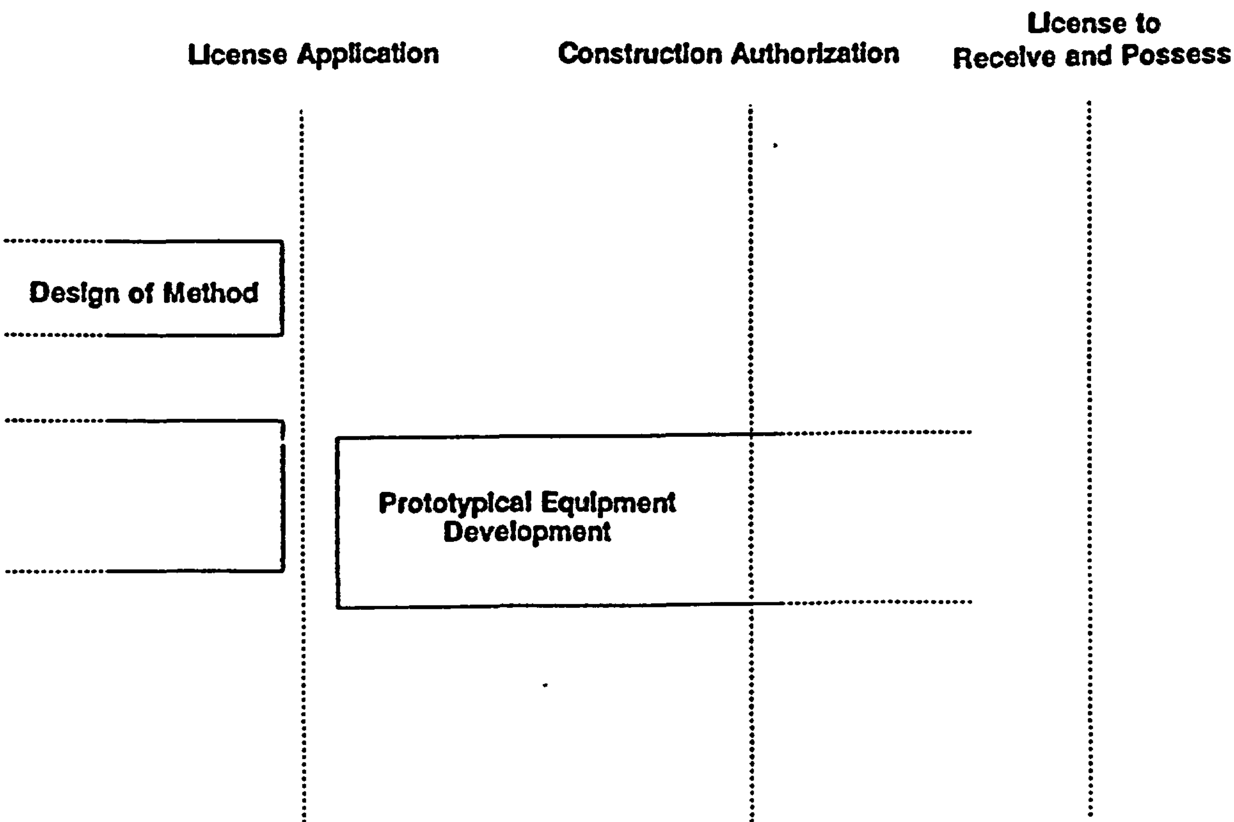


Figure 3-4. Sequence of Retrieval Equipment Development

Design of Retrieval Method

As shown in Figure 3-4, the design of the retrieval method must be completed by the time of license application submission. The design documents will specify the following:

- the sequence of retrieval activities,
- an analysis of retrieval methods under both normal and abnormal conditions,
- the anticipated time to retrieve waste,
- the potential worker radiologic exposure,
- the excavation techniques (if needed),
- the proposed responses to equipment malfunctions,
- the use of temporary storage,
- the effect of the emplacement orientation on retrieval,
- the contingencies for removal of lodged or displaced waste containers, and
- all other aspects of mechanically retrieving the emplaced waste.

Proof-of-Principle Demonstration

Retrieval may necessitate the use of nonstandard equipment (i.e., equipment that is not currently available or is not under use in similar conditions). Proof-of-principle demonstrations will be performed to establish confidence in the use of nonstandard equipment under normal and selected abnormal conditions. As specified in PRR 3.5.2, the proof-of-principle demonstrations will include only those equipment subsystems or components for which performance uncertainties exist. Consequently, fabrication of a complete set of retrieval equipment is not necessary or planned. As shown in Figure 3-4, proof-of-principle demonstrations must be completed by the time of license application submission [Requirement 2.5(b)].

Prototypical Equipment Development

In the PRR, the DOE acknowledges that unanswered questions may remain after submission of the license application regarding equipment performance under geo- technically affected conditions. A prototypical equipment development program may be needed to support confidence in the ability to perform retrieval operations under normal and credible abnormal conditions.

The time between submission of the license application and the grant of a license to receive and possess is available if needed for prototypical equipment development [Requirement 2.5(c), Figure 3-4].

The Yucca Mountain Project will develop credible retrieval scenarios from the list of normal and credible abnormal conditions (Chapter 5), the repository design (Chapter 2), and the retrieval operations (Chapter 6). From these scenarios, key geotechnical, operational, or equipment uncertainties will be identified and emphasized in the development program. Mock-up locations that are capable of simulating these key uncertainties are acceptable in demonstrations of prototypical equipment (PRR, Section 3.5.3).

In addition to simulation, the prototypical equipment development program must also consider the potential for changes in the physical condition and orientation of the waste container that could affect the ability to retrieve.

Demonstrations planned for Yucca Mountain do not include the use of radioactive material. Radiation safety equipment will be included, as needed, for demonstration purposes.

3.1.3 Operational Requirements

Table 3-4 contains a synopsis of the PRR operational requirements. Requirement 3.0(a) emphasizes that the requirement for retrievability applies as much to operations as design. Maintenance of retrieval equipment is discussed in Requirement 3.0(b), which applies to the waste transporter, the auxiliary equipment used to install the shield plugs and shielding closures, the ventilation equipment, the shielding closures, and portions of the surface facility waste-handling building (e.g., shielded closure and temporary storage). For economic reasons, an interpretation of "maintained in working condition" is proposed that includes the use of moth-ball storage as long as the ability to meet the reasonable schedule requirement in 10 CFR 60.111(b)(3) can be demonstrated. Using this definition, the following bases for equipment maintenance is proposed.

TABLE 3-4

SYNOPSIS OF OPERATIONAL REQUIREMENTS FROM THE POSITION ON RETRIEVABILITY AND RETRIEVAL

Category or Subtopic	Requirement
3.0 Operational Requirements	3.0(a) The repository shall be operated so that any or all of the emplaced waste can be retrieved within the time limits established in Subtopics 1.3 and 1.4. 3.0(b) Retrieval equipment that is in existence at the end of the emplacement period shall be maintained in working condition until the end of the retrieval period.
3.1 Barrier Integrity	3.1(a) For full repository retrieval, protection of the natural and engineered barriers is not required if no additional nuclear material is to be emplaced in the repository. 3.1(b) For partial retrieval, the retrieval method must not adversely affect the integrity of the natural and engineered barriers in areas adjacent to those where waste remains.
3.2 Backfilling	3.2(a) Backfilling of the repository is allowed (but not required) as long as all retrieval-related requirements are met.
3.3 Monitoring and Verification	3.3(a) Retrieval-related underground monitoring will be limited to areas of performance confirmation, test and evaluation facilities, and other research areas. 3.3(b) No ongoing monitoring of waste packages, over and above that required for the performance confirmation program, is required for retrievability purposes.
3.4 Access Maintenance	3.4(a) The repository will be operated and maintained so that all areas required for retrieval of waste are accessible during the retrievability period. 3.4(b) Immediate or ready access to emplacement areas for the purpose of retrieval is not required.

TABLE 3-4

SYNOPSIS OF OPERATIONAL REQUIREMENTS FROM THE POSITION ON RETRIEVABILITY AND RETRIEVAL (concluded)

Category or Subtopic	Requirement
3.5 Equipment Reversibility	3.5(a) Ready or instantaneous reversal of emplacement equipment used for retrieval is not required.
	3.5(b) Reversal of repository operations will be included in the repository design but will not be constructed unless retrieval is required.
	3.5(c) The required retrieval of waste is considered a "nonroutine" operating condition and, as such, may interrupt waste emplacement operations.

- Retrieval equipment required for performance confirmation will be maintained in operating condition.

- Retrieval equipment used underground (transporter, auxiliary equipment, and shielding closures) will be stored either underground or on the surface in a facility that provides basic protection from environmental damage.

- The structure of the waste-handling building will be maintained to protect the equipment from the environment.

- The ventilation equipment will be maintained to provide ventilation for performance confirmation and drift maintenance purposes.

3.1.3.1 Integrity of Natural and Engineered Barriers

The primary mission of the repository is the containment and isolation of waste as defined in the postclosure performance objectives contained in 10 CFR 60, Sections 112 and 113. As long as any portion of the repository is used for permanent disposal of waste, the retrieval method must not interfere with the ability of the repository to contain and isolate the remaining waste [Requirement 3.1(b)].

For Yucca Mountain, the retrieval method is being designed so that the ability of the repository to contain and isolate waste in adjacent areas will not be compromised. Reuse of emplacement rooms is allowable, at the discretion of the DOE, as long as the requirements for containment and isolation are met. However, under certain abnormal conditions, the borehole may not be reusable (e.g., conditions that require overcoring).

3.1.3.2 Backfill

The use of backfill during the preclosure period (Figure 3-2) must not preclude the ability to meet all of the retrieval-related requirements contained in the PRR [Requirement 3.2(a)]. The current repository design does not include the use of backfill before permanent closure of the repository. Consequently, Requirement 3.2(a) does not impose any restrictions on the repository design.

3.1.3.3 Monitoring and Verification

Requirement 3.3(a) places practical limits on the extent to which repository monitoring for retrieval purposes will be required. At Yucca Mountain, it is anticipated that rock properties will vary throughout the repository horizon. Key parameters will be monitored at specific locations in the repository to determine repository conditions for retrieval. The number and actual location of monitoring sites will depend upon variances in the geologic media encountered during repository construction.

The monitoring of waste packages done for performance confirmation will be sufficient to verify waste package response to the in situ environment [Requirement 3.3(b)]. The monitoring will be performed in the performance confirmation area (Figure 2-6). Although some of the data generated by the performance confirmation program will be used for retrieval-related purposes, the performance confirmation program is concerned with postclosure performance, not retrievability. Therefore, requirements for retrieval-related monitoring will not place restrictions on the performance confirmation program.

Verification of retrieval methods and equipment will be performed during proof-of-principle demonstrations and prototype development (Section 3.1.2.5). Although removal of waste for performance confirmation is not required to verify retrievability, it will demonstrate further the ability to retrieve waste.

3.1.3.4 Access Maintenance

Access to the emplaced waste for retrieval is required throughout the retrievability period [Requirement 3.4(a)]. However, access is not required to be immediately available [Requirement 3.4(b)]. For the Yucca Mountain repository design, the ramp and access drifts will be maintained continuously during the retrievability period. The emplacement drifts will be closed off after waste emplacement has been completed and then will receive periodic inspection and (as needed) maintenance on an approximately 5-yr basis to ensure waste accessibility.

3.1.3.5 Equipment Reversibility

Because retrieval is a planned contingency, the immediate reversibility of existing equipment (from emplacement to retrieval mode) is not required [Requirement 3.5(a)], and equipment and facilities required for reversal of repository operations need not be constructed unless retrieval is ordered [Requirement 3.5(b)]. Methods for reversal of repository operations will be developed as stipulated in Requirement 2.5(a).

In Requirement 3.5(c), the DOE classifies retrieval operations as nonroutine because they are allowed to interrupt routine emplacement operations. At the discretion of the DOE, simultaneous emplacement and retrieval operations are allowed. However, the decision to continue waste emplacement during retrieval operations will consider

- the reason for retrieval;
- the safety of the public and repository workers;

- equipment, personnel, and surface facility availability;
- underground ventilation; and
- any physical and operational constraints in the underground areas.

3.1.4 Performance Confirmation

Although retrieval and retrievability are not included in the performance confirmation program, the following aspects of the performance confirmation program affect the strategy for retrieval and retrievability.

- The data from the performance confirmation program may drive or directly influence the decision to retrieve.

- The duration of the retrievability period is related to the duration of the performance confirmation program (Section 3.1.1.3).

- Removal of waste for performance confirmation purposes is not considered retrieval. However, this "simulated retrieval" will support confidence in the retrieval method and equipment.

3.2 Site-Specific Retrieval Requirements

This section applies the retrieval requirements presented in Section 3.1 to the Yucca Mountain site. The philosophy for including retrievability in the Yucca Mountain repository design is followed by a discussion of the development of site-specific design criteria to implement the retrieval philosophy.

3.2.1 Retrieval Philosophy

The SCP-CDR design reflects a retrieval philosophy that is based on regulatory requirements and is consistent with the DOE guidance contained in the PRR. This philosophy is summarized below.

- The design of the repository at Yucca Mountain will incorporate the option to retrieve any or all of the emplaced waste as a planned contingency; therefore, all of the equipment and facilities necessary to carry out full repository retrieval need not be constructed at the time of repository construction.

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

- The method of retrieval will anticipate and be designed to operate under credible abnormal conditions.

- The design of facilities and equipment for retrieval will be based on technology that is reasonably available at the time of license application. The design of retrieval methods and proof-of-principle demonstrations will be completed by the time of license application.

To aid implementation of this philosophy, two tools have been developed, the first of which is a definition of items important to retrievability. Items important to retrievability are defined as those structures, systems, and components essential to maintaining the ability to retrieve all of the emplaced waste from the repository in a reasonable period of time. This definition is consistent with 10 CFR 60.111, the DOE PRR (Appendix B), and the Yucca Mountain Project's retrievability position paper (Flores, 1986).

The results of the items important to retrievability study are contained in Appendix L-2 of the SCP-CDR, which provides a preliminary list of items important to retrievability for the Yucca Mountain repository and contains a discussion of the methods used and the analyses performed to develop this list. The analyses are performed at the quality assurance level appropriate for the level and importance of design detail.

The second tool is shown in Figure 3-3. Retrieval conditions have been divided into three major categories: normal, abnormal, and not credible. The abnormal category is further subdivided into expected and credible (but less·probable) abnormal conditions. The equipment and operations designed for the normal conditions will have sufficient flexibility and capability to accommodate the expected abnormal conditions with, at most, minor modifications. This approach is intended to ensure that all events and processes with a reasonable probability of occurrence can be accommodated as essentially routine operations. For credible (but less probable) abnormal conditions, all equipment and procedures will not be on hand, but operational and design analyses will have been performed to establish that retrieval methods and design concepts for handling these conditions are feasible. As part of this effort, where it is warranted, proof-of-principle testing will have been performed before license application to demonstrate the feasibility of retrieval for these lower-probability events. It is assumed that if one of these lower-probability events were to occur, condition-specific investigations and analysis would be necessary to determine whether there is a need to refine or modify procedures and/or equipment.

In the future, the concept presented in Figure 3-3 will be used to establish a decision-making process to integrate development of retrieval conditions, demonstration requirements, equipment, and design. If the results of retrieval condition evaluations are combined with the definitions and cut-off probabilities shown in Figure 3-3, design and operational criteria can be developed, equipment development and demonstration needs can be identified, and decisions regarding what equipment must be present at the repository can be made.

3.2.2 Design Criteria

The development of design criteria has been based on the regulatory requirements and retrieval philosophy and began with the identification of four functions that must be performed to complete retrieval: (1) provision of access to the emplacement borehole, (2) provision of access to the emplaced waste container, (3) removal of the emplaced waste, and (4) transport and delivery of the waste container to the surface facility. Next, the repository processes needed to perform the functions, the performance measures for the processes, and performance goals were established. Finally, these performance goals have been translated into design criteria. The current design criteria for retrieval are listed in Table 3-5. This list will be revised as the design is refined and as work on describing retrieval conditions (Chapter 5) and operations (Chapter 6) progresses.

3.3 Additional Guidance Needed

Requirement 1.4(d) of the PRR states that all major construction and modifications necessary for retrieval must be completed before retrieval begins. If this is interpreted to mean that commencement of retrieval operations must be delayed until all necessary construction and modifications have been completed, this requirement could conflict with Requirement 1.4(a) which states that retrieval will be performed as quickly as is safely practicable. The requirement could also be interpreted to define the retrieval period as starting after the necessary construction and modifications have been completed. Clarification of this requirement is necessary.

As discussed in Section 3.1.3, the Yucca Mountain Project proposes a broad interpretation of the requirement to maintain in working condition all retrieval equipment that is in existence at the time of emplacement [Requirement 3.0(b)]. DOE review and comment on the interpretation of this requirement presented in Section 3.1.3 is needed.

The PRR does not provide guidance for the identification or classification of retrieval conditions. The Yucca Mountain Project proposes the use of the probability-based concept discussed in Section 5.2 for the classification of retrieval conditions. For the identification of retrieval conditions, a refinement of the method used in the items important to retrievability study (Appendix L-2 of the SCP-CDR) is proposed. DOE review and comment on the proposed methods for identification and classification of retrieval conditions is needed.

TABLE 3-5

RETRIEVAL-RELATED DESIGN CRITERIA

Underground Facilities

- The access and emplacement drifts will remain usable for at least 84 yr after initiation of waste emplacement activities.
- The average amount of spall in the drifts will be <5 tons/1000 ft of drift per year.
- The rock displacement in the drifts will be <6 in.
- The monitoring system will detect rock displacements in the drifts that exceed 1 in.
- The frequency of maintenance for the underground openings will be more often than every 5 yr.
- Rockfall in the emplacement boreholes will average <250 lb per foot of borehole.
- Displacement of the borehole wall will be <2 in.
- The lifetime of the borehole liner will be at least 84 yr.
- The maximum liner deflection is 2 in. in the vertical emplacement borehole and 3 in. in the horizontal borehole.
- For the horizontal emplacement borehole, the minimum allowable radius of curvature for the horizontal axis of the borehole liner is 110 ft.
- In the vertical emplacement concept, the temperature in the access drifts will not exceed 50°C for 50 yr after waste emplacement.
- In the horizontal emplacement concept, the temperature in the emplacement drifts will not exceed 50°C for 50 yr after waste emplacement.

Equipment

- A safety factor of 4 will be used for the design of retrieval equipment.
- The time required for removal of a single waste container under normal conditions will not exceed twice the amount of time required for emplacement of the waste container.

TABLE 3-5

RETRIEVAL-RELATED DESIGN CRITERIA
(concluded)

Radiologic

- Worker exposure during retrieval operations will not exceed any allowable limits established for emplacement operations.
- Radiologic exposures to the general public during retrieval operations will not exceed the limits established for emplacement operations.

Ventilation

- All applicable air quality standards will be met in operations areas.
- For cooling purposes, acceptable air quality is defined by an air-cooling power (ACP) of 300 W/m^2 and dry-bulb temperature (DB) of 45°C for inspection purposes, and an ACP of 500 W/m^2 and DB of 40°C for maintenance and retrieval purposes.
- Drift cooling for retrieval purposes should be completed within 8 wk.
- All airflow requirements and restrictions for emplacement operations will apply to retrieval operations.

General

- The ability to remove the waste under normal and abnormal conditions will be demonstrated.
- The design-basis retrieval period (retrieval of all emplaced waste) is 34 yr.
- The design-basis retrieval rate is 8 containers/day or 2000 containers/yr.
- The ability to perform retrieval operations using reasonably available technology is required.

REFERENCES FOR CHAPTER 3

DOE (U.S. Department of Energy), "Vital Records Protection Program," Order 5500.1, Washington, DC, July 1981a. (NNA.900418.0010)

DOE (U.S. Department of Energy), "Reactor and Nonreactor Nuclear Facility Emergency Planning, Preparedness and Response Program for Department of Energy Operations," Order 5500.3, Washington, DC, August 1981b. (NNA.900418.0011)

DOE (U.S. Department of Energy), "Occupational Safety and Health Program for DOE Contractor Employees at Government-Owned Contractor-Operated Facilities," Order 5483.1A, Washington, DC, June 1983a. (NNA.900418.0012)

DOE (U.S. Department of Energy), "General Design Criteria," Order 6430.1, Washington, DC, December 1983b. (HQS.880517.2268)

DOE (U.S. Department of Energy), "Environmental Protection, Safety, and Health Protection Standards," Order 5480.4, Washington, DC, May 1984. (HQS.880517.2271)

DOE (U.S. Department of Energy), "General Guidelines for the Recommendation of Sites for Nuclear Waste Repositories," <u>Code of Federal Regulations, Energy</u>," Title 10, Part 960, Washington, DC, January 1986a. (NNA.900918.0014)

DOE (U.S. Department of Energy), "Environmental Protection, Safety, and Health Protection Program for Department of Energy Operations," Order 5480.1B, Washington, DC, September 1986b. (NNA.900417.0025)

DOE (U.S. Department of Energy), "Safety Analysis and Review System," Order 5481.1B, Washington, DC, September 1986c. (NNA.900418.0013)

DOE (U.S. Department of Energy), "Environmental, Safety, and Health Appraisal Program," Order 5482.1B, Washington, DC, September 1986d. (NNA.900418.0014)

DOE (U.S. Department of Energy), "Emergency Management System," Order 5500.1A, Washington, DC, February, 1987. (NNA.900418.0015)

DOL (U.S. Department of Labor), "Safety and Health Standards--Underground Metal and Nonmetal Mines," <u>Code of Federal Regulations, Mineral Resources</u>, Title 30, Part 57, Washington, DC, July 1985. (NNA.890411.0039)

DOL (U.S. Department of Labor), "Occupational Safety and Health Standards," <u>Code of Federal Regulations, Labor</u>, Title 29, Part 1910, Washington, DC, July 1990. (NNA.910125.0074; NNA.910221.0068)

DOL (U.S. Department of Labor), "Safety and Health Regulations for Construction," <u>Code of Federal Regulations, Labor</u>, Title 29, Part 1926, Washington, DC, July 1990. (NNA.910123.0044)

EPA (U.S. Environmental Protection Agency), "National Primary and Secondary Ambient Air Quality Standards, Code of Federal Regulations, Protection of Environment, Title 40, Part 50, Washington, DC, July 1986a. (NNA.900720.0064)

EPA (U.S. Environmental Protection Agency), "EPA Administered Permit Programs: The National Pollutant Discharge Elimination System," Code of Federal Regulations, Protection of Environment, Title 40, Part 122, Washington, DC, July 1986b. (NNA.900720.0065)

EPA (U.S. Environmental Protection Agency), "National Primary Drinking Water Regulations," Code of Federal Regulations, Protection of Environment, Title 40, Part 141, Washington, DC, July 1986c. (HQS.880517.2369)

EPA (U.S. Environmental Protection Agency), "National Interim Primary Drinking Water Regulations Implementation," Code of Federal Regulations, Protection of Environment, Title 40, Part 142, Washington, DC, July 1986d. (NNA.900720.0066)

EPA (U.S. Environmental Protection Agency), "National Secondary Drinking Water Regulations," Code of Federal Regulations, Protection of Environment, Title 40, Part 143, Washington, DC, July 1986e. (NNA.900720.0067)

EPA (U.S. Environmental Protection Agency), "Regulations for the Enforcement of the Federal Insecticide, Fungicide, and Rodenticide Act," Code of Federal Regulations, Protection of Environment, Title 40, Part 162, Washington, DC, July 1986f. (NNA.900720.0068)

EPA (U.S. Environmental Protection Agency), "Environmental Radiation Protection Standards for Nuclear Power Operations," Code of Federal Regulations, Protection of Environment, Title 40, Part 190, Washington, DC, July 1986g. (HQS.880517.2921)

EPA (U.S. Environmental Protection Agency), "Environmental Radiation Protection Standards for Management and Disposal of Spent Nuclear Fuel, High-Level and Transuranic Radioactive Wastes," Code of Federal Regulations, Protection of Environment, Title 40, Part 191, Washington, DC, July 1986h. (HQS.880517.2925)

EPA (U.S. Environmental Protection Agency), "Noise Emission Standards for Construction Equipment," Code of Federal Regulations, Protection of Environment, Title 40, Part 204, Washington, DC, July 1986i. (NNA.900720.0072)

EPA (U.S. Environmental Protection Agency), "Toxic Substances Control Act," Code of Federal Regulations, Protection of Environment, Title 40, Chapter 1, Subchapter R, Washington, DC, July 1990. (NNA.910221.0001)

Flores, R. J., "Retrievability: Strategy for Compliance Demonstration," SAND84-2242, Sandia National Laboratories, Albuquerque, NM, January 1986. (HQS.880517.1627)

REFERENCES FOR CHAPTER 3
(concluded)

NRC (U.S. Nuclear Regulatory Commission), "Statements of Consideration," Code of Federal Regulations, Energy, Title 10, Part 60, Washington, DC, September 1982. (NNA.900720.0074)

NRC (U.S. Nuclear Regulatory Commission), "Standards for Protection Against Radiation," Code of Federal Regulations, Energy, Title 10, Part 20, Washington, DC, January 1986a. (NNA.890713.0151)

NRC (U.S. Nuclear Regulatory Commission), "Disposal of High-Level Radioactive Wastes in Geologic Repositories," Code of Federal Regulations, Energy, Title 10, Part 60, Washington, DC, January 1986b. (NNA.910315.0133)

NRC (U.S. Nuclear Regulatory Commission), "Domestic Licensing of Production and Utilization Facilities," Code of Federal Regulations, Energy, Title 10, Part 50, Washington, DC, January 1987a. (NNA.900720.0051)

NRC (U.S. Nuclear Regulatory Commission), "Environmental Protection Regulations for Domestic Licensing and Related Regulaory Functions," Code of Federal Regulations, Energy, Title 10, Part 51, Washington, DC, January 1987b. (NNA.900720.0073)

NWPA (Nuclear Waste Policy Act of 1982), Public Law 97-425, 96 Stat. 2201, 42 USC 10101, Washington, DC, January 1983. (NNA.890626.0312)

NWPAA (Nuclear Waste Policy Amendment Act of 1987), Public Law 100-203, 42 USC 10101, Washington, DC, December 22, 1987. (HQS.880517.3146)

SNL (Sandia National Laboratories), "Site Characterization Plan Conceptual Design Report," SAND84-2641, compiled by H. R. MacDougall, L. W. Scully, and J. R. Tillerson, Sandia National Laboratories, Albuquerque, NM, September 1987. (NNI.880902.0014-.0019)

4.0 POSTEMPLACEMENT OPERATIONS

Postemplacement operations include all operations performed after waste is emplaced and those that continue until the end of the retrievability period. These operations take place during the emplacement and caretaker phases of the repository (Figure 3-2). The discussions in this chapter will describe postemplacement operations that are currently planned. Although performance confirmation will involve postemplacement activities, those activities are not associated with retrieval; therefore performance confirmation activities are not discussed here.

4.1 Backfill

Section 111(b)(2) of 10 CFR 60 (NRC, 1986) allows for the use of backfill before the end of the retrievability period. The current design basis for the Yucca Mountain repository does not include the use of backfill during the retrievability period. If required, the repository will be backfilled during closure; therefore, backfilling is not an issue for postemplacement operations.

4.2 Ventilation

A description of the ventilation system design, equipment, and airflow requirements for the emplacement phase is contained in Section 2.3. The discussion in this section is limited to ventilation requirements during the caretaker phase. The ventilation data presented are derived from Appendix D.

During the caretaker phase, all shafts and ramps are available for use by the ventilation system. The three mains are used for air intake. The air flows to the end of the mains and then to the perimeter drift in sufficient quantities to maintain an acceptable working environment in these airways. Underground support facilities (e.g., shops) will be ventilated continuously with ventilation air going directly to the perimeter drift and then to the exhaust shaft.

4.2.1 Repository Ventilation

The airflow velocities and temperatures within the repository during the caretaker phase are shown in Figures 4-1 and 4-2 for the vertical and horizontal emplacement configurations. These figures represent ventilation scenarios typical during the caretaker phase. Cooling operations are performed in one panel (Panel No. 16 in the vertical case and Panel No. 14 in the horizontal case) while all other panels are maintained on controlled leakage. The temperatures presented in the figures are based on mean surface summer temperatures. During the winter months, the temperatures throughout the repository will be lower. The fan requirements for the airflows shown in Figures 4-1 and 4-2 are listed in Table 4-1. Because the airflow requirements for the caretaker period are lower than those for the emplacement period (Table 2-8), no additional fan capacity will be needed.

TABLE 4-1

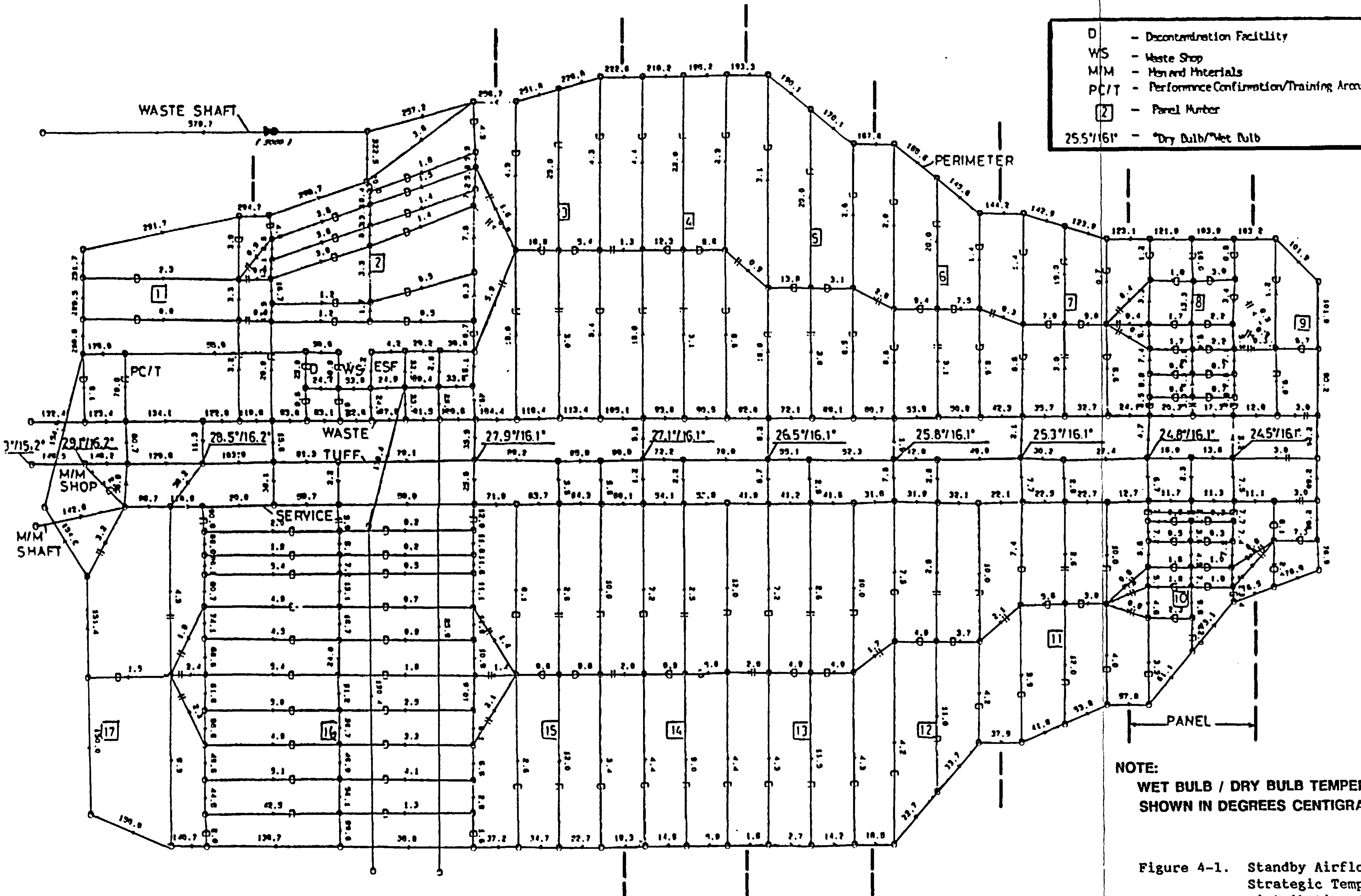
FAN REQUIREMENTS DURING CARETAKER PHASE

Configuration	Fan Pressure (in. w.g.*)	Fan Airflow (cfm x 1000)
Vertical	5.0	579.7
Horizontal	3.0	409.0

*Inches water gage at the collar of the waste emplacement area exhaust shaft.

4.2.2 Emplacement Panel Ventilation

To minimize airflow requirements for the underground area, the airflow through an emplacement panel is restricted to a small amount of controlled leakage. The airflow for a panel with vertical waste emplacement is shown in Figure 4-3. The air flows down the panel access drifts, through the emplacement and midpanel access drifts, and exhausts through the perimeter drift. Figure 4-4 illustrates the airflow for the



NOTE:
WET BULB / DRY BULB TEMPERATURES SHOWN IN DEGREES CENTIGRADE.

Figure 4-1. Standby Airflow Network and Strategic Temperature Distribution (Vertical Emplacement)

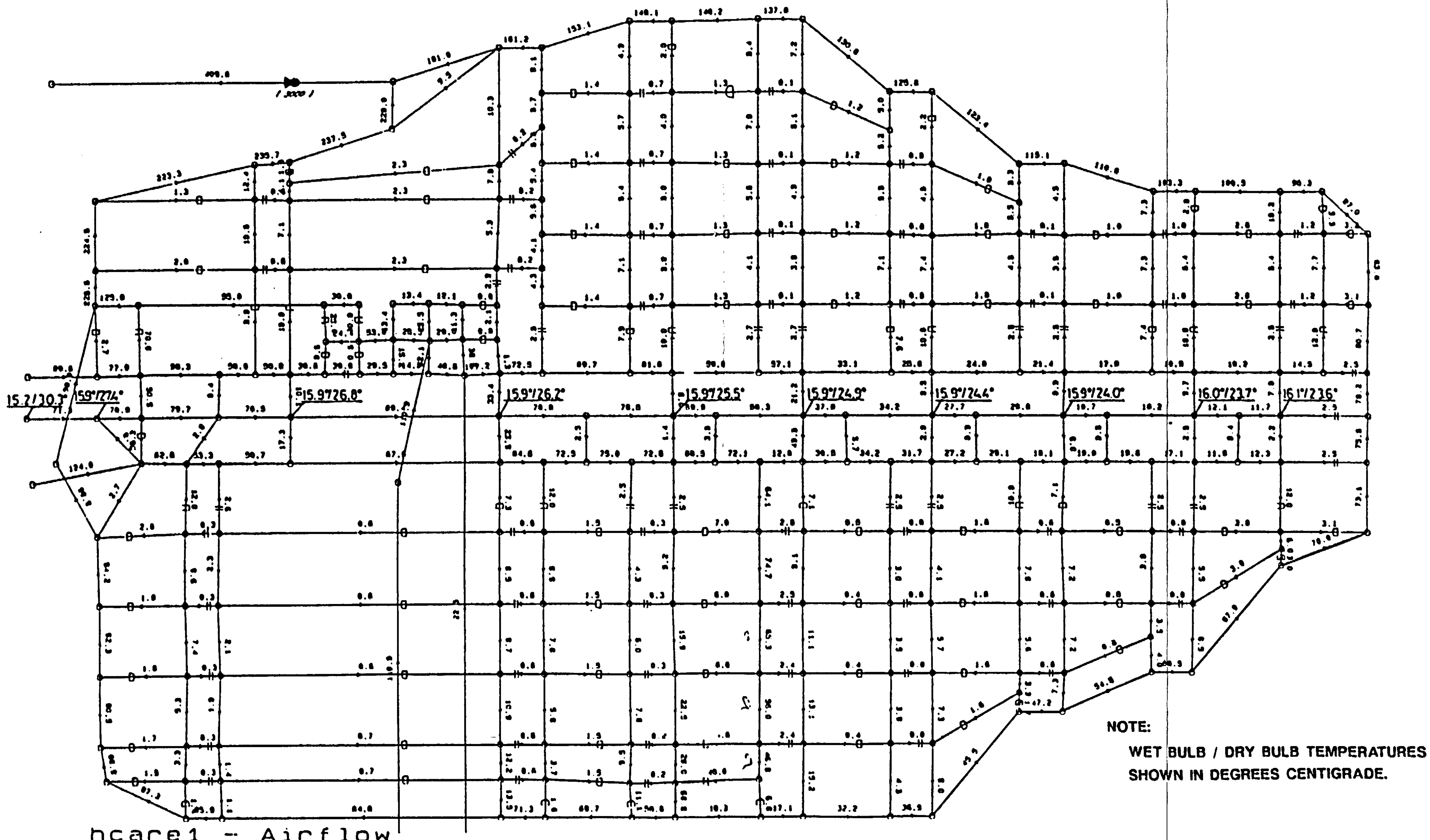


Figure 4-2. Standby Airflow Network and Strategic Temperature Distribution (Horizontal Emplacement)

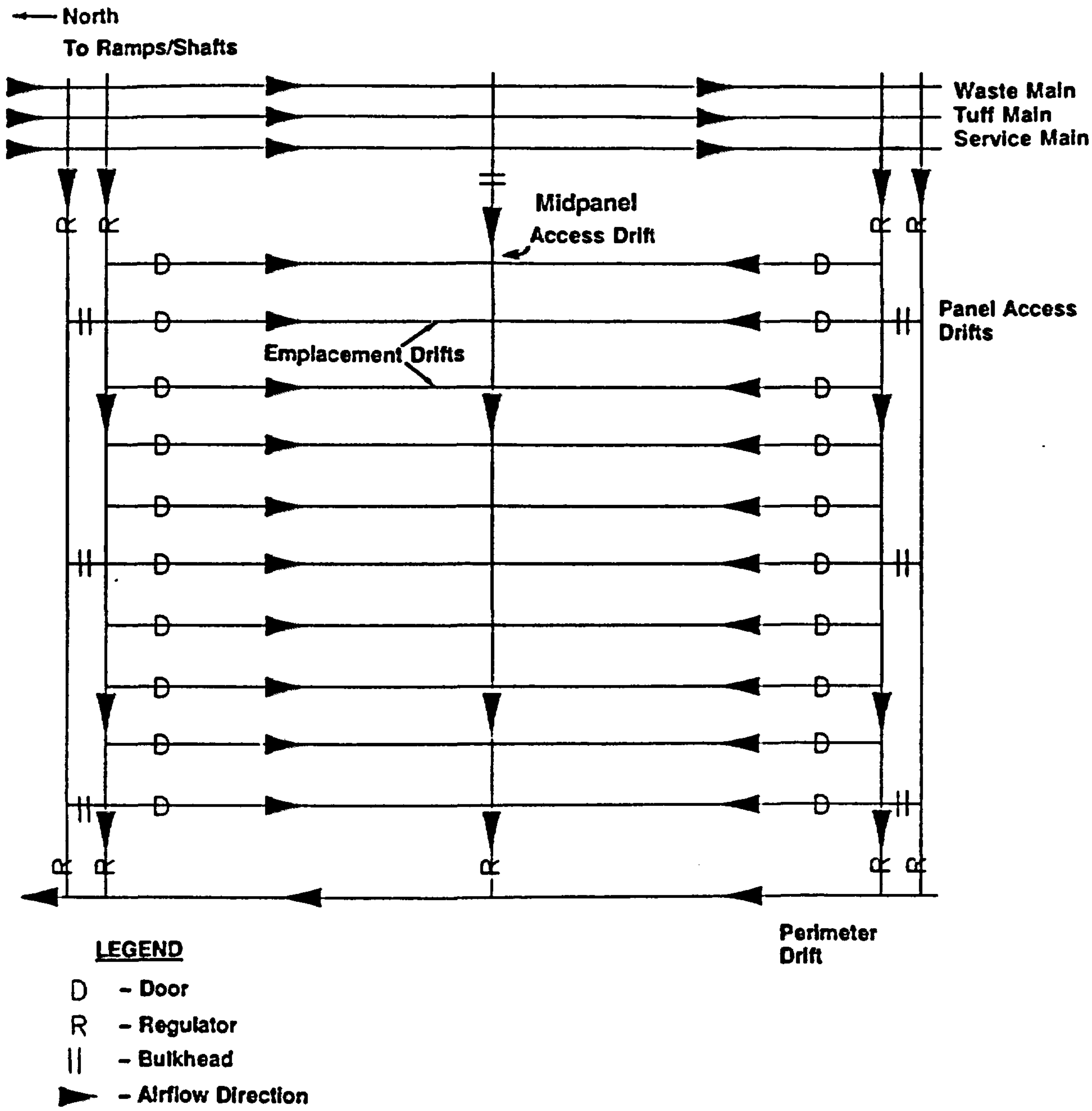


Figure 4-3. Controlled Leakage Through a Vertical Emplacement Panel

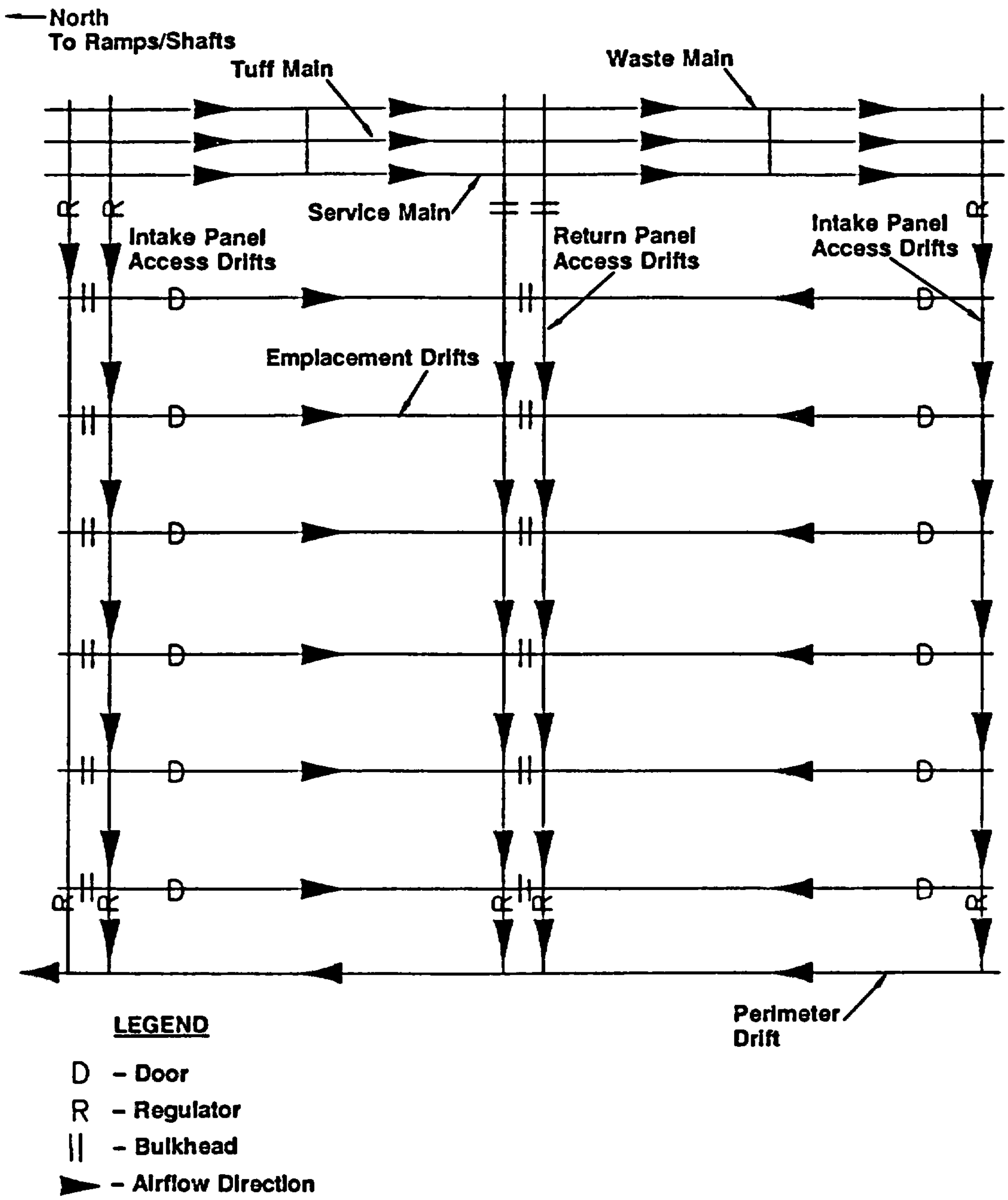


Figure 4-4. Controlled Leakage Through Horizontal Emplacement Panels

horizontal emplacement configuration; the arrangement comprises two panels because midpanel access drifts are not required for the horizontal emplacement configuration. The flow pattern for the horizontal configuration is similar to that of the vertical case.

Maintaining the airflow directions shown in Figures 4-3 and 4-4 requires a set of ventilation controls consisting of regulators, doors, and bulkheads (shown in the figures). For reentry into the drifts for inspection, maintenance, or retrieval, these controls will be adjusted to allow for greater airflows.

The expected airflows and temperatures within a panel maintained on leakage control are shown in Figures 4-5 (vertical) and 4-6 (horizontal). The temperatures have been calculated assuming that the panel had been closed for 50 yr.

4.2.3 Cooling Requirements

Results from ventilation analyses indicate that air cooling may be required in some areas of the repository for inspection, maintenance, or retrieval operations (Table 4-2).

An area is considered accessible when workers can enter the area without protection (e.g., ice jackets). For inspection, acceptable conditions are quantified as an air cooling power (ACP) of >300 W/m^2 and a dry-bulb temperature (DB) of <45°C (113°F). For maintenance or retrieval operations, an acceptable environment is defined by an ACP of >500 W/m^2 and a DB of <40°C (104°F).

The drifts can be cooled with ambient air or air cooled with a heat exchanger, which uses a chilled water spray. Table 4-3 contains estimates of cooling times needed for the emplacement drifts 50 yr after emplacement.

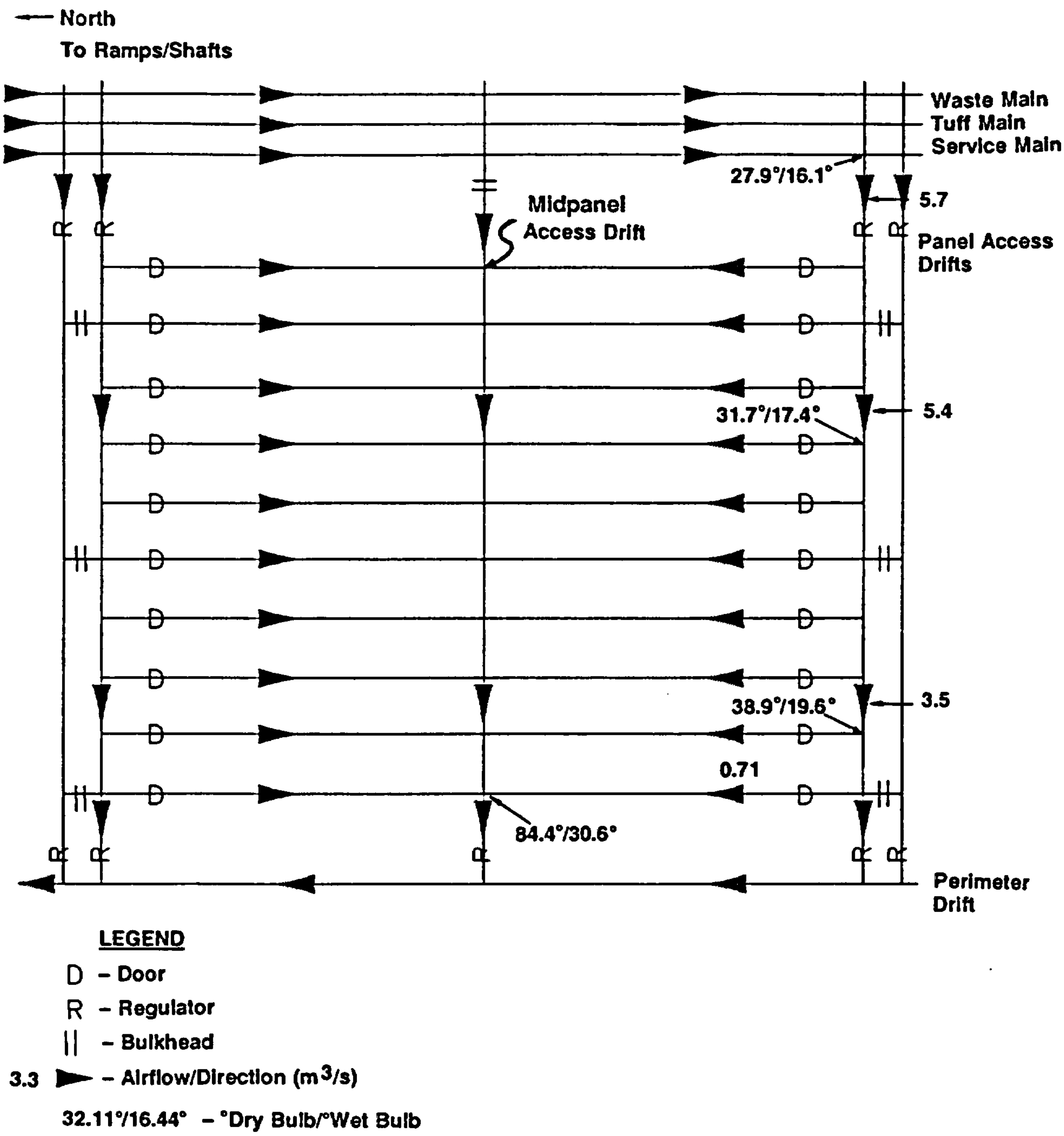


Figure 4-5. Expected Temperatures in a Panel with Leakage Airflow 50 Yr After Vertical Emplacement

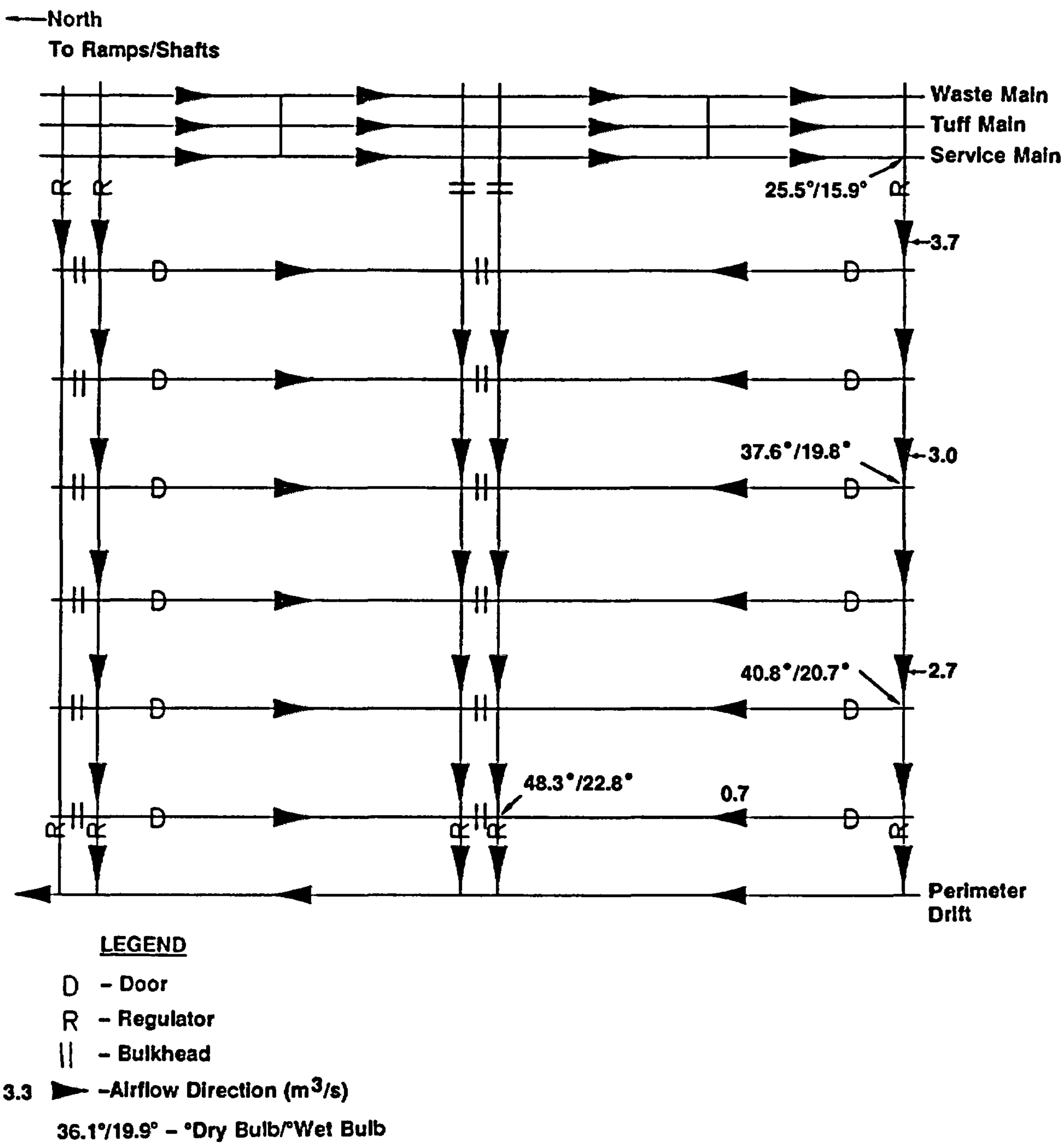


Figure 4-6. Expected Temperatures in a Panel with Leakage Airflow 50 Yr After Horizontal Emplacement

TABLE 4-2

CATEGORIZATION OF REPOSITORY AREAS BASED ON COOLING REQUIREMENTS

Areas Accessible Before Any Cooling

- Men-and-materials shaft
- Tuff ramp
- Exploratory shafts (ES-1 and ES-2)
- Waste ramp
- Wervice main
- Tuff main
- Waste main
- Development and waste shops
- Decontamination facility
- Dedicated performance confirmation area
- Training area
- Exploratory shaft facility

Areas Accessible After Minimum Cooling

- Panel access drifts
- Horizontal emplacement drifts
- Perimeter drift (for horizontal configuration only; to be cooled in a localized area)

Areas Accessible Only After Cooling

- Vertical emplacement drifts
- Perimeter drift (vertical configuration only; to be cooled in a localized area)
- Midpanel access drift (vertical configuration only; to be cooled in a localized area)

TABLE 4-3

COOLING TIMES FOR EMPLACEMENT DRIFTS

		Ambient Air		Cooled Air	
Reason for Re-entry	Emplacement Method	Time to Cool (days)	Cooling Load (RT)*	Time to Cool (days)	Cooling Load (RT)*
Inspection	Vertical	111	0	27	205
	Horizontal	11	0	6	183
Maintenance or Retrieval	Vertical	360	0	50	205
	Horizontal	50	0	15	183

*Tons of refrigeration.

4.2.4 Monitoring of Ventilation

During the emplacement and caretaker phases the ventilation system will be continuously monitored. The current planning basis includes placing monitors underground in the ramps, main drifts, panel access and return drifts, perimeter drift, intake shafts, and exhaust shaft. Each location will be monitored for the following:

- temperature,
- pressure,
- humidity,
- airflow,
- carbon monoxide,
- oxygen,
- nitrous oxides,
- smoke, and
- radiation.

At the surface, the main fans will be monitored for fan pressure, airflow, and fan bearing temperatures. All of the monitoring stations will be linked to a central monitoring station. If a hazardous condition is detected, the central station will activate the appropriate alarm and initiate the necessary response.

4.3 Repository Integrity--Inspection and Monitoring (Geotechnical)

4.3.1 Inspection

The underground openings will be inspected on a routine basis to provide data on the condition of the rock and rock support system, to visually monitor specific geotechnical characteristics (e.g., faults), and to identify areas where maintenance is needed or where potentially unsafe conditions exist. The emplacement panels will be inspected on an approximately 5-yr basis (Table 3-5). If the air conditions in the drifts are unacceptable for unprotected workers (DB of >45°C, ACP of <300 W/m^2), the drifts will be cooled (Section 4.2.3), or the inspections will be performed using protected or remotely controlled vehicles.

4.3.2 Monitoring

The repository will be monitored to determine rock response to waste-induced thermal loads and variations in geotechnical characteristics. Each emplacement panel will contain at least one monitoring station to measure rock response to thermal loads. The geotechnical monitoring station will include thermocouples to measure temperature and extensometers to measure rock movement. The location and number of these monitoring stations will depend on the variation in geotechnical conditions that are encountered during development of the repository.

4.4 Maintenance of Accesses

The emplacement drifts and panels will be closed off after all of the boreholes in each drift and panel are filled with waste. Bulkheads, doors, and regulators will be installed at the locations shown in Figures 4-3 and 4-4 for the vertical and horizontal emplacement configurations, respectively. Before re-entry into the emplacement drifts, the regulators at each end of the panel will be adjusted, the doors to the emplacement drifts opened, and the emplacement drift cooled (Section 4.2.3).

4.5 Maintenance of Standby Status

The caretaker phase begins when the last waste has been emplaced and continues until repository closure is authorized by the U.S. Nuclear Regulatory Commission (NRC) (Figure 3-2). Activities during the caretaker period include (1) performance confirmation, (2) maintenance, (3) monitoring, and (4) general support. All equipment and facilities that are not needed to support these operations will be decontaminated, if necessary, and placed in standby status (moth-balled). Primarily, this includes the waste-handling buildings, the waste treatment building, all emplacement equipment not needed for performance confirmation, and portions of the service and repair shops, warehouses, and the ventilation system.

4.5.1 Performance Confirmation

Performance confirmation continues throughout the caretaker phase. Because retrieval equipment is expected to be used in the performance confirmation program to remove waste containers from the performance confirmation area, two complete sets of emplacement/retrieval equipment will be maintained during the retrievability period. The balance of the emplacement/retrieval equipment will be moth-balled.

4.5.2 Maintenance

The surface facilities needed to support performance confirmation, site monitoring, emergency response, security, and administrative activities will be maintained continuously. In addition, the structures of moth-balled facilities will be maintained.

For the underground facilities, the openings, hoisting systems, utilities, and ventilation system will be maintained. Maintenance of underground openings consists mainly of repair and replacement of parts of the rock support system (e.g., rock bolts and wire mesh) and repair of the underground roadways. The hoisting systems, utilities, and ventilation equipment will receive safety inspections and maintenance as needed.

4.5.3 Monitoring During the Caretaker Phase

Four types of monitoring will be performed underground: (1) performance confirmation, (2) ventilation, (3) geotechnical assessment, and (4) radiation and fire. Performance confirmation monitoring will be confined to the performance confirmation area and is primarily concerned with long-term (postclosure) repository performance. Ventilation monitoring is required to verify that the underground air quality is acceptable (Section 2.3). Monitoring for geotechnical assessment is needed to verify the integrity of the underground openings (Section 4.3.2). Radiation and fire monitoring are required to notify repository workers of potentially hazardous radioactive releases or fires.

4.5.4 General Support

Support capabilities needed during the caretaker phase include

- physical security,
- supervision and administration,
- mine rescue,
- underground personnel and equipment control,
- first aid and decontamination,
- engineering support,
- safety, and
- maintenance.

4.6 Postemplacement Effects of Retrievability Maintenance

For the current design, the emplacement drifts will be continuously ventilated (by controlled leakage after emplacement) and periodically cooled and ventilated for maintenance or inspection operations. The primary effect of this ventilation is the removal of heat from the emplacement drifts. The secondary effect is the removal of small amounts of water and radon from the emplacement drifts.

Backfill operations will be delayed until closure. Delay of backfill operations facilitates retrieval by allowing access to the waste emplacement boreholes without the effort of backfill removal. Delay of backfill also makes emplacement drift ventilation and maintenance possible.

REFERENCE FOR CHAPTER 4

NRC (U.S. Nuclear Regulatory Commission), "Disposal of High-Level Radioactive Wastes in Geologic Repositories," Code of Federal Regulations, Energy, Title 10, Part 60, Washington, D.C., January 1986. (NNA.870406.0488)

5.0 REPOSITORY CONDITIONS FOR RETRIEVAL

Estimates of the repository conditions at the time of retrieval are important in developing design bases, operations requirements, and demonstration plans. In completed studies conditions have been divided into two categories: normal and credible abnormal. "Normal conditions" are conditions expected to be present most (approximately 90%) of the time. Standard equipment and procedures are used for retrieval operations when normal conditions exist. "Credible abnormal conditions" are those conditions expected to have a reasonable probability for occurring, although infrequently, during the life of the repository. "Credible abnormal" is generally used to identify those conditions that may need to be considered in developing contingency plans for related retrieval operations. Such operations may require special equipment or procedures and may require substantial time to complete.

In the future, a probability-based concept such as the one presented in Figure 3-3 may be used to classify retrieval conditions. This concept relies on a probabilistic approach to define the extent to which specific conditions will be considered in the design, demonstration plans, and anticipated degree of readiness for equipment and facilities. It is recognized that substantial engineering judgment will be used to implement this approach and that uncertainty will exist regarding the exact probability of occurrence of many of the postulated conditions; nevertheless, probability-based consideration of various conditions may be useful in conducting future design studies.

5.1 Normal Conditions

The normal conditions for retrieval are categorized as follows:

- environmental conditions--the conditions encountered within the repository, including thermal, radiologic, and ventilation air conditions;

- natural conditions--geotechnical, hydrologic, and geochemical conditions and the effect of the emplaced waste on those conditions; and

- condition of engineered structures--the condition of all engineered structures, facilities, and equipment that are retrieval related.

5.1.1 Environmental Conditions

5.1.1.1 Thermal Conditions

The thermal conditions relevant to retrieval include the rock temperatures of the emplacement borehole wall and the drifts.

Rock Temperature of the Borehole Wall

The predicted temperatures of the emplacement boreholes for vertical and horizontal emplacement are presented in Figure 5-1. As shown in the figure, the predicted maximum temperature in the vertical borehole is approximately 227°C, and that of the horizontal borehole is 214°C. Since the temperature remains above 100°C through the retrievability period, a dry environment is expected (Appendix E).

Rock Temperature in the Drifts

The surface temperature of the rock is important in determining the retrieval environment because it not only influences the ventilation requirements but also affects opening stability and retrieval equipment design. The design goal is to limit the temperature of the access drift wall in the vertical emplacement configuration or the emplacement drift wall in the horizontal emplacement configuration to 50°C for the first 50 yr after emplacement is completed in a panel. This is referred to as the "50/50 goal." Although 50°C is an unacceptable air temperature for prolonged unprotected exposure, re-entry is possible after a brief ventilation period under controlled conditions or with the use of special personal cooling equipment.

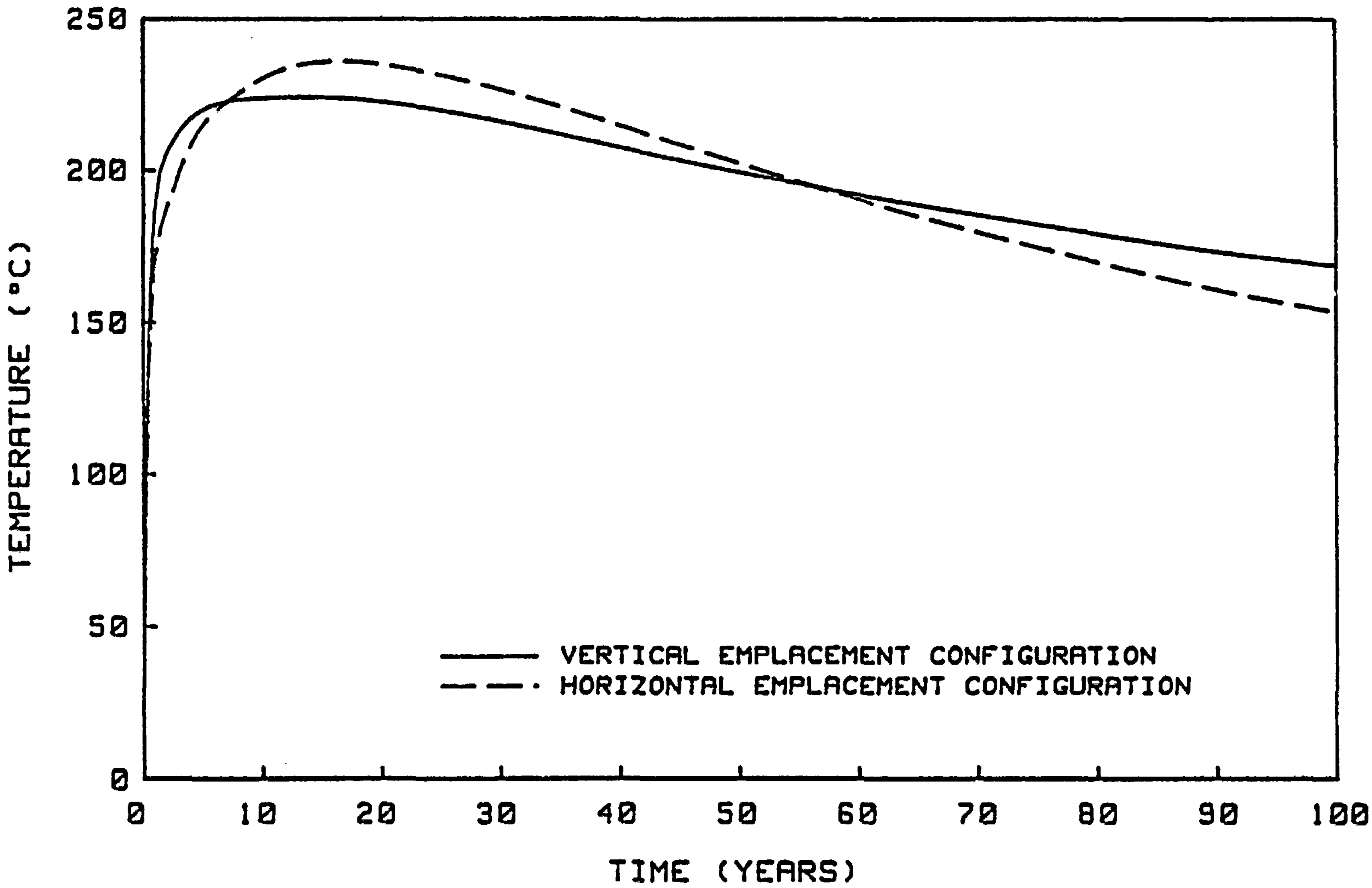


Figure 5-1. Predicted Temperatures for Emplacement Boreholes (information from Figure 2-2, Appendix J, SCP-CDR)

For vertical emplacement the estimated temperatures of the floor of the emplacement drift and the wall of the access drift are presented in Figure 5-2a and b. As shown in Figure 5-2b, the predicted temperature of the access drift wall at 50 yr is <50°C, which is consistent with the 50/50 design goal. With the short standoff of 10 ft, the temperature of the emplacement drift floor rises very quickly--to 94°C at 5 yr. Therefore, within a short period of time after waste emplacement, air cooling is needed before unprotected re-entry into the emplacement drifts is possible.

Figure 5-2c shows the expected temperature changes for the horizontal emplacement drift walls. The temperature of the emplacement drift wall at 50 yr is 53°C, which slightly exceeds the 50/50 design goal. Because of the 134-ft standoff, the temperature of the emplacement drift wall rises very slowly; consequently, only minimal cooling is needed before re-entry.

5.1.1.2 Radiologic Conditions

Radiation in the repository results from naturally occurring sources (radon-222 and radon daughters) and from the waste.

Radon-222

Preliminary estimates of radon concentration levels and corresponding dose rates are presented in Table 5-1. As shown in the table, the radon concentration levels are far below the 100 pCi/ℓ allowable concentration level (DOL, 1985). Assuming an average dose of 0.1 mrem/hr, a worker would receive a dose of 200 mrem during a 2,000-hr work year. As discussed in Appendix F (Table F-2), in a completely unventilated drift the allowable concentration could be exceeded within a week. The preliminary estimates presented in Appendix F are considered conservative and will be updated during advanced conceptual design (Section 8.2.1.1).

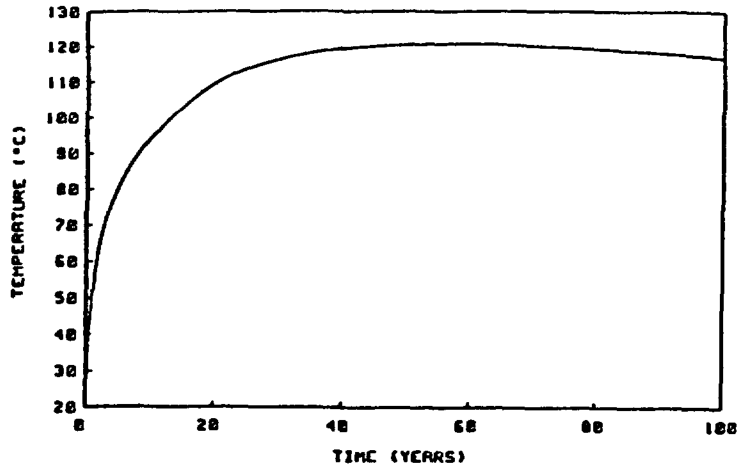


FIGURE 5-2a. EMPLACEMENT DRIFT FLOOR TEMPERATURE--VERTICAL EMPLACEMENT

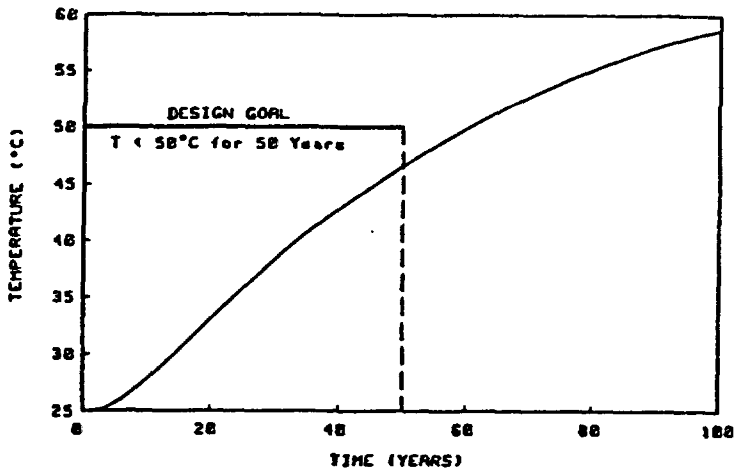


FIGURE 5-2b. ACCESS DRIFT TEMPERATURE--VERTICAL EMPLACEMENT

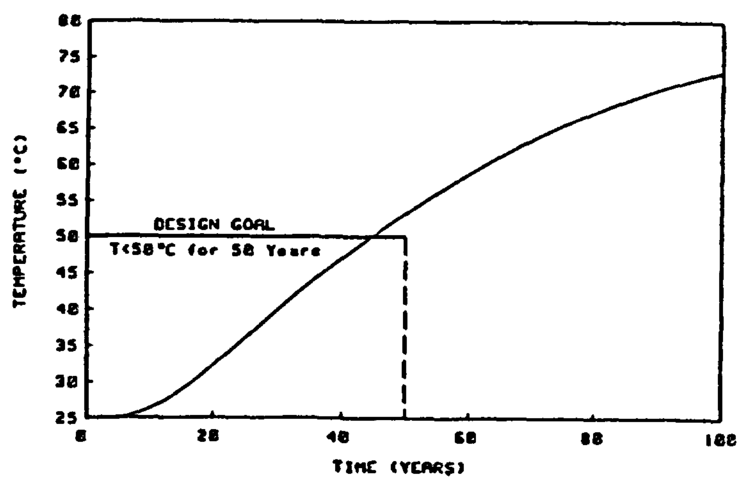


FIGURE 5-2c. EMPLACEMENT DRIFT WALL TEMPERATURE--HORIZONTAL EMPLACEMENT

Figure 5-2. Expected Drift Temperatures (from Figure 2-1, Appendix J, SCP-CDR)

TABLE 5-1

RADON CONCENTRATION LEVELS AND DOSE RATES[a]

Drift	Radon-222 Concentration (pCi/ℓ)	Radon-222 Dose Rate (mrem/hr)[b]
Waste Main (Vertical)	1.5	0.094
Waste Main (Horizontal)	1.4	0.087
Panel Access (Vertical)	1.7	0.11
Panel Access (Horizontal)	1.6	0.10
Emplacement (Vertical)	1.9[c] 2.2[d] 6.0[e]	0.12[c] 0.14[d] 0.37[e]
Emplacement (Horizontal)	1.8[c] 2.0[d] 5.5[e]	0.12[c] 0.12[d] 0.34[e]

a. From Appendix F, Table F-2.
b. Assumes a dose conversion factor of 5.2×10^4 rem/Ci radon-222 (ICRP, 1985).
c. Emplacement/retrieval operations are being performed (45,000-cfm airflow).
d. Emplacement drift is in standby for emplacement/retrieval operations (20,000-cfm airflow).
e. Emplacement drift is closed (2,000-cfm airflow).

High-Level Radioactive Waste

Radiologic conditions resulting from the waste and associated shielding requirements for the transporter cask, shield plug, and shielding collar are addressed in Appendix G. The shielding requirements and dose rates presented in Appendix G were developed as part of a preliminary scoping study. The study assumed worst-case radiation outputs for a consolidated [6 pressurized-water reactor (PWR) fuel elements] and an unconsolidated [hybrid--3 PWR and 4 boiling-water reactor (BWR) fuel elements] waste container (Section 2.1.3). Because an extremely conservative dose rate of 2 mrem/hr was assumed, the results are very conservative and should not be considered as a basis for design. Future work is discussed in Section 8.2.1.1.

Shielding requirements and resulting dose rates for the transporter are shown in Tables 5-2 and 5-3, respectively. The configuration considered and detector loca- tions are shown in Figure 5-3. As shown in Tables 5-2 and 5-3, shielding thick- nesses are as great as 23 in., and the dose rates are 2.0 mrem/hr or less.

The shielding estimates for the shield plug and shielding collar are shown in Table 5-4. The resulting dose rate at Detector Point 1 (Figure 5-4) is 2 mrem/hr. The dose rates at the other detector locations were negligible.

For the investigation of potential shielding collar sizes, an analysis was performed to locate the point at the surface of the rock where the dose rate was 2 mrem/hr. The results are shown in Table 5-5. As shown for the design-basis standoff distances, the collar only needs to extend <5 in. from the mouth of the borehole. The case where the container is at the mouth of the borehole during emplacement or retrieval operations was also included (standoff = 0). The distance at which additional shielding may be required is approximately 3 ft from the mouth of the borehole. Currently, it is anticipated that no workers will be needed near the borehole during emplacement or retrieval operations. Consequently, additional shielding around the borehole will not be required under normal conditions.

5.1.1.3 Ventilation Air Quality

In the ramp, service areas, and access drifts, acceptable air quality will be maintained by continuous ventilation until repository closure. In the emplacement drifts, ventilation will be reestablished to ensure acceptable air quality before re-entry for retrieval.

TABLE 5-2

SHIELDING REQUIREMENTS FOR THE WASTE TRANSPORTER

Container Type	Shield Location	Shielding Thicknesses: Lead Thickness (in.)	Polyethylene* Thickness (in.)	Total Thickness (in.)
Hybrid (3 PWR/4 BWR)	Side	6.8	14.8	21.6
	End	7.0	13.8	20.8
Consolidated (6 PWR)	Side	6.9	16.1	23.0
	End	7.1	15.1	22.2

*Borated polyethylene (5% boron).

TABLE 5-3

SHIELDED DOSE RATE FOR THE WASTE TRANSPORTER

Container Type	Detector* Number	Dose Rate (mrem/hr)
Hybrid (3 PWR/4 BWR)	1	2.0
	2	0.019
	3	0.80
	4	2.0
Consolidated (6 PWR)	1	2.0
	2	0.015
	3	0.80
	4	2.0

*See Figure 5-3 for detector locations.

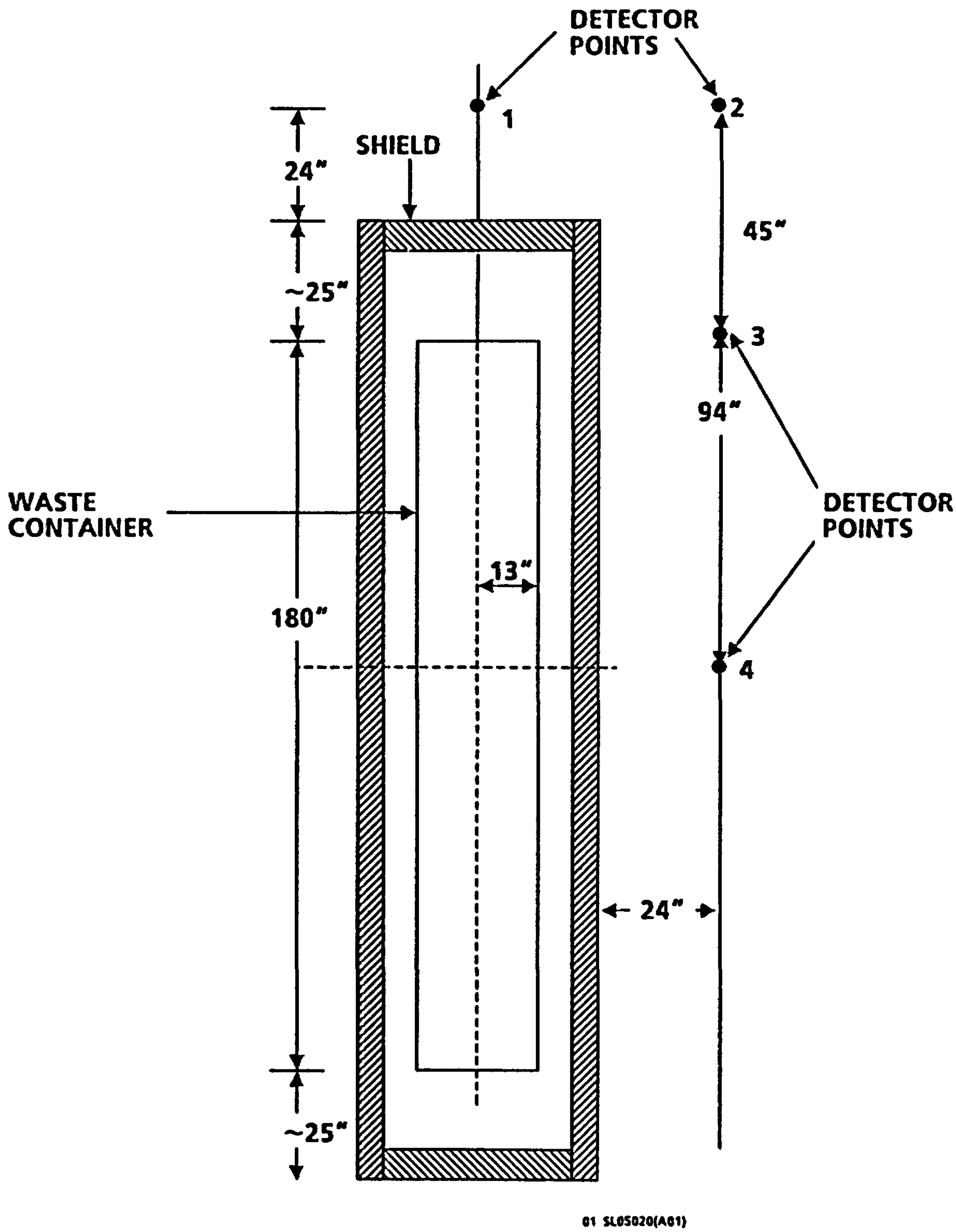
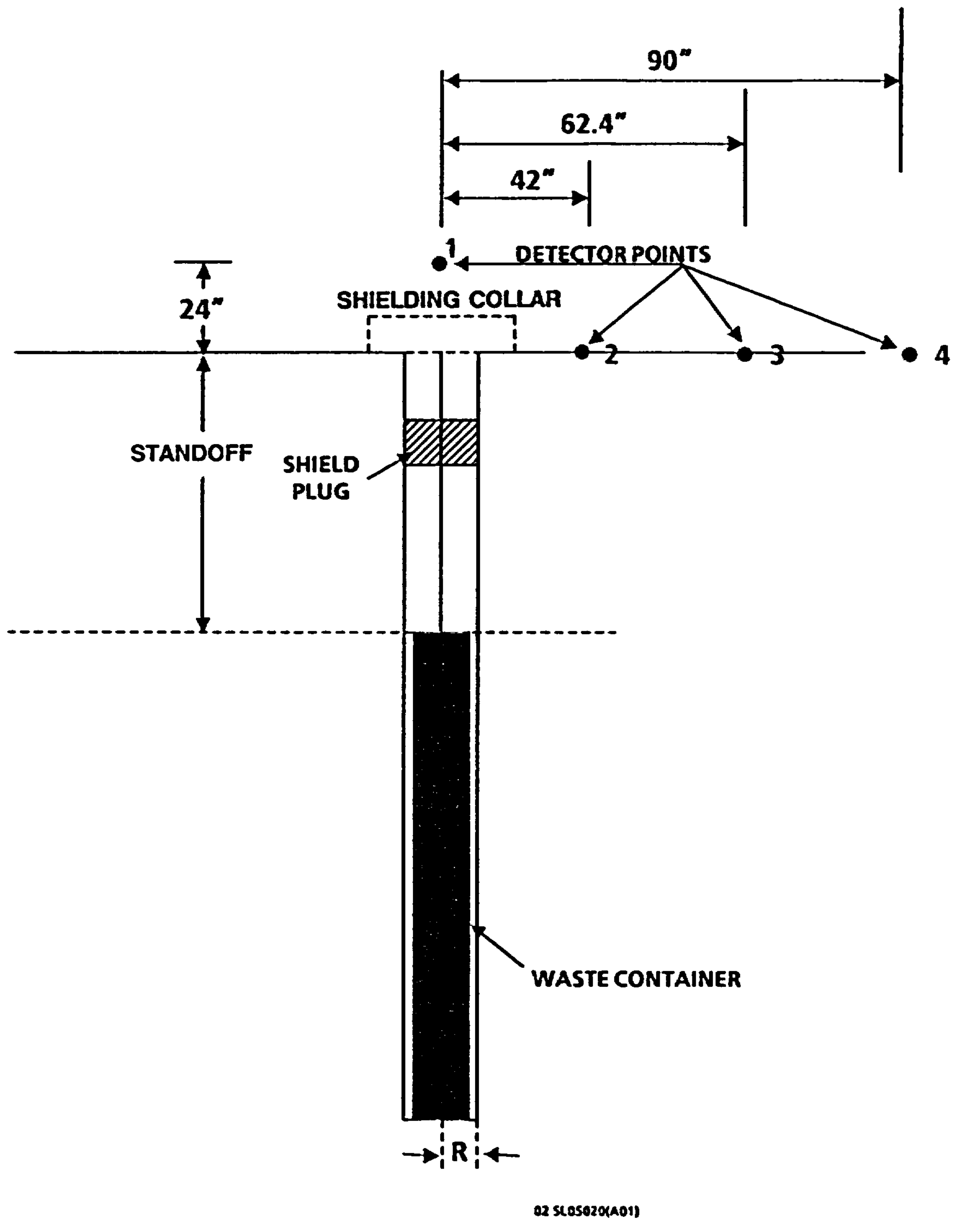


Figure 5-3. Transporter Cask Geometry for Shielding Analyses



For vertical emplacement, R = 13"
For horizontal emplacement, R = 17.5"

Figure 5-4. Borehole Geometry for Shielding Analyses

TABLE 5-4

SHIELDING REQUIREMENTS FOR THE SHIELD PLUG AND SHIELDING COLLAR

Container Type	Emplacement Configuration	Standoff (ft)	Concrete (in.)	Steel (in.)	Total (in.)
Hybrid	Vertical	10	16.5	6.7	23.2
(3 PWR/4 BWR)	Horizontal	20	10.6	7.6	18.2
	Horizontal	134	0	7.3	7.3
Consolidated	Vertical	10	18.9	6.4	25.3
(6 PWR)	Horizontal	20	13.1	7.3	20.4
	Horizontal	134	0	7.8	7.8

TABLE 5-5

CALCULATED SHIELDING COLLAR RADIUS[a,b]

Container Type	Emplacement Configuration	Container Standoff (ft)	Radius from the Centerline (in.)[c]	Distance from the Borehole Rim (in.)[d]
Hybrid	Vertical	0	51.4	38.4
(3 PWR/4 BWR)	Vertical	10	17.5	4.5
	Horizontal	0	55.6	38.1
	Horizontal	20	19.9	2.4
	Horizontal	134	17.7	0.2
Consolidated	Vertical	0	52.6	39.6
(6 PWR)	Vertical	10	17.8	4.8
	Horizontal	0	56.9	39.4
	Horizontal	20	20.0	2.5
	Horizontal	134	17.7	0.02

a. From Appendix G.
b. The shielding collar radius is defined as the radial distance to the point where the dose rate is 2 mrem/hr.
c. The shielding collar radius is measured from the centerline of the borehole.
d. The shielding collar radius is measured from the rim of the borehole. The distance from the borehole rim is the shielding collar radius less the borehole radius.

The conditions of ventilation air (e.g., temperature and airflow) during the emplacement, caretaker, and retrieval periods are discribed in Sections 2.3, 4.2, and 6.1.2, respectively.

5.1.2 Natural Conditions

The in situ natural conditions for the host rock are presented in Table 5-6. With these conditions as a basis, thermomechanical analyses were performed to analyze the rock response in the drifts and emplacement boreholes (SNL, 1987, Appendix N).

TABLE 5-6

IN SITU NATURAL ROCK CONDITIONS AT THE REPOSITORY HORIZON

Condition	Conceptual Design Value	Current Value
Rock Cohesion (MPa)	22.1	17.8
Internal Friction (deg)	29.2	23.5
Joint Orientation	Vertical	Vertical
Joint Spacing (m)	0.5	0.5
Joint Cohesion (MPa)	1.0	0.1
Joint Friction Angle (deg)	38.7	28.4
In Situ Stress (MPa)		
Horizontal	3.5-4.2	3.5-4.2
Vertical	7.0	7.0

5.1.2.1 Emplacement Boreholes

Under normal conditions, the vertical borehole is expected to be stable (SNL, 1987, Appendix N), and the rockfall into the emplacement borehole is expected to be negligible. In the horizontal borehole, minor rockfall against the liner is expected. Preliminary analysis indicates that this rockfall will have a negligible effect on liner performance (SNL, 1987, Appendix B). As noted previously, high temperatures should ensure a dry environment.

5.1.2.2 Ramp, Shafts, and Drifts

Under normal conditions, the ramp, shafts, and drifts are expected to remain stable (SNL, 1987, Appendix N). Studies indicate that standard mining techniques can be used to construct the repository and that standard methods of drift support (e.g., rock bolts, wire mesh, and shotcrete) will generally be sufficient to maintain the drifts (Dravo, 1984; Hustrulid, 1984). Small pieces of rock are expected to fall through the holes in the wire mesh used for rock support (Section 2.2.2.3), but light maintenance will be expected to manage this problem. Local, more highly fractured areas may need more extensive and frequent maintenance. Experience gained in miles of drifts affected by underground testing of nuclear weapons supports these assumptions; the drifts in Rainier Mesa at the Nevada Test Site (NTS) have been subjected to repeated high accelerations with few major problems. It is recognized that the response of the Topopah Spring Tuff may differ from that of the bedded tuffs of Rainier Mesa, but numerous sets of thermal/mechanical calculations indicate that the drifts will be stable throughout the retrievability period (SNL, 1987, Appendix N).

5.1.3 Condition of Engineered Structures

The condition of the following engineered structures is retrieval-related:

- ground support,
- the borehole liner and shield plug,
- the waste container,
- retrieval equipment,
- ventilation equipment,
- the waste-handling building, and
- support systems and facilities.

5.1.3.1 Ground Support

Ground support in the ramp, drifts, and underground support facilities will be maintained during the repository lifetime and will be functional in these areas throughout the retrievability period. In the closed emplacement panels, maintenance of the rock support system will be performed on an approximately 5-yr basis. Rock support in these areas consists primarily of rock bolts and wire mesh.

It is anticipated that repair or replacement of wire mesh and installation of new rock bolts may be required because of corrosion, minor spalling of rock, and minor rock movement. The corrosion rate for the wire mesh and rock bolts is expected to be <0.002 in./yr (NACE, 1974). If the rock bolts are set in concrete, the corrosion rate will be reduced because the surface of the bolt is protected from the air and because concrete has a high pH (alkaline). A minor amount of spalling is anticipated. During maintenance, the spalled rock is removed and the wire mesh is replaced. Minor rock movement either naturally or thermally induced may require the installation of additional rock bolts.

5.1.3.2 Borehole Liner and Shield Plug

Under normal conditions, the steel borehole liner will remain intact and will provide adequate access to the emplaced waste containers throughout the design-basis, 84-yr lifetime. Published data for corrosion rates at temperatures between 0 and 450°C and at 100% humidity predict an annual corrosion rate of <0.002 in./yr for low carbon steel (NACE, 1974). This conservative corrosion rate estimate predicts a metal loss of <0.2 in. before repository closure. For the horizontal concept, the rockfall-induced liner loads will result in a maximum bending stress in the liner of <2,400 psi (SNL, 1987, Appendix B).

The shield plug corrosion rate (like that of the liner) is predicted to be <0.002 in./yr. The structural design of the shield plug will consider loss of material resulting from corrosion. Because the shield plug will be designed with a safety factor of 4, failure is not expected under normal conditions.

5.1.3.3 Waste Container

Under normal conditions, the waste container will remain intact during removal. In vertical emplacement, the only loading is the weight of the container as it is lifted from the borehole. In horizontal emplacement, the dolly will reduce external loads on the container. Because the container is designed with a significant safety factor, failure is not expected.

5.1.3.4 Retrieval Equipment

During the waste emplacement period, the equipment needed for waste removal under normal conditions will be operational because the current design basis uses the same equipment (transporter, auxiliary equipment, and shielding collar) for emplacement and retrieval. During the caretaker phase, two sets of retrieval equipment will be kept operational to implement the performance confirmation program. If full repository retrieval is initiated during the caretaker phase, additional retrieval equipment will be made operational.

The current design basis for horizontal emplacement uses a dolly to reduce loads on the waste container during emplacement and retrieval operations. Under normal conditions, the dolly and the dolly hook [described in the Site Characterization Plan Conceptual Design Report (SCP-CDR) (SNL, 1987), Appendix D] are expected to remain operational during retrieval operations. Current plans assume that the dolly roller system will not be operable during retrieval operations under normal conditions and that sliding, rather than rolling, friction will have to be overcome.

5.1.3.5 Ventilation Equipment

The entire ventilation system will be maintained in a fully operational condition throughout the caretaker period. The ventilation equipment (fans, regulators, chillers, etc.) will continuously ventilate the ramp and access drifts, and the system to distribute and regulate air-flow to the emplacement drifts will be exercised periodically during inspection and maintenance.

5.1.3.6 Waste-Handling Building

During waste emplacement, the waste-handling building will be maintained in operating condition. Maintenance of the building in operating condition after emplacement has been completed is not currently planned. For retrieval, the structure will be repaired and maintained as necessary. In current planning, the building will not be constructed to accommodate reverse operations for full (total) retrieval; if major retrieval operations are to be undertaken, extensive modifications and additional construction will be necessary.

5.1.3.7 Support Systems and Facilities

All support systems, including utilities, lighting, and communications, and all underground support facilities will be maintained throughout the retrievability period. On the surface, only those facilities needed for performance confirmation and maintenance operations will be maintained during the caretaker phase (Section 4.5.2).

5.2 Credible Abnormal Conditions

The credible abnormal conditions presented here were identified in the items important to retrievability study (SNL, 1987, Appendix L-2). That preliminary study was performed to determine if any credible abnormal conditions could cause major problems during retrieval. The study was scoping in nature and was based primarily on engineering judgment.

Developing a list of credible abnormal conditions began with compiling a comprehensive list of approximately 75 processes and events of potential concern. Initial screening of this list identified the following processes and events that could affect the ability to retrieve:

- tectonics--seismic events and fault movement;

- variability in rock characteristics--variability in the natural in situ conditions (Section 5.1.2);

- human error--human errors that could occur during repository design and construction; equipment fabrication; and emplacement operations, maintenance operations, and retrieval operations;

- aging/corrosion--aging and corrosion effects on equipment and facilities; and

- radiolysis--radiation-induced effects on the borehole liner, shield plug, and retrieval equipment.

These events and processes were then evaluated to determine how they might affect the ability to perform the four functions necessary to complete retrieval successfully: (1) provision of access to the emplacement boreholes, (2) provision of access to the waste containers, (3) removal of the waste containers, and (4) transport and delivery of the waste to the surface facilities (SNL, 1987, Appendix J). This evaluation identified the abnormal conditions listed in Table 5-7.

The abnormal conditions presented in Table 5-7 have been used to guide the development of contingencies for retrieval operations and equipment for abnormal conditions. This table will be used as a starting point in future analyses for the application of probability-based evaluations (Figure 3-3) and for quantification of the actual conditions. The application of the concepts presented in Figure 3-3 will result in more detailed criteria for design and operations of equipment and facilities, more specific guidance for equipment development requirements and demonstration needs, and a firm basis for deciding what equipment will be needed at the repository.

The potential for combined effects (i.e., the occurrence of two or more of the events or processes at the same time) has not been considered in this analysis. The results of this preliminary analysis, which were

TABLE 5-7

ABNORMAL CONDITIONS FOR RETRIEVAL[a]

Tectonics--Seismic (0.45 to 0.6 g event)

The following conditions are postulated to ensue from a seismic event of the magnitude indicated:

- ramp rockfall--localized within the ramp;
- ventilation system malfunction--surface damage to the ventilation equipment;
- loss of offsite power--resulting from transmission line failure;
- vertical emplacement borehole rockfall--around the waste container in the vertical emplacement boreholes;
- waste container lateral movement (horizontal)--on the order of centimeters;
- waste container "tilt" (vertical)--movement of the emplaced waste containers within the vertical borehole;
- shield plug jam--resulting from borehole distortion; and
- cask/collar bind--transporter cask/emplacement collar bind resulting from seismic activity during a removal operation.

Tectonics--Faulting

The following conditions are postulated to ensue from fault movement:

- ramp rockfall--localized within the ramp,
- drift rockfall--localized in a drift, and
- excessive borehole/liner deflection (horizontal)[b]--shearing of the horizontal borehole and liner resulting from fault movement.

Variability of Rock Characteristics

The following postulated conditions result from variability in the rock characteristics:

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[a]From Table 3-1, Appendix J, SCP-CDR.
[b]Although the probability of occurrence for a shear of the borehole and liner is extremely low, it is included in this discussion because of the potential consequence.

TABLE 5-7

ABNORMAL CONDITIONS FOR RETRIEVAL
(continued)

Variability of Rock Characteristics (continued)

- ramp rockfall--localized, resulting from reduced mechanical strength;
- drift rockfall--localized, resulting from reduced mechanical strength; and
- vertical emplacement borehole rockfall--around the emplaced waste container from an area of reduced mechanical strength.

Human Error--Fabrication

The following postulated conditions result from human error during fabrication:

- heating, ventilation, and air conditioning (HVAC) failure,
- excessive liner deflection,
- collar malfunction,
- auxiliary equipment malfunction,
- shield plug jam, and
- dolly failure.

Human Error--Maintenance

The following postulated conditions result from improper or inadequate maintenance:

- ramp rockfall,
- drift rockfall,
- HVAC malfunction,
- collar/attachment malfunction,
- transporter malfunction (removal),
- transporter malfunction (transport),
- transporter malfunction (unloading), and
- surface facility collar/attachment malfunction.

Human Error--Operation

The following postulated conditions result from human error during operations:

- transporter collision with the ramp--while the transporter is moving up or down the ramp;
- transporter collision with the drift;
- transporter collision with the auxiliary equipment;

TABLE 5-7

ABNORMAL CONDITIONS FOR RETRIEVAL
(concluded)

Human Error--Operation (continued)

- transporter collision with another transporter;
- emplacement borehole alignment error;
- thermal loading--excessive thermal loading as a result of human error (e.g., the thermal output of a waste container is incorrectly determined);
- error during emplacement--an operator error made during waste emplacement (e.g., the waste container is incorrectly emplaced in the borehole);
- error during removal--an operator error made during waste removal (e.g., an alignment error is made);
- alignment error on the surface--an operator error made during alignment of the transporter cask and the surface facility loading port; and
- error during unloading--an operator error made while the waste container is being unloaded at the surface facility.

Aging or Corrosion of Equipment and Facilities

The following postulated conditions result from aging or corrosion of equipment and facilities:

- rock bolt failure and
- dolly failure (horizontal emplacement).

Radiolysis

The following postulated conditions result from radiolysis at rates above the expected levels:

- liner corrosion,
- dolly corrosion, and
- waste container corrosion.

not extremely detailed, were intended to be used to indicate areas warranting further investigation.

5.3 Method of Determining Retrieval Conditions

5.3.1 Normal Conditions

5.3.1.1 Environmental Conditions

Thermal Conditions

Temperature estimates for the boreholes and drifts have been made using a three-dimensional computer code SIM. SIM computes the temperature at any point in a homogeneous conductive medium subjected to linear, exponentially decaying thermal sources. A complete discussion of the thermal analysis is contained in Appendix E.

Radiologic Conditions

Two analyses have been performed to define the radiologic conditions: (1) radon-222 concentration calculations (Appendix F) and (2) radiation shielding scoping calculations (Appendix G). The radon concentration calculations evaluated the concentration variance with time in the drifts and considered radon-222 emanation from the rock, radon content of inlet and outlet ventilation air, and radon decay. The radiation shielding calculations used an analytical approach and assumed a linear radiation source. Self-shielding and build-up were not considered.

Ventilation Air Quality

The condition of the ventilation air has been analyzed using the computer code CLIMSIM. Given psychrometric conditions of the inlet air and thermal conditions of the rock, the code will predict the psychrometric conditions of the ventilation air within the drifts. The airflow rates have been calculated using the computer code VNETPC. This code predicts airflow and pressure drops for a given underground network. Additional details for both of these computer codes are given in Appendix D.

5.3.1.2 Natural Conditions

The conditions within the rock surrounding the shafts, ramps, drifts, and boreholes (Section 5.1.2) are based on the results of 15 reports and studies (SNL, 1987, Appendix N). Detailed discussions on the methods used for these studies are contained in the SCP-CDR. The analyses used a variety of numerical methods and empirical approaches including finite-element models, boundary-element methods, and tunnel-indexing methods. The different constitutive models used included elastic models, ubiquitous-joint models, compliant-joint models, and elastic-plastic models. Many of these analyses varied input parameters including opening sizes and shapes, depths, thermal and mechanical properties, fracture properties, and in situ conditions.

5.3.1.3 Condition of Engineered Structures

Ground Support

Estimates of the condition of the rock support system have been derived from the judgment of experts in the mining industry, published data, and experience in G-Tunnel at the NTS.

Borehole Liner and Shield Plug

The estimated corrosion rates were taken from Corrosion Data Survey (NACE, 1974). The liner stress levels were taken from Appendix B of the SCP-CDR (SNL, 1987). The analysis in the SCP-CDR used a ring loading method to simulate rockfall loading on the liner. The rockfall estimates were calculated using triangular and radial failure assumptions, and the more severe condition of 20.4 lb/in. (radial) was used. The actual stress levels were computed using superposition of known solutions (Roark and Young, 1975).

Waste Container

The condition of the waste container has been determined by reviewing the results of the waste package development program at Lawrence Livermore National Laboratory.

Equipment, Facilities, and Support Systems

No specific analyses have been performed to determine the normal conditions for the equipment, facilities, and support systems. The conditions presented in Sections 5.1.3.4 through 5.1.3.7 have been developed using the other established repository conditions, the design criteria presented in Section 3.2.2, the postemplacement operations presented in Chapter 4, and engineering judgment.

5.3.2 Credible Abnormal Conditions

The list of credible abnormal conditions presented in Table 5-7 was developed for the study of items important to retrievability (SNL, 1987, Appendix L-2). The method used in the study is presented in Figure 5-5. As shown in the figure, 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. The resulting master list of approximately 75 events and processes is shown in Table 5-8. This list was screened using the criteria in Table 5-9 to eliminate from further consideration those events and processes that either were not applicable to the Yucca Mountain site or caused a clearly insignificant delay in retrieval operations. This screening identified the following "short list" of processes and events:

- tectonics,
- variability in rock characteristics,
- human error,

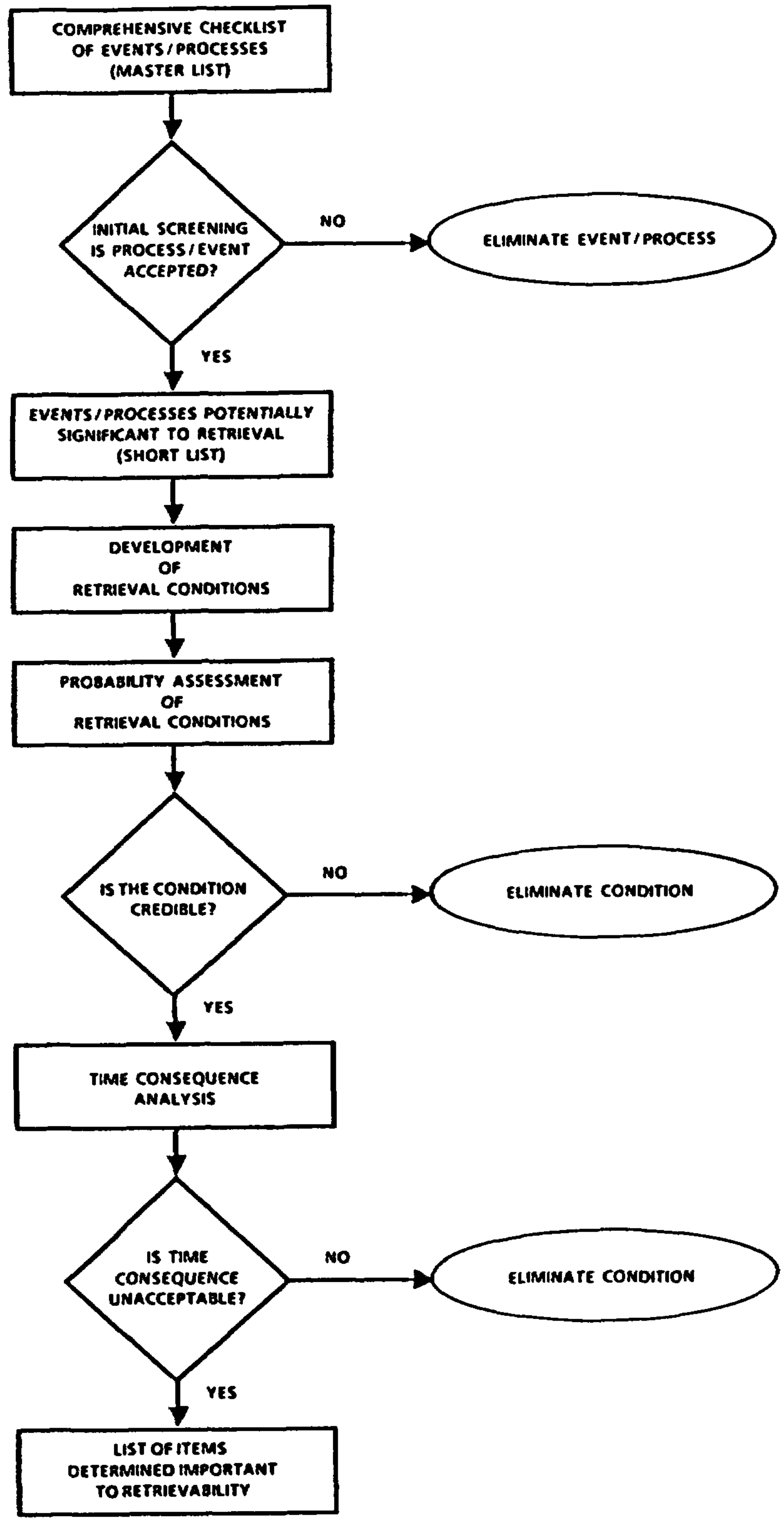

Figure 5-5. Flow Diagram Illustrating the Method for Establishing Items Important to Retrievability (from Figure 8-7, SCP-CDR)

TABLE 5-8

MASTER LIST OF EVENTS AND PROCESSES*

Natural

Hurricane
Extreme Wind
Forest Fire
Glaciation
Tsunami
Seiche
Sandstorm
Tornado
Lightning
Avalanche
Climate Change
Water Table Change
Sea Level Change
Denudation

Surface Erosion
- Stream erosion
- Glacial erosion

Flooding
Sedimentation
Diagenesis
Diapirism

Tectonics
- Faulting
- Seismicity
- Shear zone

Natural Geochemical Changes

Ground Water Flow
- Infiltration/fault

Perched Water
Dissolution
Brine Pockets

Variability of Rock Characteristics
- Thermal characteristics
- Strength characteristics

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*From Table 4-1, Appendix L, SCP-CDR.

TABLE 5-8

MASTER LIST OF EVENTS AND PROCESSES
(continued)

Natural (continued)

Undetected Features
- Breccia pipes
- Lava tubes
- Intrusive dikes
- Gas pockets

Magmatic Activity
- Intrusive
- Extrusive

Meteorite Impact

Uplift/Subsidence
- Orogenic
- Epeirogenic
- Isostatic

Human-Induced

Human-Induced Alteration of Hydrology
- Irrigation
- Reservoirs
- Intentional artificial ground water recharge or withdrawal
- Chemical liquid waste disposal

Undetected Past Intrusion
- Undiscovered boreholes
- Mine shafts

Commercial Aircraft
Military Aircraft
Weapons Testing at NTS

Intentional Intrusion
- War
- Sabotage

Loss of Offsite Power

Repository-Induced

Thermal Effects/Loading
- Rock mass response
- Hydrologic effects
- Thermal cycling

TABLE 5-8

MASTER LIST OF EVENTS AND PROCESSES
(concluded)

Repository-Induced (concluded)

Excavation Effects
Creep
Aging/Corrosion
Gas Generation

Radiological Effects
- Rock material property changes
- Radiolysis
- Decay-product gas generation
- Nuclear criticality

Human Error
- Design error
- Fabrication error
- Operator error
- Maintenance error
- Construction error

Underground Fire

- aging/corrosion, and
- radiolysis.

The next step involved identifying retrieval conditions that could 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 four retrieval functions. This method created a list of approximately 110 abnormal conditions, which were then assigned estimated probabilities of occurrence using engineering judgment. The conditions that were judged to have a negligible probability of occurrence ($<10^{-5}$/yr) were removed from further consideration, resulting in the list of credible abnormal conditions (Table 5-7).

As shown in Figure 5-5, a time consequence analysis was performed to estimate the time delay in completing retrieval operations. As a result

TABLE 5-9

SCREENING CRITERIA FOR ESTABLISHING EVENTS AND PROCESSES FOR THE SHORT LIST*

Screening Criteria Code	General Screening Criteria
A	The event is not applicable to the Yucca Mountain site region (e.g., coastal erosion, hurricanes).
B	The event is irrelevant or insignificant to preclosure operations (e.g., glacial erosion).
C	The event is considered not very likely to cause any significant time delay in retrieval operation (e.g., drought, frost). A delay to the retrieval schedule of 6 mo or more is considered to be significant.
D	The event has such an extremely low frequency of occurrence that a nuclear facility design does not need to consider it (e.g., the probability of a meteorite heavier than 2 lb is 10^{-9}/yr, so it need not be considered). A frequency of occurrence of 10^{-5}/yr or less is considered to be extremely low.
E	The impact of the external event is bounded, or within the plant design basis. Certain events such as an earthquake and extreme wind are not subject to this criterion, because their magnitude may exceed the design basis.
X	Select for further study.

*From Table 7-6, SCP-CDR.

of this analysis, the following six conditions have been judged to have a potential time delay of 6 mo or greater:

- ventilation equipment failure resulting from a tectonic (ground motion) event,
- emplacement borehole rockfall resulting from a tectonic (ground motion) event (vertical only),
- waste container "tilt" resulting from a tectonic (ground motion) event (vertical only),

- shield plug jam resulting from a tectonic (ground motion) event,
- ventilation system failure resulting from a human error related to maintenance, and
- transporter collision with the ramp resulting from operator error.

However, the time consequence only considered time delays that pertained to the overall retrieval operations. For many of the credible abnormal conditions a time delay to the overall retrieval operations was avoided by retrieving waste from another emplacement drift while corrective actions were performed in the affected drift. Although this time consequence analysis was sufficient for the items important to retrievability study, future studies will consider the effect of credible abnormal conditions on the ability to remove any affected waste containers.

REFERENCES FOR CHAPTER 5

DOL (U.S. Department of Labor), "Safety and Health Standards--Underground Metal and Nonmetal Mines," Code of Federal Regulations, Mineral Resources, Title 30, Part 57, Washington, DC, July 1985. (NNA.890411.0039)

Dravo Engineers, Inc., "Effect of Variations in the Geologic Data Base on Mining at Yucca Mountain for NNWSI," SAND84-7125, prepared for Sandia National Laboratories, Albuquerque, NM,December 1984. (HQS.880517.2283)

Hustralid, W., "Preliminary Stability Analysis for the Exploratory Shaft," SAND83-7069, prepared for Sandia National Laboratories, Albuquerque, NM, December 1984. (HQS.880517.2305)

ICRP (International Commission on Radiological Protection), "Radiation Protection of Workers in Mines," Publication 47, Pergamon Press, New York, NY, 1986. (NNA.900702.0005)

NACE (National Association of Corrosion Engineers), Corrosion Data Survey, 5th edition, March 1974. (NNA.910409.0022)

Roark, R. J., and W. C. Young, Formulas for Stress and Strain, 5th edition, pp. 209-230, McGraw Hill, Inc., New York, NY, 1975. (NNA.910306.0151)

SNL (Sandia National Laboratories), "Site Characterization Plan Conceptual Design Report," SAND84-2641, compiled by H. R. MacDougall, L. W. Scully, and J. R. Tillerson, Sandia National Laboratories, Albuquerque, NM, September 1987. (NNI.880902.0014-.0019)

6.0 RETRIEVAL METHODS

This chapter describes the retrieval methods planned for the repository at Yucca Mountain; this includes all retrieval-related operations, equipment requirements, and contingencies to accommodate abnormal conditions.

6.1 Retrieval Under Normal Conditions

This section describes the planned method of retrieval for the normal conditions defined in Section 5.1. To generate the worst-case normal conditions, it will be conservatively assumed that retrieval is ordered at the end of the retrievability period (50 yr after waste emplacement begins). The retrieval method is generally the same for partial and full repository retrieval; so, for this study, only full repository retrieval is discussed. The basis for this discussion on retrieval operations is contained in Appendix H.

Retrieval operations are performed in two phases: (1) preparation and (2) waste removal. Preparation involves preparing the repository for removal of waste and for receipt of retrieved waste at the surface. Waste removal involves activities associated with restoring the access and emplacement drifts, removing the waste from the emplacement boreholes, and returning the waste to the surface.

6.1.1 Preparation

Upon receipt of an order to retrieve emplaced waste, preparation activities will begin; these activities include preparation of the surface facilities for receipt of waste and support activities, preparation of the underground facilities for waste removal, preparation of retrieval equipment, engineering support activities, and general support activities. A synopsis of all of the activities for the preparation phase is included in Table 6-1.

TABLE 6-1

PREPARATION ACTIVITIES FOR WASTE RETRIEVAL

Surface Facilities
• Reactivation and modification of the waste-handling buildings
• Construction of additional temporary storage
• Reactivation of support facilities
• Construction of a surface cooling plant (vertical only)
Underground
• Modification of the ventilation system
• Rehabilitation of underground openings (excluding panels)
Equipment
• Reactivation of retrieval-related equipment
Engineering Support
• Performance of an initial retrieval assessment
• Preparation of the retrieval plan
• General engineering support
General Support
• Administrative activities
• Reactivation of security measures
• Training program
• Reactivation of medical facilities and capabilities
• Maintenance activities

6.1.1.1 Surface Facilities

For this discussion, it is assumed that retrieval is ordered during the caretaker period (Figure 3-2). (During the emplacement period, reactivation of facilities will not be required; all other preparation activities will be the same.)

Waste-Handling Buildings

Preparation of the waste-handling buildings begins with removing the building from "moth ball" status. The amount of maintenance and repair needed to achieve operational status will depend upon the length of time the facility had been moth-balled. Also, to accommodate retrieved waste, significant modifications to the waste-handling buildings are anticipated. Reactivation and modification of the waste-handing buildings are estimated to take approximately 2.5 yr.

Temporary Storage

Temporary storage for approximately 210 containers is included in the current conceptual design of the waste-handling buildings (SNL, 1987). Under normal conditions, this storage is expected to be adequate for retrieval. The storage areas of the waste-handling buildings are being designed for possible expansion.

Support Facilities

Portions of the support facilities, including administrative, training, and maintenance and repair facilities, will require reactivation for retrieval. This will involve repair and maintenance estimated to take 6 mo.

Surface Cooling Plant

For the vertical emplacement configuration, a surface chiller will be needed to cool the ventilation air to the emplacement drifts (Section 6.1.2.1). The construction will require approximately 6 mo.

6.1.1.2 Underground

Ventilation System (Excluding Panels)

The type and extent of modifications to the ventilation system will depend on the specific circumstances of retrieval, including the extent of retrieval operations, the location of the waste to be retrieved, and the reason for retrieval. Modifications to the ventilation system are estimated to take about 1 yr to complete.

Access Rehabilitation (Excluding Panels)

Repair and maintenance of the ramp, main drifts, and shop areas may be needed to support full retrieval. These rehabilitation activities will take approximately 1 yr.

6.1.1.3 Equipment

The current design basis for emplacement operations (Appendix H) includes five transporters (four active and one spare) and other emplacement/retrieval equipment--the transporter for dummy containers (horizontal emplacement), the shielding closure, and auxiliary equipment. During the emplacement period, all equipment will be operational. During the caretaker period, only two transporters and necessary support equipment will be maintained (for performance confirmation purposes). The rest of the equipment will be maintained on a standby status (i.e., moth-balled).

Depending on the waste-container extraction rate required, some of the moth-balled equipment may be needed. Reactivation of equipment will involve inspection, maintenance, and repair of the equipment and certification for retrieval operations. This activity is estimated to take up to 1 yr to complete.

6.1.1.4 Engineering Support

The engineering support activities include performance of an initial retrieval assessment, preparation of the removal plan, and general engineering support activities. The initial retrieval assessment is performed to determine the schedule and removal rate of the waste containers and, based on that, to decide which activities are appropriate to preparation for waste removal. The mandate for retrieval, repository status, and operational constraints will be used as a basis for these determinations.

The purpose of the removal plan is to establish a sequence and schedule for removal of the waste containers. For this, retrieval on several levels must be considered: repository, panel, emplacement drift, emplacement borehole, and waste container. This includes considering the results of the initial retrieval assessment; the receipt capabilities of the surface facility; repository documentation for the equipment, facilities, and waste containers; and any known abnormal retrieval conditions. In addition, the experience from repository monitoring, emplacement operations, and waste removal for performance confirmation purposes will help identify the potential for abnormal conditions and the need for contingencies. Specific consideration will be given to the potential effects that abnormal conditions in a borehole may have on operations in the panel and in the drift.

Various preparation activities will require general engineering support. Examples include support for facility modifications, equipment inspection and repair, maintenance operations, and development of corrective actions for abnormal conditions.

6.1.1.5 General Support

General support includes administrative support (records keeping, payroll, etc.), security, medical support, personnel training, services, and general maintenance. Staffing levels should be adequate during the emplacement period to support retrieval operations, but staffing levels will be significantly reduced during the caretaker period. Therefore, additional staff will be required to support retrieval operations. Because of the remote location of the site, hiring and training of needed personnel could take a year.

6.1.1.6 Schedule

The schedule for preparation activities is presented in Figure 6-1. It is estimated that the preparation could take up to 3 yr. Figure 6-1 is based on data presented in Appendix H.

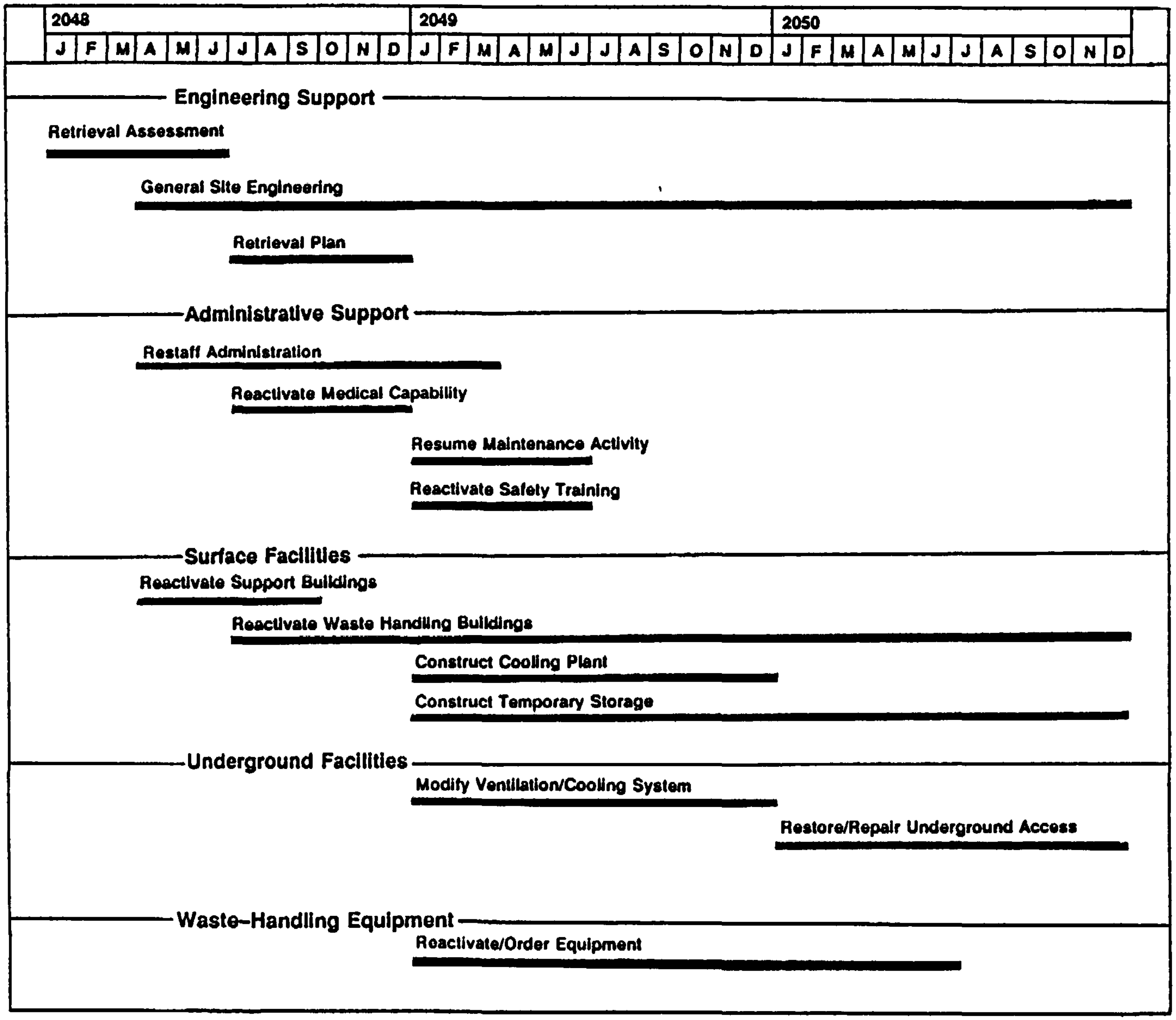

Figure 6-1. Schedule of Preparation Activities for Retrieval

6.1.2 Waste Removal Operations

The waste removal phase of retrieval includes (1) panel preparation, (2) borehole preparation, (3) actual waste removal, (4) transport and delivery of the waste at the surface, and (5) closure of the borehole. A flowchart of the waste removal phase (Figure 6-2) illustrates the cyclical nature of waste removal operations at the borehole, emplacement drift, and emplacement panel levels. Block flow diagrams of the borehole-level operations are shown in Figures 6-3 and 6-4 for vertical and horizontal emplacement, respectively. Detailed operations information, including duration and operation sequencing, is presented in Appendix H.

6.1.2.1 Vertical Emplacement

Panel Preparation

If the panel has been closed, reopening the panel access drifts will necessitate ventilation system modification, drift cooling, and minor maintenance. Reestablishing ventilation will necessitate modification of the controlled leakage arrangement. For the vertical emplacement concept, this involves adjusting the regulators at each end of the panel access drift (Figure 4-3). The horizontal emplacement configuration has two types of panel access drifts: intake and return (Figure 4-4). The modifications for the intake drifts are the same as the vertical case. For the return drifts, the regulator at the drift exit must be adjusted.

Because the panel access drifts will have been maintained infrequently after installation of controlled leakage, minor maintenance may be needed to reopen the drifts.

Preliminary studies estimate that approximately 2 wk are required for preparation of the panel access drifts up to the first emplacement drift (Appendix H).

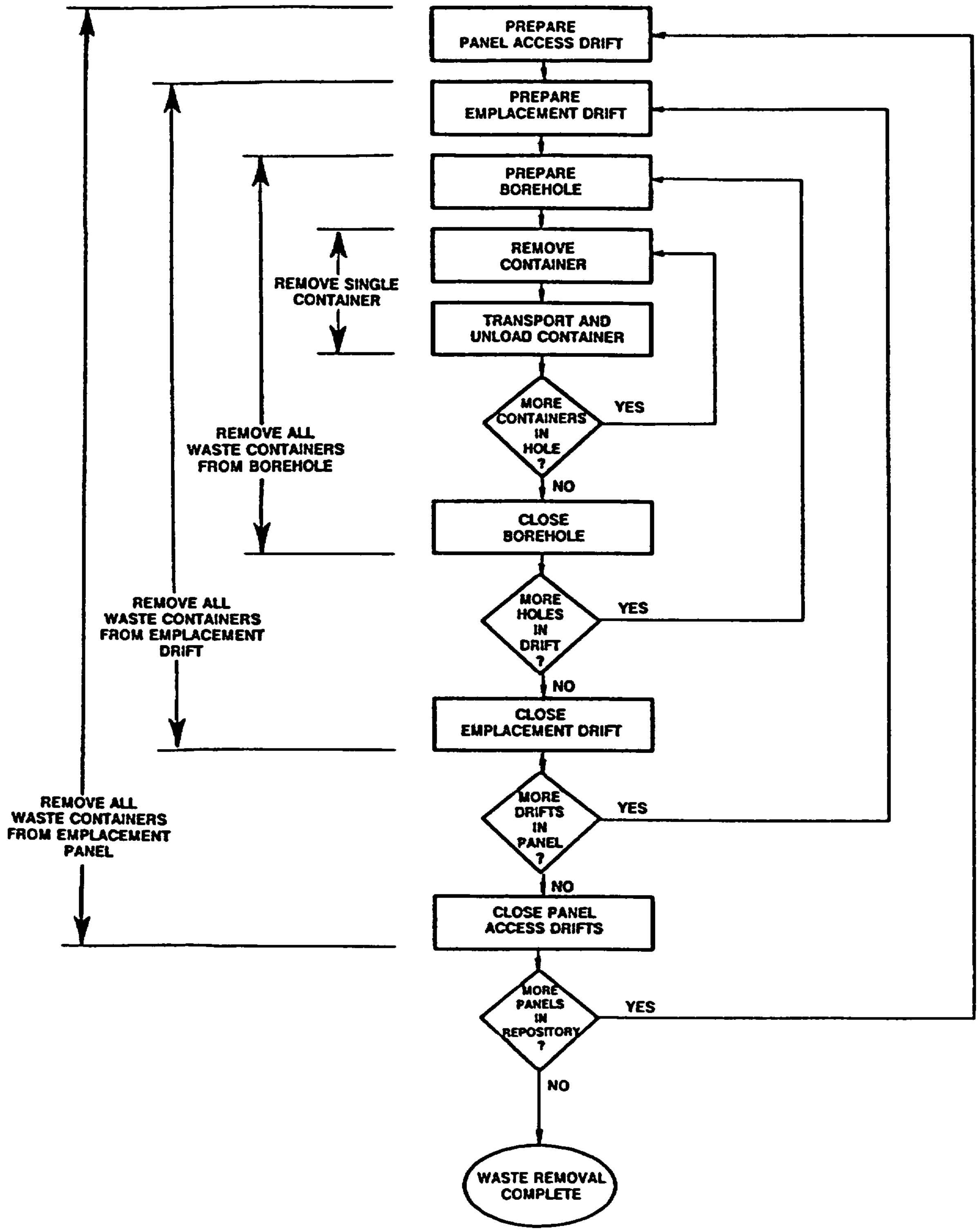

Figure 6-2. Waste Removal Phase of Retrieval

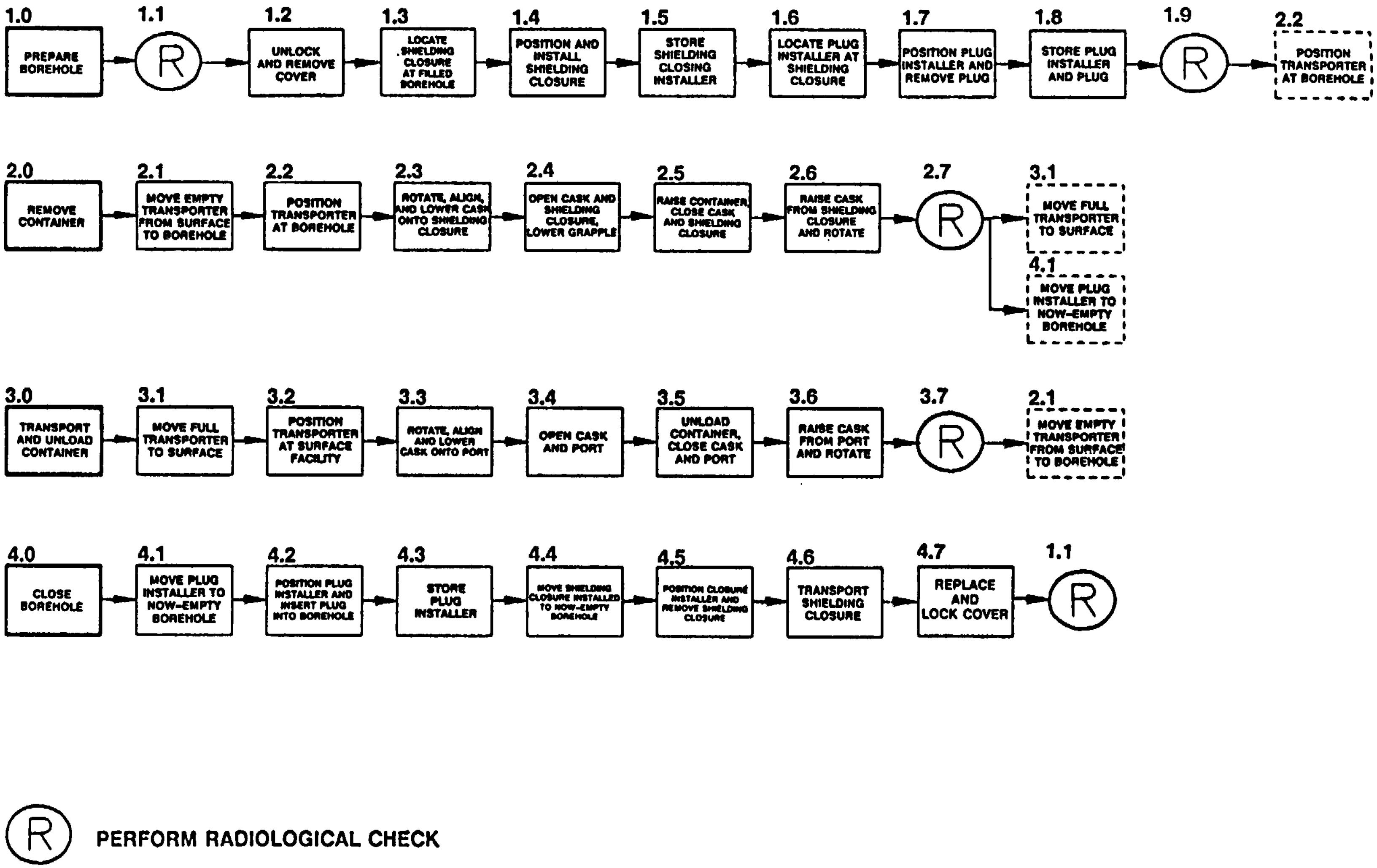

Figure 6-3. Block Flow Diagram, Waste Retrieval, Vertical Emplacement

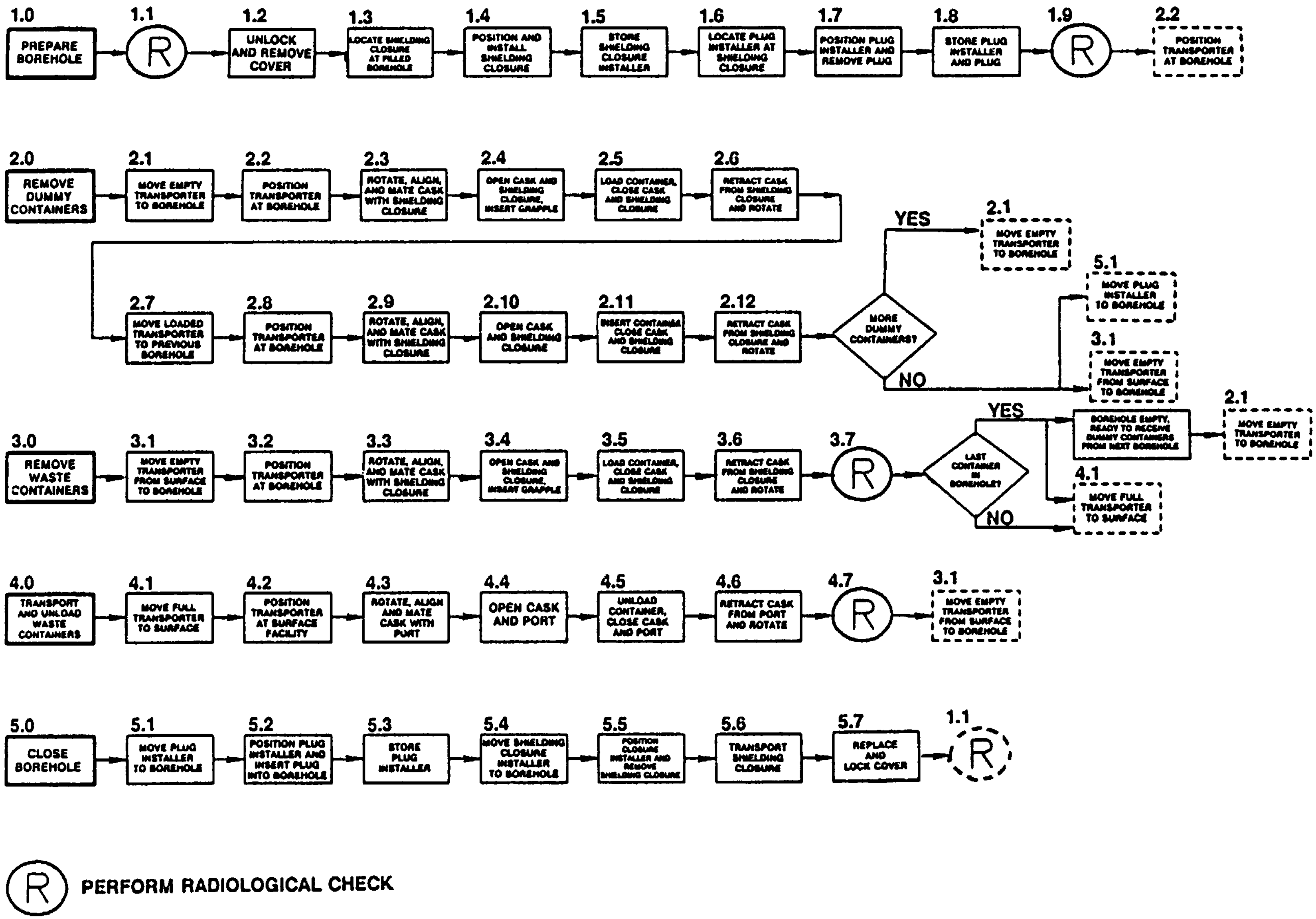

Figure 6-4. Block Flow Diagram, Waste Retrieval, Horizontal Emplacement

Emplacement Drift Preparation

Because of the high expected temperatures, preparation of the emplacement drifts begins with a drift assessment. This assessment will include temperature measurements and drift inspection. Temperature measurements will be used to determine cooling times. Drift inspection, which may be done remotely or from a protected vehicle, may be necessary to identify maintenance requirements.

Establishing ventilation to the emplacement drift will require modification of the controlled leakage configuration. For the vertical case, the door in the emplacement drift near the panel access drift is opened, and the regulator located in the midpanel access drift near the perimeter drift is adjusted (Figure 4-3). For the horizontal case, the door in the intake panel access drift near the emplacement drift is opened, and the regulator in the return access drift near the perimeter drift is adjusted (Figure 4-4).

Providing an acceptable working environment may require extensive cooling. Ventilation equipment and operations needed for drift cooling at the anticipated rock temperatures are commercially available and are routinely used in the mining industry (Smith, 1984; Stroh et al., 1984; Hamm, 1979; and Pretorious et al., 1979).

Emplacement drift cooling requirements are discussed in Section 4.2.3. As shown in Table 4-3, the time required to cool the drifts varies between the vertical and horizontal emplacement configurations. For this discussion, it is assumed that refrigeration will be used in the vertical configuration. Consequently, heat exchangers must be installed in the panel access drifts. This is followed by a period of blast cooling. Refrigeration of ventilation air is not required for the horizontal configuration. The time needed to cool the drift is largely dependent on three factors: how long the waste has been emplaced, the amount of refrigeration used, and the airflow rate. For the operations scheduling presented in Appendix H, drift cooling is assumed to take 50 days.

Once the emplacement drifts have been sufficiently cooled, maintenance and repairs will be performed on the drift. It is assumed that maintenance and repair activities will be performed during the completion of drift cooling (Appendix H).

Borehole Preparation

As shown in Figure 6-3, preparation of the emplacement borehole (Operation 1.0) involves removal of the cover, installation of the shielding closure, and removal of the shield plug (Figure 6-5). The radiologic checks shown in Figure 6-3 (Operations 1.1 and 1.9) are performed to verify the integrity of the radiation shields. Detailed operations information is presented in Table H-2 of Appendix H. It is estimated that borehole preparation will take approximately 3 hr.

Waste Container Removal

A block flow diagram for waste container removal is included in Figure 6-3 (Operation 2.0). The operations, which are illustrated in Figure 6-6, are basically the reverse of emplacement operations. The transporter is moved to the borehole. The cask is rotated to the vertical position and attached to the shielding closure. The closure is opened, and the waste container is removed. After the cask is rotated for transport, a radiological check (Operation 2.7) is performed to detect any residual radioactivity. Initial estimates from Table H-2 indicate that waste removal will take approximately 2 hr.

Waste Transport and Delivery at the Surface

The steps for transferring the waste from the borehole to surface storage are shown in Figure 6-3 (Operation 3.0), and the operation is illustrated in Figure 6-7. Initial estimates indicate that these operations will take approximately 2 hr (Appendix H).

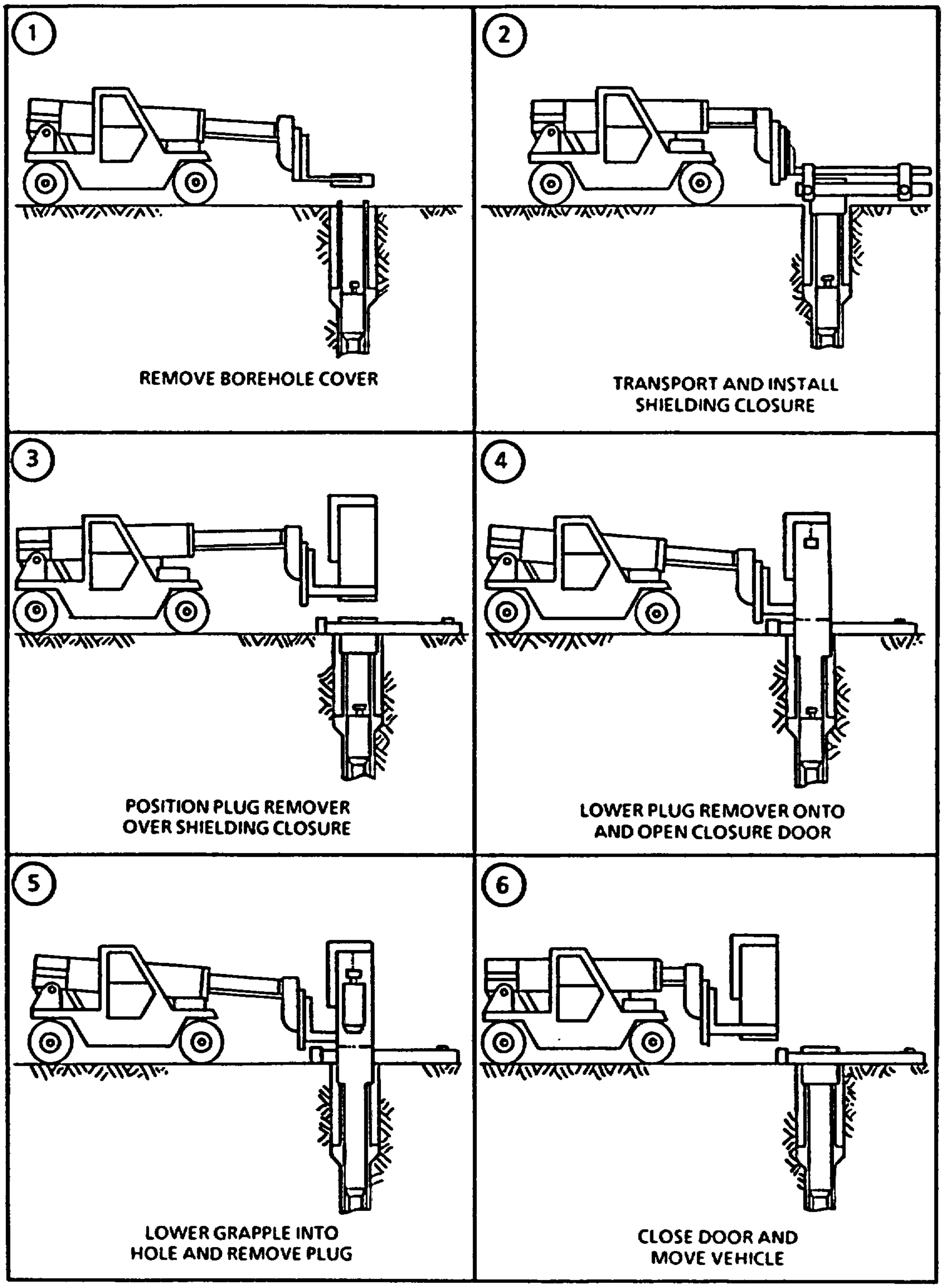

Figure 6-5. Preparation of a Vertical Borehole for Waste Container Removel (from Figure 6-38, SCP)

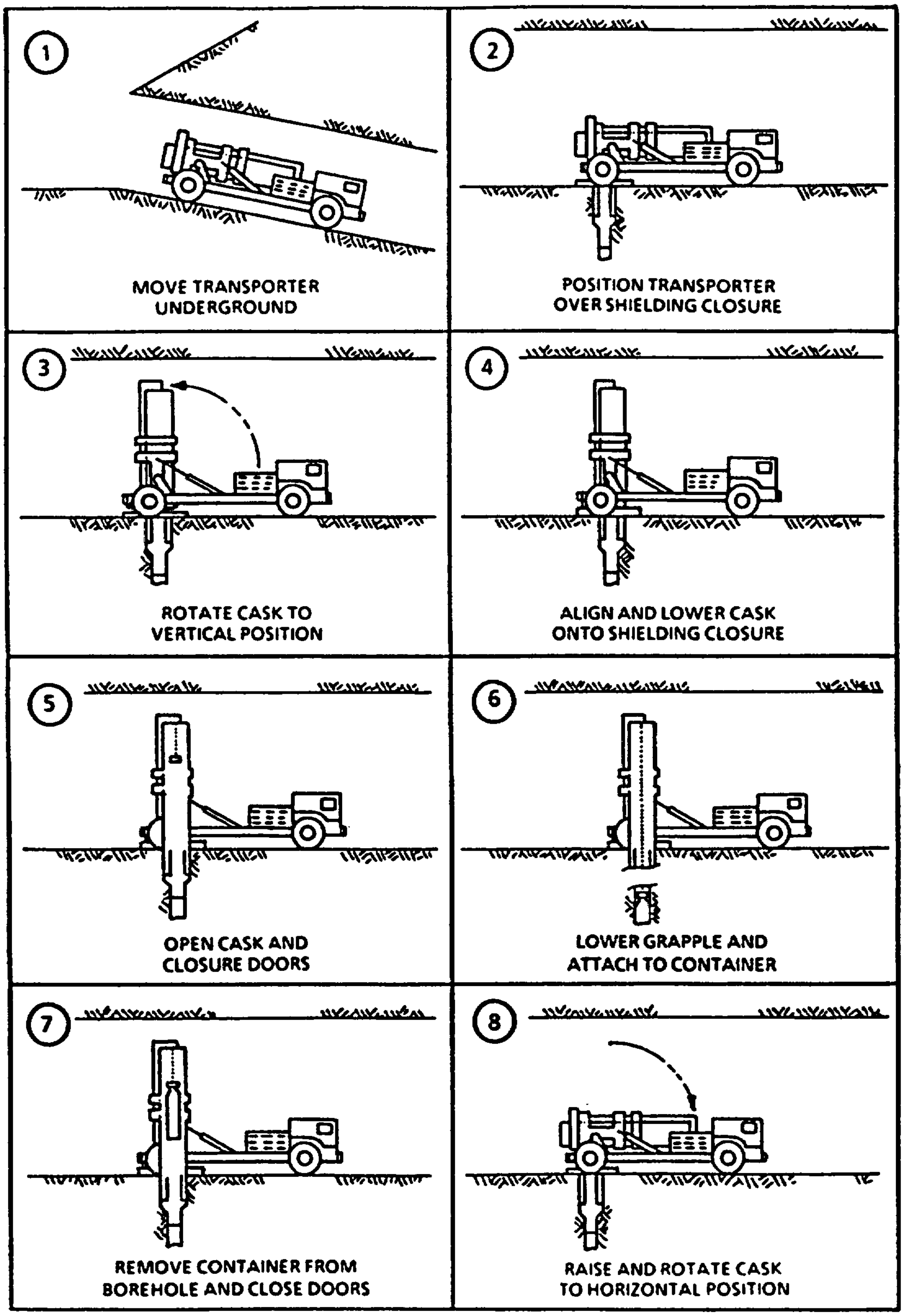

Figure 6-6. Removal of a Waste Container from a Vertical Borehole (from Figure 6-39, SCP)

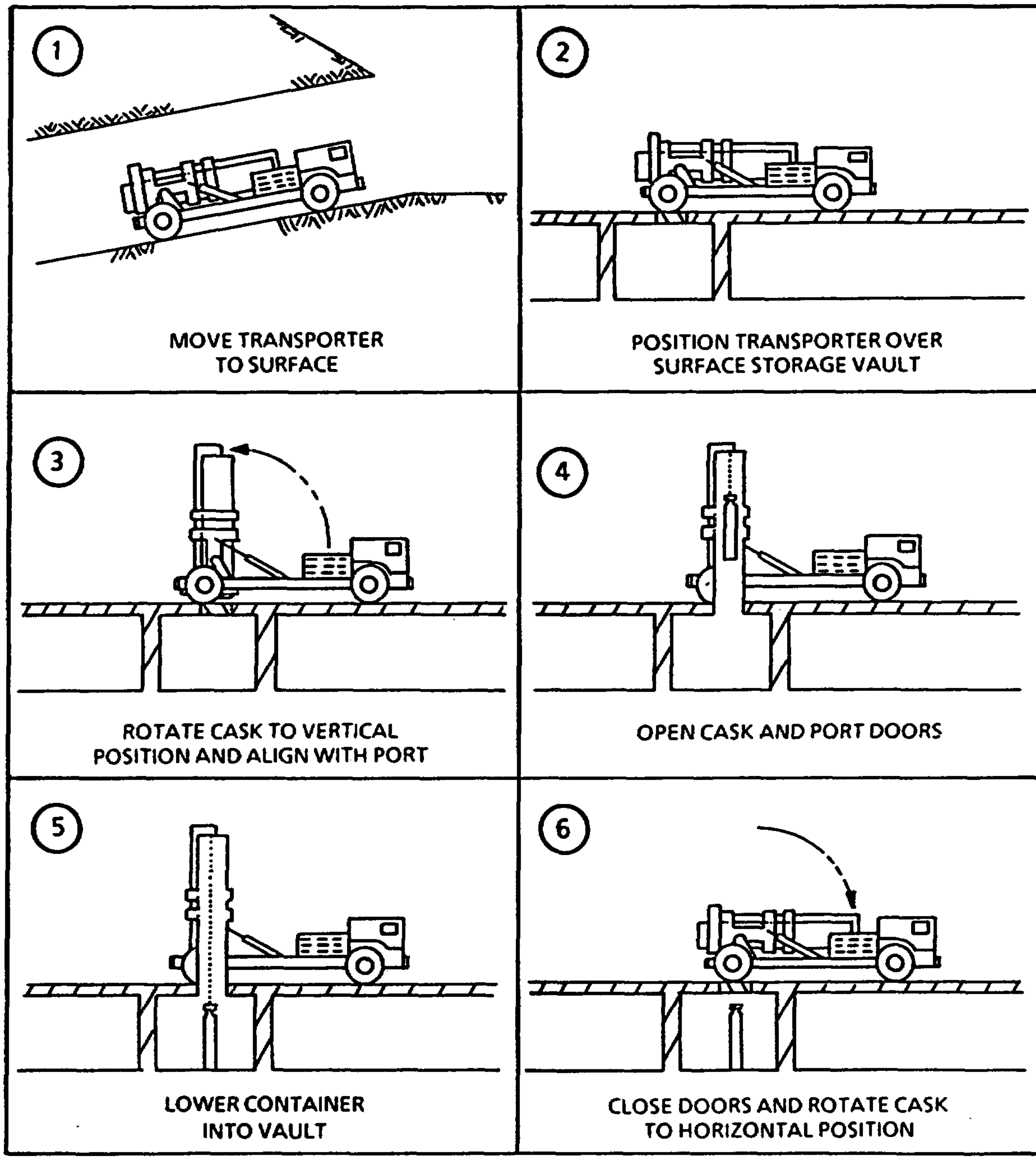

Figure 6-7. Transfer of a Waste Container from a Vertical Borehole to Surface Storage (from Figure 6-40, SCP)

Borehole Closure

While the waste is being transported and unloaded at the surface, the emplacement borehole is closed (Figure 6-3, Operation 4.0). As illustrated in Figure 6-8, borehole closure involves replacing the shield plug and cover and removing the shielding closure. Borehole closure is estimated to take approximately 2 hr (Appendix H.)

6.1.2.2 Horizontal Emplacement

A block flow diagram of the operations for the waste removal phase for the horizontal emplacement concept is shown in Figure 6-4. The major differences between the vertical and horizontal configuration affecting operations are the use of dummy containers in the horizontal configuration and the number of containers in the borehole. The current use of dummy containers requires an additional set of operations (Figure 6-4, Operation 2.0). Future design efforts will investigate horizontal configurations that do not use dummy containers.

Because the horizontal borehole contains multiple waste containers, the borehole preparation and closure operations are not required for each removal cycle. Consequently, a decision branch is included in the block flow diagram (Figure 6-4) after Operation 3.7 (Radiologic Check) to determine when it is time to move to the next borehole. In addition, dummy containers must be removed. As pictured in Figure 6-4, the rest of the operations are basically the same as for the vertical concept.

- Operation 1.0 (Borehole Preparation)--The cover and shield plug are removed, and the shielding closure is installed (Figure 6-9).

- Operation 2.0 (Remove Dummy Containers)--The dummy containers are removed from the standoff region and emplaced in the previously emptied borehole.

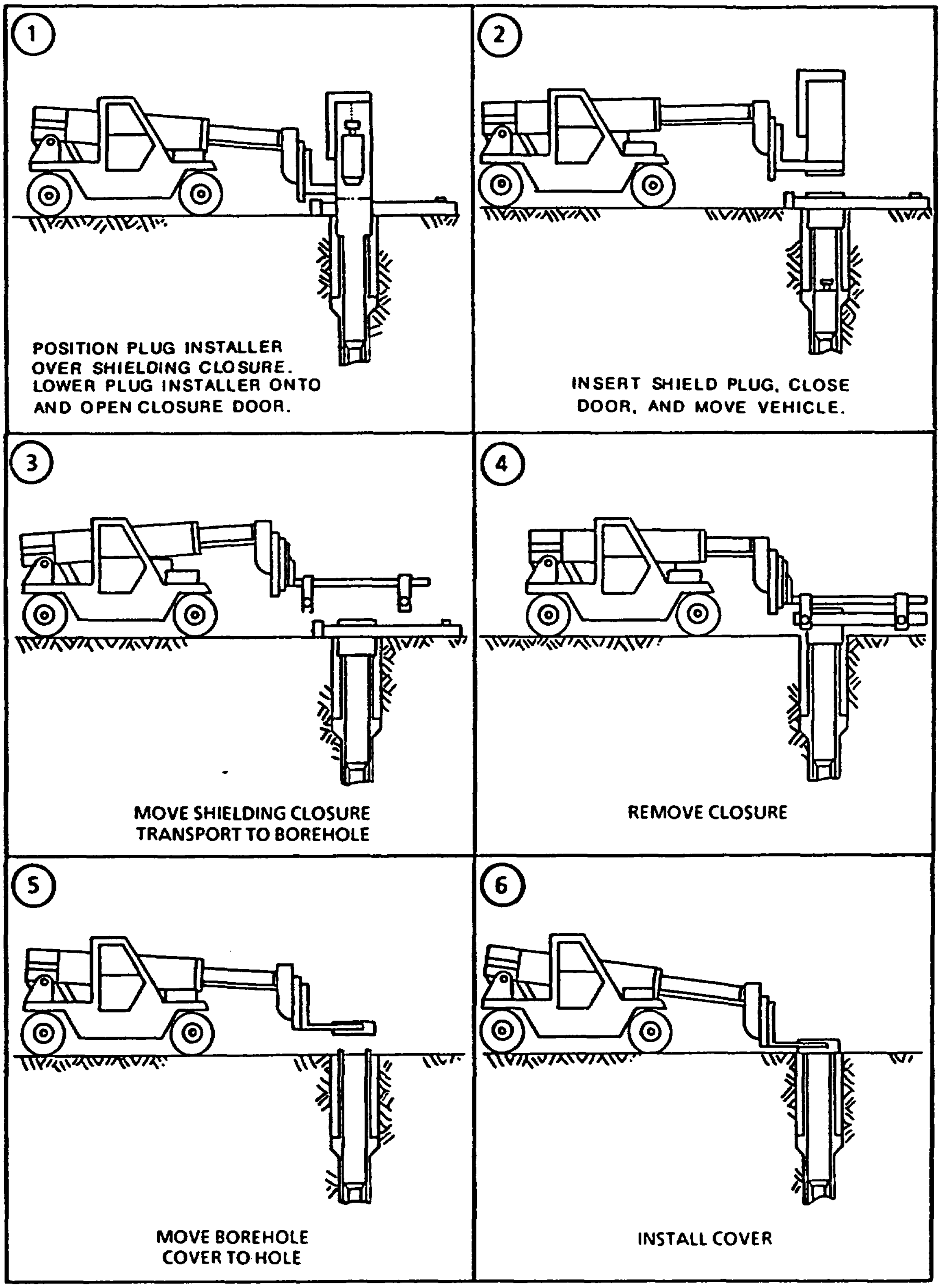

Figure 6-8. Closure of a Vertical Borehole After Waste Removal (from Figure 6-41, SCP)

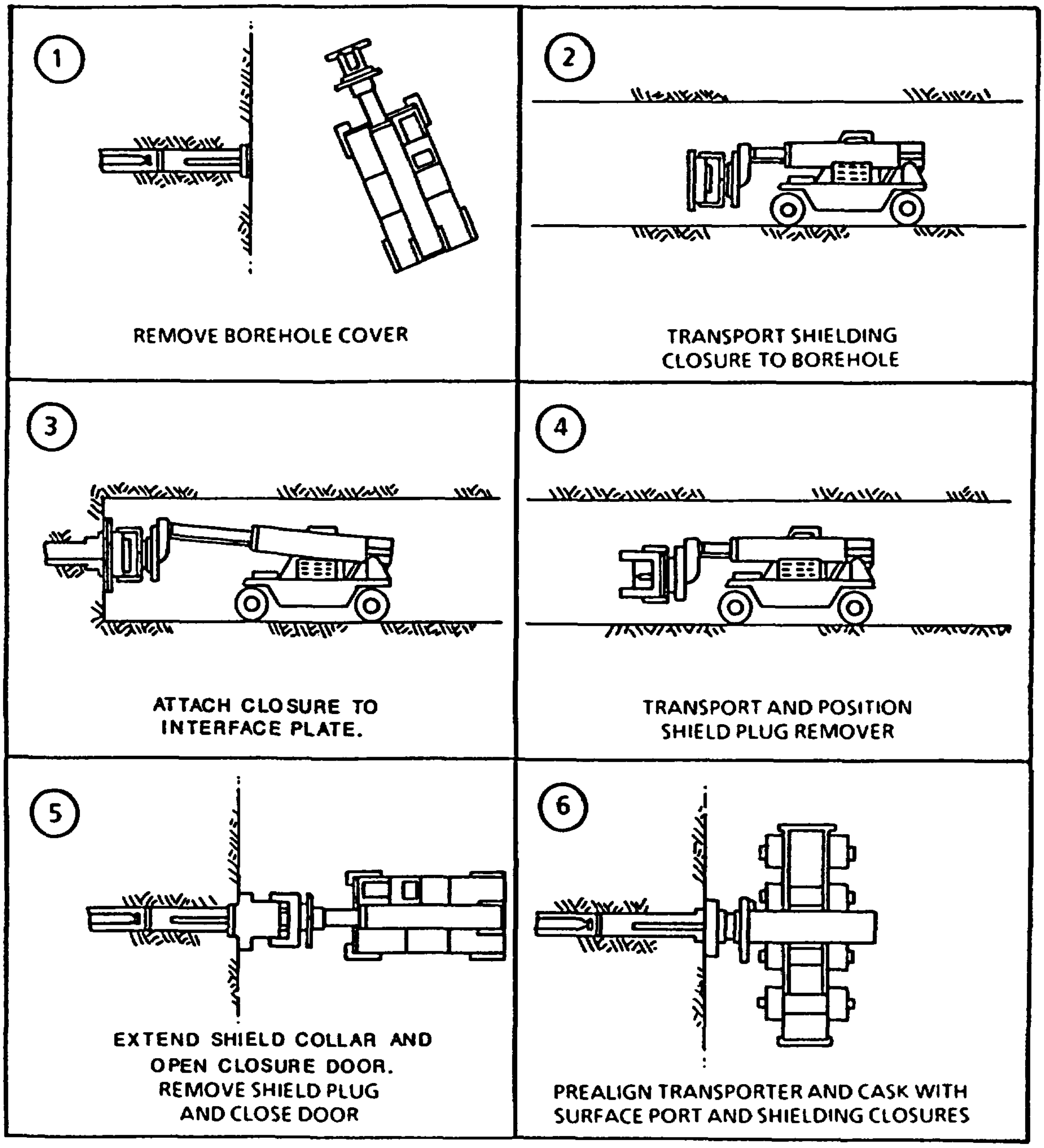

Figure 6-9. Preparation of a Horizontal Borehole for Waste Container Removal

- Operation 3.0 (Remove Waste Containers)--The transporter is moved underground, and operations required to remove the container are performed (Figure 6-10).

- Operation 4.0 (Transport and Unload Waste Containers)--The container is taken to the surface and unloaded at the waste-handling building (Figure 6-11).

- Operation 5.0 (Close Borehole)--The shield plug and cover are replaced, and the shielding closure is removed (Figure 6-12).

6.1.2.3 Schedule

Waste removal schedules for each of the operations shown in Figures 6-3 and 6-4 have been developed in Appendix H. Time lines for borehole-level operations are presented in Figures H-11 and H-12. The results at the panel level are presented in Figures 6-13 and 6-14 for the vertical and horizontal emplacement configurations, respectively.

6.1.3 Retrieval Equipment

The equipment needed for retrieval under normal conditions is the same as that for emplacement. This equipment is described in Section 2.2.3 for vertical emplacement and in Section 2.2.4 for horizontal emplacement. Additional details for retrieval equipment are included in Appendix D of the Site Characterization Plan Conceptual Design Report (SCP-CDR) (SNL, 1987). Equipment development is discussed in Section 6.3.1.

6.1.4 Radiologic Exposure

Detailed radiologic exposure calculations using the dose rate estimates in Appendix F (for radon) and Appendix G (for the waste) and using the operations presented in Appendix H have not been completed. However, doses have been estimated for worst-case normal conditions. As shown in Table 6-2, even for the conservative dose estimates, the highest dose (0.62 rem/yr) is below the allowable dose of 1 rem/yr (DOE, 1983).

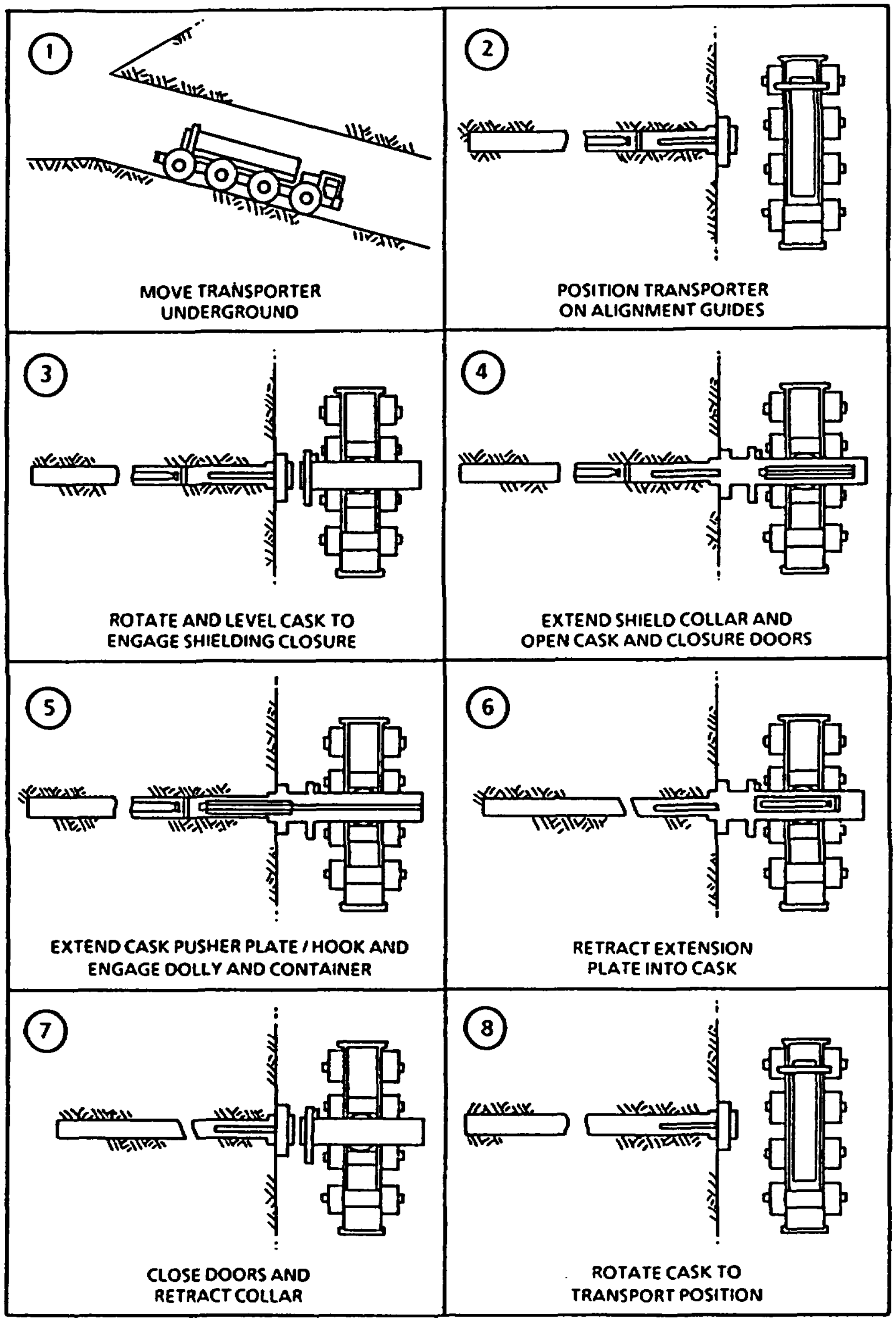

Figure 6-10. Removal of a Waste Container from a Horizontal Borehole (from Figure 6-43, SCP)

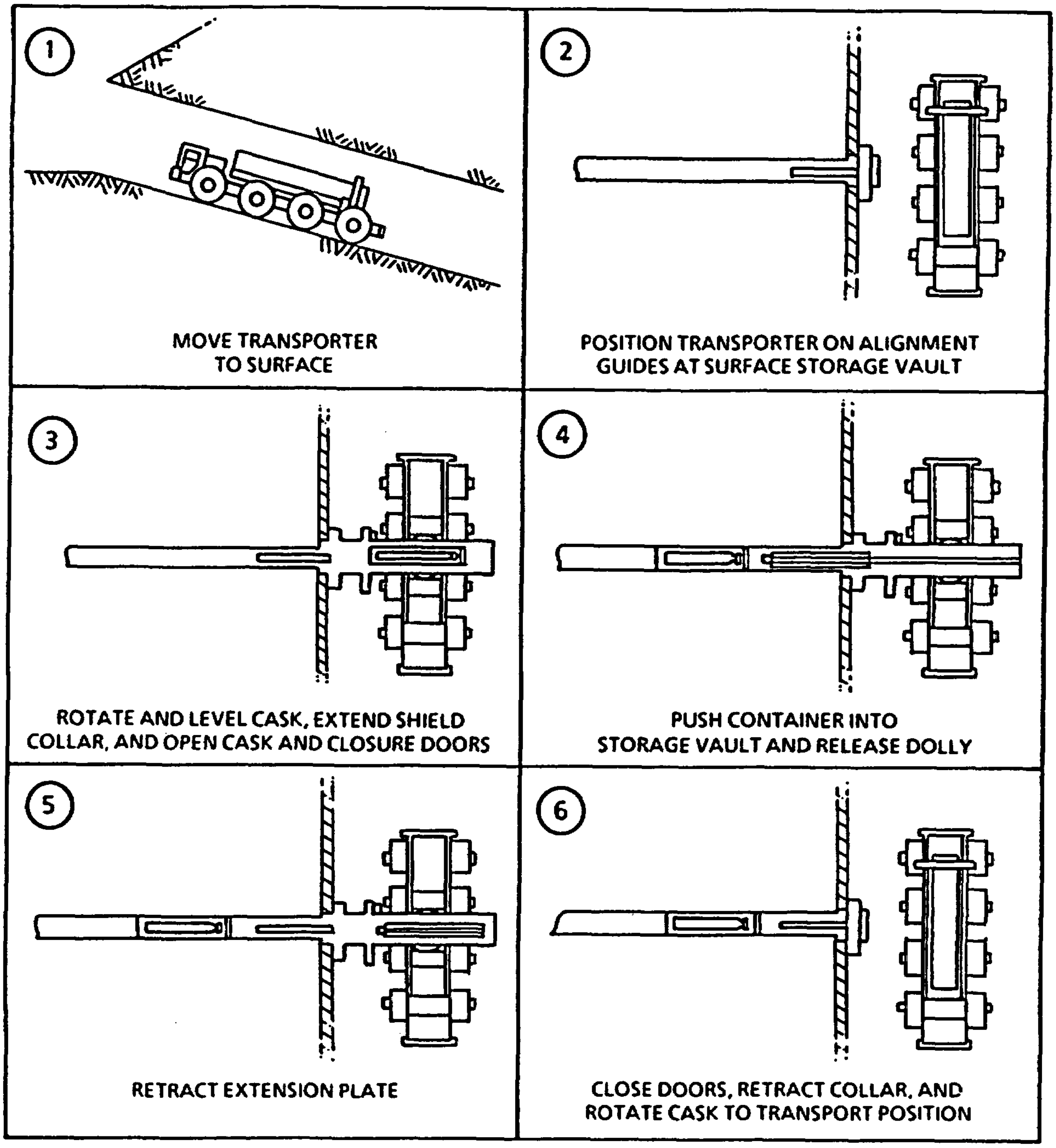

Figure 6-11. Transfer of a Waste Container from a Horizontal Borehole to Surface Storage (from Figure 6-44, SCP)

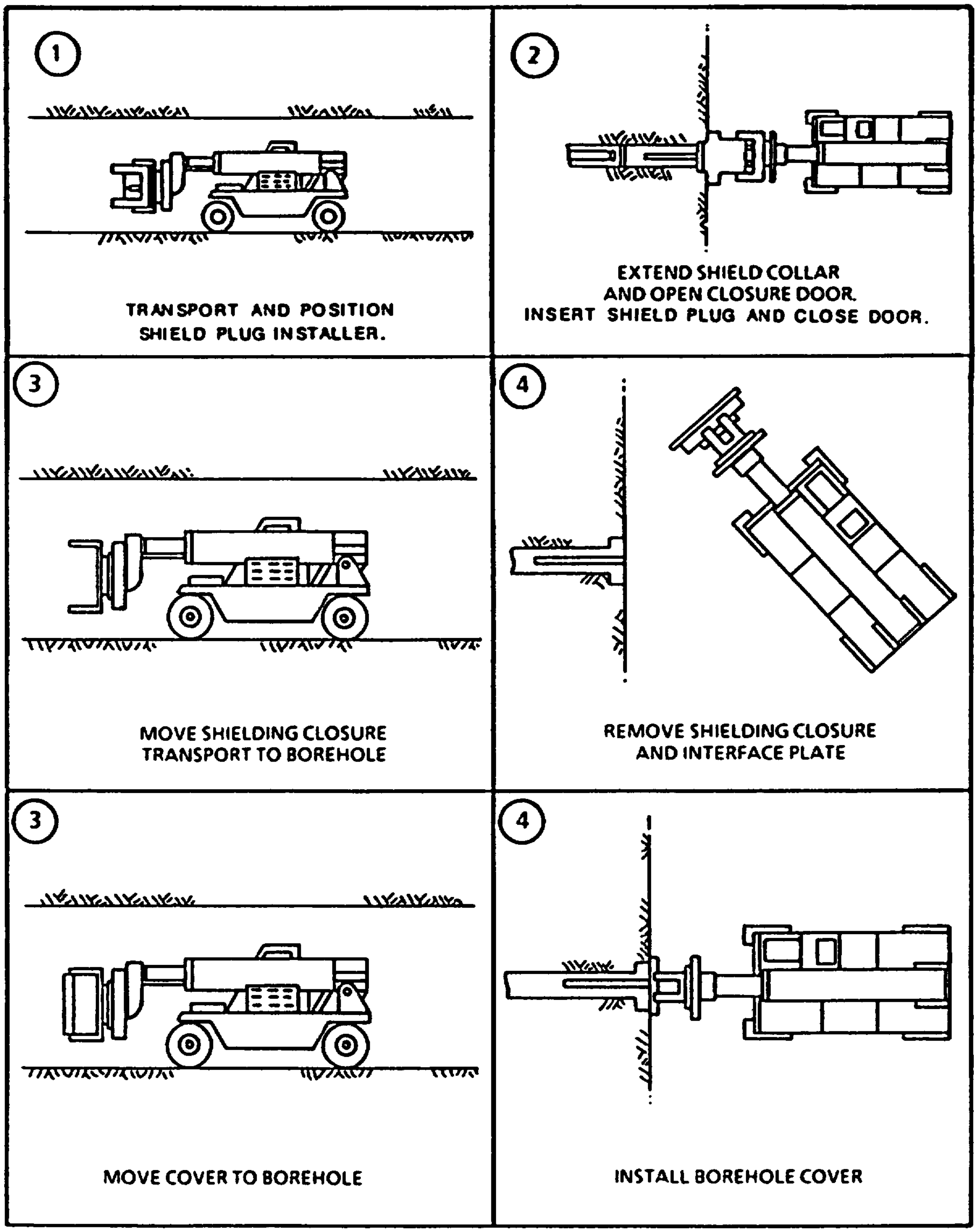

Figure 6-12. Closure of a Horizontal Borehole After Waste Removal (from Figure 8, Appendix E, SCP-CDR)

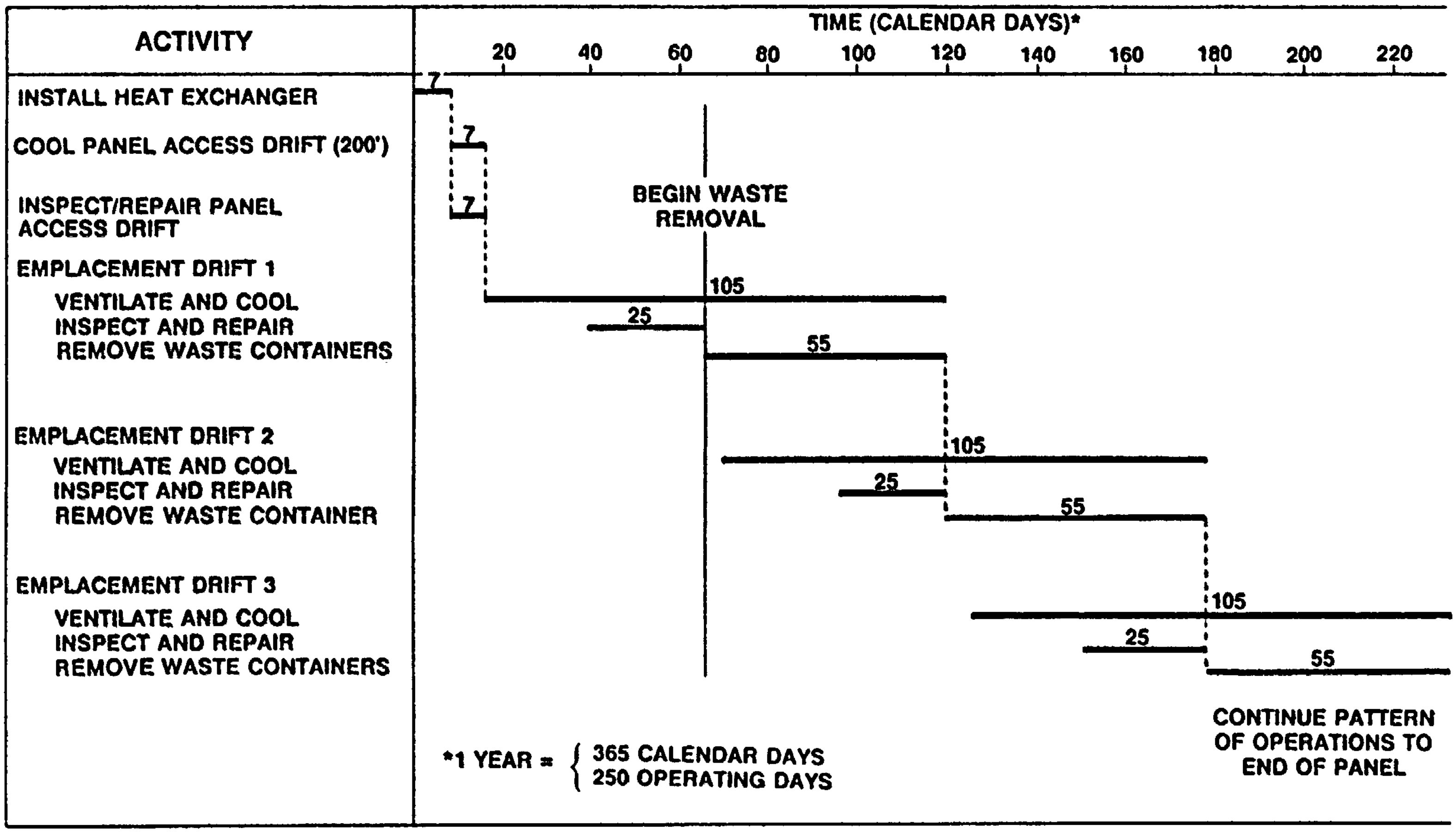

Figure 6-13. Panel-Level Waste Removal Schedule (Vertical Emplacement)

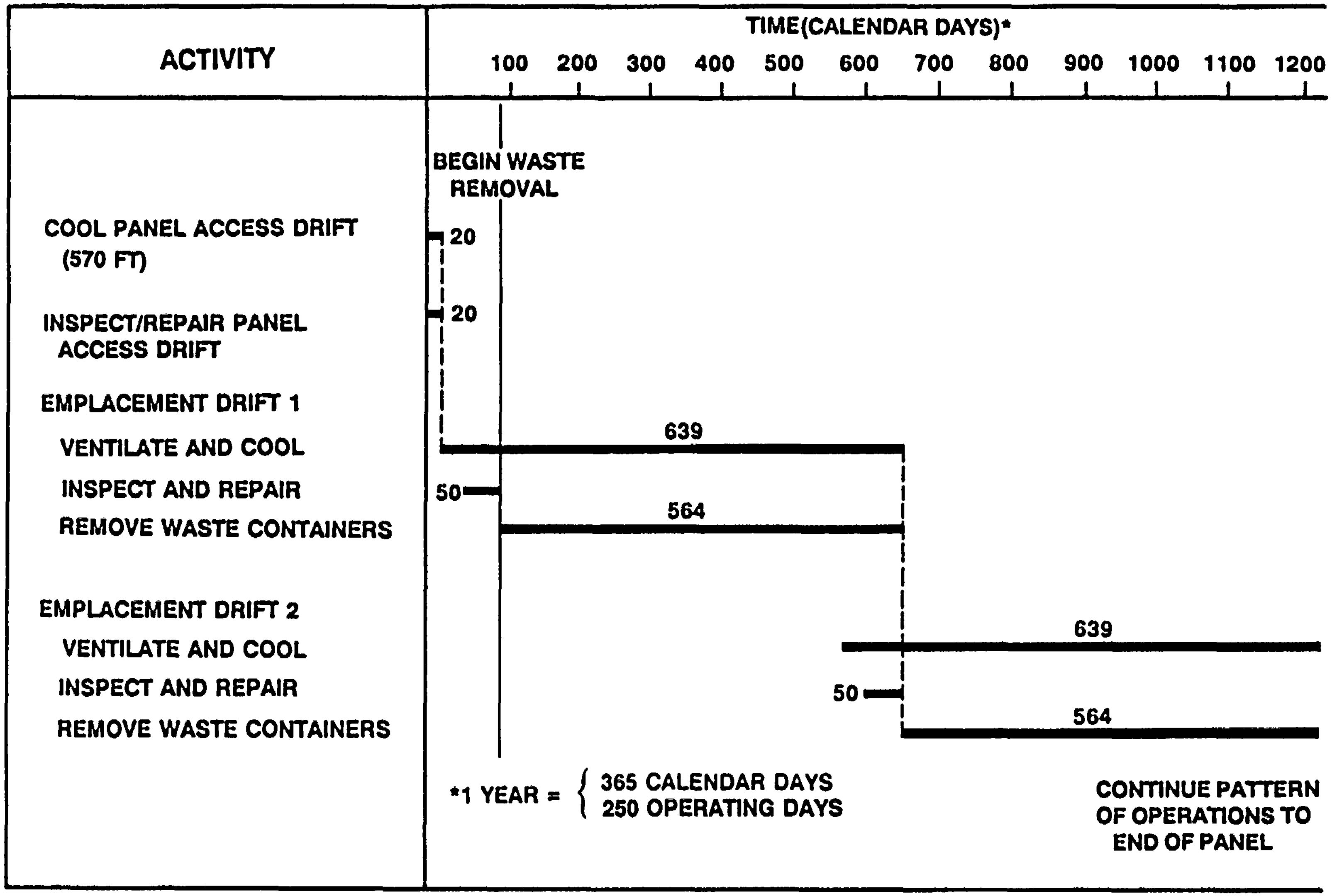

Figure 6-14. Panel-Level Waste Removal Schedule (Horizontal Emplacement)

TABLE 6-2

PRELIMINARY RADIOLOGIC DOSE ESTIMATES FOR WORST-CASE NORMAL CONDITIONS[a]

Worker	Emplacement Configuration	Radon Contribution[b] (rem/yr)	Waste Contribution (rem/yr)	Total Dose (rem/yr)
Emplacement Drift[c] Worker	Vertical	0.22	0.40[d]	0.62
	Horizontal	0.19	0.12[d]	0.31
Transporter Operator	Vertical	0.11	0.44[e]	0.55
	Horizontal	0.10	0.40[e]	0.50

a. Worst-case conditions are defined in Appendix F for radon and Appendix G for the waste. A year of exposure assumes 2000 hr of work.

b. Assumes that the emplacement drift worker is exposed 80% of the time and that the transporter operator is exposed 40% of the time. Dose rates are given in Table 5-1.

c. Assumes that waste emplacement or removal activities are in progress.

d. Assumes that the worker is in a 2 mrem/hr field for 10% of the time for the vertical configuration and 3% of the time for the horizontal configuration. (The difference between the vertical and horizontal configurations is due to the difference in the number of boreholes.)

e. Assumes 800 hr/yr in a 0.5 mrem/hr field. The vertical case is increased by 10% because the transporter is positioned over filled boreholes during waste removal.

6.1.5 Retrieval Schedule

The schedule for all retrieval activities is presented in Appendix H. As discussed in the appendix, the preparation phase is estimated to take 3 yr and waste removal will take approximately 21 yr--for a total of 24 yr. Consequently, the design goal for completion of retrieval within 34 yr (Section 3.2.2) will be met under normal conditions.

6.2 Retrieval Under Abnormal Conditions

When abnormal conditions are detected, the first step in continuing retrieval operations is to assess the conditions impeding or preventing waste retrieval. This assessment includes reviewing procedures used and events that occurred before the abnormal conditions were detected; reviewing any pertinent documentation recorded during repository construction, borehole drilling, waste emplacement, or drift maintenance; obtaining and analyzing new data on the abnormal conditions; and ascertaining the probable cause of, and possible remedies to, the abnormal conditions.

A plan for retrieval under abnormal conditions is developed based on assessment of the conditions and the procedures available for retrieval under abnormal conditions. In cases where an abnormal condition has been anticipated, plans and procedures will already exist. In other cases, the retrieval plan will be newly developed and tailored to the specific abnormal condition. In either case, the plan includes procedures for correcting or mitigating the abnormal condition, considering the impact of not correcting the abnormal condition, determining equipment and supplies to be procured and used, and considering alternative procedures deemed appropriate.

A preliminary determination of abnormal conditions has been made and is documented in SCP-CDR Appendix L-2; these abnormal conditions are presented in Table 5-7. No attempt is made in this report to calculate the probability of occurrence of any of these conditions, but the probabilities are believed to be relatively low for all abnormal conditions considered. In fact, many of the conditions described are considered not credible (according to the definition presented in Figure 3-3), but have been developed for conservatism. Therefore, most of the operations presented below are expected to be used very little, if ever, during retrieval operations.

It is recognized that development of the abnormal conditions listed in Table 5-7 used preliminary site and design data and engineering judgment. As discussed in Section 8.2.2, the identification of abnormal retrieval conditions will be refined in future studies.

The effort needed to correct or mitigate the abnormal conditions and complete waste retrieval depends on the nature and severity of the conditions, as well as the borehole configuration. A synopsis of the abnormal conditions presented in Section 5.2 is provided in Table 6-3. Concepts for waste removal under these abnormal conditions are presented in the following sections.

TABLE 6-3

SYNOPSIS OF ABNORMAL CONDITIONS FOR RETRIEVAL

- Rockfall in the ramp or drifts
- Malfunction of the ventilation system
- Malfunction of borehole shielding or closure equipment
- Binding of the shield plug
- Collapse or severe deformation of the liner (horizontal emplacement configuration)*
- Malfunction of retrieval equipment
- Structural failure of the waste container pintle
- Binding of the waste container in the borehole
- Malfunction of the transporter drive train
- Waste transporter collision

*Although no credible mechanism for this condition has been identified and the probability of occurrence is extremely low, this condition is included because of the potential consequence (SCP-CDR Appendix L-2).

6.2.1 Correcting Ramp or Drift Rockfall

It is assumed that rockfall could occur in the ramp or drifts, as the result of a seismic event, fault movement, or inadequate maintenance, that would restrict access to the emplacement boreholes. The procedures and equipment for correcting ramp or drift rockfall are the standard excavation and construction procedures and equipment used in mining. Operations include excavating the collapsed section and installing new rock support structures.

6.2.2 Correcting Ventilation System Malfunction

Part of the surface or underground ventilation system is assumed to fail as the result of a seismic event or inadequate maintenance, and full or partial malfunction of the ventilation system could cause curtailment of retrieval activities in the affected drifts. Damage to or malfunction of ventilation equipment components, such as fans and control systems, is corrected by repairing or replacing the defective components. For the current design, failure of one or two of the fans would not curtail operations because spare fans are available. Collapsed ventilation bulkheads will be repaired or reconstructed. Construction of temporary auxiliary systems may be necessary to permit access to the affected drifts for repairs. All equipment necessary for ventilation system repair is commercially available.

6.2.3 Surmounting Shielding Closure Malfunction

Even though the shielding closures on the surface and at the borehole are designed with a safety factor of 4, it is assumed that a malfunction could occur as the result of human error. The assumed malfunction involves failure of the primary drive system which operates the closure door. To surmount the malfunction, manual overrides to the primary drive system are included in the design of the shielding closures. Portable radiation shielding may be required for this operation (Appendix G).

6.2.4 Removing a Bound Shield Plug

Removal of the shield plug from the emplacement borehole is necessary for access to the waste container. In the unlikely event that the shield plug becomes bound in the borehole, special equipment and procedures may be necessary to remove the shield plug. One of two methods for removing a bound shield plug will be used depending on the severity of the problem.

- A system for vibrating the shield plug can be incorporated into the shield plug remover. Vibration coupled with a tensile force (upward for the vertical borehole shield plug or outward for the horizontal borehole shield plug) may be sufficient to free the shield plug if only the liner is binding the shield plug in the borehole.

- If vibration does not free the shield plug, the rock surrounding the shield plug can be cored and the liner cut. This would involve replacing the standard borehole shielding closure with a closure of similar design that has a larger opening, moving a coring machine into place, and coring the rock. A system similar to that for removing bound waste containers can be used (Sections 6.2.8 and 6.2.9).

Adding vibration capability to the shield plug remover requires minor modification which can be developed from existing equipment. The equipment required for coring the rock and cutting the liner would need to be developed, but that is believed possible using existing drilling technology. Substantial efforts to ensure personnel safety would be required.

6.2.5 Surmounting a Liner Collapse (Horizontal Emplacement)

Upon detecting collapse or severe deformation of the liner, the damage is assessed. Depending on the extent and location of the damage, the dollies in front of the damaged zone (between the damage zone and the entrance to the borehole) are uncoupled and the containers removed. Then, the damaged section of liner is repaired or an alternate access is mined.

6.2.5.1 Horizontal Borehole Inspection

If problems arise during removal of a waste container, the borehole may need to be inspected to determine whether the problem is borehole related or retrieval-system related, to determine whether a waste container has been breached, and to provide data on the nature and extent of the problem for subsequent waste removal.

An instrumented cart can be used to inspect the horizontal borehole. The inspection equipment may include a video camera and lights; calipers for measuring the liner's inner diameter to ascertain the severity of liner section deformation; and instruments such as temperature probes, radiation monitors, and gas-sampling equipment to accurately measure local conditions at the first waste or dummy container. The in-hole data is essential to assessing the abnormal conditions and determining possible remedies.

Instruments carried in-hole on the retrieval cart will need to be insulated from the high temperatures and shielded from the high radiation levels in the borehole. Also, because the cart and instrumentation could become contaminated during inspection operations, both will be designed to survive potential decontamination operations.

6.2.5.2 Selective Dolly Uncoupling

Coupled waste container dollies are used in the reference waste removal concept presented in the SCP-CDR for horizontal boreholes although future design efforts will consider the potential for deleting the dollies. As each waste container and dolly unit is inserted in the borehole by a cask mechanism, the dolly hooks onto the dolly of the waste container already inside the borehole entrance, and the entire dolly train is pushed into the borehole. Similarly, as each waste container and dolly unit is removed from the borehole by the cask mechanism during retrieval, the entire dolly train is pulled toward the borehole entrance, and the waste container being removed is unhooked from the train.

With coupled dollies, liner collapse or severe deformation between dollies will effectively detain all waste containers in the borehole. Removal of the containers in the front of the collapsed region must begin with uncoupling the dollies.

The method for uncoupling dollies is shown in Figure 6-15. A shielded cask containing the dolly-uncoupling mechanism is connected to the borehole shielding closure, and the shield doors are opened. The dolly-uncoupling mechanism extends into the borehole, slides under the dollies to the collapsed liner section, and disconnects the dolly in front of the damaged area. The waste containers in front of the damaged area then can be removed with the waste transporter. This leaves the borehole ready for inspection and for removal of the remaining blocked containers.

6.2.5.3 Liner Repair

In the unlikely event that the liner collapses, it may be possible to repair the liner and restore the capability to remove waste containers using the waste transporter. Two methods for performing this operation are being further evaluated: (1) using a liner expander and (2) reaming the borehole. Both concepts use an instrumented cart to assess the liner damage.

Liner repair using a liner expander is shown in Figure 6-16. As shown in the figure, the liner expander transporter is positioned at the borehole shielding closure. The liner expander cask is aligned with and connected to the shielding closure. The shielding closure doors are opened, and the liner expander and repair liner are extended into the borehole to the damaged section. The liner expander is extended beyond the end of the repair liner to the damaged section and is opened until the inner diameter of the damaged liner around the expander is slightly larger than the outer diameter of the repair liner. The repair liner is then pushed forward into the expanded section, and the liner expander (remaining stationary) is closed. The repair liner then supports the radial loads carried by the expander and keeps the borehole open over the section just expanded. This cycle is repeated until the full section of collapsed liner is expanded and fitted with repair liner. Finally, the repair liner is cut inside the borehole, the excess liner is withdrawn into the shielded cask, and the borehole shielding closure doors are closed.

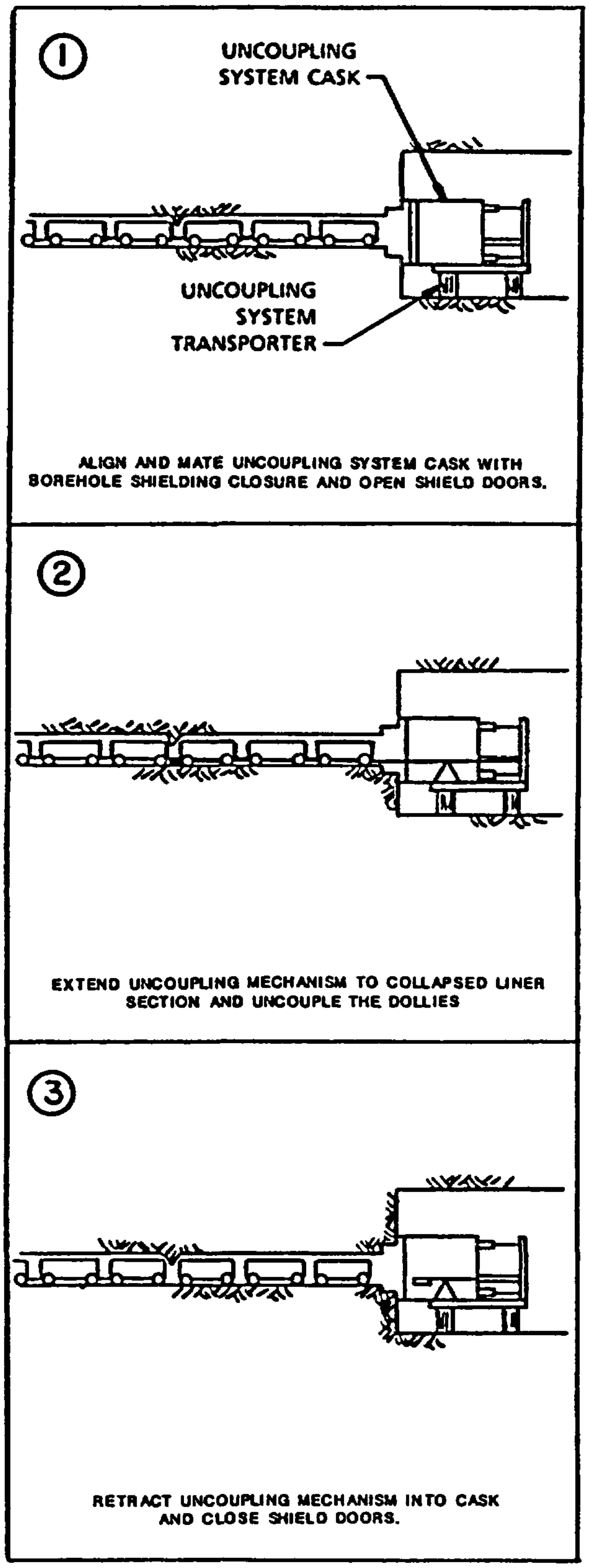

Figure 6-15. Uncoupling Dollies with an Uncoupling Mechanism (from Figure 5-6, Appendix J, SCP-CDR)

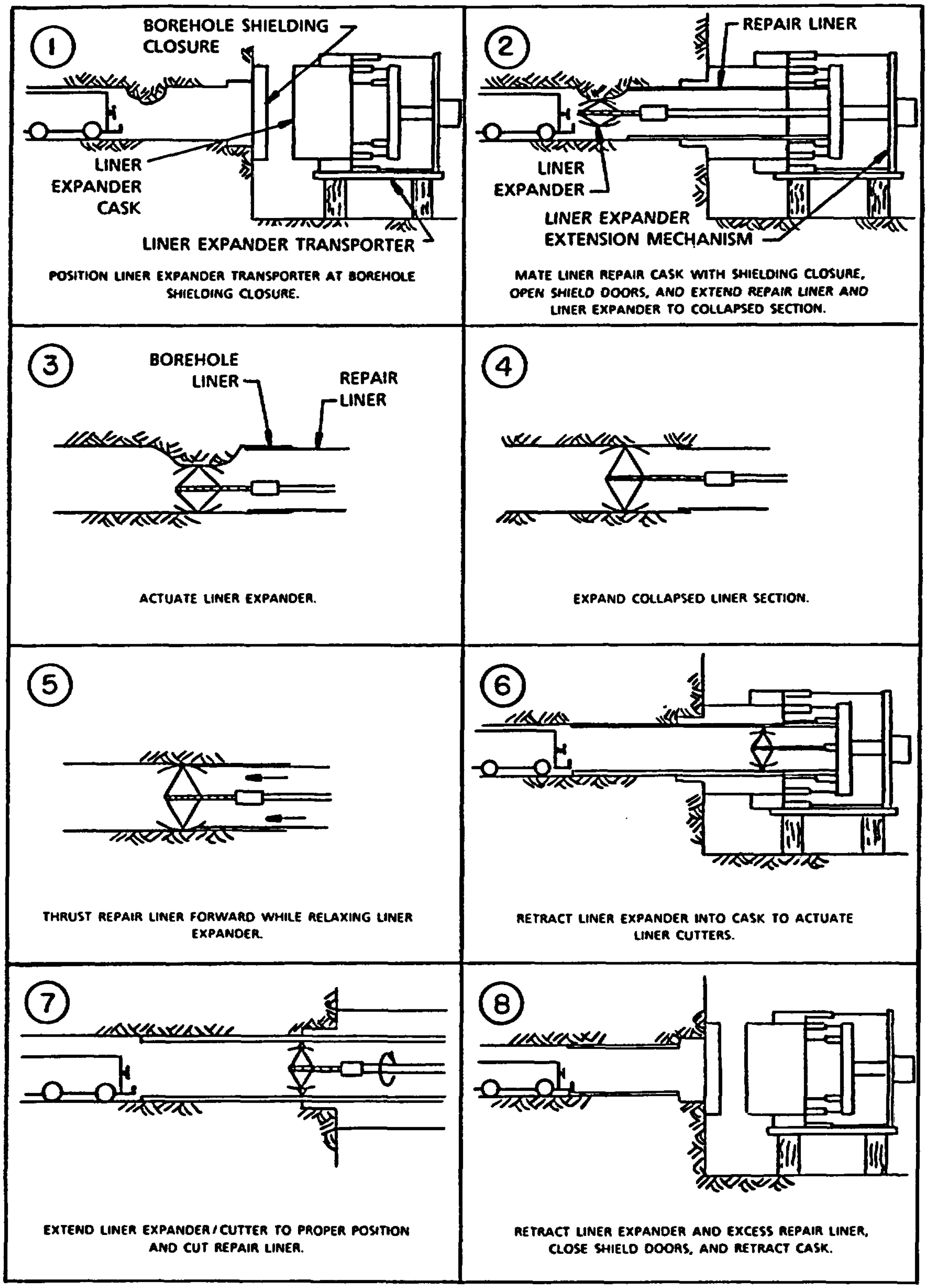

Figure 6-16. Repairing a Section of Collapsed Liner (from Figure 5-2, Appendix J, SCP-CDR)

The second method of repairing the liner differs from the first in one aspect: the liner expander is replaced by a rotating drill bit with expandable reaming arms that allow the bit to drill a hole larger than the outside diameter of the repair liner but also retract to fit inside the repair liner for withdrawal from the borehole. The drill bit used for this purpose must be capable of cutting the damaged steel liner and any rock protruding into the borehole. The repair liner, in this case, is advanced into the borehole following the drill bit's progress through the damaged section, thereby preventing subsequent rock fall and binding of the drill bit. When the damaged section has been completely drilled and reopened, the bit is withdrawn, the repair liner is cut, and the excess liner is removed. Substantial efforts to ensure personnel safety from radiation hazards would be required.

6.2.5.4 Alternate Access

Depending upon the extent and location of the damage to the liner, it may be preferable to mine an alternate access to the containers to remove them. The current panel design features parallel emplacement drifts in each emplacement panel and main, perimeter, and panel access drifts along the perimeter of each emplacement panel (Figure 6-17). Alternate access to any given borehole can be constructed by running a drift parallel to the emplacement drift serving that borehole.

As shown in Figure 6-17, the alternate access drift provides access to the blocked waste containers from the end of the borehole opposite that used for normal retrieval. For this concept to be viable, adequate shielding from the emplaced waste must be provided. It is anticipated that the rock will provide sufficient shielding for construction of the alternate access drift. Condition-specific shielding concepts would be developed for drilling from the alternate access drift to the emplacement borehole. Installation of a borehole shielding closure on the newly exposed end of the emplacement borehole would allow waste removal using a modified waste transporter. Substantial efforts to ensure personnel safety from radiation hazards would be required.

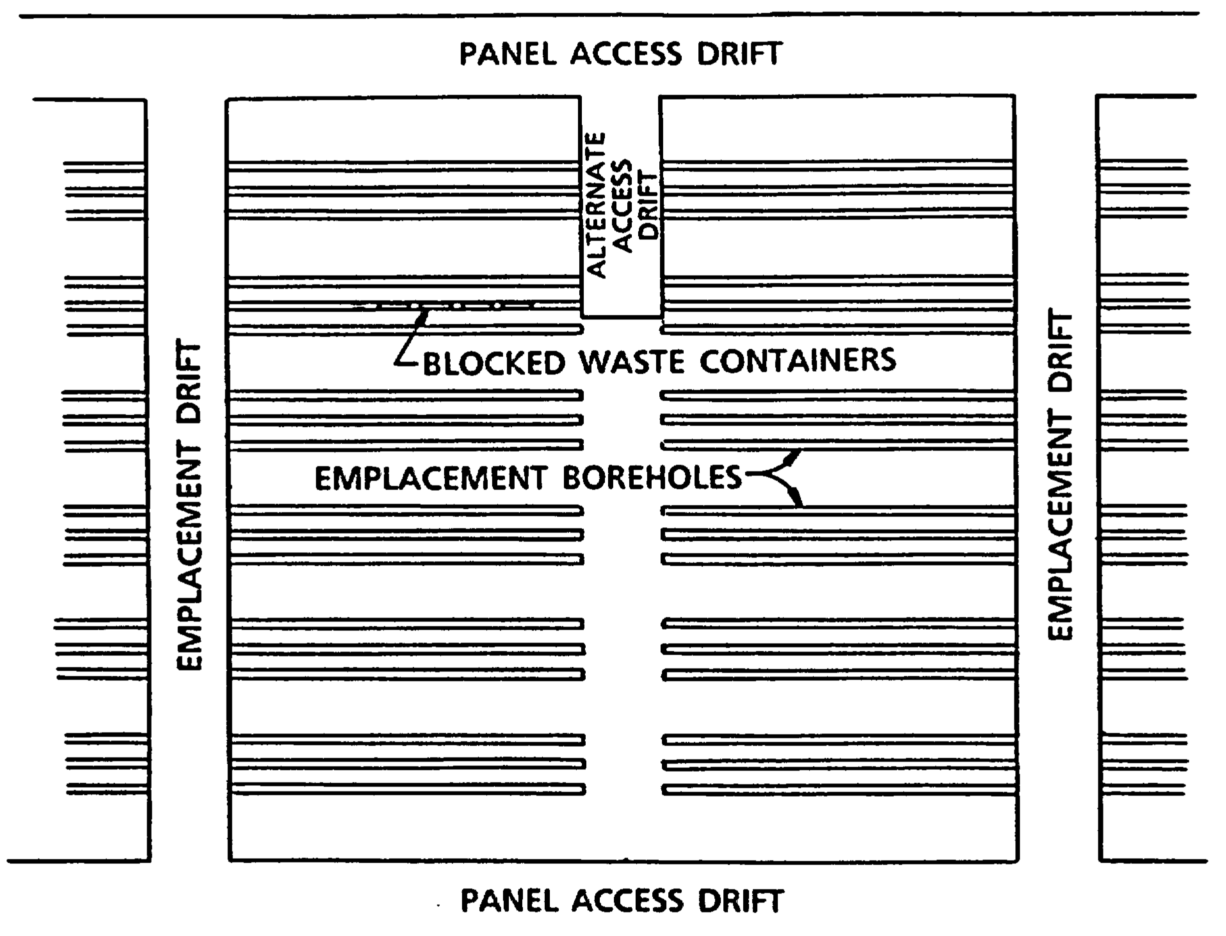

Figure 6-17. An Alternate Access to Blocked Waste Containers (from Figure 5-3, Appendix J, SCP-CDR)

6.2.6 Surmounting Retrieval Equipment Malfunction

Equipment directly related to waste removal is generally designed with a safety factor of 4. In addition, plans have been developed for the unlikely event of equipment failure during removal operations. The drive train for the lifting mechanism and the grapple attachment of the waste transporter for vertically emplaced waste are designed with override capability (Section 2.2.3). The override system permits the container to be lowered back into the borehole if the lifting system fails. Also, to the extent possible, serviceable drive train components will be accessible from outside of the transporter cask.

For the horizontal emplacement concept, the removal machinery will also be designed with a back-up that allows the container to be pushed back into the borehole in case the primary drive system fails. It also will be designed so that most serviceable drive system components are accessible from outside of the transporter cask.

The current horizontal emplacement concept uses coupled dollies (Section 2.2.4). Failure of the hooking mechanism between the dollies will result in waste containers which the transporter retrieval mechanism could not reach being left in the borehole. A grapple attached to a cart can be used to pull the remaining waste containers to the standard retrieval position. Future designs will investigate the use of uncoupled dollies to avoid this potential problem.

6.2.7 Surmounting a Structural Failure of the Waste Container Pintle

From the vertical borehole, the waste container is lifted into the transporter cask by pulling on the waste container pintle. Even though the pintle is designed with a safety factor of 4, for this discussion it is assumed that the pintle fails. (In horizontal emplacement, a failure of the waste container during retrieval operations is not credible because the dolly, not the waste container, sustains the pulling load.) For this discussion, it is assumed that the containers are not bound in the borehole. (Containers bound in the borehole are addressed in Section 6.2.8.)

In the unlikely event that a waste container pintle fails, special equipment and procedures will be needed to remove the container. A borehole inspection will be conducted followed by a waste removal operation using the removal sleeve described below.

6.2.7.1 Vertical Borehole Inspection

The procedure for inspecting a vertical borehole (Figure 6-18) involves lowering a shielded cask onto the borehole closure, opening the shield doors, and lowering the inspection module into the borehole. A cable system lowers the module into the borehole and retracts it into the cask. Instruments mounted on the inspection module will collect borehole temperature, radiation level, gas composition, and remote visual data.

Instruments and equipment on the inspection module may need to be protected from the high temperatures and radiation levels in the borehole. Also, because the instrumentation could become contaminated during inspection operations, it will be designed to survive potential decontamination operations.

6.2.7.2 Removal Sleeve Operations

To begin removal sleeve operations, the existing shielding collar is replaced with a shielding collar having a larger opening which accommodates the removal sleeve. The removal sleeve is carried to the borehole in a shielded cask by a modified transporter. The removal sleeve, which consists of a hollow cylinder with hydraulic pistons mounted on the inner wall, is lowered around the waste container. The pistons grasp the waste container, allowing it to be raised into the transporter cask.

Although a container breach as the result of a pintle failure is not considered to be credible, the removal sleeve concept can accommodate this condition. If a container breach occurs, the shielding collars, the transporter cask, and the removal sleeve would need to be decontaminated.

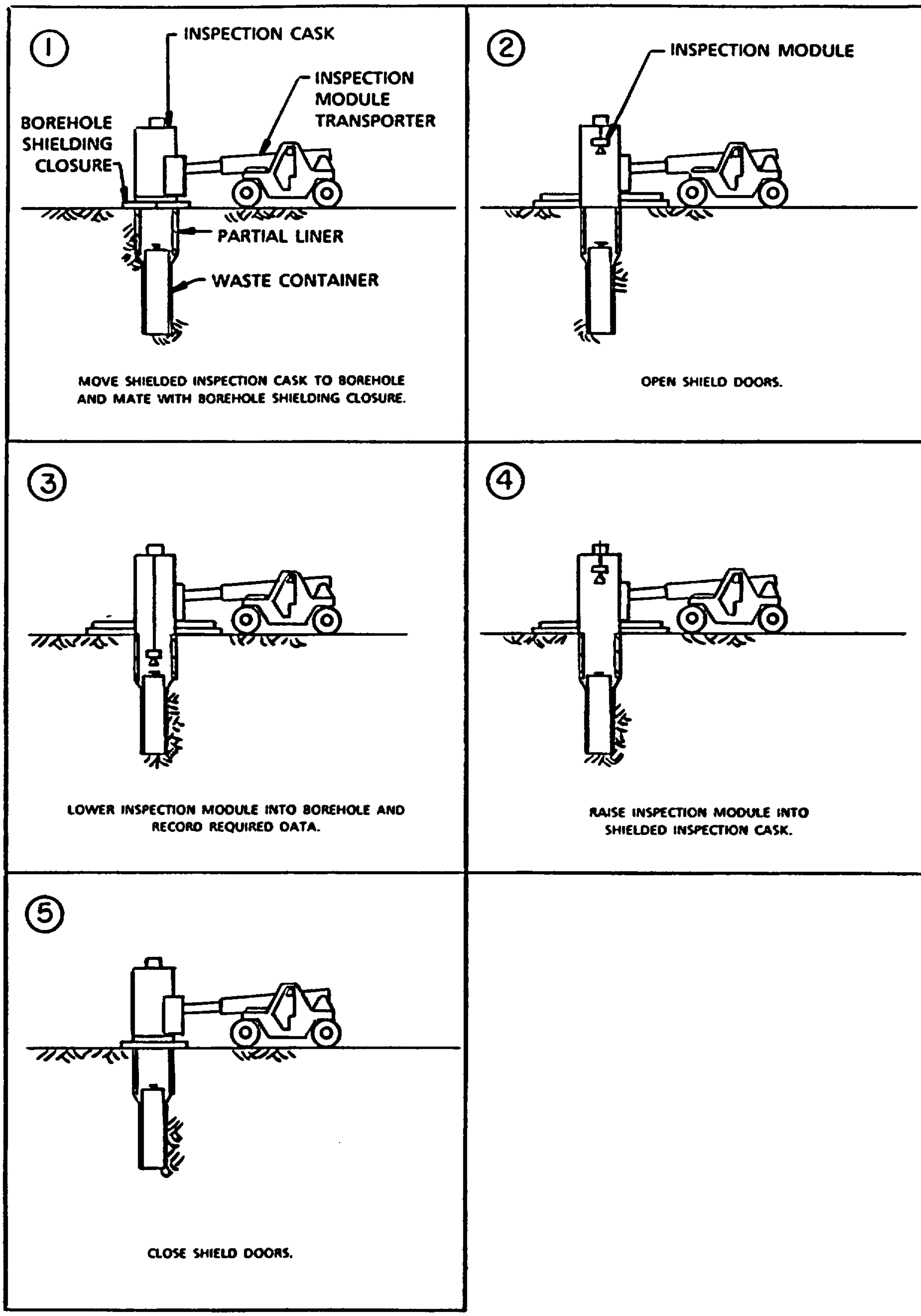

Figure 6-18. Inspecting a Vertical Borehole (from Figure 5-1, Appendix J, SCP-CDR)

6.2.8 Removing a Bound Waste Container (Vertical Emplacement)

In the unlikely event that a waste container is bound in a vertical borehole by the partial liner or rock surrounding the waste container, special procedures and equipment will be used to remove the container. One of two methods will be used, depending on the severity of the problem.

- Vibration coupled with an upward tensile force may be sufficient to free the container.

- A system for coring the rock surrounding the waste container could be used if the rock or partial liner has collapsed on the container and vibration does not free it.

6.2.8.1 Vibration

The transporter cask can be modified to provide vibrational as well as tensile force on the waste container. The resulting loads on the waste container would be closely monitored to ensure that structural failure of the waste container does not occur.

6.2.8.2 Rock Coring

Removal of a bound waste container using the vertical core drill involves coring and removing the partial liner followed by coring and removing the waste container. As shown in Figure 6-19, a core drill contained within a shielded cask is positioned above the borehole shielding closure and used to drill the rock surrounding the partial liner. When the full length of the partial liner has been cored, the core bit stops rotating and pistons positioned on the inner wall of the core barrel squeeze the core and hold it firmly within the core barrel. The core containing the partial liner and surrounding rock is then lifted into the core drill cask, the cask and closure doors are closed, and the cask is rotated to a horizontal position.

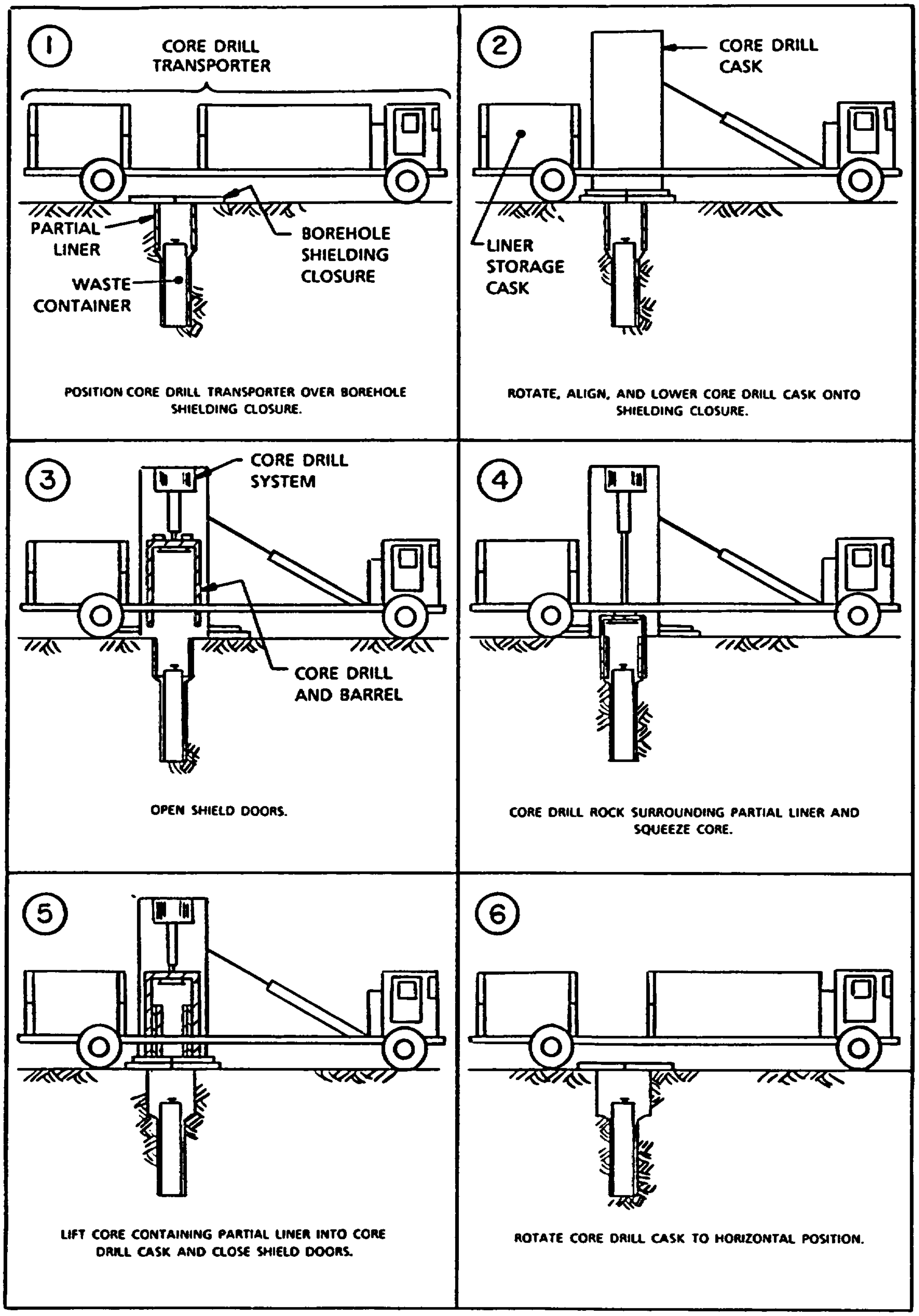

Figure 6-19. Removal of a Bound Waste Container from a Vertical Borehole Using Rock Coring (from Figure 5-4, Appendix J, SCP-CDR)

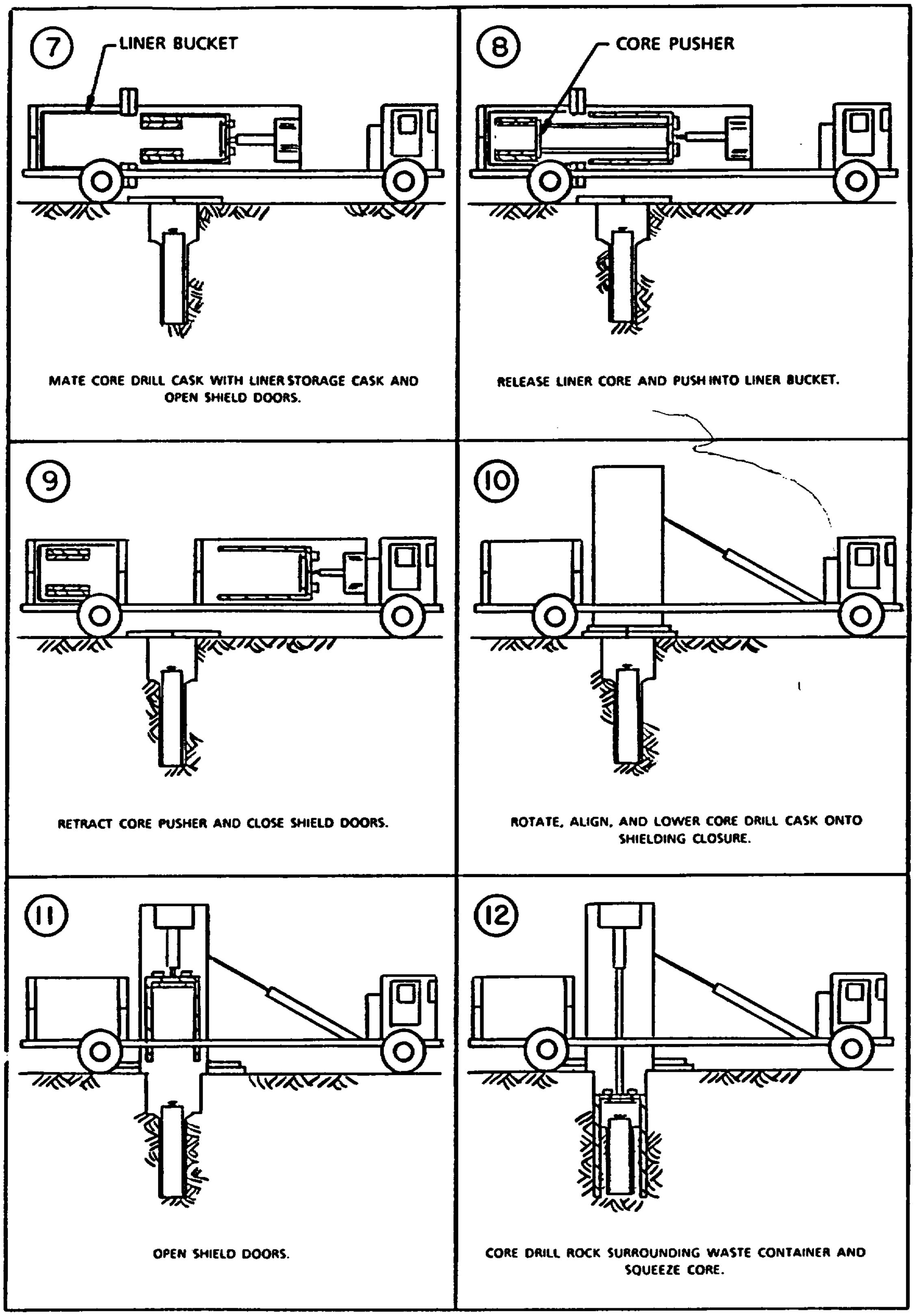

Figure 6-19. Removal of a Bound Waste Container from a Vertical Borehole Using Rock Coring (continued)

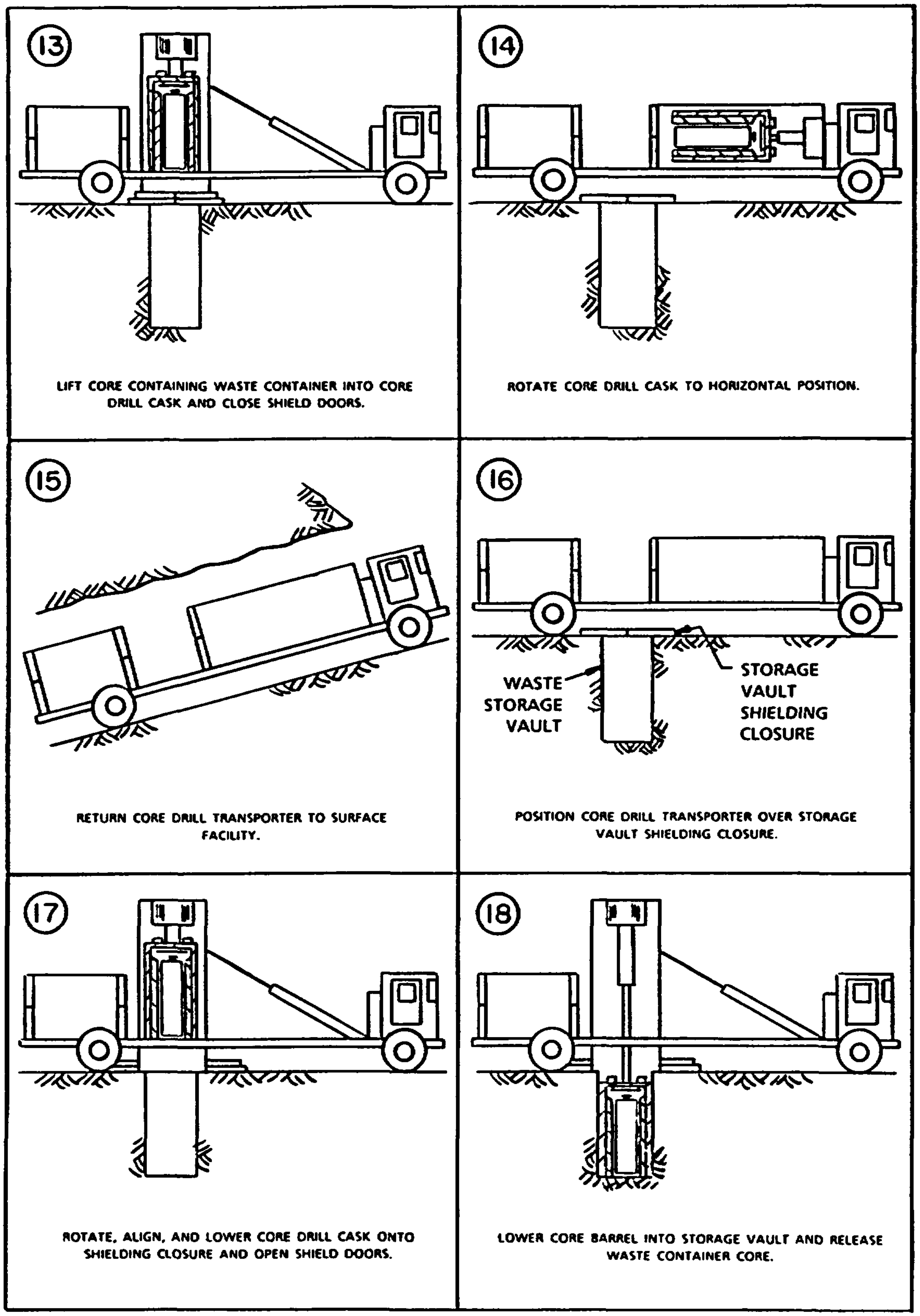

Figure 6-19. Removal of a Bound Waste Container from a Vertical Borehole Using Rock Coring (continued)

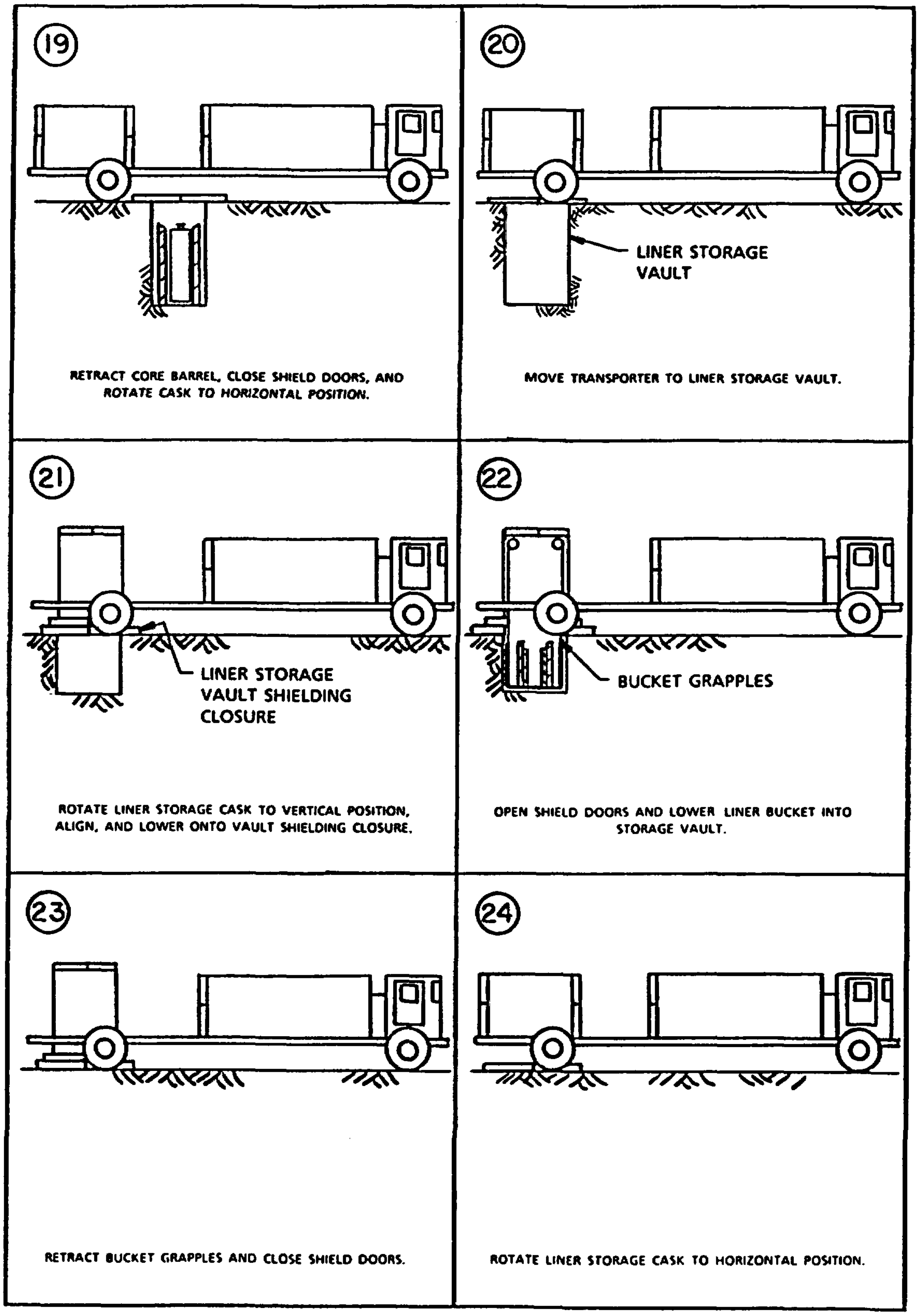

Figure 6-19. Removal of a Bound Waste Container from a Vertical Borehole Using Rock Coring (concluded)

To allow removal of the waste container before transporting the liner core to the surface, the liner core is temporarily stored in a liner storage cask. The core drill cask is positioned and mated with the liner storage cask, and the shield doors on both casks are opened. The liner core is pushed into a bucket inside the liner storage cask, the core pusher is retracted, and the cask shield doors are closed.

Then the core of rock surrounding the waste container is drilled. After the full length of the waste container is drilled, the core containing the waste container is squeezed to hold it firmly inside the core barrel. The core is retracted into the core drill cask, the shield doors are closed, and the core drill cask is rotated to its horizontal position for transport to the surface facility. At the surface facility, the cores containing the waste container and the partial liner are deposited in separate storage vaults. Even though it is unlikely that the container will be breached, initially the liner and surrounding rock will be considered to be contaminated. Design of the drilling system must address the possibility that contaminated material may be drilled. Therefore, the rock chips will be either contained within a shielded flow system outside the cask or filtered and decontaminated.

Because the liner core may be contaminated, the liner storage cask must provide adequate shielding. When the liner core is transferred from the core drill cask to the liner storage cask, it will be pushed into a bucket positioned in the liner storage cask (Figure 6-19). In the surface facility, this bucket will be lowered into the liner core storage vault and left there for convenience in handling and disposing of the core.

6.2.9 Removing a Bound Waste Container (Horizontal Emplacement)

Although unlikely, the liner could collapse on a container.* If the dollies are coupled, it will be necessary first to uncouple the dollies

*Although no mechanism for this condition has been identified and the probability of occurrence is extremely low, this condition is included because of the potential consequence (SNL, 1987, Appendix L-2).

between the borehole entrance and the bound waste container and to remove the unbound waste containers (Section 6.2.5.2). Two concepts for removing bound waste containers are being further evaluated: (1) reaming and coring through the original borehole and (2) constructing an auxiliary access drift to perform an auxiliary liner-cutting operation in addition to reaming and coring through the original borehole.

6.2.9.1 Reaming and Coring Operations

Figure 6-20 shows reaming and coring through the original horizontal borehole to remove a bound waste container. The reaming drill transporter is moved to the borehole, the reaming drill cask is connected to the borehole shielding closure, and the shield doors are opened. Using the borehole as a pilot hole, the reaming bit drills both the borehole liner and the rock surrounding it to a diameter large enough for the core bit. When the reaming bit reaches the bound waste container, it is retracted into the cask, the shield doors are closed, and the reaming drill transporter moves away from the borehole.

Then the core drill transporter is moved into place. The core drill cask is rotated and connected to the borehole shielding closure, and the shield doors are opened. The core bit advances into the enlarged borehole and begins coring when it reaches the bound waste container. When the rock surrounding the waste container has been cored the full length of the container, the core bit stops advancing, and the liner cutters are actuated. The core bit cuts through the liner and encloses the waste container core within the core barrel. The waste container core is retracted into the core drill cask, the shield doors are closed, and the core drill cask is rotated to its transport position. The core drill transporter then returns to the surface, where the waste container core is deposited in a storage vault.

If the remaining containers are not blocked or bound, they are retrieved using the alternate access drift concept described in Section 6.2.5.4. If remaining containers are bound in the borehole, the procedure described above can be repeated to retrieve them.

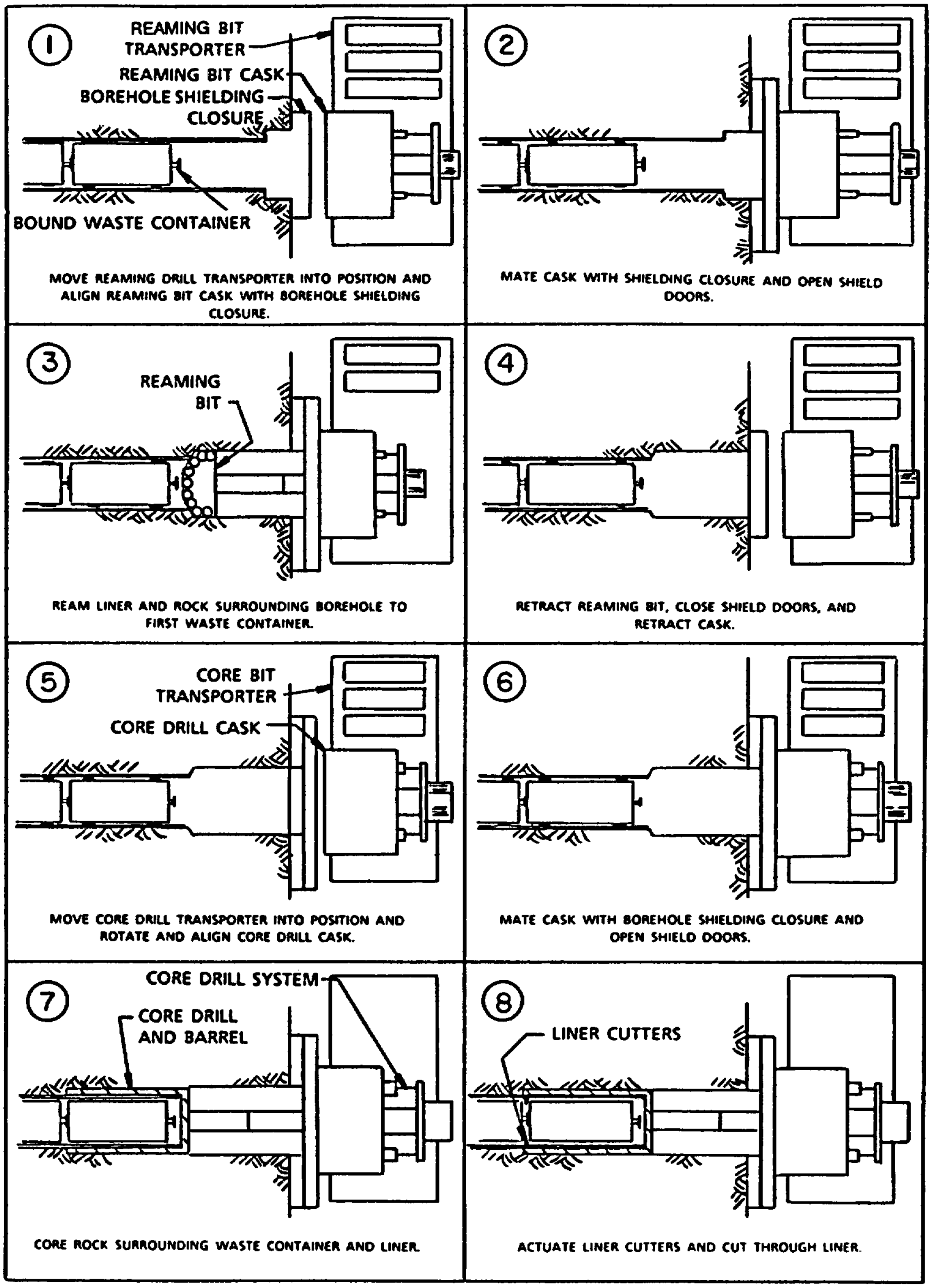

Figure 6-20. Reaming and Coring Through the Original Borehole to Remove a Bound Waste Container (from Figure 5-7, Appendix J, SCP-CDR)

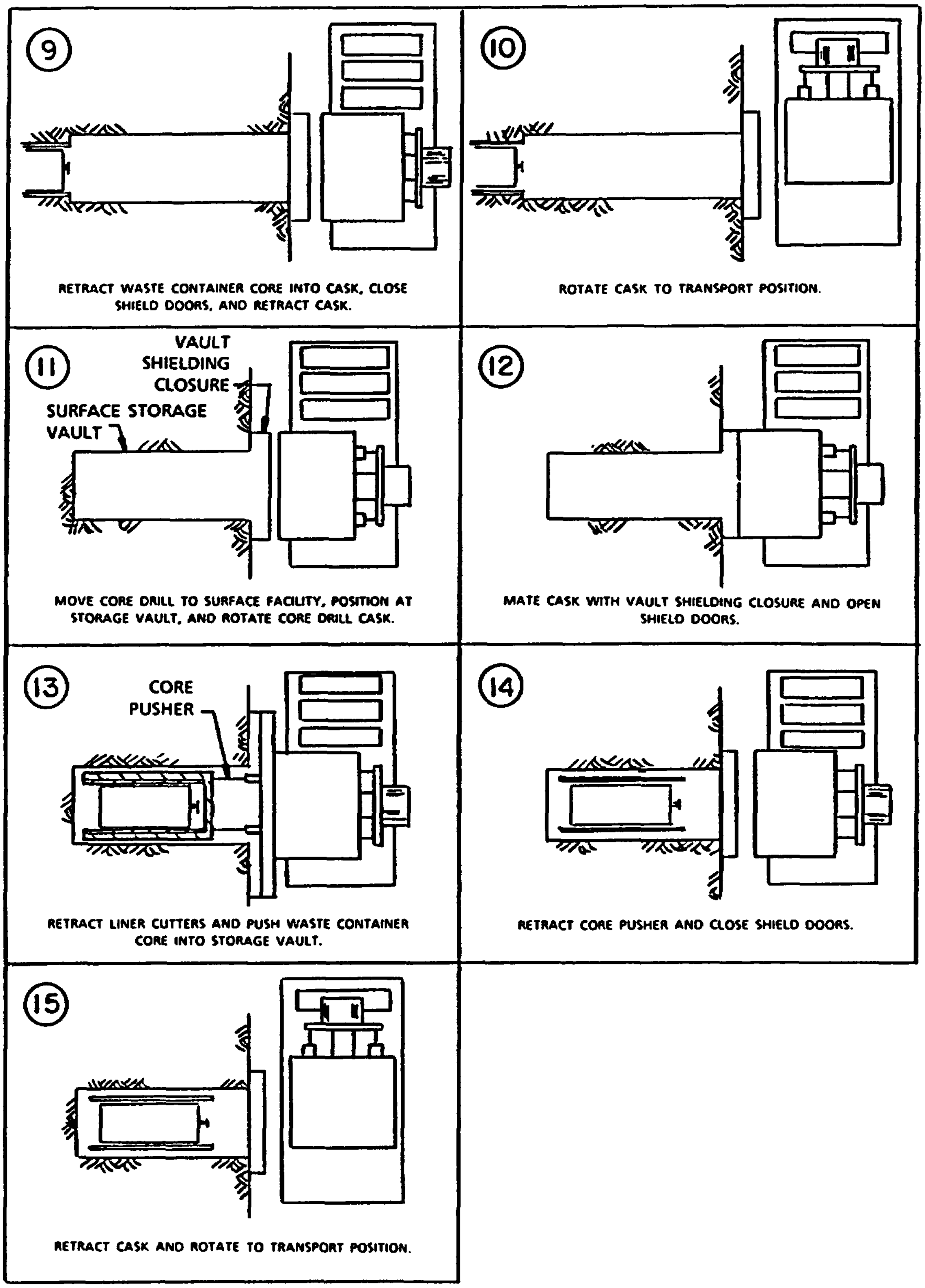

Figure 6-20. Reaming and Coring Through the Original Borehole to Remove a Bound Waste Container (concluded)

6.2.9.2 Auxiliary Liner-Cutting Operations

If the liner is greatly deformed, cutting it at the end of the waste container core to free the core for retrieval (as described above) may be impossible. Furthermore, if the dollies are coupled, it may be impossible to uncouple the dolly of the bound container from the remaining dollies. In such cases, it will be necessary to construct an auxiliary access drift for equipment to cut the liner and dolly hook from the side (Figure 6-21).

The first step in this operation is to construct an auxiliary access drift parallel to the emplacement borehole but far enough away so that the intervening rock adequately shields workers from the emplaced waste during drift construction. A borehole shielding closure is installed on the rib of the auxiliary access drift where the liner must be cut.

The shielded drill machine is moved into the auxiliary access drift, the drill cask is aligned and connected to the shielding closure, and the shield doors are opened. A borehole is then drilled from the auxiliary access drift to the emplacement borehole liner. The drill bit is retracted into the cask, the shield doors are closed, and the drilling machine is removed from the auxiliary access drift.

The shielded liner cutter is moved into place, the liner cutter cask is aligned and connected to the shielding closure, and the shield doors are opened. The liner cutter is extended to the liner, where the cutting disk cuts through the liner and, if necessary, the dolly hook. The waste container core then can be removed through the original borehole into the core drill cask. Substantial efforts to ensure worker safety related to radiation hazards would be required for the special operations described here.

6.2.10 Surmounting a Transporter Drive Train Malfunction

The waste transporter will be designed so that most of the locomotion and braking components can be repaired without moving the trans porter. If necessary, the transporter with its waste container cargo can

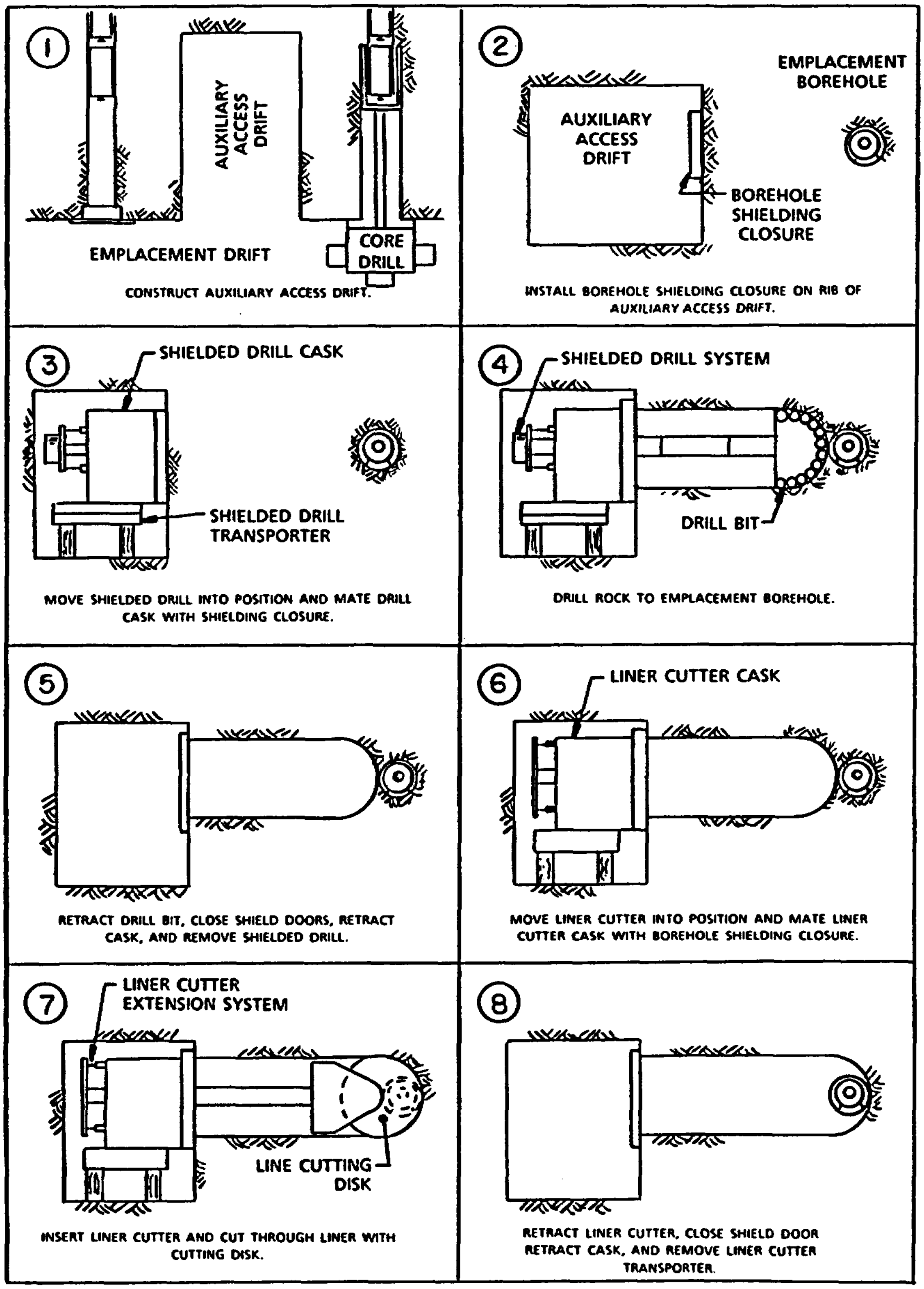

Figure 6-21. Liner-Cutting Operation from an Auxiliary Drift (from Figure 5-8, Appendix J, SCP-CDR)

be towed to the surface maintenance facility for repair. Extra transporters will be available so that major repairs do not cause significant delays in the retrieval schedule.

Equipment needed to tow waste transporters is listed in the SCP-CDR, Appendix D. This equipment is commercially available but may require minor modification.

6.2.11 Mitigating the Effects of a Waste Transporter Collision

Because travel speed of underground equipment will be restricted to 5 mph or less, any collision of a waste transporter with a ramp wall, drift, or other equipment should not result in a breach of the cask or waste container. Any damage to the transporter itself should be relatively minor. If a transporter is unable to move under its own power after a collision, it can either be repaired at the crash site or towed to the surface maintenance facility for repair.

6.3 Equipment Development

6.3.1 Equipment for Retrieval Under Normal Conditions

The equipment for retrieval from vertical and horizontal boreholes is listed in Table 6-4.

The equipment and components identified for both vertical and horizontal waste emplacement are new designs that are based on reasonably available technology, i.e., similar to equipment or components that have been used successfully under similar conditions or are extrapolations of existing technology that can be developed and demonstrated in a timely manner. The items that need the most development are the waste transporters and associated emplacement/retrieval equipment for both the vertical and horizontal configurations. Many commercially available components (e.g., running gear and power trains) are used in the major systems of these machines; however, the overall designs are new rather than being modifications of existing hardware.

TABLE 6-4

EQUIPMENT LIST FOR WASTE REMOVAL UNDER NORMAL CONDITIONS*

	Vertical Emplacement						Horizontal Emplacement					
	One Shift Per Day			Two Shifts Per Day			One Shift Per Day			Two Shifts Per Day		
Equipment Description	Required Operable Units	Spares	Total	Required Operable Units	Spares	Total	Required Operable Units	Spares	Total	Required Operable Units	Spares	Total
Waste Transporter	4	1	5	2	1	3	4	1	5	2	1	3
Dummy Container Transporter	0	0	0	0	0	0	2	1	3	1	1	2
Shielded Forklift	6	2	8	4	2	6	2	1	3	2	1	3
Shielding Closure Installer	6	2	8	4	2	6	4	2	6	4	2	6
Shielding Closure	12	2	14	12	2	14	12	2	14	12	2	14
Shield Plug Installer	6	2	8	4	2	6	4	2	6	4	2	6

*Equipment requirements are developed in Appendix H.

Conceptual designs have been completed for the transporter. A working 1/12-scale model of part of the emplacement mechanism has been fabricated and operated to test the emplacement concepts. Some concepts are firmly established, and others are being redesigned based on experience gained from testing the model. Future design work is discussed in Section 8.3.3.

6.3.2 Equipment for Retrieval Under Abnormal Conditions

The equipment for retrieval under abnormal conditions is listed in Table 6-5 for the vertical and horizontal emplacement concepts. Preliminary concepts have been developed for the equipment listed; however, continued development (i.e., final concepts, detailed design, etc.) will progress according to the concept presented in Figure 3-3. For the

TABLE 6-5

EQUIPMENT LIST FOR WASTE REMOVAL UNDER ABNORMAL CONDITIONS

Equipment Description	Emplacement Configuration	Reference Section
Vibration System for Shield Plug and Bound Container Removal	Both	6.2.4 (Shield Plug) 6.2.8.1 (Container--Vertical)
Borehole Inspection System	Both	6.2.5.1 (Horizontal) 6.2.7.1 (Vertical)
Dolly-Uncoupling System	Horizontal	6.2.5.2
Liner Repair System	Horizontal	6.2.5.3
Container Removal Sleeve System	Vertical	6.2.7.2
Waste Container Coring System	Both	6.2.8.2 (Vertical) 6.2.9.1 (Horizontal)
Borehole-Reaming System	Horizontal	6.2.9.1
Liner-Cutting System	Horizontal	6.2.9.2

conditions estimated to have a probability of occurrence greater than 10^{-3}/yr, equipment will be developed through detailed design. For the other credible abnormal conditions, more detailed concepts of the equipment will be developed. For conditions classified as not credible, no specific development of equipment is required. However, equipment concepts may be developed for conditions that are considered to have potentially significant consequences. Equipment will be fabricated and tested, as required, to prove retrieval methods and the use of reasonably available techology.

Although most of the required equipment remains to be developed, development is believed possible using available technology. For example, some of the systems could be developed from equipment that exists in the petroleum or mining industries. Plans for equipment demonstrations will be developed consistent with the guidance provided in the Department of Energy Position on Retrievability and Retrieval (Appendix B).

Radiation hazards would likely be the single biggest obstacle related to the use of the equipment for retrieval under abnormal conditions, particularly as related to condition-specific ventilation requirements.

REFERENCES FOR CHAPTER 6

DOE (U.S. Department of Energy), "General Design Criteria," Order 6430.1, Washington, DC, December 1983. (HQS.880517.2268)

Hamm, E., "Central Refrigerating Plants for Air Conditioning in the Mines of Ruhrkohle AG," Second International Mine Ventilation Congress, Reno, NV, 1979. (NNA.900515.0013)

Pretorius, B. C. B., R. O. Ferguson, and R. Ramsden, "Considerations in the Selection of a Cooling System for the Deep Sub-Shaft Area of a Mine With Very High Rock Temperatures," Second International Mine Ventilation Congress, Reno, NV, 1979. (NNA.900515.0014)

Smith, O., "Effects of a Cooler Underground Environment on Safety, Labour and Labour Productivity," Third International Mine Ventilation Congress, Harrogate, UK, 1984. (NNA.900702.0018)

SNL (Sandia National Laboratories), "Site Characterization Plan Conceptual Design Report," SAND84-2641, compiled by H. R. MacDougall, L. W. Scully, and J. R. Tillerson, Sandia National Laboratories, Albuquerque, NM, September 1987. (NNI.880902.0014-.0019)

Stroh, R. M., W. F. Gebler, and J. J. Van Deventer, "Performance of an Integrated Surface Refrigeration System on Vaal Reefs," Third International Mine Ventilation Congress, Harrogate, UK, 1984. (NNA.900702.0019)

7.0 RETRIEVAL DEMONSTRATIONS

Retrieval demonstrations comprise proof-of-principle demonstrations and prototypical equipment development. Retrieval equipment and methods that use nonstandard equipment (not commercially available) or standard equipment in unusual circumstances require proof-of-principle demonstrations. According to current plans (Glowka, 1987), proof-of-principle demonstrations will be complete by the time of license application. Where design questions remain, prototypical equipment will be developed during review of the license application and repository construction (Section 3.1.2.5). Significant schedule changes have been made since the completion of early drafts of the document; the sequence of retrieval-related activities with other design activities and with the ESF activities is shown in Figure 7-1.

7.1 Proof-of-Principle Demonstrations

After the emplacement configuration is chosen, selected equipment subsystems will be designed, fabricated at full scale, and tested in proof-of-principle demonstrations. According to Department of Energy guidance (Appendix B), demonstrations must be completed for equipment systems and operations that have a significant degree of performance uncertainty. These demonstrations must provide satisfactory evidence that the planned emplacement/retrieval method will function under both normal and credible abnormal conditions.

The activities for proof-of-principle demonstrations include equipment design, fabrication, and demonstration and documentation of results (Figure 7-1). The current schedule indicates that documentation of the proof-of-principle demonstrations will be completed before submission of the license application.

The proof-of-principle demonstrations will be conducted in facilities that simulate those aspects of the emplacement and retrieval environments that could potentially affect equipment operation. The facilities are not required to completely recreate the repository environment, but

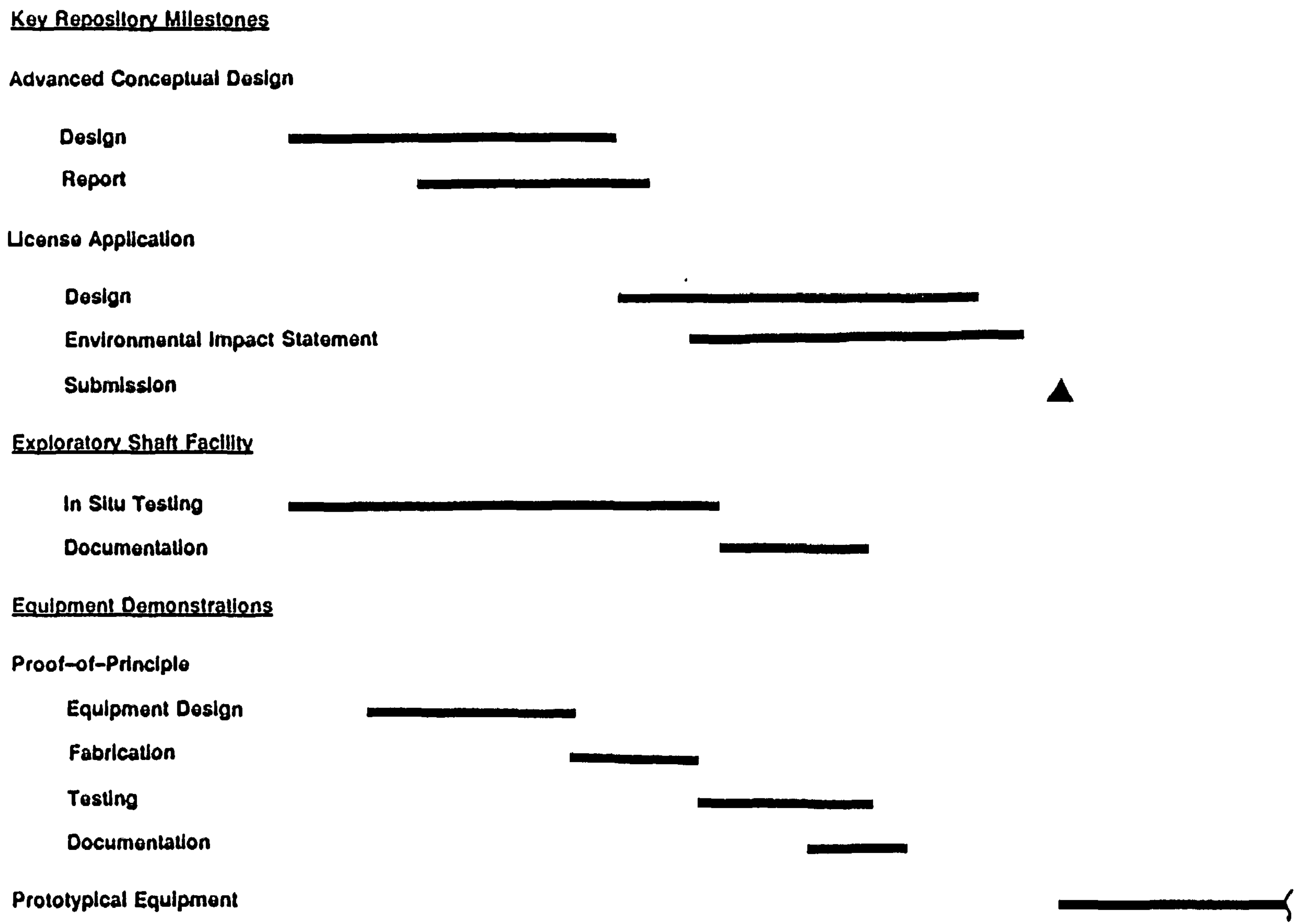

Figure 7-1. Sequence of Retrieval Demonstration and Repository Design

rather to simulate specific normal and abnormal conditions relevant to the repository and equipment designs. Surface and underground mockups of the emplacement borehole will be used for this purpose. In general, the full-scale equipment models used for these demonstrations will be complete in all details that affect the capability of the equipment to function as designed. Radioactive materials will not be used for simulated waste.

Further design work and analyses will determine which subsystems require proof-of-principle demonstration. As a planning basis, it is assumed that all equipment systems that need development will have subsystems that must be designed, fabricated, and tested in proof-of-principle demonstrations. Some equipment used in the waste-handling system will not require proof-of-principle demonstrations because similar equipment is commercially available and is currently used in similar underground environments (e.g., the trolley system that provides electric power to the transporter).

Evaluation of the probability of abnormal events will dictate what proof-of-principle demonstrations must be conducted for abnormal conditions. Systems developed for credible abnormal conditions will be tested under simulated conditions.

Proof-of-principle demonstrations will be more numerous for the horizontal emplacement configuration than for the vertical because horizontal emplacement and retrieval require more types of equipment. Therefore, costs will be higher for the proof-of-principle demonstration of horizontal emplacement.

7.2 Prototypical Equipment Development

At the time of license application, remaining questions about the performance of retrieval equipment under normal and credible abnormal conditions will be addressed by the development and testing of prototypical equipment. Prototypes are developed to verify performance and methods of retrieval under normal and credible abnormal conditions. Prototype development will also aid design refinement, which includes evaluations of human interfaces, system integration, and the environment; time and motion studies; the development of production equipment drawings and specifications; and the development of an operator training program.

Most of the data needed from prototype testing can be obtained more accurately and efficiently by using mockups of the in situ environment, rather than by testing in the emplacement area, because the test environment can be controlled.

The waste container used in the prototypical equipment demonstration will be of the same size and weight as the actual containers to be used in the repository. Any potential change in the shape, orientation, or other physical characteristic of the container that might affect operations will be simulated, as necessary, during these demonstrations. Although the use of radioactive material is not required in these demonstrations, radiation safety components will be incorporated into the prototypical equipment, as necessary, to test the mechanical systems.

Prototypical equipment development will begin shortly after submission of the license application and end before the issue of a license to receive and possess. Equipment design and data on retrieval conditions are not yet sufficient for the completion of a detailed schedule. The schedule for prototypical equipment development will be revised and expanded as equipment design and retrieval conditions are refined during studies for the advanced conceptual design.

REFERENCE FOR CHAPTER 7

Glowka, D. A., "Repository Waste-Handling Equipment Development Plan," SAND87-1245, Sandia National Laboratories, Albuquerque, NM, November 1987. (NNA.871130.0038)

8.0 FUTURE WORK

The repository design development is divided into three phases: (1) pre-advanced conceptual design (pre-ACD) studies, (2) advanced conceptual design (ACD), and (3) license application design (LAD). During the present, pre-ACD phase, various alternative repository design concepts are being identified and evaluated. During the ACD phase, a single repository design concept is planned to be selected and developed into a preliminary repository design. A final repository design is completed during LAD.

Future work to support retrieval will be performed in the following areas:

- site characterization,
- retrieval strategy,
- retrieval conditions,
- retrieval-related design requirements,
- design integration,
- retrieval operations,
- equipment tests and demonstrations, and
- retrieval compliance analysis.

In most instances, this work is necessary regardless of the retrievability requirement.

8.1 Site Characterization

Current data for site characterization have been derived from exploratory boreholes drilled at and around the Yucca Mountain site. Future characterization work will be performed in the exploratory shaft facility (ESF). Currently there are no tests planned at the ESF specifically for retrieval. However, much of the hydrologic and geotechnical data and test results obtained at the ESF will be used to support retrieval-related analyses.

8.1.1 Hydrologic Characteristics

Tests will be performed at the ESF to establish the hydrologic characteristics of the in situ rock at the Yucca Mountain site. These data will be important for refinement of the ventilation system design, estimation of corrosion rates (including radiolysis) of the container and underground structures, and the determination of retrieval conditions.

8.1.2 Geotechnical Characteristics

Geotechnical data will be acquired by geologic mapping and by measuring the properties of intact rock. Geologic mapping will identify the location of and define folds, faults, stratigraphic features, and anomalies. Properties of the intact rock will be established using in situ and laboratory tests. These tests will be used to determine in situ stress, rock strength characteristics, and joint and fracture characteristics. These data will be used to refine rock stability analyses for the ramp, shafts, drifts, and boreholes; rock support system designs; and the drift maintenance requirements.

8.1.3 Rock Mechanics Testing

Rock mechanics tests related to retrieval include rock support system tests, thermal effects tests, and mining tests. Rock support systems will be tested to evaluate various alternative approaches and materials. Thermal effects tests will evaluate the effect of the waste-induced thermal environment on the host rock. Mining tests will be performed to develop techniques that minimize overbreak. Test procedures and instrumentation have been developed during initial tests in G-Tunnel at the Nevada Test Site (NTS).

8.2 Retrieval Strategy

This retrieval strategy report contains information that is timely in nature. As the information is updated and additional information is available, the strategy report will be updated. These updates will be published during ACD and LAD.

8.3 Retrieval Conditions

As design development progresses, the retrieval conditions will be refined. Future work will use probability-based classifications of normal, credible abnormal, and not credible retrieval conditions (Figure 3-3). Only normal and credible abnormal conditions will be considered for design purposes. Retrieval condition updates will be published during ACD and LAD.

8.3.1 Normal Retrieval Conditions

The future work planned for the development of normal retrieval conditions will be discussed in terms of

- environmental conditions--the conditions encountered within the repository, including thermal, radiologic, and ventilation air conditions;

- natural conditions--geotechnical, hydrologic, and geochemical conditions and the effect of the emplaced waste on those conditions; and

- condition of engineered structures--the condition of all engineered structures, facilities, and equipment that are retrieval related.

8.3.1.1 Environmental Conditions

The planned studies to further define the environmental conditions are listed in Table 8-1.

Thermal Conditions

Future work to determine the thermal conditions includes further development of thermal models and refinement of thermal analyses. Study 1.1, Thermal (Numerical) Models, involves refinement, verification, and validation of numerical codes used to predict the temperatures in

TABLE 8-1

FUTURE STUDIES TO DEFINE ENVIRONMENTAL CONDITIONS

1.1	Thermal (Numerical) Models--Further refinement, verification, and validation of numerical models used for temperature prediction will continue.
1.2	Thermal Analyses--As input data (i.e., rock thermal characteristics), the layout, or the numerical models are refined, updated temperatures will be calculated.
1.3	Radon Studies--These studies include determining the radon-222 emination rate, investigating the potential for radon daughter plate-out, and evaluating the effect of radon on the ventilation system design.
1.4	Radiation Shielding Analyses--As radiation source terms and equipment and borehole designs are refined, radiation shielding analyses will be updated.
1.5	Particulate and Gaseous Contaminants--This study will identify contaminant sources and levels in the repository.
1.6	Ventilation Analyses--The ventilation analyses consider airflow requirements and air temperature, humidity, and airborne contaminants; these analyses are updated as the design is refined.

the emplacement boreholes, the emplacement drifts, and the access drifts. Study 1.2, Thermal Analyses, involves updating temperature predictions because of refinements in the thermal models or the input data (e.g., rock thermal characteristics, waste container thermal output, emplacement panel layout, or emplacement borehole design).

Radiologic Conditions

As discussed in Section 5.1.1.2, radiation in the repository results from naturally occurring radon-222 and radon daughters and from the radioactive waste. Study 1.3, Radon Studies, will investigate the potential for radiologic exposure from radon and radon daughters.

As shown in Table 8-1, Study 1.3 comprises three activities. The first involves the determination of the radon emination rate from the host rock. Tests may be performed in G-Tunnel at NTS in rock similar to the welded tuff at Yucca Mountain for an estimate to compare with the analytical estimates presented in Section 5.1.1.2. In situ tests will be performed in the ESF to determine the actual emination rate. The second activity will investigate the potential for contamination of the drifts as the result of radon daughter plate-out. This work will be performed during the G-Tunnel testing for radon emination rate. The last activity will evaluate the effect of radon on the ventilation system design and will include determination of air dilution requirements for continuously ventilated areas and for re-entry into closed areas.

Waste-generated radioactivity is addressed in Study 1.4, Radiation Shielding Analyses. For retrieval purposes, these analyses must predict the radiation dose rates from the waste while it is in the waste transporter and in the emplacement boreholes. As the source term definition and the design are refined, these analyses will become more sophisticated. Before ACD, approximate solutions (see Appendix G) will be used. During ACD, two-dimensional numerical models will be used. During LAD, Monte Carlo techniques will be used as needed.

Ventilation Air Conditions

Because of extensive experience in the mining industry and the simplicity of the ventilation system design, maintaining acceptable air quality is generally not expected to be a major concern for normal conditions even though limited site data are available. Study 1.5, Particulate and Gaseous Contaminates, will identify potential sources of airborne contamination of the ventilation air.

Study 1.6, Ventilation Analyses, will verify that acceptable air quality and airflow can be maintained in the working areas. These analyses will consider dilution requirements for airborne contaminants; restrictions for temperature, humidity, and airflow; and cooling requirements. These analyses will be updated as the repository design is refined.

8.3.1.2 Natural Conditions

The planned studies to further define the natural conditions are listed in Table 8-2. As indicated in Section 8.3.1, natural conditions include geotechnical, hydrologic, and geochemical conditions. Because hydrologic data will be acquired as part of site characterization (Section 8.1.1) and no retrieval-related geochemical concerns have been identified, only geotechnical conditions are addressed in this section. As site-specific data are determined in the ESF hydrologic testing, further evaluation of the impact of the observations on retrieval will be made.

TABLE 8-2

FUTURE STUDIES TO DEFINE NATURAL CONDITIONS

2.1	Thermomechanical Models--Further refinement, validation, and verification of thermomechanical models will continue through LAD.
2.2	Stability Analyses--As opening designs, rock characteristics, and numerical models are refined, stability analyses will be updated.

The geotechnical condition of primary concern at Yucca Mountain is opening stability. Study 2.1, Thermomechanical Models, involves the further development of computer codes that predict the thermomechanical response of the rock in the ramps, shafts, drifts, and emplacement boreholes, and validation and verification of the codes.

Combining the results of Study 2.1 with the refinements in geotechnical data acquired during site characterization (Section 8.1.2), Study 2.2, Stability Analyses, will update the thermomechanical analyses to verify that the underground openings will be stable.

8.3.1.3 Condition of Engineered Structures

This section describes future studies for the following engineered structures:

- ground support,
- the borehole liner and shield plug,
- the waste container,
- retrieval equipment,
- ventilation equipment,
- the waste-handling building, and
- support systems and facilities.

Planned future studies are listed in Table 8-3.

TABLE 8-3

FUTURE STUDIES TO DEFINE THE CONDITION OF ENGINEERED STRUCTURES

3.1	Ground Support Analyses--Further refinement of ground support analyses will continue throughout LAD.
3.2	Ground Support Tests--Verification tests for various ground support options will be performed in the ESF.
3.3	Liner and Shield Plug Corrosion Studies--The candidate liner materials will be analyzed and, as needed, tested to determine the corrosion rate. The potential for radiolysis and water condensate points will be included in these studies.
3.4	Liner and Shield Plug Stress Studies--These studies include liner and shield plug stress analyses and, as needed, tests to verify stress levels.
3.5	Waste Container Corrosion--This study will involve corrosion testing of the candidate materials to establish the expected corrosion rate.
3.6	Retrieval Equipment Condition--This study will determine the condition of retrieval equipment after long-term storage.
3.7	Waste-Handling Building Condition--This study will evaluate the effect of maintaining the waste-handling building in "moth ball" status on the equipment.
3.8	Condition of Support Systems and Facilities--This study will determine the condition of support systems and facilities.

Ground Support

Study 3.1, Ground Support Analyses, will be updated using geotechnical data generated during site characterization (Section 8.1.2). Study 3.2, Ground Support Testing, will be performed in the ESF to verify the analytical results (Section 8.1.3).

Borehole Liner and Shield Plug

The two concerns for survival of the liner and shield plug are corrosion and stress. Corrosion studies (Study 3.3) will evaluate the corrosion environment and estimate the corrosion rate based upon reference corrosion data. This evaluation will consider radiolytic induced corrosion and the potential for condensation on the liner. If needed, corrosion testing will be performed to provide additional support data. The evaluation, which will be done in conjunction with material compatibility studies for all borehole materials, will be performed during ACD; corrosion testing, if needed, will be performed during LAD.

Stress studies (Study 3.4) for the shield plug will focus on loads resulting from plug insertion and extraction. Liner stress studies will evaluate direct loads (e.g., rockfall loading) as well as thermally induced loads. For normal conditions, tests at the component level for the liner and shield plug are not planned. If needed, stress testing of the liner and shield plug will be included in system level tests.

Waste Container

The potential for structural degradation of the waste container under normal conditions is of concern. The primary mechanism for structural degradation is corrosion. Consequently, Study 3.5, Waste Container Corrosion, involves testing to identify potential corrosion mechanisms and corrosion rates. This work will continue through LAD.

Retrieval Equipment

Study 3.6, Retrieval Equipment Condition, will evaluate the effect of long-term storage on the equipment and estimate the repairs required to reactivate retrieval equipment. This work will continue through LAD.

Ventilation Equipment

The ventilation system will use commercially available equipment. Because a substantial maintenance data base exists for this equipment, no future work is planned to determine its condition during the retrievability period.

Waste-Handling Building

The current planning places the waste-handling building in standby or moth ball status following completion of waste emplacement activities (Section 4.5). Study 3.7, Waste-Handling Building Condition, will evaluate the effect of moth-balling on the waste-handling building and the waste-handling equipment. This work will continue through license application.

Support Systems and Facilities

Study 3.8 will evaluate the condition of support systems (e.g., utilities) and facilities during the retrievability period.

8.3.2 Abnormal Retrieval Conditions

Future work in the area of abnormal retrieval conditions primarily involves a continuation of the work presented in Section 5.2. As designs for the repository, equipment, and waste container; retrieval operations; and site data are refined, the identification and evaluation of abnormal conditions will be updated by

- identifying events and processes that could cause abnormal conditions,

- identifying the resulting abnormal conditions,
- classifying the abnormal conditions, and
- evaluating the consequence of each abnormal condition.

During ACD and LAD, the potential for the simultaneous existence of multiple abnormal conditions will be considered.

8.4 Retrieval-Related Design Requirements

Retrieval-related design requirements have been developed for the current conceptual design, using federal regulations and the DOE's Position on Retrievability and Retrieval as the basis. At the beginning of each design phase (ACD and LAD), these requirements will be updated to include performance and operational considerations for retrieval-related repository and equipment components.

8.5 Design Integration

To effectively integrate the retrieval-related requirements into the repository and equipment designs, the concept of an input item was developed. Input items identify information that will be needed for the retrieval compliance analysis. The future work needed in the design integration area includes updating the existing input items and tracking the response to the input items to ensure that sufficient information is available. The updates are performed at the beginning of each design phase, and the tracking is performed throughout each design phase.

8.6 Retrieval Operations

At the completion of each design phase descriptions of retrieval operations under normal and credible abnormal conditions will be included in the repository operations plan. A description of the retrieval operations will verify that the retrieval method is operationally viable and that retrieval can be completed in a timely manner as required in 10 CFR 60 (NRC, 1986). In addition, the retrieval operations will be used to compute worker radiologic dose rates for retrieval. These dose rates will be included in the ACD report and in the safety analysis report in the license application.

8.7 Equipment Tests and Demonstrations

The development of equipment for retrieval is described in the "Repository Waste-Handling Equipment Development Plan" (Glowka, 1987). Retrieval-related equipment includes

- the waste transporter,
- the borehole shielding closure,
- auxiliary equipment, and
- retrieval equipment for abnormal conditions.

The plans for equipment development are synopsized in Table 8-4. As indicated in the table, equipment performance will be verified by means of equipment tests and demonstrations. Future work will initially consist of the development of an acceptable method for identifying and documenting tests and demonstrations that will be required to verify that retrieval concepts and equipment meet the established retrieval-related design requirements.

8.7.1 Equipment Tests

During ACD, key equipment components that contain unproven hardware will need to be identified, designed, fabricated, and tested.

8.7.2 Retrieval Demonstrations

As discussed in Chapter 7, retrieval demonstrations consist of proof-of-principle demonstrations and prototypical equipment development. During ACD, equipment requiring proof-of-principle demonstrations will be identified, designed, and partially fabricated. Before submission of the license application, equipment fabrication will be completed, and demonstrations will be completed and documented. Prototypical equipment development will begin after submission of the license application and

TABLE 8-4

PLANS FOR DEVELOPMENT OF RETRIEVAL EQUIPMENT

Equipment	Pre-ACD	ACD	LAD
Waste Transporter (includes vehicle design,[a] cask and turntable design, and emplacement/retrieval mechanism design)	Trade-off studies made Preliminary design analyses performed Key components identified	Component testing completed Detailed system designs developed	Final designs completed Proof-of-principle demonstrations conducted
Borehole Shielding Closure	Preliminary shielding analyses performed Design concepts developed	Detailed designs developed	Final design and testing
Auxiliary Equipment	Design concepts developed Key components identified	Component testing completed Detailed system designs developed[b]	Final designs completed Testing completed
Retrieval Equipment[c] for Credible Abnormal Conditions	Preliminary concepts developed Key components identified	Component testing completed Detailed system designs developed	Final designs completed Proof-of-principle demonstrations conducted

a. The waste transporter vehicle will be developed from commercially available equipment.

b. Detailed system designs will be developed after the emplacement configuration is decided upon.

c. Development of retrieval equipment for abnormal conditions will be consistent with the developing determination of abnormal conditions shown in Figure 3-3. The exact equipment will depend on the abnormal conditions identified during ACD. As a planning basis, concepts will be developed for the equipment listed in Tables 6-5 and 6-6.

will be completed before receipt of a license to receive and possess (Figure 3-4).

8.8 Retrieval Compliance Analysis

At the end of ACD and LAD, an analysis of existing retrieval-related data and information will be performed to ensure that the repository and equipment designs comply with the retrieval-related requirements. The work will initially focus on a method for performing this compliance analysis. Then, the method will be applied during ACD and LAD. The compliance analysis will include the following:

- a compilation and evaluation of the responses to input items to ensure that they are complete;

- an evaluation of the retrieval conditions analyzed to determine whether the appropriate conditions have been considered;

- an evaluation of the design and operations to determine whether all of the PRR requirements (Section 3.1) and site specific requirements (Section 3.2) have been met; and

- an evaluation of supporting analyses, tests, and demonstrations to determine whether sufficient evidence exists to indicate that the retrieval method and equipment are viable.

REFERENCES FOR CHAPTER 8

Glowka, D. A., "Repository Waste-Handling Equipment Development Plan," SAND87-1245, Sandia National Laboratories, Albuquerque, NM, November 1987. (NNA.871130.0038)

NRC (U.S. Nuclear Regulatory Commission), "Disposal of High-Level Radioactive Wastes in Geologic Repositories," Code of Federal Regulations, Energy, Title 10, Part 60, Washington, D.C., January 1986. (NNA.910315.0133)

APPENDIX A

ANNOTATED OUTLINE FOR PROJECT STRATEGY PAPER FOR DEMONSTRATING COMPLIANCE WITH THE DECEMBER 6, 1985 DEPARTMENT OF ENERGY POSITION ON RETRIEVABILITY AND RETRIEVAL FOR A GEOLOGIC REPOSITORY

ANNOTATED OUTLINE

FOR

PROJECT STRATEGY PAPER

FOR DEMONSTRATING COMPLIANCE WITH THE

DECEMBER 6, 1985

DEPARTMENT OF ENERGY

POSITION ON RETRIEVABILITY AND RETRIEVAL

FOR A GEOLOGIC REPOSITORY

* * * * *

APRIL 3, 1986

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Table of Contents (cont'd)

RETRIEVABILITY STRATEGY PAPER

FOREWORD

This annotated outline is provided as Project guidance for the planning and design effort required to bring each Project into compliance with the requirements for retrievability as expressed in the Department of Energy December 1985 Position on Retrievability and Retrieval for a Geologic Repository (PRR). The retrieval planning performed in this regard will highlight the need for any work related to retrievability that is required in the Exploratory Shaft Facility (ESF). During the collection of data for site characterization, the potential for its use in making the necessary retrievability analyses should not be overlooked.

It is realized that each Project will be revising its strategy paper as its design evolves and matures in order to provide greater detail and maintain consistency of concepts. Nevertheless, the Projects are still expected to provide the maximum amount of information possible in the first issue of their strategy papers. Generally, presenting information inconsistent in level of detail with the current design status or which implies a more complete knowledge of site characterization data than is available is discouraged. However, in some instances it may be necessary that the strategy paper contain information which is more detailed than this to ensure that the reader obtains the proper understanding of the Project's strategy regarding retrieval and compliance with the PRR. If this occurs, then such information should be qualified as requiring further substantiation by future design or data collection activities.

In the belief that the licensing process will be expedited, the Department plans to request Nuclear Regulatory Commission (NRC) review of each successive issue of the Project-specific strategy paper as the retrievability compliance strategy evolves. The site-specific strategy papers will additionally establish the practical reasonableness of the requirements of the DOE Position and confirm the DOE's expectations on a site-specific basis. The NRC designations of creep closure in a salt repository and of long horizontal emplacement holes in other repositories as matters requiring particular scrutiny for their impacts on retrievability are well known. Its identification of added issues that it believes to be sensitive from its review of the strategy papers will be useful in saving time for the Department.

In this annotated outline, several examples of abnormal conditions and malfunctions that could affect the emplacement system are identified for each Project. These citations are included only as illustrations to improve understanding and should not be interpreted as the only abnormal conditions and malfunctions that the Projects need to consider when developing their retrieval strategies.

When determining the ranges of normal and abnormal conditions that could reasonably be expected to be encountered during retrieval (see Chapter 5), the Projects need only consider independent (i.e., uncoupled) events for the first issue of their strategy papers. For example, the event might be a gas explosion or a sudden inflow of water, but not a gas explosion resulting in a sudden inflow of water. However, in succeeding issues of this strategy, each Project should incorporate coupled events, as appropriate, in the analysis of retrieval scenarios. In order to ultimately achieve satisfactory analyses of coupled events, it is believed necessary to first have a good understanding of all plausible accidents, malfunctions, and abnormal conditions taken to be independent events.

In Sections 4.4 and 4.5 of the Annotated Outline for the Site Characterization Plan Conceptual Design Report (AO-SCP-CDR), there are specific requirements for the definition of the design concepts, the layout in detail of the underground facilities, a concise description of the operations required to receive and emplace a waste container underground, and the plan of development and design of the waste emplacement rooms and holes. The Project's strategy paper shall utilize the narrative and illustrations prepared in response to these requirements for the SCP-CDR as applicable. Any additional information developed in preparation for the Advanced Conceptual Design (ACD) and available at the time of the strategy paper preparation shall also be included.

Regarding retrievability, Section 3.2 of the AO-SCP-CDR requires a discussion of the approach toward and concepts for retrieval including diagramming of the work flow and identification of equipment and methods needing development. In Section 6.3 of the AO-SCP-CDR a description is required of the repository design concepts that preserve the retrieval option and of the confirmation program to show regulatory compliance. Subsection 6.3.1 specifies the discussion of the environment predicted for the repository during the retrieval period with particular attention to worst-case situations. The abnormal items or events reasonably expected to occur during retrieval operations are to be reviewed. Subsection 6.3.2 requires the presentation of preliminary plans for proof-of-principle demonstrations of retrieval concepts, methods, and non-standard equipment. In addition, this section specifies discussion of the planned use of equipment and procedures to accommodate the expected adverse conditions discussed for 6.3.1. Finally, a brief description of plans for prototypical equipment development is required. Subsection 6.3.3 requires a discussion of the design approach to accommodate full retrieval. It is expected that the Projects will utilize, to the maximum extent possible, in the strategy papers the narrative and illustrations prepared to complete these requirements of the SCP-CDR.

1.0 INTRODUCTION

This chapter should introduce the strategy paper for the Project. In addition to presenting a brief synopsis of the events that have occurred relevant to retrievability by or on behalf of the Project, it shall also describe the purpose and scope of the strategy paper as well as the strategy paper's relationship to other OCRWM progam documentation.

1.1 Background

In this section, briefly describe the history of retrieval activities that have occurred relevant to the Project. This shall include previous design efforts, documents prepared, NRC meetings, etc., as applicable.

1.2 Purpose and Scope of Strategy Paper

In this section, the purpose and scope of the strategy paper shall be described. As a minimum, the following points are to be discussed:

- all major activites required of the Project to comply with the PRR.

- the Project's near-term focal point for interacting with the NRC on retrieval.

- the decision methodology that will be used by the Project to determine the general type and scope of the proof-of-principle tests that are necessary, with the specific plans being discussed in Chapter 7 of the strategy paper.

- the location(s) at which the proof-of-principle tests will be conducted.

1.3 Relationship With Other Documents

In this section, the relationship of the information presented in the strategy paper to other major OCRWM Program, as well as pertinent Project documents, e.g., SCP-CDR, SCP CH 6 and 8, Subsystem Requirement documents, ACD Planning documents, etc., is to be described in sufficient detail to clearly illustrate the interrelationship of all the documentation in the OCRWM program that is relevant to retrieval.

2.0 DESCRIPTION OF EMPLACEMENT SYSTEM

The narratives in this chapter shall provide a brief overview of the Project's current concept for the receipt, handling, mechanical processing, packaging, storage, movement, and emplacement of waste to be received. Emphasis shall be placed on the subsurface portions of this process. Schematics of major equipment are to be included as appropriate to aid in understanding the details of the emplacement system's operation. A general arrangement of the underground facility showing the operational arrangement for each phase of development is also to be provided.

A detailed discussion is to be included on the physical arrangement of the emplacement rooms including room dimensions, ventilation and cooling, and waste package spacing. An isometric drawing of the waste package in an emplacement hole that shows emplacement hole dimensions, as well as liner, packing, container, and shield plug dimensions, where appropriate, shall be provided to support this discussion. Discuss the waste package design including, as appropriate, container dimensions, overpack weights and thicknesses, materials, and handling fixtures.

The primary objective of this chapter of the strategy paper is the presentation of a concise, but definitive picture of the emplacement operation. The waste container, as currently described for the SCP, shall be discussed to the same degree of detail.

2.1 Reference Emplacement Case

In this section, provide the information above for the "reference case," i.e., the emplacement operation that is currently viewed as the one most likely to be routinely utilized. Define the particular conditions of the geologic setting, the waste container(s), the waste(s) itself, and the repository designs that are viewed as making this particular emplacement operation the most suitable. Distinguish between the different types of waste to be emplaced and their unique emplacement methods.

2.2 Alternate Emplacement Cases

Provide the same information as presented in Section 2.1 in this section for each alternative mode of waste emplacement that is under active consideration by the Project.

3.0 RETRIEVAL REQUIREMENTS/DESIGN CRITERIA

The PRR contains a number of requirements whose collective aim is the preservation of the capability to retrieve any or all of the emplaced waste from the repository throughout the mandatory retrieval period. This chapter of the strategy paper shall present the Project's analysis of the PRR requirements. In addition, this chapter shall provide the further design criteria and requirements which will govern the site-specific needs of the Project's retrieval method. These additional requirements and criteria will be determined to a greater level of detail than those of the PRR.

3.1 Existing

This section shall concisely delineate the Project's interpretation of each requirement contained within the PRR. It should address the general requirements directing the overall planning and design, those requirements incumbent upon all aspects of the design activity, and the requirements that are in effect during the operational period of the repository. Any other retrieval requirements, criteria or specifications found in other program documents and not covered in the PRR should be interpreted here as well. At a minimum, include the requirements and criteria for:

- maintaining the retrievability of each waste container for the prescribed retrieval period;

- ensuring that designs, methods, and equipment used do not negatively affect isolation;

- maintaining retrievability throughout the range of underground conditions that could be caused by any singular or combination of plausible events;

- anticipating the range of thermal, hydrologic, mechanical, and chemical (T-H-M-C) conditions occurring throughout the retrieval period;

- estimating the time and labor required to provide temporary storage if it is needed;

- determining the plans for the necessary demonstrations of methods, equipment, operation, and procedures;

- designing whatever is necessary to accommodate early backfilling of various pre-designated portions of the repository; and

- implementing monitoring as deemed appropriate and necessary.

3.2 Site-Specific

This section shall present the retrieval requirements and design criteria that are (or will be) specified in the Project's Subsystem Requirements Documents for the repository and waste package. The design criteria to be established by the Project should include at a minimum, the following or similar subject categories:

- engineering limits to the physical dimensions of retrieval equipment, scope of equipment operations, etc.;

- occupational limits to the working environment during retrieval--including temperature, ventilation, radiation, dust, humidity, lighting, etc.;

- optimum and acceptable retrieval rates for both complete retrieval and partial retrieval (one and more);

- surface design criteria for disposition of retrieved waste incluidng temporary disposal locations, capabilities, etc., and/or criteria for off-site shipment preparation;

- maintenance standards for repository systems and equipment during the caretaker period;

- level-of-effort design standards at time of LA for equipment, systems, and excavation not required before retrieval is required;

- amount and type of retrieval equipment to be available for use during emplacement (if any);

- design safety factors to be used in retrieval equipment and methods;

- criteria for the determination of retrieval equipment design-based accidents and events;

- criteria necessary for the determination of backfilling requirements and/or physical support prior to closure;

- criteria necessary for the determination and design of remotely-operated retrieval equipment vs. labor-intensive retrieval equipment.

These requirements and criteria shall be as complete as possible with "to be determined" (TBD) inserted within individual requirements to cover those aspects not currently defined. An evaluation of how and when the TBD will be resolved shall follow each requirement containing a TBD.

3.3 Additional Guidance Required

State the additional criteria or definitions which affect retrieval and have not yet been provided by Headquarters in this section of the paper. Any additional guidance pertaining to requirements that the Project believes to be necessary to achieve full compliance with the PRR shall be identified and discussed in this section. In identifying this additional guidance, the narrative is to be as specific as possible regarding the nature of the requirement, who should develop it, and when it should be established.

4.0 POST-EMPLACEMENT OPERATIONS

This chapter is to discuss the planned development of the underground facility during the emplacement period and the physical state the shafts, main entries and emplacement rooms will be maintained in during the retrievability period. This discussion should address the relative location and emplacement sequence for each type of waste to be contained in each emplacement room. A discussion of any waste segregation strategy for retrieval that may exist should also be provided.

The narrative shall discuss concisely the various types of post-emplacement operational activity that can reasonably be anticipated within those portions of the repository where the capability for retrieval must be maintained. It shall include the following sections as a minimum.

4.1 Backfill

This section is to identify whether backfilling of any underground openings is to be done prior to the end of the retrievability period. If it is planned, then discuss the timing of it relative to the emplacement operation described in Chapter 2. Provide a description of the process and associated equipment to be used, and specify the normal and abnormal conditions, e.g., temperature, degree of consolidation, which could be expected to occur in the backfilled room. Describe the procedure and equipment that is to be used to place the backfill and the extent to which it is to be placed. The description is to be inclusive by beginning at the waste container and covering all aspects of the operation out to the portion of the repository space that is to be left open during the operational period. Describe the material(s) to be utilized and, in particular, estimate the changes in their properties that can be expected with time, exposure to radiation, exposure to heat, and the combined effects of the geotechnical conditions.

4.2 Ventilation

In this section, discuss the approach that will be followed for emplacement room ventilation after emplacement and before the expiration of the retrievability period. This discussion shall specify the air stream temperatures, relative humidity, velocity, etc., associated with the ventilation design. The system planned for ventilating that portion of the repository that will remain accessible to personnel after the completion of emplacement is to be described. This narrative shall include a description of the equipment which is considered to be necessary to provide the designed airflow to all segments of the system with reliability.

4.3 Repository Integrity - Inspection and Monitoring

Describe in this section the plans for inspecting and monitoring the physical integrity of the rock and engineering components of the repository, only insofar as they affect retrievability. Provide an overview of the inspection procedures that will oversee those naturally occurring events which could degrade or inhibit the ability to retrieve. Such occurrences as water inflow, creep closure, spalling, stress fields, equipment corrosion, vertical alignment of shafts, and other factors affecting retrieval should be addressed.

The inspection and monitoring activity discussed here is not to be that contained within the performance confirmation program for the long-term isolation of the emplaced waste. Rather it is to be related only to the physical plant and those rock conditions which, if allowed to deteriorate, could adversely impact retrieval.

4.4 Access Maintenance

Describe in this section those portions of the repository which are to be temporarily closed after emplacement and before the retrievability period ends. Discuss the construction and need for barriers, brattices, bulkheads and measures which may be necessary to keep the underground portion of the repository in a caretaker status until the end of retrievability. Describe the effects (if any) these measures may have on the retrieval of some or all of the emplaced waste.

4.5 Maintenance of Stand-By Status

Describe in this section the methods and procedures by which the repository will be maintained during the period of time from when emplacement ends until the termination of the retrievability period. Identify the equipment, services, and underground openings which will be preserved on stand-by status in the event retrieval becomes necessary.

Those components of the emplacement which are critical to the maintenance of the retrieval option shall also be identified. Discuss the procedures and precautions which will be taken to ensure the survivability of these components.

4.6 Post-Emplacement Effects of Retrievability Maintenance

Describe the other events and circumstances which will take place in and around the emplaced waste which are the result of purposefully maintaining the repository after emplacement in this section. Not counting the natural effect which will result from the introduction of emplaced waste into the host rock environment, identify those additional effects which are themselves caused by the delay of final decommissioning and closure. Also identify what, if any, the impact of these influences will be upon the preservation of retrievability during this period.

5.0 REPOSITORY CONDITIONS AT RETRIEVAL

Describe in this chapter the conditions that are most likely to exist at the time retrieval may be required. These conditions will be dependent on the length of time the waste has actually been emplaced prior to retrieval. For the purposes of this chapter, assume that the design-based retrieval environment has changed to the worst degree plausible whether or not that will have occurred at the time of retrieval or earlier.

In calculating the length of time waste may be in the ground prior to retrieval, assume that retrieval is not initiated until near the end of the 50-year retrievability period. This means that any given canister of waste may not be retrieved until decades after the expiration of the 50-year period (see diagram in Section 2.3 of Position on Retrievability and Retrieval).

5.1 Description

The narrative in this section shall describe concisely the situations which have been determined to likely exist for that time during the prescribed retrievability period chosen as "worst-case" under both a normal events scenario and abnormal events scenarios. This discussion will quantify, by providing the design value used as well as the current range of values for each parameter of interest, the conditions important to the design of the retrieval system that will exist. Engineering judgment may be used, but the discussion must nevertheless still be quantitative in nature. Any steps necessary to go from the underground facility status described in Chapter 4 to the status associated with the conditions specified here should be discussed.

5.1.1 Normal Events/Conditions

The narrative here shall describe the predicted "poorest retrieval conditions" that can be expected to exist for the case where the repository is under the influence of normal or ambient events and conditions. Normal events and conditions for the repository at any time during or after emplacement refers to the reasonably expected state produced by the combined effects of geotechnical properties and engineered components. The description in this subsection shall include concise estimates of the:

- environmental conditions present
- natural conditions of the geologic setting
- conditions imposed by or on engineered structures.

5.1.1.1 Environmental Conditions

Provide the temperature that will exist in the waste canister if one is used, the packing material, the waste container, the emplacement hole, the emplacement room, and at all other points important to the retrieval design.

Describe the radiation fields expected from the waste container or canister as appropriate prior to its removal, during its removal from the emplacement hole, and after it is fully tranferred to the retrieval equipment.

Identify the condition of the air in the emplacement rooms during retrieval in terms of dust content, volatiles, relative and effective humidity, temperature, air velocities, etc.

Identify any other environmental parameters not previously addressed which are significant to the design of the retrieval system.

5.1.1.2 Natural Conditions

Provide a quantitative estimate of the coupled geotechnical effects (T-H-M-C) which will influence the conditions expected to occur in the emplacement room. Address, at a minimum, the following (if applicable):

- magnitude and direction of stress

- degree of induced faulting and/or fracturing

- amount of likely heave, pinching, swelling

- rate of primary and secondary creep

- potential for rock bursting

- water inflow, temperature, character and quantity

- collapse of roof resulting from interbeds

- rock cave-in, spalling.

5.1.1.3 <u>Engineered Structures and Waste Package</u>

Provide a quantitative estimate of the condition of the engineered structures and waste package at retrieval. Address, as a minimum, the following:

- condition of any ground support that will be in place

- condition of the waste package/hole liner/shield plug

  - temperatures
  - stress
  - corrosion
  - disorientation

- condition of the haulage system, e.g., tracks.

- condition of support systems, including lighting, ventilation, power, compressed air, communications, etc.

5.1.2 Abnormal Events/Conditons

The narrative here shall describe the predicted "poorest retrieval conditions" that can be expected to exist for each case where the repository is under the influence of an abnormal event or condition. An abnormal event or condition is any plausible malfunction, accident, or deleterious change in the geotechnical properties or engineered components of the repository. This subsection shall contain the results of a systematic assessment of the range of abnormal conditions which are possible. The discussion shall include detailed fault-tree assessments and risk analyses. Where a detailed analysis is not available, the discussion shall be based on professional judgment. The information shall be quantified to the highest detail possible at the time of writing. The following annotation is provided for the Projects' consideration although the actual abnormal conditions that are to be discussed will be project-specific. However, the following annotation illustrates the expected intent of the type of analysis required.

5.1.2.1 Environmental Conditions

Identify the range of temperature variation which reasonably could be experienced at the waste container and the emplacement hole when:

- the waste package(s)' heat loading was 25% above its expected value;
- the thermal conductivity of the host rock had its lowest value; or
- other as identified by the Project for its site.

Also identify the levels of airborne radiation and air temperature that would occur in each instance.

Identify the range of radiation levels that could rasonably be expected to occur if all of the waste packages were to fail in an individual emplacement room. Assume that he maximum plausible amount has leached from the waste container. Identify the amount of contaminated rock, the radiation levels in the emplacement room during retrieval, and the levels associated with a particular waste package at removal of shield plug and during waste withdrawal. Also identify the levels of airborne radiation, noxious gases, and air temperature that would result. Identify the likelihood of supersaturated air flashing to steam within the opened emplacement hole.

Identify any other environmental parameters not prevously addressed which are significant.

5.1.2.2 Natural Conditions

Provide a quantitative estimate of the abnormal natural conditions which could exist in the emplacement room. Address, as a minimum, the following:

- State of stress - identify plausible condition(s) which could result from an increase in the state of stress and identify the magnitude of such an increase.

- Degree of fracturing and/or faulting - identify plausible condition(s) which could result from an increase in the number and size of fractures or induce faulting. Estimate the magnitude of such fracturing and faulting.

- Rate of primary and secondary creep - identify plausible condition(s) which could result from a significantly increased creep rate. Estimate the magnitude of the increase.

- Potential for rock burst - identify plausible condition(s) which could result from a significant increase in the potential for rock burst and estimate the magnitude of this potential.

- Water inflow - identify plausible condition(s) that could result from increases in water inflow. Estimate the magnitude of the increased inflow.

- Interbeds - identify plausible condition(s) that could result if undetected interbeds are encountered. Estimate the magnitude of the ground support problem that would result.

In each case, estimate the effect of the abnormal conditions upon retrieval through such events as heaving, pinching, waste container disorientation, rock bursting, etc.

5.1.2.3 Engineered Structures and Waste Package

Identify the plausible failure modes of the waste package which could influence retrieval. Address, as a minimum, the following:

- waste container disorientation (primarily salt)
- waste container(s) seizure
- totally failed package (complete rupture of the container)
- advanced state of corrosion, essentially no strength in the container
- crushed or broken concrete around hole covers or plugs
- seized emplacement hole covers.

The manner in which each of the failures could affect retrieval shall be discussed.

5.1.2.4 Accidents and Equipment Malfunctions

Identify those accidents and equipment malfunctions or failures that could reasonably be anticipated which, if they occurred, could influence retrieval. The manner in which each of these events could affect the retrieval operation shall be discussed. Those steps that would be taken to mitigate or minimize the detrimental effects of each event shall also be described.

5.2 Method of Determination

The narrative of this section shall discuss the method(s) that the Project utilized in determining the normal and abnormal events and conditions described in the previous subsections of Chapter 5.

6.0 RETRIEVAL METHOD(S) PLANNED BY PROJECT

In this chapter provide a complete description of the retrieval method(s) that contains, in as much detail as possible, all features associated with the anticipated method of retrieval. This must include a complete step-by-step description of the retrieval process, equipment, methodology and backup contingencies. Cartoon-type illustrations depicting the process would be useful.

Describe the criteria that will be necessary for the design and construction of whatever additional facilities will be needed to provide adequate ventilation and other services for retrieval, such as:

- additional shafts
- modifications to existing shafts
- additional excavation/construction
- additional ventilation and support equipment
- modifications to other services.

Also to be included in this chapter, as a minimum, is a discussion of those aspects of the repository which will affect, or be affected by, retrieval. These would include:

Major surface systems/components
Major subsurface systems/components
Additional shafts
Modifications to existing shafts
Additional excavation/construction
Ventilation
Sequencing of retrieval events
Time required to begin retrieval
Time required to retrieve (based on differing amounts and types of wastes)
Occupational exposure hazards
Backfilling
Re-excavation
Temporary storage

Transport/loading/off-loading

Overcoring

Decontamination

Contaminated muck removal

Contaminated water removal

Modifications to other services

In the description of the retrieval process, a differentiation between removing all the waste and removing only a part of the waste is to be made if the processes differ.

6.1 Retrieval for the Reference Emplacement Case

Using the criteria identified above, describe the retrieval method and process associated with the Reference Emplacement system that is detailed in Section 2.1 of the strategy paper. The description of the retrieval schemes should discuss all methods of retrieval contemplated under both normal/ambient and abnormal retrieval conditions.

6.1.1 Normal/Ambient Retrieval Conditions

Describe, in as much detail as possible, the major sequence of events that it is expected would be undertaken for the retrieval of emplaced waste. As in Chapter 5, assume that the greatest change in the underground conditions has occurred, whether or not that will have actually taken place earlier or at the time of retrieval. Reference all post-emplacement developments and maintenance alterations which were described in Chapter 4.

The description of the retrieval methods under the normal or ambient conditions that are likely to be in existence at the time of retrieval shall include the following two hypothetical situations:

- Situation 1 - Retrieval of waste has been required from a selected group of waste containers in a single emplacement room or drift. Assume all the containers in this room are to be retrieved. Further assume the environment, geotechnical conditions and engineered components to be as described in 5.1.1.

- Situation 2 - Retrieval of waste has been required of all emplaced spent fuel and high level waste in the repository. Assume the entire capacity of the originally designed first repository has been emplaced prior to this time. Further assume the environment, geotechnical conditions, and engineered components to be as described in 5.1.1.

Describe the specific subsurface operations associated with each retrieval siturafion discussed including: reconfiguration of the ventilation system, removal of bulkheads, remining of backfill (if applicable) excavation of additional shafts and passageways, monitoring, placement of retrieval equipment, retrieval, removal of waste to surface, and safe storage of waste on surface.

Describe the individual pieces of equipment that will be required for each retrieval situation discussed and provide schematic drawings of them as appropriate for understanding. Identify, thorugh a contingency analysis, the alternatives available in case of equipment malfunction. Describe the availability of back-up systems in case of component failure. List which systems must be failsafe and which can be allowed to fail if adequate redundancy is available.

Describe, in the case of partial retrieval, the effects to the adjacent areas of the repository. Give the impact (if any) to the overall integrity and physical continuity of the natural and engineered barriers. In addition, provide a description of the structural and geomechanical conditions of the emplacement rooms and boreholes from which the waste was retrieved.

6.1.2 <u>Abnormal Retrieval Conditions</u>

Describe, in as much detail as possible, the major sequence of events that it is expected would be undertaken for the retrieval of emplaced waste. As in Chapter 5, assume that the greatest change in the underground conditions has occurred, whether or not that will have actually taken place earlier or at the time of retrieval. Reference all post-emplacement developments and maintenance alterations which were described in Chapter 4.

The description of the retrieval methods under the plausible, yet abnormal, conditions that are likely to be in existence at the time of retrieval shall include three hypothetical situations. The actual situations selected by the Project for this discussion may vary; however, the following reflects the character of the discussion that is required.

- Situation 1 - Retrieval of waste has been required from a selected group of waste containers in a single emplacement room or drift. This situation is to be further broken down into three scenarios, as described below:

  Case 1: Assume that the worst combination of abnormal environmental and geotechnical events/conditions has occurred as described in Subsection 5.1.2 <u>and</u> that no waste containers have failed.

  Case 2: Assume only normal environmental and geotechnical events/conditions have occurred as described in Subsection 5.1.1 <u>but that</u> the worst combination of engineered structures and waste package failures as descrbed in Subsection 5.1.2 has occurred to all the emplaced waste in the room.

  Case 3: Assume that the worst combination of all abnormal events/conditions has occurred as were described in Subsection 5.1.2 <u>and</u> that all of the waste containers in the emplacement room have failed.

- Situation 2 - Retrieval of waste has been required of all emplaced spent fuel and high level waste in the repository. Assume the entire capacity of the originally designed first repository has been emplaced prior to that time. This situation is to be further broken down into three scenarios as described below.

Case 1: Assume that the worst combination of abnormal environmental and geotechnical events/conditions has occurred as described in Subsection 5.1.2 <u>and</u> that no waste containers have failed.

Case 2: Assume only normal environmental and geotechnical events/conditions have occurred as described in Subsection 5.1.1 <u>but that</u> the worst combination of engineered structures and waste package failures as described in Subsection 5.1.2 has occurred to 25% of all emplaced waste in the repository.

Case 3: Assume that the worst combination of all abnormal events/conditions has occurred as were described in Subsection 5.1.2 <u>and</u> that 25% of all the waste containers in the emplacement rooms have failed.

Describe the specific subsurface operations associated with each retrieval situation discussed including: reconfiguration of the ventilation system, removal of bulkheads, remining of backfill (if applicable) excavation of additional shafts and passageways, monitoring, placement of retrieval equipment, retrieval, removal of waste to surface, and safe storage of waste on surface.

Describe the individual pieces of equipment that will be required for each retrieval situation discussed and provide schematic drawings of them as appropriate for understanding. Identify, through a contingency analysis, the alternatives available in case of equipment malfunction. Describe the availability of back-up systems in case of component failure. List which systems must be failsafe and which can be allowed to fail if adequate redundancy is available.

Describe, in the case of partial retrieval, the effects to the adjacent areas of the repository. Give the impact (if any) to the overall integrity and physical continuity of the natural and engineered barriers. In addition, provide a description of the structural and geomechanical conditions of the emplacement rooms and boreholes from which the waste was retrieved.

6.2 Retrieval for the Alternate Emplacement Cases

Using the criteria identified above, describe the retrieval method and process associated with the Alternate Emplacement system(s) that is (are) detailed in Section 2.2 of the strategy paper. The description of the retrieval schemes should discuss all methods of retrieval contemplated under both normal/ambient and abnormal retrieval conditions.

6.2.1 Normal/Ambient Retrieval Conditions

Describe, in as much detail as possible, the major sequence of events that it is expected would be undertaken for the retrieval of emplaced waste. As in Chapter 5, assume that the greatest change in the underground conditions has occurred, whether or not that will have actually taken place earlier or at the time of retrieval. Reference all post-emplacement developments and maintenance alterations which were described in Chapter 4.

The description of the retrieval methods under the normal or ambient conditions that are likely to be in existence at the time of retrieval shall include the following two hypothetical situations:

- Situation 1 - Retrieval of waste has been required from a selected group of waste containers in a single emplacement room or drift. Assume all the containers in this room are to be retrieved. Further assume the environment, geotechnical conditions and engineered components to be as described in 5.1.1.

- Situation 2 - Retrieval of waste has been required of all emplaced spent fuel and high level waste in the repository. Assume the entire capacity of the originally designed first repository has been emplaced prior to this time. Further assume the environment, geotechnical conditions and engineered components to be as described in 5.1.1.

Describe the specific subsurface operations associated with each retrieval situation discussed including: reconfiguration of the ventilation system, removal of bulkheads, remining of backfill (if applicable) excavation of additional shafts and passageway, monitoring, placement of retrieval equipment, retrieval, removal of waste to surface, and safe storage of waste on surface.

Describe the individual pieces of equipment that will be required for each retrieval situation discussed and provide schematic drawings of them as appropriate for understanding. Identify, through a contingency analysis, the alternatives available in cae of equipment malfunction. Describe the availability of back-up systems in case of component failure. List which systems must be failsafe and which can be allowed to fail if adequate redundancy is available.

Describe, in the case of partial retrieval, the effects to the adjacent areas of the repository. Give the impact (if any) to the overall integrity and physical continuity of the natural and engineered barriers. In addition, provide a description of the structural and geomechanical conditions of the emplacement rooms and boreholes from which the waste was retrieved.

6.2.2 Abnormal Retrieval Conditions

Describe, in as much detail as possible, the major sequence of events that it is expected would be undertaken for the retrieval of emplaced waste. As in Chapter 5, assume that the greatest change in the underground conditions has occurred, whether or not that will have actually taken place earlier or at the time of retrieval. Reference all post-emplacement developments and maintenance alterations which were described in Chapter 4.

The description of the retrieval methods under the plausible, yet abnormal, conditions that are likely to be in existence at the time of retrieval shall include three hypothetical situations. The actual situations selected by the Project for this discussion may vary; however, the following reflects the character of the discussion that is required.

- Situation 1 - Retrieval of waste has been required from a selected group of waste containers in a single emplacement room or drift. This situation is to be further broken down into three scenarios, as described below:

  Case 1: Assume that the worst combination of abnormal environmental and geotechnical events/conditions has occurred as described in Subsection 5.1.2 <u>and</u> that no waste containers have failed.

  Case 2: Assume only normal environmental and geotechnical events/conditions have occurred as described in Subsection 5.1.1 <u>but that</u> the worst combination of engineered structures and waste package failures as described in Subsection 5.1.2 has occurred to all the emplaced waste in the room.

  Case 3: Assume that the worst combination of all abnormal events/conditions has occurred as were described in Subsection 5.1.2 <u>and</u> that all of the waste containers in the emplacement room have failed.

- Situation 2 - Retrieval of waste has been required of all emplaced spent fuel and high level waste in the repository. Assume the entire capacity of the originally designed first repository has been emplaced prior to that time. This situation is to be further broken down into three scenarios as described below.

  Case 1: Assume that the worst combination of abnormal environmental and geotechnical events/conditions has occurred as described in Subsection 5.1.2 <u>and</u> that no waste containers have failed.

Case 2: Assume only normal environmental and geotechnical events/conditions have occurred as described in Subsection 5.1.1 but that the worst combination of engineered structures and waste package failures as described in Subsection 5.1.2 has occurred to 25% of all emplaced waste in the repository.

Case 3: Assume that the worst combination of all abnormal events/conditions has occurred as were described in Subsection 5.1.2 and that 25% of all the waste containers in the emplacement room shave failed.

Describe the specific subsurface operations associated with each retrieval situation discussed including: reconfiguration of the ventilation system, removal of bulkheads, remining of backfill (if applicable) excavation of additional shafts and passageways, monitoring, placement of retrieval equipment, retrieval, removal of waste to surface, and safe storage of waste on surface.

Describe the individual pieces of equipment that will be required for each retrieval situation discussed and provide schematic drawings of them as appropriate for understanding. Identify, through a contingency analysis, the alternatives available in case of equipment malfunction. Describe the availability of back-up systems in case of component failure. List which systems must be failsafe and which can be allowed to fail if adequate redundancy is available.

Describe, in the case of partial retrieval, the effects to the adjacent areas of the repository. Give the impact (if any) to the overall integrity and physical continuity of the natural and engineered barriers. In addition, provide a description of the structural and geomechanical conditions of the emplacement rooms and boreholes from which the waste was retrieved.

7.0 RETRIEVAL DEMONSTRATIONS

In this chapter, the Project shall provide its specific plans for physically demonstrating that retrieval is, in fact, possible under the conditions specified earlier in the strategy paper. This chapter will identify those aspects of the retrieval process which are anticipated to be challenged by the NRC as being unproven or possessing components or processes whose reliable performance is uncertain. In discussing the plans in this chapter, distinguish between: (1) the plans which have already been developed for site characterization and will be presented in Chapter 8 of the SCP; and (2) those additional plans or developments which have not been identified for presentation in the SCP.

7.1 Proof-of Principle

This section shall include a brief summary of all the plans that the Project deems necessary to demonstrate its retrieval method(s) (either together, or by individual components) before License Application (LA). These plans must describe the environments (both normal and abnormal) under which the demostrations will take place. Where the plans have not yet been formulated, sufficient information to show what the plans will include and when they will be available shall be provided.

The discussion contained in the section shall also describe where the demonstration(s) will take place. The Project's plans to conduct proof-of-principle tests in the exploratory shaft, construct special simulation chambers, use existing laboratories, or excavate at other underground locations are to be presented here. The rationale for the location of the tests or demonstration shall be completely developed.

The length of time believed necessary to satisfactorily conduct the tests/demonstration and to repeat the tests if they are declared unsatisfactory by the NRC is to be discussed. Key milestones shall be closely related to the major program milestones (e.g., ACD phase, start of ESF Testing, LAD phase, etc.). The complete construction of an entire working model of retrieval concepts for each retrieval scenario considered to be plausibly abnormal is unnecessary. However, it is necessary to demonstrate (at a minimum) the mechanical operation of the more significant portions of the nonstandard retrieval equipment under adverse conditions. The planned demonstrations of these significant items shall be described fully.

7.1.1 Backfilling

If the Project plans to backfill the underground openings in the emplacement area prior to termination of the retrievability period, the plans to demonstrate, during this proof-of-principle period, the method for retrieving the waste from backfilled areas of the repository is to be described in this subsection. This description shall explain fully how this particular environment will be simulated for the demonstration.

7.1.2 Malfunctions

The proof-of-principle demonstrations must include anticipated equipment malfunctions as part of the demonstration. In this subsection, give the details of how plausible malfunctions to the retrieval equipment will be handled. Explanation of the backup schemes formulated to accommodate malfunctions are also to be provided.

7.2 Prototypical Equipment Development

Given the finite limitations of demonstrating all components of all retrieval scenarios during the proof-of-principle demonstration period, estimate in this section those portions of the retrieval system demonstrations which may, be necessity, continue after LA submittal.

Ideally, all uncertainties regarding retrieval will be completely resolved before licensing. If, however, the Project anticipates that complete resolution of any serious retrieval questions may not be possible during the proof-of-principle period, then discuss what these questions are and why their resolutions will require additional time beyond LA submittal.

8.0 FUTURE WORK REQUIRED TO SUPPORT RETRIEVABILITY

In this chapter all the work, applied research, testing, etc., that is to be done by the Project in order to support the future requirements of retrievability compliance shall be outlined. Specific details of the scope and nature of work needed is to be given for:

- Advanced Conceptual Design
- License Application Design
- Site Characterization Program
- Performance Confirmation Program
- Safety Analysis Report
- Final Procurement and Construction Design
- Other Programs Related to Retrieval.

8.1 Site Characterization

In this section, identify the tests and applied research which may have to be accomplished in the Exploratory Shaft Facility and which are not planned to be part of the proof-of-principle demonstration.

8.2 Design

In this section, the scope of responsibility that will be assigned to the Project Architect/Engineer (A/E) for design of the retrieval subsystem is to be defined. That work which needs to be done before the A/E can proceed into the ACD and LAD phases is to be described. Design studies, trade-off studies, etc., during each design phase, are to be identified. The impediments (if any) to proceeding with the work now are to be identified and the Project's plans to expedite their resolutions are to be presented. Evidence that the Project's A/E knows and understands the requirements contained in the PRR is to be given.

8.3 Equipment Testing

This section shall state what types and kinds of equipment need to be designed, fabricated, tested, or modified prior to the actual demonstrations for proof-of-principle and prototypical development. Those mechanical systems and components on the retrieval critical path which must be understood now, before design can proceed, are to be discussed.

8.4 Other Work Required

This section shall identify and quantify, to the extent possible, any future work that is needed to support retrievability and which has not been discussed adequately in the previous sections of the strategy paper. The individual items of this work are to be ranked in order of importance. These items are to be also included in the cost and schedule portion of the strategy paper.

This section shall also present the details of the Project's on-going retrievability compliance program which will continue over the next several years--before, during and after licensing.

9.0 COST AND SCHEDULE

This chapter shall provide an overview of the cost impacts and the scheduling of the activities which the Project prescribes for its strategy. If desired, the Project may prepare the material within this chapter as a separate document from its strategy paper provided it is available concurrently with the strategy paper.

9.1 Cost

In this section, provide a cost analysis that specifies the current budgeted amounts for accomplishing the activities described in the strategy paper. This analysis shall identify the connection between increments of the Project budget breakdown and the particular activities of the strategy included in each increment. It shall also identify those activities of the strategy for which there is no current budget coverage and present an estimate of the cost for each of them.

9.2 Schedule

In this section, provide a schedule that shows the order in which the strategy activities must be done to achieve verification of compliance with the PRR. The "critical path" of the essential activities that has been developed to guide the completion of the strategy in minimum time is to also be presented. Appropriate diagrams should be included.

The estimated effect of the total effort described in the strategy paper on the "master" schedule currently specifying submittal of the License Application in 1991 shall be discussed in sufficient detail to permit a complete understanding of all the impacts and their ramifications.

APPENDIX B

DEPARTMENT OF ENERGY POSITION ON RETRIEVABILITY AND RETRIEVAL FOR A GEOLOGIC REPOSITORY

TABLE OF CONTENTS

1.0 INTRODUCTION

Presented in this document is the statement of the U.S. Department of Energy position on the retrievability and retrieval of spent fuel and other high-level waste from a geologic repository.[1] This statement of position is in conformity with all Federal laws, regulations, and standards regarding the retrieval of waste [the Nuclear Waste Policy Act of 1982 (NWPA), 10 CFR Part 60, 10 CFR Part 960, and 40 CFR Part 191].

The purpose of this statement of position is to specify the period of retrievability; to state the reasons for retrieval; and to describe and document design, construction, operation, and maintenance requirements for the retrieval of waste from an operating repository. The objective is to establish a standardized understanding of retrievability and retrieval for use in the siting, design, operation and regulation of repositories.

In this statement of position, "retrievability" means the capability that is provided by the repository system--by means of design approaches, construction methods, and operational procedures--to allow retrieval to be performed. The terms "retrieval" and the act of "retrieving" mean the process of intentionally removing waste from the underground location in which it had been emplaced for disposal in order to protect the health and safety of the public (and the environment) <u>or</u> to recover the resources contained in spent fuel.

All other efforts to remove, extract, or relocate any portion of the emplaced waste during the preclosure lifetime of the repository will be done for reasons unrelated to the reasons mandating retrieval. The removal of emplaced waste for performance confirmation, inspection, analysis, or any other purpose not directly related to public health and safety (and the environment) will not be considered retrieval and will

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[1]For brevity and convenience, the term "waste" will henceforth be used in this statement of position to mean both spent fuel and other high-level waste.

not be governed by the requirements set forth here. Those activities related to waste handling and not associated with retrieval will be subject to the appropriate Nuclear Regulatory Commission (NRC) regulations.

2.0 GENERAL REQUIREMENTS

The design of the waste-retrieval capability of the repository shall conform to the NWPA and to 10 CFR Part 60, and be based on this statement of position. Retrieval, as defined here, shall be for the purposes of removing any or all of the emplaced waste.[2] The design, construction, operation, and maintenance of the repository shall be in accordance with these retrieval criteria.

2.1 Retrievability

The repository shall be designed, constructed, and operated so that, during any time within the limits set forth in this statement of position, it will be possible to retrieve any or all of the waste emplaced for disposal. The capability to retrieve the waste, if necessary, shall extend to all waste regardless of container size or shape, temperature, radiation level, and age. The capability to retrieve shall also extend to all areas of the repository in which the waste is emplaced.

No act, whether by design or circumstance, shall preclude the possibility of, or the opportunity for, retrieval for the reasons given in this statement of position. This applies to the emplacement (pre-closure) lifetime of the repository and continues through the end of the retrievability period stipulated by the U.S. Nuclear Regulatory Commission in 10 CFR 60.111(b)(1) and until the last of the waste to be retrieved is removed.

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[2]"Any or all waste" shall refer to the quantity of emplaced waste ranging from one container to the entire inventory. See Section 2.5 (Affected Waste Types) for a description of the waste to be considered for retrieval.

The act of retrieving any or all of the emplaced waste shall be considered complete and in compliance with this statement of position at the time waste is brought back to the surface of the repository.[3] The use of temporary storage during retrieval (Section 3.4) shall be addressd as part of the retrieval method discussed in the license application.

2.2 Reasons for Retrieval

There are two reasons for which the Nuclear Regulatory Commission or the Department of Energy can order the permanent retrieval of any or all of the emplaced waste. These reasons will be related to either (1) public health and safety and the environment (retrieval ordered by the Nuclear Regulatory Commission) or (2) the recovery of resources (retrieval ordered by the Department). Removal for all other reasons, whether temporary or permanent, will not be subject to the conditions, criteria, and requirements defined in this statement of position, but will be subject to appropriate NRC regulations.

The retrieval of nuclear waste would involve a reversal of the emplacement decision for that affected waste. If retrieval were to be initiated it would be an extraordinary event incurring great cost and effort. As a result, no action requiring the retrieval of substantial portions of the emplaced waste will be taken without full consideration of the consequences.

2.2.1 Public Health and Safety and the Environment

The single reason the Nuclear Regulatory Commission may require the retrieval of some, part, or all of the emplaced waste is evidence that the health and safety of the public would otherwise be adversely affected

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[3]The Department recognizes that while this meets the NRC defnition of retrieval ("... the act of intentionally removing radioactive waste from the underground location at which the waste had been previously emplaced for disposal" 10 CFR 60.2), it does not address the ultimate disposition of the retrieved waste. The conditions or process for the final destination of retrieved material will be discussed at the time of license application.

by the emplaced waste (10 CFR Part 60, Statements of Consideration, Retrievability). If the Commission has cause to believe that the geologic repository isolation system as planned and implemented will not meet the performance standards and objectives governing the disposal of the waste, they have the authority to require retrieval.

This statement of position considers the requirement of retrieval ". . . for any reason pertaining to . . . the environment . . ." (the Nuclear Waste Policy Act of 1982, Section 122) to be one and the same with public health and safety. The effects on the environment would be the same as the effects on public health and safety.

2.2.2 Resource Recovery and Economics

The permanent emplacement of waste into a repository will prevent access to potentially useful isotopes and metals of potential strategic or energy value. If, at some time before permanent closure, the Department of Energy elects to recover any or all of the waste inventory, this recovery will be accomplished under the Department's authority and policy of resource recovery.[4] Such action will be taken in full compliance with the NWPA and 10 CFR Part 60.

All other operations in which the emplaced waste is moved, relocated, or tranported to another area of the repository (surface or underground) for reasons other than those stated in this section shall be the responsibility of the respository operations management (DOE) in accordance with the provisions of the license and the NRC. This handling of the waste shall not be considered retrieval and shall not be governed by any regulations, standards, or requirements in this statement of position.[5]

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[4]The Department of Energy future policy on the retrieval of spent fuel for resource recovery will address all the conditions and criteria under which retrieval for resource recovery would be carried out.

2.3 Retrievability Duration

The period of time during which the repository operations management (DOE) must be prepared to begin the retrieval of any or all of the emplaced waste shall, at this time, be 50 years. This retrievability period begins when waste emplacement commences.

Emplacement operations are currently expected to continue for approximately 28 years. This estimate is dependent upon the rate at which waste is received and the amount of spent fuel in storage at the reactor sites. In the event that emplacement does terminate before the expiration of the 50-year retrievability period, the repository shall continue, during this emplacement dormancy, to maintain the capability to initiate retrieval.

The 50-year duration of the retrievability period is subject to change (10 CFR 60.111(b)(1).[6] Such a request for a different time period can be established by the Nuclear Regulatory Commission on a case-by-case basis as part of the construction-authorization process. "Insofar as health and safety considerations are concerned, the Commission intends to grant such approval so long as its technical criteria are satisfied . . ." (10 CFR Par 60, Statement of Consideration, Retrievability, footnote 4).

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[5]Reasons for the rehandling or removal of emplaced waste for purposes other than retrieval would include all research and inspection related to the performance-confirmation program. They also might include the redistribution of inventory for ventilation purposes or similar operational considerations not related to public health and safety.

[6]The Department may seek to extend the period of retrievability to some length greater than 50 years for the economic recovery of resources. This will be determined at an appropriate time prior to license application.

The repository design shall proceed under the assumption that retrieval can start anytime over a 50-year period beginning at the time of emplacement. Each individual component of emplaced waste[7] must, therefore, be retrievable not only during this period of retrievability (50 years at this time), but also for as long thereafter as is necessary to actually complete retrieval. Ultimately the overall preclosure operating lifetime of the repository could be 90 years or longer. This length of time would include the period of retrievability as well as the period of time required to actually retrieve (assuming retrieval is initiated near the end of the retrievability period). (See diagram below.)

<u>RETRIEVABILITY DURATION</u>

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* Subject to change (increase or decrease) by DOE request and NRC approval.

** See Section 2.4 - Time Necessary to Retrieve

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[7]The term "component of emplaced waste" is used to describe any vessel or enclosure in which waste can be safely and conveniently retrieved. Retrieval of the same or entire containment structure in which waste was originally emplaced is not required. Use of the terms "container" or "package" in this statement of position is not meant to imply that the entire ensemble must be retrieved.

2.4 Time Necessary to Retrieve

If the full inventory of emplaced waste is to be retrieved, the retrieval shall be accomplished as quickly as is safely practicable. This does not mean that all equipment, systems, and procedures must be constructed and operated in a constant state of readiness for the retrieval of the complete inventory. Rather all methods, plans, and contingencies for retrieval shall have been designed, tested (see Section 3.5, Demonstration of Retrieval Equipment and Methods), and made ready for implementation as required. If either full or partial retrieval is necessary, all changes of equipment, modifications of ventilation (Section 3.3), reversal of waste receipt and handling operations, construction of temporary storage if needed (Section 3.4), and other major operational and construction revisions shall be accomplished before retrieval begins.

The Department of Energy anticipates that the retrieval of the entire inventory of waste will require a lengthy period of preparation. It is further expected and anticipated that the retrieval of individual containers of waste will require, per unit, more time than did their emplacement. Therefore, the total amount of time to retrieve the complete inventory of waste will depend on the number of waste packages, the degree of difficulty, and the amount of preretrieval construction necessary. To the extent it is feasible, retrieval should be accomplished within a reasonable schedule which approximates the time necessary to originally construct the repository and emplace the waste (10 CFR Part 60.111(b)(3)). However, no requirement in this statement of position shall be construed as an absolute time limit for retrieval. The health and safety of repository personnel and the public is to be considered preeminent over the time necessary to actually retrieve emplaced waste.

In the event the retrieval of a specific portion of the emplaced waste is required for the recovery of resources, no specific time limit shall apply as long as repository emplacement operations are scheduled to continue. If emplacement has been concluded and partial retrieval is required, reasonable efforts shall be employed to retrieve that portion of the waste in as short a time as is safely practicable.

2.5 Affected Waste Types

All forms of spent nuclear fuel, defense high-level waste, and civilian high-level waste (including the high-level waste from the West Valley Demonstration Project) are governed by the retrievability requirements and criteria of this statement of position. The size, shape, weight, and other physical characteristics of these wastes and their packaging shall not preclude their individual or collective retrieval, if required.

Other forms of waste potentially acceptable in the repository are specifically excluded from consideration in this statement of position at this time. Transuranic waste and other forms of radioactive waste not mentioned here are not governed by the requirements of this statement of position and will be addressed, if necessary, at a later time.

3.0 DESIGN REQUIREMENTS

This section presents requirements and criteria for waste retrieval for the purpose of guiding the design of the repository. These requirements and criteria are to be used in conjunction with all design criteria in 10 CFR Part 60 and other design criteria that have been established by the Department of Energy.

Persons responsible for the design and construction of a repository shall bear in mind at all times that the function of the repository is to provide containment and isolation of the waste. Yet retrievability is a specific performance objective the repository must be prepared to meet in the event it becomes necessary. This design requirement, even though a contingency to normal emplacement, is nevertheless as important a design requirement as are the performance objectives of protection against radiation exposure and releases. The requirement of retrievability shall not affect or unnecessarily complicate the design of the repository to the exclusion, compromise, or interference with the function of the repository. Design efforts shall be directed toward making retrievability and retrieval compatible with repository operations.

The method of retrieval planned for the repository shall anticipate and identify all credible malfunctions or accidents to the emplacement system, the engineered barriers, and the host rock that could affect retrievability. The method of retrieval shall be designed to operate, if required, under these abnormal conditions. These conditions or design bases shall potentially include such credible events as loss of containment through a mechanical breach, stuck waste packages (pinched borehole liner or packing material), disoriented emplacement boreholes, sudden water inflow, release of radionuclides or any other circumstances that could affect the safety and mechanical removal of the emplaced waste.

The waste packages shall be designed and fabricated to allow retrieval of the waste, as planned, from the emplacement configuration used in the repository. Both normal and credible abnormal events affecting waste retrieval shall be accommodated in the design. The retrieval method must maintain waste containment during retrieval as required in 10 CFR 60.135.

The physical act of retrieval shall be designed to minimize occupational health and safety hazards due to radiation exposure (10 CFR Part 20), high temperatures, and other underground safety risks.

3.1 Current Technology

The design of all methods of retrieval shall be based on and employ levels of technology that are determined to be reasonably available at the time of the license application. The determination of the status of technology shall be made under the authority of the Department of Energy by technically qualified personnel who are responsible for the repository. At no time shall the engineering design of retrieval methods, equipment, and procedures exceed the technology accepted by the Department and the engineering community as capable of development within the limits of currently proved technology.

3.2 Geotechnical Effects on Rock Behavior

The effects to the host rock from geothermal, geomechanical, geohydrologic and geochemical conditions which were not present at the time of emplacement could significantly influence the method and equipment employed to retrieve emplaced waste. The design of the retrieval method and retrieval equipment for the repository shall anticipate the deterioration and degradation of ambient emplacement conditions by the time retrieval may become necessary.

The overall impact of these effects will depend on the site-specific characteristics of the host rock and the subsurface geotechnical environment in which the waste is to be emplaced. These effects, which could increase the difficulty of retrieval, will likely increase in magnitude during the period retrievability must be maintained. The retrieval design must not only plan for his normal, time-dependent increase in underground retrieval hazards; the design must also incorporate contingency plans for abnormal geotechnical conditions which might credibly exist.

The Department of Energy recognizes that some aspects of the underground environment which, of themselves, are advantageous for the long-term isolation of nuclear waste are also disadvantageous for the easy retrieval of emplaced inventory. As a consequence the repository design must both draw upon the positive effects of rock behavior to meet the ultimate repository performance standards and overcome the negative effects of this same rock behavior on retrieval.

3.3 Ventilation

The ventilation of the underground facilities of the repository shall be designed and constructed for all construction and operation demands, including mining, emplacement, and performance-confirmation testing. Additional ventilation requirements for the retrieval of any or all of the emplaced waste shall be designed at the same time as the repository.

The facilities that must provide the additional ventilation air needed for retrieval need not be constructed at the time the repository is constructed. The construction of these additional facilities shall be at the discretion of the repository operations management (DOE). Such additional facilities may include an additional shaft or shafts; larger conveyances in the existing shafts; additional drifts, cross-cuts, or stoppings; additional chilling equipment, cooling towers, and fans; and other services on surface and underground.

Design and construction criteria for the additional retrieval ventilation shall be established before the submittal of the license application. This includes, but is not limited to, space for additional shafts as required. All retrieval-ventilation structures, systems, and components important to the health and safety of the repository workers and the public shall be planned, designed, and incorporated into the overall repository layout before the license application.

The additional time required for the remedial construction of facilities to meet ventilation requirements for retrieval operations shall be consistent with Section 2.4 (Time Necessary to Retrieve).

3.4 Temporary Storage

The use of temporary or lag storage for the waste being retrieved, either underground or on the surface of the geologic repository operations area, will be acceptable. Nothing in this statement of position shall be interpreted as a requirement for temporary storage during retrieval; rather it shall be up to the repository operations management (DOE) to determine whether temporary storage for retrieved waste is necessary. The design and layout of the repository operations area, surface and underground, shall be planned so as not to preclude the possibility of constructing facilities for temporary storage at a later time, if needed.

In the event any or all of the emplaced waste is retrieved, the time and the labor necessary to provide temporary storage shall be considered part of the retrieval effort (Section 2.4) and shall be discussed as part of the license application.

A certain amount of temporary storage will be constructed at the same time as the repository to accommodate normal emplacement operations. If retrieval is later required for a small and distinct portion of the waste inventory, the use of this existing temporary storage until a final disposition of the waste is arranged will be allowed.

If emplaced waste is temporarily removed or handled for purposes of performance confirmation, it shall not be considered retrieved, and the temporary storage of this material within portions of the geologic repository operations area shall not be treated as the temporary storage of retrieved waste.

3.5 Demonstration of Retrieval Equipment and Methods

Retrieval concepts, methods, and nonstandard equipment necessary for the retrieval of any or all of the emplaced waste shall be: (1) designed and engineered, before license application, so that the retrieval method will successfully operate and function under a range of adverse underground conditions; (2) fabricated for mock-up tests during a proof-of-principle demonstration period before the license application; and (3) further developed and tested, if needed, under selected reposiory conditions during the review of the license application and repository construction. The purpose of these three activities related to the design and demontration of the retrieval capability is to show that no irretrievable steps will be taken when actual nuclear waste is emplaced underground. Therefore it shall be necessary to substantiate the fact that the retrieval method and equipment can and will operate in the intended and requisite manner. The sequencing of the activities supporting the planning and design of the retrieval method and equipment are represented in the diagram below.

SEQUENCE OF RETRIEVAL
DESIGN AND DEMONSTRATIONS

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I       Proof-of-    I                   I                     I           I
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3.5.1 Design of Retrieval Method

The repository design submitted at the time of license application shall identify the specific means by which retrieval can be accomplished under a wide range of circumstances (i.e., site-specific reference retrieval conditions). The planned method of retrieval shall include an analysis of retrieval methods that can be called upon to function under both normal and abnormal geotechnical conditions at the time retrieval may become necessary.

Impediments to retrieval will possibly create difficult and hostile operating conditions underground for both equipment and personnel. For this reason the planned retrieval method shall anticipate the need for flexibility to operate under these adverse conditions. The design shall specify the sequence of retrieval events (e.g., rock cooling followed by re-mining, followed by waste container verification, etc.). It shall also specify the anticipated time to retrieve the waste, potential exposure hazards to personnel, excavation techniques, remedial alternatives to equipment breakdown, temporary storage, and other aspects of mechanically retrieving the waste.

The retrieval method shall be specifically tied to the planned emplacement method. The effect of the orientation of the waste containers on retrieval shall be defined. The contingencies to retrieving the waste contained within lodged or disoriented waste packages shall be addressed in the retrieval design.

3.5.2 Proof-of-Principle Demonstration

The planning and design of a retrieval method may require nonstandard mechanical equipment that is not currently available or in use under similar circumstances. The waste packages themselves may be in a condition (pinched, disoriented, etc.) that would make their retrieval more difficult than their emplacement. Finally the underground environment, under which both the retrieval equipment and the operating personnel must work, may have sufficiently deteriorated as to preclude normal access.

As a consequence of the uncertainties associated with the performance of equipment and personnel in the underground retrieval environment, it may be necessary to demonstrate the mechanical operation of the more significant portions of the nonstandard retrieval equipment. This proof-of-principle demonstration shall be for the purpose of establishing a level of confidence in either the equipment or its associated retrieval technology such that an overall assessment can be made on the feasibility of the planned retrieval method.

The proof-of-principle demonstration (or demonstrations in the case of unrelated functions tested at different locations) shall be completed and documented before license application is made to the NRC.

It shall be understood that the purpose of the proof-of-principle demonstration(s) is <u>not</u> to prove, beforehand, that a fully integrated retrieval system will be functional under the complete range of credible and hypothetical geotechnical conditions. Rather, the purpose of the proof-of-principle demonstration is to select from the planned retrieval technology designed for the repository and to test those physical aspects of retrieval which may have some degree of performance uncertainty. This opportunity to demonstrate a portion of the mechanical operation must provide evidence, with reasonable assurance, that the planned retrieval method will function under the influence of the pertinent geotechnical impacts.

The proof-of-principle demonstration(s) shall take place in an environment and at a location that is relevant to the intended purpose of the demonstration. These demonstration(s) may take place in the laboratory, on the surface or underground, or in any other location suitable for the demonstration of the particular equipment or procedure in question.

The proof-of-principle demonstration(s) shall take place in an environment which can simulate both normal and some credible abnormal conditions that might exist at the time of retrieval. This mock-up (e.g., similar equipment under similar conditions) shall be limited in scope to the extent that it will not be required to completely re-create the repository environment, but instead to demonstrate the capability of the retrieval equipment to operate under specific, and possibly adverse conditions. (An example of this might be to have rubber-tired, hydraulic equipment tested in a heat chamber and to have over-coring equipment tested in a confined space--but not both tested in the same environment simultaneously unless it is deemed necessary.)

If the repository is to be operated by backfilling emplacement rooms before decommissioning, the proof-of-principle demonstration shall show the feasibility of (re)mining hot backfill material or host rock in the event retrieval becomes necessary. This may include using mock-up retrieval equipment to remove either simulated backfill material or rock (simulating consolidated backfill material) which has been heated to temperatures representative of retrieval conditions.

3.5.3 Prototypical Equipment Development

Following the submission of a repository license application to the NRC, unanswered questions may still exist concerning the actual performance of retrieval equipment under conditions resulting from the geotechnical effects of the host rock. This statement of position (Section 3.2) requires that these deleterious effects to the retrieval environment be accounted for in the planning and design of the retrieval method; however, the resolution of some of these retrieval uncertainties may not be possible during the proof-of-principle demonstration.

A period of time after LA, before and during construction of the repository, will be available to construct and demonstrate the equipment and methods which more closely resemble those designed for use at a time when retrieval may be necessary. This period of prototypical equipment development could continue, if needed, until the time the license to receive and possess is granted by the NRC.

The purpose of this prototypical equipment development program shall be to establish confidence in the overall retrieval capability under geotechnical conditions which approximate those identified in and during the design of the retrieval method. This does <u>not</u> mean that the combined, worst-case effects of all geotechnical conditions need to be simulated in order to prove retrievability. However, if significant questions remain unanswered after the proof-of-principle demonstration, prototypical equipment shall be constructed to operate under geotechnical conditions which simulate the pertinent retrieval environment necessary to resolve major uncertainties.

The development, construction, and demonstration of prototypical equipment need not necessarily occur underground at the site of the proposed repository. It will be necessary, however, to choose a location(s) which simulate(s) geotechnical conditions, stresses, and opening geometries as may reasonably be expected to exist at the proposed repository location. It is not necessary to find a surrogate location(s) for prototypical development which identically matches the geotechnical conditions of the repository--as long as the simulated retrieval conditions reasonably approximate those affecting the question of retrieval.

The documentation, data, analyses, and results obtained from the development and demonstration of prototypical retrieval equipment shall be provided to the Commission in accordance with 10 CFR Part 60.

The waste configuration (package, container, canister, etc.) used in the retrieval demonstration shall be of a size and weight approximating that actually planned for the disposal of waste at the repository. Any potential change in the shape, orientation, or other physical condition of the waste package which may credibly have an impact on retrieval shall be simulated during the prototypical equipment demonstration.

The use of radioactive material is not required in either the proof-of-priciple demonstration or the prototypical development of retrieval equipment. Furthermore, proof-of-principle demonstration(s) need not be conducted with all radiation-safety measures in place. Prototypical equipment shall incorporate radiation-safety equipment, as necessary, to test the mechanical systems.

4.0 OPERATION REQUIREMENTS

The repository shall be operated, from the time waste emplacement begins until the end of the retrieval period, in such a manner that any of the emplaced waste can be retrieved within the time guidelines given in this statement of position. The operating equipment, needed for potential retrieval, which is in existence at the time emplacement ends shall be maintained in working condition until the end of the retrieval period.

4.1 Integrity of Natural and Engineered Barriers

As long as the primary mission of the repository remains unchanged (i.e., the containment and isolation of waste), the overall integrity or physical continuity of the natural and engineered barriers must not be disturbed by the retrieval of any or all of the emplaced waste.

In the event partial retrieval is required, the method selected for retrieval must not adversely effect or disturb the adjacent areas of the repository and their associated natural and engineered barriers. The partial retrieval of waste must not alter the geohydrologic and geochemical environment in any way that would cause the performance requirements of the remaining emplacement portions of the repository to be deleteriously changed.

Following partial retrieval, the structural and geomechanical condition of the emplacement rooms and boreholes from which waste was retrieved may deteriorate as long as the integrity of the natural and engineered barriers surrounding the repository in general is not adversely affected.

If all of the waste is retrieved (for example, through a loss of confidence in the site), no further protection to the integrity of the natural and engineered barriers is necessary. This would apply only under circumstances where no additional nuclear material is emplaced in the repository. In the event of full retrieval the repository will be decommissioned according to the requirements of 10 CFR Part 60.

After retrieval, the decision to reuse emplacement rooms shall be based on safety, cost, space efficiency, and other operational considerations at the discretion of the repository operations management (DOE). If, after retrieval, new waste is emplaced in the same area, all the original performance requirements for the natural and engineered barriers in that area of the repository shall remain unchanged.

4.2 Backfilling

The placement of backfill material before the permanent closure of the repository is an option available to the repository operations management (DOE). The placement of backfill material in emplacement rooms or other areas of the repository is specifically permitted provided that all requirements of this statement of position are fulfilled.

Nothing in this statement of position shall cause the repository architect/engineer or operations management (DOE) to assume that repository backfilling before permanent closure is either required or prohibited.

However, if early backfilling is part of the planned emplacement operations of the repository, it shall be made part of he design at the time of the license application.

Backfilling, if exercised early, must not preclude the possibility of retrieval. Assurance of retrievability from backfilled areas must have occurred during the proof-of-principle retrieval demonstration before the license application (Section 3.5, Demonstration of Retrieval Equipment and Methods).

The removal of backfill material for purposes of retrieval shall not affect the integrity of the repository in areas where emplacement will not be disturbed.

If waste is to be retrieved from a portion of the repository that has been previously backfilled, the retrieval of any or all of the waste shall be subject to the time guidelines given in Section 2.4.

4.3 Monitoring and Verification

Monitoring and instrumentation, for purposes affecting retrieval, shall be confined to areas of performance confirmation, test and evaluation facilities, and any other in-situ research portions of the underground repository. No ongoing monitoring of individual waste packages shall be required for performance confirmation as identified in 10 CFR Part 60 Subpart F.

Nothing in this statement of position shall preclude the possibility or opportunity to monitor and instrument various other areas of the repository for geomechanical or other reasons associated with the overall preclosure performance of the repository.

The initial verification of the ability to retrieve emplaced waste shall be accomplished in the proof-of-principle retrieval demonstration before the license application. Further retrieval verification shall occur during the prototypical development of equipment (Section 3.5, Demonstration of Retrieval Equipment and Methods).

The performance-confirmation program, which will begin before and continue during the emplacement lifetime of the repository, may necessitate the recovery of emplaced waste on a planned schedule for inspection and analysis (Section 5, Performance Confirmation). This scheduled recovery would serve as another verification of the retrieval capability even though this is not the intended purpose of the performance-confirmation program. In the event the repository operations management (DOE) elects to backfill early, the removal of backfill shall also be accomplished in the performance-confirmation area(s), and the removal of waste from those areas shall be a further demonstration of retrieval under normal conditions.

No other specific retrieval-verification program, other than those described in this statement of position, will be necessary during the emplacement lifetime of the repository.

4.4 Access Maintenance

The repository shall not be operated or maintained in a manner such that any areas of the repository become permanently inaccessible during the period of retrievability if those areas of the repository are necessary for the retrieval of any or all of the emplaced waste.

Immediate or ready access into emplacement areas for the purpose of retrieval is not required for operating personnel or equipment. The time required to retrieve any or all of the emplaced waste does not depend on the repository operator's ability to start retrieving waste as soon as the need for retrieval is identified.

Portions of the repository that have been backfilled early or have been temporarily closed (e.g., for purposes of conserving ventilation air) need not be available for quick entry or ready access if retrieval is required.

4.5 Equipment Reversibility

Ready or instantaneous reversal of the repository emplacement equipment is not necessary for the purposes of retrieval. The reversal of the repository emplacement operations will be a designed, but not constructed, contingency.

The mechanical equipment required for the retrieval of any or all of the emplaced waste shall be tested during the proof-of-principle demonstration before the license application (and during further prototypical development, as needed). During operations, no equipment or personnel needed solely for either the partial or the complete retrieval of emplaced waste need be located at the repository. Such equipment or personnel need be available only at the time retrieval becomes necessary, but it may be available earlier at the discretion of the repository operations managment (DOE).

This exemption of onsite retrieval equipment does not include the equipment necessary to remove portions of the emplaced waste for the performance confirmation or any other reason not associated with retrieval. The equipment necessary to handle waste for these reasons shall be part of the functioning repository and shall be in place at the time emplacement operations commence.

Routine operating conditions encompass all activities necessary to carry out the repository mission for the permanent isolation of the waste. The required retrieval of any or all of the emplaced waste shall be considered a nonroutine operating condition and shall not require ongoing emplacement operations to continue without interruption. "Non-routine" means a repository operation that might, in some way, conflict with or interrupt the primary operating function of the repository--the emplacement of waste.

Routine repository emplacement operations may continue during retrieval at the discretion of the repository operations management (DOE), as long as they do not conflict or interfere with those portions of the repository where retrieval is underway.

Other nonroutine operating conditions unrelated to retrieval will not be governed by this statement of position.

5.0 PERFORMANCE CONFIRMATION

The performance-confirmation program is an integral part of the operation of the repository and will continue until permanent closure. The primary purpose of this program is to develop a level of confidence in the capacity of the repository to achieve the performance objectives required for long-term isolation (10 CFR 60.140) so that the Commission can decide with reasonable assurance that permanent closure will not cause an unreasonable risk to public health and safety.

The removal, whether temporary or permanent, of emplaced waste from the performance area(s) when done for the purposes of inspection, analysis, and research will not be classified as retrieval. Performance-confirmation data will provide the level of confidence necessary to support the conclusion that the postclosure performance objectives will be met. These same data will also serve as the basis upon which the decision to close and decommission the repository will be made. Actual retrieval, as defined in this statement of position, shall be made only for reasons of public health and safety or resource recovery.

The results and data of the performance-confirmation program will drive or directly influence the decision to retrieve. The purpose of the performance-confirmation program is not to demonstrate the capability to retrieve emplaced material. Neither is the performance-confirmation program a continuation of prelicensing retrieval demonstration(s). These have little direct connection to performance confirmation except as noted below.

The major responsibility for demonstrating retrievability rests in the proof-of-principle and prototypical equipment demonstrations (Section 3.5, Demonstration of Retrieval Equipment and Methods) conducted before the start of emplacement operations. The removal of waste from the performance-confirmation area(s) for purposes of inspection, analysis, and other reserach related to the natural and engineered barriers will, as a side benefit, help to demonstrate a continued ability to retrieve. This "simulated retrieval" from the performance-confirmation area(s) will continue through the retrievability period of the repository and will help to demonstrate that retrieval is possibile until the termination of the retrievability period.[8]

No other planned demonstrations or simulated retrieval experiments other than those required in this statement of position shall be required during the emplacement lifetime of the repository. The period of retrievability shall continue in full force and effect until the Nuclear Regulatory Commission, in accordance with 10 CFR Part 60, has reviewed and approved the performance-confirmation program.

[8] If backfilling is planned before permanent closure, portions of the performance-confirmation area(s) will have been backfilled. The selective removal of waste from these backfilled areas will also demonstrate the ability to retrieve, if necessary, from the backfilled areas of the repository.

APPENDIX C

RETRIEVABILITY REQUIREMENTS IN THE NUCLEAR WASTE POLICY ACT AND 10 CFR 60

APPENDIX C

RETRIEVABILITY REQUIREMENTS IN THE NUCLEAR WASTE POLICY ACT AND 10 CFR 60

The principal reference to retrieval in the Nuclear Waste Policy Act is contained in Section 122 (NWPA, 1983):

> Notwithstanding any other provision of this subtitle, 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, for any reason pertaining to the public health and safety, or the environment, or for the purpose of permitting the recovery of the economically valuable contents of such spent fuel. The Secretary shall specify the appropriate period of retrievability with respect to any repository at the time of design of such repository, and such aspect of such repository shall be subject to approval or disapproval by the Commission as part of the construction authorization process under subsections (b) through (d) of section 114.

The principal reference to retrievability by the Nuclear Regulatory Commission is in 10 CFR 60.111(b) (NRC, 1986).

> (1) The geologic repository operations area shall be designed to preserve the option of waste retrieval throughout the period during which wastes are being emplaced and, thereafter, until the completion of a performance confirmation program and Commission review of the information obtained from such a program. To satisfy this objective, the geologic repository operations area shall be designed so that any or all of the emplaced waste could be retrieved on a reasonable schedule starting at any time up to 50 years after waste emplacement operations are initiated, unless a different time period is approved or specified by the Commission. This different time period may be established on a case-by-case basis consistent with the emplacement schedule and planned performance confirmation program.
>
> (2) This requirement shall not preclude decisions by the Commission to allow backfilling part or all of, or permanent closure of, the geologic repository operations area prior to the end of the period of design for retrievability.
>
> (3) For purposes of this paragraph, a reasonable schedule for retrieval is one that would permit retrieval in about the same time as that devoted to construction of the geologic repository operations area and the emplacement of wastes.

In addition to the requirement for retrieval contained in Subsection 111(b), 10 CFR 60 contains the following specific retrieval-related guidance for licensing.

- The Safety Analysis Report will include the principal design criteria and a description of plans for retrieval [60.21(c)(2) and (12)].

- For construction authorization, the license application must include design criteria for retrieval and must indicate that the repository design complies with the retrievability requirement [60.31(a)(1)(iii) and (2)].

- To obtain a license to receive and possess, the Department of Energy must show that the repository has been constructed and will be operated in compliance with the application as amended, including requirements for retrievability [60.41(a) and (b)].

- Any action that would significantly affect the ability to retrieve would require an amendment to the license [60.46(a)(1)].

- The retrieval-related design criteria contained in 10 CFR 60 address the consideration of the retrievability requirement in the design of the surface facilities [60.132(a)], the underground facility [60.133(c)], the underground openings [60.133(e)], and the waste package [60.135(b)(3)]. Because retrieval involves handling of nuclear material, the radiologic protection criteria contained in Section 60.131 also apply.

REFERENCES FOR APPENDIX C

NRC (U.S. Nuclear Regulatory Commission), "Disposal of High-Level Radioactive Wastes in Geologic Repositories," Code of Federal Regulations, Energy, Title 10, Part 60, Washington, D.C., 1986. (NNA.870325.0172)

NWPA (Nuclear Waste Policy Act of 1982), Public Law 97-425, 96 Stat. 2201, 42 USC 10101, Washington, D.C., January 1983. (NNA.890626.0312)

APPENDIX D

VENTILATION ANALYSES

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TABLES

FIGURES

VENTILATION ANALYSES

1.0 Introduction

These analyses have been performed to estimate the climatic conditions in the repository during the caretaker and retrieval periods. The results have been used to estimate ventilation fan requirements and to verify that acceptable environmental conditions in the drifts can be achieved for purposes of inspection, maintenance, or retrieval. Both the vertical and horizontal emplacement configurations have been considered.

2.0 Approach and Method of Analysis

For the two repository periods modeled (caretaker and retrieval), the airflow distributions in the repository, the temperatures in airways, and the air cooling times have been calculated.

2.1 Airflow Distribution

The method used to calculate the airflow distribution and main fan duties consists of developing a schematic for each emplacement configuration, evaluating mathematically the resistance to airflow for each branch of the schematic (Attachment 1), and putting this information into the ventilation program VNETPC (Version 2.0). A description of VNETPC (Version 2.0) is included in Attachment 2. The main fan duties are varied to give the desired airflow distribution based on the airflow requirements shown in Section 3.1.

Airflow distributions have been computed for the following scenarios:

- vertical emplacement, caretaker phase, with cooling of one emplacement drift in Panel 16;
- horizontal emplacement, caretaker phase, with cooling of one emplacement drift in Panel 14;

- vertical emplacement, with retrieval operations occurring in Panels 2 and 16; and

- horizontal emplacement, with retrieval operations occurring in Panels 2 and 16.

2.2 Temperature Distribution in the Airways

The method of determining the thermodynamic and psychrometric conditions of the air as it flows in the airways uses a branch-by-branch analysis technique. Table D-1 lists the data needed for the analysis of each branch. The environmental conditions for each branch are evaluated using the computer program CLIMSIM (Version 2.0), a description of which is included in Attachment 2.

The first branch connects to the surface; the mean summer temperature and barometric pressure are used as input. Mean summer conditions are used because of the thermal fly-wheel effects of air coursing through intake shafts (Stroh, 1979) and because summer conditions will produce the highest temperature loads on the ventilation system. Airway geometries, airflow direction, and airflow quantities are incorporated from the airflow distribution study (Section 2.1). Rock thermal parameters [conductivity, diffusivity, virgin rock temperature (VRT), and geothermal gradient] are taken from the Site Characterization Plan Conceptual Design Report (SCP-CDR) (SNL, 1987), and the depth of each branch, wetness factor, age of airway, and equipment heat loads are estimated from the SCP-CDR design.

The temperature, pressure, and VRT of the first branch are used as input to the second branch. The process is repeated for all the branches for which thermodynamic and psychrometric conditions are desired. When two or more airflow streams converge, the inlet temperature is determined by an airflow/temperature balance. This balance is approximated using the following equation (for both wet and dry bulb temperatures):

TABLE D-1

DATA REQUIREMENTS FOR CLIMSIM (Version 2.0)

Description of Airway
Length (m)
Depth In (m)
Depth Out (m)
Cross-sectional Area (m^2)
Perimeter (m)
Friction Coefficient (kg/m^3)
Wetness Factor (dimensionless)
Ventilation at Intake
Quantity (m^3/s)
Pressure (kPa)
Dry Bulb Temperature (°C)
Wet Bulb Temperature (°C)
Rock Thermal Parameters
VRT at Inlet (°C)
Geothermal Step (m/°C)
Conductivity (w/m/°C)
Diffusivity (m^2/s)
Heat Sources
Machine Heat Sources (can be negative for cooling) (kW)

$$t_{mix} = \frac{Q_1 t_1 + Q_2 t_2 + \dots + Q_n t_n}{Q_1 + Q_2 + \dots + Q_n} \ (°C) \ ,$$

where

t_{mix} = airflow temperature exiting junction (°C),
Q_1 = airflow entering junction in branch 1 (m^3/s),
t_1 = temperature of air entering from branch 1 (°C),
Q_2 = airflow entering junction in branch 2 (m^3/s),
t_2 = temperature of air entering from branch 2 (°C),

Q_n = airflow entering junction in branch n (m^3/s), and

t_n = temperature of air entering from branch n (°C).

The CLIMSIM program is used iteratively with the VNETPC program because a change in airflow in the CLIMSIM analyses is often desired to yield the desired environmental conditions. This procedure is shown in Figure D-1. The CLIMSIM analyses give complete psychrometric and thermodynamic conditions of the air and calculate heat stress indices; example output is shown on Table D-2.

The heat load generated by the waste after emplacement is accounted for by modifying the VRT. For this analysis, the rock temperatures calculated in Appendix E have been used to approximate the VRT. As described in Section 3.2, this is a very conservative approach. The interaction of the computer codes is shown in Figure D-2. For this study, the following cases have been evaluated:

- temperature distribution in a sealed panel (controlled leakage), vertical emplacement configuration (Panel 16 south); and

- temperature distribution in a sealed panel (controlled leakage), horizontal emplacement configuration (Panel 3).

2.3 Drift Cooling Requirements

As a result of waste-generated heat, the environmental conditions in some of the airways will exceed the criteria described in Section 3.1. In these cases, cooling will be necessary before reentry into the drift. Two cases have been evaluated: cooling with ambient air and cooling with chilled air. For both cases the time needed to achieve an acceptable environment within the drifts has been calculated using CLIMSIM. Specifically, the following analyses have been made:

- CLIMSIM analyses that evaluate the time needed to cool a vertical emplacement drift farthest from the mains with both ambient and chilled air,

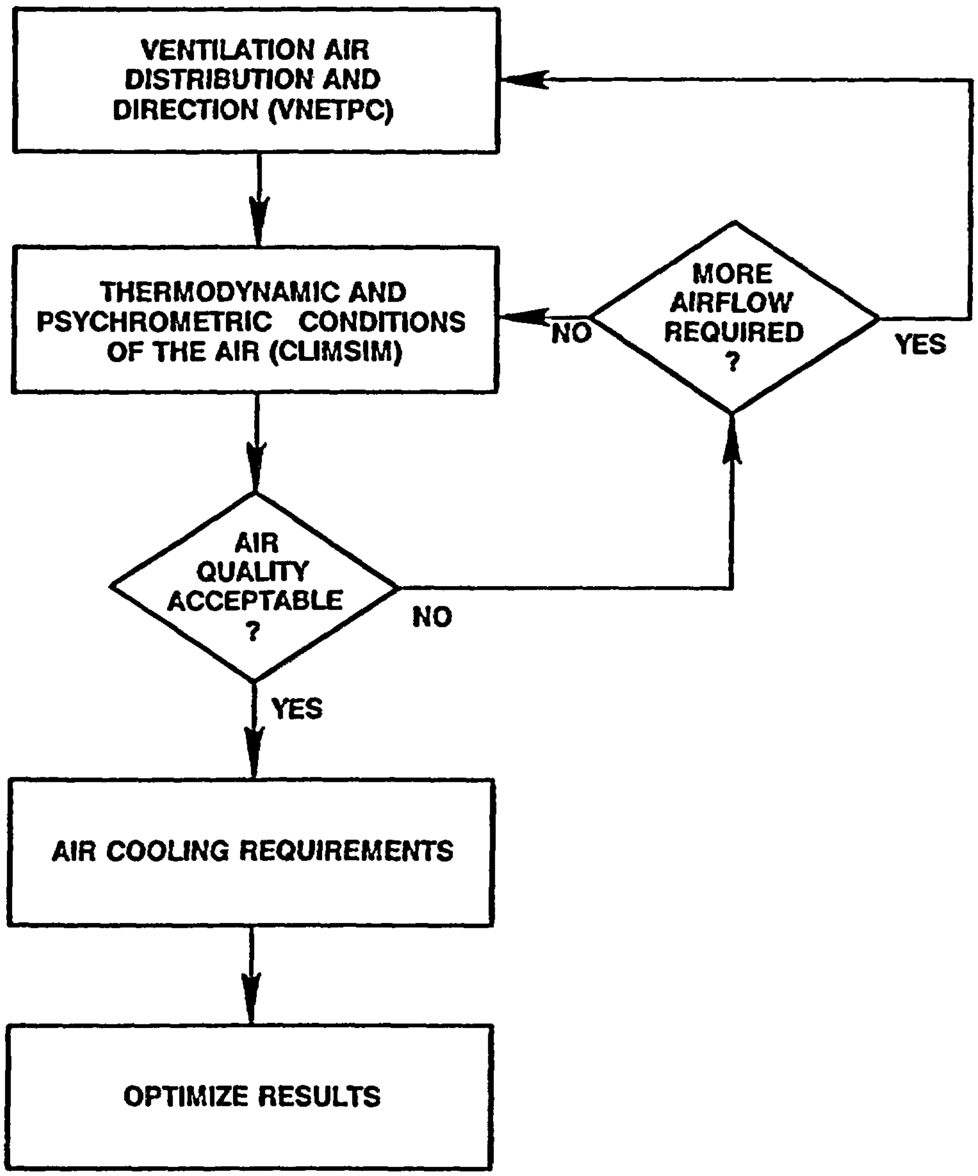


Figure D-1. Interaction between VNETPC and CLIMSIM

TABLE D-2

EXAMPLE OUTPUT FROM CLIMSIM (Version 2.0)

Predicted Environment: Cooling in Vertical Emplacement Drift

Distance Along the Drift (m)	Dry Blb (°C)	Wet Blb (°C)	Moisture Content (g/kg)	Rel Hum (%)	Air Pressure (kPa)	Density (kg/m^3)	Sigma Heat (kJ/kg)	Drift Wall Temp (°C)	ACP (W/m^2)	Wet Blb Globe Temp (°C)	Effective Temp (°C)
0	10.00	10.00	8.50	99.99	91.000	1.114	31.11	10.0	1477	10.00	-3.41
20	10.28	10.11	8.50	98.13	91.000	1.114	31.40	11.8	1464	10.62	-2.91
40	10.56	10.23	8.50	96.32	90.999	1.112	31.68	12.1	1459	10.78	-2.41
60	10.84	10.34	8.50	94.56	90.998	1.111	31.96	12.3	1454	10.94	-1.98
80	11.11	10.46	8.50	92.85	90.997	1.110	32.23	12.6	1449	11.10	-1.46
99	11.38	10.57	8.50	91.19	90.997	1.109	32.51	12.9	1445	11.26	-1.00

Sensible heat flow from rock surface to air = 62.5 kW
Latent heat flow from rock surface to air = 0.1 kW
Total heat flow from rock surface to air = 62.6 kW
Final VRT = 50.0°C
Airflow rate = 40.100 m^3/s

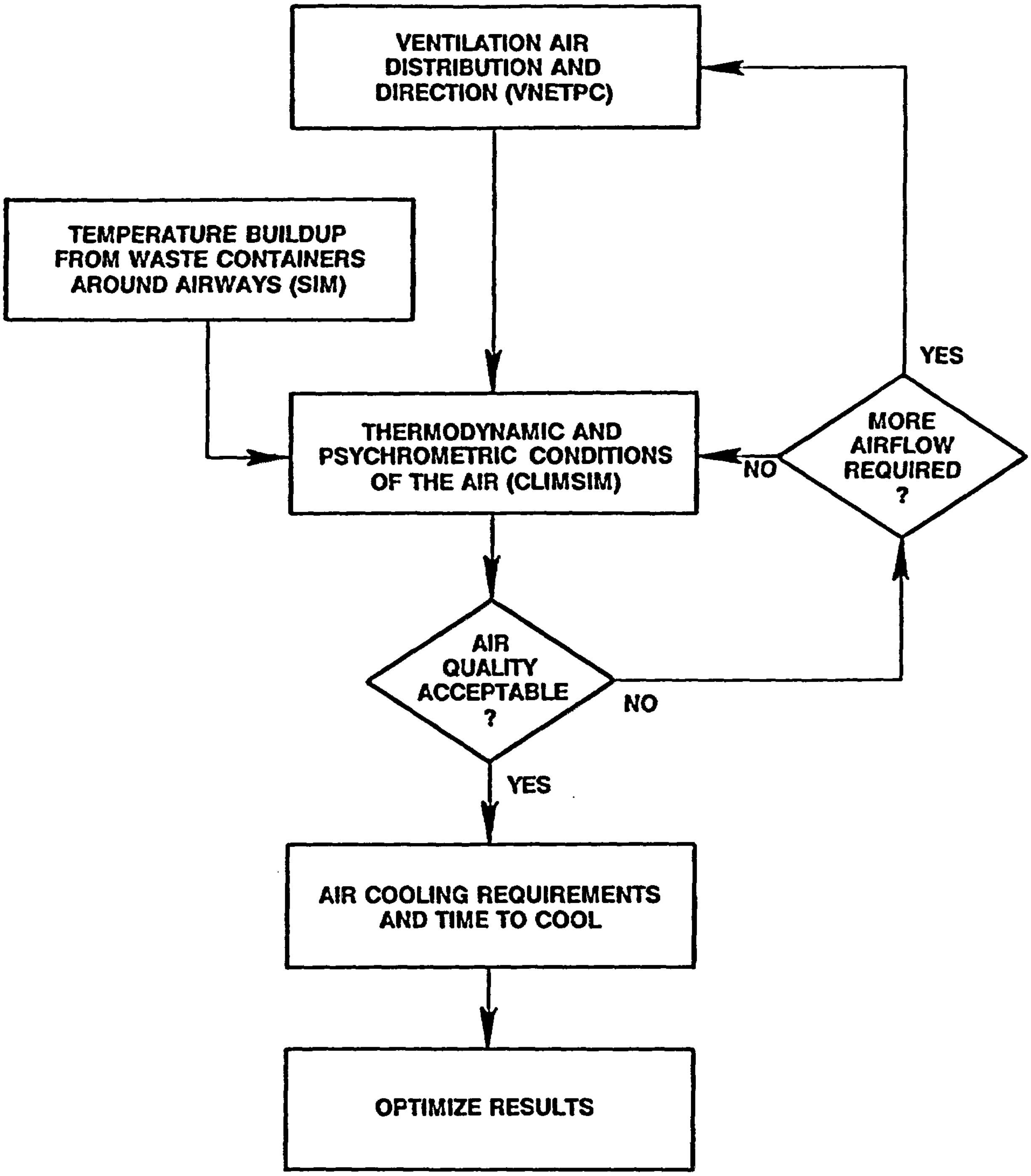


Figure D-2. Analysis Procedure Using VNETPC, CLIMSIM, and SIM Computer Programs

- CLIMSIM analyses that evaluate the time needed to cool a horizontal emplacement drift farthest from the mains with both ambient and chilled air,

- determination of the number of emplacement drifts needed to be cooled for full retrieval operations, and

- determination of the conditions in a vertical emplacement drift for various cooling times.

For the cases of cooling with ambient air, conditions at the inlet of the panel access drift have been taken directly from the results obtained from calculations described in Section 2.2. For the cases of cooling with chilled air, it has been assumed that a chiller was installed at the inlet to the panel access drift. The air from the chiller is assumed to be at 10°C (dry bulb and wet bulb). By analyzing with time increments, the time at which acceptable environmental conditions are achieved (cooling time) has been calculated for (1) inspection and (2) maintenance or retrieval operations.

3.0 Study Bases

The design criteria, assumptions, and input data presented in the following three sections form the basis for this study.

3.1 Design Criteria

The design criteria are organized in two categories: ventilation system and environmental conditions.

For the design of the ventilation system the following criteria apply (SNL, 1987).

- Airflow rates greater than 125 cfm per brake horsepower must be maintained over diesel equipment.

- In all working areas, a minimum airflow rate of 60 ft/min must be maintained.

- Each working area should also maintain 200 cfm per person.

- Air velocities should not exceed the following limits.

Area	Maximum Velocity (ft/min)
Men-and-Materials Shaft	2,300
Waste Emplacement Area Exhaust Shaft	4,000
Exploratory Shafts	4,000
Waste Ramp	1,500
Tuff Ramp	1,500
Panel Access Drifts	1,500
Mid-panel Access Drifts	1,500
Emplacement Drifts	1,500
Perimeter Drift	2,000
Waste, Tuff, and Service Mains	1,500

- All air from the waste emplacement area of the repository must be exhausted through a structure capable of filtering the airflow in the event of a radionuclide release underground. If no radionuclide release is detected, the air by-passes the filters and exhausts directly to the atmosphere.

- During the caretaker phase, leakage in the repository must be from the mains to the perimeter drift, and from the panel access drifts to the mid-panel access drifts in the vertical configuration and from the intake panel access drifts to the return panel access drifts in the horizontal configuration.

For acceptable environmental conditions the following criteria apply.

- For maintenance or retrieval operations, the air cooling power (ACP) must be >500 W/m^2 and the dry bulb temperature (DB) must be <40°C.

- For inspection operations, the ACP must be >300 W/m^2 and the DB must be <45°C.

3.2 Assumptions

The following assumptions have been made in the evaluation of the ventilation system.

- Friction factors are the following.

Airway	Friction Factor (lbf min^2/ft^4 x 10^{-10})
Waste Ramp	30
Tuff Ramp, Waste and Tuff Mains	60
Perimeter Drift	60
All Other Drifts	70
Men-and-Materials Shaft	95
Waste Emplacement Area Exhaust Shaft	40
Exploratory Shafts	16

- Compressibility effects are not taken into account. Therefore, standard air density is assumed (ρ = 0.075 lbf/ft^3).

- Ventilation controls are assumed to have the following resistances.

Ventilation Control	(P.U.)
Single Door	25
Double Door (airlock)	200
Single Bulkhead	200
Double Bulkhead	400
Brattice Line	5
Temporary Seal	25

- The following airflows to dedicated areas of the repository are assumed.

Area	Airflow (cfm x 10^3)
Main Shop (if in use)	85*
Decontamination Facility	25
Waste Emplacement Area Shop	30
Training Area	45
Dedicated Performance Confirmation Area	25

* 60,000 cfm in horizontal configuration.

- An electric transporter is assumed. (This is an update to the conceptual design.)

- A single ventilation system is assumed (no ventilation system for development exists).

The assumptions used in evaluating the temperatures in airways are the following.

- Container heat loads do not affect the shafts, ramps, or main drifts in the repository.

- The geothermal gradient is estimated using a surface VRT of 10°C, linearly increasing to a horizon temperature of 25°C.

- The in situ VRT on the entire repository horizon is assumed to be 25°C.

- For the areas where container heat loads are significant (emplacement and panel access drifts), the VRT is approximated by the surrounding rock temperatures (SRT) calculated using the conduction code SIM in Appendix E. This is a conservative assumption because SIM does not account for the effects of the ventilated airway.

- Thermal properties of the rock at the repository horizon are used in the analysis of conditions in the shafts and ramps.

- The surrounding rock will not release significant amounts of water into any airways during the repository lifetime depicted with these models. The wetness factor is taken as 0.001.

- Time after emplacement is 50 yr.

- CLIMSIM assumes that heat flow is radial toward the airway. However, an asymmetric temperature profile caused by the container heat loads will result in nonradial heat flow to the drifts. For this analysis it is assumed that the heat does flow radially toward all airways and that adjacent airways do not affect this analysis. This assumption is acceptable for this analysis because the time it takes to cool the repository is small compared to the time it takes for the repository to heat up.

- Rock thermal properties are linear and isotropic.

- Water migration to any airway will be minimal regardless of the rock temperature.

- For full repository retrieval it is assumed that two panels are being cooled while retrieval operations are being conducted in two other panels.

3.3 Input Data

3.3.1 Airflow Distribution

The input data required by VNETPC is presented in Tables D-3 and D-4 for the vertical and horizontal emplacement configurations. A complete set of example input is included in Attachment 3.

3.3.2 Temperature in the Airways

The input to CLIMSIM for computation of the temperatures in the airways includes the airflow data presented in Tables D-3 and D-4 and the inlet conditions and rock properties shown in Table D-5. For the cases where the container heat load is significant, the SRT input has been taken from Appendix E. The additional input required for the evaluation of sealed drifts is presented in Table D-6. Table D-7 shows a sample CLIMSIM input/output sheet.

3.3.3 Cooling Requirements

The input for evaluating the cooling requirements is basically the same as the input for calculating the temperatures in the airways. The only difference is for the case where a chiller is used. For that case, the panel inlet air temperature is 10°C wet bulb and 10°C dry bulb. A sample CLIMSIM input/output for the cooling analysis is shown in Table D-8.

4.0 Results

4.1 Airflow Analysis

Airflows for the vertical and horizontal emplacement configurations are shown in Figures D-3 and D-4 for the caretaker period and Figures D-5 and D-6 for retrieval operations. Requirements for the main fans are shown in Table D-9.

TABLE D-3

INPUT DATA FOR VNETPC--VERTICAL EMPLACEMENT

Airway	Dimensions[a] (ft)	Friction Factor (lbf min^2/ft^4 x 10^{-10})	Area (ft^2)	Perimeter (ft)	Resistance/Ft[b] (P.U./ft x 10^{-6})	HMD[c] (ft)	Comments
Waste Ramp	21-ft dia.	30	281	62.35	1.62	18.03	18 ft Invert
Waste Main	24-ft dia.	60	425	74.20	1.12	22.91	15 ft Invert
Tuff Ramp	24-ft dia.	60	400	86.00	1.55	18.60	15.9 ft Invert
Tuff Main	18.5 x 24[d]	70	398	73.50	1.57	21.66	
Service Main	14.5 x 24[d]	70	303	68.55	3.32	17.68	
Perimeter Drift	22-ft dia.	60	372	68.75	1.54	21.64	10 ft Invert
Panel Access Drift	13.5 x 20[d]	70	237	59.90	6.06	15.83	
Mid-panel Access Drift	13.5 x 15[d]	70	185	51.73	11.00	14.30	
Emplacement Drift	21.5 x 15[d]	70	305	67.70	3.21	18.02	

a. From the SCP-CDR (SNL, 1987).

b. From Equation 2 in Attachment 1.

c. Hydraulic mean diameter; from Equation 4 in Attachment 1.

d. Height x width.

TABLE D-4

INPUT DATA FOR VNETPC--HORIZONTAL EMPLACEMENT

Name	Dimensions[a] (ft)	Friction Factor ($lbf\ min^2/ft^4 \times 10^{-10}$)	Area (ft^2)	Perimeter (ft)	Resistance/Ft[b] ($P.U./ft \times 10^{-6}$)	HMD[c] (ft)	Comments
Waste Ramp	19-ft dia.	30	219	55.63	3.03	15.78	17 ft Invert
Waste Main	20-ft dia.	60	257	59.51	4.05	17.27	17 ft Invert
Tuff Ramp	20-ft dia.	60	248	72.29	5.46	13.72	16 ft Invert
Tuff Main	18.5 x 24[d]	70	398	73.50	1.57	21.66	
Service Main	14.5 x 24[d]	70	303	68.55	3.32	17.68	
Perimeter Drift	22-ft dia.	60	372	68.75	1.54	21.64	10 ft Invert
Panel Access Drift	13.5 x 20[d]	70	237	59.90	6.06	15.83	
Emplacement Drift	12.5 x 22[d]	70	238	61.37	6.16	15.49	

a. From the SCP-CDR (SNL, 1987).

b. From Equation 2 (Attachment 1).

c. From Equation 4 (Attachment 1).

d. Height X width.

TABLE D-5

CONDITIONS AT THE AIR INLET AND ROCK PROPERTIES

Mean Summer Inlet Conditions at the Surface[a]	
Dry Bulb Temperatures	30.3°C
Wet Bulb Temperatures	15.2°C
Barometric Pressure (M&M shaft collar)	90.24 kPa
Rock Properties[b]	
Age Since Mining	50 yr
In Situ VRT (surface)	10°C
In Situ VRT (horizon)	25°C
Geothermal Step	21.46 m/°C
Conductivity	2.07 W/m/°C
Diffusivity	9.167×10^{-7} m^2/s
Wetness Factor	0.001

a. From Eglington and Dreicer (1984).
b. From the SCP-CDR (SNL, 1987).

TABLE D-6

INPUT DATA FOR EVALUATION OF SEALED DRIFT TEMPERATURES

Design Input	Vertical Panel 16 South	Horizontal Panel 3
Inlet Dry Bulb[a] (°C)	27.9	25.5
Inlet Wet Bulb[a] (°C)	16.1	15.9
Barometric Pressure (kPa)	91.0	91.0
Panel Access Drift SRT (°C)[b]	50	50
Emplacement Drift SRT (°C)[b]	120	50

a. Panel inlet.
b. From SIM analysis.

TABLE D-7

EXAMPLE OF CLIMSIM INPUT AND OUTPUT FOR AIR TEMPERATURE CALCULATIONS

Initial parameters for the prediction of heat and humidity

Physical description of Tuff ramp

Length = 1462 m
Depth in = 0 m
Depth out = 311 m
Cross-sectional area = 23.04 m^2
Perimeter = 22.03 m

Friction coeff. = .0111 kg/m^3
Wetness factor = .02
Age at inlet = 18250 days
Age at outlet = 18250 days

Ventilation at intake

Quantity = 33.6 m^3/s
Pressure = 88 kPa

Dry bulb temp. = 30.3 Deg C
Wet bulb temp. = 15.2 Deg C

Thermal Parameters

V.R.T. at inlet = 10 Deg C
Geothermal step = 20.7 m/Deg C
Heat transfer coefficient = 15.630 W/m^2/Deg C

Conductivity = 2.070 W/m/Deg C
Diffusivity = 9.167E-07 m^2/sec

Distance between temperature outputs = 200 m - 7 output stations

Heat Sources

Virgin rock temperature is the only heat source for this simulation

Predicted Environment: Tuff ramp

dist (m)	dry blb (C)	wet blb (C)	moist cont (g/kg)	rel hum (%)	press (kPa)	den (kg/m3)	sigma heat (kJ/kg)	dwall tmp (C)	ACP (W/m2)	wbgt (C)	eff (C)
0	30.30	15.20	6.11	19.83	88.000	1.006	45.67	30.3	1054	19.73	19.91
209	29.60	15.22	6.37	21.63	88.436	1.013	45.62	29.4	1057	19.47	19.51
418	29.01	15.28	6.62	23.38	88.875	1.020	45.65	28.8	1057	19.34	19.17
627	28.51	15.36	6.87	25.06	89.317	1.026	45.74	28.4	1057	19.26	18.88
835	28.10	15.46	7.10	26.65	89.762	1.033	45.90	28.0	1054	19.22	18.65
1044	27.78	15.59	7.32	28.14	90.209	1.039	46.12	27.7	1051	19.22	18.48
1253	27.54	15.73	7.54	29.52	90.660	1.045	46.41	27.5	1047	19.26	18.36
1462	27.37	15.90	7.75	30.78	91.112	1.050	46.76	27.3	1041	19.33	18.30

Sensible heat flow from rock surface to air = -203.3 kW
Latent heat flow from rock surface to air = 137.1 kW
Total heat flow from rock surface to air = -66.2 kW

Final VRT = 25.0 Deg. C

TABLE D-8

EXAMPLE OF CLIMSIM INPUT AND OUTPUT FOR COOLING ANALYSES

Initial parameters for the prediction of heat and humidity

Physical description of Cooldown example

Length = 99.4 m	Friction coeff. = .013 kg/m^3
Depth in = 311 m	Wetness factor = .001
Depth out = 311 m	Age at inlet = 50 days
Cross-sectional area = 22.02 m^2	Age at outlet = 50 days
Perimeter = 18.26 m	

Ventilation at intake

Quantity = 40.1 m^3/s	Dry bulb temp. = 10 Deg C
Pressure = 91 kPa	Wet bulb temp. = 10 Deg C

Thermal Parameters

V.R.T. at inlet = 50 Deg C	Conductivity = 2.070 W/m/Deg C
Geothermal step = 20.7 m/Deg C	Diffusivity = 9.167E-07 m^2/sec
Heat transfer coefficient = 22.858 W/m^2/Deg C	

Distance between temperature outputs = 20 m - 5 output stations

Heat Sources

Virgin rock temperature is the only heat source for this simulation

Predicted Environment: cooldown example

dist (m)	dry blb (C)	wet blb (C)	moist cont (g/kg)	rel hum (%)	press (kPa)	den (kg/m3)	sigma heat (kJ/kg)	dwall tmp (C)	ACP (W/m2)	wbgt (C)	eff (C)
0	24.36	15.45	8.47	40.11	90.981	1.060	45.50	24.4	712	18.12	17.40
20	25.87	15.96	8.47	36.67	90.981	1.060	47.02	34.5	650	21.54	18.51
40	27.35	16.46	8.47	33.61	90.981	1.054	48.52	35.9	633	22.29	19.56
60	28.81	16.95	8.47	30.88	90.980	1.049	49.99	37.2	615	23.03	20.54
80	30.25	17.42	8.48	28.43	90.980	1.044	51.45	38.5	598	23.75	21.46
101	31.66	17.87	8.48	26.24	90.980	1.039	52.88	39.8	581	24.45	22.32
121	33.05	18.32	8.48	24.26	90.980	1.034	54.29	41.1	564	25.14	23.13
141	34.42	18.74	8.48	22.48	90.980	1.029	55.67	42.3	548	25.81	23.90
161	35.77	19.16	8.48	20.87	90.980	1.025	57.04	43.5	531	26.47	24.61
181	37.10	19.56	8.48	19.42	90.980	1.020	58.38	44.7	516	27.11	25.29
201	38.40	19.95	8.49	18.10	90.980	1.016	59.71	45.9	500	27.74	25.93

Sensible heat flow from rock surface to air = 300.8 kW
Latent heat flow from rock surface to air = 0.8 kW
Total heat flow from rock surface to air = 301.6 kW

Final VRT = %120.0 Deg. C
Airflow Rate = 19.970m^3/s

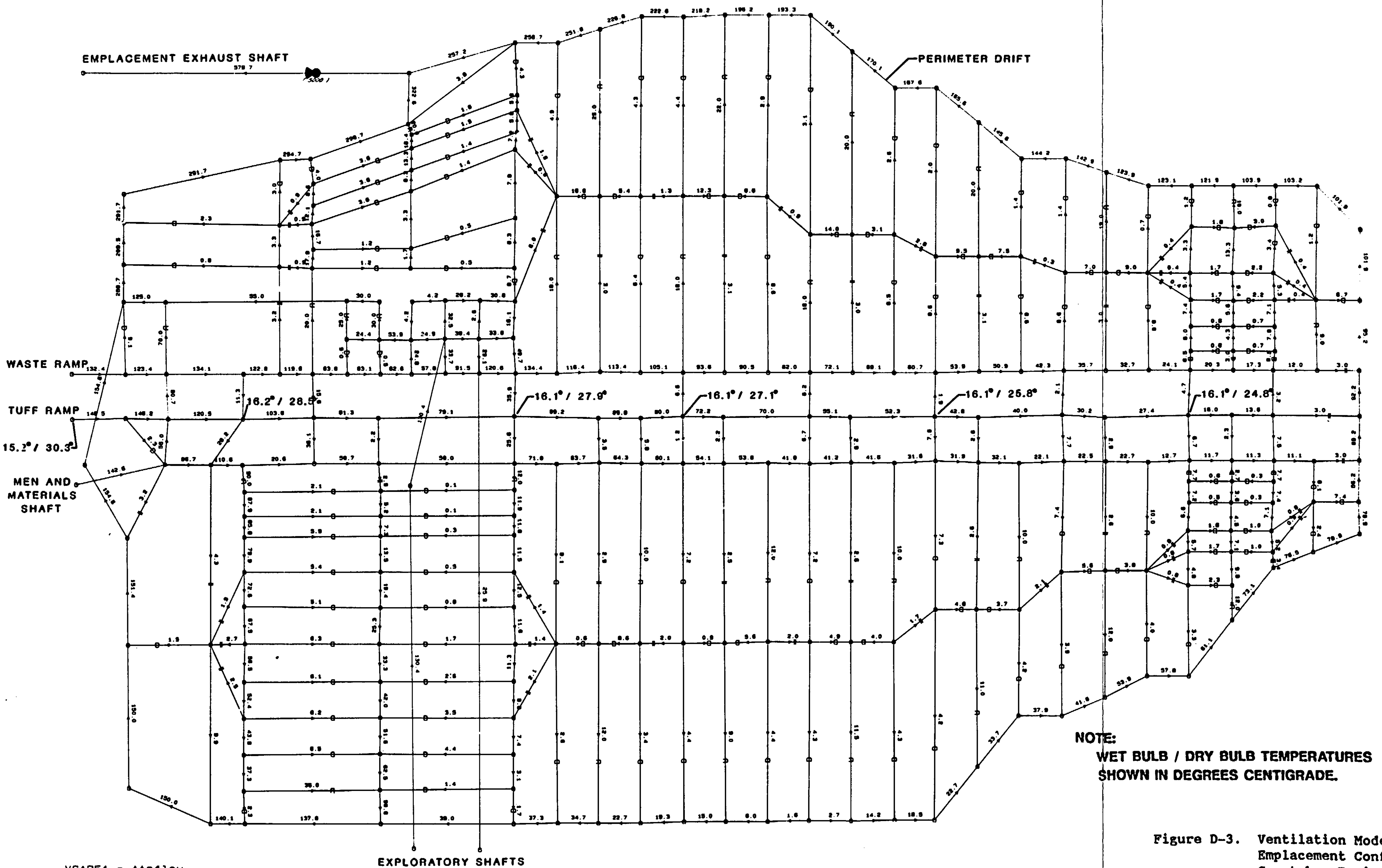
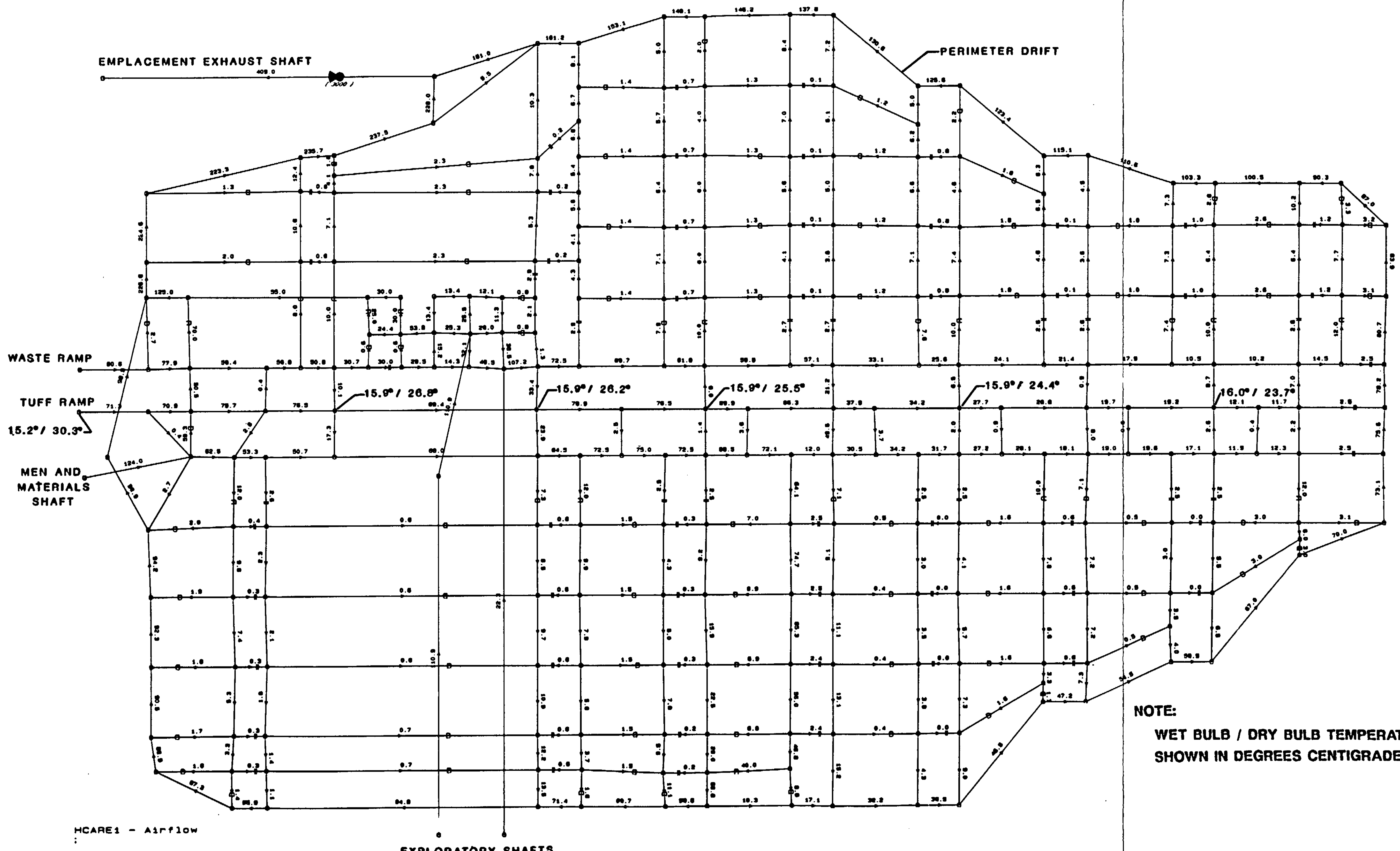


Figure D-3. Ventilation Model, Vertical Emplacement Configuration, Caretaker Period



NOTE:

WET BULB / DRY BULB TEMPERATURES SHOWN IN DEGREES CENTIGRADE.

Figure D-4. Ventilation Model, Horizontal Emplacement Configuration, Caretaker Period

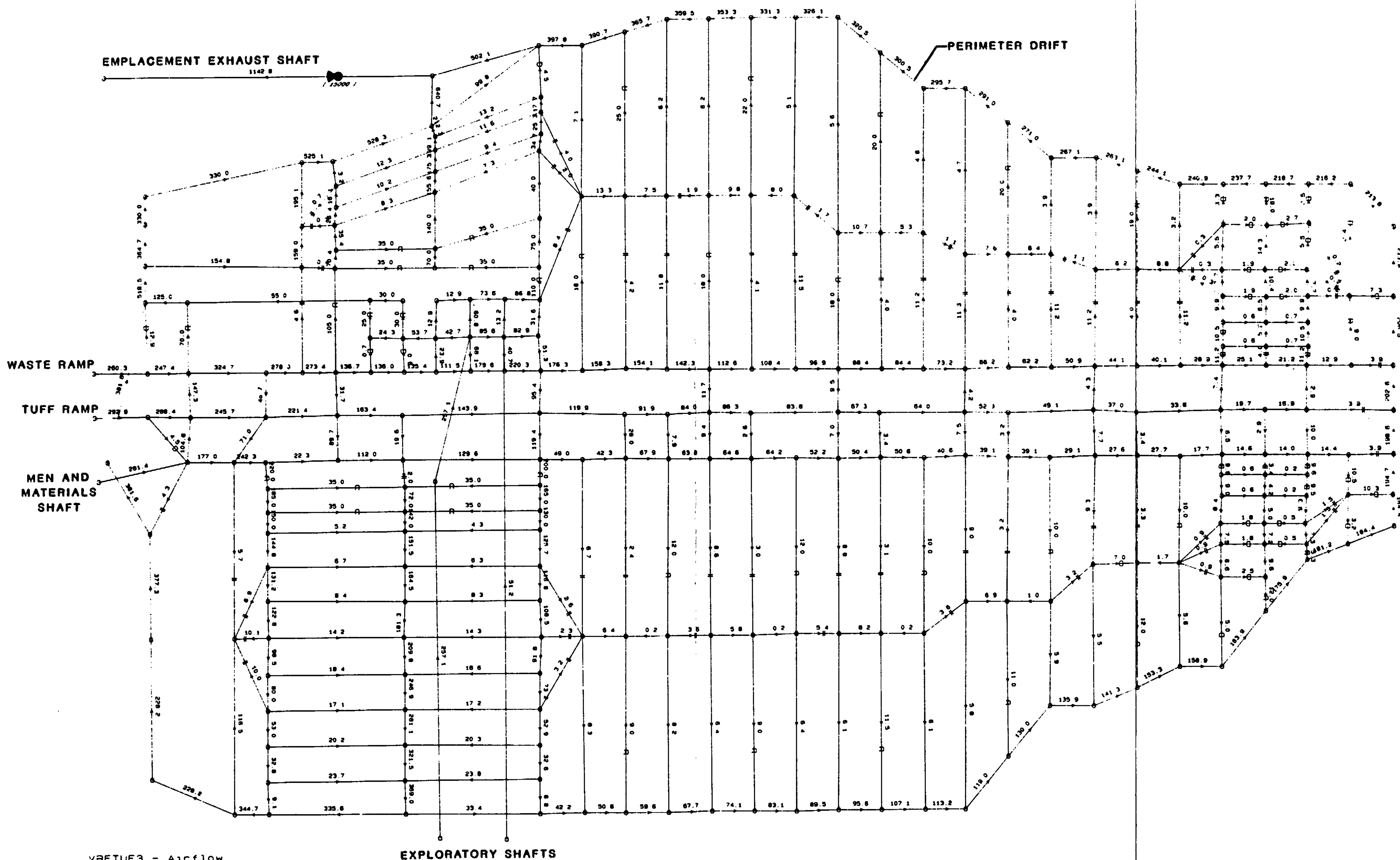


Figure D-5. Ventilation Model, Vertical Emplacement Configuration, Full Retrieval

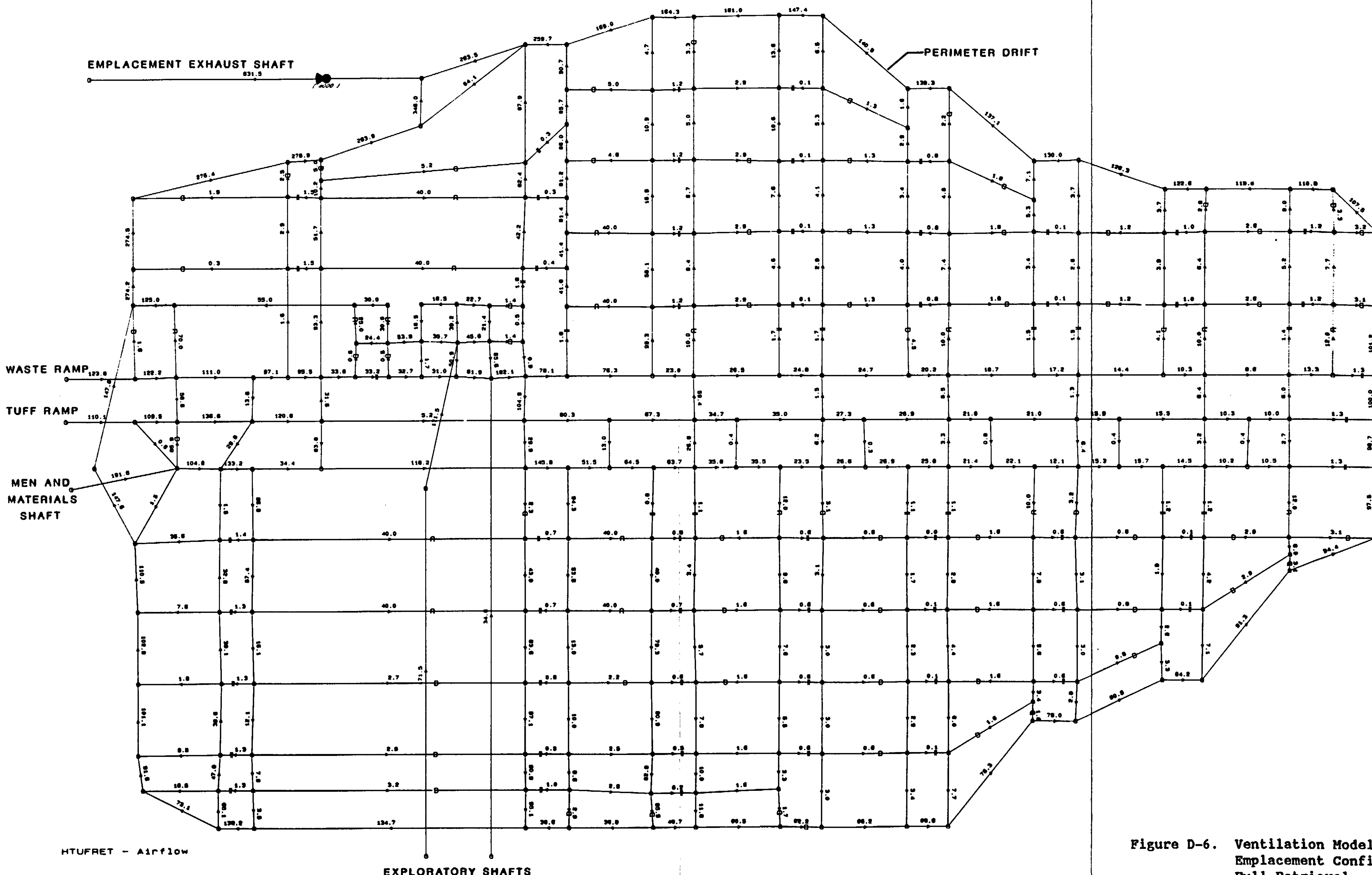


Figure D-6. Ventilation Model, Horizontal Emplacement Configuration, Full Retrieval

TABLE D-9

REQUIREMENTS FOR THE MAIN FANS FOR THE CARETAKER PERIOD AND RETRIEVAL OPERATIONS

Emplacement Configuration	Caretaker Period Pressure (in w.g.)	Caretaker Period Airflow (cfm x 10^3)	Retrieval Operations Pressure (in w.g.)	Retrieval Operations Airflow (cfm x 10^3)
Vertical	5.0	579.7	15.0	1142.8
Horizontal	3.0	409.0	4.0	631.5

4.2 Airway Temperatures

The air temperatures for the main drifts in the vertical and horizontal emplacement configurations are also shown in Figures D-3 and D-4 for the caretaker period. The temperatures of the air in a sealed panel are listed in Table D-10.

4.3 Cooling Requirements

Panel cooling requirements are presented in Table D-11. The table indicates that for the horizontal emplacement configuration, cooling can be accomplished using ambient air. For the vertical emplacement configuration, chilled air would be needed.

The air temperature in the emplacement drift for the vertical emplacement configuration during cooling of the drift has been investigated because of the relatively high temperatures that have been predicted. The results are presented in Table D-12. The table identifies the location in the drift where an acceptable environment is predicted.

TABLE D-10

SUMMARY OF AIR TEMPERATURES IN A SEALED PANEL

Emplacement Configuration	Location	Airflow (m^3/s)	Wet Bulb (°C)	Dry Bulb (°C)
Vertical	Panel inlet	5.7	16.1	27.9
	Midpoint--panel access drift	5.4	17.4	31.7
	Near last emplacement drift	3.5	19.6	38.9
	End of emplacement drift	0.7	30.6	84.4
Horizontal	Panel inlet	3.7	15.9	25.5
	Midpoint--panel access drift	3.0	19.8	37.6
	Near last emplacement drift	2.7	20.7	40.8
	End of emplacement drift	0.7	22.8	48.3

TABLE D-11

SUMMARY OF COOLING ANALYSES FOR VERTICAL AND HORIZONTAL EMPLACEMENT CONFIGURATIONS

Emplacement Configuration	Air Conditions at Panel Inlet		Heat Exchanger Duty		Airflow into Panel		Airflow into Emplacement Drift		Cooling time[a]	
	Dry Bulb (°C)	Wet Bulb (°C)	(kW)	(RT)[c]	(kcfm)	(m3/s)	(kcfm)	(m3/s)	Insp. (days)	Main./ Retr. (days)
Vertical[b]	27.9	16.1	0	0	90.0	42.5	45.0	21.2	111	≥360
Horizontal[b]	25.5	15.9	0	0	84.1	39.7	40.0	18.9	11	50
Vertical	10.0	10.0	721	205	90.0	42.5	45.0	21.2	27	50
Horizontal	10.0	10.0	645	183	84.1	39.7	40.0	18.9	6	15

a. For inspection purposes the time to cool is based on an ACP >300 W/m2 and DB <40°C. For maintenance or retrieval purposes, the time to cool is based on an ACP >500 W/m2 and DB <40°C.

b. Ambient panel inlet temperatures.

c. Refrigeration tons.

TABLE D-12

LOCATION OF AN ACCEPTABLE ENVIRONMENT IN A VERTICAL EMPLACEMENT DRIFT DURING COOLING

	Time (days)	Length (m)	Governing Criterion (ACP or DB)
For Maintenance and Retrieval[a]			
	10	27.5	ACP
	20	89.0	ACP
	30	132.0	ACP
	40	173.0	ACP
	50	201.0	ACP
For Inspection[b]			
	5	55.6	DB
	10	105.0	DB
	20	189.0	DB
	30	236.0	DB

a. An acceptable environment is defined by ACP >500 W/m^2, DB <40°C.
b. An acceptable environment is defined by ACP >300 W/m^2, DB <40°C.

REFERENCES FOR APPENDIX D

Eglinton, T. W., and R. J. Dreicer, "Meteorological Design Parameters for the Candidate Site of a Radioactive Waste Repository at Yucca Mountain, Nevada," SAND84-0440/2, Sandia National Laboratories, Albuquerque, NM, December 1984. (NNA.870407.0048)

Hartman, H. L., Mine Ventilation and Air Conditioning, Second edition, John Wiley & Sons, New York, NY, 1982. (NNA.910304.0107)

McElroy, G. E., "Engineering Factors in the Ventilation of Metal Mines," U.S. Bureau of Mines, Bulletin No. 385, 1935. (NNA.900720.0075)

SNL (Sandia National Laboratories), "Site Characterization Plan Conceptual Design Report," SAND84-2641, compiled by H. R. MacDougall, L. W. Scully, and J. R. Tillerson, Sandia National Laboratories, Albuquerque, NM, September 1987. (NNI.880902.0014-.0019)

Stroh, R., "A Note on the Downcast Shaft as a Thermal Flywheel," Journal of the Mine Ventilation Society of South Africa, Vol. 32, July 1979. (NNA.900702.0020)

ATTACHMENT 1

METHODS USED TO CALCULATE AIRFLOW RESISTANCE

Resistances for each branch are required as input to the computer program VNETPC (Version 2.0) for each of the ventilation cases analyzed. To simplify the resistance calculation, airway resistances are calculated for the airways on a per foot basis. Shock losses are calculated independently based on shock loss factors or equivalent length.

The resistance of a drift is calculated by

$$R = \frac{k(L + Leq)\ per\ \rho}{A^3\ \rho_s}\ , \qquad (1)^*$$

where

R = resistance [P.U. = (milli-in. w.g.)/(kcfm^2)],
k = friction factor (lbf min^2/ft^4 x 10^{-10}),
L = length (ft),
Leq = equivalent length (ft),
per = perimeter (ft),
ρ = air density (lbf/ft^3)--assumed to be 0.075 lbf/ft^3,
A = area (ft^2), and
ρ_s = standard density (0.075 lbf/ft^3).

Equation 1 reduces to the following when based on a per foot basis and $\rho_s = \rho$.

$$R = \frac{k\ per}{A^3} \qquad (2)$$

In practical units (P.U.) the equation becomes

$$R = \frac{k\ per}{A^3}\ \frac{10^{10}}{52}\ \text{(P.U. per foot of airway).}$$

Equation 2 was used to determine the resistance for each branch in the ventilation network.

---

* Atkinson Equation, modified from Hartman (1982).

Any time air bends or airway sizes change, there is an increase in resistance. To account for such an increase, two resistance calculation techniques are employed. The first technique is called equivalent length. The added resistance caused by a bend in an airway is accounted for by adding a calculated length of drift. The following equation has been applied for this technique:

$$Leq = x \ HMD \quad , \tag{3}$$

where

x = number of HMDs and

HMD = hydraulic mean diameter, which is calculated by

$$HMD = 4A/per \quad . \tag{4}$$

The number of HMDs (x) is a design parameter based on the following.

Type		Number of HMDs (dimensionless)
Acute Round Bend		10.0
Acute Sharp Bend		30.0
Right Angle Bend, Sharp		20.0
Right Angle Bend, Round		3.8
Obtuse Sharp Bend		15.0
Obtuse Round Bend		2.0
Discharge		14.0
Inlet		4.6
Abrupt Contraction (Ao/Ai)*		
	0.75	1.2
	0.50	2.8
	0.25	4.3
Abrupt Expansion (Ao/Ai)		
	0.75	1.2
	0.50	2.8
	0.25	4.3
Obstruction (Aob/A)**		
	0.20	20.5
	0.40	41.0

*Ao = Outer area; Ai = Inner area.
**Aob = Obstruction area; A = Airway area.

The values represented in this table are based on isolated airways having more than 70 HMDs between obstructions or bends. If obstructions or bends are closer than 40 HMDs, then the number of hydraulic mean diameters is less than the sum of the two x's. This is due to interference of the turbulent wake downstream from the first obstruction or bend. Engineering judgment is used to determine shock loss factors in this situation.

The number of HMDS is calculated from the following general equation:

$$x = \frac{Leq}{HMD} = \frac{3235\ X}{4\ k}\ (ft) \quad ,$$

where X = shock loss factor (dimensionless).

For a sharp bend, X = 1.4 - 1.6.

Assuming $k = 70\ lbf\ min^2/ft^4 \times 10^{10}$,

$$x = \frac{Leq}{HMD} = \frac{(3235)(1.6)}{(4)(70)} = 18.5 \simeq 20 \quad .$$

The second technique of calculating the resistance associated with bends or obstructions is given by the following equation:

$$R_{sh} = \frac{62.21\ X}{A^2}\ (P.U.) \quad . \tag{5}$$

The shock loss factors (X) can be determined from formulas and tables found in Appendix A-3 of Hartman (1982) (based on McElroy, 1935). This technique has been used for shafts, and the equivalent length technique has been used for airways.

A single branch on a schematic may represent more than one airway. If a branch represents a set of parallel airways, the following equation applies:

$$\frac{1}{R_\tau} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \ldots + \frac{1}{R_n} \text{ (P.U.)} \quad , \tag{6}$$

where

R_τ = total equivalent resistance of parallel branches (P.U.),
R_1 = resistance of first parallel airway (P.U.),
R_2 = resistance of second parallel airway (P.U.),
R_3 = resistance of third parallel airway (P.U.), and
R_n = resistance of n-th parallel airway (P.U.).

If each parallel branch resistance is equivalent, Equation 6 reduces to

$$R_\tau = \frac{R}{n^2} \text{ (P.U.)} \quad , \tag{7}$$

where

R = resistance of each parallel airway (P.U.) and
n = number of parallel airways.

ATTACHMENT 2

DESCRIPTIONS OF COMPUTER CODES

FEDERAL INFORMATION PROCESSING STANDARD SOFTWARE SUMMARY

Field	Entry
01. Summary date (Yr. Mo. Day)	86 10 02
02. Summary prepared by (Name and Phone)	Keith G. Wallace, Jr. (415) 284-5912
03. Summary action	New ☐ Replacement ☒ Deletion ☐
Previous Internal Software ID	CLIMSIM
04. Software date (Yr. Mo. Day)	86 06 16
05. Software title	CLIMSIM (Version 2.0)
06. Short title	
07. Internal Software ID	
08. Software type	☐ Automated Data System ☒ Computer Program ☐ Subroutine/Module
09. Processing mode	☒ Interactive ☐ Batch ☐ Combination
10. Application area — General	☐ Computer Systems Support/Utility ☒ Scientific/Engineering ☐ Bibliographic/Textual ☐ Management/Business ☐ Process Control ☐ Other
10. Application area — Specific	Predicting Underground Climatic Conditions
11. Submitting organization and address	Mine Ventilation Services, Inc. 3717 Mt. Diablo Blvd. Suite 101 Lafayette, CA 94549
12. Technical contact(s) and phone	Keith G. Wallace, Jr. Malcolm J. McPherson (415) 284-5912

13. Narrative

Given the air quantity and psychrometric conditions at the inlet to an underground airway (tunnel) the geometry of the airway, rock thermal parameters and type and location of artificial sources of heat or cooling, the program will predict the variations in psychrometric and thermodynamic properties and indices of heat stress at user-chosen intervals along the airway. The program is completely interactive and is a powerful tool for the prediction of underground environmental conditions especially for hot mining or tunnelling operations. Version 2.0 incorporates a new set up program for utilization on a broader range of computers as well as an easier to read input and output format.

14. Keywords

Underground Climatic Prediction, Psychrometry, Thermodynamic

15. Computer manuf'r and model	16. Computer operating system	17. Programming language(s)	18. Number of source program statements
IBM PC XT or AT or IBM Compatible	MS DOS 2.1 or higher or PC DOS	BASIC	1509
19. Computer memory requirements	**20. Tape drives**	**21. Disk/Drum units**	**22. Terminals**
128 k bytes	N/A	N/A	N/A

23. Other operational requirements

Parallel Printer (optional Hewlett Packard 7475A Plotter)

24. Software availability: Available ☒ Limited ☐ In-house only ☐

25. Documentation availability: Available ☐ Inadequate ☒ In-house only ☐

26. FOR SUBMITTING ORGANIZATION USE

Program is proprietary to Mine Ventilation Services, Inc.

STANDARD FORM 185
JULY 1974
U.S. DEPT. COMMERCE-NBS
(FIPS PUB 30)

ENGINEERING DIVISION - OAKLAND
APPROVED DESIGN PROGRAM ABSTRACT

PROGRAM: CLIMSIM VERSION 2.0

DISCIPLINE: MINING ENGINEERING

PROGRAM NO.:

TYPE: CLIMATIC SIMULATION PROGRAM

PROGRAM ABSTRACT

1. Program Name: CLIMSIM (2.0)
   Descriptive title: Prediction of climate variables along a subsurface airway. Current version: CLIMSIM 2.0 June 1986.

2. Description of function: Given the quantity and psychrometric conditions at the inlet to an airway, the geometry of the airway, rock thermal properties, type and locations of artifical sources of heat or cooling, the program will predict the variations in psychrometric and thermodynamic properties, and indices of heat stress, at user-chosen intervals along the airway.

3. Method of solution: Based on Fourier's Law of conduction and the Laplace equation for time-transient radial heat flow into an underground airway. The numerical procedure utilize Gibson's algorithm for the Carslaw and Jagger solution of the Laplace equation. Steady-state energy and psychrometric relationships are employed to track variations in the climatic variables along the airway. The difference between CLIMSIM (2.0) and CLIMSIM (1.1) is that version 2.0 incorporates a new setup program to allow for utilization of the program on a broader range of computers. Also, an easier to read input/output format is used.

4. Related material: The program is self-contained and requires no auxiliary program or external data files.

5. Restrictions: Strata heat flow is assumed to be radial. Inlet conditions are assumed to have remained constant since the creation of the airway.

6. Computers: Earlier versions of the code (against which the current version has been verified) have run successfully on IBM and INCL main-frame machines and Tektronix 4050 and 4054 minicomputers. The current version runs on an IBM PC XT or AT or IBM compatible personal computer.

7. Running Time: Typically, 1 minute.

8. Programming language: BASIC

APPROVED FOR USE BY ______________________ DATE ______________

ENGINEERING DIVISION - OAKLAND
APPROVED DESIGN PROGRAM ABSTRACT

PROGRAM▸ CLIMSIM VERSION 2.0

DISCIPLINE▸ MINING ENGINEERING

PROGRAM NO.▸

TYPE▸ CLIMATIC SIMULATION PROGRAM

9. Operating system: IBM PC XT or AT or IBM compatible, MS DOS 2.1 or higher or PC DOS

10. Machine requirements: IBM PC XT or AT or IBM compatible: 8087 co-processor recommended but not mandatory: printer: Hewlett Packard 7475 A or compatible peripheral (the program can be run without graphics facilities).

11. Authors: Mine Ventilation Services, Inc., 3717 Mt. Diablo Blvd., Lafayette, California 94549.
Current individuals responsible: M.J. McPherson, K.G. Wallace, D.J. Brunner.

12. References:

(1) CLIMSIM (2.0) User's Manual (Mine Ventilation Services, 1986.
(2) McPherson, M.J., The analysis and simulation of heat flow into underground airways. International Journal of Mining Engineering, Vol. 4, October 1986.
(3) Gibson, K. (1976), The computer simulation of climatic conditions in underground Mines. Ph.D. thesis. University of Nottingham, U.K.
(4) McPherson, M.J. (1984) Mine ventilation planning in the 80's. International Journal of Mining Engineering, Vol. 2, pgs. 185-227.

13. Material available: The complete software system is available on two 5 1/4 inch double density diskettes. It is supplied complete with user's manual and commissioning instructions from Mine Ventilation Services, Inc., 3717 Mt. Diablo Blvd., Lafayette, California 94549, Telephone: (415)284-5912 or (415)284-5924.

APPROVED FOR USE BY ______________________ DATE ____________

FEDERAL INFORMATION PROCESSING STANDARD SOFTWARE SUMMARY

01. Summary date: Yr. 86, Mo. 10, Day 07

02. Summary prepared by (Name and Phone): Keith G. Wallace, Jr. (415) 284-5912

03. Summary action: New [ ] Replacement [X] Deletion [ ]

Previous Internal Software ID: VNETPC

04. Software date: Yr. 86, Mo. 10, Day 07

05. Software title: VNETPC (2.0)

06. Short title: N/A

07. Internal Software ID:

08. Software type: [ ] Automated Data System; [X] Computer Program; [ ] Subroutine/Module

09. Processing mode: [ ] Interactive; [ ] Batch; [X] Combination

10. Application area:

General: [ ] Computer Systems Support/Utility; [X] Scientific/Engineering; [ ] Bibliographic/Textual; [ ] Management/Business; [ ] Process Control; [ ] Other

Specific: Predicting Underground Ventilation Systems

11. Submitting organization and address:
Mine Ventilation Services, Inc.
3717 Mt. Diablo Blvd., Suite 101

12. Technical contact(s) and phone:
Keith G. Wallace
Malcolm J. McPherson
(415) 284-5912

13. Narrative

VNETPC predicts distributions of airflows, pressure drops and operating costs in underground ventilation networks. The program utilizes Kirchhoff's laws, Atkinson's equations and the square law, the branch tree technique for optimized mesh selection and an accelerated Hardy Cross iterative procedure for the determination of airflow distribution. VNETPC is completely interactive and designed for a micro-computer. Both printed and graphical results are possible. Version 2.0 uses pressure closure as the criteria for the solution of the network analysis.

14. Keywords

Ventilation, Airflow, Ventilation Software, Ventilation Program Underground.

15. Computer manuf'r and model	16. Computer operating system	17. Programming language(s)	18. Number of source program statements
IBM PC XT or AT or IBM Compatible	MS DOS 2.1 or higher or PC DOS	BASIC/FORTRAN	3275
19. Computer memory requirements	**20. Tape drives**	**21. Disk/Drum units**	**22. Terminals**
256 k bytes	N/A	N/A	N/A

23. Other operational requirements

Parallel Printer (optional Hewlett Packard 7475 A Plotter)

24. Software availability: Available [X] Limited [ ] In-house only [ ]

25. Documentation availability: Available [X] Inadequate [ ] In-house only [ ]

26. FOR SUBMITTING ORGANIZATION USE

Program is proprietary to Mine Ventilation Services, Inc.

STANDARD FORM 185
JULY 1974
U.S. DEPT. COMMERCE-NBS
(FIPS. PUB. 30)

RKE/PB

ENGINEERING DIVISION - OAKLAND
APPROVED DESIGN PROGRAM ABSTRACT

PROGRAM: VNETPC VERSION 2.0

DISCIPLINE: MINING ENGINEERING

PROGRAM NO.:

TYPE: VENTILATION SIMULATION PROGRAM

PROGRAM ABSTRACT

1. Program name: VNETPC (2.0)
Descriptive Title: Analysis of subsurface ventilation networks. Current Version: Version 2.0 June 1986.

2. Description of function: Predicts distributions of airflows, pressure drops and operating costs in underground ventilation networks.

3. Method of solution: Utilizes Kirchhoff's Laws, Atkinson's equations and the Square Law, the branch tree technique for optimized mesh selection, and an accelerated Hardy Cross iterative procedure. The difference between VNETPC (2.0) and VNETPC (1.1) is that version 2.0 uses pressure closure as the criteria for the solution of the network analysis.

4. Related material: The system is a self contained software package and requires no auxiliary programs or external data files.

5. Restrictions: The model assumes a Square Law relationship between pressure drop and airflow for all branches. It is also restricted to steady-state conditions, a maximum of 500 branches and 20 fans.

6. Computers: The numerical code has run successfully on IBM, ICL, and CDC mainframe machines and PDP 11 minicomputers. The current system (of which the numerical code is a part) runs on IBM PC XT or AT or IBM compatible microcomputers.

7. Running time on IBM PC XT (using an 8087 co-processor chip): For a 200 branch network, about 2 minutes. For a 500 branch network, up to 15 minutes.

8. Programming languages: The numerical analysis code forms approximately 30 percent of the system and is written in FORTRAN IV. The remaining programs for data management and interaction with the operator are written in BASIC.

9. Operation System: IBM PC XT or AT or IBM compatible, MS DOS 2.1 or higher and PC DOS

APPROVED FOR USE BY ______________________ DATE ______________

ENGINEERING DIVISION - OAKLAND
APPROVED DESIGN PROGRAM ABSTRACT

PROGRAM: VNETPC VERSION 2.0

DISCIPLINE: MINING ENGINEERING

PROGRAM NO.:

TYPE: VENTILATION SIMULATION PROGRAM

10. Machine requirements: IBM PC XT or AT or IBM compatible: 256k byte memory: dual diskette/hard disk combination: 8087 co-processor advisable but not vital: printer: Hewlett Packard 7475 A or compatible plotter (the program can be run without graphics facilities).

11. Authors: Mine Ventilation Services, Inc., 3717 Mt. Diablo Blvd., Lafayette, California 94549.
Current individuals responsible: M.J. McPherson, K.G. Wallace, D.J. Brunner.

12. References:

(1) VNETPC (2.0) User's Manual (Mine Ventilation Services, Inc.) 1986.
(2) McPherson, M.J., Ventilation Network Analysis on a Microcomputer: To be published in the International Journal of Mining Engineering, 1986.
(3) McPherson, M.J. (1982), Ventilation Network Analysis: Environmental Enginering in South Africa Mines, Chapter 8.
(4) McPherson, M.J. (1984) Mine ventilation planning in the 80's. International Journal of Mining Engineering, Vol. 2, pgs. 185-227.

13. Material available: The complete software system is available on two 5 1/4 inch double density diskettes. It is supplied complete with user's manual and commissioning instructions from Mine Ventilation Services, Inc., 3717 Mt. Diablo Blvd., Lafayette, California 94549, Telephone: (415)284-5912 or (415)284-5924.

APPROVED FOR USE BY ______________________ DATE ____________

ATTACHMENT 3

SAMPLE VNETPC INPUT AND OUTPUT

File Name: VCARE2
Network Title: VERTICAL CARETAKER
Mine Name: NNWSI
Company: pbqd
Comments: PARSONS BRINCKERHOFF / MVS

**** Data Supplied By User ****

Fan Data:

Fan No.	From	To	Operating Pressure in.w.g.	No. Characteristic Pts.
1	4	3	5.000	0

Branch Data:

Branch	From	To	Resistance P.U.	Pressure Dp m.in.wg.	Airflow kcfm
1	1	102	0.0059		
2	102	106	0.0059		
3	2	107	0.3047		
4	2	1	0.0000		
5	78	79	0.0089		
6	78	1	0.0000		
7	60	59	0.0076		
8	59	1	0.0000		
9	27	28	0.0104		
10	27	1	0.0000		
11	4	3	0.0069		
12	3	1	0.0000		
13	4	183	0.0008		
14	4	5	0.0013		
15	5	6	0.0002		
16	6	7	0.0010		
17	7	8	0.0010		
18	8	9	0.0013		
19	9	10	0.0012		
20	10	11	0.0010		
21	11	12	0.0001		
22	12	13	0.0011		
23	13	14	0.0011		
24	14	15	0.0001		
25	15	16	0.0011		
26	16	17	0.0011		
27	17	18	0.0002		
28	18	19	0.0011		
29	19	20	0.0011		
30	20	21	0.0001		
31	21	22	0.0010		
32	22	23	0.0010		

33	23	24	0.0001
34	24	25	0.0018
35	25	26	0.0012
36	26	58	0.0009
37	28	29	0.0006
38	29	30	0.0001
39	30	31	0.0001
40	31	32	0.0001
41	32	33	0.0002
42	33	34	0.0002
43	34	35	0.0002
44	35	36	0.0004
45	36	37	0.0004
46	37	38	0.0003
47	38	39	0.0001
48	39	40	0.0007
49	40	41	0.0007
50	41	42	0.0001
51	42	43	0.0007
52	43	44	0.0007
53	44	45	0.0001
54	45	46	0.0007
55	46	47	0.0007
56	47	48	0.0001
57	48	49	0.0009
58	49	50	0.0007
59	50	51	0.0001
60	51	52	0.0009
61	52	53	0.0009
62	53	54	0.0003
63	54	55	0.0007
64	55	56	0.0009
65	56	57	0.0001
66	58	57	200.0000
67	61	29	0.0011
68	62	30	0.0011
69	32	63	0.0011
70	64	38	0.0011
71	66	42	0.0004
72	68	45	0.0004
73	48	70	0.0004
74	51	72	0.0004
75	54	74	0.0004
76	56	76	0.0004
77	77	58	0.0001
78	60	61	0.0008
79	61	62	0.0006
80	62	63	0.0003
81	63	196	0.0011
82	196	64	0.0011
83	64	288	0.0014
84	65	66	0.0002
85	66	67	0.0012
86	67	68	0.0014
87	68	69	0.0012
88	69	70	0.0015

89	70	71	0.0012
90	71	72	0.0015
91	72	73	0.0012
92	73	74	0.0016
93	74	75	0.0012
94	75	76	0.0014
95	76	77	200.0000
96	79	60	2.7800
97	79	61	0.0011
98	198	62	0.0011
99	81	63	0.0011
100	197	196	0.0001
101	82	64	0.0011
102	85	65	0.0004
103	86	66	0.0004
104	87	67	0.0004
105	89	68	0.0004
106	90	69	0.0004
107	92	70	0.0004
108	93	71	0.0004
109	95	72	0.0004
110	96	73	0.0004
111	98	74	0.0004
112	99	75	0.0004
113	100	76	0.0004
114	101	77	0.0004
115	79	198	0.0018
116	198	80	0.0003
117	80	81	0.0006
118	81	197	0.0017
119	197	82	0.0023
120	82	83	0.0003
121	83	84	0.0021
122	84	85	0.0021
123	85	86	0.0003
124	86	87	0.0022
125	87	88	0.0022
126	88	89	0.0003
127	89	90	0.0022
128	90	91	0.0022
129	91	92	0.0003
130	92	93	0.0022
131	93	94	0.0022
132	94	95	0.0003
133	95	96	0.0022
134	96	97	0.0022
135	97	98	0.0003
136	98	99	0.0022
137	99	100	0.0022
138	100	199	0.0003
139	199	101	200.0000
140	28	114	25.0000
141	114	132	0.0005
142	132	147	0.0013
143	147	161	0.0003
144	161	174	0.0007

145	174	175	0.0002	
146	175	183	0.0010	
147	183	5	0.0012	
148	29	115	0.0010	70.00 - Fixed
149	103	116	0.0010	25.00 - Fixed
150	104	117	0.0010	30.00 - Fixed
151	117	116	0.0032	
152	116	115	0.0074	
153	115	114	0.0054	
154	33	103	25.0000	
155	34	104	25.0000	
156	104	103	0.0016	
157	118	119	0.0044	
158	119	120	0.0024	
159	120	121	0.0021	
160	106	105	0.0052	
161	106	107	0.0032	
162	107	108	0.0021	
163	118	105	0.0035	
164	105	35	0.0022	
165	119	106	0.0029	
166	106	36	0.0030	
167	120	107	0.0020	
168	107	37	0.0022	
169	105	104	0.0016	
170	133	148	0.0051	
171	31	133	200.0000	
172	148	174	25.0030	
173	32	134	0.0046	20.00 - Fixed
174	134	249	0.0008	
175	249	149	0.0015	
176	149	250	0.0023	
177	250	251	0.0017	
178	251	175	25.0002	
179	135	247	0.0014	
180	247	162	0.0028	
181	162	246	0.0042	
182	246	245	0.0042	
183	245	252	0.0028	
184	252	183	0.0002	20.00 - Fixed
185	38	108	0.0016	
186	108	121	0.0015	
187	121	136	25.0043	
188	136	241	0.0007	
189	241	176	0.0008	
190	176	242	0.0015	
191	242	244	0.0023	
192	244	122	0.0023	
193	122	5	25.0023	
194	39	163	0.0088	18.00 - Fixed
195	163	6	25.0088	
196	40	164	200.0000	
197	164	7	0.0178	25.00 - Fixed
198	41	165	25.0000	
199	165	8	25.0098	
200	42	166	0.0100	18.00 - Fixed

201	166	9	25.0096	
202	43	167	200.0146	
203	167	10	0.0183	22.00 - Fixed
204	44	168	25.0105	
205	168	11	25.0087	
206	45	153	0.0098	18.00 - Fixed
207	153	12	25.0098	
208	46	154	200.0000	
209	154	13	0.0166	20.00 - Fixed
210	47	155	25.0084	
211	155	14	25.0084	
212	132	133	25.0019	
213	147	148	25.0000	
214	133	134	200.0000	
215	148	149	200.0000	
216	148	251	200.0000	
217	163	244	50.0000	
218	163	176	200.0000	
219	163	121	50.0000	
220	134	135	25.0022	
221	136	135	25.0022	
222	249	247	25.0022	
223	241	247	25.0022	
224	149	162	2.7800	
225	176	162	2.7800	
226	250	246	2.7800	
227	242	246	2.7800	
228	251	245	2.7800	
229	244	245	2.7800	
230	122	252	2.7800	
231	163	164	0.0472	
232	165	164	0.0434	
233	165	166	50.0000	
234	166	167	1.5625	
235	168	167	1.5625	
236	168	153	50.0000	
237	153	154	0.0472	
238	155	154	0.0567	
239	288	65	0.0012	
240	84	288	0.0004	
241	155	140	8.0000	
242	140	141	0.0625	
243	141	142	0.0865	
244	142	143	12.5000	
245	143	144	0.1276	
246	144	145	0.1736	
247	184	193	25.0025	
248	194	193	25.0025	
249	185	192	25.0025	
250	500	192	25.0025	
251	186	191	2.7800	
252	501	191	2.7800	
253	146	195	2.7800	
254	130	195	2.7800	
255	189	190	2.7800	
256	502	190	1.5600	

257	145	189	200.0000	
258	145	146	200.0000	
259	145	186	200.0000	
260	131	502	200.0000	
261	131	130	200.0000	
262	131	501	200.0000	
263	131	26	0.1479	
264	48	140	25.0000	
265	140	15	25.0082	
266	49	141	200.0000	
267	141	16	0.0139	20.00 - Fixed
268	50	142	25.0000	
269	142	17	25.0065	
270	51	143	25.0000	
271	143	18	25.0063	
272	52	144	200.0095	
273	144	19	0.0098	19.00 - Fixed
274	53	145	25.0000	
275	145	20	25.0047	
276	54	184	25.0016	
277	184	185	0.0010	
278	185	186	0.0015	
279	186	146	0.0023	
280	146	189	0.0023	
281	189	21	25.0015	
282	55	193	200.0022	
283	193	192	0.0014	
284	192	191	0.0028	
285	191	195	0.0042	
286	195	190	0.0042	
287	190	22	0.0042	18.00 - Fixed
288	56	194	25.0016	
289	194	500	0.0010	
290	500	501	0.0015	
291	501	130	0.0023	
292	130	502	0.0027	
293	502	23	25.0023	
294	57	131	0.0055	9.00 - Fixed
295	131	24	25.0000	
296	79	201	200.0163	
297	201	200	0.0014	
298	200	114	0.0016	
299	201	204	0.0031	
300	204	208	0.0010	
301	208	217	0.0013	
302	217	219	0.0001	
303	219	221	0.0012	
304	221	223	0.0010	
305	223	233	0.0001	
306	233	243	0.0010	
307	243	253	0.0012	
308	253	255	0.0001	
309	255	257	0.0010	
310	257	259	0.0010	
311	259	261	0.0014	
312	261	263	0.0011	

313	263	265	0.0011	
314	265	267	0.0001	
315	267	269	0.0011	
316	269	271	0.0011	
317	271	273	0.0001	
318	273	275	0.0011	
319	275	277	0.0011	
320	277	279	0.0002	
321	279	281	0.0013	
322	281	283	0.0013	
323	283	285	0.0002	
324	285	287	0.0008	
325	287	286	0.0004	
326	286	101	0.0004	
327	198	212	100.0283	
328	212	217	0.0090	
329	80	202	0.0050	90.00 - Fixed
330	202	203	0.0010	
331	203	205	0.0015	
332	205	206	0.0023	
333	206	207	0.0023	
334	207	218	0.0027	
335	218	209	0.0030	
336	209	210	0.0027	
337	210	211	0.0023	
338	211	213	0.0023	
339	213	219	25.0015	
340	197	214	200.0022	
341	214	215	0.0022	
342	215	216	0.0036	
343	216	503	0.0042	
344	503	224	0.0042	
345	224	220	0.0049	
346	220	225	0.0055	
347	225	226	0.0049	
348	226	227	0.0042	
349	227	229	0.0042	
350	229	221	0.0028	
351	82	230	0.0016	12.00 - Fixed
352	230	231	0.0009	
353	231	232	0.0015	
354	232	234	0.0023	
355	234	235	0.0023	
356	235	222	0.0027	
357	222	236	0.0030	
358	236	237	0.0027	
359	237	239	0.0023	
360	239	240	0.0023	
361	240	223	25.0015	
362	83	228	25.0147	
363	228	233	25.0073	
364	84	238	200.0220	
365	238	243	0.0163	12.00 - Fixed
366	85	248	0.0147	10.00 - Fixed
367	248	253	25.0073	
368	86	254	25.0000	

369	254	255	25.0113	
370	87	256	200.0000	9.00 - Fixed
371	256	257	0.0206	12.00 - Fixed
372	88	258	0.0113	
373	258	259	25.0113	
374	89	260	25.0000	
375	260	261	25.0112	
376	90	262	200.0000	11.50 - Fixed
377	262	263	0.0184	10.00 - Fixed
378	91	264	0.0091	
379	264	265	25.0091	
380	92	266	25.0000	
381	266	267	25.0090	
382	93	268	200.0000	11.00 - Fixed
383	268	269	0.0152	10.00 - Fixed
384	94	270	0.0078	
385	270	271	25.0078	
386	95	272	25.0000	
387	272	273	25.0077	
388	96	274	200.0000	12.00 - Fixed
389	274	275	0.0128	10.00 - Fixed
390	97	276	0.0061	
391	276	277	25.0061	
392	98	123	25.0016	
393	123	124	0.0010	
394	124	137	0.0015	
395	137	278	0.0023	
396	278	138	0.0027	
397	138	279	25.0027	
398	99	152	200.0022	
399	152	151	0.0014	
400	151	150	0.0028	
401	150	280	0.0042	
402	280	139	0.0049	12.00 - Fixed
403	139	281	0.0049	
404	100	177	25.0016	
405	177	178	0.0010	
406	178	179	0.0015	
407	179	282	0.0015	
408	282	283	25.0002	
409	199	284	25.0000	
410	284	285	25.0024	
411	212	204	25.0000	
412	202	214	25.0025	
413	230	214	25.0025	
414	203	215	25.0025	
415	231	215	25.0025	
416	205	216	2.7800	
417	232	216	2.7800	
418	206	503	2.7800	
419	234	503	2.7800	
420	207	224	2.7800	
421	235	224	2.7800	
422	218	220	1.5600	
423	222	220	1.5600	
424	209	225	1.5600	

425	236	225	1.5600	
426	210	226	1.5625	
427	237	226	1.5625	
428	211	227	1.5625	
429	239	227	1.5625	
430	213	229	0.0025	42.50 - Fixed
431	240	229	25.0025	
432	212	210	22.2000	
433	212	206	50.0000	
434	212	218	22.2000	
435	228	234	50.0000	
436	228	222	50.0000	
437	228	237	22.2000	
438	228	238	1.5600	
439	248	238	1.5600	
440	248	254	50.0000	
441	254	256	0.0319	
442	256	258	0.0319	
443	258	260	4.0816	
444	260	262	0.0343	
445	262	264	0.0434	
446	264	266	8.0000	
447	266	268	0.0516	
448	268	270	0.0625	
449	270	272	12.5000	
450	272	274	0.0772	
451	274	276	0.0977	
452	123	152	25.0025	
453	177	152	25.0025	
454	124	151	25.0025	
455	178	151	25.0025	
456	137	150	2.7800	
457	179	150	2.7800	
458	278	280	2.7800	
459	282	280	2.7800	
460	138	139	1.5600	
461	276	137	200.0000	
462	276	278	200.0000	
463	276	138	200.0000	
464	284	179	200.0000	
465	284	282	200.0000	
466	284	286	2.7800	

**** OUTPUT DATA ****

Annual costs are based on electricity charges of 4.5 cents per kWhr and fan efficiencies of 70.0%
Cost given for an NVP represents money saved by natural ventilation

*** FAN OPERATING POINTS ***

Fan No.	From	To	Pressure in.w.g.	Quantity kcfm	Air Power hp	Op.Cost $/year
1	4	3	5.000	579.74	456.77	191,826

*** BRANCH RESULTS ***

Branch	From	To	Press.Dp m.in.wg.	Airflow kcfm	Resist. P.U.	AP Loss hp	Op.Cost $/year
1	1	102	99	130.38	0.0059	2.0	854.2
2	102	106	99	130.38	0.0059	2.0	854.2
3	2	107	204	25.89	0.3047	0.8	349.5
4	2	1	0	-25.89	0.0000	0.0	0.0
5	78	79	181	142.55	0.0089	4.1	1,707.5
6	78	1	0	-142.55	0.0000	0.0	0.0
7	60	59	-167	-148.49	0.0076	3.9	1,641.0
8	59	1	0	-148.49	0.0000	0.0	0.0
9	27	28	183	132.43	0.0104	3.8	1,603.8
10	27	1	0	-132.43	0.0000	0.0	0.0
11	4	3	2335	579.74	0.0069	213.3	89,582.5
12	3	1	0	579.74	0.0000	0.0	0.0
13	4	183	-85	-322.55	0.0008	4.3	1,814.3
14	4	5	-85	-257.19	0.0013	3.4	1,446.7
15	5	6	-9	-256.72	0.0002	0.4	152.9
16	6	7	-66	-251.86	0.0010	2.6	1,100.0
17	7	8	-54	-226.86	0.0010	1.9	810.7
18	8	9	-64	-222.58	0.0013	2.2	942.7
19	9	10	-58	-218.21	0.0012	2.0	837.5
20	10	11	-39	-196.21	0.0010	1.2	506.4
21	11	12	-4	-193.31	0.0001	0.1	51.2
22	12	13	-39	-190.17	0.0011	1.2	490.8
23	13	14	-31	-170.17	0.0011	0.8	349.1
24	14	15	-2	-167.59	0.0001	0.1	22.2
25	15	16	-30	-165.60	0.0011	0.8	328.8
26	16	17	-23	-145.60	0.0011	0.5	221.6
27	17	18	-3	-144.23	0.0002	0.1	28.6
28	18	19	-22	-142.89	0.0011	0.5	208.0
29	19	20	-16	-123.88	0.0011	0.3	131.2
30	20	21	-1	-123.16	0.0001	0.0	8.2
31	21	22	-15	-121.96	0.0010	0.3	121.1
32	22	23	-11	-103.96	0.0010	0.2	75.7
33	23	24	-1	-103.19	0.0001	0.0	6.8
34	24	25	-18	-101.96	0.0018	0.3	121.5
35	25	26	-11	-101.96	0.0012	0.2	74.2
36	26	58	-8	-95.23	0.0009	0.1	50.4
37	28	29	8	123.37	0.0006	0.2	65.3
38	29	30	2	134.07	0.0001	0.0	17.7
39	30	31	1	122.79	0.0001	0.0	8.1
40	31	32	1	119.58	0.0001	0.0	7.9
41	32	33	1	83.75	0.0002	0.0	5.5
42	33	34	1	83.13	0.0002	0.0	5.5
43	34	35	1	82.59	0.0002	0.0	5.5
44	35	36	1	57.84	0.0005	0.0	3.8
45	36	37	3	91.50	0.0004	0.0	18.2
46	37	38	4	120.60	0.0003	0.1	31.9

47	38	39	1	134.40	0.0001	0.0	8.9
48	39	40	9	116.40	0.0007	0.2	69.3
49	40	41	9	113.43	0.0007	0.2	67.6
50	41	42	1	105.05	0.0001	0.0	7.0
51	42	43	6	93.63	0.0007	0.1	37.2
52	43	44	6	90.54	0.0007	0.1	35.9
53	44	45	0	81.98	0.0001	0.0	0.0
54	45	46	3	72.14	0.0007	0.0	14.3
55	46	47	3	69.14	0.0007	0.0	13.7
56	47	48	0	60.68	0.0001	0.0	0.0
57	48	49	2	53.93	0.0009	0.0	7.1
58	49	50	1	50.88	0.0007	0.0	3.4
59	50	51	0	42.27	0.0001	0.0	0.0
60	51	52	1	35.74	0.0009	0.0	2.4
61	52	53	1	32.70	0.0009	0.0	2.2
62	53	54	0	24.12	0.0003	0.0	0.0
63	54	55	0	20.34	0.0007	0.0	0.0
64	55	56	0	17.32	0.0009	0.0	0.0
65	56	57	0	11.99	0.0001	0.0	0.0
66	58	57	-1782	-2.99	200.0000	0.8	352.1
67	61	29	6	80.69	0.0011	0.1	32.0
68	62	30	0	-11.28	0.0011	0.0	0.0
69	32	63	0	15.83	0.0011	0.0	0.0
70	64	38	-1	-35.94	0.0011	0.0	2.4
71	66	42	0	6.58	0.0004	0.0	0.0
72	68	45	0	8.16	0.0004	0.0	0.0
73	48	70	0	-1.87	0.0004	0.0	0.0
74	51	72	0	-2.07	0.0004	0.0	0.0
75	54	74	0	-4.73	0.0004	0.0	0.0
76	56	76	0	-3.17	0.0004	0.0	0.0
77	77	58	0	92.24	0.0001	0.0	0.0
78	60	61	17	146.22	0.0008	0.4	164.5
79	61	62	9	120.51	0.0007	0.2	71.8
80	62	63	3	103.60	0.0003	0.0	20.6
81	63	196	7	81.32	0.0011	0.1	37.7
82	196	64	6	79.10	0.0011	0.1	31.4
83	64	288	10	89.24	0.0014	0.1	59.1
84	65	66	1	79.99	0.0002	0.0	5.3
85	66	67	6	72.19	0.0012	0.1	28.7
86	67	68	6	69.97	0.0014	0.1	27.8
87	68	69	3	55.14	0.0012	0.0	10.9
88	69	70	4	52.26	0.0015	0.0	13.8
89	70	71	2	42.79	0.0012	0.0	5.7
90	71	72	2	40.04	0.0015	0.0	5.3
91	72	73	1	30.23	0.0012	0.0	2.0
92	73	74	1	27.35	0.0015	0.0	1.8
93	74	75	0	15.97	0.0012	0.0	0.0
94	75	76	0	13.63	0.0014	0.0	0.0
95	76	77	1782	2.99	200.0000	0.8	352.0
96	79	60	-14	-2.27	2.7800	0.0	2.1
97	79	61	3	54.99	0.0011	0.0	10.9

98	198	62	0	-28.20	0.0011	0.0	0.0
99	81	63	-1	-38.11	0.0011	0.0	2.5
100	197	196	0	-2.22	0.0001	0.0	0.0
101	82	64	0	-25.80	0.0011	0.0	0.0
102	85	65	0	-5.79	0.0004	0.0	0.0
103	86	66	0	-1.22	0.0004	0.0	0.0
104	87	67	0	-2.21	0.0004	0.0	0.0
105	89	68	0	-6.68	0.0004	0.0	0.0
106	90	69	0	-2.87	0.0004	0.0	0.0
107	92	70	0	-7.61	0.0004	0.0	0.0
108	93	71	0	-2.75	0.0004	0.0	0.0
109	95	72	0	-7.74	0.0004	0.0	0.0
110	96	73	0	-2.88	0.0004	0.0	0.0
111	98	74	0	-6.65	0.0004	0.0	0.0
112	99	75	0	-2.34	0.0004	0.0	0.0
113	100	76	0	-7.47	0.0004	0.0	0.0
114	101	77	3	89.25	0.0004	0.0	17.7
115	79	198	13	86.69	0.0018	0.2	74.6
116	198	80	3	110.59	0.0003	0.1	22.0
117	80	81	0	20.59	0.0006	0.0	0.0
118	81	197	5	58.70	0.0017	0.0	19.4
119	197	82	7	57.97	0.0023	0.1	26.9
120	82	83	1	71.77	0.0003	0.0	4.7
121	83	84	8	63.69	0.0021	0.1	33.7
122	84	85	8	64.30	0.0021	0.1	34.0
123	85	86	1	60.09	0.0003	0.0	4.0
124	86	87	6	54.11	0.0022	0.1	21.5
125	87	88	6	53.78	0.0022	0.1	21.4
126	88	89	0	41.78	0.0003	0.0	0.0
127	89	90	3	41.24	0.0022	0.0	8.2
128	90	91	3	41.57	0.0022	0.0	8.2
129	91	92	0	31.57	0.0003	0.0	0.0
130	92	93	2	31.92	0.0022	0.0	4.2
131	93	94	2	32.10	0.0022	0.0	4.2
132	94	95	0	22.10	0.0003	0.0	0.0
133	95	96	1	22.45	0.0022	0.0	1.5
134	96	97	1	22.71	0.0022	0.0	1.5
135	97	98	0	12.71	0.0003	0.0	0.0
136	98	99	0	11.67	0.0022	0.0	0.0
137	99	100	0	11.28	0.0022	0.0	0.0
138	100	199	0	11.05	0.0003	0.0	0.0
139	199	101	1778	2.98	200.0000	0.8	350.9
140	28	114	2049	9.06	25.0000	2.9	1,227.9
141	114	132	40	288.63	0.0005	1.8	764.0
142	132	147	109	289.46	0.0013	5.0	2,087.9
143	147	161	27	291.71	0.0003	1.2	521.2
144	161	174	62	291.71	0.0007	2.9	1,196.9
145	174	175	13	294.66	0.0002	0.6	253.5
146	175	183	91	298.69	0.0010	4.3	1,798.7
147	183	5	0	-3.86	0.0012	0.0	0.0
148*	29	115	1956	70.00	0.3993	21.6	9,060.8 -Regulator Required

149*	103	116	1918	25.00	3.0691	7.6	3,173.1	-Regulator Required
150*	104	117	1916	30.00	2.1292	9.1	3,803.8	-Regulator Required
151	117	116	2	30.00	0.0032	0.0	4.0	
152	116	115	22	55.00	0.0073	0.2	80.1	
153	115	114	84	125.00	0.0054	1.7	694.8	
154	33	103	9	0.62	25.0000	0.0	0.4	
155	34	104	7	0.54	25.0000	0.0	0.3	
156	104	103	0	24.38	0.0016	0.0	0.0	
157	118	119	0	-4.23	0.0044	0.0	0.0	
158	119	120	1	28.22	0.0024	0.0	1.9	
159	120	121	1	30.80	0.0021	0.0	2.0	
160	106	105	3	24.86	0.0052	0.0	4.9	
161	106	107	4	39.40	0.0032	0.0	10.4	
162	107	108	2	33.61	0.0021	0.0	4.5	
163	118	105	0	4.23	0.0035	0.0	0.0	
164	105	35	-1	-24.75	0.0022	0.0	1.6	
165	119	106	-3	-32.45	0.0029	0.0	6.4	
166	106	36	3	33.66	0.0030	0.0	6.7	
167	120	107	0	-2.58	0.0020	0.0	0.0	
168	107	37	1	29.10	0.0022	0.0	1.9	
169	105	104	4	53.85	0.0016	0.0	14.3	
170	133	148	0	3.32	0.0051	0.0	0.0	
171	31	133	2060	3.21	200.0000	1.0	437.6	
172	148	174	217	2.95	25.0030	0.1	42.3	
173*	32	134	1882	20.00	4.7055	5.9	2,490.9	-Regulator Required
174	134	249	0	17.86	0.0008	0.0	0.0	
175	249	149	0	16.66	0.0015	0.0	0.0	
176	149	250	0	12.14	0.0023	0.0	0.0	
177	250	251	0	8.57	0.0017	0.0	0.0	
178	251	175	406	4.03	25.0002	0.3	108.3	
179	135	247	0	1.67	0.0014	0.0	0.0	
180	247	162	0	3.33	0.0028	0.0	0.0	
181	162	246	0	8.30	0.0042	0.0	0.0	
182	246	245	0	13.30	0.0042	0.0	0.0	
183	245	252	0	18.40	0.0028	0.0	0.0	
184*	252	183	460	20.00	1.1524	1.4	608.8	-Regulator Required
185	38	108	-3	-49.74	0.0016	0.0	9.9	
186	108	121	0	-16.12	0.0015	0.0	0.0	
187	121	136	1904	8.73	25.0043	2.6	1,099.6	
188	136	241	0	8.26	0.0007	0.0	0.0	
189	241	176	0	7.79	0.0008	0.0	0.0	
190	176	242	0	7.22	0.0015	0.0	0.0	
191	242	244	0	5.80	0.0023	0.0	0.0	
192	244	122	0	5.93	0.0023	0.0	0.0	
193	122	5	468	4.33	25.0023	0.3	134.0	
194*	39	163	1764	18.00	5.4473	5.0	2,101.2	-Regulator Required

195	163	6	591	4.86	25.0088	0.5	190.2	
196	40	164	1768	2.97	200.0000	0.8	347.9	
197*	164	7	511	25.00	0.8191	2.0	845.4	-Regulator Required
198	41	165	1757	8.39	25.0000	2.3	974.9	
199	165	8	459	4.28	25.0098	0.3	130.1	
200*	42	166	1673	18.00	5.1661	4.7	1,992.8	-Regulator Required
201	166	9	477	4.37	25.0096	0.3	137.9	
202	43	167	1905	3.09	200.0146	0.9	389.1	
203*	167	10	181	22.00	0.3747	0.6	263.5	-Regulator Required
204	44	168	1832	8.56	25.0105	2.5	1,037.6	
205	168	11	209	2.89	25.0087	0.1	40.0	
206*	45	153	1788	18.00	5.5215	5.1	2,129.8	-Regulator Required
207	153	12	246	3.14	25.0098	0.1	51.1	
208	46	154	1794	3.00	200.0000	0.8	355.6	
209*	154	13	198	20.00	0.4968	0.6	262.1	-Regulator Required
210	47	155	1790	8.46	25.0084	2.4	1,002.3	
211	155	14	167	2.58	25.0084	0.1	28.6	
212	132	133	-17	-0.83	25.0019	0.0	0.9	
213	147	148	-126	-2.25	25.0000	0.0	18.8	
214	133	134	-177	-0.94	200.0000	0.0	11.0	
215	148	149	-176	-0.94	200.0000	0.0	10.9	
216	148	251	-175	-0.94	200.0000	0.0	10.9	
217	163	244	133	1.63	50.0000	0.0	14.4	
218	163	176	133	0.82	200.0000	0.0	7.2	
219	163	121	-1771	-5.95	50.0000	1.7	697.5	
220	134	135	36	1.20	25.0022	0.0	2.9	
221	136	135	5	0.47	25.0022	0.0	0.2	
222	249	247	35	1.20	25.0022	0.0	2.8	
223	241	247	5	0.47	25.0022	0.0	0.2	
224	149	162	35	3.58	2.7800	0.0	8.3	
225	176	162	5	1.39	2.7800	0.0	0.5	
226	250	246	35	3.57	2.7800	0.0	8.3	
227	242	246	5	1.42	2.7800	0.0	0.5	
228	251	245	36	3.60	2.7800	0.0	8.6	
229	244	245	6	1.50	2.7800	0.0	0.6	
230	122	252	7	1.60	2.7800	0.0	0.7	
231	163	164	13	16.64	0.0472	0.0	14.3	
232	165	164	1	5.39	0.0434	0.0	0.4	
233	165	166	-82	-1.29	50.0000	0.0	7.0	
234	166	167	238	12.34	1.5625	0.5	194.4	
235	168	167	67	6.57	1.5625	0.1	29.1	
236	168	153	-40	-0.90	50.0000	0.0	2.4	
237	153	154	9	13.95	0.0472	0.0	8.3	
238	155	154	0	3.05	0.0567	0.0	0.0	
239	288	65	8	85.78	0.0012	0.1	45.4	
240	84	288	0	-3.45	0.0004	0.0	0.0	

241	155	140	63	2.83	8.0000	0.0	11.8	
242	140	141	5	9.45	0.0625	0.0	3.1	
243	141	142	-4	-7.50	0.0865	0.0	2.0	
244	142	143	0	-0.25	12.5000	0.0	0.0	
245	143	144	6	7.00	0.1276	0.0	2.8	
246	144	145	-13	-8.96	0.1736	0.0	7.7	
247	184	193	7	0.55	25.0025	0.0	0.3	
248	194	193	12	0.72	25.0025	0.0	0.6	
249	185	192	7	0.55	25.0025	0.0	0.3	
250	500	192	12	0.72	25.0025	0.0	0.6	
251	186	191	7	1.66	2.7800	0.0	0.8	
252	501	191	12	2.16	2.7800	0.0	1.7	
253	146	195	7	1.69	2.7800	0.0	0.8	
254	130	195	13	2.18	2.7800	0.0	1.9	
255	189	190	8	1.76	2.7800	0.0	0.9	
256	502	190	13	2.99	1.5600	0.0	2.6	
257	145	189	-26	-0.37	200.0000	0.0	0.6	
258	145	146	-27	-0.37	200.0000	0.0	0.7	
259	145	186	-27	-0.37	200.0000	0.0	0.7	
260	131	502	23	0.35	200.0000	0.0	0.5	
261	131	130	23	0.35	200.0000	0.0	0.5	
262	131	501	23	0.35	200.0000	0.0	0.5	
263	131	26	6	6.74	0.1479	0.0	2.7	
264	48	140	1856	8.62	25.0000	2.5	1,058.3	
265	140	15	99	1.99	25.0082	0.0	13.0	
266	49	141	1858	3.05	200.0000	0.9	374.9	
267*	141	16	65	20.00	0.1631	0.2	86.0	-Regulator Required
268	50	142	1852	8.61	25.0000	2.5	1,054.9	
269	142	17	46	1.36	25.0065	0.0	4.2	
270	51	143	1849	8.60	25.0000	2.5	1,052.3	
271	143	18	45	1.35	25.0063	0.0	4.0	
272	52	144	1853	3.04	200.0095	0.9	373.3	
273*	144	19	15	19.00	0.0442	0.0	18.9	-Regulator Required
274	53	145	1839	8.58	25.0000	2.5	1,043.8	
275	145	20	13	0.73	25.0047	0.0	0.6	
276	54	184	1813	8.52	25.0016	2.4	1,021.9	
277	184	185	0	7.96	0.0010	0.0	0.0	
278	185	186	0	7.41	0.0015	0.0	0.0	
279	186	146	0	5.39	0.0023	0.0	0.0	
280	146	189	0	3.33	0.0023	0.0	0.0	
281	189	21	36	1.20	25.0015	0.0	2.9	
282	55	193	1821	3.02	200.0022	0.9	363.6	
283	193	192	0	4.29	0.0014	0.0	0.0	
284	192	191	0	5.56	0.0028	0.0	0.0	
285	191	195	0	9.38	0.0042	0.0	0.0	
286	195	190	0	13.25	0.0042	0.0	0.0	
287*	190	22	12	18.00	0.0373	0.0	14.3	-Regulator Required
288	56	194	1808	8.50	25.0016	2.4	1,017.5	

289	194	500	0	7.78	0.0010	0.0	0.0	
290	500	501	0	7.06	0.0015	0.0	0.0	
291	501	130	0	5.25	0.0023	0.0	0.0	
292	130	502	0	3.41	0.0027	0.0	0.0	
293	502	23	14	0.77	25.0023	0.0	0.7	
294*	57	131	1784	9.00	22.0280	2.5	1,062.5	-Regulator Required
295	131	24	37	1.22	25.0000	0.0	3.0	
296	79	201	1980	3.15	200.0163	1.0	412.3	
297	201	200	32	154.58	0.0014	0.8	327.3	
298	200	114	37	154.58	0.0016	0.9	378.5	
299	201	204	-71	-151.43	0.0031	1.7	711.5	
300	204	208	-22	-149.97	0.0010	0.5	218.3	
301	208	217	-30	-149.97	0.0013	0.7	297.7	
302	217	219	-1	-140.67	0.0001	0.0	9.3	
303	219	221	-23	-138.66	0.0012	0.5	211.0	
304	221	223	-1	-38.83	0.0010	0.0	2.6	
305	223	233	0	-37.21	0.0001	0.0	0.0	
306	233	243	-1	-34.63	0.0010	0.0	2.3	
307	243	253	0	-22.63	0.0012	0.0	0.0	
308	253	255	0	-19.28	0.0001	0.0	0.0	
309	255	257	0	-14.91	0.0010	0.0	0.0	
310	257	259	0	-5.91	0.0010	0.0	0.0	
311	259	261	0	-1.53	0.0014	0.0	0.0	
312	261	263	0	2.76	0.0011	0.0	0.0	
313	263	265	0	14.26	0.0011	0.0	0.0	
314	265	267	0	18.56	0.0001	0.0	0.0	
315	267	269	0	22.76	0.0011	0.0	0.0	
316	269	271	1	33.76	0.0011	0.0	2.2	
317	271	273	0	37.96	0.0001	0.0	0.0	
318	273	275	1	41.88	0.0011	0.0	2.8	
319	275	277	3	53.88	0.0011	0.0	10.7	
320	277	279	0	57.83	0.0002	0.0	0.0	
321	279	281	4	61.16	0.0013	0.0	16.2	
322	281	283	6	73.16	0.0013	0.1	29.0	
323	283	285	0	76.53	0.0002	0.0	0.0	
324	285	287	4	78.92	0.0008	0.1	20.9	
325	287	286	2	78.92	0.0004	0.0	10.4	
326	286	101	2	86.27	0.0004	0.0	11.4	
327	198	212	1842	4.29	100.0283	1.2	523.2	
328	212	217	0	9.30	0.0090	0.0	0.0	
329*	80	202	1647	90.00	0.2034	23.4	9,809.3	-Regulator Required
330	202	203	7	88.01	0.0010	0.1	40.8	
331	203	205	11	86.10	0.0015	0.1	62.7	
332	205	206	14	80.72	0.0023	0.2	74.8	
333	206	207	12	74.05	0.0023	0.1	58.8	
334	207	218	12	69.59	0.0027	0.1	55.3	
335	218	209	11	61.77	0.0030	0.1	45.0	
336	209	210	8	56.78	0.0027	0.1	30.1	
337	210	211	5	49.63	0.0023	0.0	16.4	

338	211	213	4	44.51	0.0023	0.0	11.8	
339	213	219	100	2.01	25.0015	0.0	13.3	
340	197	214	1740	2.95	200.0022	0.8	339.7	
341	214	215	0	5.12	0.0022	0.0	0.0	
342	215	216	0	7.21	0.0036	0.0	0.0	
343	216	503	0	13.12	0.0042	0.0	0.0	
344	503	224	1	18.67	0.0042	0.0	1.2	
345	224	220	2	24.04	0.0049	0.0	3.2	
346	220	225	5	31.18	0.0055	0.0	10.3	
347	225	226	7	38.68	0.0049	0.0	17.9	
348	226	227	9	46.88	0.0042	0.1	27.9	
349	227	229	13	56.08	0.0042	0.1	48.2	
350	229	221	27	99.83	0.0028	0.4	178.4	
351*	82	230	1731	12.00	12.0259	3.3	1,374.6	-Regulator Required
352	230	231	0	11.82	0.0009	0.0	0.0	
353	231	232	0	11.64	0.0015	0.0	0.0	
354	232	234	0	11.11	0.0023	0.0	0.0	
355	234	235	0	11.87	0.0023	0.0	0.0	
356	235	222	0	10.95	0.0027	0.0	0.0	
357	222	236	0	10.61	0.0030	0.0	0.0	
358	236	237	0	8.10	0.0027	0.0	0.0	
359	237	239	0	6.94	0.0023	0.0	0.0	
360	239	240	0	2.87	0.0023	0.0	0.0	
361	240	223	65	1.62	25.0015	0.0	7.0	
362	83	228	1630	8.07	25.0147	2.1	870.9	
363	228	233	166	2.58	25.0073	0.1	28.4	
364	84	238	1622	2.85	200.0220	0.7	305.7	
365*	238	243	165	12.00	1.1471	0.3	131.0	-Regulator Required
366*	85	248	1497	10.00	14.9738	2.4	990.7	-Regulator Required
367	248	253	280	3.35	25.0073	0.1	62.1	
368	86	254	1299	7.21	25.0000	1.5	619.7	
369	254	255	477	4.37	25.0113	0.3	138.0	
370	87	256	1292	2.54	200.0000	0.5	217.4	
371*	256	257	477	9.00	5.8973	0.7	284.1	-Regulator Required
372*	88	258	1285	12.00	8.9273	2.4	1,020.4	-Regulator Required
373	258	259	478	4.37	25.0113	0.3	138.4	
374	89	260	1301	7.22	25.0000	1.5	621.2	
375	260	261	462	4.30	25.0112	0.3	131.4	
376	90	262	1298	2.55	200.0000	0.5	218.9	
377*	262	263	461	11.50	3.4871	0.8	350.8	-Regulator Required
378*	91	264	1294	10.00	12.9433	2.0	856.3	-Regulator Required
379	264	265	462	4.30	25.0091	0.3	131.5	
380	92	266	1316	7.26	25.0000	1.5	632.0	
381	266	267	439	4.19	25.0090	0.3	121.8	

382	93	268	1315	2.56	200.0000	0.5	223.2	
383*	268	269	438	11.00	3.6266	0.8	318.8	-Regulator Required
384*	94	270	1312	10.00	13.1258	2.1	868.2	-Regulator Required
385	270	271	441	4.20	25.0078	0.3	122.6	
386	95	272	1368	7.40	25.0000	1.6	669.7	
387	272	273	385	3.93	25.0077	0.2	100.0	
388	96	274	1369	2.62	200.0000	0.6	237.0	
389*	274	275	384	12.00	2.6721	0.7	304.9	-Regulator Required
390*	97	276	1367	10.00	13.6701	2.2	904.6	-Regulator Required
391	276	277	389	3.95	25.0061	0.2	101.6	
392	98	123	1479	7.69	25.0016	1.8	753.0	
393	123	124	0	7.15	0.0010	0.0	0.0	
394	124	137	0	6.60	0.0015	0.0	0.0	
395	137	278	0	5.72	0.0023	0.0	0.0	
396	278	138	0	4.83	0.0027	0.0	0.0	
397	138	279	276	3.33	25.0027	0.1	60.8	
398	99	152	1486	2.73	200.0022	0.6	268.1	
399	152	151	0	3.60	0.0014	0.0	0.0	
400	151	150	0	4.48	0.0028	0.0	0.0	
401	150	280	0	7.09	0.0042	0.0	0.0	
402	280	139	0	9.75	0.0049	0.0	0.0	
403*	139	281	273	12.00	1.9004	0.5	216.8	-Regulator Required
404	100	177	1483	7.70	25.0016	1.8	756.1	
405	177	178	0	7.37	0.0010	0.0	0.0	
406	178	179	0	7.04	0.0015	0.0	0.0	
407	179	282	0	5.22	0.0015	0.0	0.0	
408	282	283	283	3.37	25.0002	0.1	63.1	
409	199	284	1625	8.06	25.0000	2.1	867.1	
410	284	285	143	2.39	25.0024	0.1	22.6	
411	212	204	53	1.46	25.0000	0.0	5.1	
412	202	214	98	1.99	25.0025	0.0	12.9	
413	230	214	0	0.18	25.0025	0.0	0.0	
414	203	215	91	1.91	25.0025	0.0	11.5	
415	231	215	0	0.18	25.0025	0.0	0.0	
416	205	216	80	5.38	2.7800	0.1	28.5	
417	232	216	0	0.53	2.7800	0.0	0.0	
418	206	503	66	4.89	2.7800	0.1	21.3	
419	234	503	1	0.66	2.7800	0.0	0.0	
420	207	224	55	4.46	2.7800	0.0	16.2	
421	235	224	2	0.92	2.7800	0.0	0.1	
422	218	220	45	5.38	1.5600	0.0	16.0	
423	222	220	4	1.76	1.5600	0.0	0.5	
424	209	225	38	4.99	1.5600	0.0	12.5	
425	236	225	9	2.51	1.5600	0.0	1.5	
426	210	226	37	4.90	1.5625	0.0	12.0	
427	237	226	16	3.29	1.5625	0.0	3.5	
428	211	227	41	5.12	1.5625	0.0	13.9	

429	239	227	25	4.08	1.5625	0.0	6.7	
430*	213	229	49	42.50	0.0274	0.3	137.8	-Regulator Required
431	240	229	39	1.25	25.0025	0.0	3.2	
432	212	210	-112	-2.25	22.2000	0.0	16.7	
433	212	206	-158	-1.78	50.0000	0.0	18.6	
434	212	218	-132	-2.44	22.2000	0.1	21.4	
435	228	234	100	1.42	50.0000	0.0	9.4	
436	228	222	100	1.42	50.0000	0.0	9.4	
437	228	237	101	2.14	22.2000	0.0	14.3	
438	228	238	0	0.52	1.5600	0.0	0.0	
439	248	238	116	8.63	1.5600	0.2	66.3	
440	248	254	-197	-1.99	50.0000	0.1	25.9	
441	254	256	0	0.85	0.0319	0.0	0.0	
442	256	258	-1	-5.61	0.0319	0.0	0.4	
443	258	260	16	2.02	4.0816	0.0	2.1	
444	260	262	0	4.94	0.0343	0.0	0.0	
445	262	264	0	-4.02	0.0434	0.0	0.0	
446	264	266	22	1.68	8.0000	0.0	2.5	
447	266	268	1	4.75	0.0516	0.0	0.3	
448	268	270	0	-3.69	0.0625	0.0	0.0	
449	270	272	55	2.11	12.5000	0.0	7.7	
450	272	274	2	5.58	0.0772	0.0	0.7	
451	274	276	-1	-3.80	0.0977	0.0	0.3	
452	123	152	7	0.55	25.0025	0.0	0.3	
453	177	152	2	0.33	25.0025	0.0	0.0	
454	124	151	7	0.54	25.0025	0.0	0.3	
455	178	151	2	0.33	25.0025	0.0	0.0	
456	137	150	7	1.63	2.7800	0.0	0.8	
457	179	150	2	0.98	2.7800	0.0	0.1	
458	278	280	7	1.65	2.7800	0.0	0.8	
459	282	280	2	1.01	2.7800	0.0	0.1	
460	138	139	7	2.25	1.5600	0.0	1.0	
461	276	137	112	0.75	200.0000	0.0	5.6	
462	276	278	112	0.75	200.0000	0.0	5.6	
463	276	138	113	0.75	200.0000	0.0	5.6	
464	284	179	-141	-0.84	200.0000	0.0	7.9	
465	284	282	-141	-0.84	200.0000	0.0	7.9	
466	284	286	150	7.35	2.7800	0.2	73.0	

Number of Iterations = 99

*** REGULATOR AND BOOSTER FAN LIST ***

Branch	From	To	Regulator Resistance Required (P.U.)
148	29	115	0.3983
149	103	116	3.0681
150	104	117	2.1282
173	32	134	4.7009
184	252	183	1.1522
194	39	163	5.4385

197	164	7	0.8013
200	42	166	5.1561
203	167	10	0.3564
206	45	153	5.5117
209	154	13	0.4802
267	141	16	0.1492
273	144	19	0.0344
287	190	22	0.0331
294	57	131	22.0225
329	80	202	0.1984
351	82	230	12.0243
365	238	243	1.1308
366	85	248	14.9591
371	256	257	5.8767
372	88	258	8.9160
377	262	263	3.4687
378	91	264	12.9342
383	268	269	3.6114
384	94	270	13.1180
389	274	275	2.6593
390	97	276	13.6640
403	139	281	1.8955
430	213	229	0.0249

APPENDIX E

THERMAL ANALYSES FOR RETRIEVAL CONDITIONS

TABLES

FIGURES

APPENDIX E

THERMAL ANALYSIS

Introduction

The purpose of this analysis is to calculate the rock temperatures in the emplacement boreholes, the emplacement drifts, and the access drifts during preclosure (over a period of approximately 100 yr). Temperatures are calculated for both the vertical and the horizontal emplacement configurations described in the Site Characterization Plan Conceptual Design Report (SCP-CDR) (SAND84-2641, compiled by H. R. MacDougall, L. W. Scully, and J. R. Tillerson, Sandia National Laboratories, Albuquerque, NM, September 1987).

Approach

Rock temperatures at selected locations (data points) on the borehole wall, emplacement drift floor, and access drift floor are calculated using the computer code SIM. (The data points are shown in Figures E-1, E-2, and E-3.) SIM is a three-dimensional thermal analysis code that predicts the temperatures within a conductive medium subjected to thermal loading. An abstract for SIM is included as Attachment E-1. For purposes of this analysis, the waste is simulated by a set of thermal line loads surrounded by a solid, homogeneous rock mass with linear, isotropic thermal characteristics. The thermal loads are arranged to simulate the waste emplacement layouts presented in the SCP-CDR. To reduce computer time, the loads are simulated by horizontal line loads at the waste container midpoint. A comparison of this approximation with a discrete loading configuration is presented in Attachment E-2. Rock temperatures at the data points were calculated at selected times starting at waste emplacement and continuing for 100 yr.

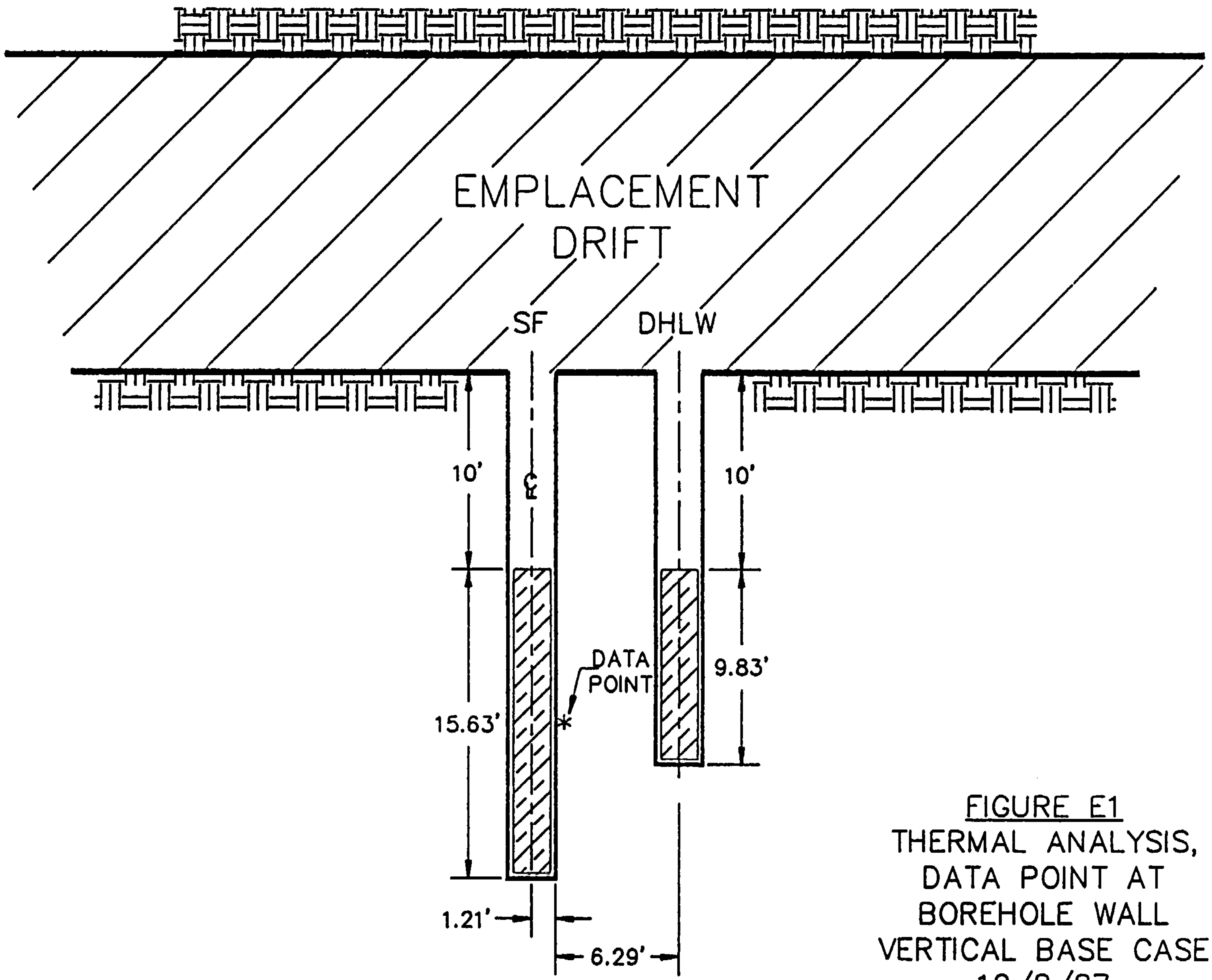


Figure E-1. Thermal Analysis, Borehole Wall, Vertical Configuration

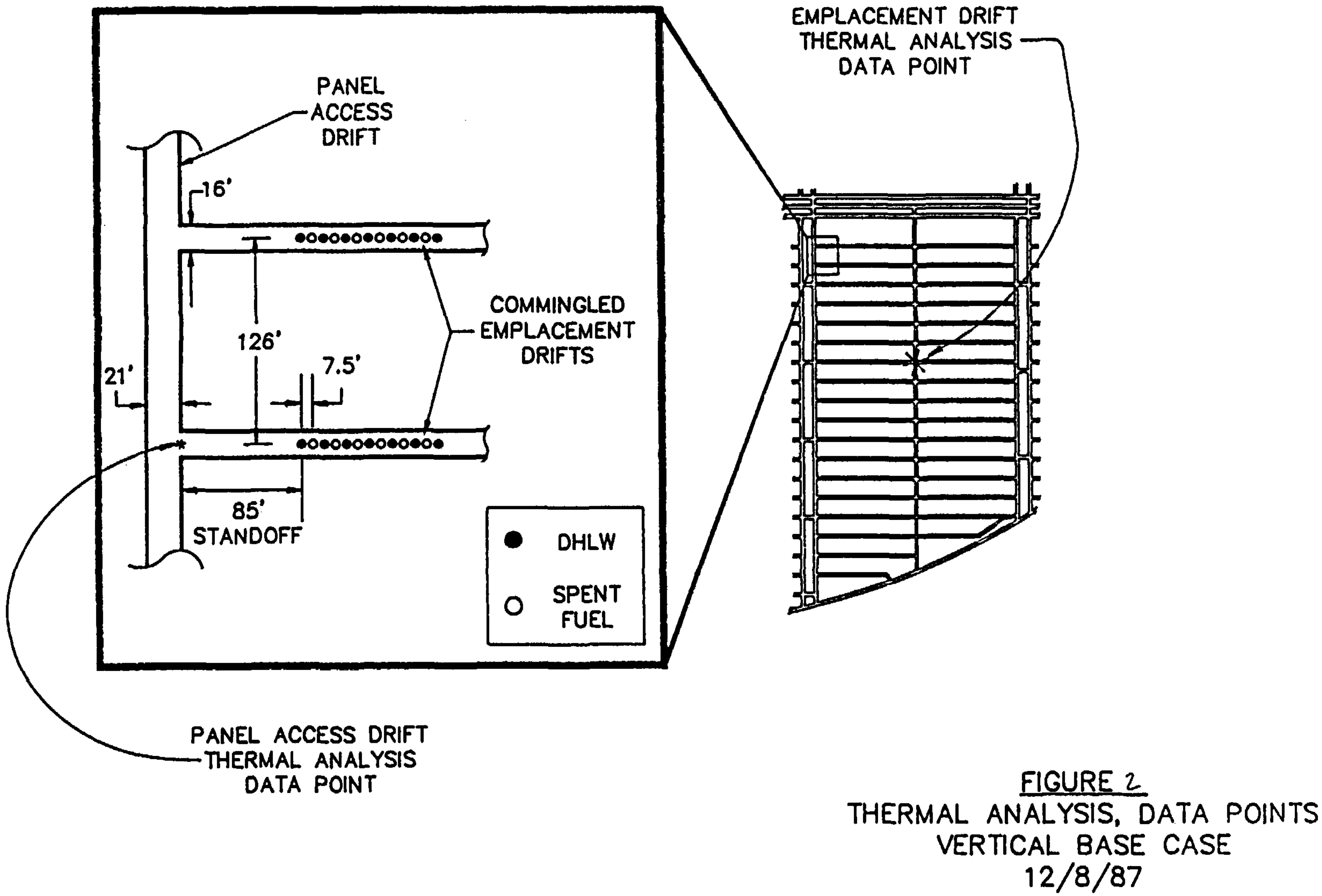


Figure E-2. Thermal Analysis, Emplacement and Access Drifts, Vertical Configuration

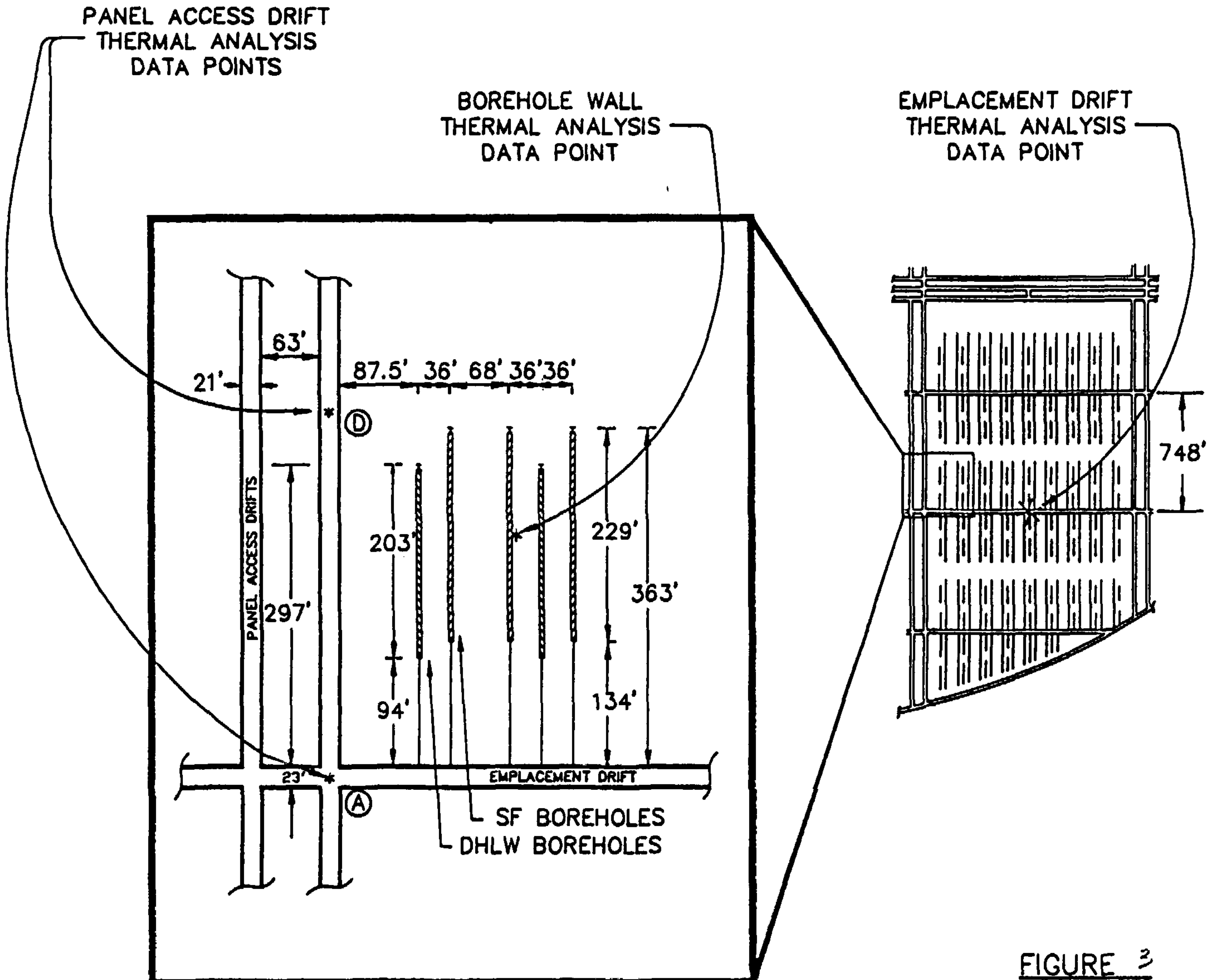


FIGURE 3
THERMAL ANALYSIS, DATA POINTS
HORIZONTAL BASE CASE
12/8/87

Figure E-3. Thermal Analysis, Horizontal Configuration

For the vertical emplacement configuration, the data points are

1) on the borehole wall at the midpoint of the waste container (Figure E-1),

2) on the emplacement drift floor at midpanel (Figure E-2), and

3) on the panel access drift floor at the intersection of the emplacement drift (Figure E-2).

For the horizontal emplacement configuration, the data points are

1) on the borehole wall at the midpoint of the entire line source (Figure E-3),

2) on the emplacement drift floor at midpanel (Figure E-3), and

3) on the midpanel access drift floor at the intersection of the emplacement drift and at the midpoint between emplacement drifts.

Assumptions

The following assumptions have been made for this analysis.

- The waste emplacement layouts, waste characteristics, and rock properties used are those described in the SCP-CDR.

- The numerical model assumes pure conduction in a solid, homogeneous medium. The presence of drifts is ignored. Because ventilation air will remove some heat from the rock, the calculated temperatures will be higher than actually experienced in the repository.

- Borehole wall temperatures are calculated assuming that the borehole is fitted with pressurized-water reactor (PWR) spent fuel (worst case).

- A spent fuel mix of 60% PWR and 40% boiling-water reactor (BWR) is used in the drift temperature calculations.

- The thermal contribution from defense high-level waste (DHLW) is 200 W per container.

- The in situ rock temperature is 77°F.

Input Data

Figures E-2 and E-3 show the layouts for the vertical and horizontal emplacement configurations. The rock properties used are the following.

Density	146 lb/ft^3
Thermal Diffusivity	313.26 ft^2/yr
Heat Capacity	0.23 Btu/lb °F
Conductivity	1.2 Btu/hr - ft°F

Waste characteristics are shown in Table E-1.

Results

The results of the thermal analyses are presented in Tables E-2 through E-4 for the vertical emplacement configuration and Tables E-5 through E-7 for the horizontal emplacement configuration. The results are presented graphically in Figures E-4 and E-5.

The borehole temperatures (Figure E-4) were calculated assuming that they were filled with consolidated PWR spent fuel. The resulting temperatures are considered to be worst case because PWR fuel produces more heat than BWR fuel.

Although the fuel mix for computing drift temperature represents an average case (60% PWR and 40% BWR), the temperatures represent a worst case estimate because the model ignores the existence of drifts and consequently does not consider the removal of heat by ventilation air. Therefore, the calculated temperatures (Figure E-5) are conservatively high.

TABLE E-1

WASTE CHARACTERISTICS[a]

Waste Type	Heat Load (Watts/ft)	Length (ft)	Decay Coefficients[b] α_n (kW/MTU)	β_n (Yr^{-1})
PWR (consolidated)	201.92[c]	15.63	0.16094	-0.0013643
			0.62179	-0.019105
			0.16001	-0.052712
			0.05726	-0.43326
60% PWR 40% BWR	174.73[d]	15.63	0.16755	-0.0013539
			0.62669	-0.019142
			0.15217	-0.051888
			0.053598	-0.43768
DHLW	47.8[c]	9.83	0.888	-0.02026
	20.3[d]		0.112	-0.0456

a. From the SCP-CDR.
b. Power is calculated using $P(t) = \text{Heat Load} * \Sigma_n \alpha_n \exp(\beta_n t)$.
c. Worst case heat load used for borehole temperature calculations.
d. Average case heat load used for drift temperature calculations.

TABLE E-2

THERMAL ANALYSIS OF BOREHOLE WALL TEMPERATURE FOR VERTICAL EMPLACEMENT

Time Since Emplacement (yr)	Rock Temperatures °F	°C
1	366.3	185.7
2	392.5	200.3
4	410.9	210.5
7	425.0	218.3
10	432.6	222.6
20	433.4	223.0
40	405.9	207.7
60	377.5	191.9
80	353.7	178.7
100	334.9	168.3

TABLE E-3

THERMAL ANALYSIS OF EMPLACEMENT DRIFT MIDPOINT FLOOR TEMPERATURE FOR VERTICAL EMPLACEMENT

Time Since Emplacement (yr)	Rock Temperatures °F	°C
1	122.6	50.3
3	159.8	71.0
5	177.5	80.8
10	203.0	95.0
30	241.5	116.4
50	249.1	120.6
70	248.4	120.2
100	242.3	116.8

TABLE E-4

THERMAL ANALYSIS OF PANEL ACCESS DRIFT TEMPERATURE FOR VERTICAL EMPLACEMENT

Time Since Emplacement (yr)	Rock Temperatures °F	Rock Temperatures °C
1	77.0	25.0
3	77.3	25.2
5	78.3	25.7
10	82.1	27.8
30	100.9	38.3
50	115.9	46.6
70	126.9	52.7
100	137.7	58.7

TABLE E-5

THERMAL ANALYSIS OF BOREHOLE WALL TEMPERATURE FOR HORIZONTAL EMPLACEMENT

Time Since Emplacement (yr)	Rock Temperatures °F	Rock Temperatures °C
1	333.5	167.5
2	368.3	186.8
4	405.0	207.2
7	431.4	221.9
10	446.0	230.0
20	454.3	234.6
40	418.2	214.6
60	374.5	190.3
80	337.4	169.7
100	308.2	153.4

TABLE E-6

THERMAL ANALYSIS OF EMPLACEMENT DRIFT MIDPOINT TEMPERATURE FOR HORIZONTAL EMPLACEMENT

Time Since Emplacement (yr)	Rock Temperatures °F	Rock Temperatures °C
10	79.6	26.4
30	103.8	39.9
50	128.0	53.3
70	146.2	63.5
90	159.3	70.7
110	168.5	75.8

TABLE E-7

THERMAL ANALYSIS OF PANEL ACCESS DRIFT TEMPERATURE FOR HORIZONTAL EMPLACEMENT

	Rock Temperatures			
Time Since	Point A*		Point D**	
Emplacement (yr)	°F	°C	°F	°C
10	77.3	25.2	80.8	27.1
30	83.7	28.7	104.0	40.0
50	94.4	34.7	122.7	50.4
70	104.6	40.3	134.2	56.8

*At emplacement drift intersection (Figure E-3).
**At midpoint between emplacement drifts (Figure E-3).

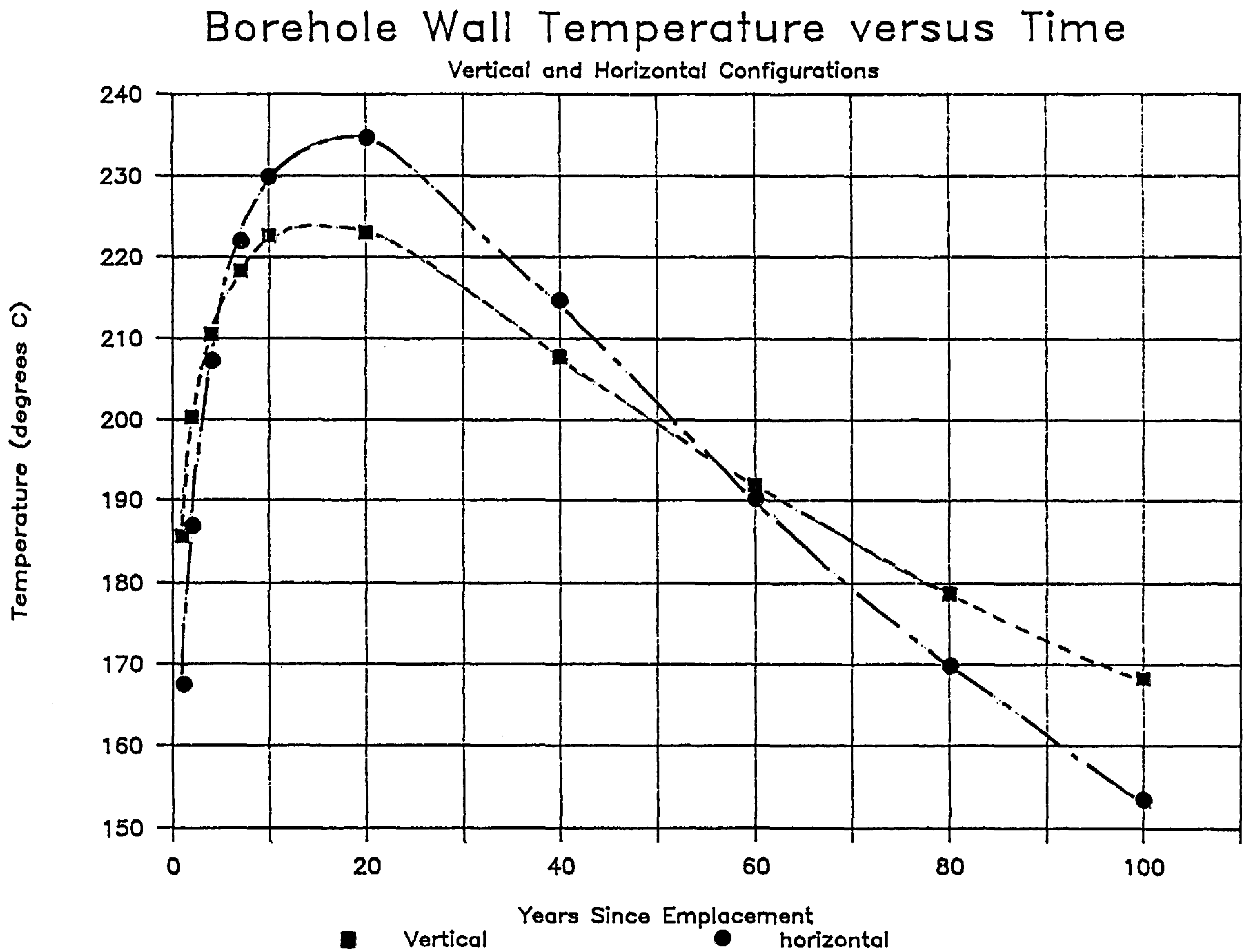


Figure E-4. Borehole Wall Temperature Versus Time

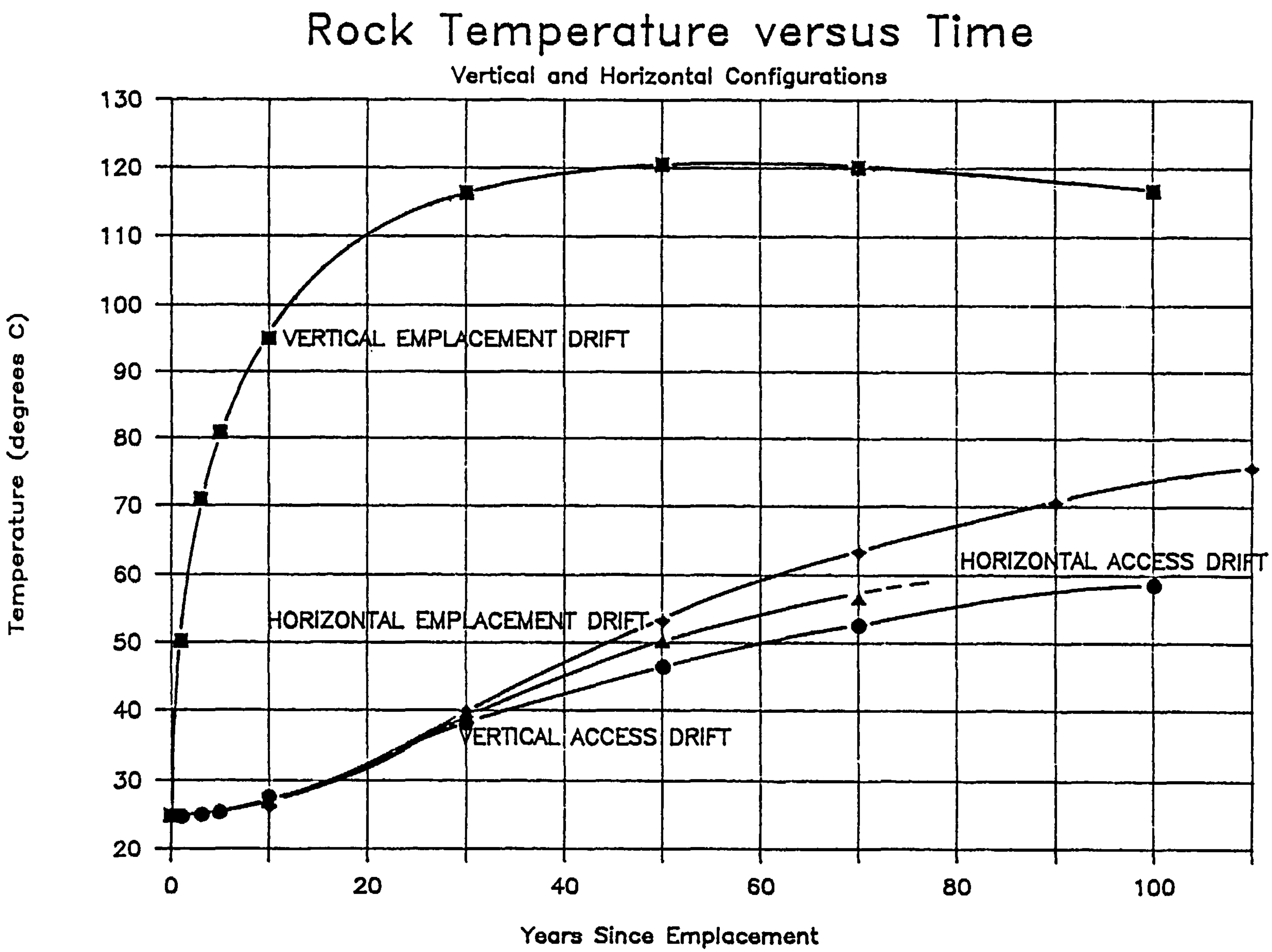


Figure E-5. Rock Temperature Versus Time

ATTACHMENT E-1

ABSTRACT FOR THE SIM PROGRAM

APPROVED DESIGN PROGRAM ABSTRACT

PROGRAM: SIM

DISCIPLINE: Geotechnical Engineering

PROGRAM NO.:

TYPE: Heat Transfer Program

Program Abstract

1. Program Name: SIM Version 1.1

   Description Title: Three-dimensional thermal analysis of a conductive medium subject to exponentially decaying thermal loading.

2. Description of Functions: Predicts the temperature at any point in a layout at any time after emplacement of the heat source.

3. Method of Solution: The code is based on the general heat conduction equation which considers the temperature due to a single finite line source as a function of time. The contribution of finite line sources in a pattern and the contribution of patterns in a layout were superimposed to find the final temperature. The numerical method used for evaluating the integrals is composite Gaussian quadrature.

4. Related Material: The system is a self-contained software package and requires no auxiliary programs or external data files.

5. Restrictions: The model assumes a homogeneous conductive medium with linear isotropic thermal characteristics. The solution ignores the presence of voids.

6. Computer: Personal computer, or VAX.

7. Running Time: Depends on the layout geometry, the chosen time after emplacement, and the type of computer. A run on an IBM-AT for a horizontal case 10 years after emplacement will take about 30 minutes.

8. Program Language: The code is written in FORTRAN 77 and compiled with the Microsoft FORTRAN compiler (version 4.1).

9. Operating System: DOS 2.1 or higher (for PC version), or VMS (for VAX version).

10. Machine Requirements: IBM PC-XT, AT, or compatible; 512 K byte RAM memory; dual diskette or diskette/hard disk combination; printer; an 8087 or 80287 coprocessor; or VAX.

APPROVED FOR USE BY See Page 2 of 2 DATE ____________

APPROVED DESIGN PROGRAM ABSTRACT

PROGRAM: SIM

DISCIPLINE: Geotechnical Engineering

PROGRAM NO.:

TYPE: Heat Transfer Program

11. Author: Ahmad Badie, Parsons Brinckerhoff Quade & Douglas, Inc., 1625 Van Ness Avenue, 4th Floor, San Francisco, CA 94109

12. References:

    (1) KE/PB, 1986. SIM: A Heat Transfer Code for Three-Dimensional Thermal Analysis of a Conductive Medium Subject to Exponentially Decaying Thermal Loading, User's/Theoretical Manual, Oakland, CA, October.

    (2) KE/PB, 1986. SIM Verification Report, Oakland, CA, October.

13. Material Available: The complete software system is on one 5-¼ in., double-sided, double-density diskette and is available through PBQD/Tuff Document Control Center, 1625 Van Ness Avenue, 4th Floor, San Francisco, CA 94109. A User's/Theoretical Manual and Verification Report are also available.

APPROVED FOR USE BY ____________________ DATE ____________

ATTACHMENT E-2

COMPARISON OF THE RESULTS WITH A DISCRETE LOAD APPROACH

This attachment presents a discrete line solution for temperature of the emplacement drift in the vertical emplacement configuration 30 yr after emplacement and compares the solution with the horizontal line sources approximation. The input data is that listed under Input Data, and the data point is shown in Figure E-1. The raw data input to SIM is shown in Table E-8, and the output is shown in Table E-9. As shown in the table, the emplacement drift temperature at 30 yr is 242.667°F (117.03°C). The calculated temperature listed in Table E-3 is 241.5°F (116.4°C). The difference of only 0.5% is acceptable for this analysis.

TABLE E-8

RAW DATA INPUT FOR SIM EXAMPLE

```
1
2 313.26 0.23 146 77.0 0 0
SF, VERTICAL EMPLACEMENT DRIFT FLOOR, PATTERN #1
1 15.63 15 126 1
174.7 10 30
177.67 -0.0013539 793.93 -0.019142 267.46 -0.051888 4462.4 -0.43768
0 0 17.82
DHLW, VERTICAL EMPLACEMENT DRIFT FLOOR, PATTERN #2
1 9.83 15 126 1
20.3 0 30
0.888 -0.02026 0.112 -0.0456 0 0 0 0
7.5 0 14.92
```

TABLE E-9

OUTPUT FROM SIM EXAMPLE RUN

```
****************************************************
****                    SIM                     ****
****        VERSION 1.1 - FEBRUARY 1987         ****
****   DEVELOPED AND MAINTAINED BY AHMAD BADIE  ****
**** C/O PBQD 1625 VAN NESS AVE. S F, CA. 94109 ****
****************************************************


*************************
*******  RUN # 1  *******
*************************


NUMBER OF PATTERN(S)         =      2
DENSITY OF MEDIUM            =    146.00 LB/CUFT
THERMAL DIFFUSIVITY OF MED.=    313.26 SQFT/YEAR
HEAT CAPACITY OF MEDIUM      =      0.23 BTU/LB DEG F
INITIAL TEMPERATURE          =   77.0000 DEG F


SF, VERTICAL EMPLACEMENT DRIFT FLOOR, PATTERN #1
VERTICAL CONFIGURATION
INPUT DATA FOR PATTERN # 1
LENGTH OF THE LINE SOURCE  =     15.63 FEET
PITCH (CONTAINERS  C/C)    =     15.00 FEET
ROW DISTANCE (ROWS  C/C)   =    126.00 FEET
WASTE AGE                  =     10.00 YEAR
TIME SINCE STORAGE         =     30.00 YEAR
HEAT LOAD                  =    174.70 WATTS/FT
HEAT DECAYING COEFF.       = 0.1675471 0.6266895 0.1521651 0.0535983
HEAT DECAYING EXPONENTS    =-0.0013539-0.0191420-0.0518880-0.4376800

  **** VALUE(S) OF TEMP. RISE FOR PATTERN # 1 ****
POINT NO.     X-COOR        Y-COOR        Z-COOR   TEM. RISE, F
    1     0.0000E+00    0.0000E+00    0.1782E+02    0.1541E+03
```

TABLE E-9

OUTPUT FROM SIM EXAMPLE RUN
(concluded)

```
DHLW, VERTICAL EMPLACEMENT DRIFT FLOOR, PATTERN #2
VERTICAL CONFIGURATION
INPUT DATA FOR PATTERN #  2
LENGTH OF THE LINE SOURCE =      9.83 FEET
PITCH (CONTAINERS  C/C)   =     15.00 FEET
ROW DISTANCE (ROWS  C/C)  =    126.00 FEET
WASTE AGE                 =      0.00 YEAR
TIME SINCE STORAGE        =     30.00 YEAR
HEAT LOAD                 =     20.30 WATTS/FT
HEAT DECAYING COEFF.      = 0.8880000 0.1120000 0.0000000 0.0000000
HEAT DECAYING EXPONENTS   =-0.0202600-0.0456000 0.0000000 0.0000000

  **** VALUE(S) OF TEMP. RISE FOR PATTERN # 2 ****
POINT NO.     X-COOR        Y-COOR        Z-COOR  TEM. RISE, F
    1     0.7500E+01    0.0000E+00    0.1492E+02    0.1160E+02



   SUM OF TEMPERATURE RISE FOR 2 PATTERN(S)
  ************************************************
      POINT NUMBER       TEMP. RISE      TOTAL TEMP.
            1             165.667         242.667

SAMP1.DAT

SAMP1.OUT


END OF OUTPUT
```

APPENDIX F

PRELIMINARY CALCULATIONS TO ESTIMATE RADON-222 CONCENTRATIONS

PRELIMINARY CALCULATIONS TO ESTIMATE RADON-222 CONCENTRATIONS

Introduction

The Nevada Nuclear Waste Storage Investigations Project staff at Sandia National Laboratories are investigating potential radiologic exposures to workers in an underground nuclear waste repository in tuff. Radon gas emanating from the tuff rock provides one potential source of radiologic exposure to repository workers. These preliminary calculations are made to predict the radon concentrations in both ventilated and unventilated drifts. This study addresses both the vertical and the horizontal emplacement configurations.

Approach

The change in the radon concentration as a function of time is given by

$$\frac{dC}{dt} = \frac{SE}{V} + \frac{QC_i}{V} - \frac{QC}{V} - \lambda C \quad , \tag{F-1}$$

where

C = the concentration of radon in the drift,
C_i = the concentration of radon in the inlet air,
S = the drift surface area,
E = the radon emanation rate,
V = the drift volume,
Q = the air flow rate,
λ = the radon decay constant, and
t = time.

Equation F-1 is solved for the ventilated and unventilated cases in Attachment 1.

Ventilated Case

For the purposes of this study, the equilibrium radon concentration in ventilated drifts is given by Equation F-8 (Attachment 1):

$$C = \frac{SE}{Q} + C_i \quad .$$

The equilibrium concentration of radon in a drift is calculated along the ventilation flow path from the intake to exhaust. By progressing in the direction of ventilation flow, the inlet concentration (C_i) will always be the concentration in the preceding drift.

Unventilated Case

The maximum concentration of radon in unventilated panel access and emplacement drifts is calculated using Equation F-4 (Attachment 1):

$$C_m = SE/\lambda V \quad .$$

The change in radon concentration with time is calculated using Equation F-5:

$$C = C_m(1 - e^{-\lambda t}) \quad .$$

Finally, the time for the concentration level to reach the limit of 1 WL is calculated using Equation F-6:

$$t = \frac{-1}{\lambda}\ln \; 1 - \frac{C}{C_m} \quad .$$

Assumptions

The following assumptions have been made for this analysis.

- Only radon-222 from uranium-238 decay is considered. Radon-220 from thorium-232 decay is not considered because of the extremely short half-life of radon-220 (55 sec). Radon-220 will be addressed in the future.

- The radon-222 emanation rate is assumed to be 0.48 pCi/m^2-sec. This value has been determined experimentally using desert soil (Nevada tuff) (Colle et al., 1981) and is considered to be conservative.

- For the ventilated case, the following assumptions have been made.

  - For the intake air, $C_i = 0$. This assumes that the radon concentration level of the intake air is at background levels.

  - Radon decay is negligible. In comparing the average air travel time of approximately 1 hr and the radon-222 half-life of 3.8 days, radioactive decay of radon-222 is negligible.

  - It is assumed that transient equilibrium has been reached in the air stream.

- The initial radon concentration C(0) is assumed to be zero.

- Radon-daughter plate-out is not considered.

- Drift dimensions and layouts are those described in the Site Characterization Plan Conceptual Design Report (SNL, 1987).

- The radon emanation into the ramp and shafts is neglected. This assumption is reasonable because the ramp and shafts are lined.

- The maximum allowable radon concentration level is 1 WL or 100 pCi/ℓ. This level is established in 30 CFR 57.5-39 (DOL, 1985).

- The airflows assumed for this study are shown in Table F-1. The airflows represent minimum allowable values, which result in worst case radon concentration levels.

- Retrieval from the last emplacement drift in Panel 9 is assumed. This results in the longest ventilated flow path and, consequently, the highest radon concentration levels. (The radon concentrations are cumulative along the flow path.)

Input Data

The following input data have been used for this analysis:

$\lambda = 2.1 \times 10^{-6}\ \text{sec}^{-1}$ and
$E = 0.48\ \text{pCi/m}^2\text{-sec}$.

Drift dimensions and airflow data are contained in Table F-1. The drift shapes are shown in Figures F-1 and F-2 for the vertical and horizontal emplacement configurations, respectively.

Results

The radon concentration levels are presented in Table F-2. For the ventilated case where workers are present, the maximum concentration of 2.2 pCi/ℓ is far below the allowable level (100 pCi/ℓ). For post-emplacement (after the emplacement drifts are placed in the controlled leakage configuration), the maximum concentration of radon is calculated at 6 pCi/ℓ.

TABLE F-1

DRIFT INPUT DATA

Drift	Perimeter[a] (ft)	Cross-sectional Area[a] (ft^2)	Length[b] (ft)	Surface Area (ft^2)	Airflow[c] (cfm)
Waste Main (Vertical)	77.5	465	10,500	813,750	50,000
Waste Main (Horizontal)	70.2	371	10,500	737,100	50,000
Panel Access	62.5	259	1,650	103,125	50,000
Emplacement (Vertical)	70.3	331	1,300	91,390	45,000[d] 20,000[e] 2,000[f]
Emplacement (Horizontal)	64.0	258	1,300	83,200	45,000[d] 20,000[e] 2,000[f]

a. Derived in Attachment 2.
b. Path assumes the last emplacement drift in Panel 9 (worst case).
c. Minimum airflows are assumed (worst case).
d. Active emplacement drift.
e. Standby emplacement drift.
f. Emplacement drift with controlled leakage.

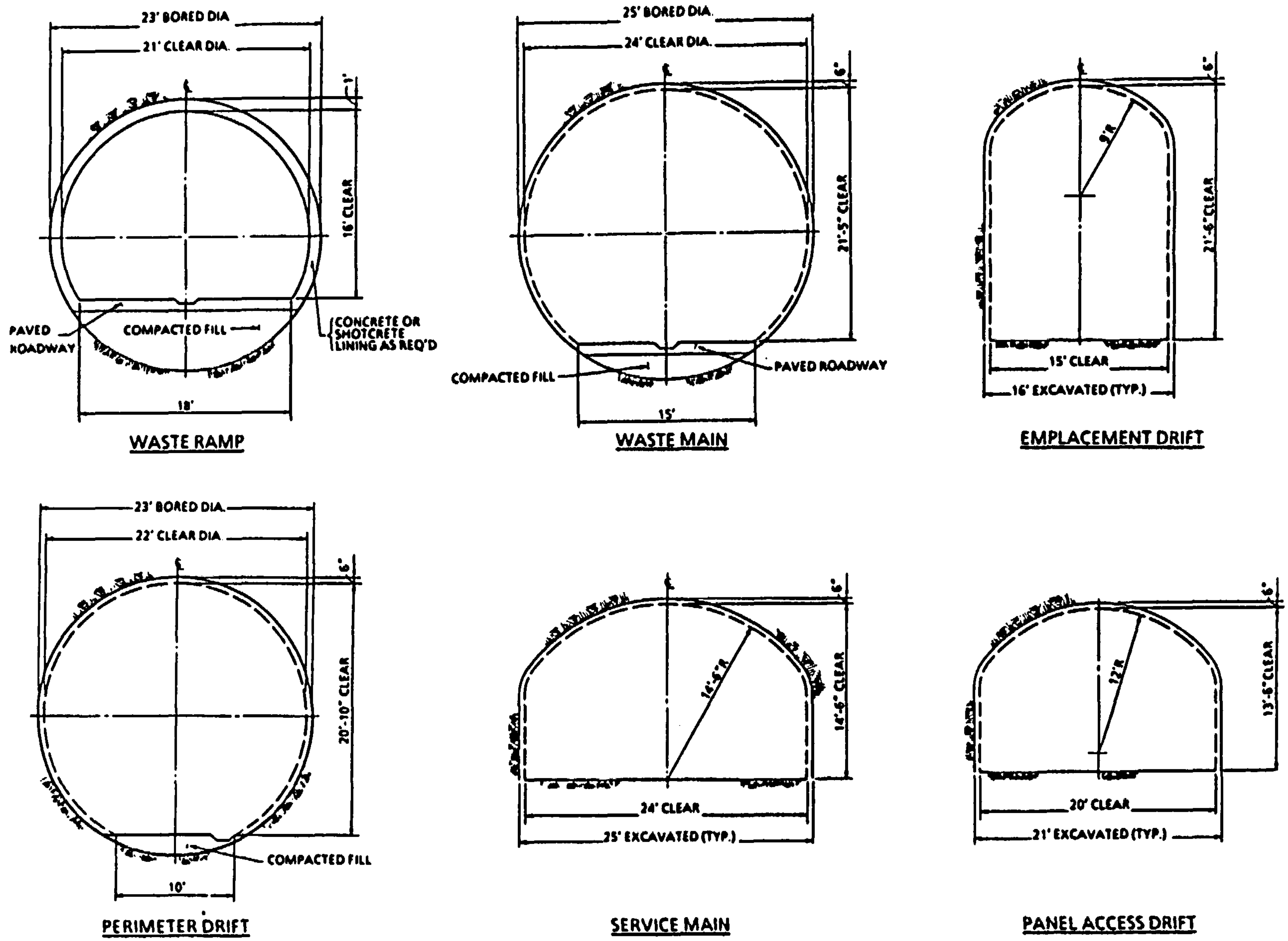


Figure F-1. Drift and Ramp Cross Sections, Vertical Emplacement Configuration

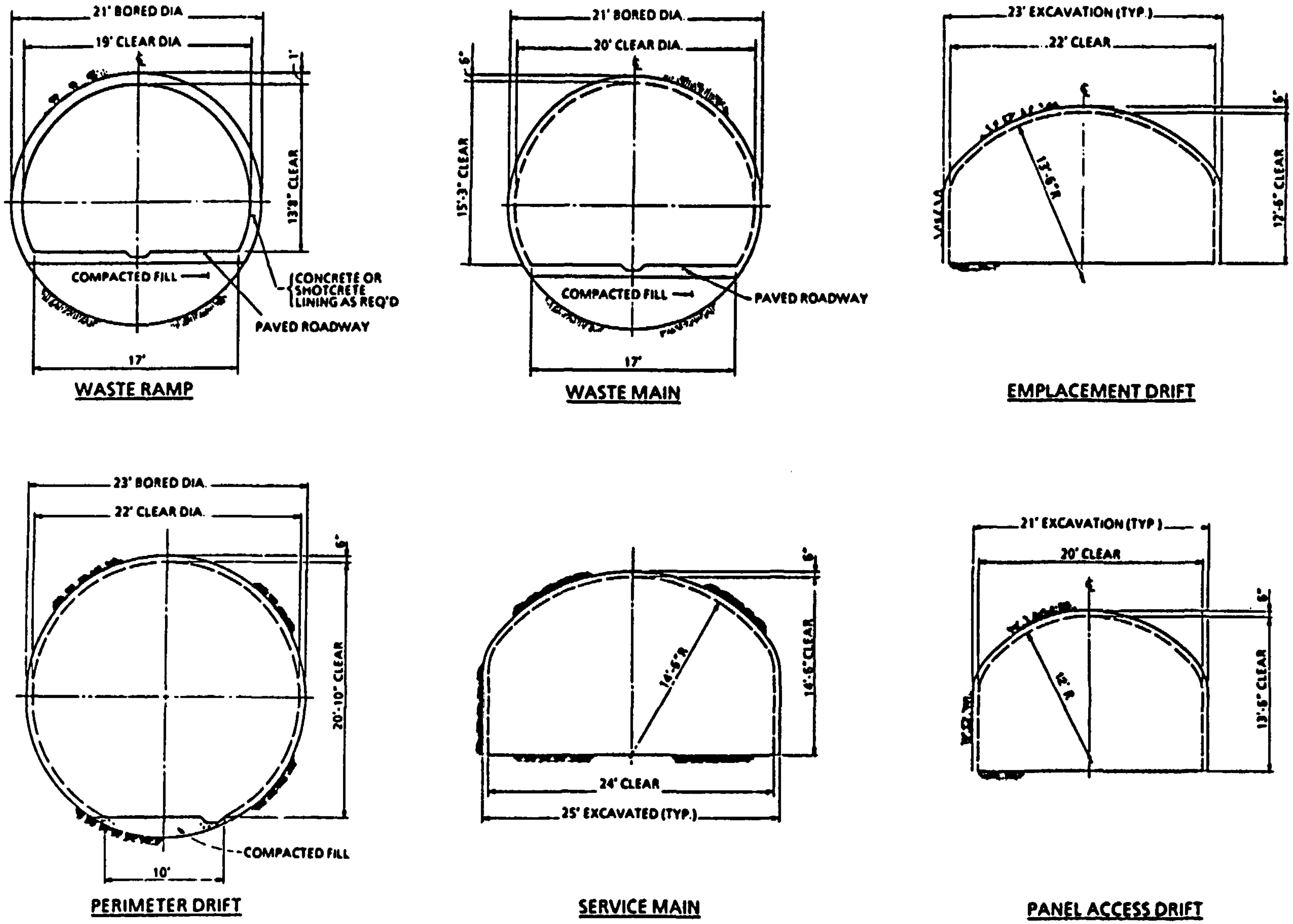


Figure F-2. Drift and Ramp Cross Sections, Horizontal Emplacement Configuration

TABLE F-2

AIRBORNE RADON CONCENTRATIONS

Drift	Ventilated[a] (pCi/ℓ)	Maximum Unventilated[b] pCi/ℓ	Time for 1 WL[c] (Days)
Waste Main (Vertical)	1.5	--	--
Waste Main (Horizontal)	1.4	--	--
Panel Access (Vertical)	1.7	181	4.4
Panel Access (Horizontal)	1.6	181	4.4
Emplacement (Vertical)	1.9[d] 2.2[e] 6.0[f]	159	5.5
Emplacement (Horizontal)	1.8[d] 2.0[e] 5.5[f]	186	4.3

a. Calculated from Equation F-8 of Attachment 1.
b. Calculated from Equation F-4 of Attachment 1.
c. Calculated from Equation F-6 of Attachment 1.
d. Emplacement or retrieval operations are in effect.
e. Drift is standby for emplacement or retrieval operations.
f. Drift is in controlled leakage configuration.

For the unventilated case the allowable levels are exceeded in approximately 5 days. A plot of the radon concentration levels for unventilated emplacement drifts is shown in Figure F-3.

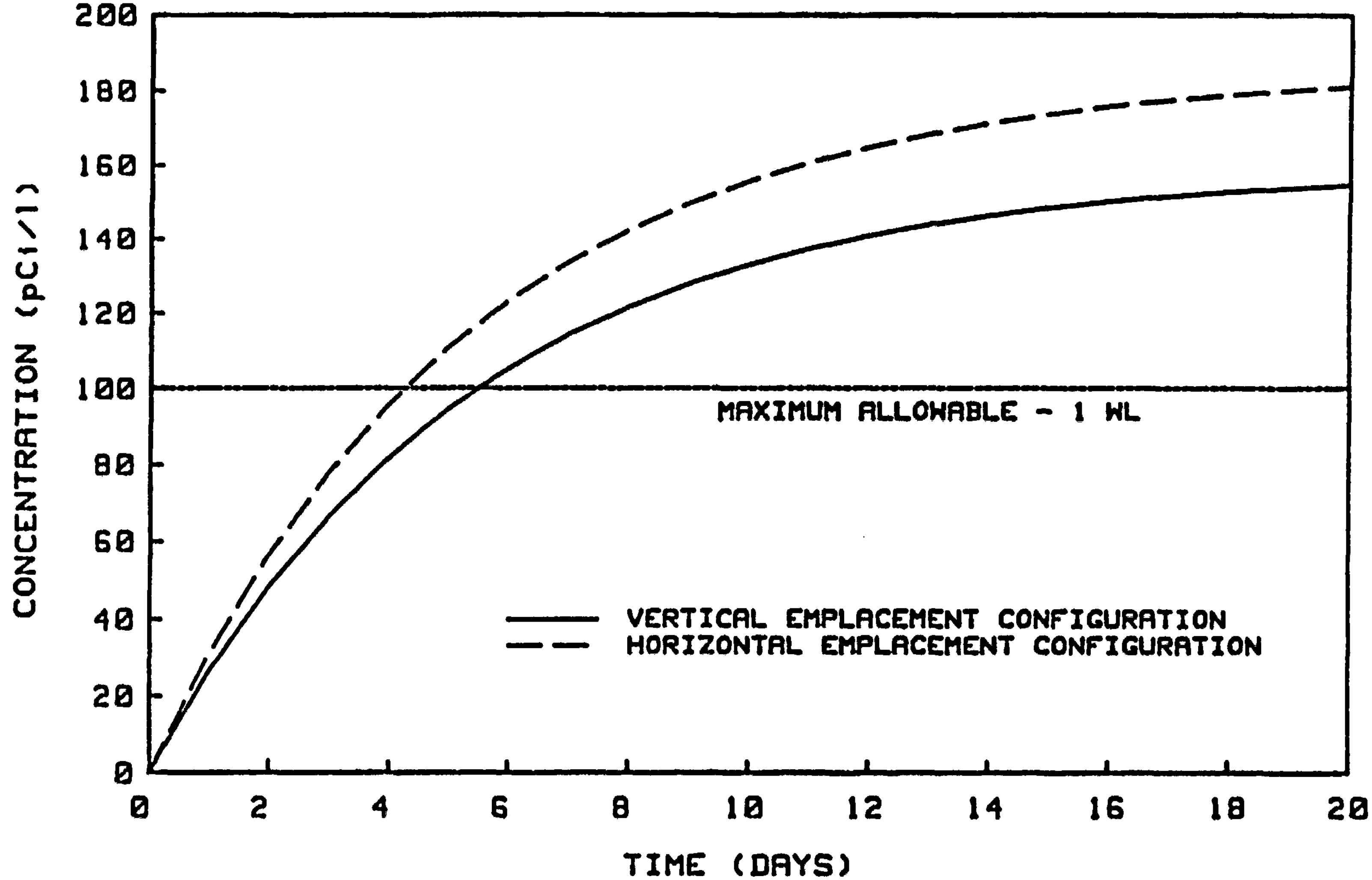


Figure F-3. Radon Concentration Levels for Unventilated Emplacement Drifts

REFERENCES FOR APPENDIX F

Colle, R., R. J. Rubin, L. I. Knab, and J. M. R. Hutchinson,"Radon Transport Through and Exhalation From Building Materials: A Review and Assessment," National Bureau of Standards Technical Note 1139, U.S. Department of Commerce, Washington, D.C., September 1981. (NNA.900702.0021)

DOL (U.S. Department of Labor), "Safety and Health Standards--Underground Metal and Nonmetal Mines," Code of Federal Regulations, Mineral Resources, Title 30, Part 57, Washington, D.C., July 1985. (NNA.890411.0039)

SNL (Sandia National Laboratories), "Site Characterization Plan Conceptual Design Report," SAND84-2641, compiled by H. R. MacDougall, L. W. Scully, and J. R. Tillerson, Sandia National Laboratories, Albuquerque, NM, September 1987. (NNI.880902.0014-.0019)

ATTACHMENT 1

DERIVATION OF CONCENTRATION EQUATIONS

Assuming $C(0) = 0$, the solution to Equation F-1 (p. F-1) is

$$C(t) = \frac{SE + QC_i}{\lambda V + Q} \left[1 - e^{-\left(\lambda + \frac{Q}{V}\right)t} \right] . \tag{F-2}$$

<u>Unventilated Case</u>

For the unventilated case the airflow is zero ($Q = 0$). From Equation F-2,

$$C(t) = \frac{SE}{\lambda V} \left[1 - e^{-\lambda t} \right] . \tag{F-3}$$

The maximum concentration (C_m) is given by

$$C_m = \frac{SE}{\lambda V} . \tag{F-4}$$

Then,

$$C(t) = C_m (1 - e^{-\lambda t}) . \tag{F-5}$$

Solving for time,

$$t = \frac{-1}{\lambda} \ln \left[1 - \frac{C(t)}{C_m} \right] . \tag{F-6}$$

<u>Ventilated Case</u>

Assuming that equilibrium has been obtained, the exponential approaches zero and Equation F-2 becomes

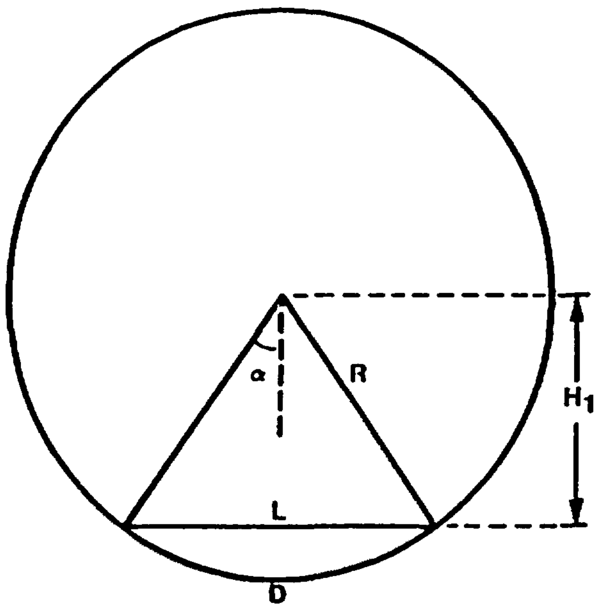
$$C = \frac{SE + QC_i}{\lambda V + Q} . \tag{F-7}$$

Assuming that decay of the radon is negligible, $\lambda V \ll Q$ and Equation F-7 reduces to

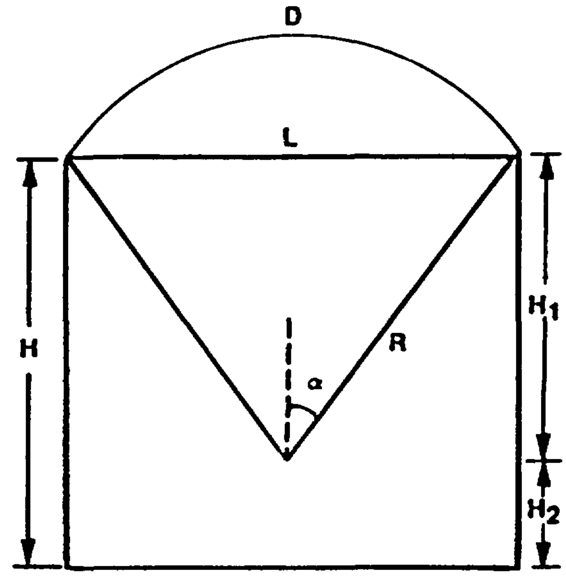
$$C = \frac{SE}{Q} + C_i . \tag{F-8}$$

ATTACHMENT 2

GEOMETRIC COMPUTATIONS



Waste Main



Emplacement and Access Drifts

General Relationships:

$$\sin\alpha = \frac{L}{2R} \qquad \tan\alpha = \frac{L}{2H_1} \qquad \frac{D}{\alpha} = \frac{2\pi R}{180°}$$

Reorganizing:

$$\alpha = \sin^{-1}\left(\frac{L}{2R}\right) \qquad H_1 = \frac{L}{2}\cot(\alpha) \qquad D = \frac{2\pi R\alpha}{180°}$$

Waste Main:

Perimeter	Area
$P = 2\pi R - D + L$	$A = \pi R^2\left(1 - \frac{\alpha}{180°}\right) + \frac{LH_1}{2}$

Emplacement and Access Drifts:

Perimeter	Area
$P = 2H + L + D$	$A = \pi R^2\left(\frac{\alpha}{180°}\right) + L\left(\frac{H_1}{2} + H_2\right)$

RESULTS OF GEOMETRIC COMPUTATIONS FOR DRIFT PERIMETERS AND AREAS

Drift	L(ft)	R(ft)	α	H_1(ft)	H_2(ft)	H(ft)	D(ft)	P(ft)	A(ft^2)
Waste Main (Vertical)	15	12.5	36.87	10	--	--	16.1	77.5	465
Waste Main (Horizontal)	17	11.5	47.66	7.75	--	--	19.1	70.2	371
Access Drift	21	12.5	57.1	6.8	1.5	8.3	24.9	62.5	259
Emplacement (Vertical)	16	9.5	57.4	5.1	12.5	17.6	19.0	70.3	331
Emplacement (Horizontal)	23	14	55.2	8.0	-1.0	7.0	27.0	64.0	258

APPENDIX G

RADIATION SHIELDING SCOPING CALCULATIONS

RADIATION SHIELDING SCOPING CALCULATIONS

Introduction

The purpose of this scoping analysis is to make preliminary estimates of radiation shielding requirements for the transporter cask, borehole shield plug, and shielding closures. Both the vertical and horizontal emplacement configurations and two spent fuel arrangements in the waste container are considered. This analysis also investigates the dose rate through the rock from the emplaced waste for normal conditions and the potential abnormal condition where a waste container is detained at the mouth of the borehole. Materials considered for the transporter cask are lead and borated polyethylene. For the shield plug and shielding closure, steel and concrete are considered.

These preliminary scoping calculations are based on source terms from the Site Characterization Plan Conceptual Design Report (SCP-CDR) (SNL, 1987) and simple analytical models as discussed in the next section. This approach is adequate for obtaining shielding estimates that would serve as bases for more rigorous analysis using appropriate discrete ordinates transport and Monte Carlo codes.

Approach

To calculate shielding thicknesses, an allowable dose rate must be specified. This scoping analysis assumes 2 mrem/hr, based on the design objective of (draft) DOE Order 5480.11, Section 8e(2) (DOE, 1985), which specifies that the maximum potential exposure to a worker in areas where occupancy is not continuous is 1 rem/yr. If one assumes that a worker will be in areas subject to radiation exposure one-fourth of the time and that he works 2,000 hr/yr, his exposure rate must be limited to 2 mrem/hr to limit the annual dose to 1 rem. Radiation exposure one-fourth of the time is considered to be extremely conservative. Many operational tasks and task durations remain to be determined, especially regarding maintenance and repair functions in the emplacement drifts. The driver of the waste transporter can be shielded, but further analysis is needed to estimate how frequently and how long other workers might be needed in the vicinity of the loaded transporter for both normal operations and equipment failures.

For the shielding calculations, an allowable dose rate must be assigned to both photons and neutrons. Such factors as shielding size, weight, and cost are very sensitive to assignments of allowable dose rate contributions. Criteria for these factors have not yet been established. As a starting point for the calculations, an arbitrary assignment of 1 mrem/hr was made for both neutrons and photons. This assignment resulted in fairly thick polyethylene and concrete shields, and, in the absence of criteria, it was decided not to change the assignment for this preliminary scoping analysis. For final shielding design calculations, dose rate contributions from photons and neutrons will be determined by optimizing such factors as cost, thickness, and weight. Such a sensitivity analysis is beyond the scope of these calculations.

Various calculational models may be used for this analysis. For these scoping calculations, the waste container is treated as a line source. This is a conservative approach, which permits reasonably simple calculations. This approach is demonstrated for on-axis calculations in Attachment 1, which gives a comparison of the line source model and a more rigorous disk model that takes self-attenuation and build-up within the shield into account. For the specific geometry evaluated in Attachment 1, the on-axis line source model results in a 16% greater shielding thickness than the more rigorous approach. It is assumed that the line source model is similarly adequate for off-axis calculations (Assumption 3).

Transporter Cask Shielding Thicknesses

A schematic diagram of the transporter cask is shown in Figure 1. This analysis will determine the end and side shielding thicknesses that reduce the dose rate 2 ft from these surfaces (Detector Points 1 and 4, respectively, in Figure 1) to 2 mrem/hr. A composite shield is required because both photons and neutrons are emitted. For this analysis, the neutrons will be shielded by borated polyethylene (5 wt% boron) and the photons by the combination of lead and the borated polyethylene. Because the outer material has a greater circumference than the inner material, weight considerations make surrounding the lead with the polyethylene preferable.

Initially unshielded dose rates are calculated at four detector points (Figure 1). Because Detector Point 4 yields the largest unshielded dose rate, it is used to establish the side shielding thickness. Detector Point 1 is used to determine the end shielding thickness (Figure 1). At these two detector points, the thickness of the borated polyethylene needed to attenuate neutrons to 1 mrem/hr is calculated first; this result is

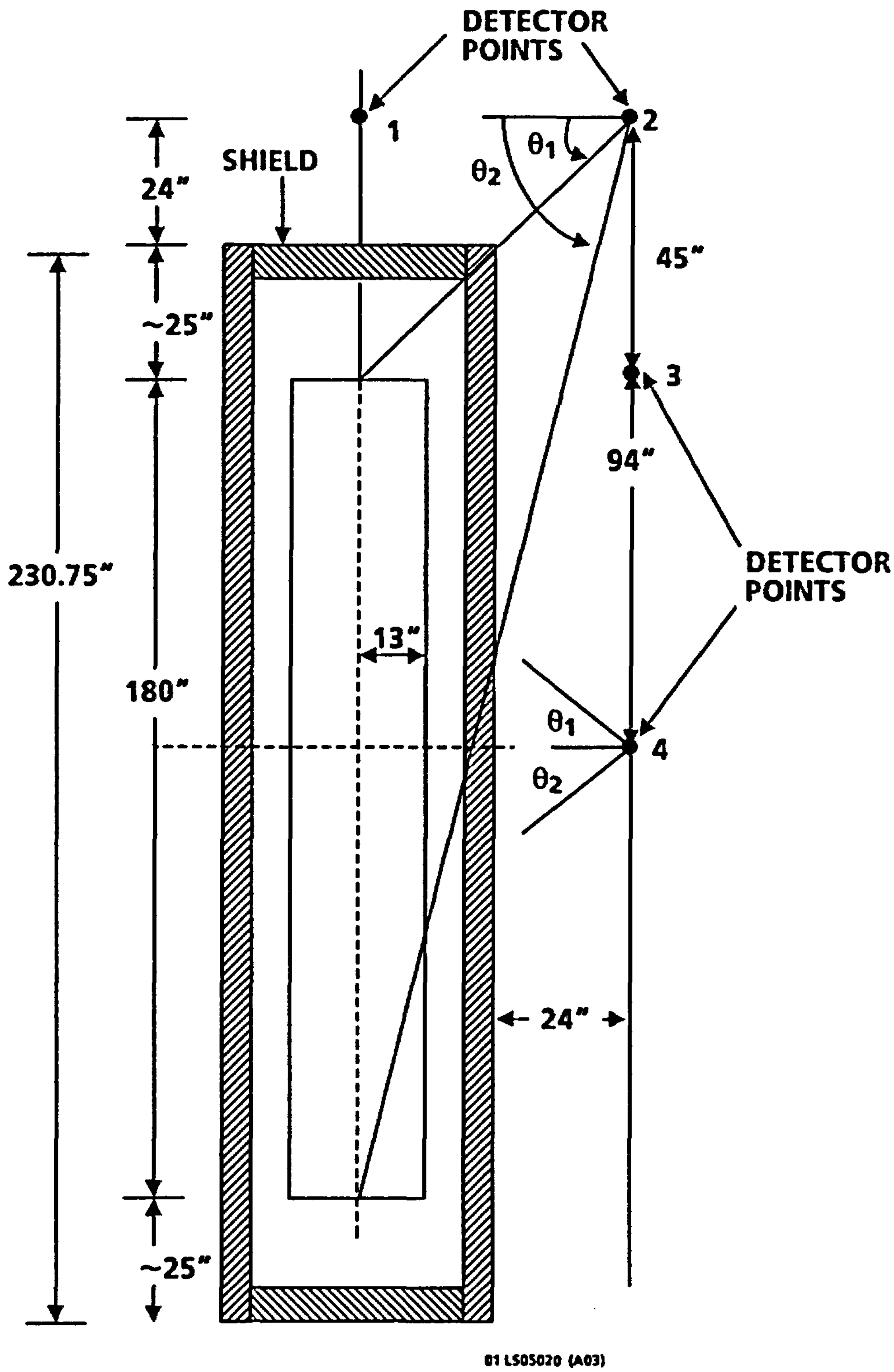


Figure 1. Transporter Cask Geometry

then factored into the calculations to determine the thickness of lead needed to attenuate the gamma photons to 1 mrem/hr. This results in a total shielded dose rate of 2 mrem/hr.

As discussed above, the waste container is treated as a line source. For calculating dose rates at Detector Points 2 and 3 in Figure 1, Equation 1 applies; at Detector Point 4 in Figure 1, Equation 2 applies (ANS/SD, 1976).

$$DR = \frac{BQ(DF)}{4\pi a L}[F(\theta_2, b) - F(\theta_1, b)]. \tag{1}$$

$$DR = \frac{BQ(DF)}{2\pi a L}[F(\theta, b)]. \tag{2}$$

The terms in these equations are explained in Table 1 and Figure 1.

TABLE 1

TERMS USED IN THE LINE-SOURCE EQUATIONS

B	=	buildup factor. This is set to unity in order to simplify the calculations and to partially offset the conservatism of neglecting self-attenuation.
DR	=	dose rate (rem/hr)
Q	=	source strength (photons/sec or neutrons/sec)
DF	=	flux-to-dose factor (rem/hr per unit flux, where flux = photon/cm^2-sec or neutrons/cm^2-sec)
a	=	perpendicular distance from the line source to the detector point
L	=	length of line source (15 ft)
μ	=	linear absorption coefficient of shield
t	=	shield thickness
$F(\theta,b)$	=	$\int_0^{\theta} e^{-b \sec \theta} d\theta$
b	=	$\sum \mu_i t_i$
d	=	distance from the top of the line source to the detector

For calculating the dose rate at a point along the axis of the line source (detector point 1 in Figure 1), an equation must be derived (see Attachment 1). The result is

$$DR = \frac{BQ\,(DF)\,e^{-\mu t}}{4\pi d\,(L+d)} \; . \tag{3}$$

For the specified geometry and dose rate goal, all parameters in the above equations are known except for the shielding thickness. An initial thickness is assumed, and the equation is solved iteratively by increasing the thickness incrementally until the calculated dose rate is within an acceptable range. For the dose rate contribution from neutrons or photons, the following criterion is used:

0.99 mrem/hr $\leq$ DR $\leq$ 1.01 mrem/hr.

Shield Plug and Shielding Closure Thicknesses

Figure 2 is a schematic diagram of the borehole for both the vertical and horizontal emplacement configurations. (Measurements are made from the drift floor for the vertical emplacement configuration and from the drift wall for the horizontal. For ease of discussion, reference is made consistently to measurements from the drift wall.) This analysis will determine the thickness necessary for the shield plug and shielding closure to reduce the dose rate to 2 mrem/hr at the borehole centerline, 2 ft from the drift wall (Detector Point 1).

As discussed above, a composite shield is needed. For this analysis, the neutrons will be shielded by concrete and the photons by the combination of steel and concrete. For the calculational methods used in this analysis, it makes no difference which type of shielding material is on top. More rigorous analysis would be expected to determine the most advantageous configuration. Calculations are performed using Equation 3 as described for the transporter cask. Shielding thicknesses are calculated for various standoff distances (distance from the end of the waste package nearest the drift to the drift surface). For horizontal emplacement, the standoff distances used are 0, 6, 20, and 134 ft; for vertical emplacement, a 10-ft standoff is used. Future work should include a trade-off analysis for increasing this vertical standoff distance.

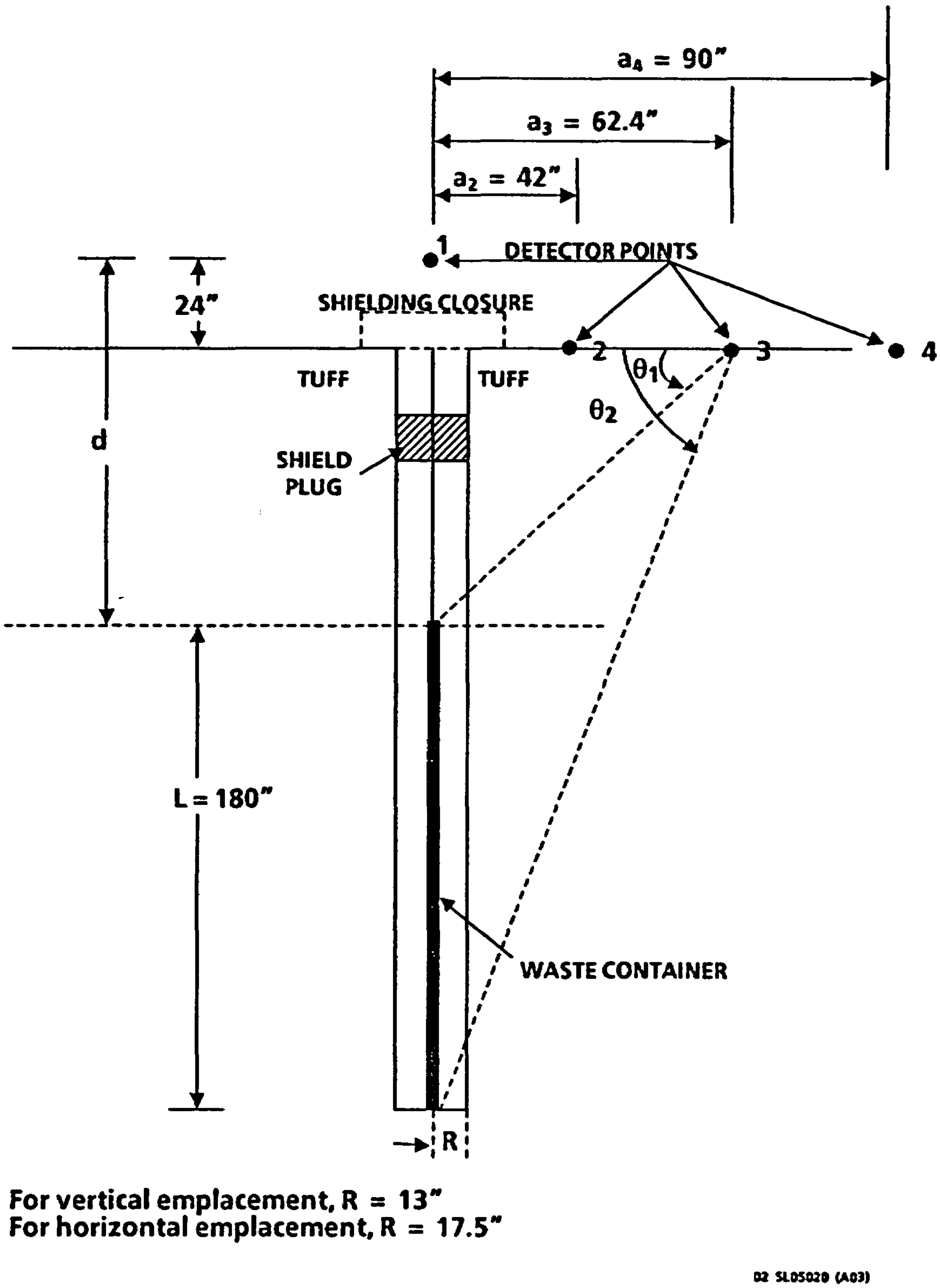


Figure 2. Borehole Geometry

In addition to calculating shielding thicknesses that attenuate the radiation dose rate to 2 mrem/hr (at Detector Point 1 in Figure 2), dose rates are calculated at three arbitrary points on the drift wall (Detector Points 2, 3, and 4 in Figure 2). This is done to ensure that radiation is sufficiently attenuated by the tuff to meet the 2-mrem/hr criterion.

Shielding Closure Radius

Calculations are made for both horizontal and vertical emplacement and for various standoff distances to determine the shielding closure radius needed to limit the dose rate at the drift wall to 2 mrem/hr. The design of the shielding closure cannot take credit for any shielding by the shield plug because the plug generally will not be in place when the closure is present. For horizontal emplacement, standoff distances of 0, 6, 20, and 134 ft are considered; for vertical emplacement, 0 and 10 ft are considered. (The 134-ft standoff distance is the reference case for horizontal emplacement in the SCP-CDR.) The 0-ft standoff corresponds to the potential abnormal condition where a waste container is detained at the mouth of the borehole. Calculations are performed using Equation 1. Thicknesses for the concrete and steel in the shielding closure are known from the previous calculations. The only unknowns in Equation 1 are the angles θ_1 and θ_2 (Figure 2). These angles are determined at that radial distance from the borehole along the drift wall at which the shielding closure is no longer needed to supplement attenuation by the tuff to meet the 2-mrem/hr criterion. An initial radial distance (shielding closure radius) is assumed from which θ_1 and θ_2 are calculated, and the equation is solved iteratively by increasing the radial distance incrementally until the calculated dose rate is

$$1.99 \text{ mrem/hr} \leq DR \leq 2.01 \text{ mrem/hr}.$$

Assumptions

The following assumptions have been made for this analysis.

1. Spent fuel assemblies will be packaged intact or consolidated. It is assumed that fuel burnup is 33,000 and 27,500 MWd/MTU for the PWR and BWR fuel, respectively, and that the fuel has been out of the reactor 10 yr (SCP-CDR, Appendix P). For these cases, the worst-case intact waste package is a hybrid

container with three pressurized water reactor (PWR) assemblies and four boiling water reactor (BWR) assemblies, and the worst-case consolidated waste package contains six PWR assemblies.

2. It is assumed that some underground workers will be exposed to the design-basis dose rate one-fourth of the time. This is considered to be extremely conservative. Working 2,000 hr/yr, the design objective annual dose of 1 rem/hr (DOE Order 5480.11) would be reached with an average dose rate of 2 mrem/hr. For this scoping analysis, 2 mrem/hr is the assumed design-basis dose rate.

3. For these preliminary scoping calculations, it is reasonable to neglect self-attenuation and buildup and to treat the waste package as a line source. To test this assumption, calculations are made in Attachment 1 for an on-axis geometry using a more rigorous model, which includes build-up and treats the waste container as a series of disks, thereby taking self-attenuation into account. As shown in Attachment 1, use of the line source model for the particular geometry considered gives conservative results. It is assumed that the line source model is similarly adequate for off-axis calculations.

4. The photon and neutron attenuation coefficients for tuff are assumed to be the same as for concrete. For photons, this assumption is based on comparable densities for tuff and concrete: tuff--2.3 g/cm^3 (SCP-CDR, Chapter 2); concrete, siliceous--2.25-2.4 g/cm^3 (ANS/SD, 1976, Table 1.3). For neutrons, this assumption is not as firm because of differing water contents between the tuff and the concrete. For the Topopah Spring Member, which will contain the emplaced waste, the porosity is 0.12 ± 0.3 (SCP-CDR, Table 2-4). This is the ratio of volume of void space to total volume. The in situ saturation is 65 ± 19% (SCP-CDR 2.2.4.2). Assuming the lower limit for saturation, the water content for tuff would be 0.12 x 0.46 = 0.06, or 6% by volume. For concrete with a 3-in. slump, water volume percent varies from approximately 8% to 20% depending on the aggregate size (Meritt, 1976, Figure 5-2). It thus appears that it would be more accurate to use a lower attenuation coefficient for tuff than that assumed. However, as shown in Results, in all cases where the shielding consists of

tuff, dose rates are insignificant and thus a more accurate neutron attenuation coefficient for tuff would not materially affect the result.

Input Data

Figures 1 and 2 show geometrical constants and parameters for the transporter cask and borehole, respectively. The borehole schematic is general and applies to the horizontal and vertical boreholes, where either the shield plug or the shielding closure is in place, and to different standoff distances of the waste container from the borehole opening. The standoff distances analyzed are 0, 6, 10, 20, and 134 ft. The case of a 0-ft standoff is the assumed abnormal situation where the waste package is detained just inside the horizontal borehole.

Photon and neutron source strengths per MTU for the fuel used in these calculations (see Assumption 1) are given in Tables 3.18, 3.20, 3.26, and 3.28 of Roddy et al. (1986). These values are converted to photons/second and neutrons/second per assembly using the factors 0.52 MTU/PWR assembly and 0.20 MTU/BWR assembly (SCP-CDR, Appendix P). Photon source terms are shown in Table 2. The neutron source term for the hybrid container is 3.9×10^8 n/s and for the consolidated container is 5.8×10^8 n/s.

For each of the photon energy groups listed in Table 2, linear attenuation coefficients and flux-to-dose factors are given in Table 3.

As seen in Tables 2 and 3, source strengths are relatively high at lower photon energies, but so are attenuation coefficients. At higher photon energies, attenuation is lower, but so are the source strengths. Considering source strength, attenuation, and flux-to-dose factors, only the 1.25-, 1.75-, and 2.25-MeV photons contribute significantly to dose rate (Attachment 1).

Linear attenuation coefficients for the 1.25-, 1.75-, and 2.25-MeV photons in borated polyethylene are as follows (NSRDS-NBS, 1969, Table 3.-34):

μ (1.25) = 0.066 cm^{-1}
μ (1.75) = 0.055 cm^{-1}
μ (2.25) = 0.048 cm^{-1}.

TABLE 2

WASTE PACKAGE GAMMA RADIATION LEVELS

	Total Source Strength (photons/s)	
Photon Mean Energy (MeV)	Hybrid Container[a]	Consolidated Container[b]
0.575	7.28E+15	1.03E+16
0.85	5.70E+14	8.27E+14
1.25	5.18E+14	8.24E+14
1.75	6.86E+12	9.77E+12
2.25	1.54E+11	2.27E+11
2.75	1.02E+10	1.49E+10

a. The hybrid container holds three PWR and four BWR assemblies.
b. The consolidated container holds six consolidated PWR assemblies

TABLE 3

LINEAR ATTENUATION COEFFICIENTS AND FLUX-TO-DOSE FACTORS[a]

Photon Energy (MeV)	μ - Lead[b]	μ - Concrete[b]	μ - Steel[b]	Flux-to-Dose Factor[c]
0.575	1.42	0.19	0.62	1.32E-06
0.85	0.90	0.16	0.51	1.76E-06
1.25	0.67	0.13	0.43	2.3E-06
1.75	0.54	0.11	0.36	2.93E-06
2.25	0.50	0.098	0.32	3.45E-06
2.75	0.48	0.089	0.30	3.98E-06

a. Tables 3.-16, 3.-22, and 3.-28, NSRDS-NBS, 1969; and Table 3, ANSI/ANS, 1977.

b. Values for μ given in NSRDS-NBS, 1969 are in cm^2/g. These are multiplied by the following densities to get cm^{-1}.

lead: 11.3 g/cm^3
concrete: 2.3 g/cm^3
steel: 7.9 g/cm^3

c. (rem/hr)/(photons/cm^2-s)

Tables 3.18 and 3.20 of Roddy et al. (1986) show that spontaneous fission of Cm-244 accounts for about 98% of neutron production. Based on data in ICRP38, the average neutron energy for Cm-244 is approximately 2.0 MeV. For this neutron energy, the flux-to-dose factor is 1.26 E-04 (rem/hr)/(n/cm^2-s) (ANSI/ANS, 1977, Table 1). The dose decade length (thickness required to reduce the dose by a factor of 10) for concrete is 25.4 cm and for polyethylene with 5 wt% boron, it is 16.8 cm (AEC, 1973, Figure 8.12). These dose decade lengths can be converted to linear attenuation coefficients as follows:

$$e^{-\mu t} = .1, \text{ where } t = 1 \text{ dose decade length as described above}$$

$$-\mu t = \ln(.1) = -2.3.$$

Thus,

$$\mu = 2.3/t \text{ and}$$

$$\mu \text{ (concrete)} = 0.0905 \text{ cm}^{-1}$$

$$\mu \text{ (borated polyethylene)} = 0.137 \text{ cm}^{-1}.$$

Calculations

Attachments 2, 3, and 4 are the computer codes used for calculations. Attachment 5 documents the verifications of these codes.

Results

Transporter Cask

To reduce dose rates to 2 mrem/hr at 2 ft from the transporter cask, the following shield thicknesses are calculated.

	Hybrid		Consolidated	
	Lead	Borated Polyethylene (5% boron)	Lead	Borated Polyethylene (5% boron)
		-		-
Transporter cask thickness--side (cm)	18.0	31.4	18.4	34.0
Transporter cask thickness--end (cm)	18.5	29.1	18.9	32.0

At the four detector points in Figure 1, the following shielded and unshielded dose rates are calculated.

HYBRID CONTAINER

	DP 1	DP 2	DP 3	DP 4
Shielded Dose Rates (mrem/hr)				
Gamma Dose	1.0E + 00	3.1E - 04	3.8E - 01	1.0E + 00
Neutron Dose	1.0E + 00	1.8E - 02	4.3E - 01	1.0E + 00
Total Dose	2.0E + 00	1.9E - 02	8.0E - 01	2.0E + 00
Unshielded Dose Rates (mrem/hr)				
Gamma Dose	1.3E + 06	9.7E + 05	2.1E + 06	3.6E + 06
Neutron Dose	5.4E + 01	3.9E + 01	8.4E + 01	1.5E + 02
Total Dose	1.3E + 06	9.7E + 05	2.1E + 06	3.6E + 06

CONSOLIDATED CONTAINER

	DP 1	DP 2	DP 3	DP 4
Shielded Dose Rates (mrem/hr)				
Gamma Dose	1.0E + 00	2.6E - 04	3.7E - 01	1.0E + 00
Neutron Dose	1.0E + 00	1.6E - 02	4.3E - 01	1.0E + 00
Total Dose	2.0E + 00	1.6E - 02	8.1E - 01	2.0E + 00
Unshielded Dose Rates (mrem/hr)				
Gamma Dose	2.1E + 06	1.5E + 06	3.3E + 06	5.8E + 06
Neutron Dose	8.0E + 01	5.9E + 01	1.3E + 02	2.2E + 02
Total Dose	2.1E + 06	1.5E + 06	3.3E + 06	5.8E + 06

Design of the transporter cask will entail analysis of many factors not considered in this preliminary study, such as structural and thermal considerations. Alternatives should be considered to reduce size, weight, and cost.

Shield Plug and Shielding Closure Thicknesses

To reduce the dose rate to 2 mrem/hr at a point 2 ft from the drift wall along the borehole centerline, shield plug and shielding closure thicknesses are calculated as follows:

	Shield Plug and Shielding Closure Thickness (cm)			
	Hybrid		Consolidated	
	Steel	Concrete	Steel	Concrete
Horizontal Emplacement				
Standoff: 6 ft	20.6	34.7	20.4	39.1
Standoff: 20 ft	22.1	18.2	21.8	22.6
Standoff: 134 ft	18.6	0.0	19.8	0.0
Vertical Emplacement				
Standoff: 10 ft	21.2	28.4	20.9	32.8

At the four detector points in Figure 2, the following shielded dose rates are calculated.

HYBRID CONTAINER

	DP 1	DP 2	DP 3	DP 4
Horizontal Emplacement				
Standoff: 6 ft				
Gamma Dose	1.00E + 00	8.34E - 03	1.19E - 05	6.94E - 09
Neutron Dose	9.94E - 01	4.91E - 05	3.67E - 07	1.03E - 09
Total Dose	2.00E + 00	8.39E - 03	1.22E - 05	7.97E - 09
Standoff: 20 ft				
Gamma Dose	1.00E + 00	2.57E - 15	1.93E - 19	1.44E - 22
Neutron Dose	9.91E - 01	2.62E - 15	5.02E - 19	6.92E - 22
Total Dose	1.99E + 00	5.19E - 15	6.96E - 19	8.37E - 22
Standoff: 134 ft				
Gamma Dose	1.78E + 00	0.00E + 00	0.00E + 00	0.00E + 00
Neutron Dose	2.05E - 01	0.00E + 00	0.00E + 00	0.00E + 00
Total Dose	1.98E + 00	0.00E + 00	0.00E + 00	0.00E + 00

Vertical Emplacement				
Standoff: 10 ft				
Gamma Dose	1.01E + 00	1.94E - 08	7.24E - 11	2.05E - 13
Neutron Dose	9.94E - 01	2.18E - 09	2.14E - 11	1.36E - 13
Total Dose	2.00E + 00	2.16E - 08	9.39E - 11	3.40E - 13

	CONSOLIDATED CONTAINER			
	DP 1	DP 2	DP 3	DP 4
Horizontal Emplacement				
Standoff: 6 ft				
Gamma Dose	1.00E + 00	1.30E - 02	1.81E - 05	1.02E - 08
Neutron Dose	9.93E - 01	7.31E - 05	5.45E - 07	1.53E - 09
Total Dose	2.00E + 00	1.31E - 02	1.86E - 05	1.18E - 08
Standoff: 20 ft				
Gamma Dose	1.02E + 00	3.75E - 15	2.84E - 19	2.13E - 22
Neutron Dose	9.90E - 01	3.90E - 15	7.47E - 19	1.03E - 21
Total Dose	2.01E + 00	7.65E - 15	1.03E - 18	1.24E - 21
Standoff: 134 ft				
Gamma Dose	1.69E + 00	0.00E + 00	0.00E + 00	0.00E + 00
Neutron Dose	3.05E - 01	0.00E + 00	0.00E + 00	0.00E + 00
Total Dose	1.99E + 00	0.00E + 00	0.00E + 00	0.00E + 00
Vertical Emplacement				
Standoff: 10 ft				
Gamma Dose	1.00E + 00	2.88E - 08	1.06E - 10	2.98E - 13
Neutron Dose	9.43E - 01	3.24E - 09	3.19E - 11	2.02E - 13
Total Dose	2.00E + 00	3.20E - 08	1.38E - 10	5.00E - 13

These results indicate insignificant radiation exposures except in the immediate vicinity of the shield plug and shielding closure. Because of the conservative 2-mrem/hr criterion used to calculate the above shielding thicknesses, these results should be considered upper bounds.

Shielding Closure Radii

To reduce dose rates to 2 mrem/hr at the surface of the drift, the following shielding closure radii are calculated.

Shield Closure Radius (cm)

	Hybrid	Consolidated
Horizontal		
Standoff: 0 ft	141.0	144.2
Standoff: 6 ft	76.7	78.7
Standoff: 20 ft	50.6	50.9
Vertical		
Standoff: 0 ft	130.2	133.4
Standoff: 10 ft	44.5	45.2

The 0-ft standoff is for the potential abnormal condition where the waste container is detained at the mouth of the borehole. For such a low-probability event, a special shielding overpack for the shielding closure would be cost effective. Again, these radii should be considered upper bounds because of the conservative 2-mrem/hr criterion used for this analysis.

REFERENCES FOR APPENDIX G

AEC (U.S. Atomic Energy Commission), "Reactor Shielding for Nuclear Engineers," TID-25951, N. M. Schaeffer, ed., USAEC Technical Information Center, Oak Ridge, TN, 1973. (NNA.900515.0011)

ANSI/ANS-6.1.1, "American National Standard Neutron and Gamma-Ray Flux-to-Dose-Rate Factors," American Nuclear Society, LaGrange Parke, IL, March 1977. (NNA.900702.0022)

ANS/SD-76/14, "A Handbook of Radiation Shielding Data," Nuclear Science Center, Louisiana State University, Baton Rouge, LA, July 1976. (NNA.900522.0254)

DOE (U.S. Department of Energy), "Radiation Protection," Order 5480.11, Washington, D.C., November 1985 (draft). (NNA.900515.0015)

ICRP (International Commission on Radiological Protection), "Radionuclide Transformations: Energy and Intensity of Emissions," Publication 38, Pergamon Press, New York, NY, 1983. (NNA.900918.0001)

LANL (Los Alamos National Laboratory), "MCNP - A General Monte Carlo Code for Neutron and Photon Transport, Version 3A," LA-7396-M, Rev. 2, J. F. Breismeister, ed., Los Alamos National Laboratory, Los Alamos, NM, September 1986. (NNA.900702.0023)

Merritt, Frederick S., ed., <u>Standard Handbook for Civil Engineers</u>, pp. 5-6, McGraw-Hill Book Co., New York, NY, 1976, 2nd ed. (NNA.910306.0152)

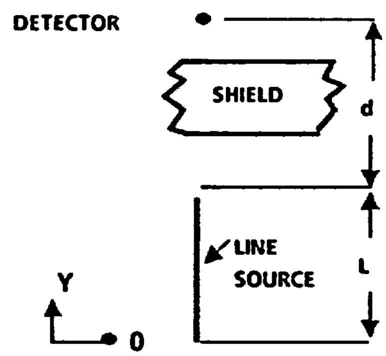
NSRDS-NBS 29, "Photon Cross Sections, Attenuation Coefficients, and Energy Absorption Coefficients From 10 KeV to 100 GeV," Center for Radiation Research, National Bureau of Standards, Washington, D.C., August 1969. (NNA.900711.0094)

Roddy, J. W., H. C. Claiborne, R. C. Ashline, P. J. Johnson, and B. T. Rhyne, "Physical and Decay Characteristics of Commercial LWR Spent Fuel," ORNL/TM-9591/V1&RI, Oak Ridge National Laboratory, Oak Ridge, TN, January 1986. (HQS.880517.2529)

SNL (Sandia National Laboratories), "Site Characterization Plan Conceptual Design Report," SAND84-2641, compiled by H. R. MacDougall, L. W. Scully, and J. R. Tillerson, Sandia National Laboratories, Albuquerque, NM, September 1987. (NNI.880902.0014-.0019)

ATTACHMENT 1

1.0 Derivation of Flux Along Axis of Line Source



The unshielded flux (Φ_u) from this line source at the detector is

$$\phi_u = \int_0^L \frac{S_l\,dY}{4\pi(L + d - Y)^2} \quad ,$$

where

Q	=	total source strength (photons or neutrons per second)
L	=	source length (cm)
S_l	=	Q/L (photons or neutrons per centimeter per second)
d	=	distance from top of source to detector (cm)
Y	=	distance along ordinate axis.

Let

u	=	L + d - Y
du	=	-dY
for Y = 0, u	=	L + d;
for Y = L, u	=	d.

Therefore,

$$\phi_u = \int_{L+d}^{d} - \frac{S_l\,du}{4\pi u^2} = - \frac{S_l}{4\pi} \int_{L+d}^{d} u^{-2}du$$

$$\phi_u = -\frac{S_l}{4\pi}\left[\frac{\mu^{-l}}{-1}\right]_{L+d}^{d} = \frac{S_l L}{4\pi d\,(L+d)}$$

$$\phi_u = \frac{Q}{4\pi d\,(L+d)} \quad .$$

For shielding thickness t, the shielded flux (Φ_S) at the detector is

$$\phi_s = B\phi_u e^{-\mu t}$$

$$\phi_s = \frac{BQ\,e^{-\mu t}}{4\pi d\,(L+d)} \quad ,$$

where

B = buildup factor
μ = linear attenuation coefficient
t = shield thickness (cm).

The dose rate is

$$DR = \phi_s\,(DF)$$

$$DR = \frac{BQ\,(DF)\,e^{-\mu t}}{4\pi d\,(L+d)} \quad , \tag{1-1}$$

where

DF = flux to dose conversion factor.

2.0 Determining Major Gamma Contributor

To demonstrate that the 1.25-MeV gamma contributes about 75% of the gamma dose rate total, the dose rates from selected other gammas near the 1.25 MeV will be evaluated and compared. Using lead shielding of 20 cm, d = 124.5 cm, the source strengths from the hybrid container, the following results are (in rem/hr):

For 0.575 MeV, $$DR = \frac{(7.28 \times 10^{15})(1.32 \times 10^{-6})e^{-(1.44)(20)}}{4\pi\,(124.5)\,(124.5 + 457.2)} = 3.28 \times 10^{-9}.$$

For 0.85 MeV, $$DR = \frac{(5.7 \times 10^{14})(1.76 \times 10^{-6})e^{-(.90)(20)}}{4\pi(124.5)(581.7)} = 1.68 \times 10^{-5}.$$

For 1.25 MeV, $$DR = \frac{(5.18 \times 10^{14})(2.3 \times 10^{-6})e^{-(.67)(20)}}{4\pi(124.5)(581.7)} = 1.98 \times 10^{-3}.$$

For 1.75 MeV, $$DR = \frac{(6.86 \times 10^{12})(2.93 \times 10^{-6})e^{-(.54)(20)}}{4\pi(124.5)(581.7)} = 4.50 \times 10^{-4}.$$

For 2.25 MeV, $$DR = \frac{(1.54 \times 10^{11})(3.45 \times 10^{-6})e^{-(.5)(20)}}{4\pi(124.5)(581.7)} = 2.65 \times 10^{-5}$$

$$\sum DR = 2.47 \times 10^{-3}.$$

The percent contribution of the above gamma are:

$$\% = \frac{DR_{MeV}}{\Sigma DR} x\,100.$$

Thus

$$\%\,.575\ MeV = \frac{3.28 x 10^{-9}}{2.47 x 10^{-3}} x\,100 \approx .0001$$

$$\%\,.85\ MeV = \frac{1.68 x 10^{-5}}{2.47 x 10^{-3}} x\,100 \approx .7$$

$$\% \, 1.25 \text{ MeV} = \frac{1.98 \times 10^{-3} \times 100}{2.47 \times 10^{-3}} = 80.0\%$$

$$\% \, 1.75 \, MeV = \frac{4.50 \, x \, 10^{-4}}{2.47 \, x \, 10^{-3}} \, x \, 100 \approx 18$$

$$\% \, 2.25 \, MeV = \frac{2.65 \, x \, 10^{-5}}{2.47 \, x \, 10^{-3}} \, x \, 100 \approx 1$$

3.0 Comparison of Line Source Model to More Rigorous Method

The adequacy of this model is determined by comparing results to those obtained using a more rigorous method. For this purpose, build-up is taken into account and the waste container is treated as a series of disk sources.

3.1 Application of Disk Source Method

In order to take self-attenuation into account, the waste container is partitioned into disks. The flux contribution from each disk source is calculated, taking into account the self-attenuation from disks between each disk and the detector point. Figure 1-1 depicts the geometry used for the calculations. The detector point is arbitrarily set 2 ft from the end of the waste package. For the calculations, only photons will be considered.

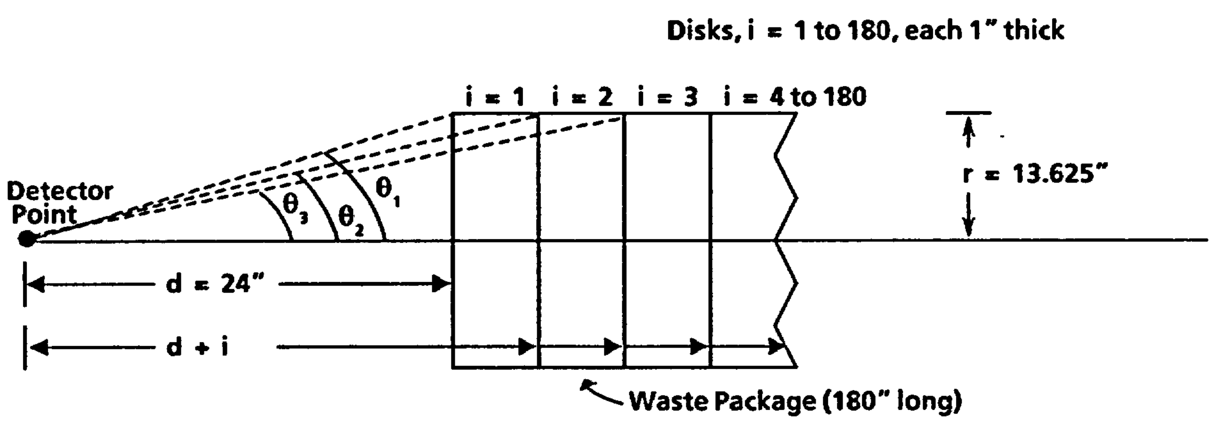


Figure 1-1. Disk Source Model

To calculate the total unshielded dose rate, the contribution from each disk must be summed.

$$DR = \sum_{i=1}^{180} DR_i \quad .$$

The unshielded dose rate from any given disk source is given by the following general equation (ANS/SD, 1976, p. 2-4):

$$\dot{DR}_i = \frac{B Q_A (DF)}{2} \left| E_1 (b_1)_i - E_1 (b_1 \sec\theta)_i \right| . \tag{1-2}$$

The term "unshielded dose rate" means that the waste container has no extermal shielding. The terms in this equation are explained in Table 1-1. This equation takes self-shielding into account because intermediate disks between the source disk and the detector point are treated as shields.

TABLE 1-1

TERMS USED IN EQUATION 1-2

DR	=	dose rate (rem/hr)
B	=	build-up factor
Q_A	=	source strength of a plane source (photons/cm^2-sec)
DF	=	flux-to-dose factor (rem/hr per photons/cm^2-sec)
$E_1(b_1)$	=	$\int_{b_1}^{\infty} \frac{e^{-y}}{y} dy$
$(b_1)_i$	=	$u_s t_i + \sum_i \mu_{i-1} t_{i-1}$
μ	=	attenuation coefficient (cm^{-1})
t	=	thickness of disk (cm)

In the following paragraphs, the terms for Equations 1-2 and 1-3 are given.

B = 1. For the initial calculation (unshielded dose rate), the build-up factor (B) equals 1.

Q_A. For these calculations only, the 1.25-MeV photon will be considered because it accounts for approximately 80% of the dose rate from photons. The source strength for this photon is 5.18×10^{14} photons/sec for the hybrid container (Table 2, Radiation Shielding Scoping Calculations). The source strength of each disk is

$$\frac{5.18 \times 10^{14}}{180} = 2.88 \times 10^{12} \text{ photons/sec.}$$

Therefore,

$$Q_A = \frac{2.88 \times 10^{12}}{\pi r^2}$$

$$= \frac{2.88 \times 10^{12}}{\pi (13.625)^2 (2.54)^2}$$

$$= 7.65 \times 10^8 \text{ photons/cm}^2\text{-sec.}$$

DF = 2.3×10^{-6} rem/hr per photons/cm^2-sec. The flux-to-dose factor (DF) for the 1.25-MeV photon is given in Table 3, Radiation Shielding Scoping Calculations.

Self-attenuation from intermediate disks between the source disk and the detector point is factored into the equation by the term b_1. For the first disk, i = 1, there is no self-attenuation; however, it is assumed that the steel end of the waste container is 1.5 in. thick. (This is the minimum thickness of the endcap and was chosen as a conservative assumption.) Thus, for i = 1,

$$(b_1)_{i=1} = \mu_s t_s = (0.43 \text{ cm}^{-1}) (1.5 \text{ in.}) (2.54 \text{ cm/in.}) = 1.638.$$

For i = 2 to 180, $(b_1)_i$ is as follows:

$$(b_1)_i = 1.638 + (\mu_{wc}) (i - 1) (1 \text{ in.}) (2.54 \text{ cm/in.}).$$

μ_{wc}. The attenuation coefficient for the waste is calculated as follows. It is assumed that the radioactive waste is homogeneous throughout the container. The interior volume of the container is

$$\pi r^2 l = \pi (13.625 \text{ in.})^2 (180 \text{ in.}) (2.54 \text{ cm/in.})^3 = 1.72 \times 10^6 \text{ cm}^3.$$

The combined weight of the three PWR and four BWR assemblies is (SCP-CDR, Appendix P)

$$(3 \times 1{,}450 \text{ lb} + 4 \times 600 \text{ lb})\ (1{,}000 \text{ g}/2.205 \text{ lb}) = 3.06 \times 10^6 \text{g}.$$

Thus, the density of the homogeneous source is

$$\frac{3.06 \times 10^6 \text{g}}{1.72 \times 10^6 \text{ cm}^3} = 1.78 \text{ g/cm}^3 \ .$$

The attenuation coefficient for photons is assumed to be proportional to density. For lead, $\mu = .67 \text{ cm}^{-1}$ and the density is 11.3 g/cm^3.

$$\frac{\mu_{wc}}{0.67 \text{ cm}^{-1}} = \frac{1.78 \text{ g/cm}^3}{11.3 \text{ g/cm}^3} \ .$$

Thus, $$\mu_{wc} = 0.106 \text{ cm}^{-1} \ .$$

From Figure 1-1,

$$\sec\theta = \frac{1}{\cos\theta} = \frac{a}{d} = \frac{\sqrt{d^2 + r^2}}{d} = \frac{\sqrt{d^2 + r^2}}{d} = \sqrt{1 + \left(\frac{r}{d}\right)^2} = \sqrt{1 + \left(\frac{13.625 \text{ in.}}{(23 + i) \text{ in.}}\right)^2} \ .$$

Taylor's build-up formula (p. 5-24, et. seq., ANS/SD, 1976) is used to calculate the build-up factor (B), where A, α_1, and α_2 are the Taylor coefficients, and $b = \mu t$, as before. For lead, $b = 0.67t$. The Taylor coefficients for 1.25-MeV photons are as follows (ANS/SD, 1976, Table 5.7):

Buildup =

$$Ae^{-\alpha_1 b} + (1 - A)e^{-\alpha_2 b} \ . \qquad (1\text{-}3)$$

$A = 3.0515,$
$\alpha_1 = -0.04025,$ and
$\alpha_2 = 0.1221 \ .$

3.2 Calculation of Shield Thickness

The build-up factor is used in conjunction with the equation for dose rate from a point source (ANS/SD, 1976, p. 5-24):

$$DR = \frac{BQ\,(DF)\,e^{-b}}{4\pi d^2} \quad , \tag{1-4}$$

where d is the distance from the point source to the detector point, and the other terms are as previously defined. For the unshielded case, t = 0; therefore, b = μt = 0. Thus, for the unshielded case, B = 1, as seen in Equation 1-3, and allowing for all disk contributions,

$$\frac{Q\,(DF)}{4\pi d^2} = 74 \; rem/hr \quad ,$$

as shown in Table 1-2.

Because the photon contribution to the dose rate goal is 1 mrem/hr, and because only the 1.25-MeV photon (which contributes to approximately 80% of the photon dose rate) is considered in this calculation, DR = 0.80 mrem/hr. The shielding thickness may be calculated by inserting Equation 1-3 into Equation 1-4 and using the above unshielded flux.

Solutions of Equation 1-2 for disks that contribute significantly to the unshielded dose rate (arbitrary cutoff of 0.01 rem/hr) are given in Table 1-2.

$$0.80 \text{ mrem/hr} = \left(74 \times 10^3 \text{ mrem/hr}\right)\left[Ae^{-(1+\alpha_1)b} + (1-A)e^{-(1+\alpha_2)b}\right]$$

$$\frac{0.80}{74 \times 10^3} = 3.0515e^{-(0.9598)(0.67)\,t} - 2.052e^{-(1.1221)(0.67)\,t}$$

This equation is solved either graphically or by iteration. The result is

$t \approx 19.4$ cm (lead).

TABLE 1-2

CALCULATIONS OF EQUATION 1-2

i	b_1	sec θ	b_1 sec	$E_1(b_1) - E_1(b_1 \sec\theta)$	DR (rem/hr)
1	1.638	1.15	1.884	2.414×10^{-2}	21.239
2	1.907	1.14	2.174	1.713×10^{-2}	15.066
3	2.176	1.13	2.459	1.211×10^{-2}	10.654
4	2.445	1.12	2.739	8.535×10^{-3}	7.509
5	2.715	1.11	3.014	5.989×10^{-3}	5.269
6	2.984	1.105	3.297	4.347×10^{-3}	3.824
7	3.253	1.098	3.522	3.106×10^{-3}	2.732
8	3.523	1.092	3.847	2.224×10^{-3}	1.959
9	3.791	1.087	4.122	1.612×10^{-3}	1.418
10	4.061	1.082	4.394	1.157×10^{-3}	1.018
11	4.330	1.077	4.664	8.320×10^{-4}	.732
12	4.589	1.073	4.924	6.047×10^{-4}	.536
13	4.858	1.069	5.193	4.411×10^{-4}	.388
14	5.128	1.066	5.466	3.220×10^{-4}	.285
15	5.397	1.062	5.732	2.320×10^{-4}	.204
16	5.666	1.059	6.000	1.690×10^{-4}	.149
17	5.935	1.056	6.267	1.228×10^{-4}	.108
18	6.205	1.054	6.540	9.037×10^{-5}	.080
19	6.474	1.051	6.804	6.546×10^{-5}	.058
20	6.743	1.049	7.076	4.800×10^{-5}	.042
21	7.012	1.047	7.342	3.530×10^{-5}	.031
22	7.282	1.045	7.610	2.585×10^{-5}	.023
23	7.551	1.043	7.876	1.892×10^{-5}	.017
24	7.820	1.041	8.141	1.382×10^{-5}	.012
25	8.089	1.040	8.413	1.029×10^{-5}	.009
				Total*	73.360

* Assume 74 rem/hr total for all disk contributions.

3.3 Comparision with Line Source Model

Using the on-axis line source model and d = 24 in., the result for lead is

t = 22.6 cm.

This is approximately 16.46% greater than the thickness calculated using the self-absorbing disk model with buildup and is thus conservative. This comparison verifies that the line source method is adequate for the on-axis calculations in this scoping analysis.

```
10    !
20    !                       Attachment 2
30    !
40    !
50    !                       PROGRAM TRANS
60    !
70    !
80    ! THIS PROGRAM COMPUTES THE SHIELDING REQUIRED FOR THE TRANSPORTER.
90    ! NO OPTIMIZATION IS ATTEMPTED.  A 1 mR DOSE LIMIT IS A ASSUMED FOR
100   ! NEUTRON AND GAMMA RADIATION FOR A TOTAL OF 2 mR.
110   !
120   PRINTER IS 701                  ! DEFAULT PRINTER
130   !
140   OPTION BASE 1
150   DIM Th1(4),Th2(4),Dr(4),Drn(4)
160   !
170   !
180   !
190   !                  INPUT DATA
200   !
210   Sel=2                          ! 1=HYBRID  2=CON
220   !
230   CALL In_data(Sel,Q(*),Qn,Df(*),Dfn,Mu(*),Mup(*),Mun)
240   !
250   !                 DIMENSIONS
260   !
270   L=180*2.54                     ! SOURCE LENGTH (cm)
280   A=49*2.54                      ! RADIAL LOCATION (cm)
290   D=A                            ! AXIAL LOCATION FOR DET 1 (cm)
300   !
310   GOSUB Input_data               ! PRINT THE INPUT DATA
320   !
330   !
340   !            DETERMINE THE UNSHIELDED DOSE RATE
350   !
360   !
370   !  CALCULATE THETA ANGLES
380   !
390   Th1(2)=ATN(D/A)
400   Th2(2)=ATN((D+L)/A)
410   Th1(3)=ATN((D-(45*2.54))/A)
420   Th2(3)=ATN((D+L-(45*2.54))/A)
430   Th1(4)=ATN(L/(2*A))
440   Th2(4)=Th1(4)
450   !
460   !  CALCULATE DOSE FOR IN LINE
470   !
480   Thick=0                         ! GAMMA
490   Tn=0                            ! NEUTRON
500   !
510   J=1                             ! DET 1
520   GOSUB In_line                   ! GAMMA
530   GOSUB N_in_line                 ! NEUTRON
540   !
550   !  CALCULATE DOSE FOR OFF AXIS
560   !
570   FOR J=2 TO 4
580      GOSUB Off_axis               ! DET 2 - 4  GAMMA
590      GOSUB N_off_axis             ! DET 2 - 4  NEUTRON
600   NEXT J
610   !
620   GOSUB Unshielded                ! PRINT OUT UNSHIELDED DOSE RATES
630   !
```

```
640   !
650   !                DETERMINE SHIELD THICKNESS
660   !
670   !  TO DETERMINE THE END THICKNESS, DET 1 WILL BE USED.
680   !  THE THICKNESS IS ESTIMATED, AND ITERATED TO GET A
690   !  DOSE RATE OF 1 mr/hr.
700   !
710   J=1                        !DET 1
720   SELECT Sel
730      CASE 1
740         Thick=18.5
750         Tn=29.2
760      CASE 2
770         Thick=18.9
780         Tn=32.0
790   END SELECT
800   !
810   LOOP                       !NEUTRON
820      GOSUB N_in_line
830      Dif=1-(Drn(1)*1000)
840   EXIT IF -.01<Dif AND Dif<.01
850      IF Dif<0 THEN
860         Tn=Tn+.05
870      ELSE
880         Tn=Tn-.05
890      END IF
900   END LOOP
910   !
920   !
930   LOOP                       !GAMMA
940      GOSUB In_line
950      Dif=1-(Dr(1)*1000)
960   EXIT IF -.01<Dif AND Dif<.01
970      IF Dif<0 THEN
980         Thick=Thick+.02
990      ELSE
1000        Thick=Thick-.02
1010     END IF
1020  END LOOP
1030  !
1040  T_end=Thick              ! END THICKNESS FOR GAMMA
1050  Tn_end=Tn                ! END THICKNESS FOR NEUTRON
1060  !
1070  !
1080  !  TO DETERMINE THE SIDE THICKNESS, DET 4 WILL BE USED
1090  !  THE THICKNESS IS ESTIMATED, AND ITERATED TO GET A
1100  !  DOSE RATE OF 2 mr/hr.
1110  !
1120  J=4                        !DET 4
1130  SELECT Sel
1140     CASE 1
1150        Thick=18.0
1160        Tn=31.4
1170     CASE 2
1180        Thick=18.4
1190        Tn=34.0
1200  END SELECT
1210  !
1220  LOOP                       !NEUTRON
1230     GOSUB N_off_axis
1240     Dif=1-(Drn(4)*1000)
1250  EXIT IF -.01<Dif AND Dif<.01
1260     IF Dif<0 THEN
1270        Tn=Tn+.1
1280     ELSE
1290        Tn=Tn-.1
```

```
1300     END IF
1310  END LOOP
1320  !
1330  !
1340  LOOP                        !GAMMA
1350     GOSUB Off_axis
1360     Dif=1-(Dr(4)*1000)
1370  EXIT IF -.01<Dif AND Dif<.01
1380     IF Dif<0 THEN
1390        Thick=Thick+.02
1400     ELSE
1410        Thick=Thick-.02
1420     END IF
1430  END LOOP
1440  !
1450  !               CALCULATE SHIELDED DOSE RATES
1460  !
1470  FOR J=2 TO 3
1480     GOSUB Off_axis
1490     GOSUB N_off_axis
1500  NEXT J
1510  !
1520  GOSUB Shielded                       ! PRINT THE RESULTS
1530  !
1540  PRINTER IS 1                         ! RESET THE PRINTER DIRECTIVE
1550  !
1560  STOP
1570  !
1580  !*****************************************************************
1590  !
1600  !          CALCULATES THE ON-AXIS DOSE RATES - GAMMA
1610  !
1620 In_line: !
1630  Dr(1)=0
1640  FOR K=1 TO 3
1650     Do(K)=Q(K)*Df(K)*(EXP(-Mu(K)*Thick-Mup(K)*Tn))/(4*PI*D*(L+D))
1660     Dr(1)=Do(K)+Dr(1)
1670  NEXT K
1680  RETURN
1690  !
1700  !*************************************************************
1710  !
1720  !          CALCULATES THE ON-AXIS DOSE RATES - NEUTRON
1730  !
1740 N_in_line: !
1750  Drn(1)=Qn*Dfn*(EXP(-Mun*Tn))/(4*PI*D*(L+D))
1760  RETURN
1770  !
1780  !**************************************************************
1790  !
1800  !          CALCULATES THE OFF-AXIS DOSE RATES - GAMMA
1810  !
1820 Off_axis: !
1830  Dr(J)=0
1840  FOR K=1 TO 3
1850     B(K)=Mu(K)*Thick+Mup(K)*Tn
1860  NEXT K
1870  SELECT J
1880      CASE 4                                 ! DET 4
1890         FOR K=1 TO 3
1900            CALL Fint(0,Th2(J),B(K),Ffun)
1910            Ffun=2*Ffun
1920            Do(K)=(Q(K)*Df(K)*Ffun)/(4*PI*A*L)
1930            Dr(J)=Dr(J)+Do(K)
1940         NEXT K
1950      CASE ELSE
```

```
1960         FOR K=1 TO 3
1970            CALL Fint(Th1(J),Th2(J),B(K),Ffun)
1980            Do(K)=(Q(K)*Df(K)*Ffun)/(4*PI*A*L)
1990            Dr(J)=Dr(J)+Do(K)
2000         NEXT K
2010  END SELECT
2020  RETURN
2030  !
2040  !***************************************************************
2050  !
2060  !           CALCULATES THE OFF-AXIS DOSE RATES - NEUTRON
2070  !
2080 N_off_axis: !
2090  Bn=Mun*Tn
2100  SELECT J
2110      CASE 4                                  ! DET 4
2120         CALL Fint(0,Th2(J),Bn,Ffun)
2130         Ffun=2*Ffun
2140      CASE ELSE
2150         CALL Fint(Th1(J),Th2(J),Bn,Ffun)
2160   END SELECT
2170   Drn(J)=(Qn*Dfn*Ffun)/(4*PI*A*L)
2180   RETURN
2190   !
2200   !**********************************************************
2210   !
2220 Input_data:  !
2230   !
2240   !           PRINT OUT THE INPUT DATA
2250   !
2260   PRINT TAB(22);"PROGRAM 'TRANS' BY R. J. FLORES"
2270   PRINT
2280   PRINT
2290   SELECT Sel
2300      CASE 1
2310         PRINT TAB(27);"3/4 HYBRID CONTAINER"
2320      CASE 2
2330         PRINT TAB(24);"6 PWR CONSOLIDATED CONTAINER"
2340      CASE ELSE
2350         DISP "ERROR - SEL OUT OF BOUNDS => ABORT!"
2360         PAUSE
2370   END SELECT
2380   PRINT
2390   PRINT
2400   PRINT
2410   PRINT "INPUT DATA:"
2420   PRINT
2430   PRINT USING 2440
2440   IMAGE 17X,"1.25 MeV",8X,"1.75 MeV",8X,"2.25 MeV",8X,"NEUTRON"
2450   PRINT USING 2460
2460   IMAGE 16X,"----------",6X,"----------",6X,"----------",6X,"----------"
2470   PRINT USING 2480;Q(1),Q(2),Q(3),Qn
2480   IMAGE "FLUX RATE",4(8X,D.DDE)
2490   PRINT USING 2500;Df(1),Df(2),Df(3),Dfn
2500   IMAGE "F/D RATE ",4(8X,D.DDE)
2510   PRINT USING 2520;Mup(1),Mup(2),Mup(3),Mun
2520   IMAGE "MU (POLY)",4(11X,Z.DDD,)
2530   PRINT USING 2540;Mu(1),Mu(2),Mu(3),0
2540   IMAGE "MU (LEAD)",4(11X,Z.DDD)
2550   PRINT
2560   PRINT
2570   PRINT USING 2580;L,A,D
2580   IMAGE "    DIMENSIONS (cm)",10X,"L=",3D.D,10X,"A=",3D.D,10X,"D=",3D.D,3/
2590   RETURN
2600   !
2610   !********************************************************************
```

```
2620   !
2630   !                PRINT OUT THE UNSHIELDED DOSE RATES
2640   !
2650 Unshielded:  !
2660   FOR S=1 TO 4
2670      Dr(S)=Dr(S)*1000
2680      Drn(S)=Drn(S)*1000
2690   NEXT S
2700   PRINT TAB(20),"UNSHIELDED DOSE RATES (mrem/hr)"
2710   PRINT
2720   PRINT USING 2730
2730   IMAGE 20X,"DET 1",10X,"DET 2",10X,"DET 3",10X,"DET4"
2740   PRINT USING 2750
2750   IMAGE 20X,"-----",10X,"-----",10X,"-----",10X,"----"
2760   PRINT USING 2770;Dr(1),Dr(2),Dr(3),Dr(4)
2770   IMAGE "GAMMA DOSE  ",7X,4(D.DE,8X)
2780   PRINT USING 2790;Drn(1),Drn(2),Drn(3),Drn(4)
2790   IMAGE "NEUTRON DOSE",7X,4(D.DE,8X)
2800   RETURN
2810   !
2820   !*****************************************************************
2830   !
2840   !                PRINT OUT THE RESULTS
2850   !
2860 Shielded:  !
2870   PRINT
2880   PRINT
2890   PRINT
2900   PRINT TAB(25);"SHIELDING THICKNESSES"
2910   PRINT
2920   PRINT USING 2930
2930   IMAGE 21X,"LEAD (cm)",8X,"POLY (cm)",7X,"TOTAL (cm)"
2940   PRINT USING 2950
2950   IMAGE 21X,"---------",8X,"---------",7X,"----------"
2960   PRINT USING 2970;Thick,Tn,Tn+Thick
2970   IMAGE 6X,"SIDE ",3(12X,DD.D,X)
2980   PRINT USING 2990;T_end,Tn_end,T_end+Tn_end
2990   IMAGE 6X,"END  ",3(12X,DD.D,X)
3000   FOR S=1 TO 4
3010      Dr(S)=Dr(S)*1000
3020      Drn(S)=Drn(S)*1000
3030      Td(S)=Dr(S)+Drn(S)
3040   NEXT S
3050   PRINT
3060   PRINT
3070   PRINT
3080   PRINT TAB(20),"SHIELDED DOSE RATES (mrem/hr)"
3090   PRINT
3100   PRINT USING 3110
3110   IMAGE 20X,"DET 1",10X,"DET 2",10X,"DET 3",10X,"DET4"
3120   PRINT USING 3130
3130   IMAGE 20X,"-----",10X,"-----",10X,"-----",10X,"----"
3140   PRINT USING 3150;Dr(1),Dr(2),Dr(3),Dr(4)
3150   IMAGE "GAMMA DOSE  ",7X,4(D.DE,8X)
3160   PRINT USING 3170;Drn(1),Drn(2),Drn(3),Drn(4)
3170   IMAGE "NEUTRON DOSE",7X,4(D.DE,8X)
3180   PRINT USING 3190;Td(1),Td(2),Td(3),Td(4)
3190   IMAGE "TOTAL DOSE  ",7X,4(D.DE,8X)
3200   RETURN
3210   !
3220   ! ***********************************************************
3230   END
3240   ! ***********************************************************
3250   !
3260   SUB Fint(L1,L2,B,Ffun)
3270   !
```

```
3280  !                  Simpson's Rule
3290  !
3300  St=10      ! NUMBER OF STEPS
3310  Delta=(L2-L1)/(2*St)
3320  Ffun=0
3330  Z=(2*St)+1
3340  FOR I=1 TO Z
3350      SELECT I
3360         CASE 1,Z
3370            X=1
3380         CASE ELSE
3390            IF INT(I/2)=I/2 THEN
3400               X=4
3410            ELSE
3420               X=2
3430            END IF
3440      END SELECT
3450      T=L1+(I-1)*Delta
3460      Ffun=Ffun+X*FNSev(B,T)
3470  NEXT I
3480  Ffun=Ffun*Delta/3
3490  SUBEND
3500  !
3510  !***************************************************************
3520  !
3530  DEF FNSev(B,T)
3540  F=EXP(-B/COS(T))
3550  RETURN F
3560  FNEND
3570  !
3580  !*****************************************************************
3590  !
3600  SUB In_data(Sel,Q(*),Qn,Df(*),Dfn,Mu(*),Mup(*),Mun)
3610  !
3620  !  THIS SUBPROGRAM FILLS THE DATA ARRAYS FOR THE TYPE
3630  !  OF WASTE THAT IS SPECIFIED.
3640  !
3650  !                  1 => HYBRID
3660  !                  2 => CONSOLIDATED
3670  !
3680  FOR I=1 TO 3
3690     READ Df(I),Mu(I),Mup(I)
3700  NEXT I
3710  READ Dfn,Mun
3720  FOR I=1 TO Sel
3730     FOR J=1 TO 3
3740        READ Q(J)
3750     NEXT J
3760     READ Qn
3770  NEXT I
3780  !
3790  !
3800  !              Mu's AND FLUX TO DOSE
3810  !
3820  DATA 2.30E-6,0.67,0.066
3830  DATA 2.93E-6,0.54,0.055
3840  DATA 3.45E-6,0.5,0.048
3850  DATA 1.26E-4,0.137
3860  !                  1 => HYBRID
3870  !
3880  DATA 5.18E+14,6.86E+12,1.54E+11,3.9E+8
3890  !
3900  !                  2 => CONSOLIDATED
3910  !
3920  DATA 8.24E+14,9.77E+12,2.27E+11,5.8E+8
3930  SUBEND
```

Attachment 3

```
10   !
20   !
30   !
40   !                    PROGRAM PLUG
50   !
60   !     PROGRAM TO DETERMINE SHIELDING REQUIREMENTS
70   !              FOR THE SHIELD PLUG
80   !
90   !
100  Print_out=701
110  PRINTER IS Print_out          ! DEFAULT PRINTER
120  !
130  OPTION BASE 1
140  DIM Th1(4,4),Th2(4,4),Dr(4,4),Drn(4,4),A(4),D(4),Ts(4),Tc(4),R(4),St(4)
150  DIM Td(4,4)
160  !
170  !                  INPUT DATA
180  !
190  Sel=2                         ! 1=HYBRID     2=CON
200  !
210  CALL In_data(Sel,Q(*),Qn,Df(*),Dfn,Muc(*),Mus(*),Mu)
220  !
230  !                 DIMENSIONS
240  !
250  A(2)=3.5*12*2.54              ! LOCATION OF DET 2 (cm)
260  A(3)=5.2*12*2.54              ! LOCATION OF DET 3 (cm)
270  A(4)=7.5*12*2.54              ! LOCATION OF DET 4 (cm)
280  !
290  St(1)=10                      !  10 FT STANDOFF
300  St(2)=20                      !  20 FT STANDOFF
310  St(3)=6                       !   6 FT STANDOFF
320  St(4)=134                     ! 134 FT STANDOFF (CDR)
330  !
340  R(1)=13*2.54                  ! RADIUS FOR VERT.
350  R(2)=17.5*2.54                ! RADIUS FOR HORZ.
360  R(3)=17.5*2.54                ! RADIUS FOR HORZ.
370  R(4)=17.5*2.54                ! RADIUS FOR HORZ.
380  !
390  L=180*2.54                    ! SOURCE LENGTH (cm)
400  !
410  !
420  !
430  !                 CALCULATE THETA ANGLES
440  !
450  FOR I=1 TO 4
460     D(I)=St(I)*12*2.54
470     FOR J=2 TO 4
480        Th1(J,I)=ATN(D(I)/A(J))
490        Th2(J,I)=ATN((D(I)+L)/A(J))
500     NEXT J
510  NEXT I
520  !
530  GOSUB Input_data              ! PRINT THE INPUT DATA
540  !
550  !
560  !               DETERMINE SHIELD PLUG THICKNESS
570  !
580  !  TO DETERMINE THE PLUG THICKNESS, DET 1 WILL BE USED.
590  !  THE THICKNESS IS ESTIMATED, AND THEN ITERATED TO
600  !  GET A 1 mr/hr DOSE RATE FOR EACH.
610  !
620  J=1                           ! DET 1
630  !
```

```
640   !            FIRST GUESSES
650   !
660   DATA 17.1,42,19.4,27,15.7,51,18.6,0
670   DATA 16.3,48,18.6,33.2,14.9,57.1,19.8,0
680   !
690   FOR Kk=1 TO Sel
700      FOR K=1 TO 4
710         READ Ts(K),Tc(K)
720      NEXT K
730   NEXT Kk
740   !
750   !        CALCULATE DOSE FOR IN LINE - NEUTRON
760   !
770   FOR I=1 TO 4
780      LOOP
790         GOSUB N_in_line
800         Dif=1-(Drn(1,I)*1000)
810      EXIT IF -.01<Dif AND Dif<.01
820      EXIT IF Tc(I)=0 AND Dif>0           ! NO NEUTRON SHIELDING
830         IF Dif<0 THEN
840            Tc(I)=Tc(I)+.05
850         ELSE
860            Tc(I)=Tc(I)-.05
870         END IF
880      END LOOP
890      !
900      !     CALCULATE DOSE FOR IN LINE - GAMMA
910      !
920      LOOP
930         GOSUB In_line
940         Dif=1-(Dr(1,I)*1000)
950         IF I=4 THEN                     ! NO NEUTRON SHIELDING
960            Allow=2-(Drn(1,I)*1000)
970            Dif=Allow-(Dr(1,I)*1000)
980         END IF
990      EXIT IF -.02<Dif AND Dif<.02
1000        IF Dif<0 THEN
1010           Ts(I)=Ts(I)+.05
1020        ELSE
1030           Ts(I)=Ts(I)-.05
1040        END IF
1050     END LOOP
1060  NEXT I
1070  !
1080  !          CALCULATE THE SHIELDED DOSE RATES
1090  !
1100  FOR I=1 TO 4
1110     FOR J=2 TO 4
1120        GOSUB Off_axis              ! GAMMA
1130        GOSUB N_off_axis            ! NEUTRON
1140     NEXT J
1150  NEXT I
1160  !
1170  GOSUB Shielded                    ! OUTPUT RESULTS
1180  !
1190  PRINTER IS 1
1200  !
1210  STOP
1220  !
1230  !************************************************************
1240  !
1250  !          CALCULATES ON-AXIS DOSE RATES - GAMMA
1260  !
1270 In_line: !
1280  Dp2=D(I)+(2*2.54*12)             ! ADD 2 FT
1290  Dr(1,I)=0
```

```
1300   FOR K=1 TO 3
1310      Do(K)=Q(K)*Df(K)*(EXP(-Mus(K)*Ts(I)-Muc(K)*Tc(I)))/(4*PI*Dp2*(L+Dp2))
1320      Dr(1,I)=Do(K)+Dr(1,I)
1330   NEXT K
1340   RETURN
1350   !
1360   !***********************************************************
1370   !
1380   !           CALCULATES ON-AXIS DOSE RATES - NEUTRON
1390   !
1400 N_in_line: !
1410   Dp2=D(I)+(2*2.54*12)          ! ADD 2 FT
1420   Drn(1,I)=Qn*Dfn*(EXP(-Mu*Tc(I)))/(4*PI*Dp2*(L+Dp2))
1430   RETURN
1440   !
1450   !***************************************************************
1460   !
1470   !           CALCULATES OFF-AXIS DOSE RATES - GAMMA
1480   !
1490 Off_axis: !
1500   Dr(J,I)=0
1510   FOR K=1 TO 3
1520     B(K)=Muc(K)*(A(J)-R(I))
1530     CALL Fint(Th1(J,I),Th2(J,I),B(K),Ffun)
1540     Do(K)=(Q(K)*Df(K)*Ffun)/(4*PI*A(J)*L)
1550     Dr(J,I)=Dr(J,I)+Do(K)
1560   NEXT K
1570   RETURN
1580   !
1590   !*************************************************************
1600   !
1610   !           CALCULATES OFF-AXIS DOSE RATES - NEUTRON
1620   !
1630 N_off_axis: !
1640   Bn=Mu*(A(J)-R(I))
1650   CALL Fint(Th1(J,I),Th2(J,I),Bn,Ffun)
1660   Drn(J,I)=(Qn*Dfn*Ffun)/(4*PI*A(J)*L)
1670   RETURN
1680   !
1690   !**********************************************************
1700   !
1710 Input_data:  !
1720   !
1730   !                PRINT OUT THE INPUT DATA
1740   !
1750   PRINT
1760   PRINT TAB(23);"PROGRAM 'PLUG' BY R. J. FLORES"
1770   PRINT
1780   PRINT
1790   SELECT Sel
1800      CASE 1
1810         PRINT TAB(27);"3/4 HYBRID CONTAINER"
1820      CASE 2
1830         PRINT TAB(24);"6 PWR CONSOLIDATED CONTAINER"
1840      CASE ELSE
1850         DISP "ERROR - SEL OUT OF BOUNDS => ABORT!!"
1860         PAUSE
1870   END SELECT
1880   PRINT
1890   PRINT
1900   PRINT
1910   PRINT
1920   PRINT
1930   PRINT "INPUT DATA:"
1940   PRINT
1950   PRINT USING 1960
```

```
1960   IMAGE 17X,"1.25 MeV",8X,"1.75 MeV",8X,"2.25 MeV",8X,"NEUTRON"
1970   PRINT USING 1980
1980   IMAGE 16X,"----------",6X,"----------",6X,"----------",6X,"----------"
1990   PRINT USING 2000;Q(1),Q(2),Q(3),Qn
2000   IMAGE "FLUX RATE",4(8X,D.DDE)
2010   PRINT USING 2020;Df(1),Df(2),Df(3),Dfn
2020   IMAGE "F/D RATE ",4(8X,D.DDE)
2030   PRINT USING 2040;Muc(1),Muc(2),Muc(3),Mu
2040   IMAGE "MU (CONCRETE)",7X,3(Z.DDD,11X),Z.DDD
2050   PRINT USING 2060;Mus(1),Mus(2),Mus(3),0
2060   IMAGE "MU (STEEL)",10X,3(Z.DDD,11X),Z.DDD
2070   PRINT
2080   PRINT
2090   PRINT
2100   PRINT USING 2110
2110   IMAGE 30X,"  DIMENSIONS (cm)"
2120   PRINT
2130   PRINT
2140   PRINT USING 2150
2150   IMAGE 5X,"CONTAINER LENGTH",8X,"DET. LOCATIONS",8X,"STAND-OFF (CONFIG.)"
2160   PRINT USING 2170
2170   IMAGE 5X,"----------------",8X,"--------------",8X,"-------------------"
2180   PRINT USING 2190;L,A(1),D(1)
2190   IMAGE 10X,3D.D,16X,3D.D,"  (1)",12X,3D.D,"  (VERT.)"
2200   PRINT USING 2210;A(2),D(2)
2210   IMAGE 31X,3D.D,"  (2)",12X,3D.D,"  (HORIZ.)"
2220   PRINT USING 2230;A(3),D(3)
2230   IMAGE 31X,3D.D,"  (3)",12X,3D.D,"  (HORIZ.)"
2240   PRINT USING 2250;A(4),D(4)
2250   IMAGE 31X,3D.D,"  (4)",12X,4D.D,"  (HORIZ.)"
2260   RETURN
2270   !
2280   !*****************************************************************
2290   !
2300   !                    PRINT OUT THE RESULTS
2310   !
2320 Shielded:  !
2330   PRINT
2340   PRINT
2350   PRINT
2360   PRINT
2370   PRINT
2380   PRINT "OUTPUT:"
2390   PRINT
2400   PRINT
2410   PRINT TAB(25);"SHIELDING THICKNESSES"
2420   PRINT
2430   PRINT
2440   PRINT USING 2450
2450   IMAGE  10X,"STAND-OFF (ft)",10X,"CONCRETE (cm)",10X,"STEEL (cm)"
2460   PRINT USING 2470
2470   IMAGE  10X,"--------------",10X,"-------------",10X,"----------"
2480   FOR Ii=1 TO 4
2490      PRINT USING 2500;St(Ii),Tc(Ii),Ts(Ii)
2500      IMAGE 15X,DDD,21X,DD.D,19X,DD.D
2510      FOR S=1 TO 4
2520         Dr(S,Ii)=Dr(S,Ii)*1000
2530         Drn(S,Ii)=Drn(S,Ii)*1000
2540         Td(S,Ii)=Dr(S,Ii)+Drn(S,Ii)
2550      NEXT S
2560   NEXT Ii
2570   IF Print_out=701 THEN PRINT CHR$(12)      ! FORM FEED
2580   PRINT
2590   PRINT
2600   PRINT TAB(14);"PROGRAM 'PLUG' BY R. J. FLORES - CONTINUED"
2610   PRINT
```

```
2620   PRINT
2630   PRINT
2640   PRINT
2650   PRINT TAB(20),"SHIELDED DOSE RATES (mrem/hr)"
2660   PRINT
2670   PRINT
2680   PRINT
2690   FOR De=1 TO 4
2700         IF Dr(De,4)<1.E-20 THEN Dr(De,4)=0
2710         IF Drn(De,4)<1.E-20 THEN Drn(De,4)=0
2720         IF Td(De,4)<1.E-20 THEN Td(De,4)=0
2730   NEXT De
2740   FOR Ii=1 TO 4
2750      PRINT
2760      PRINT USING 2770;St(Ii)
2770      IMAGE "STAND-OFF = ",DDD," FEET"
2780      PRINT
2790      PRINT USING 2800
2800      IMAGE 20X,"DET 1",10X,"DET 2",10X,"DET 3",10X,"DET 4"
2810      PRINT USING 2820
2820      IMAGE 20X,"-----",10X,"-----",10X,"-----",10X,"----"
2830      PRINT USING 2840;Dr(1,Ii),Dr(2,Ii),Dr(3,Ii),Dr(4,Ii)
2840      IMAGE "GAMMA DOSE  ",7X,4(D.DDE,7X)
2850      PRINT USING 2860;Drn(1,Ii),Drn(2,Ii),Drn(3,Ii),Drn(4,Ii)
2860      IMAGE "NEUTRON DOSE",7X,4(D.DDE,7X)
2870      PRINT USING 2880;Td(1,Ii),Td(2,Ii),Td(3,Ii),Td(4,Ii)
2880      IMAGE "TOTAL DOSE  ",7X,4(D.DDE,7X)
2890      PRINT
2900      PRINT
2910   NEXT Ii
2920   RETURN
2930   !
2940   !************************************************************
2950   END
2960   !************************************************************
2970   !
2980   SUB Fint(L1,L2,B,Ffun)
2990   !
3000   !            Simpson's Rule Integration
3010   !
3020   St=10        ! NUMBER OF STEPS
3030   Delta=(L2-L1)/(2*St)
3040   Ffun=0
3050   Z=(2*St)+1
3060   FOR I=1 TO Z
3070      SELECT I
3080         CASE 1,Z
3090            X=1
3100         CASE ELSE
3110            IF INT(I/2)=I/2 THEN
3120               X=4
3130            ELSE
3140               X=2
3150            END IF
3160      END SELECT
3170      T=L1+(I-1)*Delta
3180      Ffun=Ffun+X*FNSev(B,T)
3190   NEXT I
3200   Ffun=Ffun*Delta/3
3210   SUBEND
3220   !
3230   !********************************************************
3240   !
3250   DEF FNSev(B,T)
3260   F=EXP(-B/COS(T))
3270   RETURN F
```

```
3280  FNEND
3290  !
3300  !*****************************************************
3310  !
3320  SUB In_data(Sel,Q(*),Qn,Df(*),Dfn,Muc(*),Mus(*),Mu)
3330  !
3340  !  THIS SUBPROGRAM FILLS THE DATA ARRAYS FOR THE TYPE
3350  !  OF WASTE THAT IS SPECIFIED.
3360  !
3370  !                    1 => HYBRID
3380  !                    2 => CONSOLIDATED
3390  !
3400  FOR I=1 TO 3
3410     READ Df(I),Muc(I),Mus(I)
3420  NEXT I
3430  READ Dfn,Mu
3440  FOR I=1 TO Sel
3450     FOR J=1 TO 3
3460        READ Q(J)
3470     NEXT J
3480     READ Qn
3490  NEXT I
3500  !
3510  !                Mu's AND FLUX TO DOSE
3520  !
3530  DATA 2.30E-6,0.13,0.43
3540  DATA 2.93E-6,0.11,0.36
3550  DATA 3.45E-6,0.098,0.32
3560  DATA 1.26E-4,0.0905
3570  !
3580  DATA 5.18E+14,6.86E+12,1.54E+11,3.9E+8       ! HYBRID - 1
3590  !
3600  DATA 8.24E+14,9.77E+12,2.27E+11,5.8E+8       ! CON - 2
3610  SUBEND
```

```
10    !
20    !                      Attachment 4
30    !
40    !                      PROGRAM COLLAR
50    !
60    !
70    !  PROGRAM TO DETERMINE THE LOCATION OF 2 MR/HR FOR THE
80    !  SHIELDING COLLAR
90    !
100   !
110   PRINTER IS 701                      !DEFAULT PRINTER
120   !
130   OPTION BASE 1
140   DIM Th1(6),Th2(6),Dr(6),Drn(6),A(6),D(6),R(6),St(6)
150   DIM Mus(4),Muc(4),Q(4),Df(4)
160   !
170   !
180   !
190   !                   INPUT DATA
200   !
210   Sel=2                     ! 1=HYBRID     2=CON
220   !
230   CALL In_data(Sel,Q(*),Qn,Df(*),Dfn,Muc(*),Mus(*),Mu)
240   !
250   !                  DIMENSIONS
260   !
270   DATA 10,0                         ! STANDOFF - VERTICAL
280   DATA 20,6,0                       ! STANDOFF - HORIZONTAL
290   !
300   FOR K=1 TO 5
310      READ St(K)
320      IF K=1 OR K=2 THEN
330         R(K)=13                     ! RADIUS FOR VERT.
340      ELSE
350         R(K)=17.5                   ! RADIUS FOR HORZ.
360      END IF
370   NEXT K
380   !
390   L=180*2.54                        ! SOURCE LENGTH (cm)
400   !
410   !
420   FOR I=1 TO 5                      ! UNIT CONVERSIONS
430      D(I)=St(I)*12*2.54
440      R(I)=R(I)*2.54
450   NEXT I
460   !
470   GOSUB Input_data                  ! PRINT THE INPUT DATA
480   !
490   !
500   !          DETERMINE LOCATION OF 2 mr/hr DOSE RATE
510   !          LOCATION IS ESTIMATED, THEN ITERATED
520   !
530   !                  FIRST GUESSES
540   !
550   DATA 44.5,130.2,50.6,76.7,141.0
560   DATA 45.2,133.4,50.9,78.7,144.2
570   !
580   FOR Kk=1 TO Sel
590      FOR K=1 TO 5
600         READ A(K)
610      NEXT K
620   NEXT Kk
630   !
```

```
640   !
650   !                   CALCULATE THETA ANGLES
660   !
670   FOR I=5 TO 5
680      Th1(I)=ATN(D(I)/A(I))
690      Th2(I)=ATN((D(I)+L)/A(I))
700      !
710      LOOP
720         GOSUB N_off_axis                ! NEUTRON DOSE
730         GOSUB Off_axis                  ! GAMMA DOSE
740         Dif=2-((Dr(I)+Drn(I))*1000)     ! CHECK FOR 2 mr/hr
750      EXIT IF -.01<Dif AND Dif<.01
760         IF Dif<0 THEN
770            A(I)=A(I)+.01
780         ELSE
790            A(I)=A(I)-.01
800         END IF
810      END LOOP
820   NEXT I
830   !
840   GOSUB Out_put                           ! PRINT THE RESULTS
850   !
860   PRINTER IS 1
870   STOP
880   !
890   !*************************************************************
900   !
910   !                CALCULATES THE OFF-AXIS DOSE RATES - GAMMA
920   !
930 Off_axis:  !
940   Dr(I)=0
950   FOR K=1 TO 3
960      B(K)=Muc(K)*(A(I)-R(I))
970      CALL Fint(Th1(I),Th2(I),B(K),Ffun)
980      Do(K)=(Q(K)*Df(K)*Ffun)/(4*PI*A(I)*L)
990      Dr(I)=Dr(I)+Do(K)
1000  NEXT K
1010  RETURN
1020  !
1030  !*************************************************************
1040  !
1050  !                CALCULATES THE OFF-AXIS DOSE RATES - NEUTRON
1060  !
1070 N_off_axis: !
1080   Bn=Mu*(A(I)-R(I))
1090   CALL Fint(Th1(I),Th2(I),Bn,Ffun)
1100   Drn(I)=(Qn*Dfn*Ffun)/(4*PI*A(I)*L)
1110   RETURN
1120   !
1130   !*************************************************************
1140   !
1150 Input_data:  !
1160   !
1170   !            PRINT OUT THE INPUT DATA
1180   !
1190   PRINT
1200   PRINT
1210   PRINT
1220   PRINT TAB(22);"PROGRAM 'COLLAR' BY R. J. FLORES"
1230   PRINT
1240   SELECT Sel
1250      CASE 1
1260         PRINT TAB(28);"3/4 HYBRID CONTAINER"
1270      CASE 2
1280         PRINT TAB(24);"6 PWR CONSOLIDATED CONTAINER"
1290   END SELECT
```

```
1300   PRINT
1310   PRINT
1320   PRINT
1330   PRINT
1340   PRINT
1350   PRINT "INPUT DATA:"
1360   PRINT
1370   PRINT
1380   PRINT USING 1390
1390   IMAGE 17X,"1.25 MeV",8X,"1.75 MeV",8X,"2.25 MeV",8X,"NEUTRON"
1400   PRINT USING 1410
1410   IMAGE 16X,"----------",6X,"----------",6X,"----------",6X,"---------"
1420   PRINT USING 1430;Q(1),Q(2),Q(3),Qn
1430   IMAGE "FLUX RATE",4(8X,D.DDE)
1440   PRINT USING 1450;Df(1),Df(2),Df(3),Dfn
1450   IMAGE "F/D RATE ",4(8X,D.DDE)
1460   PRINT USING 1470;Muc(1),Muc(2),Muc(3),Mu
1470   IMAGE "MU (CONCRETE)",7X,3(Z.DDD,11X),Z.DDD,
1480   !PRINT USING 1740;Mus(1),Mus(2),Mus(3),0
1490   IMAGE "    MU (STEEL)",10X,3(Z.DDD,11X),Z.DDD,
1500   PRINT
1510   PRINT
1520   PRINT USING 1530;L
1530   IMAGE "CONTAINER LENGTH = ",3D.D,"(cm)"
1540   RETURN
1550   !
1560   !*********************************************************************
1570   !
1580   !                    PRINT OUT THE RESULTS
1590   !
1600 Out_put:   !
1610   PRINT
1620   PRINT
1630   PRINT
1640   PRINT
1650   PRINT
1660   PRINT "OUTPUT:"
1670   PRINT
1680   PRINT
1690   PRINT USING 1700
1700   IMAGE 35X,"STAND-OFF",11X,"2mr/hr LOCATION"
1710   PRINT USING 1720
1720   IMAGE 5X,"CONFIGURATION ",14X,"(cm)  /  (ft)",10X,"(cm)  /  (ft)"
1730   PRINT USING 1740
1740   IMAGE 5X,"-------------",14X,"---------------",8X,"---------------"
1750   FOR I=1 TO 5
1760      SELECT I
1770         CASE 1,2
1780            C$="VERTICAL"
1790         CASE ELSE
1800            C$="HORIZONTAL"
1810      END SELECT
1820      PRINT USING 1830;C$,D(I),St(I),A(I),A(I)/30.48
1830      IMAGE 7X,10A,13X,5D.D,5X,DDD.D,9X,3D.D,5X,D.DD
1840   NEXT I
1850   RETURN
1860   !**********************************************
1870   END
1880   !**********************************************
1890   !
1900   SUB Fint(L1,L2,B,Ffun)
1910   !
1920   !          Simpson's Rule
1930   !
1940   St=10       ! NUMBER OF STEPS
1950   Delta=(L2-L1)/(2*St)
```

```
1960   Ffun=0
1970   Z=(2*St)+1
1980   !
1990   FOR I=1 TO Z
2000       SELECT I
2010          CASE 1,Z
2020             X=1
2030          CASE ELSE
2040             IF INT(I/2)=I/2 THEN
2050                X=4
2060             ELSE
2070                X=2
2080             END IF
2090       END SELECT
2100       T=L1+(I-1)*Delta
2110       Ffun=Ffun+X*FNSev(B,T)
2120   NEXT I
2130   !
2140   Ffun=Ffun*Delta/3
2150   !
2160   SUBEND
2170   !
2180   !*******************************************************
2190   !
2200   DEF FNSev(B,T)
2210   F=EXP(-B/COS(T))
2220   RETURN F
2230   FNEND
2240   !
2250   !********************************************************
2260   !
2270   SUB In_data(Sel,Q(*),Qn,Df(*),Dfn,Muc(*),Mus(*),Mu)
2280   !
2290   !  THIS SUBPROGRAM FILLS THE DATA ARRAYS FOR THE TYPE
2300   !  OF WASTE THAT IS SPECIFIED.
2310   !
2320   !                  1 => HYBRID
2330   !                  2 => CONSOLIDATED
2340   !
2350   FOR I=1 TO 3
2360      READ Df(I),Muc(I),Mus(I)
2370   NEXT I
2380   READ Dfn,Mu
2381   !
2390   FOR I=1 TO Sel
2400      FOR J=1 TO 3
2410         READ Q(J)
2420      NEXT J
2430      READ Qn
2440   NEXT I
2450   !
2460   !               Mu's AND FLUX TO DOSE
2470   !
2480   DATA 2.30E-6,0.13,0.43
2490   DATA 2.93E-6,0.11,0.36
2500   DATA 3.45E-6,0.098,0.32
2501   !
2510   DATA 1.26E-4,0.0905
2520   !
2530   !                  1 => HYBRID
2540   !
2550   DATA 5.18E+14,6.86E+12,1.54E+11,3.9E+8
2560   !
2570   !                  2 => CONSOLIDATED
2580   !
2590   DATA 8.24E+14,9.77E+12,2.27E+11,5.8E+8
2600   !
2610   SUBEND
```

ATTACHMENT 5

Computer Code Verifications

Code for Transporter Cask Analysis

Date:	7/14/88
Code:	TRANS, Version 3.0, A Program To Determine Shielding Requirements for the Transporter Cask (Attachment 2)
Author:	Richard Flores
Subject:	This code calculates the lead and borated polyethylene thicknesses at the end and sides of the transporter cask that reduce dose rate to 2 mrem/hr at perpendicular distances from the cask surface of 2 ft.
Data Input:	See Input, Radiation Shielding Scoping Calculations.
Results:	Hand calculations using the following representative parameters verify the computer code.

	Hand Calculation	Computer Code
Transporter Cask		
End Thickness (cm)		
Lead	18.5	18.5
Polyethylene	29.1	29.1
Side Thickness (cm)		
Lead	18.0	18.0
Polyethylene	31.4	31.4

Code for Analysis of Shield Plug and Shielding Closure Thicknesses

Date: 7/13/88

Code: PLUG, Version 2.0, A Program to Determine Shielding Requirements for the Shield Plug and Shielding Closure (Attachment 3)

Author: Richard Flores

Subject: This code calculates the stainless steel and concrete thicknesses in the shield plug and shielding closure that reduce dose rate to 2 mrem/hr at a perpendicular distance from the center of the plug or closure of 2 ft.

Data Input: See Input, Radiation Shielding Scoping Calculations.

Results: Hand calculations using the following representative parameters verify the computer code.

	Thickness of Shield Plug (cm) and Shielding Closure			
	Hand Calculation		Computer Code	
	Steel	Concrete	Steel	Concrete
Horizontal Emplacement				
6-ft standoff	20.4	39.1	20.4	39.1
20-ft standoff	21.8	22.6	21.8	22.6
Vertical Emplacement				
10-ft standoff	20.9	32.8	20.9	32.8

Code for Analysis of Shielding Collar Radius

Date: 7/14/88

Code: COLLAR, Version 3.0, A Program to Determine the Radius of the Shielding Collar at which the Dose Rate is 2 mrem/hr (Attachment 4)

Author: Richard Flores

Subject: This code calculates the required radius for the shielding closure to reduce the dose rate at the surface of the drift wall to 2 mrem/hr. Standoff distances considered for horizontal emplacement are 0, 6, and 20 ft; for vertical emplacement they are 0 and 10 ft).

Data Input: See Input, Radiation Shielding Scoping Calculations.

Results: Hand calculations using the following representative parameter verifies the computer code.

	Shielding Closure Radius (cm)	
	Hand Calculation	Computer Code
Horizontal Emplacement		
0' Standoff	141.0	141.0

APPENDIX H

RETRIEVAL OPERATIONS AND SUPPORTING CALCULATIONS

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RETRIEVAL OPERATIONS AND SUPPORTING CALCULATIONS

1.0 Introduction

This appendix summarizes the results of the following five studies performed to evaluate retrieval operations:

1) Retrieval Sequence (Panel Level),
2) Panel Preparations,
3) Container Removal,
4) Overall Retrieval Schedule, and
5) Retrieval Equipment Requirements.

These studies indicate that retrieval of emplaced waste on a reasonable schedule [as defined in 10 CFR 60.111(b) (NRC, 1986)] is feasible.

2.0 Approach

This section describes the methods used to develop a schedule for retrieval operations.

2.1 Retrieval Sequence (Panel Level)

A panel sequence for the removal of the waste containers from the underground facility was selected from the following four options:

1) first waste in/first waste out,
2) last waste in/first waste out,
3) north to south (advancing), and
4) south to north (retreating).

Each alternative was evaluated by a group of underground design engineers for relative safety, ventilation controls, cooling requirements, and operability.

2.2 Panel Preparation

Each panel must be re-opened, cooled, inspected, and repaired as necessary. Estimates of the time needed to prepare a panel for waste removal are based on an analysis of the cooling capabilities of the ventilation system and on assumptions of the time needed to repair and rehabilitate a typical drift.

2.3 Container Removal

Once safe access to a panel or emplacement drift has been established, the retrieval operations proceed. The order in which vertically emplaced containers are removed from a drift is determined by establishing a minimum distance between two simultaneous operations (i.e., removal of a container from one hole and preparation for removal from another). The order of removing containers from horizontal boreholes is not as critical because of the relatively large distance between holes (36-68 ft) and the number of containers per hole (14-18 containers).

Developing the method for estimating the time needed to retrieve a single container begins with the development of block flow diagrams that describe the sequence of mechanical operations. Major activities are depicted by blocks that represent a group of detailed tasks. Time estimates are derived by estimating travel time and fixed times for each process or task. The schedule for single-container retrieval then serves as the basis for all schedules and estimates of needed equipment that follow.

2.4 Overall Retrieval Schedule

The time period for retrieval of all waste in the repository is defined to start when the decision to retrieve is made and to end when the last container of waste has been removed. This period includes the time allowed for preparation of the surface and underground facilities. The initial preparation phase is assumed to be 3 yr for both emplacement configurations. The time needed for removal of the waste is the same for vertical and horizontal emplacement configurations because a removal rate of eight containers per day is assumed for both cases.

2.5 Retrieval Equipment Requirements

Requirements for major retrieval equipment are estimated using the retrieval schedules and cycle times. The operating time for each piece of equipment is assumed to equal the full duration of the task where the particular piece of equipment is used.

The number of equipment items needed to maintain a steady retrieval rate of eight containers per day depends on the number of shifts per day. Cases for one and two shifts per day are evaluated. Miscellaneous hardware and spare equipment are assigned using engineering judgment.

3.0 Design Basis

The concepts reported here for retrieval operations are based on the repository design and emplacement configurations described in the Site Characterization Plan Conceptual Design Report (SCP-CDR) (SNL, 1987). The primary exception to this is the use in this study of an electric waste transporter instead of the diesel version described in the SCP-CDR.

3.1 Design Criteria

The key design criterion imposed on the retrieval schedule is that complete retrieval of all emplaced waste be achievable within a period of time approximately equal to the time it takes to construct the repository and emplace the waste [10 CFR 60.111(b)]. The repository life-cycle schedule presented in the SCP-CDR allows a 6-yr construction period followed by up to 28 yr of emplacement.

3.2 Assumptions

- Normal conditions are assumed for the rock, drifts, air quality, and engineered structures.

- It is assumed that no backfill is emplaced before retrieval.

- The decision to retrieve is assumed to occur 50 yr after the first emplacement of waste.

- The repository operations schedule is as follows:

  - 250 operating days/yr,
  - 5 days/wk,
  - 2 shifts/day, and
  - 8 hr/shift.

- To permit a gradual build-up to a maximum daily rate of eight containers per day, the following three-stage retrieval schedule is assumed:

Year 1	1000 containers/yr
Year 2	1500 containers/yr
Year 3 and thereafter	2000 containers/yr

- Waste transporter crews that begin and end their shift at the surface facilities have seven and a half available working hours in an 8-hr shift. All other underground operations have six available working hours per 8-hr shift, which accounts for travel and a lunch break.

- The waste transporter can travel over full or empty boreholes that are fitted with a shielding closure.

- Shielding closure installation and removal and/or shield plug manipulation can be performed in a drift where a container is being removed.

- The waste transporter is electrically powered, using overhead trolley wires when traveling in the waste ramp, waste main, and panel access drifts and batteries when traveling in the emplacement drifts.

- The average speed of a waste transporter will be 5 mph (440 ft/min).

- The waste transporters exit the emplacement drifts from the end that they enter. This requires the transporter to travel in forward or reverse modes when empty or loaded.

- Underground activities described here assume total retrieval of all emplaced waste but would also apply to partial retrieval (i.e., all waste from a single drift or emplacement borehole).

- It will take 7 calendar days (about 5 operating days) to install a heat exchanger at the entrance to a typical panel access drift.

- Once ventilation and cooling of a panel access drift have begun, inspection and maintenance of the accessible portions of the panel access drift can begin (before the entire drift reaches acceptable conditions).

- Maintenance and repairs in an emplacement drift can begin when half of the emplacement drift has been cooled to conditions acceptable for retrieval.

- The time required for inspection and maintenance of an emplacement drift is proportional to the length of the drift. A period of 25 calendar days is allowed for a 650-ft vertical emplacement drift. Fifty days are allowed for a 1300-ft horizontal emplacement drift.

- Two separate retrieval areas are defined for this study--one on each side of the main drifts. Each retrieval area is assumed to have a complete set of equipment that is used exclusively in that area except waste and dummy-container transporters, which are not assigned to a single area.

- A dedicated waste transporter is used to transfer dummy containers to a nearby empty borehole. (Dummy containers are those used to achieve the standoff distance in the horizontal emplacement configuration.)

3.3 Input Data

Input data for each section of this study are obtained from the SCP-CDR and from analyses presented in Appendices D (Ventilation) and E (Thermal Analyses) of the Retrieval Strategy Report.

3.3.1 Retrieval Sequence (Panel Level)

The evaluation of the overall panel sequence for retrieval is based on engineering judgment of the designers of the underground repository layout and the repository ventilation systems. This judgment derives from a knowledge of the repository layout described in the SCP-CDR and from an understanding of factors that affect ventilation flow and leakage in a network of airways.

3.3.2 Panel Preparation

The time needed to cool a drift for general access governs the time needed to prepare an emplacement panel for waste removal. Emplacement drift cooling times for inspection and retrieval are based on the ventilation analyses (using CLIMSIM) described in Appendix D. Distances into the emplacement drift accessible for inspection, retrieval, or maintenance as a function of cooling time are reproduced in Table H-1 for a typical 650-ft (200-m) vertical emplacement drift.

3.3.3 Container Removal

The emplacement panel layout and drift capacities are the following.

Vertical: 76 containers of spent fuel and defense high-level waste (DHLW) per drift at a typical center-to-center spacing of 7.5 ft/container (SCP-CDR).

TABLE H-1

ACCESSIBILITY OF EMPLACEMENT DRIFT AS A FUNCTION OF COOLING TIME

For Inspection[a]		For Retrieval or Maintenance[b]	
Time (days)	Accessible Emplacement Drift Length (m)	Time (days)	Accessible Emplacement Drift Length (m)
5	55.6	10	27.5
10	105.0	20	89.0
20	189.0	30	132.0
30	236.0	40	173.0
		50	201.0

a. Air cooling power (ACP) >300 W/m^2; dry bulb temperature (T_d) <45°C.

b. ACP >500 W/m^2; T_d <40°C.

Horizontal: 32 spent fuel boreholes and 18 DHLW boreholes in a typical emplacement drift. Each spent fuel borehole contains 8 dummy containers and 14 waste containers. Each DHLW borehole contains 8 dummy containers and 18 waste containers (SCP-CDR).

The determination of how close two simultaneous operations can occur in the same vertical emplacement drift depends on equipment dimensions. Dimensions for the vertical emplacement equipment are provided by Stinebaugh and Frostenson (1986). The waste transporter measures 25 ft long x 10 ft wide x 8 ft high when in the traveling mode. The shielding closure measures 74 in. long x 38 in. wide x 12 in. high when installed on a vertical borehole.

Block flow diagrams of the container retrieval process for the vertical emplacement configuration are developed from the descriptions of retrieval operations provided by Stinebaugh and Frostenson (1986). Comparable descriptions of the retrieval operations for the horizontal emplacement configuration are given by Stinebaugh, White, and Frostenson (1986).

3.3.4 Overall Retrieval Schedule

The duration of the overall retrieval process is governed by the annual retrieval rate and the total inventory of emplaced waste. The SCP-CDR waste inventory represents 70,000 metric tons uranium equivalent (MTU) packaged in containers as follows:

Spent fuel (62,000 MTU):	24,614	containers
	1,099	hardware containers
DHLW and West Valley high-level waste (WVHLW) (8,000 MTU):	14,720	containers of DHLW
	310	containers of WVHLW
	40,743	total containers

3.3.5 Retrieval Equipment Requirements

Equipment capabilities and concepts for the vertical emplacement configuration are described by Stinebaugh and Frostenson (1986). Corresponding information for the horizontal emplacement configuration is contained in the report by Stinebaugh, White, and Frostenson (1986).

4.0 Results

4.1 Retrieval Sequence (Panel Level)

The recommended panel sequence for retrieval within the repository is advancing from north to south with simultaneous operations on both sides of the waste mains.

The north-to-south panel sequence for retrieval was selected from four alternatives (Section 2.1) by ranking each alternative according to relative safety, ventilation control, cooling requirements, and operability. Table H-2 compares the advantages and disadvantages of each

TABLE H-2

COMPARISON OF OPTIONS FOR OVERALL SEQUENCE OF RETRIEVAL

Option	Advantages	Disadvantages
First Waste In, First Waste Out (FIFO)	Oldest waste is retrieved first resulting in most time for decay and cooling of waste.	Because full panels continue to be maintained as during the caretaker phase, this option results in a large potential for air leakage into full panels on west side of repository.
Last Waste In, First Waste Out	If retrieval follows immediately after the end of emplacement, the operation could begin without extensive cooling because the residence time of the first waste retrieved would be lowest.	Ventilation leakage into full panels on east side of mains becomes progressively greater as retrieval proceeds southward. Suffers same ventilation disadvantage as FIFO option. First waste to be retrieved would be youngest in terms of time-since-reactor.
North to South Advancing	Most efficient use (least leakage) of intake air because empty panels can be closed completely as retrieval progresses southward.	Waste to be retrieved from west side would be youngest.
South to North Retreating	New equipment would be used when haulage distances were greatest. Fewer bulkheads required to close mains on retreat than to close panel access drifts.	Results in largest number of potential leakage paths since air must be carried to southern end of repository for blast cooling while remaining panels are maintained in caretaker status.

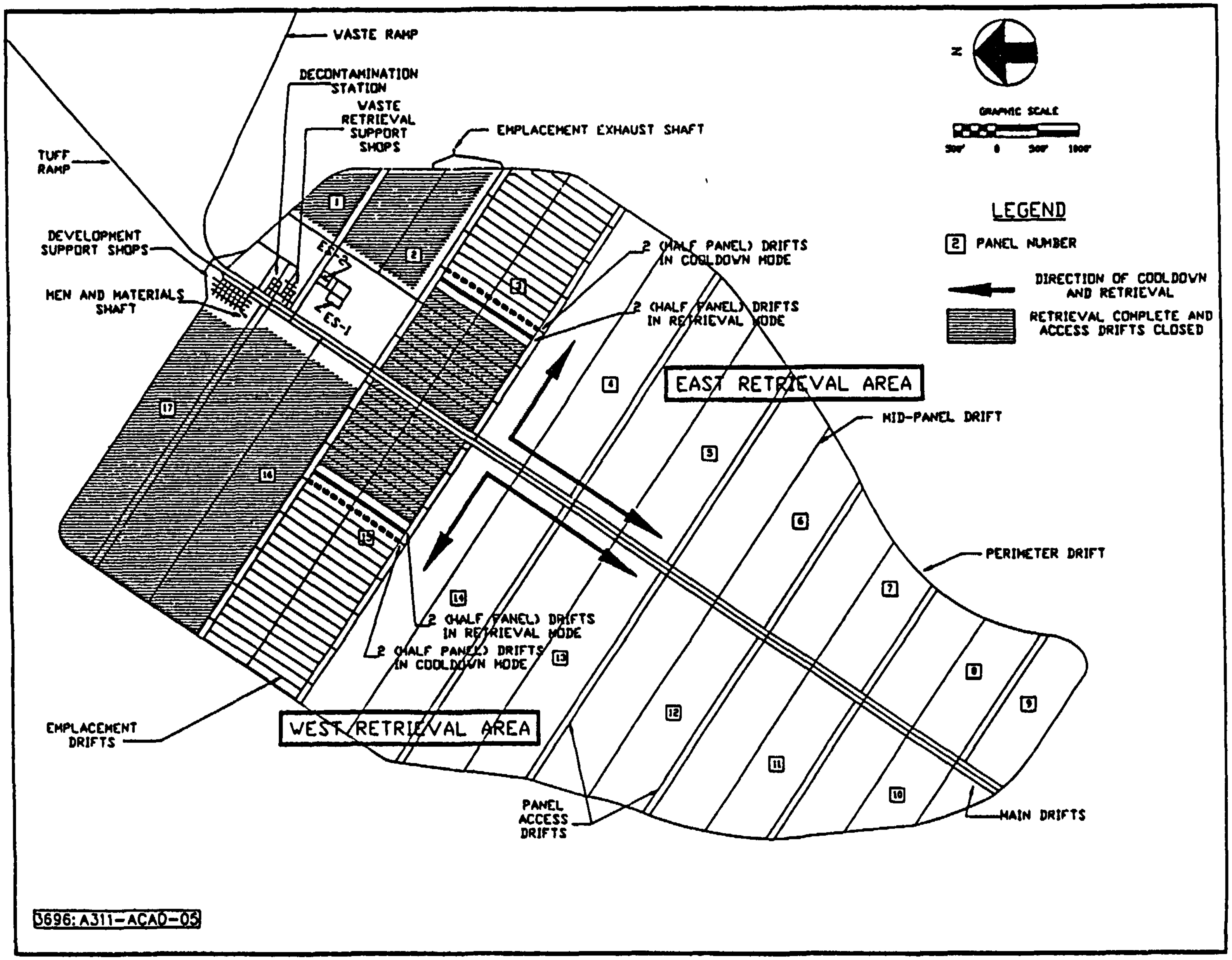


Figure H-1. Recommended Sequence for Retrieval of All Waste from the Repository option. The comparison between options applies to both vertical and horizontal emplacement configurations. Figure H-2 shows the preferred order of operations.

4.2 Panel Preparation

Preparation for retrieval from a typical emplacement panel involves reestablishing ventilation in the panel access drift and the first emplacement drift, cooling the panel access and emplacement drifts to acceptable temperatures, and inspecting and performing maintenance on the two drifts. Notes in Figure H-2 describe the preparation activities for a typical vertical emplacement panel.

The conditions of a typical emplacement panel before retrieval are assumed to be as follows.

- Having been routinely maintained during the caretaker period, the ground support is assumed to be in good order and to require only scaling of loose rock and occasional replacement of rock bolts.

- Road surfaces may be cracked but are passable following cleanup of rock that has sloughed from drift walls.

- The temperature of the surrounding rock ranges from 50 to 120°C in the vertical emplacement configuration and from 50 to 55°C in the horizontal emplacement configuration (Figure H-3).

- Doors into panel access drifts are closed allowing a controlled amount of leakage into panel. Doors in all but the emplacement drift farthest from the main are closed.

All schedules assume 250 operating days per 365-day year. Drift cooling is assumed to operate continuously. The durations described here are based on a calendar schedule where

$$1.0 \text{ operating day} = 365/250 = 1.460 \text{ calendar days.}$$

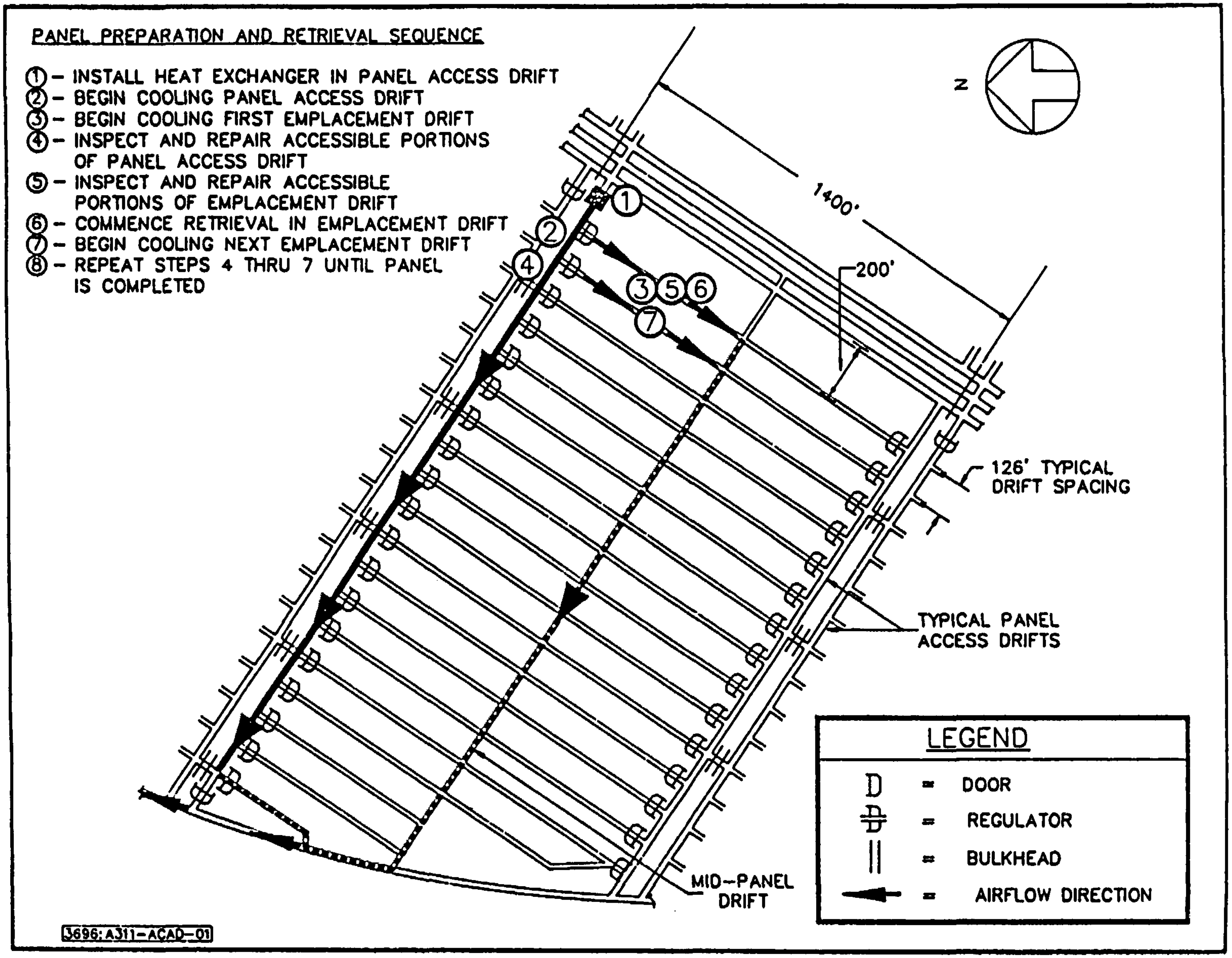


Figure H-2. Panel Preparation Sequence, Vertical Emplacement Configuration

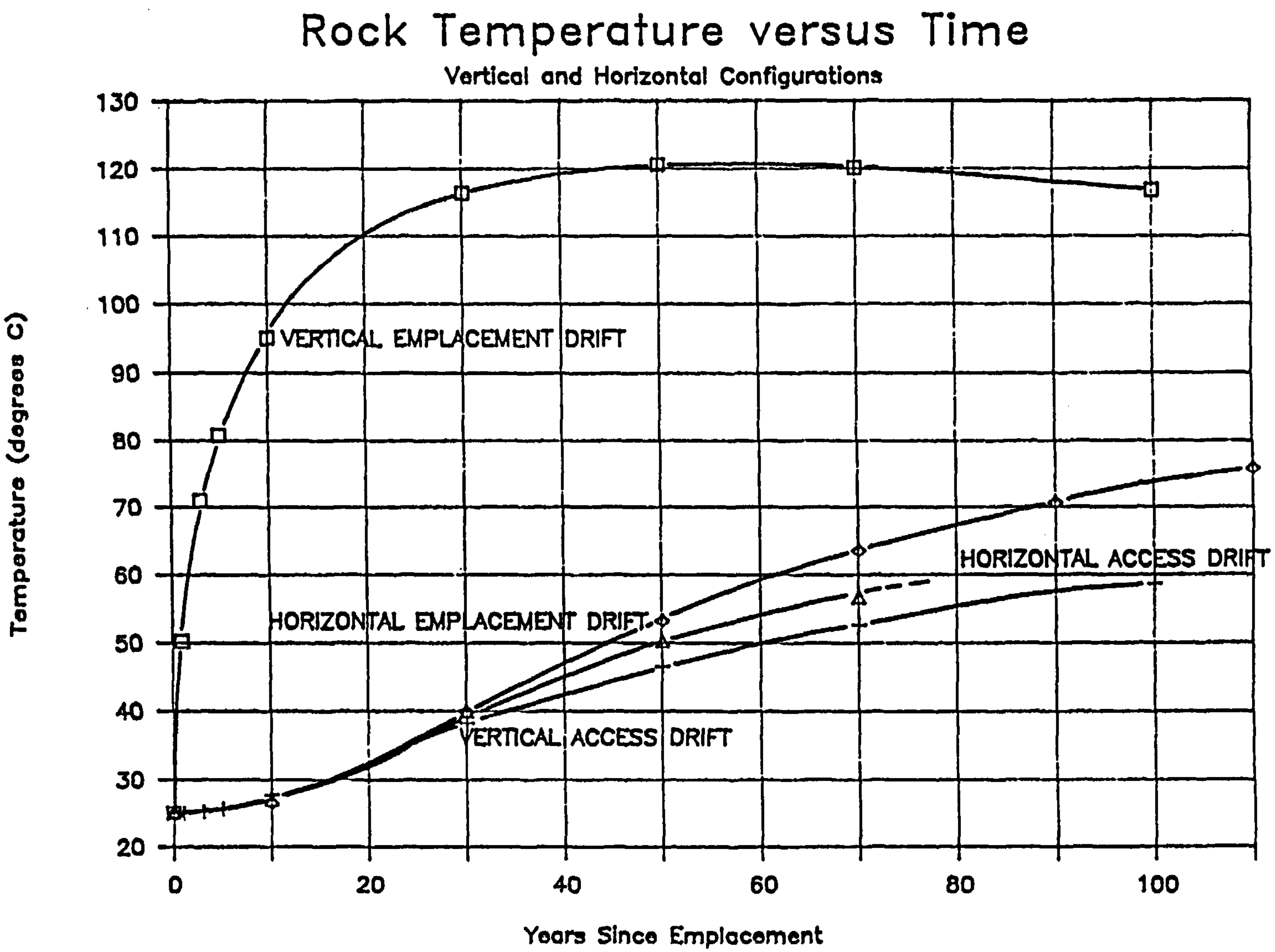


Figure H-3. Drift Temperature in a Typical Emplacement Panel as a Function of Time Since Emplacement (Appendix E)

4.2.1 Reestablish Ventilation

To reestablish ventilation, the doors in the panel access drifts are opened. The horizontal emplacement configuration can be cooled in sufficient time using air at ambient temperature, but the vertical emplacement configuration will require chilled air to cool the drifts. Heat exchangers will be installed which, for the vertical emplacement configuration, involves towing a skid-mounted spray-chamber and fan into the panel access drift and situating it in an existing sealing frame adjacent to the door. Complete installation is assumed to take one calendar week or approximately five operating days.

4.2.2 Drift Cooling

Design criteria imposed on the SCP-CDR panel design for the vertical emplacement configuration limit the temperature of the rock surrounding the panel access drift to <50°C after 50 yr (Figure H-3). The time needed to cool a panel access drift will be considerably less than that needed to cool an emplacement drift. For the purposes of this study, it is assumed that 7 days are needed to cool the portion of the panel access drift between the mains and the first emplacement drift.

For the horizontal emplacement configuration, the rock temperature in the panel access drift is expected to be approximately the same as in the vertical configuration. It is assumed that the cooling period is proportional to the length of drift. The distance to the first horizontal emplacement drift is approximately 570 ft, versus 200 ft to the vertical emplacement drift. Twenty calendar days (20 calender days = 570/200 x 7 days) are allowed for cooling the panel access drift in the schedule for the horizontal emplacement configuration. No heat exchangers are required, and the panel access drift and the emplacement drift are cooled using ambient air.

While any emplacement drifts are being cooled, a controlled amount of the ventilation air continues past the emplacement drift to cool the panel access drift downwind of the open emplacement drift. Therefore, it is assumed that no additional time is needed in the operations schedule to cool the panel access drift beyond the first emplacement drift.

At any given time, two vertical emplacement drifts are being ventilated and cooled in each half-panel. The time needed to cool an entire 650-ft drift to acceptable conditions for maintenance and retrieval is approximately 50 days (Figure H-4). However, in 25 days the entire length is accessible for inspection, and half the total length is cool enough for drift maintenance.

The time needed to cool a typical 1300-ft horizontal emplacement drift to acceptable conditions for maintenance and retrieval without using heat exchangers is approximately 50 days. It is assumed that the entire drift is accessible for inspection in 25 days (as was possible in the vertical case).

4.2.3 Inspection and Maintenance

4.2.3.1 Inspection and Maintenance of Panel Access Drift

It is assumed that inspection and maintenance of the 200-ft section of panel access drift leading to the first vertical emplacement drift will occur during the 7-day initial cooling period.

Inspection and maintenance of the panel access drift are assumed to progress for the horizontal case at the same rate as for the vertical case. The 7-day period assumed for the vertical configuration is factored by 570/200 to yield a 20-day period for the horizontal case.

4.2.3.2 Inspection and Maintenance of Emplacement Drift

It is assumed that each vertical emplacement drift is inspected and repaired as needed during the latter half of the 50-day cooling period. After 25 days of cooling, the first half of the drift is accessible for maintenance, and the full length of the drift is accessible for inspection. A period of 25 calendar days is allowed to perform necessary

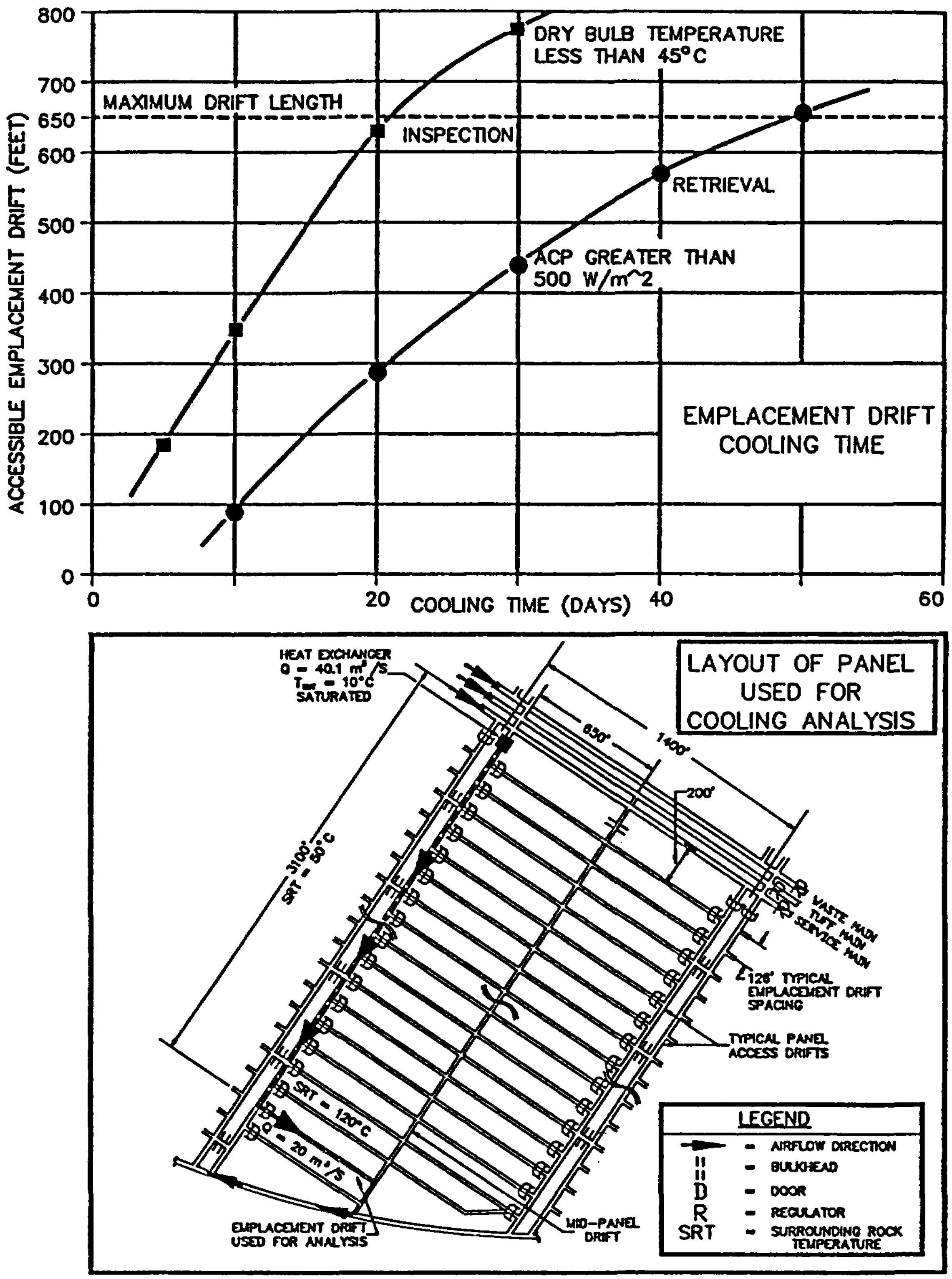


Figure H-4. Emplacement Drift Cooling Time repairs in each emplacement drift. This translates to 25/1.46 = 17 operating days to inspect and repair 650 ft of drift, or 38 ft per operating day.

At the same rate that was established for the vertical configuration, the inspection and maintenance of a 1300-ft horizontal emplacement drift will require 50 calendar days. It is assumed that maintenance can begin after 25 days of cooling with ambient air.

Figure H-5 shows the timeline for preparation of a typical emplacement panel in the vertical emplacement configuration. Initial preparation requires 64 calendar days (44 operating days) before waste retrieval operations can begin in a panel.

Figure H-6 shows the timeline for the horizontal emplacement configuration. Ninety-five calendar days (65 operating days) are needed before waste retrieval can begin in the panel.

4.3 Container Removal

Waste removal begins at the borehole nearest the panel access drift and proceeds inward at a rate of two containers per operating day. A typical vertical emplacement drift contains 76 waste containers. The calendar time required for retrieval of all the containers is determined as follows:

76 containers/2 containers per operating day = 38 operating days

38 operating days * 1.46 calendar days per operating day = 55.5 calendar days.

Therefore, removal of all of the waste containers from a typical vertical emplacement drift will take 55 calendar days. This duration balances the 50-day cooling time required for a typical emplacement drift.

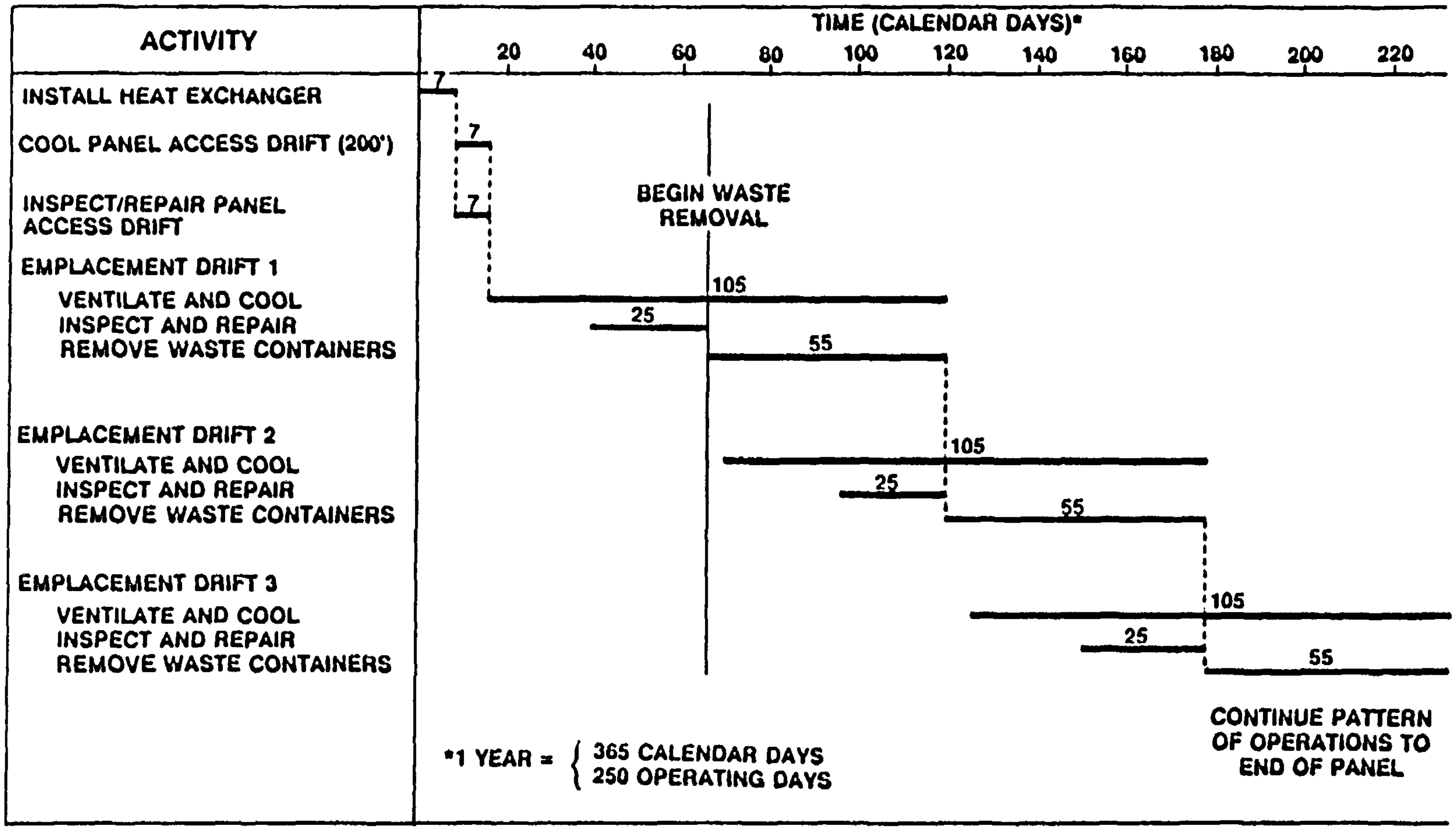


Figure H-5. Overall Schedule for Preparation of and Retrieval from a Typical Vertical Emplacement Drift

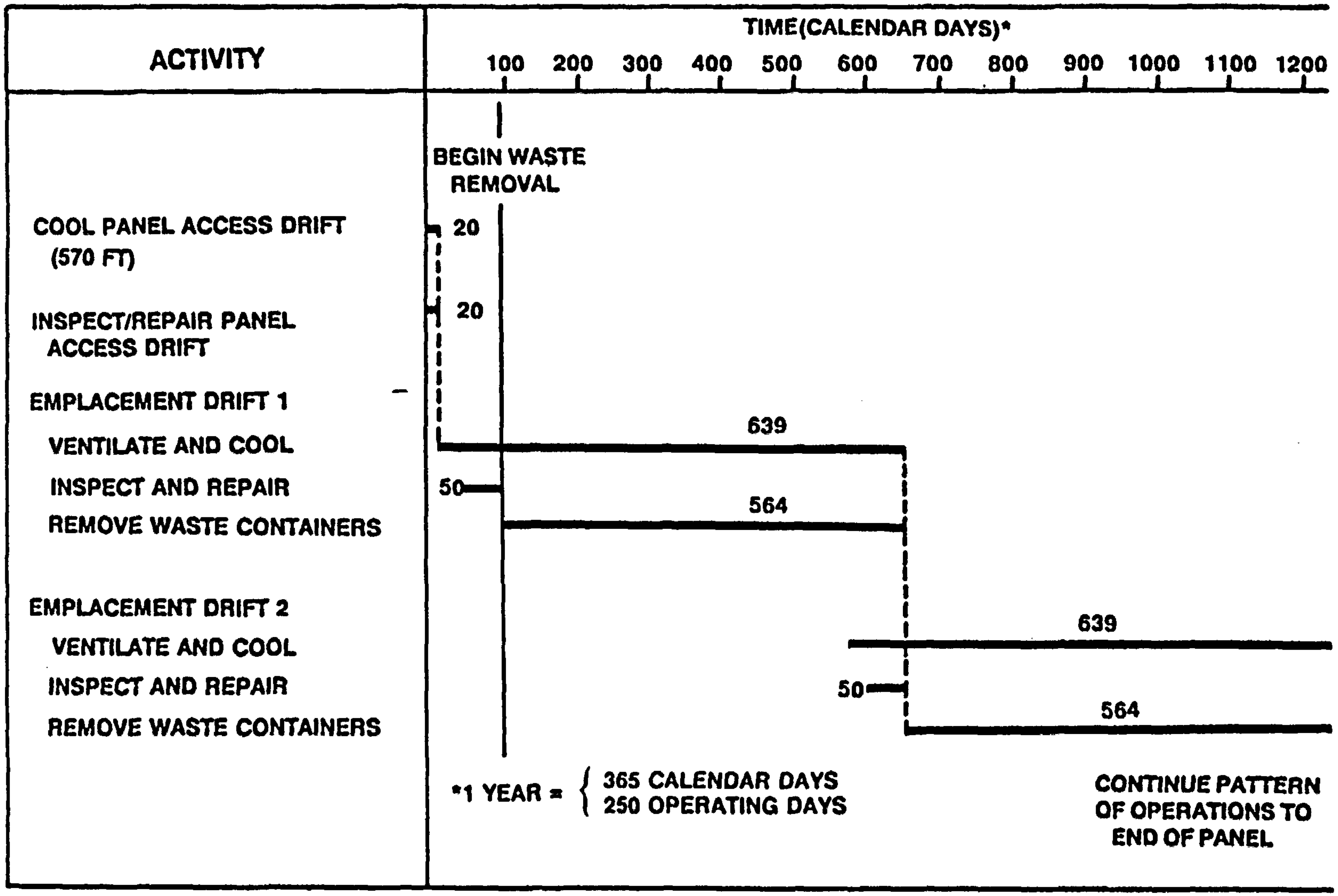


Figure H-6. Overall Schedule for Preparation of and Retrieval from a Typical Horizontal Emplacement Drift

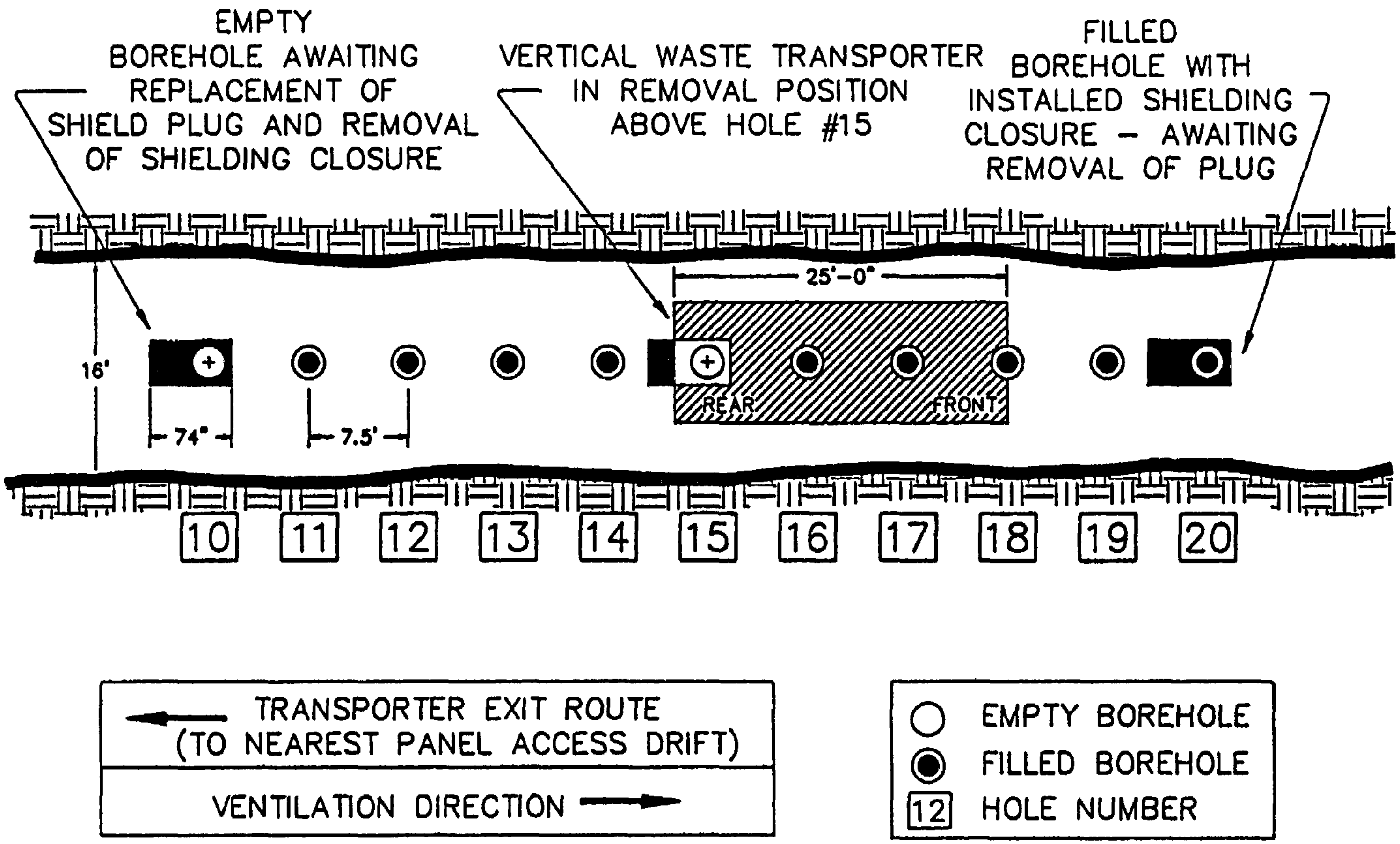
A typical horizontal emplacement drift contains 772 spent fuel and DHLW containers. At a rate of two containers per operating day per drift, the removal of all waste from a single emplacement drift requires 772/2 = 386 operating days. This corresponds to 386 * 1.46 = 564 calendar days. Each emplacement drift also contains approximately 400 dummy containers which must be transferred to empty boreholes. Unlike the vertical case, there is a large difference between the time it takes to cool a drift (50 days) and the time it take to remove the emplaced waste (564 days). Hence, it is not necessary to cool an emplacement drift until 50 calendar days before retrieval begins in the drift.

4.3.1 Removal Sequence

The 7.5-ft spacing between vertical emplacement boreholes is sufficiently small that an alternating retrieval sequence must be adopted if the desired retrieval rate (2 containers/day/drift) is to be maintained from a single emplacement drift in each half-panel (4 drifts total). The situation is more complex if a single shift per day schedule is employed. Figure H-7 shows equipment dimensions and the theoretical distance between operations if a five-hole spacing pattern is used. This approach assumes that the transporter exits the drift from the same end that it enters. Also, the borehole preparation equipment upwind of the transporter must be able to move out without delaying the waste transporter.

4.3.2 Removal Operations

The individual steps for retrieving an emplaced container from a vertical borehole are identified in the block flow diagram shown in Figure H-8. The corresponding block flow diagram for the horizontal emplacement configuration is shown in Figure H-9. The block flow diagrams serve as the basis for the development of the operations schedules. The determination of each schedule begins with organizing all required mechanical operations into a logical sequence.



NOTE: EVERY FIFTH CONTAINER IS REMOVED IN A PATTERN THAT ALLOWS SIMULTANEOUS ACTIVITIES WITHIN THE SAME DRIFT WITH SUFFICIENT WORK SPACE TO MANIPULATE THE SHIELDING CLOSURE AND PLUGS.

Figure H-7. Container Retrieval Order within a Typical Vertical Emplacement Drift

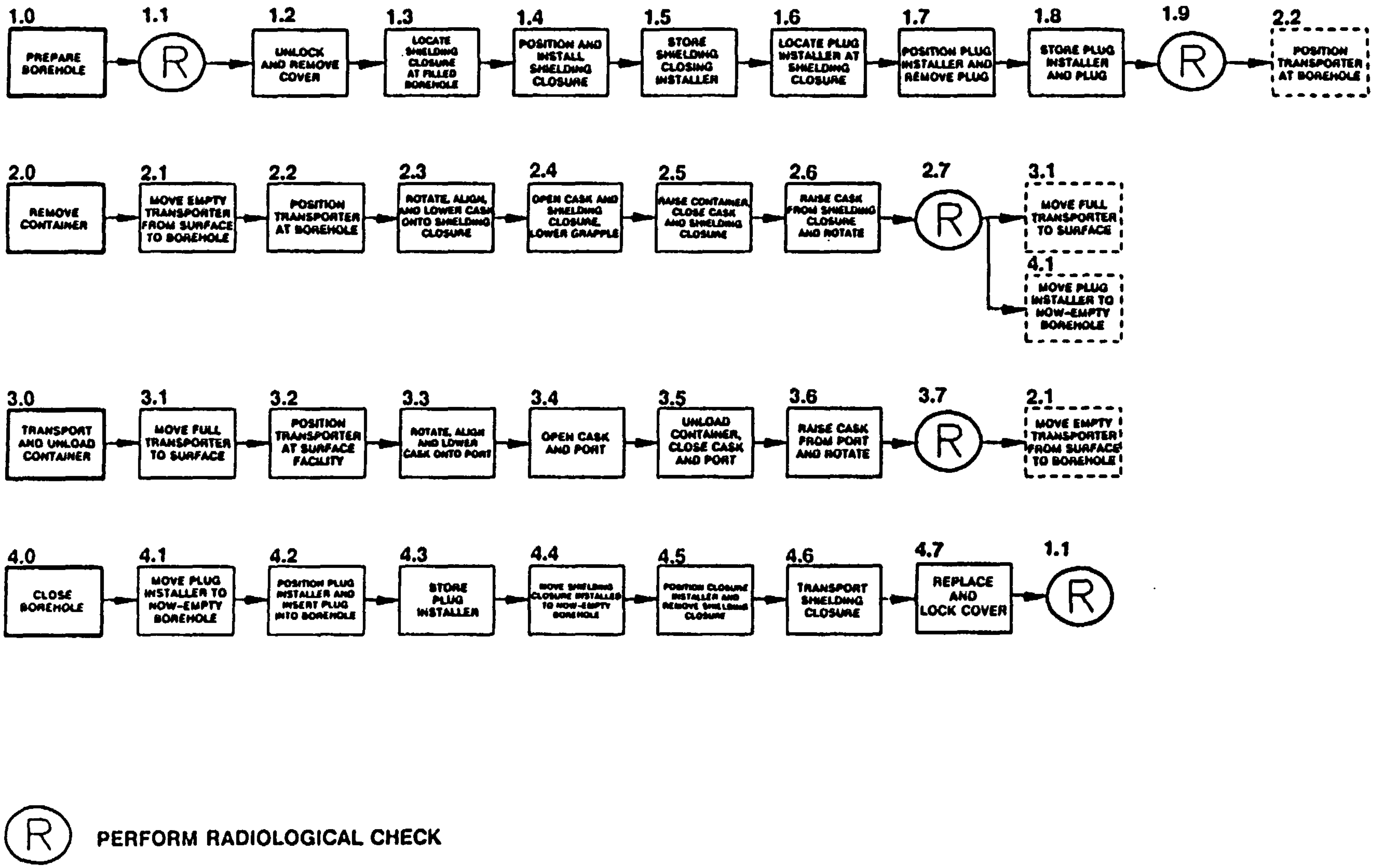


Figure H-8. Block Flow Diagram, Waste Retrieval, Vertical Emplacement Configuration

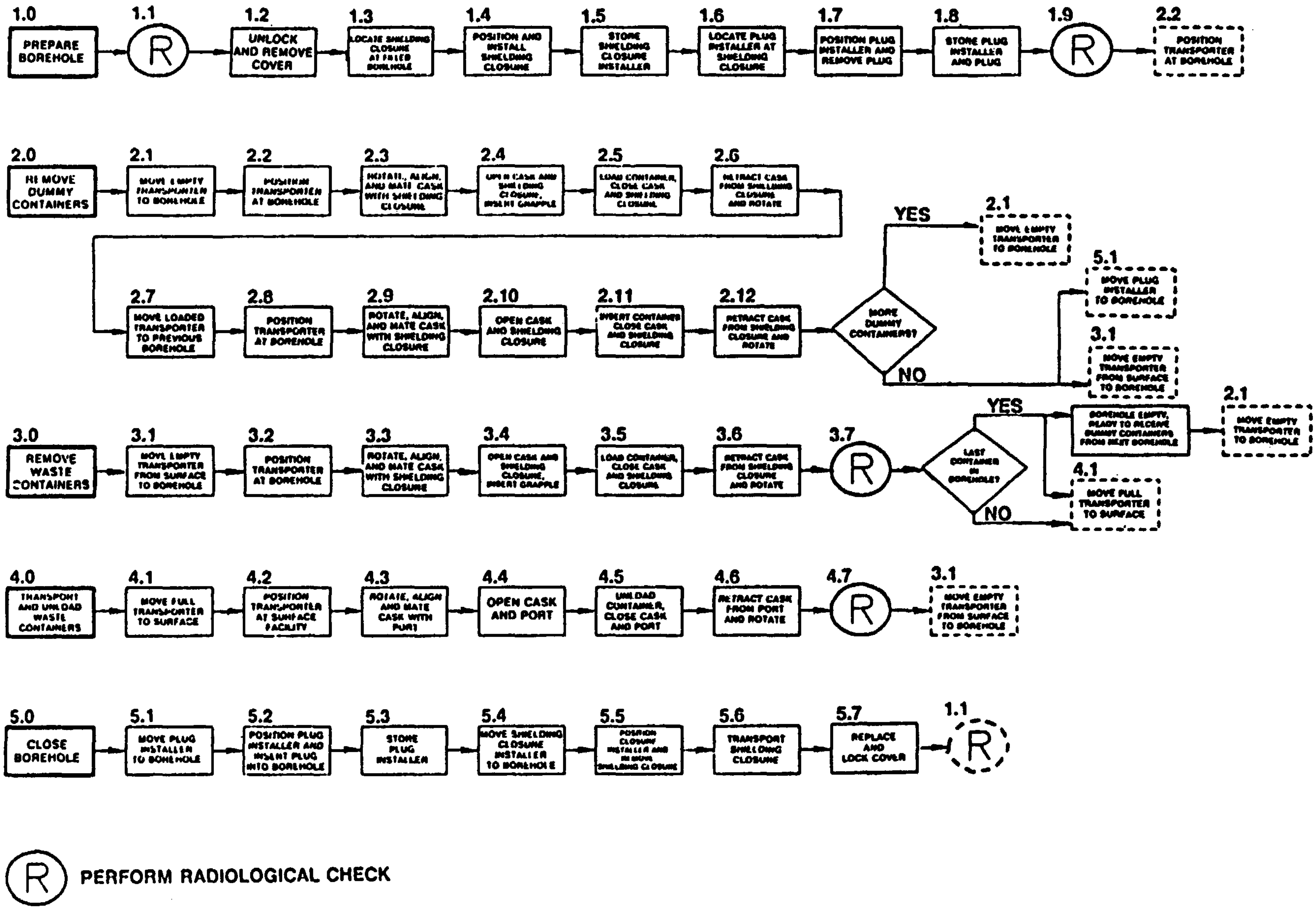


Figure H-9. Block Flow Diagram, Waste Retrieval, Horizontal Emplacement Configuration

4.3.3 Removal Schedule

Each activity block in the block flow diagrams comprises many tasks. Tables H-3 and H-4 list the detailed tasks within each block for the vertical and horizontal emplacement configurations, respectively.

By examining the individual tasks within each block it is possible to approximate the time needed to complete all of the tasks within a block and ultimately to use the task-block time requirements to estimate the time needed to perform the overall retrieval process. Hence, these tables serve as the basis for all retrieval schedules that follow.

For each block, the total time is made up of travel time, which is based on the travel distances shown in Figure H-10, and fixed time, which is estimated using engineering judgment. The distance from the waste ramp portal to an emplacement drift is assumed to be 15,100 ft for both emplacement configurations.

Borehole preparation and shielding equipment are assumed to be stored temporarily in three designated areas in the panel access drifts at each end of the active emplacement drifts. The shielded forklifts used to prepare the boreholes are assumed to operate within two emplacement drifts. A one-way travel distance between a typical hole and a storage area of 375 ft is assumed for the vertical configuration and 700 ft for the horizontal case.

Average travel speeds are assumed to be 5 mph for the waste transporter and 2.5 mph for the shielded forklifts. A lower speed is used for the forklifts because of the relatively short travel distances and the fact that most of the travel occurs in the emplacement drifts.

The retrieval cycle for a single container in a vertical borehole is depicted in Figure H-11; the cycle is estimated to require 377 min. Borehole preparation and closure are performed by separate crews that operate in conjunction with the waste transporter crews. Emplacement boreholes are prepared and closed at a rate that ensures that the waste transporters are not idle.

TABLE H-3

DESCRIPTION OF WASTE RETRIEVAL OPERATIONS, VERTICAL EMPLACEMENT CONFIGURATION

ACTIVITY DESCRIPTION	EQUIPMENT	CREW	TRAVEL TIME (min)	FIXED TIME (min)	TOTAL TIME (min)
1.0 Prepare Borehole					
1.1 Perform Radiological Check		QC-V	1.7	15.0	16.7
1.1.1 Move test equipment to hole.					
1.1.2 Record hole identification data.	Radiation monitoring equipment				
1.1.3 Measure for radiation around hole cover.					
1.1.4 Record data.					
1.1.5 Remove test equipment.					
1.2 Unlock and Remove Cover		HP-V	1.7	10.0	11.7
1.2.1 Move shielded forklift to hole.	Shielded forklift (vertical)				
1.2.2 Unlock cover.					
1.2.3 Lift cover using forklift.					
1.2.4 Place cover on floor of drift adjacent to borehole.					
1.3 Locate Shielding Closure at Filled Borehole		HP-V	3.4	20.0	23.4
1.3.1 Move shielded forklift to temporary storage area.					
1.3.2 Mount shielding closure installer to shielded forklift.	Shielded forklift (vertical)				
1.3.3 Engage shielding closure with closure installer.	Closure installer (vertical)				
1.3.4 Transport shielding closure to borehole.	Shielding closure (vertical)				
1.4 Position and Install Shielding Closure		HP-V	0.0	20.0	20.0
1.4.1 Position shielding closure with shielded forklift.	Shielded forklift (vertical)				
1.4.2 Connect shielding closure to borehole.	Closure installer (vertical)				
1.4.3 Disengage shielding closure from installer.	Shielding closure (vertical)				
1.4.4 Test mechanical/electrical systems on shielding closure.					
1.5 Store Shielding Closure Installer		HP-V	1.7	10.0	11.7
1.5.1 Transport shielding closure installer to temporary storage area.	Shielded forklift (vertical) Closure installer (vertical)				
1.5.2 Dismount shielding closure installer from forklift.					
1.6 Locate Plug Installer at Shielding Closure		HP-V	1.7	20.0	21.7
1.6.1 Move forklift to available shield plug installer.	Shielded forklift (vertical)				
1.6.2 Mount plug installer to shielded forklift.	Shield plug installer (vertical)				
1.6.3 Test mechanical/electrical systems on plug installer.					
1.6.4 Transport plug installer to borehole from temporary storage area.					
1.7 Position Plug Installer and Remove Plug		HP-V	0.0	30.0	30.0
1.7.1 Position plug installer with shielded forklift.	Shielded forklift (vertical)				
1.7.2 Mate shield plug installer to shielding closure.	Shield plug installer (vertical)				
1.7.3 Open plug installer door.					
1.7.4 Open shielding closure door.					
1.7.5 Lower plug grapple onto pintle on plug.					
1.7.6 Lift plug.					
1.7.7 Close shielding closure door.					
1.7.8 Close plug installer door.					

WT-V= Transporter crew, HP-V= Hole prep crew, QC-V= Quality control and Radiation monitoring crew

TABLE H-3

DESCRIPTION OF WASTE RETRIEVAL OPERATIONS, VERTICAL EMPLACEMENT CONFIGURATION (continued)

ACTIVITY DESCRIPTION	EQUIPMENT	CREW	TRAVEL TIME (min)	FIXED TIME (min)	TOTAL TIME (min)
1.8 Store Plug Installer and Plug		HP-V	1.7	15.0	16.7
1.8.1 Release plug installer from shielding closure.					
1.8.2 Transport plug installer with plug to temporary storage area.	Shielded forklift (vertical) Shield plug installer (vertical)				
1.8.3 Dismount plug installer containing plug from forklift.					
1.9 Perform Radiological Check		QC-V	1.7	15.0	16.7
1.9.1 Move test equipment to borehole.					
1.9.2 Measure for radiation around shielding closure.	Radiation monitoring equipment				
1.9.3 Record data.					
1.9.4 Remove test equipment.					
1.9.5 Flag borehole as "ready to retrieve".					
1.9.6 Clear immediate retrieval area.					
2.0 Remove Container					
2.1 Move Empty Transporter from Surface to Borehole		WT-V	34.3	10.0	44.3
2.1.1 Prepare transporter for retrieval operations at surface.	Waste transporter (vertical)				
2.1.2 Communicate retrieval location to operator.					
2.1.3 Move transporter to retrieval area.					
2.1.4 Locate borehole for retrieval.					
2.2 Position Transporter at Borehole	Waste transporter (vertical)	WT-V	0.0	20.0	20.0
2.2.1 Move transporter into position at borehole.					
2.2.2 Level and align transporter with shielding closure.					
2.3 Rotate, Align, and Lower Cask onto Shielding Closure		WT-V	0.0	15.0	15.0
2.3.1 Rotate cask to vertical position.	Waste transporter (vertical)				
2.3.2 Align cask over borehole.					
2.3.3 Mate cask with shielding closure.					
2.4 Open Cask And Shielding Closure, Lower Grapple		WT-V	0.0	5.0	5.0
2.4.1 Open cask shield door.	Waste transporter (vertical)				
2.4.2 Open shielding closure door.	Shielding closure (vertical)				
2.4.3 Lower grapple.					
2.5 Raise Container, Close Cask and Shielding Closure		WT-V	0.0	15.0	15.0
2.5.1 Engage grapple to container pintle.	Waste transporter (vertical)				
2.5.2 Raise container into cask.	Shielding closure (vertical)				
2.5.3 Close cask door.					
2.5.4 Close shielding closure door.					
2.6 Retract Cask from Shielding Closure and Rotate		WT-V	0.0	10.0	10.0
2.6.1 Retract cask from shielding closure.	Waste transporter (vertical)				
2.6.2 Raise cask.	Shielding closure (vertical)				
2.6.3 Rotate cask to traveling position.					

WT-V= Transporter crew, HP-V= Hole prep crew, QC-V= Quality control and Radiation monitoring crew

TABLE H-3
DESCRIPTION OF WASTE RETRIEVAL OPERATIONS, VERTICAL EMPLACEMENT CONFIGURATION (continued)

ACTIVITY DESCRIPTION	EQUIPMENT	CREW	TRAVEL TIME (min)	FIXED TIME (min)	TOTAL TIME (min)
2.7 Perform Radiological Check		QC-V	1.7	15.0	16.7
2.7.1 Move test equipment to borehole.	Waste transporter (vertical)	WT-V	0.0	15.0	15.0
2.7.2 Record cask and transporter identification.	Radiation monitoring equipment				
2.7.3 Measure for radiation on cask and shielding closure.					
2.7.4 Record data.					
2.7.5 Remove test equipment.					
3.0 Transport and Unload Container					
3.1 Move Full Transporter to Surface		WT-V	34.3	10.0	44.3
3.1.1 Notify control center.	Waste transporter (vertical)				
3.1.2 Wait for clearance.					
3.1.3 Move transporter to surface facilities.					
3.2 Position Transporter at Surface Facility		WT-V	0.0	10.0	10.0
3.2.1 Notify surface control center of arrival.	Waste transporter (vertical)				
3.2.2 Position transporter at receiving bay.					
3.3.3 Verify container data with surface control.					
3.3 Rotate, Align, and Lower Cask onto Port		WT-V	0.0	10.0	10.0
3.3.1 Rotate loaded cask into vertical position.	Waste transporter (vertical)				
3.3.2 Align cask with port.					
3.3.3 Mate cask with port.					
3.4 Open Cask and Port		WT-V	0.0	5.0	5.0
3.4.1 Open cask door.	Waste transporter (vertical)				
3.4.2 Open port door.					
3.5 Unload Container, Close Cask and Port		WT-V	0.0	10.0	10.0
3.5.1 Lower container through port.	Waste transporter (vertical)				
3.5.2 Release grapple.					
3.5.3 Raise grapple into cask.					
3.5.4 Close cask door.					
3.5.5 Close port door.					
3.6 Retract Cask from Port and Rotate		WT-V	0.0	10.0	10.0
3.6.1 Retract cask from port.	Waste transporter (vertical)				
3.6.2 Raise cask.					
3.6.3 Rotate cask to traveling position.					
3.7 Perform Radiological Check		QC-V	1.7	15.0	16.7
3.7.1 Move test equipment to port.	Waste transporter (vertical)	WT-V	0.0	15.0	15.0
3.7.2 Record cask, port, and transporter identification.	Radiation monitoring equipment				
3.7.3 Measure for radiation on transporter and cask.					
3.7.4 Record data.					
3.7.5 Remove test equipment.					

WT-V= Transporter crew, HP-V= Hole prep crew, QC-V= Quality control and Radiation monitoring crew

TABLE H-3
DESCRIPTION OF WASTE RETRIEVAL OPERATIONS, VERTICAL EMPLACEMENT CONFIGURATION (concluded)

ACTIVITY DESCRIPTION	EQUIPMENT	CREW	TRAVEL TIME (min)	FIXED TIME (min)	TOTAL TIME (min)
4.0 Close Borehole					
4.1 Move Plug Installer to Now-empty Borehole		HP-V	1.7	20.0	21.7
4.1.1 Move forklift to storage area.					
4.1.2 Mount plug installer with plug to shielded forklift.	Shielded forklift (vertical)				
4.1.3 Transport plug installer to now-empty borehole from temporary storage area.	Shield plug installer (vertical)				
4.1.4 Position plug installer over shield closure.					
4.2 Insert Shield Plug into Borehole		HP-V	0.0	20.0	20.0
4.2.1 Mate plug installer with shield closure.	Shielded forklift (vertical)				
4.2.2 Open shield closure door.	Shield plug installer (vertical)				
4.4.3 Open plug installer door.					
4.4.4 Lower shield plug into borehole.					
4.4.5 Release grapple.					
4.4.6 Raise grapple.					
4.4.7 Close shield closure door.					
4.4.8 Close plug installer door.					
4.3 Store Plug Installer		HP-V	1.7	15.0	16.7
4.3.1 Release plug installer from shielding closure.	Shielded forklift (vertical)				
4.3.2 Transport empty plug installer to temporary storage area.	Shield plug installer (vertical)				
4.3.3 Dismount plug installer from shielded forklift.					
4.4 Move Shielding Closure Installer to Now-empty Borehole		HP-V	1.7	20.0	21.7
4.4.1 Move forklift to temporary storage area.					
4.4.2 Mount shielding closure installer to shielded forklift.	Shielded forklift (vertical)				
4.4.3 Transport shielding closure installer to borehole.	Closure installer (vertical)				
4.5 Remove Shielding Closure		HP-V	0.0	15.0	15.0
4.5.1 Disconnect shielding closure from borehole.					
4.5.2 Engage shielding closure installer with closure.	Shielded forklift (vertical)				
4.5.3 Lift shielding closure from borehole.	Shielding closure (vertical)				
	Closure installer (vertical)				
4.6 Transport Shielding Closure		HP-V	1.7	20.0	21.7
4.6.1 Transport shielding closure to temporary storage area.	Shielded forklift (vertical)				
4.6.2 Disengage shielding closure from installer.	Shielding closure (vertical)				
4.6.3 Dismount shielding closure installer from forklift.	Closure installer (vertical)				
4.7 Replace and Lock Cover		HP-V	1.7	10.0	11.7
4.7.1 Move shielded forklift to borehole.	Shielded forklift (vertical)				
4.7.2 Place cover over empty borehole with forklift.					
4.7.3 Lock cover.					
4.7.4 Flag hole as EMPTY.					

TABLE H-4

DESCRIPTION OF WASTE RETRIEVAL OPERATIONS, HORIZONTAL EMPLACEMENT CONFIGURATION

ACTIVITY DESCRIPTION	EQUIPMENT	CREW	TRAVEL TIME (min)	FIXED TIME (min)	TOTAL TIME (min)
1.0 Prepare Borehole					
1.1 Perform Radiological Check		QC-H	3.2	15.0	18.2
1.1.1 Move test equipment to hole.					
1.1.2 Record hole identification data.	Radiation monitoring equipment				
1.1.3 Measure for radiation around hole cover.					
1.1.4 Record data.					
1.1.5 Remove test equipment.					
1.2 Unlock and Remove Cover		HP-H	3.2	20.0	23.2
1.2.1 Move shielded forklift to hole.	Shielded forklift (horizontal)				
1.2.2 Unlock cover.					
1.2.3 Remove cover using forklift.					
1.2.4 Place cover on floor of drift adjacent to borehole.					
1.3 Locate Shielding Closure at Filled Borehole		HP-H	6.4	30.0	36.4
1.3.1 Move shielded forklift to temporary storage area.					
1.3.2 Mount shielding closure installer to shielded forklift.	Shielded forklift (horizontal)				
1.3.3 Engage shielding closure with closure installer.	Shielding closure (horizontal)				
1.3.4 Transport shielding closure to borehole.	Closure installer (horizontal)				
1.4 Position and Install Shielding Closure		HP-H	0.0	30.0	30.0
1.4.1 Position shielding closure with shielded forklift.	Shielded forklift (horizontal)				
1.4.2 Connect shielding closure to borehole.	Shielding closure (horizontal)				
1.4.3 Disengage shielding closure from installer.	Closure installer (horizontal)				
1.4.4 Test mechanical/electrical systems on shielding closure.					
1.5 Store Shielding Closure Installer		HP-H	3.2	15.0	18.2
1.5.1 Transport shielding closure installer to temporary storage area.	Shielded forklift (horizontal) Closure installer (horizontal)				
1.5.2 Dismount shielding closure installer from forklift.					
1.6 Locate Plug Installer at Shielding Closure		HP-H	3.2	30.0	33.2
1.6.1 Move forklift to available shield plug installer.	Shielded forklift (horizontal)				
1.6.2 Mount plug installer to shielded forklift.	Shield plug installer (horizontal)				
1.6.3 Test mechanical/electrical systems on plug installer.					
1.6.4 Transport plug installer to borehole from temporary storage area.					
1.7 Position Plug Installer and Remove Plug		HP-H	0.0	45.0	45.0
1.7.1 Position plug installer with shielded forklift.	Shielded forklift (horizontal)				
1.7.2 Mate shield plug installer to shielding closure.	Shield plug installer (horizontal)				
1.7.3 Open plug installer door.					
1.7.4 Open shielding closure door.					
1.7.5 Engage plug grapple with pintle on plug.					
1.7.6 Remove plug.					
1.7.7 Close shielding closure door.					
1.7.8 Close plug installer door.					

WT-H=Transporter crew, HP-H=Hole prep crew, QC-H=Quality Control and Radiation Monitor Crew, DT-H=Dummy container transporter crew

TABLE H-4

DESCRIPTION OF WASTE RETRIEVAL OPERATIONS, HORIZONTAL EMPLACEMENT CONFIGURATION (continued)

ACTIVITY DESCRIPTION	EQUIPMENT	CREW	TRAVEL TIME (min)	FIXED TIME (min)	TOTAL TIME (min)
1.8 Store Plug Installer And Plug		HP-H	3.2	20.0	23.2
1.8.1 Release plug installer from shielding closure.					
1.8.2 Transport plug installer with plug to temporary storage area.	Shielded forklift (horizontal) Shield plug installer (horizontal)				
1.8.3 Dismount plug installer containing plug from forklift.					
1.9 Perform Radiological Check		QC-H	3.2	15.0	18.2
1.9.1 Move test equipment to borehole.					
1.9.2 Measure for radiation around shielding closure.	Radiation monitoring equipment				
1.9.3 Record data.					
1.9.4 Remove test equipment.					
1.9.5 Flag borehole as "ready to retrieve".					
1.9.6 Clear immediate retrieval area.					
2.0 Remove Dummy Containers					
2.1 Move Empty Transporter To Borehole		DT-H	34.3	10.0	44.3
2.1.1 Notify control center.	Dummy transporter (horizontal)				
2.1.2 Move transporter to active borehole.					
2.2 Position Transporter At Borehole	Dummy transporter (horizontal)	DT-H	0.0	30.0	30.0
2.2.1 Adjust transporter into position at borehole.					
2.2.2 Level and align transporter with shielding closure.					
2.3 Rotate, Align, and Mate Cask with Shielding Closure		DT-H	0.0	20.0	20.0
2.3.1 Rotate cask to loading position.	Dummy transporter (horizontal)				
2.3.2 Align cask with borehole.					
2.3.3 Mate cask with shielding closure.					
2.4 Open Cask And Shielding Closure, Insert Grapple		DT-H	0.0	5.0	5.0
2.4.1 Open cask shield door.	Dummy transporter (horizontal)				
2.4.2 Open shielding closure door.	Shielding closure (horizontal)				
2.4.3 Extend grapple.					
2.5 Load Container, Close Cask And Shielding Closure		DT-H	0.0	15.0	15.0
2.5.1 Engage grapple with container dolly.	Dummy transporter (horizontal)				
2.5.2 Pull container into cask.	Shielding closure (horizontal)				
2.5.3 Close cask door.					
2.5.4 Close shielding closure door.					
2.6 Retract Cask from Shielding Closure and Rotate		DT-H	0.0	10.0	10.0
2.6.1 Retract cask from shielding closure.	Dummy transporter (horizontal)				
2.6.2 Rotate cask to traveling position.	Shielding closure (horizontal)				
2.7 Move Loaded Transporter to Previous Hole		DT-H	0.2	10.0	10.2
2.7.1 Notify control center.	Dummy transporter (horizontal)				
2.7.2 Move transporter to previous borehole.					
2.8 Position Transporter at Borehole		DT-H	0.0	30.0	30.0
2.8.1 Move transporter into position at borehole.	Dummy transporter (horizontal)				
2.8.2 Level and align transporter with shielding closure.					

WT-H=Transporter crew, HP-H=Hole prep crew, QC-H=Quality Control and Radiation Monitor Crew, DT-H=Dummy container transporter crew

TABLE H-4

DESCRIPTION OF WASTE RETRIEVAL OPERATIONS, HORIZONTAL EMPLACEMENT CONFIGURATION (continued)

ACTIVITY DESCRIPTION	EQUIPMENT	CREW	TRAVEL TIME (min)	FIXED TIME (min)	TOTAL TIME (min)
2.9 Rotate, Align, and Mate Cask with Shielding Closure		DT-H	0.0	20.0	20.0
2.9.1 Rotate cask to unloading position.	Dummy transporter (horizontal)				
2.9.2 Align cask with borehole.					
2.9.3 Mate cask with shielding closure.					
2.10 Open Cask and Shielding Closure		DT-H	0.0	5.0	5.0
2.10.1 Open cask door.	Dummy transporter (horizontal)				
2.10.2 Open shielding closure door.					
2.11 Insert Container, Close Cask and Shielding Closure		DT-H	0.0	15.0	15.0
2.11.1 Insert dummy container into borehole.	Dummy transporter (horizontal)				
2.11.2 Release grapple.	Shielding closure (horizontal)				
2.11.3 Withdraw grapple into cask.					
2.11.4 Close cask door.					
2.11.5 Close shielding closure door.					
2.12 Retract Cask from Shielding Closure and Rotate		DT-H	0.0	10.0	10.0
2.12.1 Retract cask from shielding closure.	Dummy transporter (horizontal)				
2.12.2 Rotate cask to traveling position.					
2.13 Return Empty Transporter to Borehole		DT-H	0.2	10.0	10.2
2.13.1 Notify control center.	Dummy transporter (horizontal)				
2.13.2 Move transporter to active borehole.					
3.0 Remove Waste Container					
3.1 Move Empty Transporter from Surface to Borehole		WT-H	34.3	10.0	44.3
3.1.1 Prepare transporter for retrieval operations at surface.	Waste transporter (horizontal)				
3.1.2 Communicate retrieval location to operator.					
3.1.3 Move transporter to retrieval area.					
3.1.4 Locate borehole for retrieval.					
3.2 Position Transporter at Borehole	Waste transporter (horizontal)	WT-H	0.0	30.0	30.0
3.2.1 Move transporter into position at borehole.					
3.2.2 Level and align transporter with shielding closure.					
3.3 Rotate, Align, and Mate Cask with Shielding Closure		WT-H	0.0	20.0	20.0
3.3.1 Rotate cask to loading position.	Waste transporter (horizontal)				
3.3.2 Align cask with borehole.					
3.3.3 Mate cask with shielding closure.					
3.4 Open Cask and Shielding Closure, Insert Grapple		WT-H	0.0	5.0	5.0
3.3.1 Open cask shield door.	Waste transporter (horizontal)				
3.3.2 Open shielding closure door.	Shielding closure (horizontal)				
3.3.3 Extend grapple.					

WT-H=Transporter crew, HP-H=Hole prep crew, QC-H=Quality Control and Radiation Monitor Crew, DT-H=Dummy container transporter crew

TABLE H-4
DESCRIPTION OF WASTE RETRIEVAL OPERATIONS, HORIZONTAL EMPLACEMENT CONFIGURATION (continued)

ACTIVITY DESCRIPTION	EQUIPMENT	CREW	TRAVEL TIME (min)	FIXED TIME (min)	TOTAL TIME (min)
3.5 Load Container, Close Cask and Shielding Closure		WT-H	0.0	15.0	15.0
3.5.1 Engage grapple with container dolly.	Waste transporter (horizontal)				
3.5.2 Pull container into cask.	Shielding closure (horizontal)				
3.5.3 Close cask door.					
3.5.4 Close shielding closure door.					
3.6 Retract Cask from Shielding Closure and Rotate		WT-H	0.0	10.0	10.0
3.6.1 Retract cask from shielding closure.	Waste transporter (horizontal)				
3.6.2 Rotate cask to traveling position.	Shielding closure (horizontal)				
3.7 Perform Radiological Check		QC-H	3.2	15.0	18.2
3.7.1 Move test equipment to borehole.	Waste transporter (horizontal)	WT-H	0.0	15.0	15.0
3.7.2 Record cask and transporter identification.	Radiation monitoring equipment				
3.7.3 Measure for radiation on cask and shielding closure.					
3.7.4 Record data.					
3.7.5 Remove test equipment.					
4.0 Transport and Unload Waste Container					
4.1 Move Full Transporter To Surface		WT-H	34.3	10.0	44.3
4.1.1 Notify surface control center.	Waste transporter (horizontal)				
4.1.2 Wait for clearance.					
4.1.3 Move transporter to surface facilities.					
4.2 Position Transporter at Surface Facility		WT-H	0.0	10.0	10.0
4.2.1 Notify surface control center of arrival.	Waste transporter (horizontal)				
4.2.2 Position transporter at receiving bay.					
4.2.3 Verify container data with surface control.					
4.3 Rotate, Align, and Mate Cask with Port		WT-H	0.0	10.0	10.0
4.3.1 Rotate loaded cask into unloading position.	Waste transporter (horizontal)				
4.3.2 Align cask with port.					
4.3.3 Mate cask with port.					
4.4 Open Cask and Port		WT-H	0.0	5.0	5.0
4.4.1 Open cask door.	Waste transporter (horizontal)				
4.4.2 Open port door.					
4.5 Unload Container, Close Cask and Port		WT-H	0.0	10.0	10.0
4.5.1 Insert container through port.	Waste transporter (horizontal)				
4.5.2 Release grapple.					
4.5.3 Retract grapple into cask.					
4.5.4 Close cask door.					
4.5.5 Close port door.					
4.6 Retract Cask from Port and Rotate		WT-H	0.0	10.0	10.0
4.6.1 Retract cask from port.	Waste transporter (horizontal)				
4.6.2 Rotate cask to traveling position.					

WT-H=Transporter crew, HP-H=Hole prep crew, QC-H=Quality Control and Radiation Monitor Crew, DT-H=Dummy container transporter crew

TABLE H-4

DESCRIPTION OF WASTE RETRIEVAL OPERATIONS, HORIZONTAL EMPLACEMENT CONFIGURATION (concluded)

ACTIVITY DESCRIPTION	EQUIPMENT	CREW	TRAVEL TIME (min)	FIXED TIME (min)	TOTAL TIME (min)
4.7 Perform Radiological Check		QC-H	0.0	15.0	15.0
4.7.1 Move test equipment to port.	Waste transporter (horizontal)	WT-H	0.0	15.0	15.0
4.7.2 Record cask, port, and transporter identification.	Radiation monitoring equipment				
4.7.3 Measure for radiation on transporter and cask.					
4.7.4 Record data.					
4.7.5 Remove test equipment.					
<u>5.0 Close Borehole</u>					
5.1 Move Plug Installer to Borehole		HP-H	3.2	30.0	33.2
5.1.1 Move forklift to plug installer in storage area.					
5.1.2 Mount plug installer with plug to shielded forklift.	Shielded forklift (horizontal)				
5.1.3 Transport plug installer to previous borehole from temporary storage area.	Closure installer (horizontal)				
5.1.4 Align plug installer with shield closure.					
5.2 Insert Shield Plug into Borehole		HP-H	0.0	30.0	30.0
5.2.1 Mate plug installer with shield closure.	Shielded forklift (horizontal)				
5.2.2 Open shield closure door.	Shield plug installer (horizontal)				
5.2.3 Open plug installer door.					
5.2.4 Insert shield plug into borehole.					
5.2.5 Release grapple.					
5.2.6 Retract grapple.					
5.2.7 Close shield closure door.					
5.2.8 Close plug installer door.					
5.3 Store Plug Installer		HP-H	3.2	20.0	23.2
5.3.1 Release plug installer from shielding closure.	Shielded forklift (horizontal)				
5.3.2 Transport empty plug installer to temporary storage area.	Shield plug installer (horizontal)				
5.3.3 Dismount plug installer from shielded forklift.					
5.4 Move Shielding Closure Installer to Borehole		HP-H	3.2	30.0	33.2
5.4.1 Move forklift to temporary storage area.					
5.4.2 Mount shielding closure installer to shielded forklift.	Shielded forklift (horizontal)				
5.4.3 Transport shielding closure installer to borehole.	Closure installer (horizontal)				
5.5 Remove Shielding Closure		HP-H	0.0	20.0	20.0
5.5.1 Engage shielding closure installer to closure.					
5.5.2 Disconnect shielding closure from borehole.	Shielded forklift (horizontal)				
5.5.3 Remove shielding closure from borehole.	Shielding closure (horizontal)				
	Closure installer (horizontal)				
5.6 Transport Shielding Closure		HP-H	3.2	30.0	33.2
5.6.1 Transport shielding closure to temporary storage area.	Shielded forklift (horizontal)				
5.6.2 Disengage shielding closure from installer.	Shielding closure (horizontal)				
5.6.3 Dismount shielding closure installer from forklift.	Closure installer (horizontal)				
5.7 Replace and Lock Cover		HP-H	3.2	20.0	23.2
5.7.1 Move shielded forklift to borehole.	Shielded forklift (horizontal)				
5.7.2 Replace cover over empty borehole with forklift.					
5.7.3 Lock cover.					
5.7.4 Flag hole as EMPTY.					

WT-H=Transporter crew, HP-H=Hole prep crew, QC-H=Quality Control and Radiation Monitor Crew, DT-H=Dummy container transporter crew

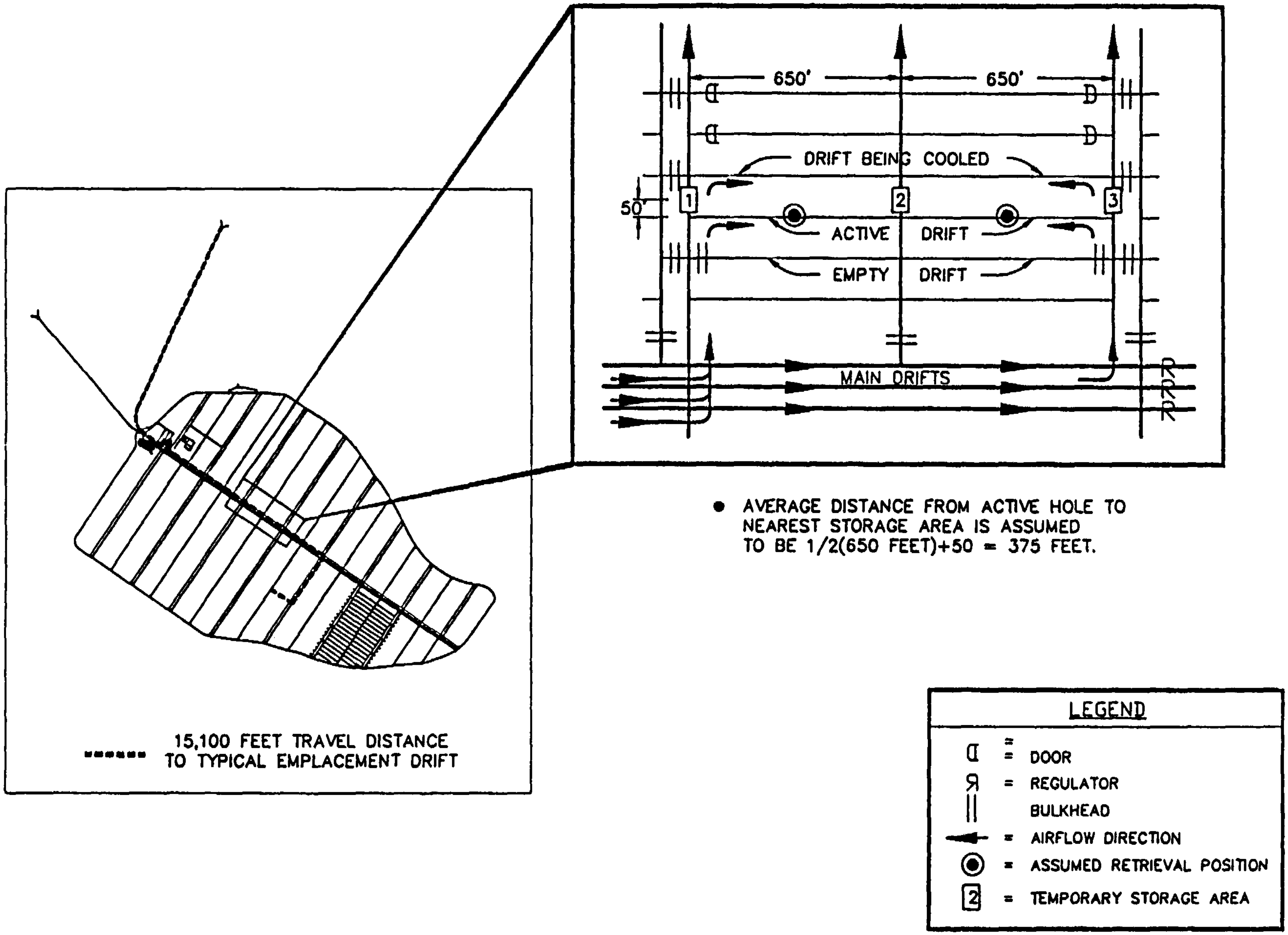


Figure H-10. Retrieval Equipment Storage Locations and Travel Distances, Vertical Emplacement Configuration

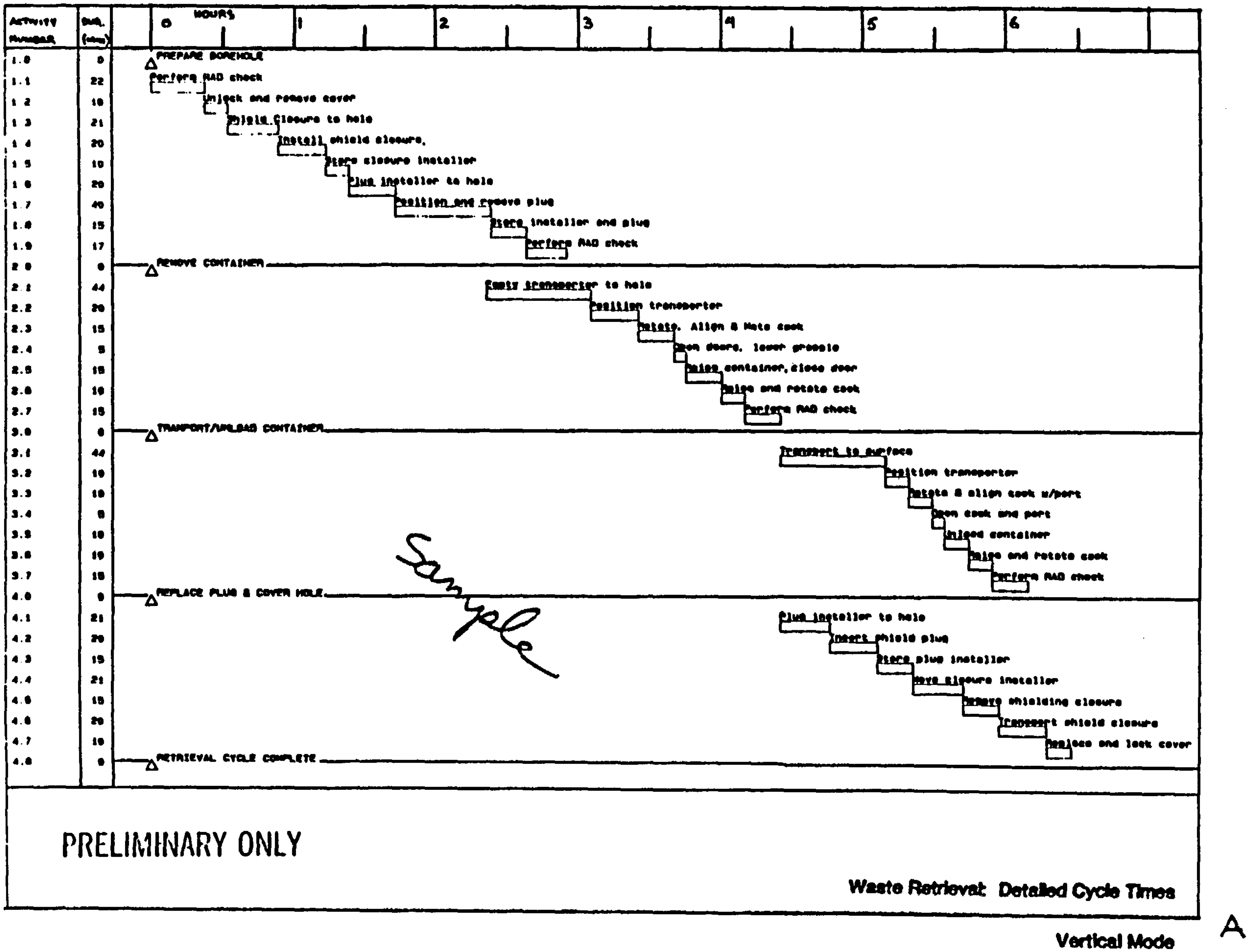


Figure H-11. Cycle for Retrieval of a Typical Container from a Vertical Borehole

The removal cycle for the horizontal emplacement configuration differs from the vertical case in that each borehole contains 14-18 waste containers and as many as 8 dummy containers. The estimated minimum time for preparing a horizontal borehole and removing 14 containers of spent fuel is 5,043 min or approximately 360 min per spent fuel container. The retrieval cycle for a horizontal borehole is shown in Figure H-12.

Not all activities are performed each shift. For the vertical emplacement configuration, a schedule of the daily activities required to retrieve four containers from either one of the two assumed areas is presented in Table H-5. Table H-5 includes the cases for one-shift per day and two-shifts per day. A similar table was not developed for the horizontal configuration because borehole preparation activities are not required for each container (multiple containers per borehole) and borehole spacing is greater. Consequently, sequencing of horizontal borehole preparation activities is not a concern.

4.3.4 Overall Retrieval Schedule

The overall retrieval schedule begins with the notice to retrieve and ends with the retrieval of the last container. The schedule is identical for vertical and horizontal emplacement configurations because the assumed retrieval rate for both cases is 8 containers/day or 2000 containers/yr. The schedules for both cases assume a gradual buildup to the steady-state retrieval rate of 2000 containers/yr (8/day). During the first year, 1000 containers (4 per day) are retrieved. Fifteen hundred containers are retrieved the second year, and 2000 containers are retrieved per year thereafter. Figure H-13 shows the overall retrieval schedule.

4.3.5 Retrieval Equipment Requirements

The equipment needed specifically for waste retrieval includes waste transporters, shielded forklifts, and shielding hardware. Equipment lists are prepared for retrieval of waste from vertical and horizontal boreholes on one and two shift per day schedules. The estimation of the equipment requirements is carried out in the following tables:

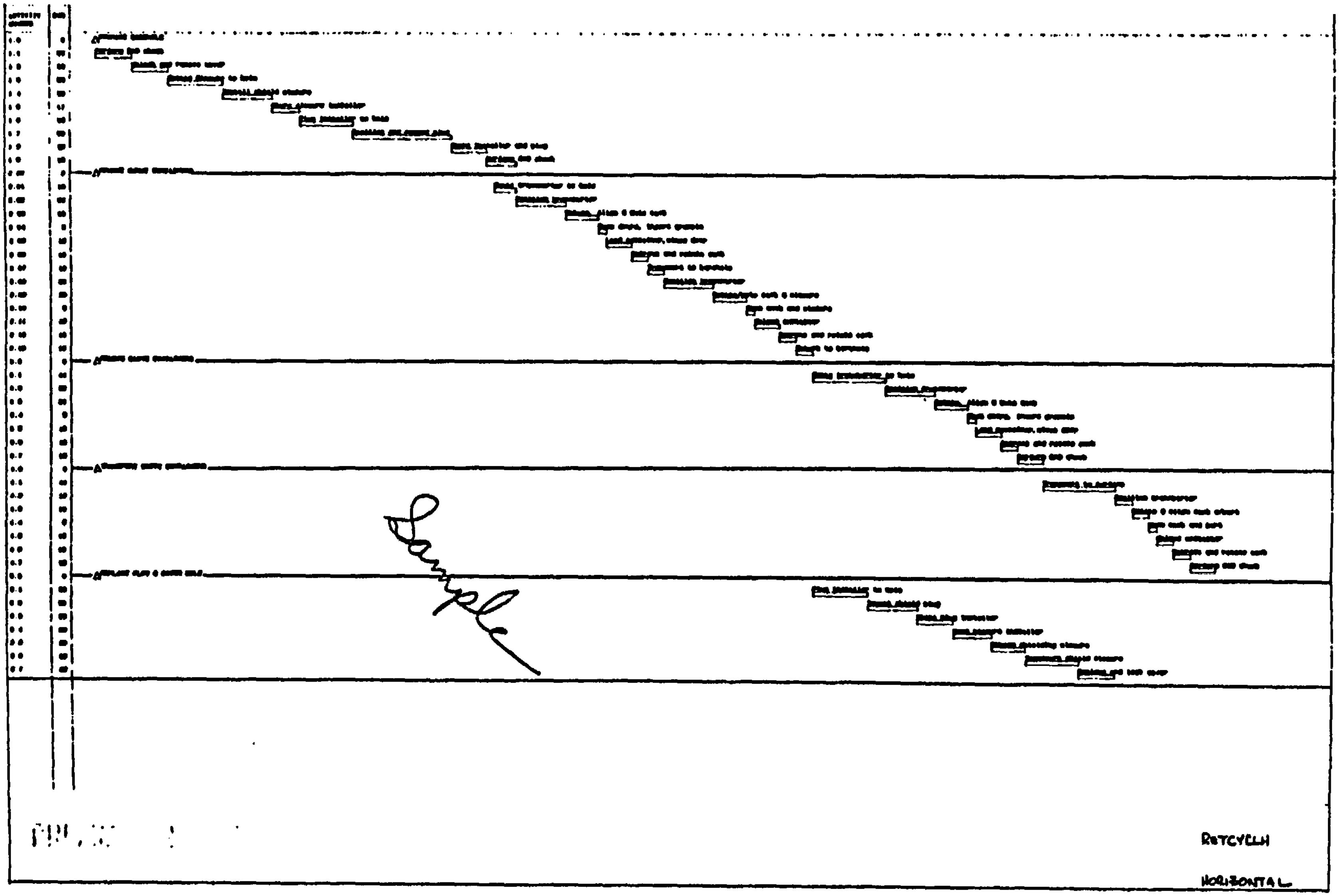


Figure H-12. Cycle for Retrieval of a Typical Container from a Horizontal Borehole

TABLE H-5

RETRIEVAL ACTIVITIES DURING A TYPICAL SHIFT, VERTICAL EMPLACEMENT CONFIGURATION, ONE AND TWO SHIFTS PER DAY

		ONE SHIFT PER DAY (note 3)														TWO SHIFT PER DAY													
		NORTH HALF OF PANEL							SOUTH HALF OF PANEL							NORTH HALF OF PANEL							SOUTH HALF OF PANEL						
BOREHOLE POSITION IN DRIFT (note 1) -> ACTIVITY	CREW (note 2)	5	10	15	20	25	16	21	5	10	15	20	25	16	21	5	10	15	20	25	16	21	5	10	15	20	25	16	21
1-1 Check borehole for radiation	QCV	.	.	.	.	1	1	.	.	.	.	.	1	1	.	.	.	.	.	1	1	.	.	.	.	.	1	1	.
1-2 Install shielding closure	HPV1	.	.	.	.	.	1	.	.	.	.	.	.	.	.	.	.	.	1	1	.	.	.	.	.	.	.	.	.
	HPV2	.	.	.	.	1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1	1	.	.
	HPV3	.	.	.	.	.	.	.	.	.	.	.	1	1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
1-3 Remove shield plug	HPV1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1	1	.	.	.	.	.	.	2	.	.
	HPV2	.	.	.	1	1	.	.	.	.	.	1	1	.	.	.	.	.	.	.	.	.	.	.	.	1	.	.	.
	HPV3	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
1-4 Check borehole for radiation	QCV	.	.	.	1	1	.	.	.	.	.	1	1	.	.	.	.	.	1	2	.	.	.	.	.	1	2	.	.
2-1 Travel and remove container	WTV1	.	.	1	1	.	.	.	.	.	.	.	.	.	.	.	.	1	2	.	.	.	.	.	1	2	.	.	.
	WTV2	.	.	.	.	.	.	.	.	.	1	1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
2-2 Check transporter for radiation	QCV	.	.	1	1	.	.	.	.	.	1	1	.	.	.	.	.	1	2	.	.	.	.	.	1	2	.	.	.
3-1 Unload container at surface	WTV1	.	.	1	1	.	.	.	.	.	.	.	.	.	.	.	.	1	2	.	.	.	.	.	1	2	.	.	.
	WTV2	.	.	.	.	.	.	.	.	.	1	1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
4-1 Replace shield plug	HPV1	.	1	1	.	.	.	.	.	.	.	.	.	.	.	.	.	1	2	.	.	.	.	.	2	.	.	.	.
	HPV2	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1	.	.	.	.	.
	HPV3	.	.	.	.	.	.	.	.	1	1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
4-2 Remove shielding closure	HPV1	.	1	1	.	.	.	.	.	.	.	.	.	.	.	.	.	1	2	.	.	.	.	.	2	.	.	.	.
	HPV2	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1	.	.	.	.	.
	HPV3	.	.	.	.	.	.	.	.	1	1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.

NOTES :

1) Borehole position refers to the relative position of the container being removed within the emplacement drift. The count begins at the panel access drift.

2) WTVn Waste Transport Crew No. n
HPVn Borehole Preparation Crew No. n
QCV Quality Control/Radiation Monitoring Crew

3) The activities shown in each half of table apply equally to the east and west retrieval areas. It is assumed that activities in each retrieval area are identical and that four containers are removed from each area per day. The number in each cell refers to the shift during which each task is performed.

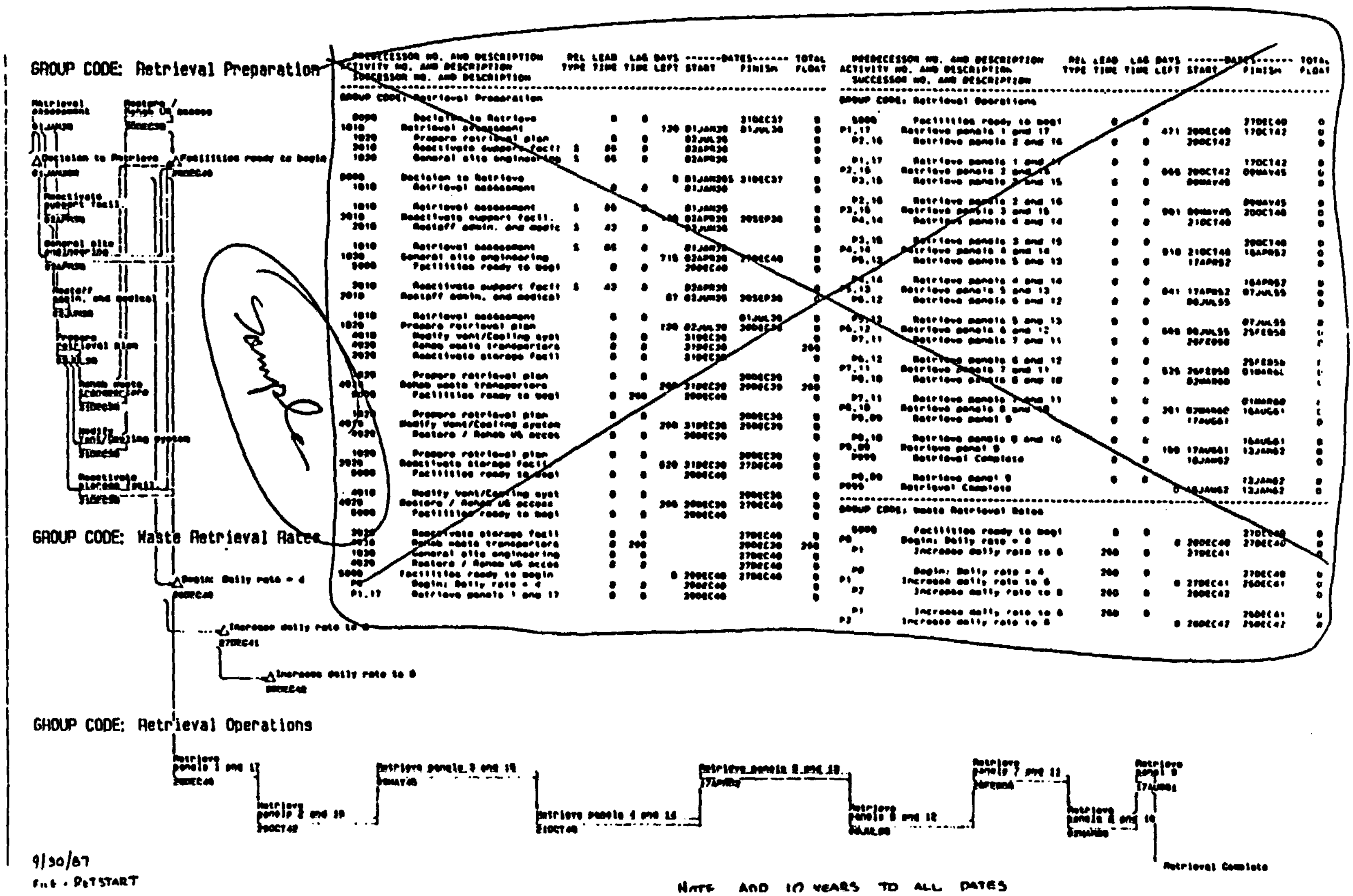


Figure H-13. Timeline for Retrieval of All Waste from the Repository

Table H-6 Daily Crew and Equipment Operating Time for Retrieval of Eight Containers Per Day from Vertical Boreholes,

Table H-7 Calculation of Equipment Requirements for Retrieval from Vertical Boreholes for One and Two Shifts Per Day,

Table H-8 Daily Crew and Equipment Operating Time for Retrieval of Eight Containers Per Day from Horizontal Boreholes,

Table H-9 Calculation of Equipment Requirements for Retrieval from Horizontal Boreholes for One and Two Shifts Per Day, and

Table H-10 Summary of Retrieval Equipment Requirements.

TABLE H-6

DAILY CREW AND EQUIPMENT OPERATING TIME FOR RETRIEVAL OF EIGHT CONTAINERS PER DAY FROM VERTICAL BOREHOLES

ACTIVITY NUMBER	GENERAL ACTIVITY DESCRIPTION	CREW	DETAILED ACTIVITY NUMBER (Table H-2)	DURATION CALCULATED (min)	DURATION USED (min)	CYCLES PER HOLE	CYCLES PER WASTE CONTAINER	TIME PER DAY (min)	CREW TIMES (minutes) HP-V	WT-V	QC-V
1-1	Check borehole for radiation	QC-V	1.1	16.7	17	1	1	136	0	0	136
1-2	Install shielding closure		1.2	11.7							
			1.3	23.4							
			1.4	20							
			1.5	11.7							
		HP-V		66.8	67	1	1	536	536	0	0
1-3	Remove shield plug		1.6	21.7							
			1.7	30							
			1.8	16.7							
		HP-V		68.4	68	1	1	544	544	0	0
1-4	Check borehole for radiation	QC-V	1.9	16.7	17	1	1	136	0	0	136
2-1	Travel and remove container										
	2-1a Travel from surface to hole	WT-V	2.1	44.3	44	1	1	352	0	352	0
	2-1b Remove container		2.2	20							
			2.3	15							
			2.4	5							
			2.5	15							
			2.6	10							
			2.7	15							
		WT-V		80	80	1	1	640	0	640	0
2-2	Check transporter for radiation	QC-V	2.7	16.7	17	1	1	136	0	0	136

WT-V= Transporter crew, HP-V= Hole prep crew, QC-V= Quality control and Radiation Monitoring crew

TABLE H-6

DAILY CREW AND EQUIPMENT OPERATING TIME FOR RETRIEVAL OF EIGHT CONTAINERS PER DAY FROM VERTICAL BOREHOLES (concluded)

ACTIVITY NUMBER	GENERAL ACTIVITY DESCRIPTION	CREW	DETAILED ACTIVITY NUMBER (Table H-2)	DURATION CALCULATED (min)	DURATION USED (min)	CYCLES PER HOLE	CYCLES PER WASTE CONTAINER	TIME PER DAY (min)	CREW TIMES (minutes) HP-V	WT-V	QC-V
3-1	Travel and unload container		3.1	44.3							
			3.2	10							
			3.3	10							
			3.4	5							
			3.5	10							
			3.6	10							
			3.7	15							
		WT-V		104.3	104	1	1	832	0	832	0
4-1	Replace shield plug		4.1	21.7							
			4.2	20							
			4.3	16.7							
		HP-V		58.4	58	1	1	464	464	0	0
4-2	Remove shielding closure		4.4	21.7							
			4.5	15							
			4.6	21.7							
			4.7	11.7							
		HP-V		70.1	70	1	1	560	560	0	0
						Crew minutes			2104	1824	408
						Crew hours (60 minute hour)			35.1	30.4	6.8

SCHEDULING BASIS

8 waste containers per day

1 container per borehole

TABLE H-7

CALCULATION OF EQUIPMENT REQUIREMENTS FOR RETRIEVAL FROM VERTICAL BOREHOLES FOR ONE AND TWO SHIFTS PER DAY

CREW OR EQUIPMENT ITEM	COMMENTS	CREW-HOUR PER DAY	SHIFTS PER DAY	RETRIEVAL AREAS	AVAILABLE HR PER SHIFT	CREWS PER AREA CALC	CREWS PER AREA USE	EQUIPMENT AT ONE UNIT PER CREW	EQUIPMENT SPARES	EQUIPMENT TOTAL
ONE SHIFT PER DAY										
HP-V (Hole prep Crew) Shielded forklifts	Calculated	35.1 /	1 /	2 /	6 =	2.93	3	6	2	8
WT-V (Transporter Crew) Waste transporters	Calculated	30.4 /	1 /	2 /	7.5 =	2.03	2	4	1	5
Shielding closure installer	Allow 3 per active area.						6	na	2	8
Shielding closures	Allow 3 per active drift.						12	na	2	14
Shield plug installers	Allow 3 per active area.						6	na	2	8
TWO SHIFTS PER DAY										
HP-V (Hole prep Crew) Shielded forklifts	Calculated	35.1 /	2 /	2 /	6 =	1.46	2	4	2	6
WT-V (Transporter Crew) Waste transporters	Calculated	30.4 /	2 /	2 /	7.5 =	1.01	1	2	1	3
Shielding closure installer	Allow 2 per active area.						4	na	2	6
Shielding closures	Allow 3 per active drift.						12	na	2	14
Shield plug installers	Allow 2 per active area.						4	na	2	6

BASIS:

4 active drifts available for retrieval
8 containers per day
6 productive hours per shift for underground crews
7.5 productive hours per shift for waste transporter crews
2 retrieval areas

TABLE H-8

DAILY CREW AND EQUIPMENT OPERATING TIME FOR RETRIEVAL OF EIGHT CONTAINERS PER DAY FROM HORIZONTAL BOREHOLES

ACTIVITY NUMBER	GENERAL ACTIVITY DESCRIPTION	CREW	DETAILED ACTIVITY NUMBER (Table H-3)	DURATION CALCULATED (min)	DURATION USED (min)	CYCLES PER HOLE	CYCLES PER WASTE CONTAINER	TIME PER DAY (min)	CREW TIMES (minutes) HP-H	WT-H	QC-H	DT-H
1-1	Check borehole for radiation	QC-H	1.1	18.2	18	1	0.065	9	0	0	9	0
1-2	Install shielding closure		1.2	23.2								
			1.3	36.4								
			1.4	30								
			1.5	18.2								
		HP-H		107.8	108	1	0.065	56	56	0	0	0
1-3	Remove shield plug		1.6	33.2								
			1.7	45								
			1.8	23.2								
		HP-H		101.4	101	1	0.065	52	52	0	0	0
1-4	Check borehole for radiation	QC-H	1.9	18.2	18	1	0.065	9	0	0	9	0
2-1	Travel to and remove dummy container											
	2-1a Travel to retrieval area	DT-H	2.1	44.3	44	1	0.065	23	0	0	0	23
	2-1b Remove container		2.2	30								
			2.3	20								
			2.4	5								
			2.5	15								
			2.6	10								
		DT-H		80	80	8	0.518	332	0	0	0	332
2-2	Unload dummy container in previous hole		2.7	10.2								
			2.8	30								
			2.9	20								
			2.10	5								
			2.11	15								
			2.12	10								
			2.13	10.2								
		DT-H		100.4	100	8	0.518	415	0	0	0	415
3-1	Travel and remove waste container		3.1	44.3								
			3.2	30								
			3.3	20								
			3.4	5								
			3.5	15								
			3.6	10								
			3.7	15								
		WT-H		139.3	139	15.44	1.000	1112	0	1112	0	0

WT-H=Transporter crew, DT-H=Dummy container transporter crew, HP-H=Hole prep crew, QC-H=Quality Control and Radiation Monitor Crew

TABLE H-8

DAILY CREW AND EQUIPMENT OPERATING TIME FOR RETRIEVAL OF EIGHT CONTAINERS PER DAY FROM HORIZONTAL BOREHOLES (concluded)

ACTIVITY NUMBER	GENERAL ACTIVITY DESCRIPTION	CREW	DETAILED ACTIVITY NUMBER (Table H-3)	DURATION CALCULATED (min)	DURATION USED (min)	CYCLES PER HOLE	CYCLES PER WASTE CONTAINER	TIME PER DAY (min)	CREW TIMES (minutes) HP-H	WT-H	QC-H	DT-H
3-2	Check transporter for radiation	QC-H	3.7	18.2	18	15.44	1.000	144	0	0	144	0
4-1	Travel and unload waste container		4.1	44.3								
			4.2	10								
			4.3	10								
			4.4	5								
			4.5	10								
			4.6	10								
			4.7	15								

		WT-H		104.3	104	15.44	1.000	832	0	832	0	0
5-1	Replace shield plug		5.1	33.2								
			5.2	30								
			5.3	23.2								

		HP-H		86.4	86	1	0.065	45	45	0	0	0
5-2	Remove shielding closure		5.4	33.2								
			5.5	20								
			5.6	33.2								
			5.7	23.2								

		HP-H		109.6	110	1	0.065	57	57	0	0	0
							Crew minutes		210	1944	163	769
							Crew hours (60 minute hour)		3.50	32.40	2.71	12.82

SCHEDULING BASIS

8 waste containers per day

Capacity of typical horizontal emplacement drift is determined as follows:

WASTE TYPE	HOLES	CONTAINERS PER BOREHOLE WASTE	CONTAINERS PER BOREHOLE DUMMY	TOTAL CONTAINERS PER DRIFT WASTE	TOTAL CONTAINERS PER DRIFT DUMMY
Spent fuel boreholes	32	14	8	448	256
DHLW boreholes	18	18	8	324	144
	-----			-----	-----
Total	50			772	400
Average containers per borehole --->				15.44	8

TABLE H-9

CALCULATION OF EQUIPMENT REQUIREMENTS FOR RETRIEVAL FROM HORIZONTAL BOREHOLES FOR ONE AND TWO SHIFTS PER DAY

CREW OR EQUIPMENT ITEM	METHOD	CREW-HOUR PER DAY	SHIFTS PER DAY	RETRIEVAL AREAS	AVAILABLE HR PER SHIFT	CREWS PER AREA CALC	CREWS PER AREA USE	EQUIPMENT AT ONE UNIT PER CREW	EQUIPMENT SPARES	EQUIPMENT TOTAL
ONE SHIFT PER DAY										
HP-H (Hole prep Crew) Shielded forklifts	Calculated	3.5 /	1 /	2 /	6 =	0.29	1	2	1	3
WT-H (Transporter Crew) Waste transporters	Calculated	32.4 /	1 /	2 /	7.5 =	2.16	2	4	1	5
DT-H (Dummy Container Crew) Dummy container transporters	Calculated	12.82 /	1 /	2 /	6 =	1.07	1	2	1	3
Shielding closure installer	Allow 2 per active area.						4	na	2	6
Shielding closures	Allow 3 per active drift.						12	na	2	14
Shield plug installers	Allow 2 per active area.						4	na	2	6
TWO SHIFTS PER DAY										
HP-H (Hole prep Crew) Shielded forklifts	Assumes 1 shift/day	3.5 /	1 /	2 /	6 =	0.29	1	2	1	3
WT-H (Transporter Crew) Waste transporters	Calculated	32.4 /	2 /	2 /	7.5 =	1.08	1	2	1	3
DT-H (Dummy Container Crew) Dummy container transporters	Shared between active areas.	12.82 /	2 /	2 /	6 =	0.53	0.5	1	1	2
Shielding closure installer	Allow 2 per active area.						4	na	2	6
Shielding closures	Allow 3 per active drift.						12	na	2	14
Shield plug installers	Allow 2 per active area.						4	na	2	6

BASIS:

4 active drifts (1300 ft each) available for retrieval.
8 containers per day
6 productive hours per shift for underground crews.
7.5 productive hours per shift for waste transporter crews.
2 retrieval areas

TABLE H-10

SUMMARY OF RETRIEVAL EQUIPMENT REQUIREMENTS

EQUIPMENT DESCRIPTION	VERTICAL EMPLACEMENT CONFIGURATION						HORIZONTAL EMPLACEMENT CONFIGURATION					
	ONE SHIFT PER DAY			TWO SHIFT PER DAY			ONE SHIFT PER DAY			TWO SHIFT PER DAY		
	REQUIRED OPERATING UNITS	SPARES	TOTAL	REQUIRED OPERATING UNITS	SPARES	TOTAL	REQUIRED OPERATING UNITS	SPARES	TOTAL	REQUIRED OPERATING UNITS	SPARES	TOTAL
Waste Transporter	4	1	5	2	1	3	4	1	5	2	1	3
Dummy container transporter	0	0	0	0	0	0	2	1	3	1	1	2
Shielded forklift	6	2	8	4	2	6	2	1	3	2	1	3
Shielding closure installer	6	2	8	4	2	6	4	2	6	4	2	6
Shielding closure	12	2	14	12	2	14	12	2	14	12	2	14
Shield plug installer	6	2	8	4	2	6	4	2	6	4	2	6

REFERENCES FOR APPENDIX H

NRC (U.S. Nuclear Regulatory Commission), "Disposal of High-Level Radioactive Wastes in Geologic Repositories," Code of Federal Regulations, Energy, Title 10, Part 60, Washington, D.C., January 1986. (NNA.910315.0133)

SNL (Sandia National Laboratories), "Site Characterization Plan Conceptual Design Report," SAND84-2641, compiled by H. R. MacDougall, L. W. Scully, and J. R. Tillerson, Sandia National Laboratories, Albuquerque, NM, September 1987. (NNI.880902.0014-.0019)

Stinebaugh, R. E., and J. C. Frostenson, "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, NM, December 1986. (HQS.880517.2878)

Stinebaugh, R. E., I. B. White, and J. C. Frostenson, "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, NM, December 1986. (HQS.880517.2880)

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