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Nevada Nuclear Waste Storage Investigations Preliminary Repository Concepts Report

Compiled by J. L. Jackson

Prepared by
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NEVADA NUCLEAR WASTE STORAGE INVESTIGATIONS PRELIMINARY REPOSITORY CONCEPTS REPORT

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Abstract

This report presents the preliminary repository concepts developed for the Nevada Nuclear Waste Storage Investigations Project. The concepts are for a high-level radioactive waste repository with a capacity of up to 70,000 metric tons (77,175 tons) of heavy metal initially loaded in commercial power reactors. The repository site being investigated is on and adjacent to the Nevada Test Site. The 8,094,000-m^2 (2,000-acre) underground portion of the repository to be used for waste emplacement is above the water table and beneath Yucca Mountain within a welded tuff formation. The surface facilities of the repository will be located to the east of Yucca Mountain on a 304,000-m^2 (75-acre) site and include the waste-handling and surface support structures. Concepts for final closure of the underground portion of the repository and for decommissioning the surface facilities are also discussed. The engineering studies being performed in support of the design bases and design criteria are summarized. The preliminary concepts presented here will be used as a basis for the conceptual design of the repository.

ACKNOWLEDGEMENTS

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SUMMARY

As part of the National Waste Terminal Storage (NWTS) Program, and as directed by the Nuclear Waste Policy Act (NWPA) of 1982, the U.S. Department of Energy (DOE) is developing facilities, processes, and systems for the safe, long-term isolation of high-level radioactive wastes. Four geologic media (tuff, salt, basalt, and crystalline rock) are prime candidates for the disposal of these wastes. Sandia National Laboratories (SNL), under the direction of the DOE, and in cooperation with Lawrence Livermore National Laboratory (LLNL), Los Alamos National Laboratory (LANL), and the U.S. Geological Survey (USGS), is engaged in the conceptual design of a repository in tuff for commercially generated radioactive waste.

This Nevada Nuclear Waste Storage Investigations (NNWSI) Preliminary Repository Concepts Report (PRCR) is a product of the design process that may culminate in the construction of a repository on and adjacent to the Nevada Test Site (NTS). The decision on where to construct a repository for radioactive waste has not been made. The Nevada site is one of several prospective sites that are being studied in different areas of the nation for the first full-scale repository for high-level radioactive waste. For the sake of readability in this report, the indicative mood is used to describe current concepts for the design of a repository at the NTS if this site is selected as the site for the first repository. Although the indicative mood indicates that an action is being or will definitely be taken, the reader should not conclude from this usage that the decision has been made to construct the first repository at the NTS.

Design Process

There are four major phases in the design process leading to the construction of a repository: (1) preliminary concepts development phase, (2) conceptual design phase, (3) Title I design phase, and (4) Title II design phase.

In the first phase, design bases and design criteria derived from the NWPA, government policy and regulations, and national codes and standards are

used to develop preliminary concepts for the repository. The design bases --(1) the radioactive waste and (2) the repository site at which that waste will be emplaced--are the principal determinants that establish the overall design of the repository. Design criteria are requirements placed on specific repository systems, structures, and components and are derived from policy and regulations issued by various government agencies to implement the NWPA. Design criteria are also derived from national codes and standards developed by various professional societies for design and construction of buildings and mines.

The second phase of the design process is the development of the conceptual design of the repository. In this phase, an overall picture of the repository facilities and the functions performed by these facilities is prepared. Initial construction plans, including costs and schedule, are provided. Equipment items that require research and development are identified.

The third phase is the development of the Title I (Preliminary) design. At this point in the design process, a more detailed, though not complete, representation of the repository facilities and their functions is prepared. Refined construction costs and schedule are included.

The fourth phase is the development of the Title II (Final) design. During this phase, detailed construction drawings and specifications sufficient to permit a government cost estimate are prepared. These drawings and specifications are also used by qualified contractors to prepare bid proposals for repository construction.

The preliminary concepts presented in this report represent the effort expended to date in the first phase of the design process. These concepts are under continual review and will be refined and changed as the design evolves. This PRCR is therefore a "snapshot" taken at this particular time in the design process.

<u>Facility Concepts</u>

The terrain directly above the underground portion of the repository is rugged; therefore, the surface facilities will be located on the relatively flat areas that occur to the east of the underground portion of the repository. A study is under way to identify locations for the surface facilities. In addition to the waste-handling facilities, a number of other surface facilities, including administrative, service, and mine support buildings, will be required.

Access to the underground areas for personnel and equipment will be provided by ramps, shafts, and/or a combination of shafts and horizontal drifts. Ramp access will be used for waste emplacement operations. Access for mining operations will be separate from access for waste emplacement operations. Further study is necessary before a choice of mining access method can be made. Surface facilities for waste-handling and mining operations may or may not be collocated.

Two configurations--vertical or horizontal--are currently being considered for the emplacement of waste underground. In the vertical configuration, a single waste canister is placed in a vertical borehole drilled in the drift floor. In the horizontal configuration, a number of canisters are inserted in a long horizontal borehole drilled into the drift wall.

Layouts of the underground areas for both vertical and horizontal configurations have been prepared. These layouts are based on preliminary calculations and engineering judgment. Vertical emplacement will require more excavation and hence more miners and equipment than will be required for horizontal emplacement. Ventilation requirements for vertical emplacement will be much higher because greater volumes of air will be needed to ventilate a larger underground area.

The development of the underground facility will require the use of special equipment for boring the vertical or horizontal emplacement holes. The vertical boring machine, which is routinely used in mining operations, requires little additional development for use at the repository. Therefore, development efforts are concentrated on the horizontal boring machine, which must be able to drill holes approximately 1 meter (3 feet) in diameter and about 183 to 213 meters (600 to 700 feet) in length. The machine must also be able to insert a steel liner in the hole, either as it drills or after the hole has been completed.

Construction of underground drifts may also require the development of special equipment. The use of a mechanical miner for drift excavation is being considered. Use of the mechanical miner would reduce the use of explosives, with the result that safety would be improved and drift floor preparation costs would be lower.

Waste-Handling Concepts

The equipment necessary for unloading shipping packages and preparing the various types of waste packages for disposal will be located in the waste-handling facilities. The waste packages will be removed from their transportation containers, inspected, and stored, pending transfer to the disposal horizon. In the case of spent fuel, packaging for emplacement will be required. In order to reduce the total number of spent fuel disposal packages, consolidation of fuel assemblies is being considered.

The waste disposal packages are loaded into shielded casks for transfer to the disposal horizon. Waste transport vehicles then carry the casks underground via a ramp access. Different conceptual designs have been developed for the transporter in each waste emplacement method. For vertical emplacement, the cask is upended and aligned with the borehole. The waste disposal package is then lowered into the vertical borehole. Emplacement is complete when the shield plug has been installed. For horizontal emplacement, the transporter is aligned with the borehole, and the waste disposal package is transferred to an in-borehole conveyor system. The conveyor system moves the package into the borehole. This sequence is repeated until the borehole has been filled to the design limits with waste packages. A shield plug is then installed and emplacement is complete.

Retrieval of the waste may be ordered if the repository design or site proves unsuitable or if spent fuel is recovered for reprocessing. The repository is therefore being designed to permit retrieval of the waste. Waste retrieval involves essentially the same steps as those for emplacement except that the steps occur in reverse order. A design feature that will aid the retrieval of canisters from vertical or horizontal boreholes is the borehole liner. The liner will prevent small pieces of rock from falling into and obstructing the borehole.

Waste-handling operations will require development of new equipment. Studies of receiving operations have identified several areas where conventional unloading methods will result in operator exposures that are unacceptably high. To correct this problem, remotely operated equipment must be developed. If the fuel is consolidated, then equipment must also be developed for disassembling and packaging the fuel rods and fuel assembly hardware after the spent fuel has been unloaded into the hot cell. Prototype disassembly equipment has been developed by others, and some demonstrations using actual and simulated spent fuel have been made. Preliminary concepts for equipment to transport, emplace, and retrieve waste for both vertical and horizontal emplacement have been developed. Prototype equipment for transport, emplacement, and retrieval for the vertical emplacement configuration have been developed and demonstrated by others. Additional refinement of these concepts for horizontal emplacement equipment is required, as well as development and demonstration of prototype equipment.

The surface and subsurface facilities in which the waste-handling operations occur will be equipped with filtered ventilation systems that will maintain an internal pressure less than atmospheric pressure to ensure confinement of radioactive particulates. The underground ventilation system will consist of two separate circuits designed to allow mining and waste emplacement operations to proceed simultaneously and independently. The advantages and disadvantages of continuous ventilation in the emplacement drifts after the waste has been emplaced are under investigation.

Concepts for the Final Closure of the Repository

Preliminary concepts for the final closure of the repository have been prepared. These concepts include decommissioning the surface facilities and sealing and backfilling the underground workings, where appropriate.

Engineering Studies

Engineering studies are under way to further define the design bases and design criteria and to provide additional data and calculations needed during the conceptual design phase. Summaries of the engineering studies that support the design bases are included in Appendix A, and the studies that support the design criteria are provided in Appendix B.

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INTRODUCTION

As part of the National Waste Terminal Storage (NWTS) Program, the U.S. Department of Energy (DOE) is developing facilities, processes, and systems for the safe, long-term isolation of high-level radioactive wastes. Four geologic media (tuff, salt, basalt, and crystalline rock) are prime candidates for the disposal of such waste.

The southwest corner of the Nevada Test Site (NTS) and adjacent federal property are currently being investigated as a site for the first repository. This effort is being directed by DOE's Nevada Operations Office, which manages the Nevada Nuclear Waste Storage Investigations (NNWSI) Project. Should it be determined that the physical characteristics of this site are satisfactory and that the site and repository design meet the regulatory criteria specified by the Nuclear Regulatory Commission (NRC) in 10 CFR 60, "Disposal of High-Level Radioactive Waste in Geologic Repositories," then a disposal facility for spent fuel, high-level waste, and transuranic waste generated by commercial reactors may be constructed at the NTS. This site may also be used for the disposal of solidified high-level waste resulting from defense activities.

This Preliminary Repository Concepts Report (PRCR) is a product of the design process that may culminate in the construction of a repository at the Yucca Mountain site on and adjacent to the NTS. A decision has not been made to construct a repository for radioactive waste at this site. The Yucca Mountain site is one of several prospective sites being studied in different areas of the nation for the first full-scale repository for high-level radioactive waste. For the sake of readibility in this report, the indicative mood is used to tell what will be done if the NNWSI repository is built. Although the indicative mood indicates that an action is being or will definitely be taken, the reader should not conclude from this usage that a decision has been made to construct the first repository at the Nevada site.

There are four major phases in the design process leading to the construction of a repository: (1) preliminary concepts development phase, (2) conceptual design phase, (3) Title I design phase, and (4) Title II design phase. These phases are presented in schematic format as Figure I-1.

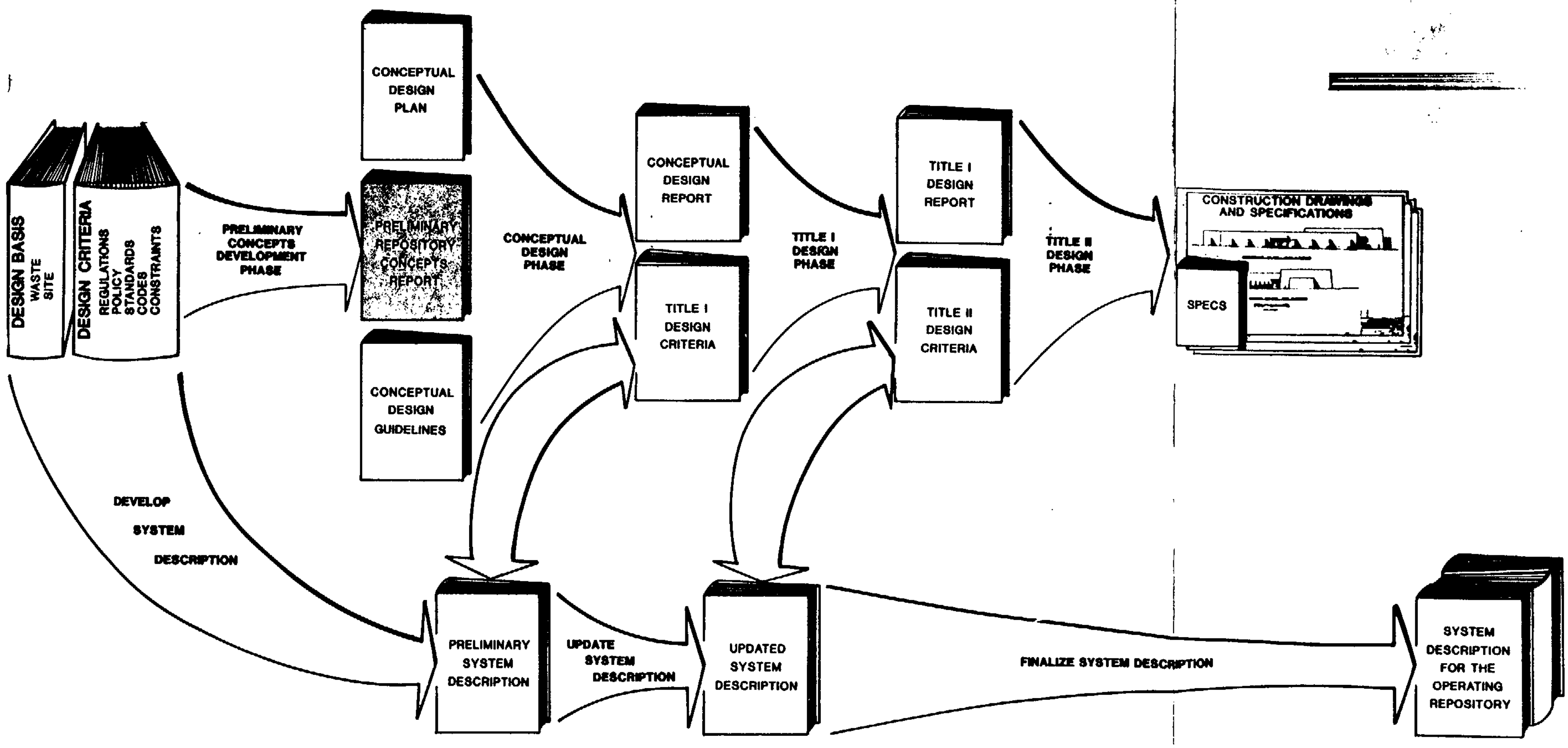
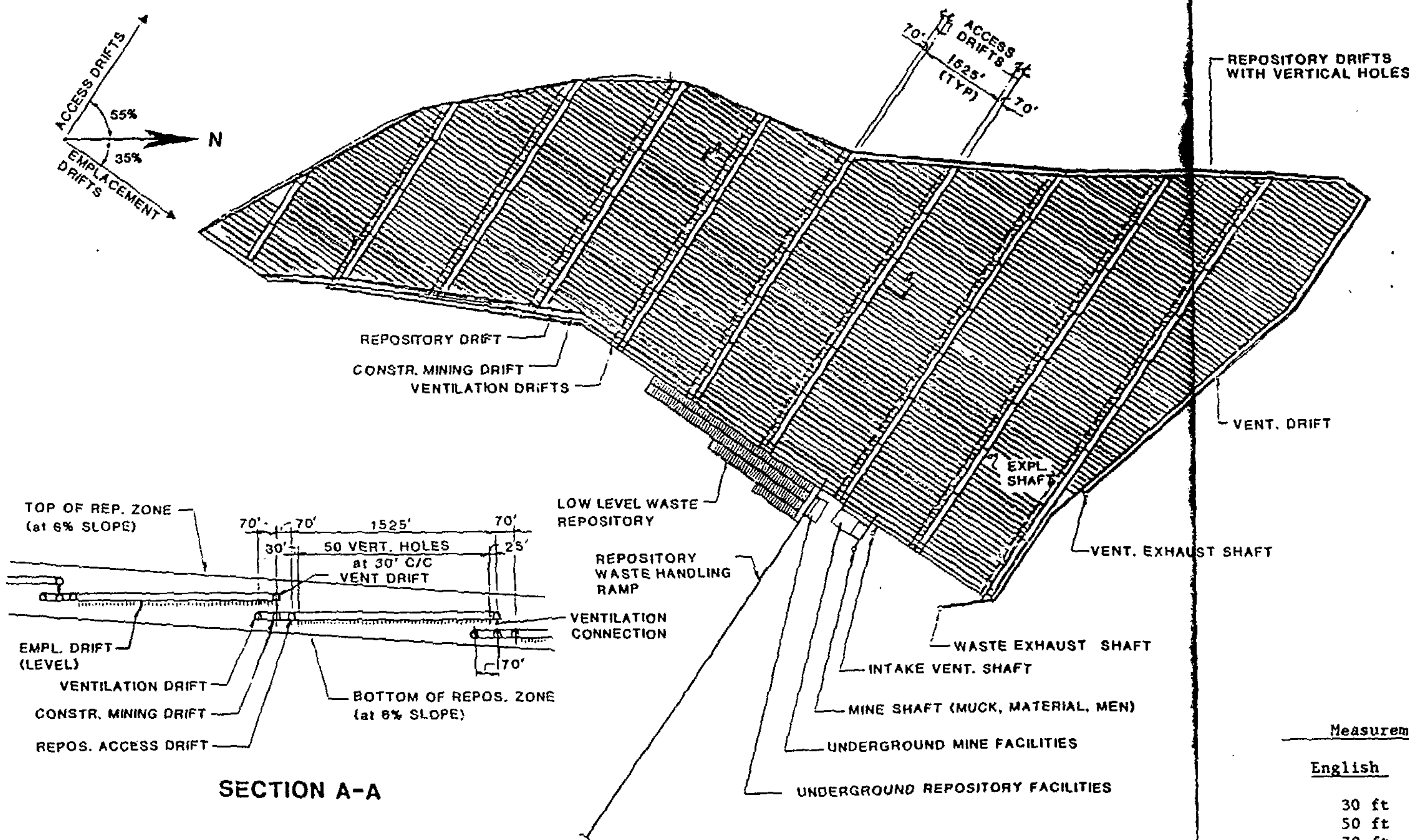


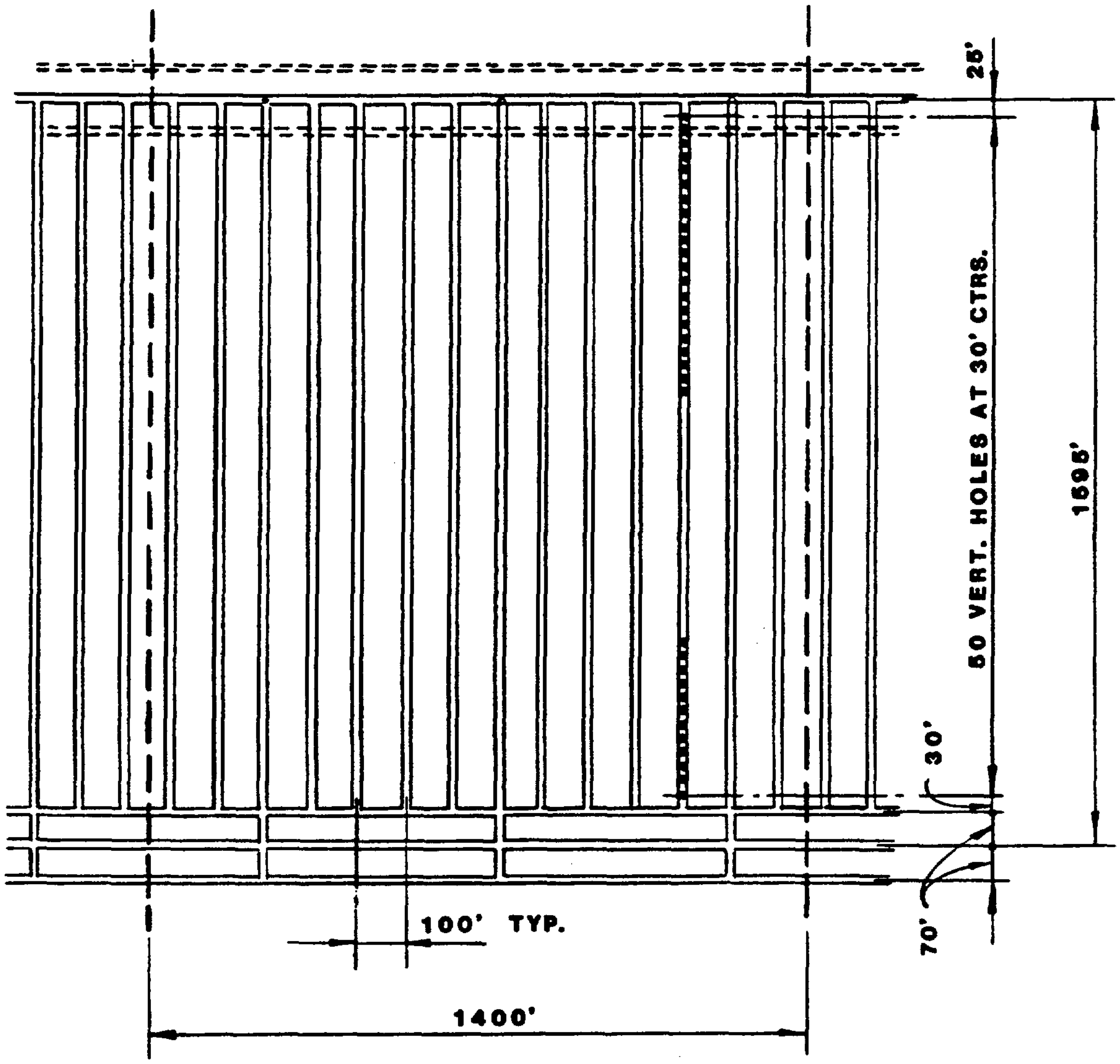
Figure I-1. Repository Design Process



Measurement Conversions

English	Metric
30 ft	9.2 m
50 ft	15.2 m
70 ft	21.3 m
525 ft	160.0 m
1,525 ft	464.8 m

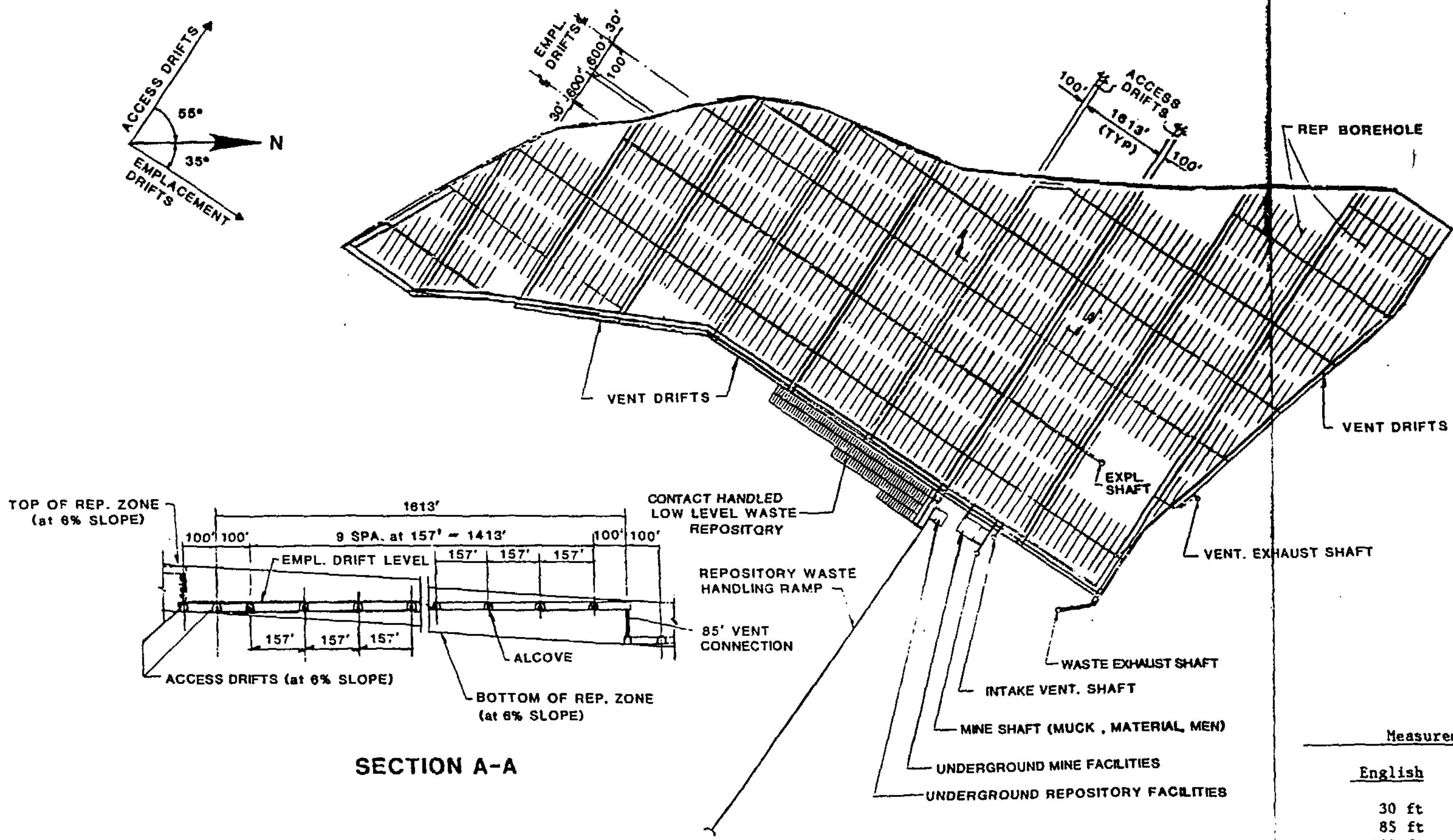
Figure 2-12. Preliminary Concept for the Underground Layout Using Vertical Emplacement



Measurement Conversions

English	Metric
25 ft	7.6 m
30 ft	9.1 m
70 ft	21.3 m
100 ft	30.5 m
1,400 ft	426.7 m
1,595 ft	486.2 m

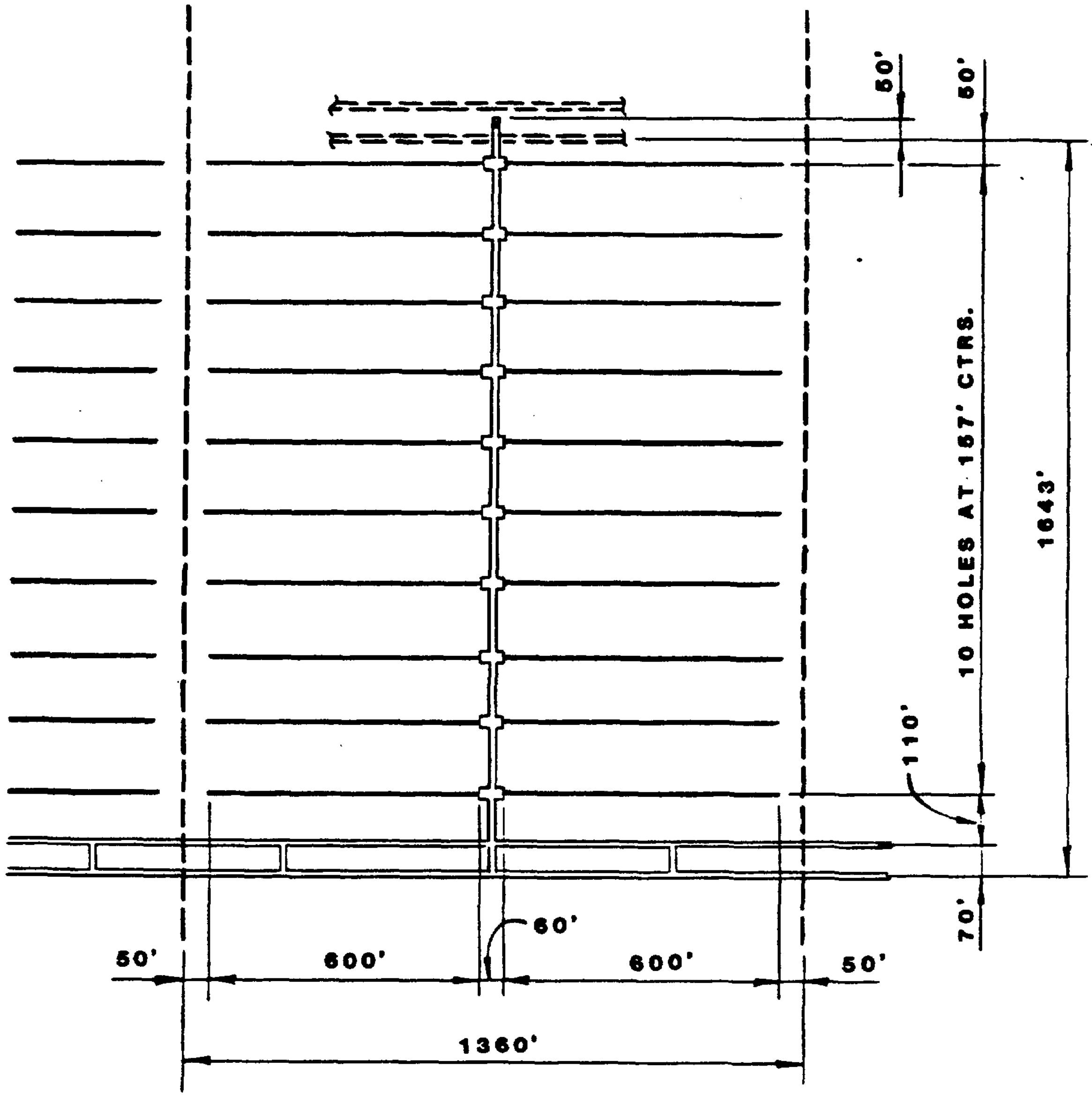
Figure 2-13. Vertical Emplacement Panel



Measurement Conversions

English	Metric
30 ft	9.1 m
85 ft	25.9 m
100 ft	30.5 m
157 ft	47.9 m
600 ft	182.9 m
1,413 ft	430.7 m
1,613 ft	491.6 m

Figure 2-14. Preliminary Concept for the Underground Layout Using Horizontal Emplacement



Measurement Conversions	
English	Metric
50 ft	15.2 m
60 ft	18.3 m
70 ft	21.3 m
110 ft	33.5 m
600 ft	183.9 m
1,360 ft	414.5 m
1,643 ft	500.8 m

Figure 2-15. Horizontal Emplacement Panel

2.5.2 Underground Design Factors

Influence of Fracture Orientation on Repository Stability

In order to minimize ground support and stability problems in the underground excavations, drifts will be oriented so that they are not parallel to a dominant joint direction. The dominant fracture strike is about N 15° W (Scott et al., 1983). Because the stability of the emplacement drifts and access drifts is equally important, and because, as shown later in this subsection, the emplacement drifts and access drifts are perpendicular to each other, the drifts are oriented at 45° to the currently estimated joint direction. This orientation results in a direction of N 35° E for emplacement drifts and N 55° W for access drifts. Figure 2-16 shows the relationships among the dominant and minor joint directions and the underground layout.

Measurements to date indicate that the in situ horizontal stresses do not exceed the vertical stress (see Appendix A.2). Linear-elastic analyses for underground openings using horizontal-to-vertical stress ratios ranging from zero to one have shown that excavation stability problems do not arise for the vertical stress magnitudes that have been estimated (Agbabian, in review). As the in situ stress state becomes more completely defined, this information, along with thermal load and other stress perturbations, will be incorporated in the underground opening stability analyses.

The average strike of the disposal horizon is N 10° W (Scott et al., 1983). By placing the drifts at about 45° to the strike, and thus 45° to the direction of the disposal horizon dip of 10%, the maximum drift grade is 6%.

Future testing and exploration data may show that the joint directions and principal horizontal stresses vary from those described above. Moreover, future data may show that these directions vary at different locations within the underground area. A study is currently being performed that addresses the effect of such geologic uncertainties on the orientation of the underground workings. This study will result in recommended ways of incorporating

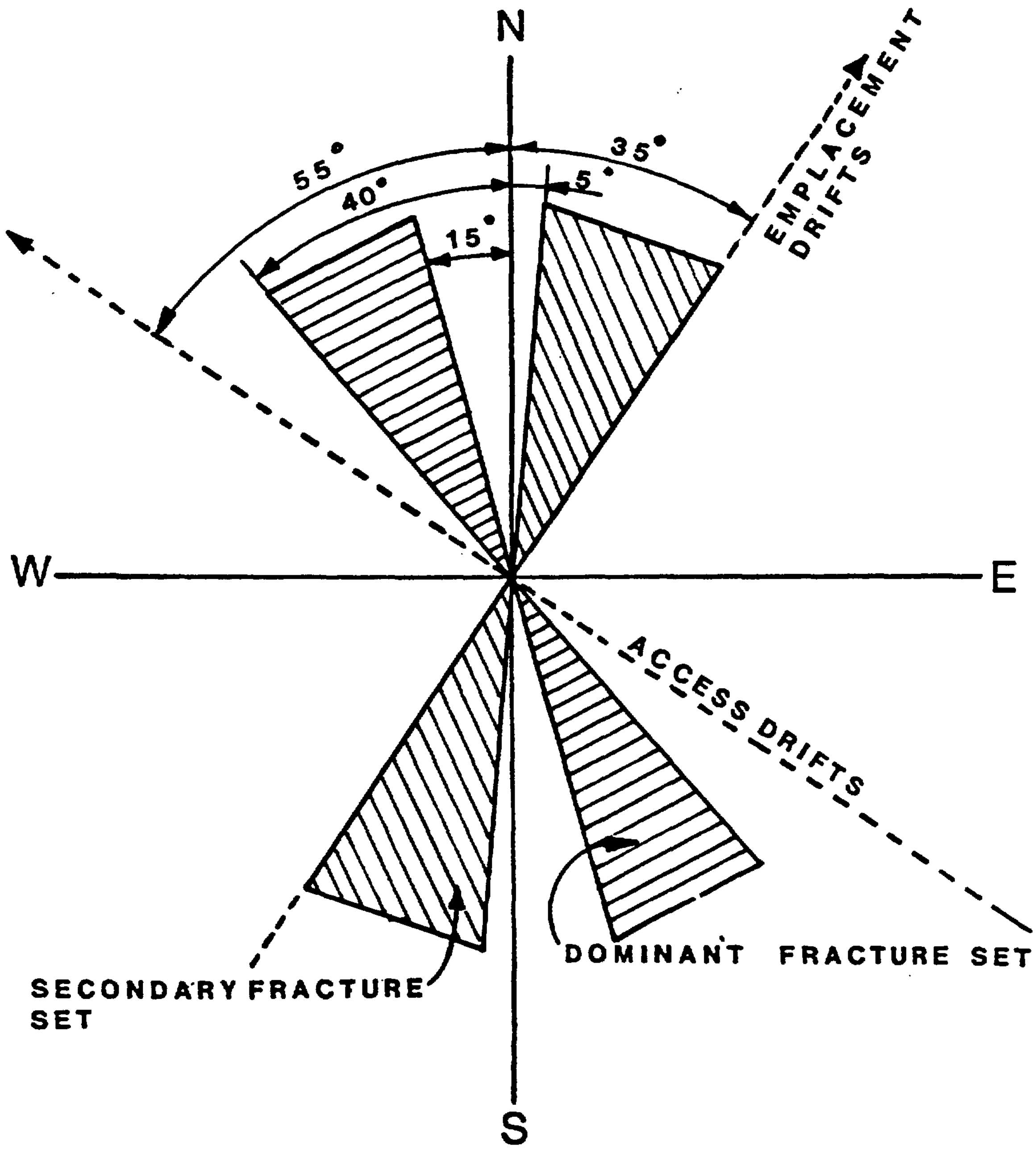


Figure 2-16. Relationship of Fracture Direction to Underground Layout

flexibility in the repository design so that as many geologic uncertainties as practical can be accommodated.

Ground Support

Artificial ground support is provided by engineered structures designed to ensure that underground excavations remain stable and safe. Ground support design is a "living design" that must be adapted to the particular conditions of the rock being excavated. The following discussion is based on geologic data obtained at Yucca Mountain and on the type of ground support traditionally used at the NTS. The ES will provide in situ data for establishing ground support requirements.

The basic type of ground support for all underground openings can be provided by 8-ft-long rockbolts on 4-ft centers used in combination with wire screen. In addition, 6-ft-long rockbolts can be used to stabilize the surface of the excavation, if necessary. Wire screen is attached to the threaded rockbolt heads to help prevent pieces of rock between the rockbolts from falling. A typical rockbolt and wire screen installation is shown in Figure 2-17.

Shotcrete

Shotcrete may be used in areas where the wire screen will not prevent rock between the rockbolts from falling. Such areas may occur near fault zones and in areas that have extensive jointing. Shotcrete also helps seal the rock surface.

Steel Arches

Sets of yieldable steel arches are being considered for possible use in fault areas. Lagging behind the steel sets provides support by filling in the gaps between the steel set and the rock. Spacing of the sets can be varied widely to suit the actual ground conditions encountered.

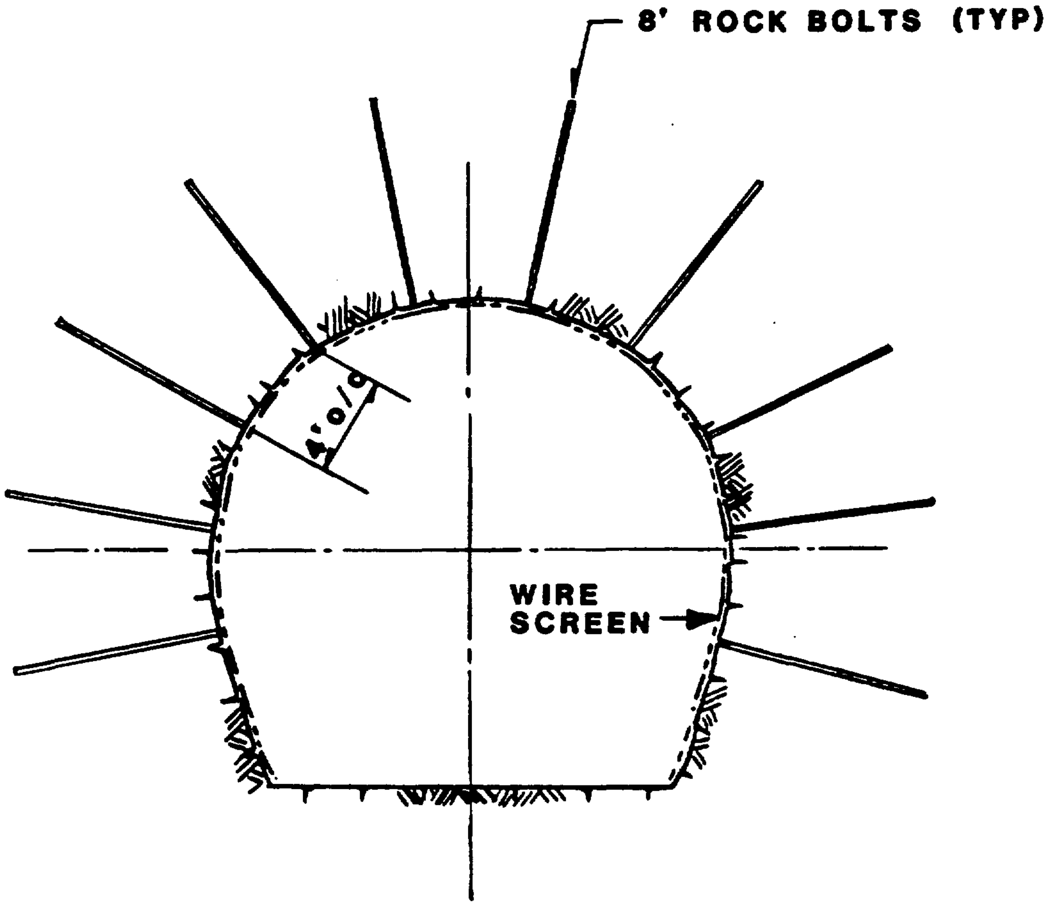


Figure 2-17. Typical Rockbolt and Wire Screen Ground Support

Reinforced Concrete Liner

Reinforced concrete may be used in areas that are too wide to be stabilized by arching or in areas, such as the brows (intersections of the drifts and shafts), where arches cannot be formed effectively.

Design of Drifts and Boreholes

Reference dimensions and orientations have been established for the access drifts, emplacement drifts, and boreholes for both vertical and horizontal waste emplacement concepts (Scully, 1983). The dimensions and orientations will be refined as waste characterization and the design process continue. The layouts for the two emplacement concepts are described in detail in Appendix B.6, and the cross-sectional dimensions for the preliminary concepts are shown in Table 2-2.

TABLE 2-2

DRIFT DIMENSIONS FOR THE
VERTICAL AND HORIZONTAL EMPLACEMENT METHODS

	Vertical Emplacement		Horizontal Emplacement	
	Height	Width	Height	Width
Access Drifts	3.7 m (12 ft)*	6.1 m (20 ft)	3.7 m (12 ft)*	6.1 m (20 ft)
Emplacement Drifts	6.7 m (22 ft)	6.1 m (20 ft)	3.7 m (12 ft)*	6.1 m (20 ft)

* Preliminary layouts prepared by Dravo (in review, a) assumed a drift height of 4.6 m (15 ft) rather than 3.7 m (12 ft). It was later determined that 3.7 m (12 ft) was sufficient for the passage of waste emplacement equipment; therefore, 3.7 m (12 ft) is used in this discussion.

The drifts will be approximately rectangular in cross section, and the corners of the drifts will be rounded to minimize stress concentrations. The design for a rectangular shape may evolve into one with a fully arched back (see Figure 2-17) or some other form, depending on requirements identified from future structural analyses and/or depending on the design of the mining and waste-handling equipment. The size of the drift is determined by structural stability and by the size of the equipment. Clearance space has been added to provide safety and to allow maneuverability. As the dimensions and types of equipment evolve during the conceptual design, the cross-sectional dimensions will change accordingly.

The length of the emplacement drifts in these preliminary concepts (measured from access drift centerline to access drift centerline) is 461 m (1,512 ft)* for vertical emplacement and 488 m (1,601 ft)* for horizontal emplacement. A standard drift length has been selected for each emplacement concept to facilitate mining and ventilation system design calculations based on preliminary thermal, stability, and ventilation analyses. These standard lengths provide drifts that accommodate boreholes with the spacings and access drift standoffs for commercial high-level waste (CHLW). These standard lengths may change as the emplacement design evolves.

Spacing between emplacement drifts for each emplacement method has been estimated from preliminary thermal, stability, and ventilation calculations. The space between vertical emplacement drifts is 30.48 m (100 ft). The space between horizontal emplacement drifts is 428.2 m (1,405 ft)* for spent fuel and 416.0 m (1,365 ft)* for other high-level wastes. The drift spacing between horizontal emplacement drifts for spent fuel is larger in order to accommodate the alcoves centered around the opening of each borehole. The alcoves, which measure 6.1 m (20 ft) wide by 3.7 m (12 ft) high by 6.1 m (20 ft) deep, provide extra space for maneuvering and positioning the transporter during emplacement and retrieval operations.

Access drift lengths are determined by the underground layout considerations described in Subsection 2.5.1.

* The dimensions shown here are not consistent with the repository layout dimensions given in Figures 2-12 through 2-15. The reason for this discrepancy is that different initial assumptions have been made (Dravo, in review, a). The dimensions given here represent the current assumptions.

Borehole diameters for the vertical emplacement method were selected to provide a 10-cm (4-in.) diametric clearance for the reference waste package with the largest diameter (see Appendix A.1). The range of waste package diameters was divided at 0.5 m (19.7 in.), resulting in a standard borehole diameter of 0.61 m (24 in.) for packages smaller than 0.5 m (19.7 in.) and 0.71 m (28 in.) for waste packages larger than 0.5 m (19.7 in.). This standardization may or may not be useful for vertical emplacement because vertical boreholes of various diameters can be readily drilled. Vertical emplacement borehole depths of 7.54 m (24.77 ft) for spent fuel and 6.05 m (19.84 ft) for other canistered wastes were selected to accommodate the reference waste package lengths (see Table 1-1) and to provide 3.05 m (10 ft) above the waste in the borehole for shield plugs and thermal standoff (vacant space left in the boreholes to delay temperature rises in the drift caused by decay heat from the waste packages).

Horizontal boreholes will be lined to provide stability and to facilitate retrieval. The borehole diameters selected for horizontal emplacement provide at least a 5-cm (2-in.) diametric clearance for the borehole liner and a 10-cm (4-in.) diametric clearance within the liner to accommodate the largest waste package (see Appendix A.1). Again, the range of waste package diameters was divided at 0.5 m (19.7 in.), resulting in a standard borehole diameter of 0.69 m (27 in.) for packages smaller than 0.5 m (19.7 in.) and 0.79 m (31 in.) for waste packages larger than 0.5 m (19.7 in.).

A standard horizontal borehole length of 200 m (656 ft), including standoff distance, was selected as a basis for future design analyses. On the basis of preliminary thermal calculations, a standoff distance of 25 m (82 ft) between the drift wall and the first canister was selected for spent fuel and for CHLW. A standoff distance of 10 m (32.8 ft) was selected for other wastes. These standoff distances are provided in order to reduce drift temperatures and to accommodate shield plugs.

For both emplacement concepts, the standoff distance from the access drift centerline to the centerline of the nearest borehole is 28 m (91.9 ft) for spent fuel and CHLW and 13 m (42.7 ft) for other wastes. These distances were selected on the basis of preliminary thermal and stability calculations (see Appendix B.7). Borehole spacings ranging from 2.13 m (7 ft) to 8 m (26.25 ft) in the vertical emplacement method and from 3.35 m (11 ft) to 36 m (118.11 ft) in the horizontal method were selected based on the range of initial thermal power values specified for the various waste forms.

Analysis of Stability of Drifts

Excavation of drifts results in stress concentrations in the rock surrounding the drifts. Engineering judgment and finite element calculations have been used to evaluate the stability of the drifts before waste emplacement. Engineering judgment is based on empirical techniques and predicts pillar factors of safety ranging from 2 to 10 and emplacement drift factors of safety of 1.5 to 2.5, depending on the particular formula used. Finite element calculations showed no roof failure for either horizontal or vertical waste emplacement and only local joint movement in the walls. It was predicted that joint movement in the walls would occur as the result of slippage along assumed, preexisting, ubiquitous vertical joints. Joint slippage does not constitute a failure of drift stability; it is merely a result of natural redistribution of stresses around the drift (Johnstone et al., 1984).

Empirical methods, using an assumed 100°C (212°F) temperature differential, give pillar factors of safety of 1.5 to 2.5 after the rock is heated. The finite element calculations for both horizontal and vertical waste emplacement showed no roof failure, but the joint movement in the walls increased over preheated conditions and included opening of the joints as well as slippage. For horizontal emplacement only, the finite element calculations also predicted that thermal stresses will cause local failure of intact rock in the walls of the drift (fracturing of the rock where there is not already a joint). However, the degree and nature of joint movement and intact rock failure did not imply a drift stability problem (Johnstone et al., 1984).

Analysis of Stability of Boreholes

The stability of the horizontal boreholes has been analyzed using finite element techniques to predict stress both in the vicinity of the plug and midway down the borehole. In the vicinity of the plug, the stresses are not large enough to be a problem. Midway down the borehole, intact rock failure is predicted; however, predicted failure is very local (Flanagan and Subia, 1983). Field testing experience has not shown such failures around a small-scale heater (Zimmerman et al., 1983). This experience suggests that the potential for failure may be an artifact of the model rather than representative of real conditions during underground construction. In any case, protection from intact rock failure will be provided by placing a liner in the borehole.

2.5.3 Mining Operations

Estimates of the amount and rate of mining required are based directly on the daily canister emplacement rate and the area required to accommodate the heat output of the canisters. The rate at which mining must occur was estimated using either the horizontal or vertical underground layout, an emplacement rate of 10 canisters per day, and equipment productivities based on operating experience. Conventional drill and blast mining methods, along with currently available mechanized mining equipment, were used as a basis for mining rate estimates. Details on the underground mining operations are provided in a Dravo report (in review, b).

Blast hole drilling, blasting, mucking, and ground control are the main steps in drift development. Drilling will be done by electrohydraulic drill jumbos. A crew operating a self-contained explosive-loading machine loads and blasts the explosives. Low-profile loaders called "LHDs" (load/haul/dump units) are used to remove the muck from the blasting face and to haul it to a discharge point in the access drift. The last part of the mining cycle consists of a series of three tasks to stabilize the surfaces of the excavated areas: scaling, rockbolting, and screening. As a safety measure, a long articulating boom with a scaling "tooth" mounted on the end knocks loose any unstable rock. Rockbolts are then installed using an automatic process in which a boom-mounted, remotely controlled device drills holes, injects resin, and spins in the bolts. Screen is placed over the protruding rockbolts and fastened to the bolts by nuts and washers.

Vertical Emplacement

For vertical emplacement, 13.9 hr are required to complete the entire mining cycle for a 3.66-m (12-ft) length of mined drift 6.7 m (22 ft) high and 6.1 m (20 ft) wide. Using 106 m/day (349 ft/day) of required drift advance and a 3-shift/day operation, it has been calculated that 29 working faces must be available at all times. The manpower requirements to support this effort are summarized in Table 2-3, and a schematic of typical underground mining operations is shown in Figure 2-18.

TABLE 2-3

MANPOWER REQUIREMENTS DURING MINING OPERATIONS FOR VERTICAL EMPLACEMENT

Operation	Estimated Cycle Time (hr)	Number of Miners per Shift	Total Personnel Requirements
Mining			
Drilling	2.75 hr	6	18
Blasting	2.9 hr	11	33
Mucking	2.7 hr	16	48
Ground Control	5.57 hr	24	72
Total Mining	13.92 hr/cycle	57	171
Other Operations			
Maintenance	NA	20	60
Construction	NA	30	90
Emplacement Hole Drilling	5.92 hr/hole	16	48
Materials Handling	NA	5	15
Supervision	NA	24	72
Total Personnel Requirements		152	456

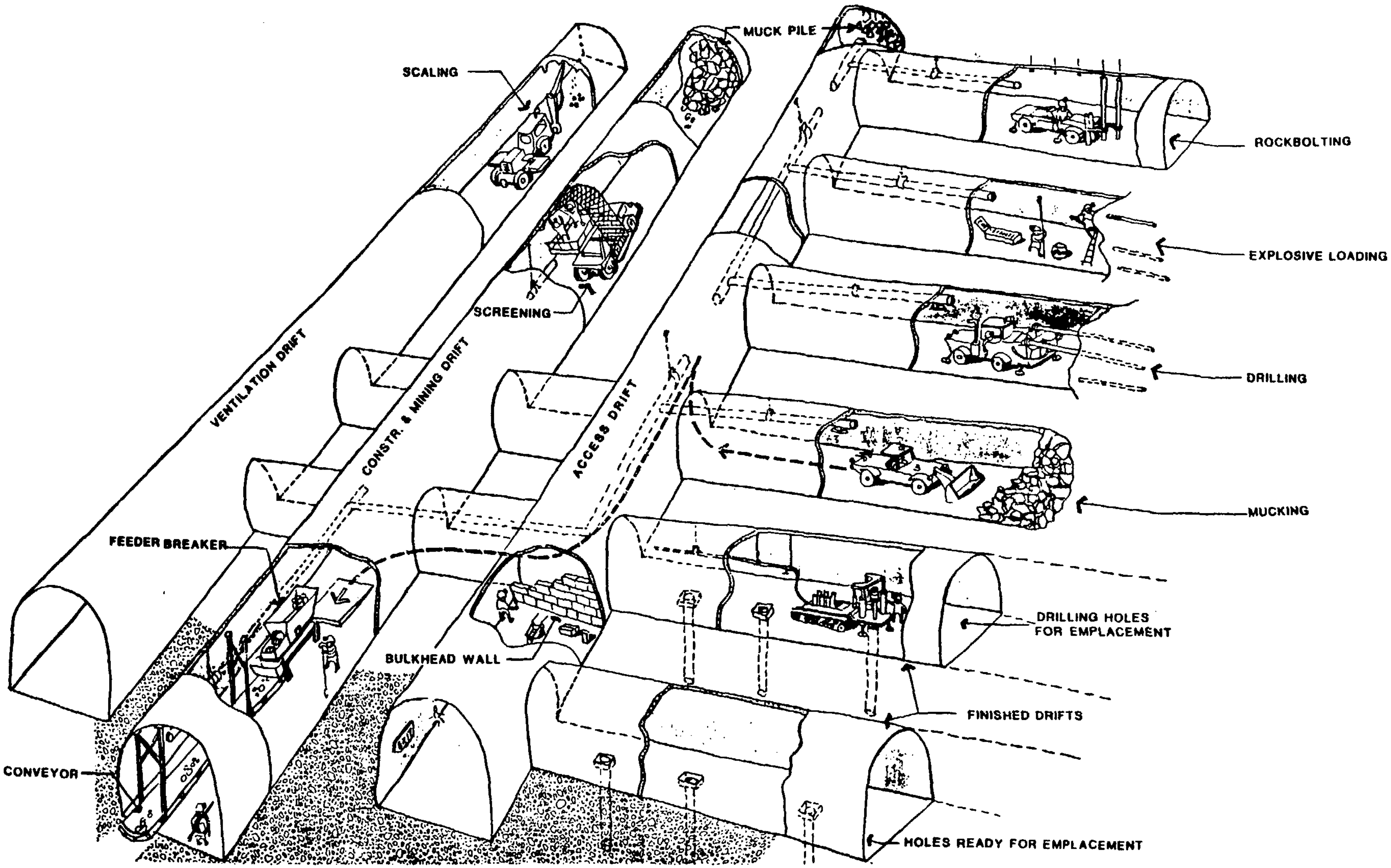


Figure 2-18. Sequence of Typical Underground Mining Operations

In addition to direct mining operations, maintenance, construction, emplacement hole drilling, and material-handling operations are a part of repository development. Support operations are described in detail (Dravo, in review, b) and are summarized below.

- Maintenance is performed by mechanics, electricians, and underground warehouse personnel. Their primary responsibility is to repair and maintain numerous pieces of mobile equipment, the underground mine plant (e.g., conveyors, fans, loading pockets), and bays for specialized functions.

- Construction operations consist of conveyor installation, road and drift maintenance, bulkhead construction, and emplacement hole preparation.

- Emplacement hole drilling for vertical boreholes is described in Subsection 2.5.4.

- Muck-handling operations during mine development include the removal of muck and the handling of construction and mining equipment and materials.

Horizontal Emplacement

For horizontal emplacement, 12.82 hr are required to complete the entire mining cycle for a 3.66-m (12-ft) length of mined drift 3.7 m (12 ft) high and 6.1 m (20 ft) wide. Using 19.2 m/day (63 ft/day) of required drift advance and a 3-shift/day operation, it has been calculated that 6 working faces must be available at all times. The manpower requirements to support this effort are summarized in Table 2-4.

Support activities for mining in the horizontal emplacement method are almost identical to those for the vertical emplacement method. The exception is that there are fewer pieces of mobile equipment to be maintained in the horizontal method. Details of emplacement hole drilling for horizontal emplacement are provided below.

TABLE 2-4

MANPOWER REQUIREMENTS DURING MINING OPERATIONS FOR HORIZONTAL EMPLACEMENT

Operation	Estimated Cycle Time (hr)	Number of Miners per Shift	Total Personnel Requirements
Mining			
Drilling	2.5	2	6
Blasting	2.5	3	9
Mucking	2.25	3	9
Ground Control	5.57	7	21
Total Mining	12.82	15	45
Other Operations			
Maintenance	NA	7	21
Construction	NA	9	27
Emplacement Hole Drilling	7.95 days	7	21
Materials Handling	NA	5	15
Supervision	NA	7	21
Total Personnel Requirements		50	150

2.5.4 Drilling Operations

If the panels are stair-stepped, the borehole drilling operations will consist of drilling the waste emplacement holes and the ventilation connections between adjacent panels. Details on drilling personnel, drilling equipment, and drilling time requirements for both horizontal and vertical emplacement are contained in reports by Dravo (in review, b) and Robbins (1984). Details on the equipment design are contained in Subsections 2.6.1, 2.6.2, 2.6.3, B.10, and in the Robbins report (1984).

Vertical Emplacement

In general, the equipment for drilling vertical emplacement holes is commercially available. Approximately two or three emplacement holes can be drilled per day using a single vertical boring machine (Robbins, 1984).

Horizontal Emplacement

A preliminary concept for a horizontal boring machine has been prepared (Robbins, 1984). This concept is for a machine capable of drilling holes 0.76 m (30 in.) to 1.06 m (42 in.) in diameter and up to 213 m (700 ft) long. These horizontal holes are drilled with 1/4° accuracy on either side of the emplacement drift. Each borehole will hold about 30 spent fuel canisters. The horizontal boring machine is capable of operating in a drift 3.66 m (12 ft) high by 6.09 m (20 ft) wide. A steel liner will be placed in the borehole to ensure integrity during retrieval. Conceptual design of the liner is now in progress. Emplacing a liner after completion of drilling and concurrent drilling and lining are both being considered. Approximately 1 borehole 213 m (700 ft) in length could be drilled per week using a single horizontal boring machine (Robbins, 1984).

Raise Drilling

If adjoining panels are stair-stepped, raise drilling will be used for ventilation connections between panels. These connections consist of vertical holes 1.2 m (4 ft) in diameter and approximately 30.5 m (100 ft) long. The holes are drilled in a two-phase operation. In the first phase, a pilot hole is drilled from one drift to the drift below. In the next phase, a raise bit 1.2 m (4 ft) in diameter is attached to the drill string in the lower drift and is pulled back to the drill in the upper drift. All of the equipment used in these operations is conventional and readily available.

2.6 Mining Equipment

2.6.1 Mechanical Miner

The use of mechanical miners for excavating the disposal area is being studied. Mechanical miners offer the following potential advantages: (1) reduction in the use of explosives, (2) elimination of costs for drift floor preparation, (3) reduction in ventilation flow friction, (4) easier bulkhead installation and maintenance, and (5) improved ground stability. Additional study and demonstration of equipment are needed before a complete evaluation of the mechanical miner can be made.

A two-phase test program has been established to provide the proper data. In the first phase, samples of welded tuff will be tested in the laboratory. Manufacturers of mechanical miners have already expressed an interest in performing such tests. This first-phase testing will provide an estimate of costs and production data and will give an indication of the potential for using mechanical miners on the Nevada Nuclear Waste Storage Investigations (NNWSI) repository.

If the first-phase results are favorable, then a demonstration test of a prototype mechanical miner in a representative welded tuff will follow. This second phase of testing will provide data on actual operations, including data on machine availability, machine maintenance, production capacity of the miner, cutter life, and costs. The production rates and costs would then be compared to those of conventional mining. If feasible, a mechanical miner could be used for both vertical and horizontal emplacement methods. More mechanical miners would be needed for vertical emplacement than for horizontal emplacement.

2.6.2 Vertical Boring Machine

Preliminary concepts for a vertical boring machine have been prepared (Robbins, 1984). Two designs have been developed: one for vertical emplacement holes up to 0.66 m (26 in.) in diameter and the other for vertical holes greater than 0.66 m (26 in.) in diameter.

The 0.66-m- (26-in.-) diameter emplacement hole involves a one-pass drilling operation that uses the largest pilot bit commercially available. A borehole 0.66 m (26 in.) in diameter and approximately 9.1 m (30 ft) deep is drilled by using compressed air and direct water circulation to remove chipped rock. The drilling unit is mounted on a slightly modified drilling rig and has a self-contained, trailer-mounted compressed air system (see Figure 2-19).

Emplacement holes greater than 0.66 m (26 in.) in diameter require a two-phase operation. After a pilot hole has been drilled, the emplacement hole is reamed to the desired diameter. The equipment used to drill the

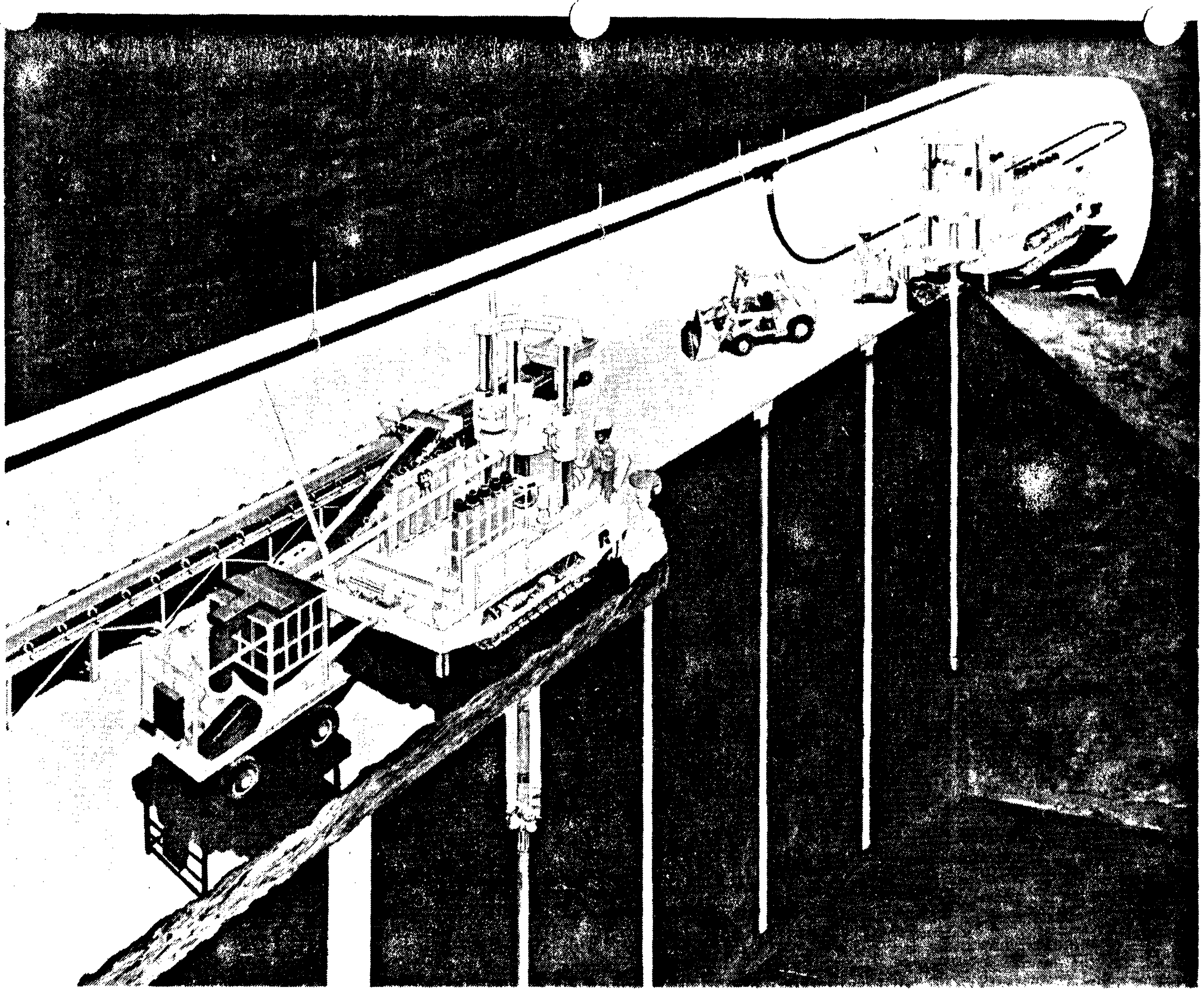


Figure 2-19. Vertical Boring Machine

pilot hole is entirely conventional. The reaming is somewhat unconventional because it involves the use of vacuum equipment to remove muck, and this method is not in common use. However, it is believed that the vacuum method is well within the state of the art and that there will be no significant technological problems in developing the vacuum system for this purpose.

No further conceptual or design effort is contemplated until it has been decided whether to use the vertical or horizontal emplacement method. The technology for vertical drilling equipment exists; therefore, a long lead time for development will not be required.

2.6.3 Horizontal Boring Machine

A preliminary concept for a horizontal boring machine has also been prepared (Robbins, 1984). The design features a nonrotating-stem boring machine capable of boring horizontal holes 0.76 m (30 in.) in diameter to a length of approximately 213 m (700 ft).

The horizontal boring machine shown in Figure 2-20 consists of a cutterhead assembly rotated by an electric motor through a fixed-ratio gear train. The cutterhead is thrust against the rock face by a nonrotating drill pipe. Thrust to the drill pipe is provided by hydraulic cylinders mounted in a derrick assembly. The drill pipe also transfers the torque (developed by the action of the cutters against the rock face) to the derrick structure. Controls for operating and steering the machine are mounted in a separate console convenient to the derrick. Boring accuracy is monitored by a laser beam guidance system. All of the machine system components are of a size that can be fitted into a haulageway 2.6 m (10 ft) high and 4.8 m (16 ft) wide.

While the machine is boring, the derrick and crawler are braced and held secure by hydraulic cylinders acting against the excavated drift walls. The rock chips produced by the boring are removed from the cutterhead by a vacuum system through a separate muck pipe attached to the side of the drill pipe. The vacuum system is powered by a separate muck/vacuum pack located in the haulageway. A front-end loader may be used to clear the collection hopper.

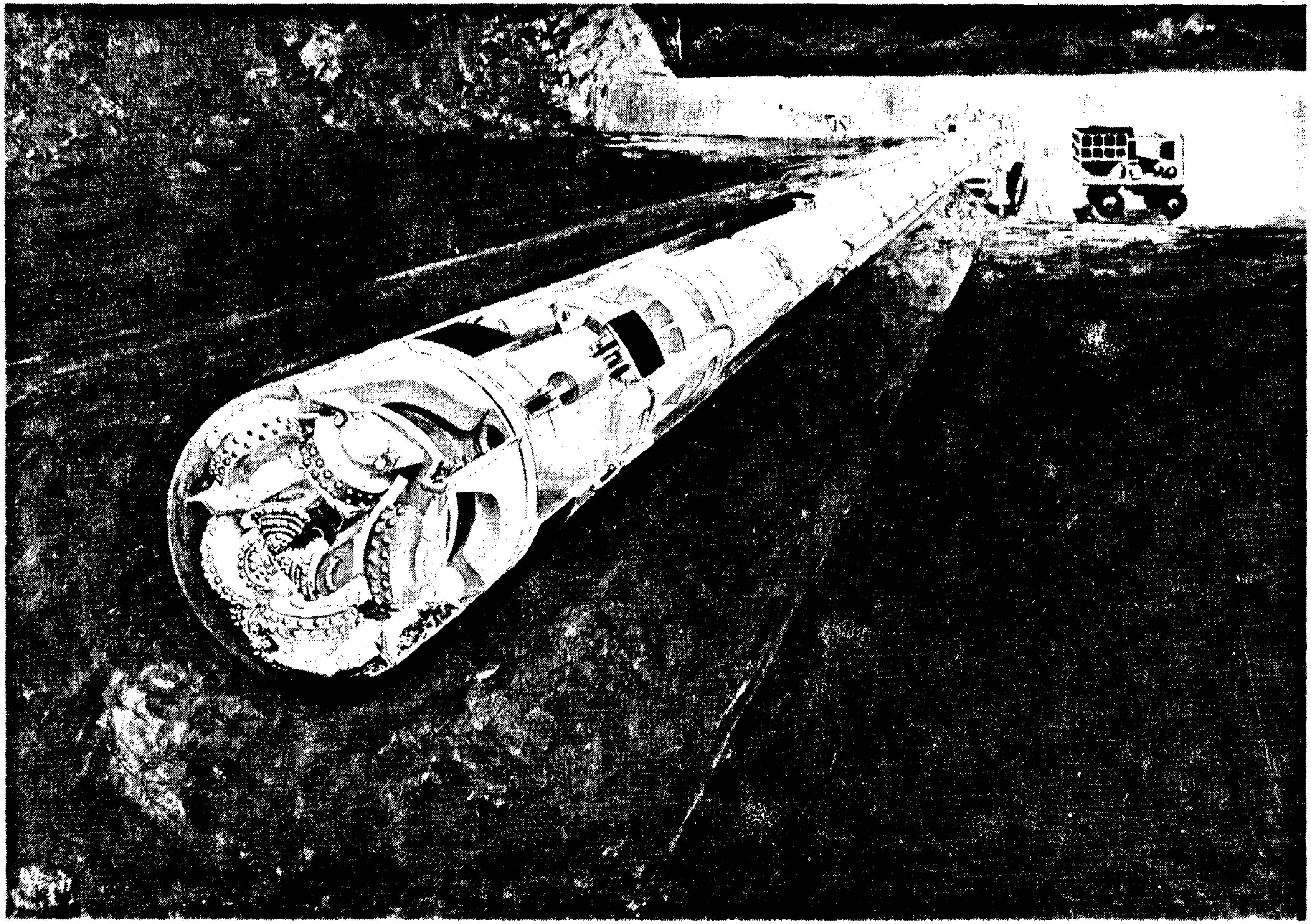


Figure 2-20. Horizontal Boring Machine

After a distance equal to one drill pipe length, 1.2 m (4 ft), has been bored, boring and muck-handling operations are stopped while another length of drill pipe and muck pipe is installed.

To improve the mobility of the horizontal boring machine between drilling sites, the derrick assembly is mounted on a crawler assembly. The cutterhead and drive train assembly are fully retracted into the derrick assembly while the crawler is being moved from one drilling site to another.

The development of the horizontal boring machine concept is continuing with the further study of placing a steel liner in the emplacement hole either during the boring operation or after the hole has been bored. Upon completion of the concept development, a prototype horizontal boring machine will be designed and built.

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3.0 WASTE-HANDLING CONCEPTS

Waste handling from receipt at the repository to emplacement in the disposal horizon and waste handling during retrieval are discussed in this section. To date, disposal of high-level waste (including spent reactor fuel) has been regarded as the primary focus of facility design, and disposal of transuranic (TRU) waste has been regarded as secondary.

Commercial high-level waste (CHLW) and defense high-level waste (DHLW) will be emplaced as received in canisters unless inspection reveals that the packaging of these wastes has been damaged. Spent reactor fuel will be shipped to the repository as intact fuel assemblies. At the repository, the intact fuel assemblies may be placed directly in canisters for disposal, or the fuel rods may be removed from the intact assemblies, consolidated, and packaged for disposal in canisters.

A substantial portion of the TRU waste received at the repository (those containers with surface dose rates greater than 200 mrem/hr) will be handled in a manner similar to that used for disposal of DHLW. The less radioactive TRU waste will be handled in a manner similar to that planned for handling low-level defense TRU wastes at the Waste Isolation Pilot Plant (WIPP) facility in southeast New Mexico (SL, 1977).

3.1 Waste-Handling Equipment

3.1.1 Receiving and Unloading Equipment

The equipment necessary for receiving and handling spent fuel shipping packages is available and in use at commercial power reactors. At present, compliance with worker radiation exposure guidelines at these facilities is not a major problem because workers typically handle only a few spent fuel shipments per year. However, in a repository, where the unloading of spent fuel and other high-level waste casks is a daily occurrence, greater reliance on remote-handling methods will be necessary to meet Department of Energy (DOE) guidelines on radiation exposure.

Worker exposure calculations based on current hands-on cask-handling and inspection methods have identified a number of receiving operations that must be performed remotely in order to meet DOE design guidelines (DOE, 1981). The expected annual radiation exposure of workers has been calculated for the preliminary concepts for high-level-waste-handling operations (Dennis et al., 1984b).

Much of the remotely controlled equipment planned for the repository, including radiation sensors, TV viewing systems, and x-y position bridge cranes, is currently available. Vehicle washdown equipment, cask decontamination equipment, and equipment for sampling gas in the cask cavity must be modified to permit remote operation. In some cases, new remotely operated equipment must be developed. The two principal items of remotely controlled receiving equipment to be developed are (1) a system for inspecting the surface of shipping packages for contamination, and (2) a system for removing the closure(s) on casks and on TRU shipping packages.

Optimization studies for shipping packages within the receiving facilities will be conducted during the conceptual design phase. However, handling the packages will be accomplished using conventional means (e.g., bridge cranes, rail-mounted carts, or air pallets) operated by remote control. Equipment development requirements are expected to be minimal.

3.1.2 Handling and Packaging Equipment

All waste-handling and packaging equipment will be located in hot cells or in other areas that have special radiation shielding; hence, all equipment discussed in this subsection will be remotely controlled.

Three principal operations are required for unloading waste from the casks. The operations are (1) opening and closing the hot cell port, (2) removing and installing cask closure(s), and (3) removing the waste package(s) from the cask. Equipment for performing these operations will require design work but will not require significant additional development work.

Prototypical fuel consolidation equipment has been designed, built, and operated (on mock fuel assemblies) under government sponsorship by Allied General Nuclear Services and Nuclear Assurance Corporation and under private sponsorship by Westinghouse and others. Production-level fuel consolidation equipment is not currently available and will require development.

Packaging equipment must be able to assemble waste packages in a reliable manner. At this time, it is assumed that package assembly will be completed by closing the canister with a full-penetration butt weld. Inspection equipment must be able to detect unacceptable flaws in butt welds.

After the waste package has been inspected and accepted, it will be placed in a surface surge storage area before being transferred to the disposal horizon. A remotely controlled bridge crane manipulator will be required to transfer canisters to and from surge storage. Remotely controlled equipment must be developed to load the waste disposal package into the facility cask for transfer to the disposal horizon.

Miscellaneous ancillary equipment will be required to transfer waste packages between surface work stations, to decontaminate waste packages, and to repair waste packages. Equipment requirements for handling TRU waste in drums and boxes are being identified. Consideration is being given to using automated warehousing equipment to handle the TRU drums and boxes.

3.1.3 Waste Transporters

The preliminary concepts for the waste transporters are based on two major design criteria. First, the concepts for the transporters must be based on chassis and drive components currently used in high-capacity commercial equipment such as ore haulers, load/haul/dump (LHD) units, and road-building equipment. The advantages of using existing commercial designs include:

- development costs are minimal,
- spare parts are readily available,
- life cycle and maintenance histories exist, and
- operations costs are documented.

Secondly, the concepts chosen must provide a high margin of safety in terms of braking capacity, load capacity, and traction.

<u>Waste Transporters for Canistered Waste</u>

In the transporter concepts for both vertical and horizontal emplacement methods, the running gear is skid-steered and powered by a diesel and hydraulic system. The running gear consists of four wheels on each side of the transporter frame (see Figure 3-1). The wheels on each side are independently powered through a hydraulic power divider. The running gear is similar to that of a crawler tractor except that rotation of the drive system on one side can be reversed from the rotation on the other side. Thus, the vehicle can be turned without laterally displacing the center of the vehicle, and less area is required for turning. To further facilitate turning and to minimize tire wear, the two center tires on each side of the vehicle carry most of the load during turning. The tires at the extremities stabilize the vehicle while the vehicle is in motion and during braking.

There are no axles or differentials in skid-steered running gear, which allows the facility cask to be mounted in a low position between the tires. This position results in a low center of gravity and allows the horizontal emplacement boreholes to be located closer to the floor of the emplacement drift.

The cab of the transporter for canistered waste has redundant controls for two operators. Cab pressure is controlled so that the pressure inside is always greater than the pressure outside the cab. Inlet air for the cab's air-conditioning system passes through high-efficiency particulate air (HEPA) filters.

Facility casks for horizontal and vertical emplacement will probably be very similar if not identical in dimensions and appearance. Facility casks for both emplacement configurations will provide radiation shielding adequate to lower the outside surface dose rate to required levels. These levels will be established later.

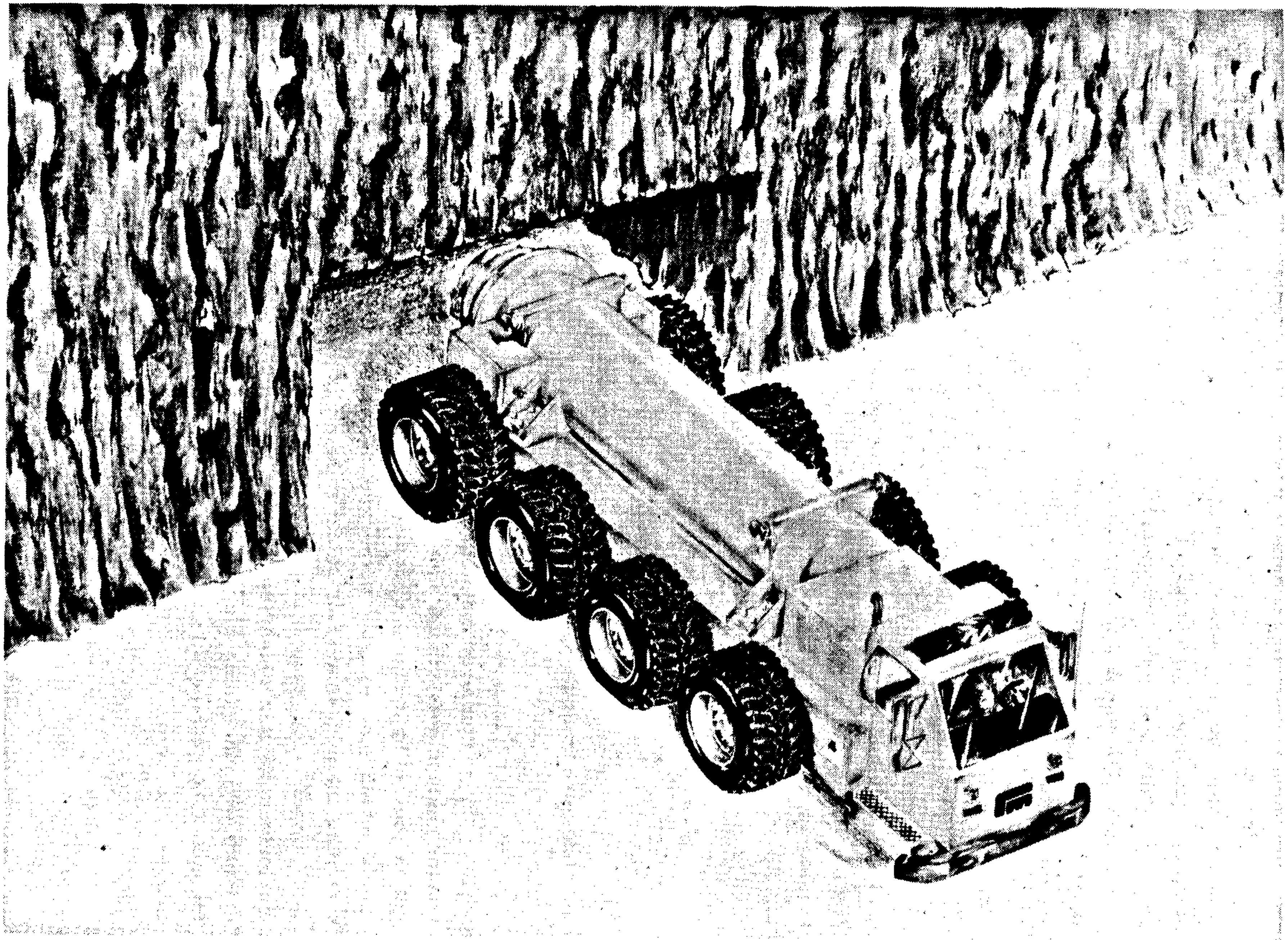


Figure 3-1. Waste Transporter for Canistered Waste

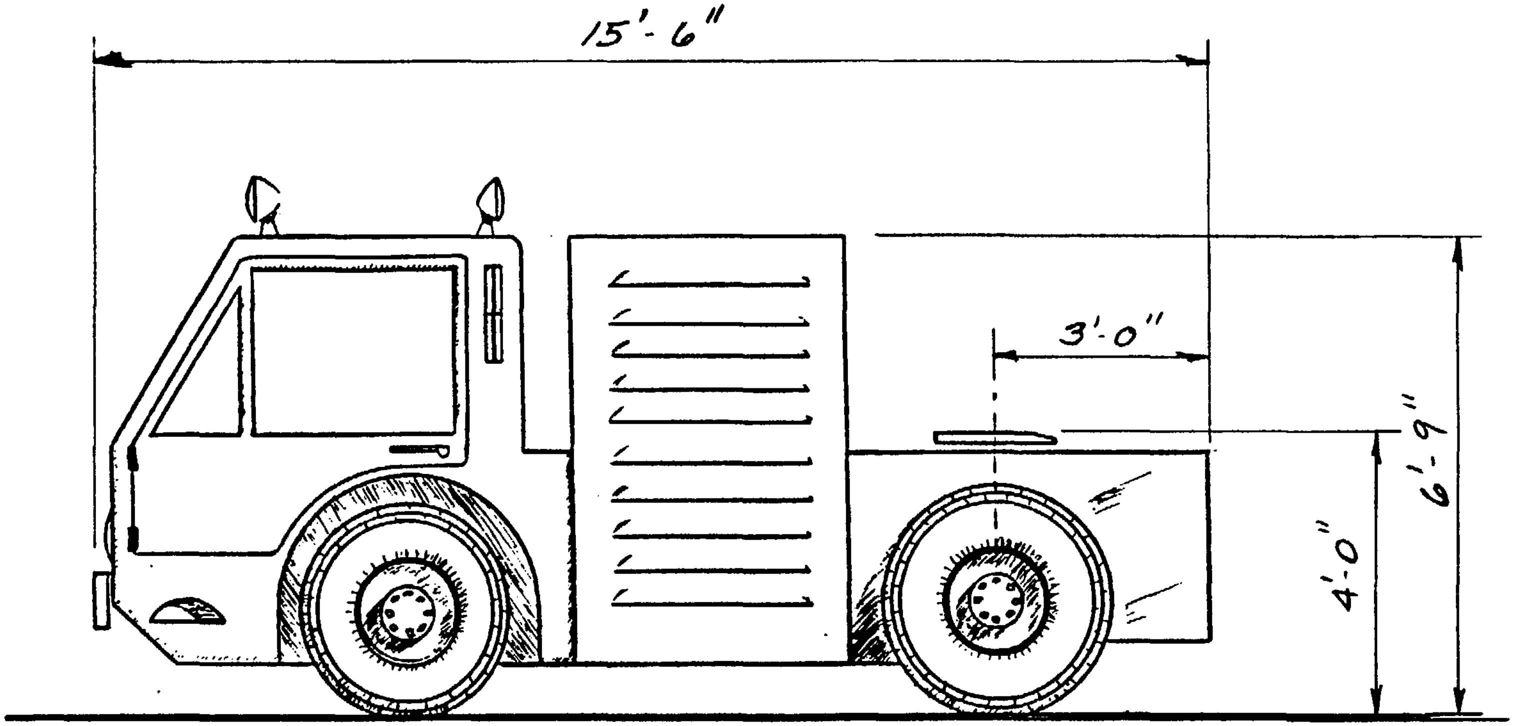
In the horizontal emplacement method, the facility cask incorporates two features required for waste emplacement and retrieval: (1) a remotely operated shielding lid located at the rear end of the cask through which waste canisters are loaded and unloaded, and (2) an internally powered roller system that will move a canister into and out of the cask. The facility cask is rigidly secured to the running gear. Figure 3-1 shows the concepts for the facility cask and running gear.

The facility cask for vertical emplacement incorporates a remotely operated shielding lid identical to that used for horizontal emplacement. However, unlike the facility cask used for horizontal emplacement, the cask used for vertical emplacement incorporates an internal winch and grapple for loading and unloading the waste canister. The vertical emplacement cask is secured to the waste transporter running gear by trunnion pins. The cask is carried in the horizontal position until it reaches a vertical borehole. The cask is then rotated to a vertical position by hydraulic cylinders.

Waste Transporters for TRU Waste

TRU waste packaged in canisters is transported by the transporters used for canistered spent fuel and high-level waste.

TRU waste packaged in drums or boxes is transported from the surface facility to the underground disposal area on a tractor/trailer unit. The tractor concept consists of a vehicle built with standard drive components and is powered by a diesel/electric system. The tractor has conventional air brakes but is also equipped with regenerative braking to provide additional safety on the ramp that leads to the underground facilities. The tractor cab is equipped with redundant controls for two operators, and the cab environment is controlled so that the pressure inside is greater than the pressure outside. Inlet air to the air-conditioning system in the cab passes through HEPA filters. Figure 3-2 presents the concept for the TRU waste tractor.



Measurement Conversions

English	Metric
3'0"	0.9 m
4'0"	1.2 m
6'9"	2.0 m
15'6"	4.7 m

Figure 3-2. Preliminary Concept for the TRU Waste Tractor

A low-boy trailer of special design is used to carry drums and boxes of TRU waste. The front of the trailer is equipped with a combination radiation shield and cargo restraint barrier to protect the operators in the tractor from radiation and sudden shifting of cargo. Removable panels provide radiation shielding and cargo retention along the sides and at the rear of the trailer. The concept for the TRU waste trailer is shown in Figure 3-3.

3.1.4 Waste Emplacement Equipment

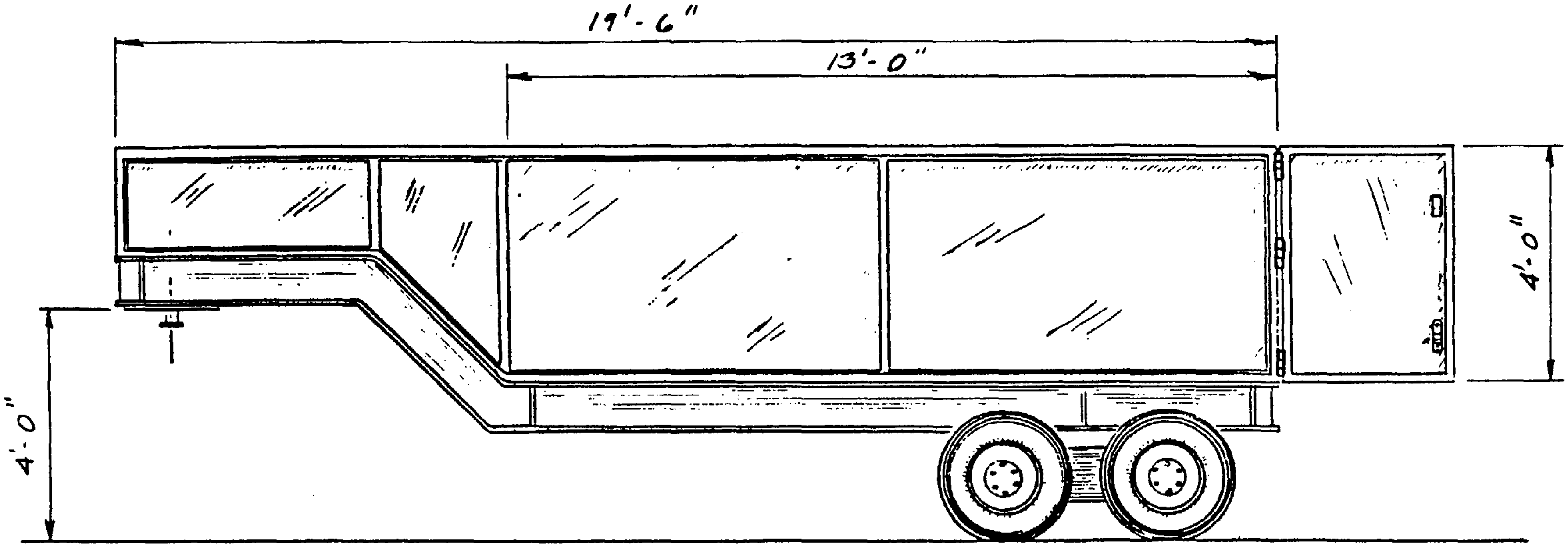
Equipment for Emplacing Spent Fuel and High-Level Waste

Vertical Emplacement

In addition to the waste transporter described in Subsection 3.1.3, other equipment is required to vertically emplace canistered spent fuel and high-level waste.

The shielding closure shown in Figure 3-4 is placed over the vertical borehole during waste emplacement and is removed after the permanent shield plug has been installed. The shielding closure contains three elements: (1) the closure housing, (2) a gate, and (3) the housing extension shield. The electrically operated gate is contained within the housing. It is opened to admit a canister and is closed after the waste canister has been lowered into the borehole. The gate and the housing shield extension provide temporary shielding from radiation until the permanent shield plug has been installed. The shielding closure is transported to the next vacant borehole by a four-wheeled straddle-type lift dolly.

The preliminary concept for the vertical borehole is shown in Figure 3-5. The partial steel liner fits in the mouth of the hole and protrudes above the drift floor to serve as a positioning aid for the shielding closure. A steel support plate is placed in the bottom of the borehole to provide support for the waste canister. The permanent shield plug is fabricated from a steel tube and designed to fit into the borehole liner with a minimum clearance. The lower portion of the shield plug is filled with an



Measurement Conversions

English	Metric
4'0"	1.2 m
13'0"	4.0 m
19'6"	5.9 m

Figure 3-3. Preliminary Concept for the TRU Waste Trailer

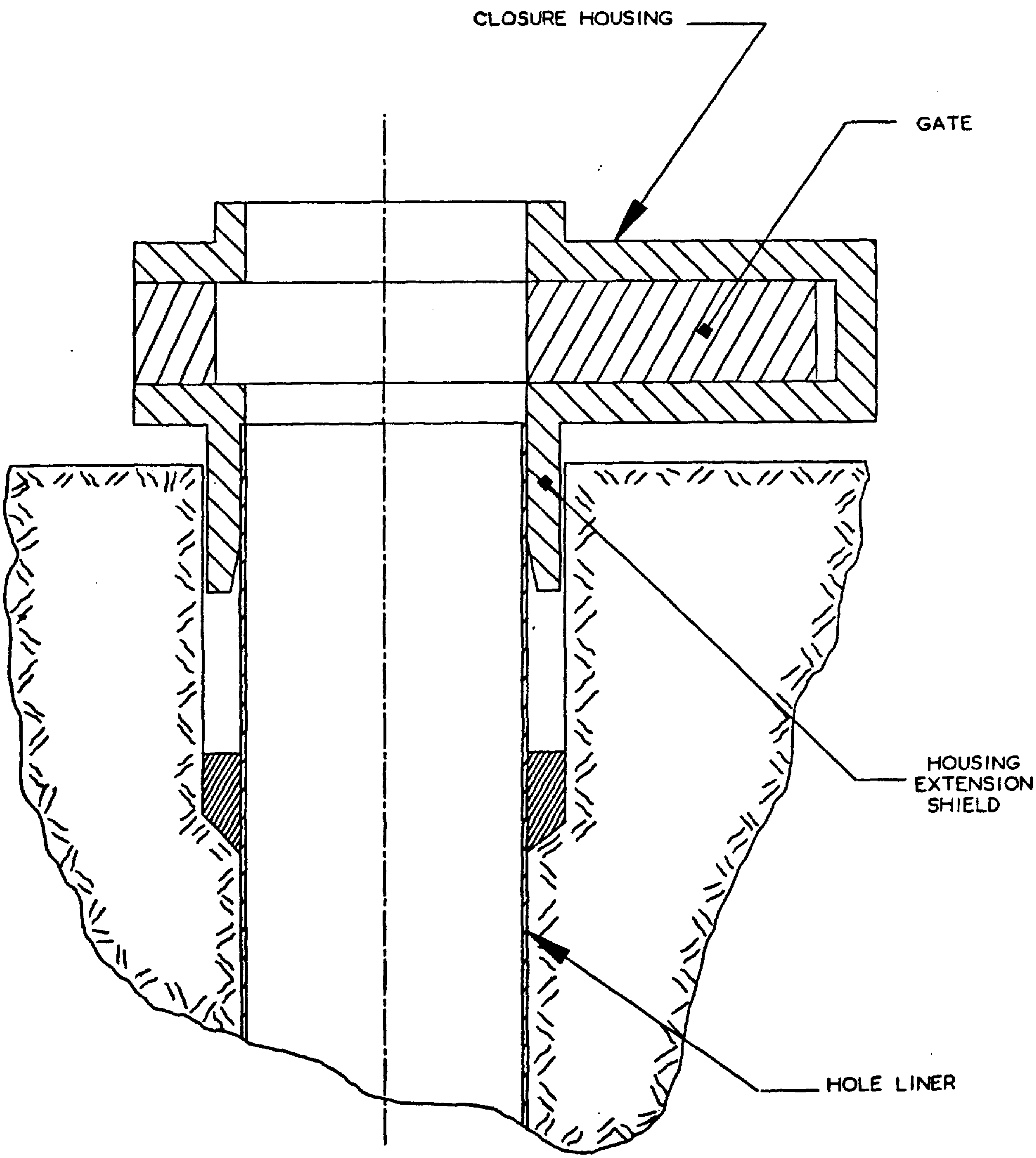


Figure 3-4. Preliminary Concept for the Temporary Shielding Closure Used on Vertical Boreholes

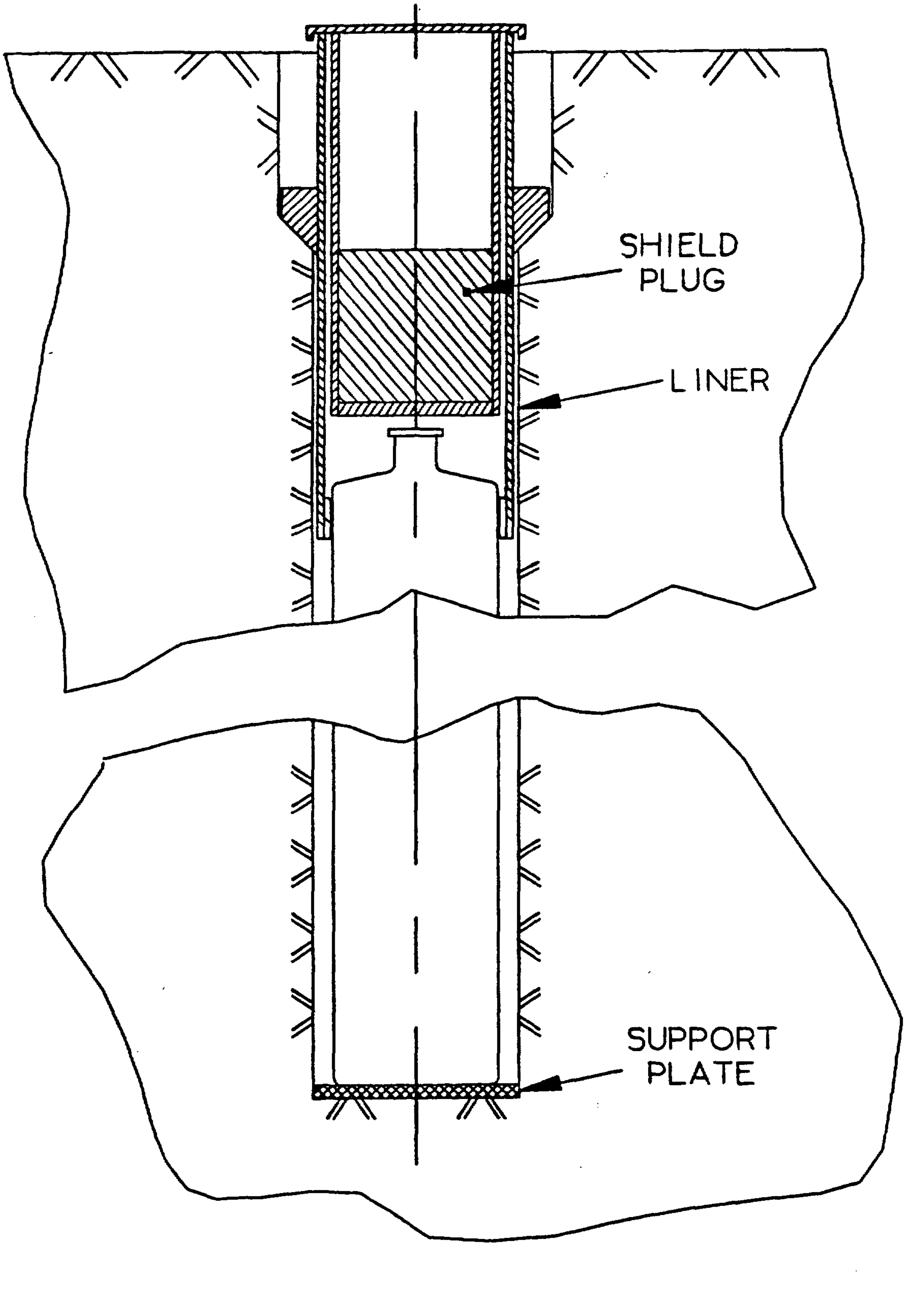


Figure 3-5. Preliminary Concept for the Outfitting of a Vertical Borehole

appropriate shielding material (e.g., cast iron, steel, lead, or high-density concrete). The upper end of the shield plug is flanged so that the plug is supported by the hole liner.

Horizontal Emplacement

In addition to the waste transporter, other hardware will be required to horizontally emplace canistered spent fuel and high-level waste.

A segmented in-hole conveyor system will be installed for the full length of a vacant horizontal borehole. The conveyor includes a feature that automatically disconnects the power to each section as it is covered by a waste canister. After a borehole has been filled, the conveyor system is withdrawn and disassembled. The segments are taken on a fork-lift truck to the next vacant borehole for reassembly.

A shielding closure similar to that used for vertical emplacement is placed over the horizontal borehole during waste emplacement and is removed after the permanent shield plug has been installed. The shielding closure is moved and reinstalled at the next borehole by a high-capacity fork-lift truck equipped with special adapters that attach to the shielding closure.

The platform used to dock and align the transporter is adjustable and functions to position the waste transporter for connection with the shielding closure. The platform has a base frame equipped with leveling and elevation jacks and a roller-mounted subframe that engages and supports the waste transporter as it moves onto the platform. The platform is moved from one borehole to another by a fork-lift truck.

The horizontal borehole is lined with steel along its entire length. The liner is flared at the mouth of the borehole to accept the permanent shield plug. The shield plug is fabricated from a steel tube and fits into the mouth of the liner with a minimum clearance. The shield plug is filled with an appropriate shielding material (e.g. cast iron, steel, lead, or high-density concrete). The permanent shield plug is loaded on the horizontal waste transporter and installed in the same manner as a waste canister by use of the conveyor system contained within the transporter.

Equipment for Emplacing TRU Waste

Equipment for Emplacing Canistered TRU Waste

Canistered TRU waste is emplaced using the same equipment as that used for spent fuel and high-level waste. The type of equipment used will depend on whether the vertical or horizontal emplacement method is chosen.

Equipment for Emplacing TRU Waste in Drums and Boxes

The major piece of equipment for emplacing TRU drums and boxes will be a commercially available truck equipped with a fork lift at the end of an extending boom.

The advantages of this vehicle over conventional fork lifts include:

- The extending boom increases the distance between the waste being handled and between the operator and the stacked waste.

- The cab can be shielded easily.

- The cab is offset from the boom, providing greater visibility for the operator.

- The extendable boom can reach into a TRU transportation package up to a distance of 6.1 m (20 ft), which eliminates the need for roller conveyors, winches, or other special equipment to remove TRU drums or boxes from their transportation packages.

- The vehicle incorporates crab steering and has four-wheeled drive, thus providing greater maneuverability and traction.

The vehicle cab is equipped with an environment control system featuring air conditioning and HEPA-filtered air intakes. The concept for this TRU waste emplacement vehicle is shown in Figure 3-6.

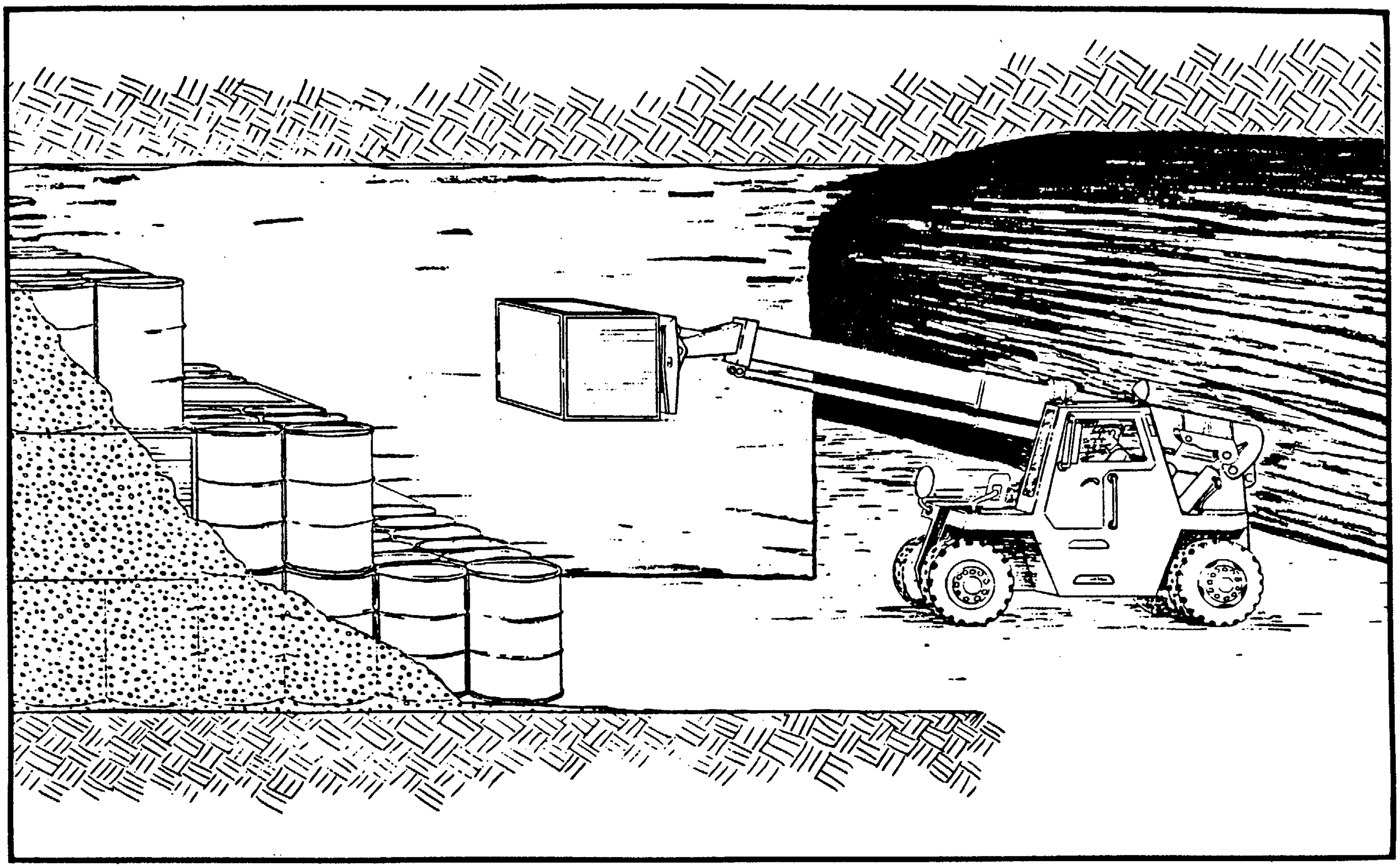


Figure 3-6. Preliminary Concept for the TRU Waste Emplacement Vehicle

3.1.5 Waste Retrieval Equipment

The most important piece of retrieval equipment is the borehole liner, which serves to maintain the integrity of the borehole for a 50-yr period following initial waste emplacement. Retrieval may be ordered at any time during this period if the site or repository design proves unsuitable or if it is decided to recover the spent fuel canisters for reprocessing (NRC, 1983.)

Equipment for Normal Retrieval from Vertical Boreholes

In the vertical emplacement method, a single waste canister has been positioned in a partially lined vertical hole drilled into the emplacement floor drift (Figure 3-5). The partial steel liner protrudes approximately 10.16 cm (4 in.) above the drift floor and extends into the borehole to a point just below the canister pintle, about 3.045 m (10 ft) below the drift floor. The main function of the liner is to maintain borehole integrity down to the point just below the canister pintle so that the canister may be retrieved. If the integrity of the borehole has been maintained, then normal waste retrieval can be accomplished by using, in reverse order, the equipment used for waste emplacement. The liner also serves (1) to support the permanent shield plug until such time as the canister is retrieved, (2) to indicate the location of the emplacement borehole in the drift floor, and (3) to support the shielding closure used during retrieval.

Equipment for Normal Retrieval from Horizontal Boreholes

In horizontal emplacement, 30 or more waste canisters have been positioned in a fully lined horizontal hole drilled into the side of the emplacement drift. The main function of the liner is to maintain borehole integrity through the entire length of the borehole so that all of the canisters may be retrieved. The liner also serves to house the permanent shield plug until such time as retrieval may be ordered.

Liner materials and appropriate liner thickness are being studied, taking into consideration three design criteria: (1) the liners must be structurally capable of withstanding rockfalls without deforming to the point where the waste canisters are jammed within the liner; (2) the clearances between the liner and boreholes must be minimized to preclude liner deformation resulting from external loading by the surrounding rock; (3) liner materials and thickness must be chosen to minimize corrosion and to provide sufficient sacrificial material beyond that required for structural support.

If borehole integrity has been maintained, normal waste retrieval can be accomplished by using, in reverse order, the equipment used for waste emplacement.

Equipment for Retrieval under Adverse Conditions

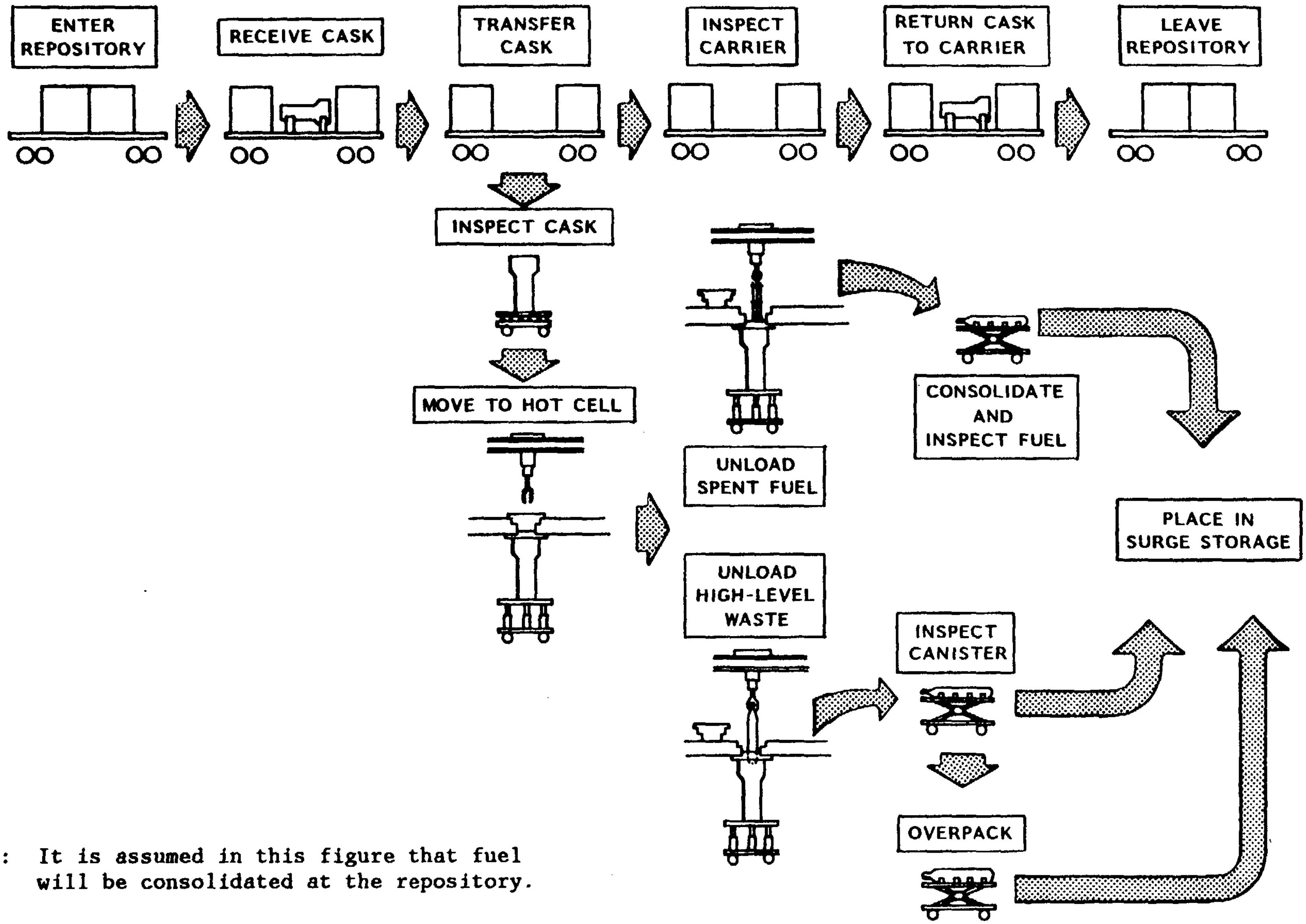
It is possible that catastrophic events will occur that are so severe that damage to the borehole liner will be unavoidable. Only general concepts for retrieval equipment for catastrophic events have been developed. Future work will be directed towards developing credible scenarios in which liner damage occurs and towards developing equipment for retrieval of casks from damaged borehole liners.

3.2 Waste Operations

The major steps in receiving and preparing waste for emplacement are shown in Figure 3-7, and the steps for transferring the waste disposal packages from surface surge storage to the disposal horizon are shown in Figure 3-8. Except as noted, the operations discussed in this section apply to wastes emplaced in canisters, including CHLW, DHLW, spent reactor fuel, and canistered TRU waste. Operations for TRU waste received in drums and boxes are still under development and will be discussed in the Conceptual Design Report (CDR). The repository operations discussed in this section are described in detail in a repository operations report (Dennis et al., 1984a.)

3.2.1 Receiving Operations

Receiving operations for canistered waste begin when the shipping cask arrives at the repository gate and terminate when the shipping cask is



Note: It is assumed in this figure that fuel will be consolidated at the repository.

Figure 3-7. Receiving, Handling and Packaging, and Storage of Spent Fuel and High-Level Waste

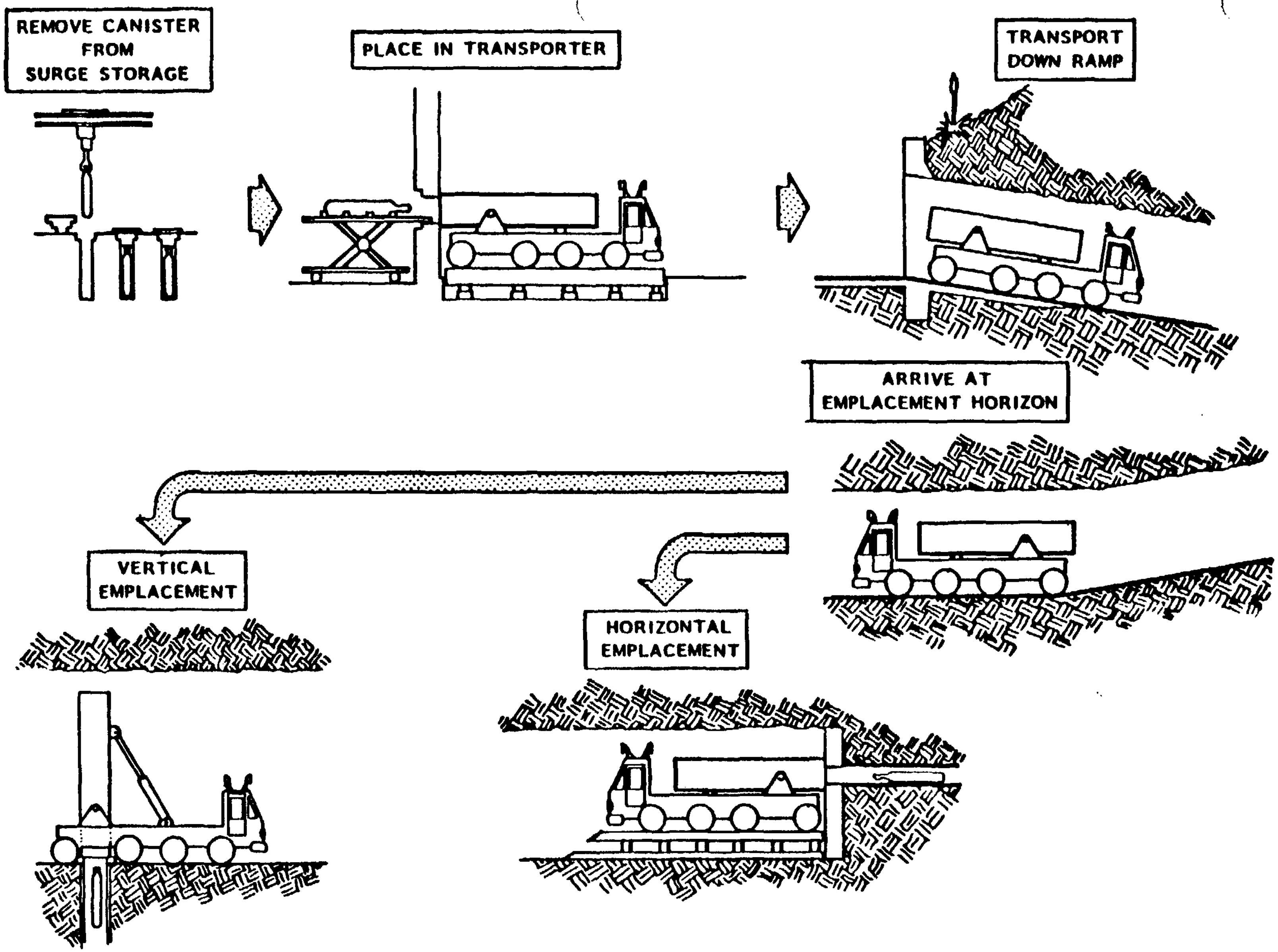


Figure 3-8. Transfer of Waste Disposal Packages from Surface Storage to the Disposal Horizon

attached to the unloading port of a hot cell. The major steps in this operation are identified in Figure 3-9. If at any point during receiving operations inspections reveal anything unusual, the operations can be interrupted and the shipment can be placed in suspect storage until remedial measures can be implemented.

3.2.2 Surface Handling and Packaging Operations

Waste-handling and packaging operations begin when the shipping casks are opened and the spent fuel or canistered wastes are removed. These operations terminate when the waste disposal packages are placed in surface surge storage to await emplacement. The major steps in these operations for spent reactor fuel are shown in Figure 3-10. Figure 3-11 shows the waste-handling and packaging operations for high-level waste and canistered TRU waste.

It may be more cost-effective to consolidate spent fuel than to package and emplace intact fuel assemblies. It is assumed that fuel consolidation will reduce the number of disposal packages by a factor of 2 (Gregg and O'Neal, 1983). For example, if the intact fuel assemblies are consolidated, the fuel rods from six pressurized water reactor (PWR) assemblies will be placed in a single package rather than placing three intact fuel assemblies in a single package. The handling and packaging procedures depicted in Figure 3-10 show the disassembly of the intact spent fuel assemblies and the consolidation of the fuel rods from several fuel assemblies into a single disposal package. In order to determine the capital and operating costs for each spent fuel packaging method, the conceptual design must be sufficiently developed to establish equipment, facilities, and operations costs. The conceptual design will include the design and pricing of surface facilities and equipment, underground facilities and equipment, and the waste disposal packages for both consolidated and intact spent fuel assemblies.

3.2.3 Transfer to Underground

Access from the surface facilities to the disposal horizon will be provided by ramp. Canistered waste and TRU waste in drums and boxes will be loaded on transporter vehicles and driven down the ramp to the the disposal area. The reasons a ramp was chosen are given in Subsection 2.4.2.

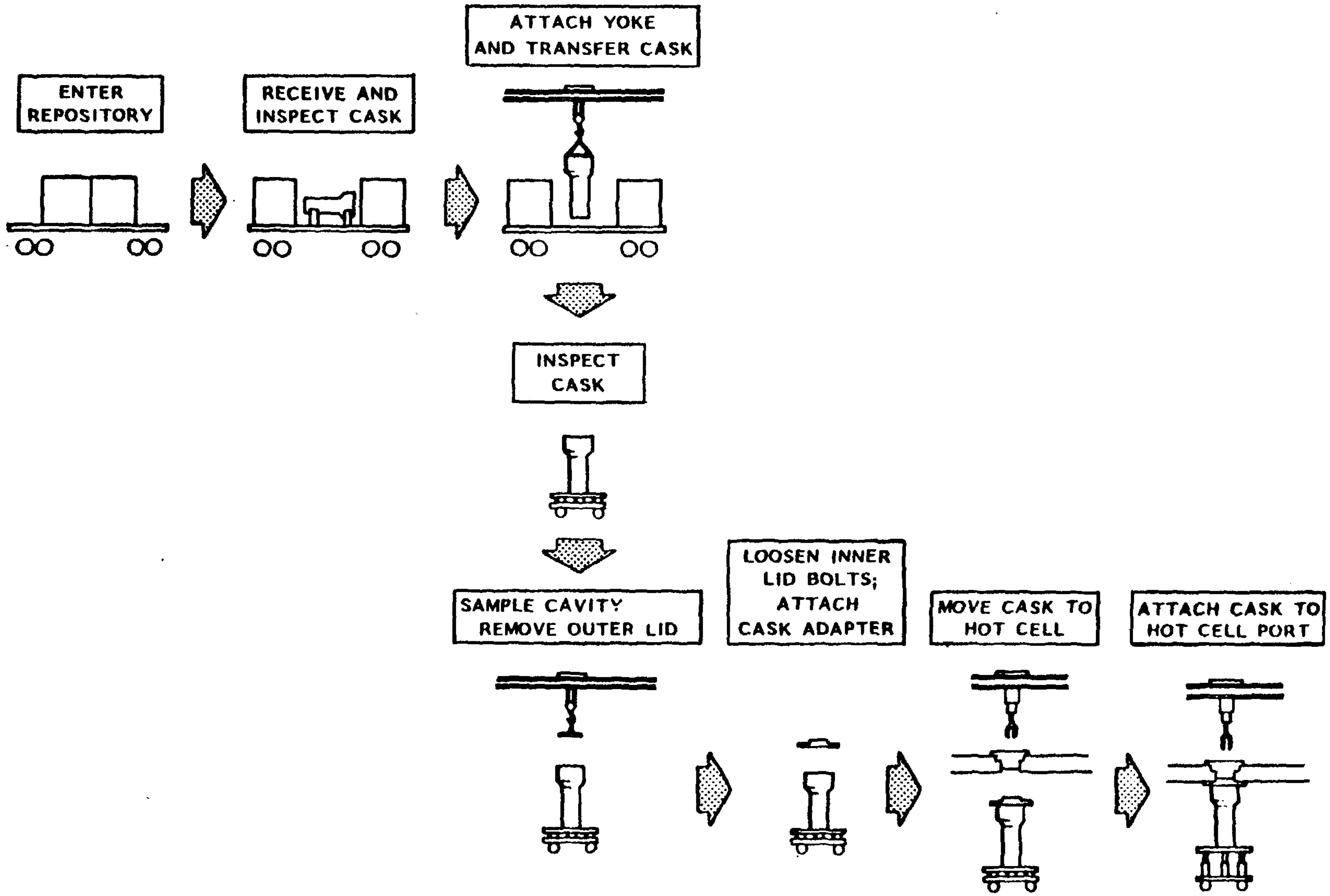
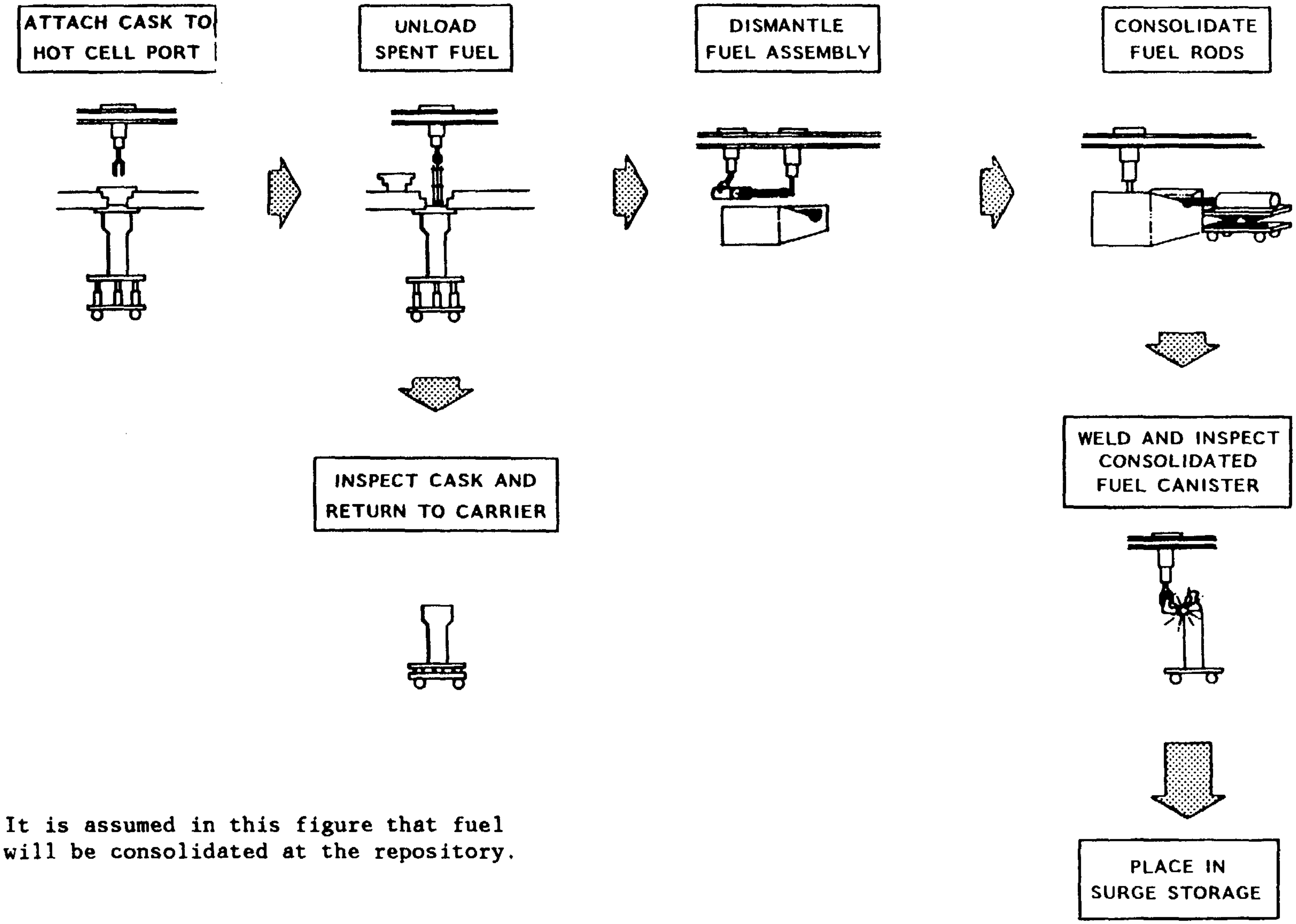


Figure 3-9. Receiving and Handling of Canistered Waste



Note: It is assumed in this figure that fuel will be consolidated at the repository.

Figure 3-10. Handling and Packaging Operations for Spent Fuel

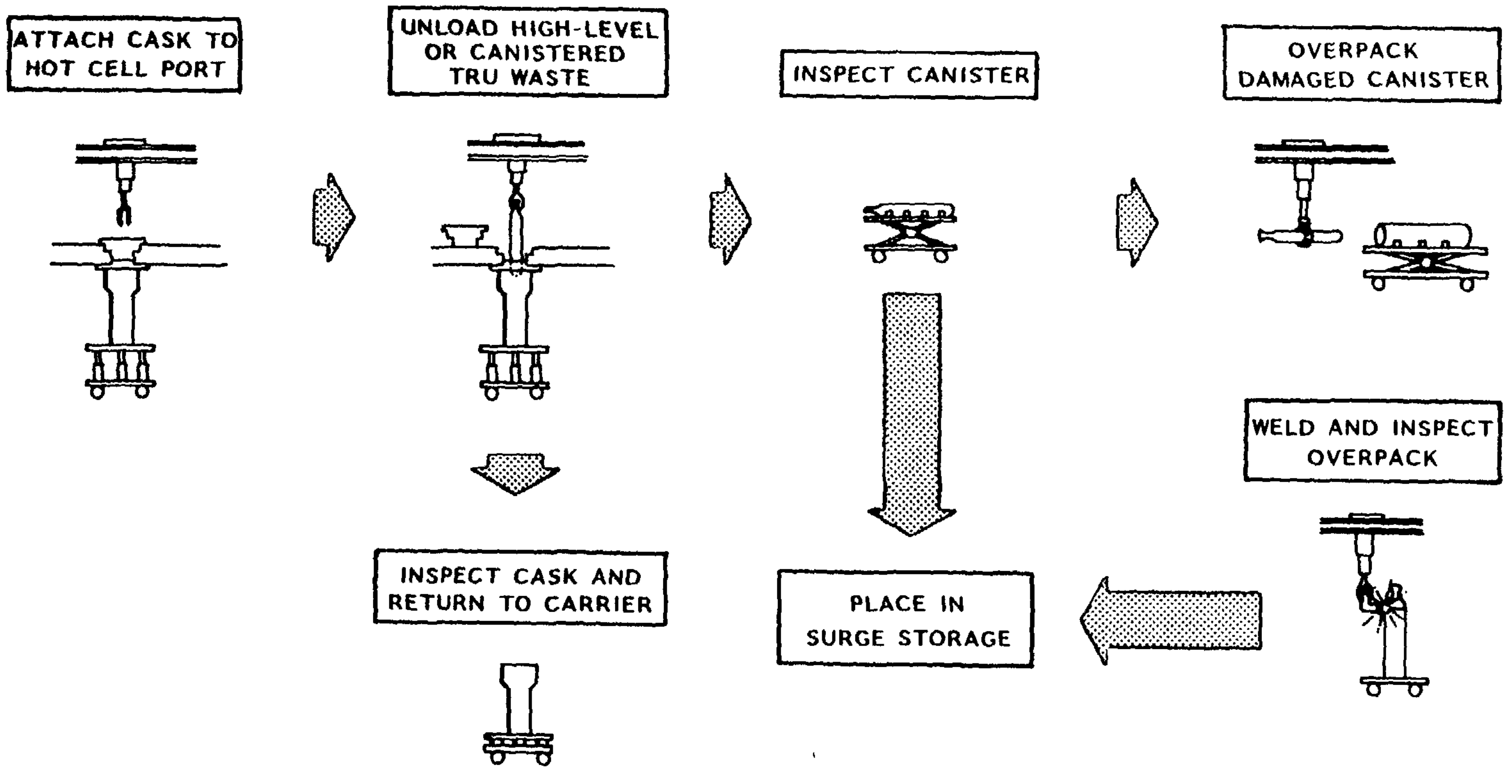


Figure 3-11. Handling and Packaging Operations for High-Level Waste and Canistered TRU Waste

3.2.4 Waste Emplacement Operations

Vertical Emplacement Operations

Two methods of waste emplacement are currently being developed. The reference method consists of emplacing the waste in vertical boreholes. In vertical emplacement, the waste package is driven down the access ramp in a facility cask mounted on a waste transporter. The transporter is driven to a borehole covered with a temporary shielding closure (Figure 3-4), and the transporter cask is upended and attached to the shielding closure. The cask lid and the shielding closure gate are moved horizontally until the passageway between the cask and the emplacement hole is unrestricted. Using the transporter hoist unit, the waste package is lowered until it contacts the bottom of the borehole. The cask lid and shielding closure gate are returned to a closed position. The empty cask is rotated back to the horizontal position, and the transporter returns for another waste package. A permanent shield plug is installed later by using the transporter hoist unit. The shielding closure is moved to the next vacant borehole. Emplacement of waste in the vertical method is illustrated in Figure 3-12.

Horizontal Emplacement Operations

In the alternate method, the waste is emplaced in long horizontal boreholes (see Figure 3-13). The transporter is driven to the emplacement hole with the waste package inside the facility cask.

Figure 3-14 shows the facility cask after it has been aligned and docked and the canister has been partially inserted in the borehole. The platform below the cask aligns and centers the cask, using the support rollers to locate the cask vertically and allow positioning fore and aft.

The cask lid is unlocked and removed. The lid is removed with two power screws mounted within the sides of the cask that move the lid axially from the cask and engage the cask lid with the temporary shielding closure. The shielding closure consists of an exterior gate and an exterior shielding housing. Once the lid has been positioned against the shielding closure, the

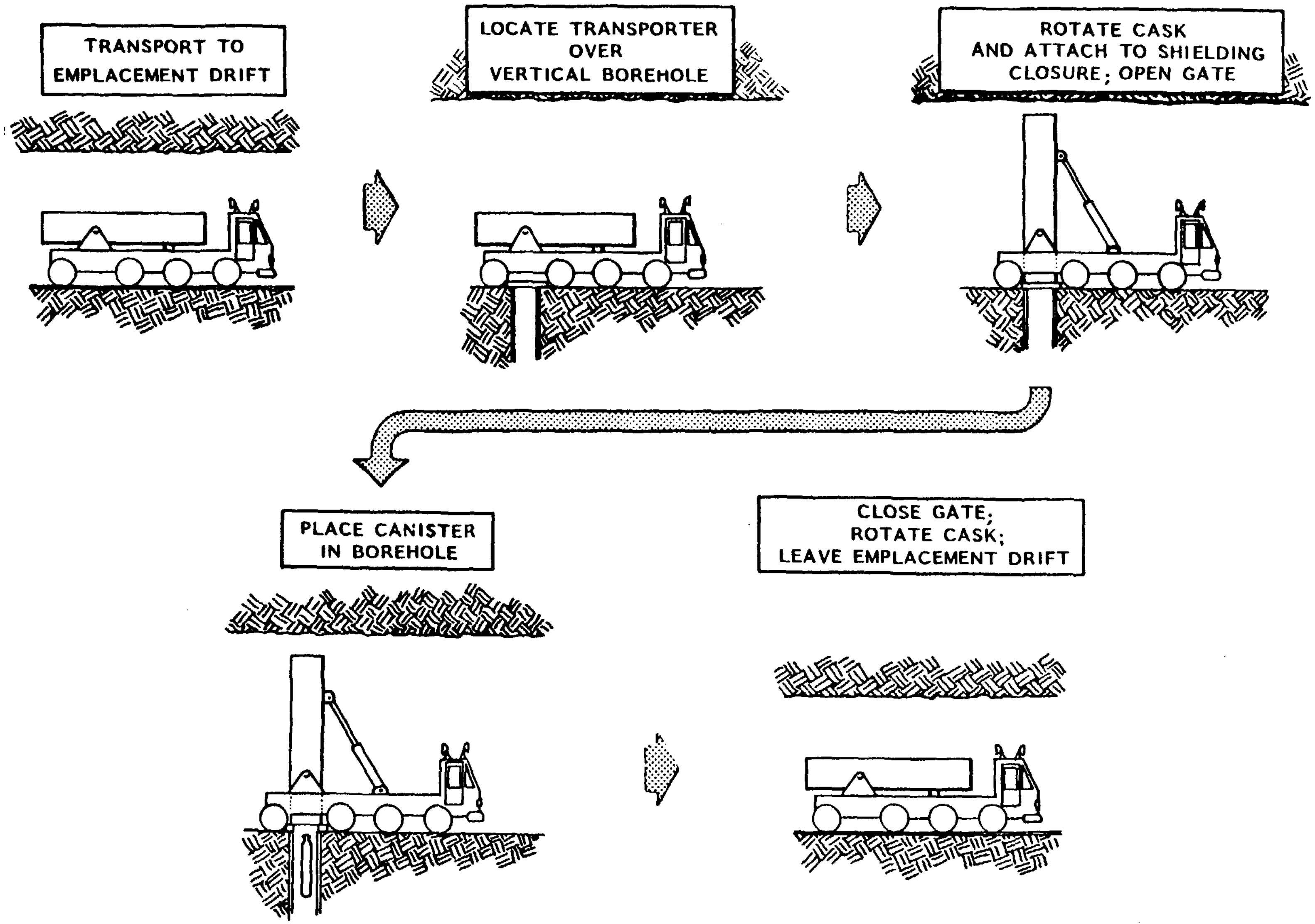


Figure 3-12. Emplacement of Waste in the Vertical Method

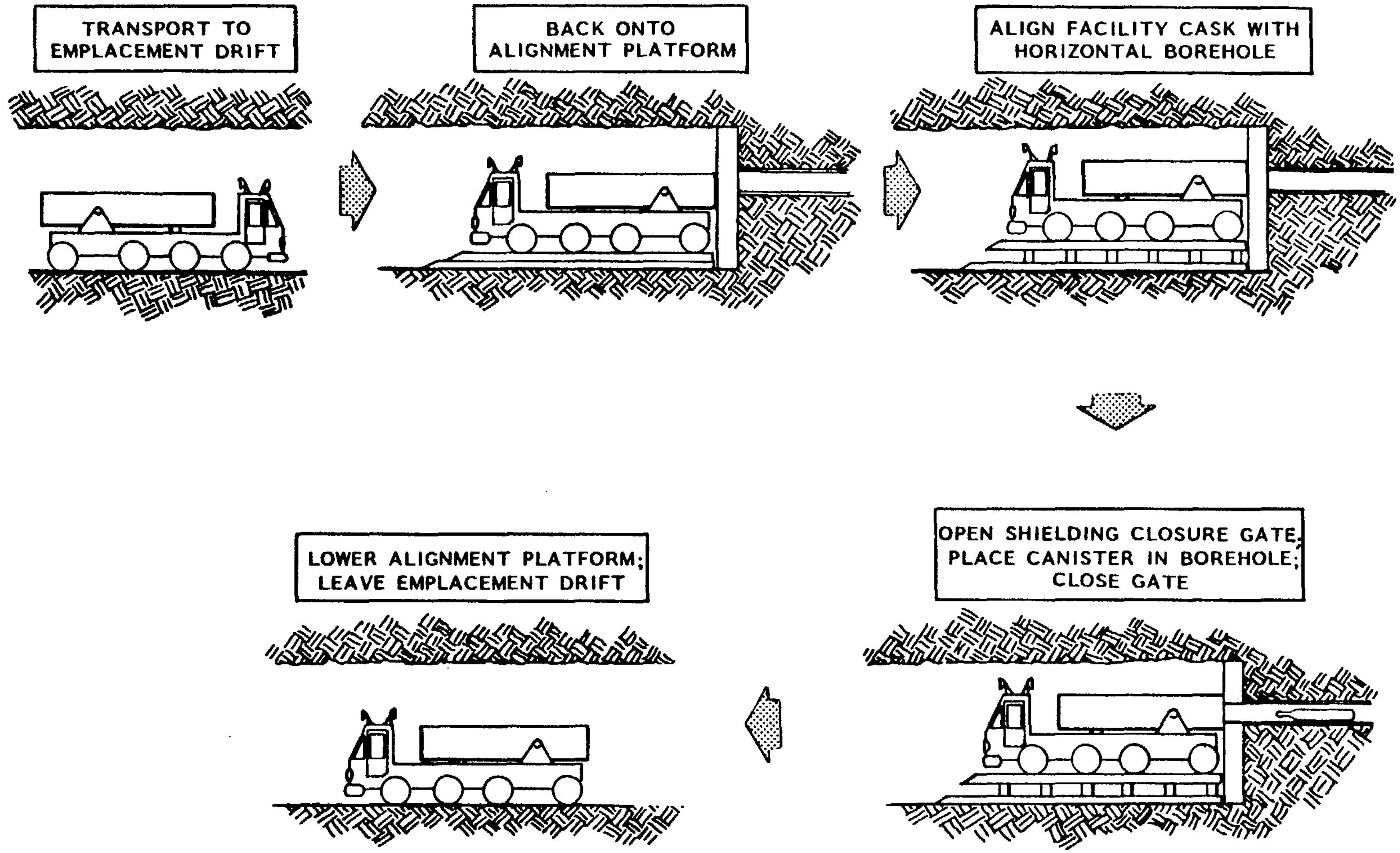


Figure 3-13. Emplacement of Waste in the Horizontal Method

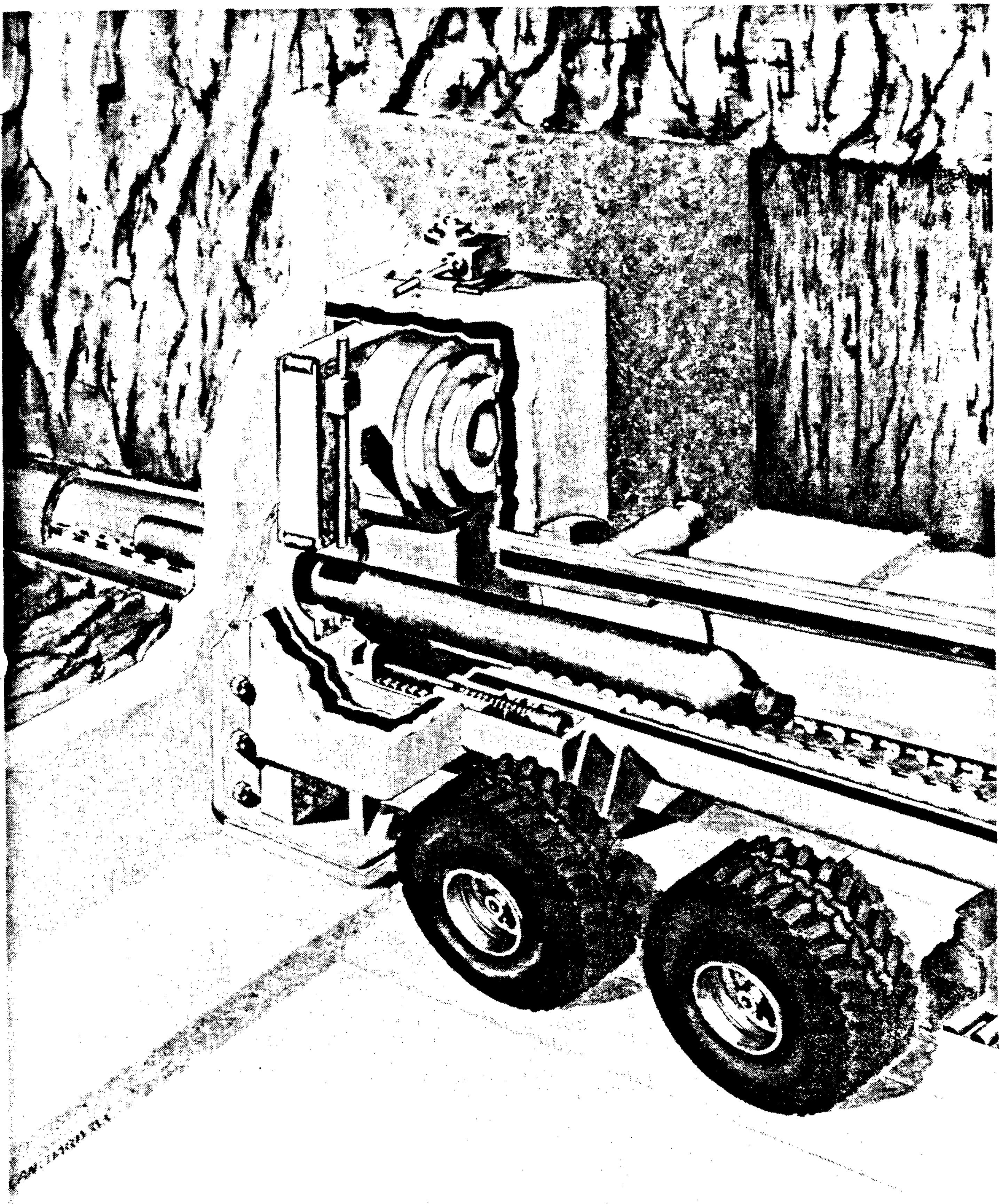


Figure 3-14. Emplacement of a Canister in a Horizontal Borehole

lid and the shielding closure are both raised by power screws inside the shielding housing and the gate is opened. At this point, no obstructions remain in the passageway between the cask and the mouth of the borehole. All drives are simple, single degree-of-freedom mechanisms.

Once the gate and cask lid have been opened, the canister can be transferred by activating the roller/conveyor within the facility cask. This conveyor moves the canister out of the cask, through the gate, and onto the in-hole powered roller system. Once the canister has been inserted into the hole about a foot, the gate and cask lid are closed by reversing the opening process. The transporter is then undocked and returns to the hot cell for another waste canister. Safety interlocks ensure that undocking cannot occur until both the gate and the cask lid have been closed.

Final emplacement of the canister is accomplished by activating the in-hole roller/conveyor. When a canister reaches its final location in the borehole [a distance of up to 213 m (700 ft)], it trips a single lever at the end of the conveyor section on which it is rolling. This lever allows the linkage to collapse, resting the canister on blocks beside the conveyor. This process continues until the hole has been filled with canisters, after which the in-hole conveyor is removed. Conveyor removal is accomplished by a separate machine that connects with the temporary shielding closure and retracts and decouples the entire string of conveyor sections.

The final operation is recovery of the temporary shielding closure and the docking/alignment platform. A permanently grouted shield plug is placed just inside the gate before this final operation. All emplacement hardware is used again at the next emplacement hole.

3.2.5 Waste Retrieval Operations

The repository will not be closed and sealed until the requirement for maintaining retrievability has passed.

Retrieval operations are divided into two categories: retrieval under normal conditions and retrieval under adverse conditions. Normal retrieval operations involve steps similar to those used in emplacement operations, but the sequence is reversed.

To retrieve the waste canister in the vertical emplacement method, the temporary shielding closure is installed (see Figure 3-4). The gate is opened, and a lifting device from within the waste transporter is lowered into the borehole. The canister is withdrawn into a shielded cask for removal from the underground area. The permanent shield plug is reinstalled in the empty borehole, and the temporary shielding closure is moved to the next borehole.

In the horizontal emplacement method, the steps are similar. When the gate is opened, the in-hole conveyor system used during the emplacement operations is reinserted in the borehole, and the canisters are withdrawn, one at a time, into facility casks.

Retrieval under adverse conditions (such as borehole collapse and ruptured or jammed canisters) may be necessary. Procedures are being developed to counter adverse conditions. These procedures may include removal of debris from emplacement holes or redrilling the borehole. Because the precise location of each waste package is recorded at the time of emplacement, drilling, even from adjacent drifts, will be possible if required by extreme conditions.

3.3 Waste Facility Requirements

3.3.1 Receiving Facilities

The receiving facilities are designed to accommodate approximately 2,000 truck and 1,000 rail shipments per year (Dennis et al., 1984a). Approximately 65% of all truck shipments and 40% of all rail shipments are expected to contain spent fuel and high-level waste packages. Assuming 250 operating days per year, the design basis for waste-receiving facilities is 8 truck and 4 rail shipments per operating day. This level of activity was determined using available information on the amount of waste received annually, the truck/rail shipment split, and the capacities of the shipping containers.

For example, the repository will receive 2,016 PWR assemblies per year (see Table 1-1). About 30% of these assemblies (600) will be shipped by truck, and 70% (1,416) will be shipped by rail (DOE, in preparation). It is assumed that truck casks have a capacity of 1 PWR assembly and that rail casks have a capacity of 12 PWR assemblies; therefore, the repository will receive 600 truck casks (1 assembly per cask) and 118 rail casks (12 PWR assemblies per cask) of PWR fuel each year. Similar calculations have been made for other types of waste.

The receiving facilities include (1) rail and truck inspection stations where both incoming and outgoing traffic are inspected, (e.g., radiation surveys, security inspections, and shipping document transactions), (2) a suspect parking area where incoming shipments that do not meet repository acceptance standards are held until remedial measures are taken, (3) a parking area for incoming and outgoing shipments, (4) a vehicle washdown facility, (5) a loading and unloading bay where the shipping packages are removed from and loaded onto their carriers, (6) a decontamination station where packages are checked and decontaminated, and (7) a station where cask closure(s) are prepared for connecting the casks to the hot cell port and for unloading.

3.3.2 <u>Handling and Packaging Facilities</u>

Facilities for Spent Fuel and High-Level Waste

The handling and packaging facility for spent fuel and high-level waste (HLW) are designed to accommodate 1,300 truck casks and 400 rail casks per year. At this time, it is believed that these facilities will consist of a cask preparation area, 2 hot cells for unloading HLW canisters, 2 hot cells for unloading spent fuel, 2 hot cells for consolidating fuel, 1 hot cell for packaging and inspecting waste, and a surface surge storage area sufficient to accommodate 150 HLW disposal packages.

Facilities for TRU Waste

The handling and packaging facilities for TRU waste are designed to accommodate 550 truck and 100 rail shipments of canistered TRU wastes annually. In addition, these facilities receive 650 shipments per year of TRU waste in drums and boxes. One hundred fifty shipments arrive by truck and 500 by rail. The TRU facilities consist of an area for unloading and preparing shipping packages and a surface surge storage area. Storage requirements for TRU wastes will be developed.

3.3.3 Access to the Disposal Horizon

As currently conceived, the surface facilities will be located approximately 2.2 km (1-1/4 mi) east of the point of access to the disposal horizon. Access for waste transfer to the disposal horizon will be provided by a ramp with a maximum grade of 10%. The ramp portal will be located close to the waste-handling building. The reasons a ramp access was chosen for waste transfer are given in Subsection 2.4.2.

3.3.4 Waste Emplacement Facilities

The size of the waste emplacement area is directly related to the total number of canisters of spent fuel, HLW, and TRU waste that must be emplaced. A canister emplacement rate of 10 canisters/day has been used during preliminary conceptual design studies. This daily rate is based on the annual receipt rates given in Table 1-1. However, these studies are continuing, and the required emplacement rate will change as the project evolves. Additional details on emplacement facility requirements are given by Dravo (in review, a; in review, b; in review, c) and Robbins (1984).

Vertical Emplacement Facilities

To achieve the desired canister emplacement rate in the vertical method, approximately 9,072 metric tons/day (10,000 tons/day) of rock must be mined. To sustain the required mining and emplacement rates, 500 miners and 50 waste emplacement personnel are needed. The extraction ratio for the underground excavations is about 23%, and the air required for underground ventilation to support both mine development and waste emplacement, excluding leakage allowances, is about 16,900 m^3/min (598,000 cfm). The total linear footage of vertical emplacement hole drilling is estimated at approximately 304,800 m (1,000,000 ft) (derived from Scully, 1983).

Horizontal Emplacement Facilities

To achieve the desired canister emplacement rate in the horizontal method, approximately 1,360 metric tons (1,500 tons/day) of rock must be mined, which requires about 150 miners and 50 waste emplacement personnel. The extraction ratio for the underground excavations is about 6%, and the air required for underground ventilation to support both mine development and waste emplacement, excluding leakage allowances, is about 12,300 m^3/min (433,000 cfm). The total linear footage of horizontal emplacement hole boring is estimated at approximately 182,890 m (600,000 ft) (derived from Scully, 1983).

In general, all of the underground facility requirements for vertical emplacement are significantly larger than those for horizontal emplacement, including requirements for water, power, mining equipment, drift maintenance, underground shops, conveyances, and shaft sizes.

A preliminary conceptual design cost comparison between mining costs for vertical and horizontal emplacement has been made (Dravo, in review, a; Scully et al., in review). The mining costs for vertical emplacement are estimated to be about three times higher than those for horizontal emplacement. This ratio could double if operating requirements and surface facility requirements for mining are included.

3.3.5 Waste Retrieval Facilities

If required, the facilities used for waste emplacement will also be used for retrieval. Maintaining retrievability for 50 yr after the first waste has been emplaced has a significant impact on the design and operation of the underground facility. Present estimates indicate that it will take about 25 yr to emplace all of the waste shown in Table 1-1. As a result, the entire facility must be designed so that it can be maintained in a standby mode for 25 yr after the last waste package has been emplaced. This standby period will permit the same amount of time for retrieval as was required for emplacement.

The preliminary concepts for the underground facilities have incorporated the features necessary to permit retrieval for 50 yr. In order to improve the long-term stability of the underground excavations, as little rock will be removed as possible. Analyses of the long-term stability of the underground excavations are continuing.

Another design feature that is important in meeting the 50-yr retrievability requirement is ventilation (see Subsection 3.4.3). A maximum drift temperature of 50°C (122°F) is being considered as a design criterion for the operating and retrieval periods. One method of keeping the temperature at or below 50°C (122°F) is continuous ventilation of all emplacement drifts from the time of emplacement to retrieval. Another method would be to use large volumes of air for cooling just before retrieval. Analyses of these approaches are continuing and will be completed during the conceptual design effort.

The design problems posed by the 50-yr retrievability requirement in the vertical emplacement method are different from those in the horizontal method. Because the vertically emplaced canisters are very close to the emplacement drift floor, the temperatures in the emplacement drifts will rise rapidly. Preliminary analyses show that if the vertical emplacement drift is not ventilated, the drift temperatures will increase to 50°C (122°F) after the waste has been emplaced for approximately 10 yr (Melo, 1983).

In the horizontal emplacement method, studies are being conducted to determine the length of standoff distance necessary to keep drift temperatures below 50°C (122°F) during the retrieval period without using ventilation. Preliminary results indicate that a standoff distance of 25 m (82 ft) to 35 m (114.8 ft) is sufficient for emplacement of spent fuel.

3.4 Ventilation Systems

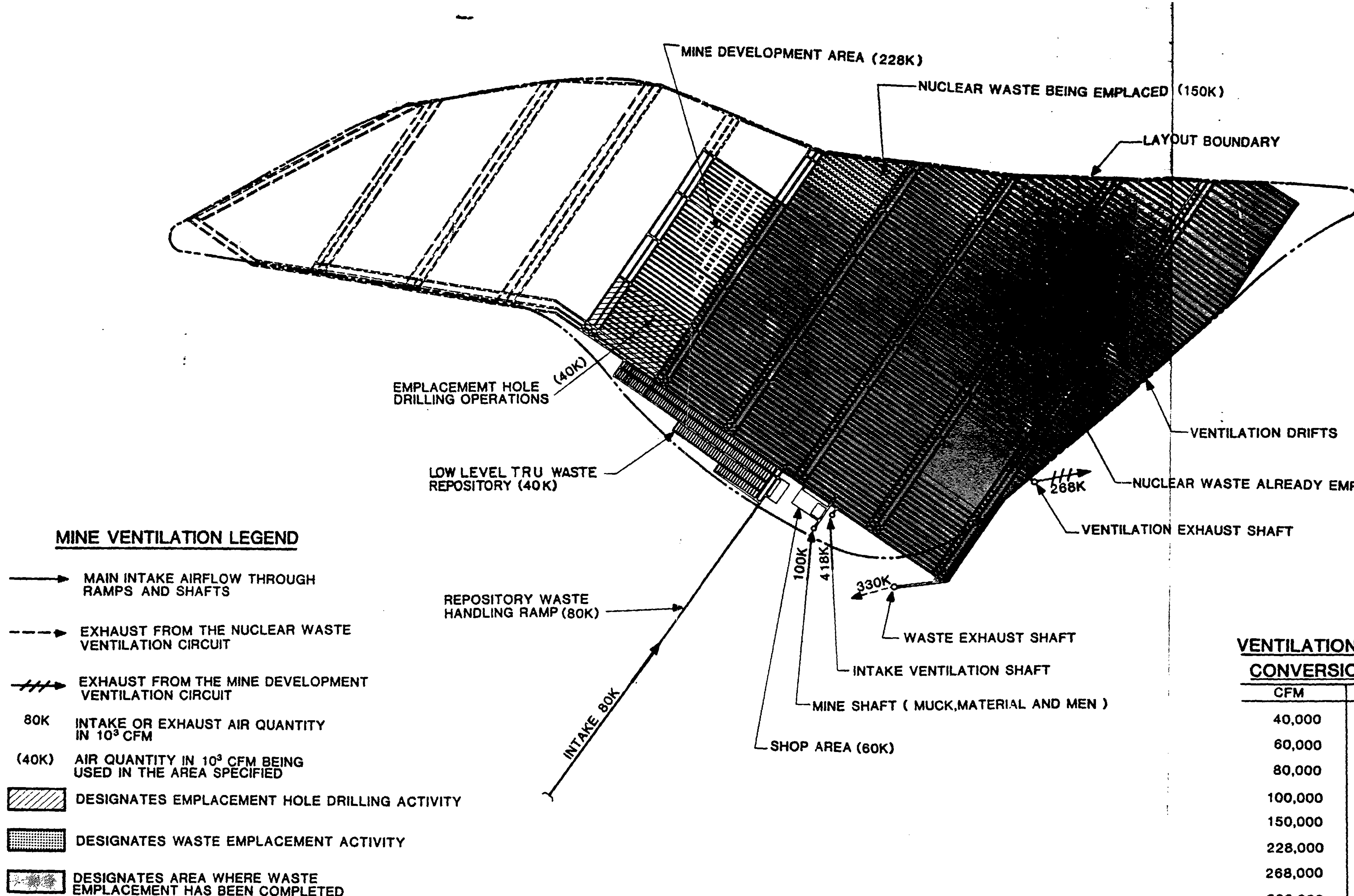
3.4.1 Waste-Handling Building Ventilation System

The waste-handling areas in the waste-handling building are serviced by both a primary and a secondary ventilation system. The primary ventilation system serves areas, such as hot cells, in which contamination potential is high; the secondary ventilation system serves areas such as the cask-receiving area in which contamination potential is low. Fan-and-filter trains that contain HEPA filters serve the primary system and provide conditioned air to the interior via sheet metal ducts. Both systems are maintained at a pressure less than atmospheric. The systems will be designed so that any leakage is channeled toward areas of successively higher contamination. Both primary and secondary exhausts are routed to the exhaust stack of the waste-handling building. Air flow, temperature, differential pressure, and monitoring and alarm functions are controlled both by local microprocessor units and by the process systems console in the main control room of the waste-handling building.

3.4.2 Ventilation for Mine Development and Waste Emplacement

Figure 3-15 is a diagram of the ventilation flow through the disposal horizon for the vertical emplacement method, and Figure 3-16 shows ventilation flow for the horizontal emplacement method. Details on these ventilation systems, which are based on personnel and diesel equipment requirements, are provided in a study on subsurface ventilation requirements (Dravo, in review, b). In both emplacement methods, the subsurface ventilation system consists of two separate ventilation circuits designed to allow mine development and radioactive waste emplacement operations to proceed simultaneously and independently.

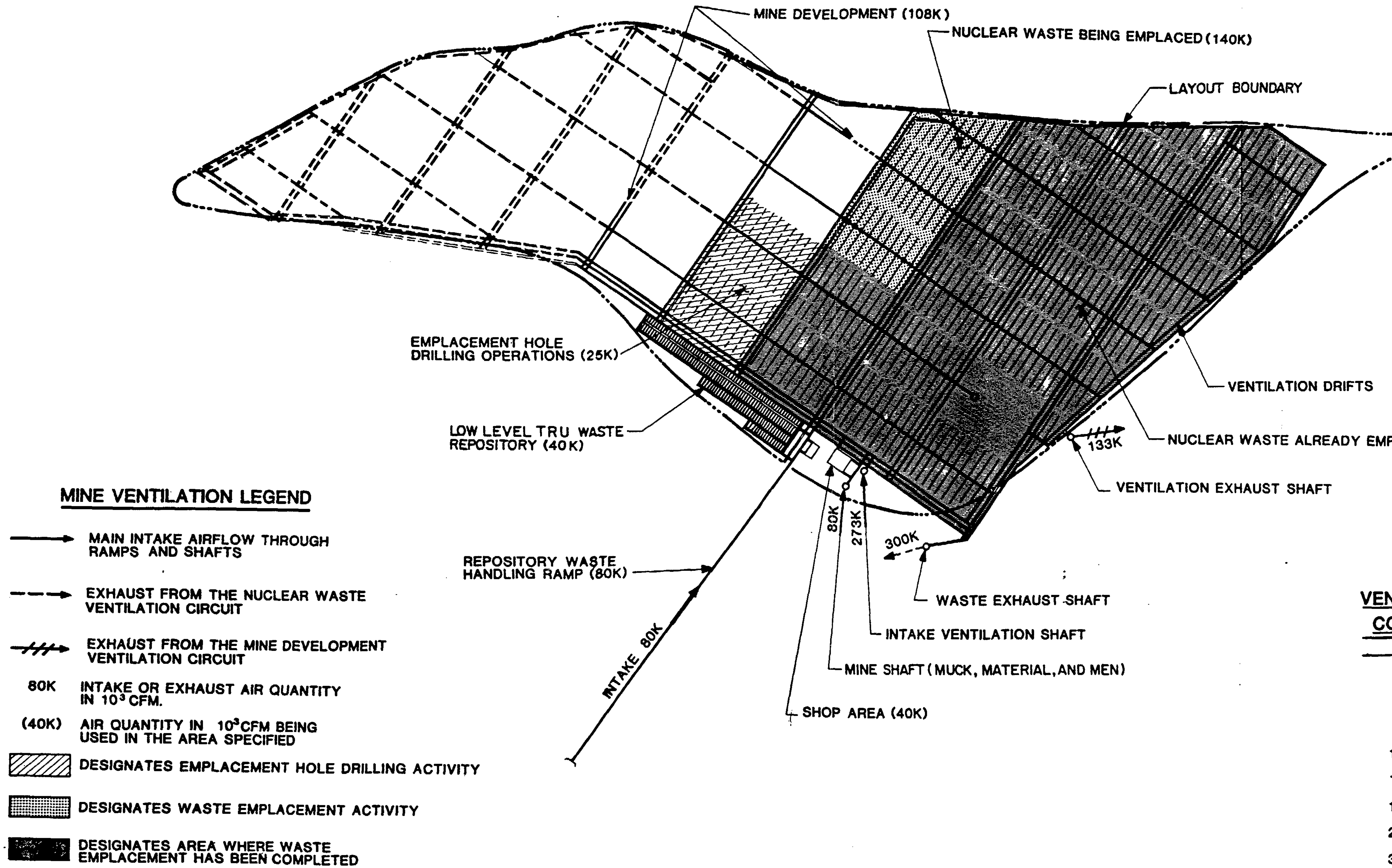
Dravo's analyses (in review, b) indicate that the intake air volume required in the mine development circuit is 7,590 m^3/min (268,000 cfm) for vertical emplacement and 3,767 m^3/min (133,000 cfm) for horizontal emplacement (excluding leakages) as shown in Table 3-1. A system of bulkheads, air locks, doors, regulators, and fans with ventilation ducting distributes the



VENTILATION QUANTITY CONVERSION TABLE

CFM	m³ / MIN
40,000	1133
60,000	1699
80,000	2266
100,000	2832
150,000	4248
228,000	6457
268,000	7590
330,000	9346
418,000	11,838

Figure 3-15. Ventilation Flow for Vertical Emplacement



VENTILATION QUANTITY CONVERSION TABLE

CFM	m³ / MIN
25,000	708
40,000	1133
80,000	2266
108,000	3059
133,000	3767
140,000	3965
273,000	7732
300,000	8496

Figure 3-16. Ventilation Flow for Horizontal Emplacement

air to the working faces. After ventilating the working faces, the air flows through the return airway to the mine development exhaust shaft.

TABLE 3-1

VENTILATION AIR REQUIREMENTS*

Phase	Vertical Emplacement m^3/min(cfm)		Horizontal Emplacement m^3/min(cfm)	
Mine Development	7,590	(268,000)	3,767	(133,000)
Emplacement Operations	9,346	(330,000)	8,496	(300,000)
	16,936	(598,000)	12,263	(433,000)
Continuous Ventilation after Waste Emplacement	31,300	(1,104,000)	18,400	(650,000)

* Excluding leakages.

In both emplacement methods, the second circuit provides ventilation air for all activities related to waste emplacement operations. This circuit services the TRU waste and HLW disposal areas separately. The ventilation air in the waste transportation ramp is directly exhausted to the waste exhaust shaft. It is desirable that the emplacement drifts be ventilated only during emplacement operations; however, it will be possible to restore ventilation for maintenance and retrieval operations.

The estimated fresh air required is 9,346 m^3/min (330,000 cfm) for vertical waste emplacement operations and 8,496 m^3/min (300,000 cfm) for horizontal waste emplacement operations if only the active emplacement drifts are ventilated (Dravo, in review, b). These volumes include the ventilation needed for the ramp and underground shops.

The possibility of continuously ventilating all emplacement drifts after the waste has been emplaced is being considered to help dissipate heat and to control buildups of naturally occurring contaminants such as silica dust and radon daughters. Ventilation requirements for control of natural contaminants are being investigated and will be incorporated in the conceptual design.

A study has been performed for both emplacement methods to determine the size of the ventilation systems needed to provide continuous ventilation to all emplacement drifts (Dravo, in review, b). Continuous ventilation after the waste has been emplaced in the vertical method will increase from a total of 16,936 m^3/min (598,000 cfm) for mine development and waste emplacement operations to 31,300 m^3/min (1,104,000 cfm), excluding leakages. For horizontal emplacement, the continuous ventilation requirements after emplacement of the waste will increase from a total of 12,263 m^3/min (433,000 cfm) to 18,400 m^3/min (650,000 cfm), excluding leakages. Ventilation quantities necessary for control of naturally occurring contaminants, including silica dust, radon daughters, and others, have not been factored into these requirements.

3.4.3 Ventilation During Retrieval

In the preliminary concepts, continuous ventilation is provided to all underground access drifts. These access drifts are inspected and maintained periodically to keep the drifts in a safe and stable condition so that they are ready for use should retrieval be required. It is also possible to restore ventilation in the emplacement drifts to allow periodic inspection and maintenance. Consideration is being given to providing continuous ventilation or blast cooling in all emplacement drifts to maintain acceptable temperatures should retrieval be required. Ongoing studies and analysis will provide data on whether continuous ventilation or blast cooling of emplacement drifts is necessary (Dravo, in review, b; Hickox, 1983).

The ventilation system for retrieval operations is similar to that for waste emplacement operations. Ventilation is supplied to the drift from which waste is being retrieved. Once fresh air has ventilated these areas, it is directed to the exhaust shaft in the disposal area. Employees will not normally work downstream of retrieval operations. If radioactive particulates should be released during retrieval operations, the HEPA filters in the filter building on the surface will collect the particulates before discharging this ventilation air to the atmosphere. The detailed requirements for the ventilation system during retrieval will be established during the conceptual design phase.

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4.0 CONCEPTS FOR THE FINAL CLOSURE OF THE REPOSITORY

Preliminary concepts for the final closure of the repository assume that it takes approximately 25 yr to emplace the waste. The repository may then be maintained in a "standby" mode for another 25 yr until a final decision has been made on whether to retrieve the waste. It is assumed for the purposes of this discussion that the waste is not retrieved. Whether or not retrieval occurs, all ramps and shafts are backfilled and the surface facilities decommissioned as part of final closure.

4.1 Repository Standby Period

All repository systems and waste records are maintained during the standby period so that, should it become necessary to retrieve the waste, retrieval operations can be started without delay. Any contaminated areas, either underground or on the surface, are decontaminated to levels required by contemporary standards.

4.2 Sealing of Shafts and Ramps

The main reason for sealing in both ramps and vertical shafts is to prevent water from entering the waste disposal areas through these openings. The preliminary sealing and backfill concepts discussed here are based on studies by Fernandez and Freshley (in review). An important goal is to design and then demonstrate the performance of seals, backfill, and plugs.

It is important to understand the geohydrologic setting of Yucca Mountain when designing sealing components. Two types of water flow are considered typical at Yucca Mountain: (1) matrix (equivalent porous) flow in nonwelded zeolitized, argillized, and vitric tuffs and (2) fracture flow in densely welded, highly fractured tuffs. It is assumed that groundwater flow in the unsaturated zone is vertical and that the flow is small [less than 1.0 mm/yr (0.04 in./yr)]. The distribution of matrix or fracture flow in the vertical direction is the primary concern in developing the preliminary concepts of sealing components. Generally, flow in excess of about 1.0 mm/yr (0.04 in./yr) travels through fractures in the densely welded and zeolitic tuff units (Sinnock et al., in review).

Figure 4-1 shows the components of the sealing system for the shaft. The upper portion of the sealing system, including the cover, the construction liner, the core material, and the anchor-to-bedrock plug/seal, is called the surface barrier. The cover at the top of the surface barrier bears a descriptive marker advising that a filled shaft is located below. The construction liner consists of a reinforced concrete liner inside a steel liner supported by ring beams. A core material, which has a permeability less than or equal to the effective permeability of the surface stratigraphic unit, is placed between the shaft cover and anchor-to-bedrock plug/seal. This plug/seal provides structural support for the material above, thereby preventing settlement and inhibiting preferential flow of water into the shaft.

At final closure, any equipment in the shaft is removed, and the shaft interior below the surface barrier is filled with a coarse, unreactive material such as crushed tuff. Shaft fill material can be graded to minimize settlement. If acceptable settlement control cannot be achieved in this manner, additional settlement plugs can be emplaced at intervals. These settlement plugs should have an adequate mechanical strength to provide the necessary support for the fill immediately above. Moreover, the settlement plugs should be designed so that water can pass to the bottom of the shaft. These design features convert the shaft to a large drain that permits incoming water to bypass the disposal horizon and to drain through the highly fractured tuff at the base of the shaft.

There are no indications of perched water in the nonwelded tuff above the Topopah Spring Member; therefore, no special precautions are needed to prevent water from entering a shaft. However, if water should be encountered, a shaft might facilitate water drainage, potentially reducing groundwater movement through the underground workings.

If necessary, a massive plug could be installed at the intersection of horizontal drifts and vertical shafts to control settlement of shaft fill. In addition, it may be desirable for this plug to have a high permeability to permit drainage from the horizontal drift to the shaft. To improve the draining functions of the shaft, the concrete liner should be removed from the junction of the shaft and the access drift to the bottom of the shaft.

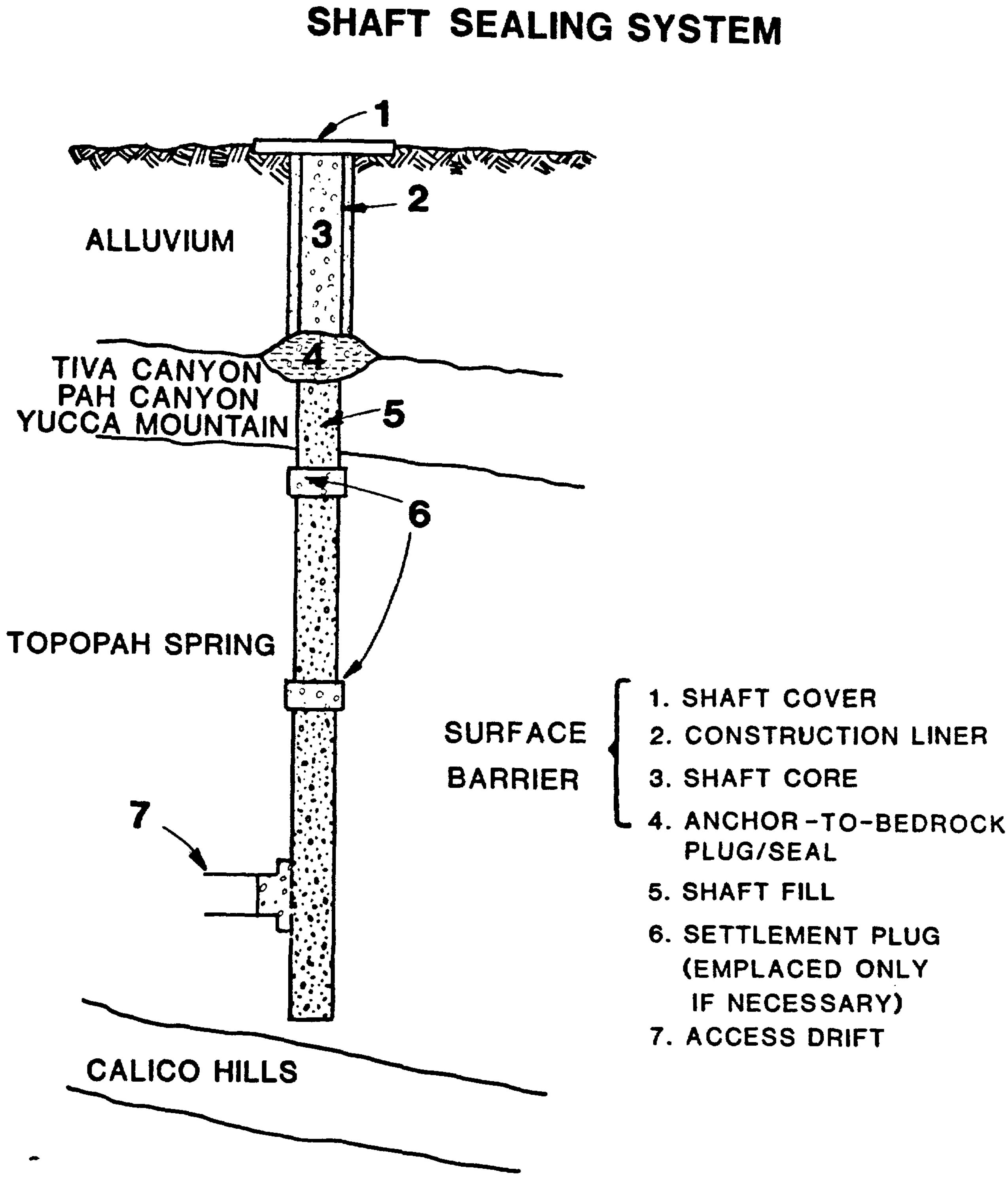

Figure 4-1. Shaft Collar Seal

The concepts for sealing ramps are similar to those for sealing vertical shafts. If necessary, most of the space in the ramp is filled with crushed tuff. The major difference may be the installation of dams at intervals to divert water inflow. However, because any water that drains into the ramp is expected to drain rapidly through the floor of the ramp, these dams are considered redundant design features, and the need for and number of dams will be evaluated. Any dam constructed should span the entire ramp cross section and extend into the rock around the opening. Should a discrete fault/fracture yielding a continuous supply of water be encountered during the excavation of a ramp, a seal designed for discrete fractures in horizontal drifts could be installed.

4.3 Backfilling of Drifts and Emplacement Boreholes

Equivalent porous-flow analyses indicate that no backfill is necessary in either the access or emplacement drifts to reduce contact of wastes with groundwater. If excavated tuff on the surface requires disposal, then some of this material may be used to backfill the emplacement and access drifts.

It may be desirable to prevent groundwater originating from discrete fault systems from contacting waste canisters. If groundwater flow is small, dams made of concrete or other suitable material can be placed on either side of the fault zone in the floor of the drift. Additionally, a trough can be excavated in the drift floor to collect water, or drains can be constructed in the floor of the drift. If the volume of flow is large, the fault zone can be sealed off entirely (e.g., by grouting), thus restricting the flow of water into the drifts.

Currently, the backfilling of vertical boreholes to isolate water from the waste canisters does not appear necessary. Placing waste canisters away from water-bearing faults or fractures is one means of minimizing contact between water and waste disposal packages. Investigations of how to minimize the amount of water that enters a horizontal borehole are being conducted.

4.4 Sealing of Exploratory Boreholes

Three types of exploratory boreholes are located in the disposal area:

- shallow boreholes that require no special sealing;
- relatively deep boreholes in the saturated zone up-gradient from the proposed disposal area that require no special sealing; and
- boreholes that may require special sealing because they could enhance the transport of radionuclides to the accessible environment.

Because the number and size of the exploratory boreholes in the third category are extremely small, it is difficult to create a reasonable and factually based scenario in which a significant number of radionuclides is released through exploratory boreholes. However, it is tentatively recommended that the casing be left in the exploratory borehole unless the borehole is in contact with the Tuffaceous Beds of the Calico Hills. The exploratory boreholes that penetrate the Calico Hills Unit and the zone immediately below should be sealed with a grout, slurry, or tamped substance possibly containing zeolites or other sorptive materials. To provide support for material placed in these zones, a plug may have to be installed below the sealed zone. Below this plug, standard well-plugging procedures should be followed. Above the seal proposed for the interval penetrating the Calico Hills Unit, a granular material may be used; however, because water inflow into an exploratory borehole will probably be negligible, grouting would also be acceptable.

Additional components include settlement plugs that can be emplaced if needed. Also, a borehole cover should be used as a marker to indicate the presence of a borehole.

4.5 Decommissioning of the Surface Facilities

At the end of the standby period, the surface facilities will be decommissioned. The surface facilities will be decontaminated to meet contemporary standards, and permanent markers will be erected advising that the surface facilities were once part of a repository for radioactive waste.

Records showing the location and quantities of waste emplaced will be preserved in appropriate archive(s) (NRC, 1983; DOE, 1983). Other precautions will be considered during the conceptual design phase to minimize monitoring and maintenance.

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APPENDIX A

ENGINEERING STUDIES FOR THE DESIGN BASES

This appendix summarizes the engineering studies that are being conducted to describe in greater detail the design bases presented in Section 1. The design bases are the principal determinants that establish the overall design of the repository--(1) the radioactive waste and (2) the repository site at which the waste will be emplaced. Included in this appendix are additional data and calculations to support the design basis during the conceptual design phase.

The objective of the waste characterization studies described in Appendix A.1 is to further define the types, quantities, receipt rates, and characteristics of the radioactive waste that will be emplaced at the repository.

The objective of the engineering study of the physical model of Yucca Mountain summarized in Appendix A.2 is the collection and interpretation of the physical data gathered during site characterization and geologic unit selection activities. The geologic and hydrologic data needed for repository design are being compiled in a data management system that includes a three-dimensional computer graphics capability.

A.1 Waste Characterization

Characterization of wastes is fundamental to the design of waste-receiving facilities and waste-handling equipment and to the development of mining and waste emplacement schedules. Ongoing studies are providing details of waste characteristics, and the waste descriptions are modified as the program evolves. The waste forms listed in Table 1-1 on p. 1-3 are described in more detail below. The order of description follows Table 1-1. Current waste package descriptions and constraints are given in Lawrence Livermore National Laboratory documents (Gregg and O'Neal, 1983).

.1 Spent Fuel

Spent fuel, which will probably be shipped to the repository as intact fuel assemblies, is the only waste type that will be received in a configuration different from that of the actual disposal package. The waste-receiving facilities may include a special hot cell (or cells) in which individual fuel rods are removed from the assemblies and consolidated in stainless steel canisters designed specifically for the Nevada Nuclear Waste Storage Investigations (NNWSI) repository.

It is assumed in the June 1983 draft of the mined geologic disposal system (MGDS) planning base document (DOE, in preparation, a) that spent fuel will be received at the repository at the rate of 1,500 MTU/yr. Sixty-two percent of the spent fuel (930 MTU/yr) will come from pressurized water reactors (PWRs), and 38% (570 MTU/yr) will come from boiling water reactors (BWRs).

The present plan is to use canisters of different diameters for PWR and BWR fuel rods. If canisters containing spent fuel are damaged, they will be returned to the waste-handling facility where the fuel rods will be repackaged.

It is assumed that PWR spent fuel has the following characteristics:

- 3.2% fresh fuel enrichment;
- 32,717 MWd/MTIHM (megawatt-days/metric ton of initial heavy metal) burnup;
- 38.4 MW(t) [megawatts (thermal)]/MTIHM specific power;
- 3 separate irradiation periods of 284 days, each irradiation period separated by a decay period of 106 days to allow for reactor downtime;
- burnup, specific power, and irradiation history based on assumptions in a reference definitions document for commercial high-level waste (CHLW) and canisters (Slate et al., 1981);
- 10 yr out-of-reactor at the time of emplacement in the repository; and

- other input compositions as defined in the PWR model developed for the ORIGEN code (Croff et al., 1978).

It is assumed that BWR spent fuel has the following characteristics:

- 2.75% fresh fuel enrichment;
- 27,500 MWd/MTIHM burnup;
- 25.9 MW(t)/MTIHM specific power;
- 4 separate irradiation periods of 265 days, each irradiation period separated by a decay period of 106 days to allow for reactor downtime;
- 10 yr out-of-reactor at the time of emplacement in the repository; and
- other input compositions as defined in the BWR model developed for the ORIGEN code (Croff et al., 1978).

C. Alexander at Oak Ridge National Laboratory has calculated the thermal power of PWR and BWR spent fuel as a function of time after emplacement by using ORIGEN2 and the assumed characteristics listed above. For use in thermal and thermal/structural computer codes requiring analytic functions for thermal power, the following thermal power decay functions result for spent fuel (Scully, 1983):

$$P(t)_{PWR} = 508.5\ [0.77e^{-0.027t} + 0.20e^{-0.0021t} + 0.025e^{-0.000053t}] \quad \text{(Equation 1)}$$

$$P(t)_{BWR} = 166.7\ [0.77e^{-0.027t} + 0.20e^{-0.0021t} + 0.025e^{-0.000053t}] \quad \text{(Equation 2)}$$

where the thermal power, $P(t)$, has units of watts/assembly, and time after emplacement, t, is in units of years. The PWR equation has an average error of 10% in reproducing the ORIGEN2 data for the first 50,000 yr. The average error of the BWR equation is 7%. Curve fits for these functions are illustrated in Figure A-1 (Scully, 1983).

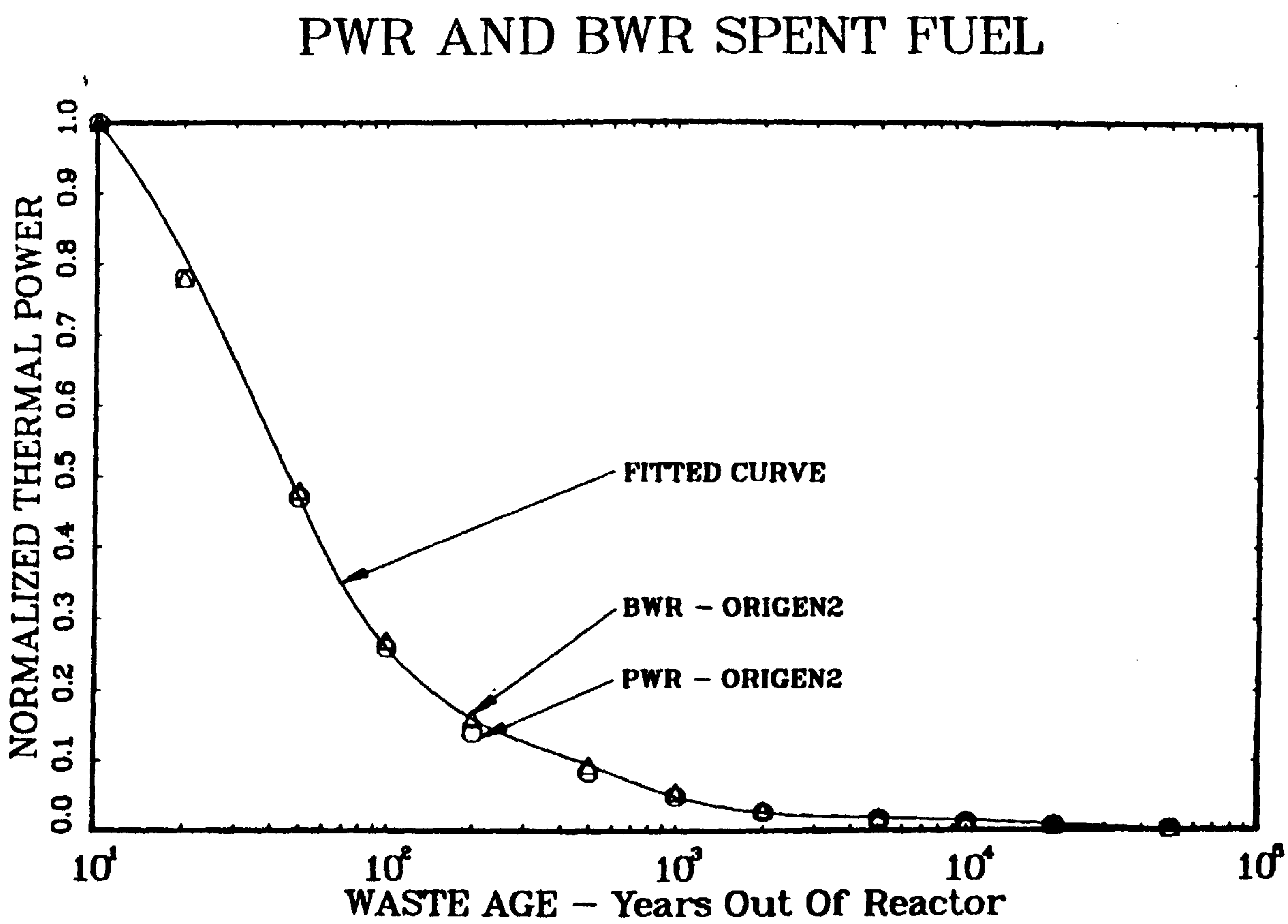

Figure A-1. Normalized Thermal Power Curve Fit for PWR and BWR Spent Fuel (10 Yr Out-of-Reactor)

A.1.2 Cladding Waste

Cladding waste (hulls) is a byproduct of spent fuel reprocessing and will arrive at the repository in canisters. The reference NNWSI cladding waste package is different from that indicated in the draft MGDS planning base document in two significant ways: (1) a 0.61-m- (24-in.-) diameter canister [similar to the defense high-level waste (DHLW) canister to be used at the proposed Savannah River Defense Waste Processing Facility (DWPF)] replaces the Allied General Nuclear Services (AGNS) 2,271-ℓ (600-gal) drum (Darr, 1983), and (2) it is assumed that the cladding hulls are compacted (with a 2:1 volume reduction ratio), whereas no compaction is assumed in the MGDS planning base. Cladding waste packages have low thermal power (approximately 68 W).

The change in canister size was made because (1) the AGNS 2,271-ℓ (600-gal) drum probably cannot be transported in a legal-weight truck (LWT) cask; (2) based on planned handling operations at the repository, the drum, as currently designed, would not survive a drop test, and (3) the drum size, as currently designed, creates waste-handling problems at the repository. It is anticipated that hull compaction may be cost-effective. The recent AGNS report (Darr, 1983) on waste model characterization indicates that the assumed 2:1 volume reduction ratio is achievable.

A.1.3 Spent Fuel Hardware Waste

If spent fuel is consolidated at the repository, the spent fuel hardware, including nozzles, spacer grids, and end plates that result from fuel rod packaging operations, will be placed in separate canisters from those used for the fuel rods. The canisters for spent fuel hardware waste are assumed to be equal in size to those used for DHLW (see Table 1-1).

A.1.4 Commercial High-Level Waste (CHLW)

MGDS planning base data for CHLW are taken from a report prepared at Battelle Pacific Northwest Laboratory (Slate et al., 1981). The waste form consists of actinide and fission product oxides and activation products (about 30 weight percent) immobilized in a matrix of borosilicate glass (about 70 weight percent). The reference receipt rate is 1,500 MTU/yr, which is equivalent to the output from one reprocessing plant the size of the Barnwell Nuclear Fuel Plant. Secondary wastes from such a plant include cladding waste and transuranic (TRU) waste.

The diameter of the CHLW canister is determined by the thermal properties of the waste package, by the surrounding heat transfer conditions, and by the temperature at which glass devitrifies [about 500°C (932°F)]. The reference CHLW canister is 0.32 m (12.75 in.) in diameter, 3 m (118 in.) in length, and contains the vitrified high-level waste (HLW) that results from the reprocessing of 2.28 MTU of spent fuel.

It is assumed that the PWR CHLW has been derived from PWR spent fuel described on page A-2 and that

- spent fuel is reprocessed 10 yr after discharge from the reactor;
- the resulting CHLW is emplaced in the repository 10 yr after discharge from the reactor;
- the following fractions of PWR spent fuel nuclide inventory are contained in the PWR CHLW:
    - 0.005 of the uranium and plutonium;
    - 0.995 of all other heavy metals;
    - 0.0 of the tritium, krypton, and xenon;
    - 0.001 of the fluorine, chlorine, bromine, and iodine;
    - 0.995 of the other fission products;
    - 0.0 of the oxygen;
    - 0.995 of the activated fuel impurities.

It is assumed that BWR CHLW has been derived from BWR spent fuel described on page A-3 and that

- spent fuel is reprocessed 10 yr after discharge from the reactor;
- the resulting CHLW is emplaced in the repository at this same time;
- the following fractions of BWR spent fuel nuclide inventory are contained in the BWR CHLW:

- 0.005 of the uranium and plutonium;
- 0.995 of all other heavy metals;
- 0.0 of the tritium, krypton, and xenon;
- 0.001 of the fluorine, chlorine, bromine, and iodine;
- 0.995 of the other fission products;
- 0.0 of the oxygen;
- 0.995 of the activated fuel impurities; and
- 0.0 of the structural material.

C. Alexander at Oak Ridge National Laboratory has calculated the thermal power of PWR and BWR CHLW as a function of time after emplacement by using ORIGEN2 and the assumed characteristics listed above. For use in thermal and thermal/structural computer codes requiring analytic functions for thermal power, the following thermal power decay functions result for CHLW (Scully, 1983):

$$P(t)_{PWR} = 984.3\ [0.088e^{-0.26t} + 0.85e^{-0.024t} + 0.068e^{-0.0015t} + 0.00068e^{-0.000037t}] \quad \text{(Equation 3)}$$

$$P(t)_{BWR} = 808.7\ [0.088e^{-0.26t} + 0.85e^{-0.024t} + 0.068e^{-0.0015t} + 0.00068e^{-0.000037t}] \quad \text{(Equation 4)}$$

where the thermal power, P(t), has units of watts (W)/MTU, and time after emplacement, t, is in units of years. The PWR equation has an average error of 9% in reproducing the data for the first 50,000 yr. The BWR equation average error is 7%. Curve fits for these functions are illustrated in Figure A-2 (Scully, 1983).

A.1.5 Defense High-Level Waste (DHLW)

The characteristics of DHLW have been included in the design basis in the event that these wastes are disposed in the repositories for commercial waste. The reference DHLW is based on the process flow sheet of the DWPF.

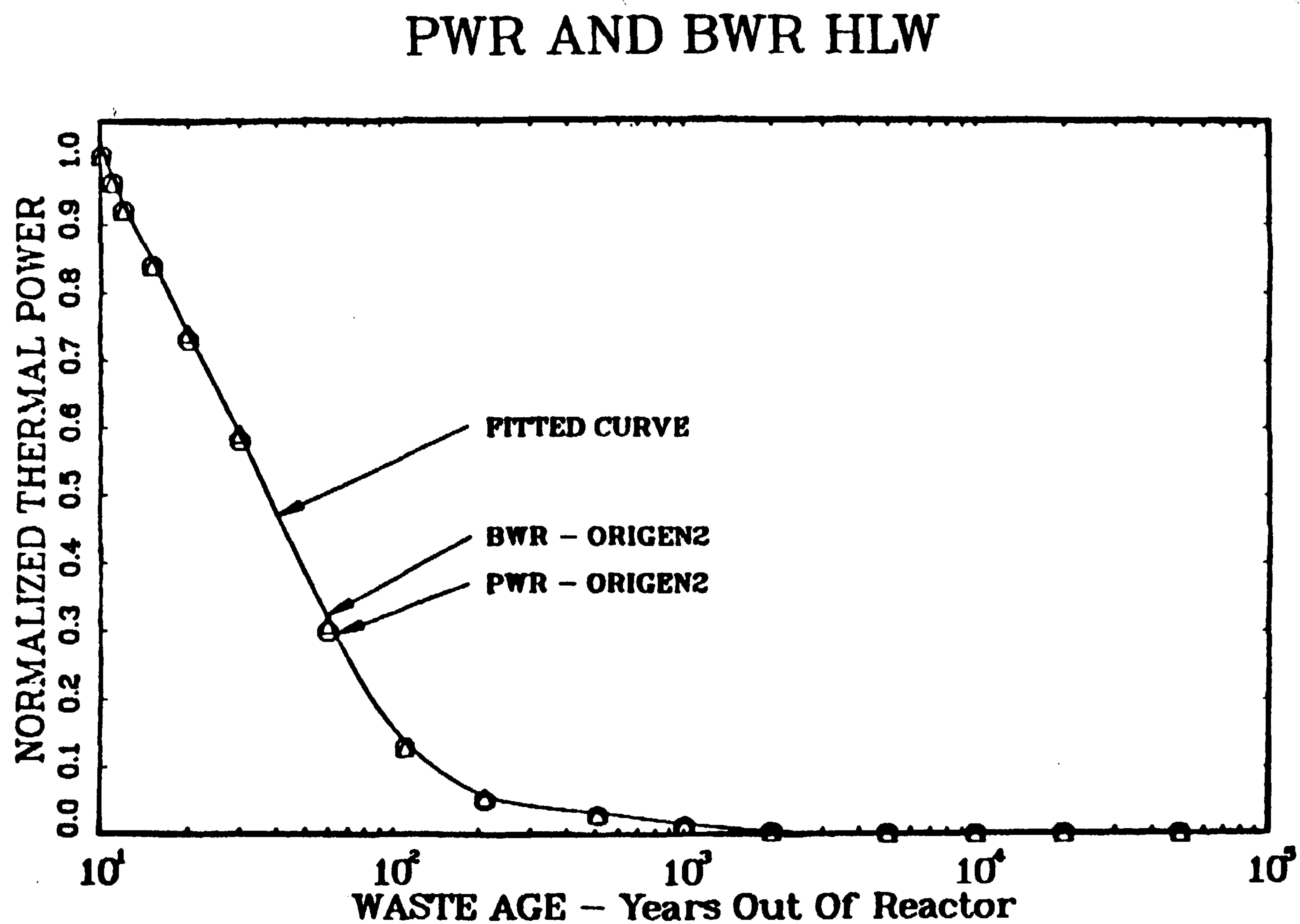

Figure A-2. Normalized Thermal Power Curve Fit for PWR and BWR High-Level Waste (10 Yr Out-of-Reactor)

It is likely that both Hanford Reservation and the Idaho National Engineering Laboratory will produce a less radioactive waste product whose characteristics may differ considerably from those of the DWPF waste.

The reference form for DHLW is actinide and fission product oxides and activation products immobilized in borosilicate glass; the waste loading is 28 weight percent. The thermal power density of DWPF DHLW is substantially lower than that of the reference CHLW, and the diameter of the DWPF canister, 0.61 m (24 in.), is correspondingly large. The length of the canisters for both DHLW and CHLW is 300 cm (118.1 in.). The estimated thermal power of a DWPF canister is 423 W (Baxter, 1983).

A.1.6 West Valley High-Level Waste (WVHLW)

No decisions or commitments have been made regarding the processing or packaging of West Valley high-level waste (WVHLW). It is assumed in this report, as in the MGDS planning base document (DOE, in preparation, a), that the waste form and canister will be similar to those proposed for DWPF DHLW. WVHLW will be less radioactive than DWPF DHLW. It is estimated in the MGDS planning base document that the thermal power of a single WVHLW canister will not exceed 300 W.

A.1.7 Transuranic (TRU) Waste

TRU waste is derived from two sources--spent fuel reprocessing and mixed-oxide (MOX) fuel fabrication. The AGNS report (Darr, 1983) provides the most authoritative data available for characterizing TRU waste from reprocessing. The June 1983 draft of the MGDS planning base document has been used to estimate the volume of TRU waste produced in MOX fuel fabrication (DOE, 1983).

In accordance with an AGNS recommendation, it is assumed that compactible TRU waste is compacted with a volume reduction ratio of 4:1 at the site where the waste is produced. This compaction results in an overall reduction ratio of about 3:1 for all TRU waste from reprocessing. It has been assumed that the same volume reduction is attainable for TRU waste from MOX fuel fabrication.

AGNS data show that only about 30 volume percent of the commercial TRU waste from reprocessing will exhibit a surface dose rate of less than 200 mrem/hr. One-half to two-thirds of the waste will have a dose rate greater than 10 rem/hr. Uncompacted TRU waste from MOX fuel fabrication is less radioactive, having a surface dose rate less than 10 mrem/hr (DOE, in preparation, a). However, even assuming a volume reduction ratio of 3:1, the volume of MOX TRU waste is 4 times as great as the volume of under-200-mrem/hr TRU waste from reprocessing. A large volume of above-200-mrem TRU waste may be handled at the repository. In the interest of minimizing the radiation dose to workers, it may be advantageous to handle all TRU waste by remote or semiremote (e.g., shielded fork-lift trucks) methods.

To facilitate handling, the radiation exposure level of the TRU waste may be the basis for package selection. It is assumed here that the under-200-mrem/hr waste will be packaged in metal boxes and drums and will be shipped in truck-sized transportation packagings. The over-200-mrem/hr waste will be packaged in metal canisters and shipped in shielded casks for truck rail shipment. It is assumed that the under-200-mrem/hr waste is divided evenly by volume between 6-packed 208-ℓ (55-gal) drums and 1.74-m (68-in.) × 1.37-m (54-in.) × 0.98-m (38.5-in.) boxes. It is further assumed that the over-200-mrem/hr waste is packaged in a 0.61-m- (24-in.-) diameter canister similar to that being developed by Rockwell Hanford Operations for defense TRU waste. These canisters are being designed to be compatible with the transportation and handling systems for DWPF DHLW.

A.2 Physical Model of Yucca Mountain

A.2.1 Background

An understanding of the physical setting in which the disposal area will be located is fundamental to the design process. The current status of this understanding is expressed in a physical model of Yucca Mountain. This subsection describes the ongoing efforts to develop this physical model.

The model consists of (1) the geologic description of Yucca Mountain; (2) properties of Yucca Mountain rock; (3) determination of the in situ stresses that exist within the mountain; (4) the definition of the waste disposal area; and (5) hydrologic description of Yucca Mountain.

A.2.2 Status

Geologic Description of Yucca Mountain

The repository location shown in Figure 1-1 on p. 1-5 is in the middle of a group of north-trending, en echelon, fault-block ridges that form Yucca Mountain. The surface topography is controlled by high-angle Basin and Range faults that have elevated and tilted the original depositional surfaces of the volcanic rock. Slopes are steep on the west-facing fault escarpments and along some of the valleys cut by erosion into the more gradual east-facing slopes. The proposed disposal horizon is located above the regional water table (i.e., in the unsaturated zone) within the Topopah Spring Member of the Paintbrush Tuff. Below this member is the Calico Hills Unit, which, because of its zeolite content, forms a retardation barrier to radionuclide migration to the water table.

Figure 1-2 on p. 1-6 is a cross section of the central structural block, the area under primary consideration for waste emplacement. Figure 1-3 on p. 1-7 shows the location of the cross section. Several features shown in the cross section influence the spatial arrangement of the underground portion of the repository. For the underground facilities to remain in the bottom of the densely welded devitrified Topopah Spring Member and below zones of potentially higher lithophysal content, the emplacement horizon must dip to the east. The required minimum dip calculated in a recent analysis is 5° E (Mansure and Ortiz, in review). To the east of the central structural block boundary, the Calico Hills Unit dips below the water table. The location of the eastern boundary of the repository may depend on the thickness of the Calico Hills Unit above the water table.

To the west, there is a significant vertical offset of approximately 244 m (800 ft) at the southern end of the central structural block boundary.

is offset requires that any westward extension of the repository be at a level separate from the level within the central block. The offset of this fault system decreases to the north and is essentially zero at the northern tip of the central structural block. Thus, westward extension of the disposal horizon from the northern end of the central structural block could require little or no vertical separation of emplacement areas.

The structural block to the north is very similar to the central structural block and, in contrast to the Abandoned Wash Block to the southeast, has a low incidence of faults. Because the structural block to the south has a higher incidence of faults, extension of the disposal area to the north may be more feasible than extension to the southeast.

Rock Properties

The portion of the stratigraphy at Yucca Mountain relevant to the design of the underground layout consists of alternating layers of three different types of tuff. One type is the densely welded portion of the Topopah Spring Member, which is a highly fractured, relatively nonporous, but highly transmissive ash-flow tuff. There are also zones of high lithophysal content in the Topopah Spring Member. Lithophysae are voids up to tens of centimeters in diameter formed from gas-filled pockets as the member cooled. Lithophysal regions may affect the thermal and mechanical suitability of these subunits for waste emplacement. For this reason, further laboratory and field tests will be conducted to identify the extent and location of the lithophysal regions and to determine their physical properties more precisely.

Below this zone of densely welded devitrified tuff is the second type of tuff, a glassy portion of the Topopah Spring Member in which the degree of welding decreases from densely welded at the top to nonwelded at the base. The third type of tuff is the Calico Hills Unit, which is a series of nonfractured to slightly fractured, nonwelded, highly porous, but relatively nontransmissive, ash-flow tuffs. These tuffs are heavily zeolitized in the northern part of the mountain but are vitric at the southern end of the mountain.

These three types of tuff have distinct sets of physical properties, which are described in a "physical property stratigraphy." Thermal and thermal/mechanical modeling and design of the repository are based on property differences corresponding to this stratigraphy. A comprehensive discussion of the physical properties of tuffs at Yucca Mountain is provided by Scott et al. (1983), Lappin (1980a and b), and Lappin et al. (1982). A description of the physical properties used as a design basis for the repository conceptual design can be found in the design guidelines (Scully et al., in preparation).

In Situ Stress State of Yucca Mountain

The design of the underground workings requires an understanding of stresses induced by excavation, thermally induced stresses, and the in situ stress state of Yucca Mountain before construction. All of these stresses affect underground opening size and stability. Design parameters (e.g., drift spacing, width, and orientation) can be varied to control the magnitude and direction of stresses induced by excavation. Panel layout, including canister spacing and areal power density (APD), can be varied to control thermally induced stresses. However, the existing in situ stresses cannot be varied, and their effects must be considered in addition to those of the induced stresses. Therefore, knowledge of both the direction and magnitude of existing in situ stresses is important to underground design.

Available tectonic and geologic evidence suggests that for the last 15 to 20 million yr the Great Basin has undergone relative extension. The minimum principal stress is currently estimated to trend N 50° W (Carr, 1974). Overcoring measurements of in situ stresses in nonwelded tuff in tunnels and mesas north of Yucca Mountain have been analyzed, and the minimum horizontal stress direction was found to be N 56° W (Ellis and Magner, 1980).

Results of hydrofracturing tests conducted at Yucca Mountain indicate a minimum horizontal stress direction of N 60° W ±10° (Healy et al., 1983). This direction may be influenced by the presence of nearby faults. Magnitudes of presumed minimum horizontal stresses measured were 4.3 MPa (623 psi) t a depth of 646 m (2,120 ft), increasing to 14.8 MPa (2,145 psi) at 1,288 m (4,226 ft). Corresponding vertical stresses are calculated to be 14.6 MPa (2,116 psi) and 29.1 MPa (4,217 psi), respectively. Thus, minimum horizontal stresses are generally less than vertical stresses.

Data and information on the state of in situ stress were used for near- and far-field analyses in the unit evaluation study (Johnstone et al., 1984). In the near field, vertical stresses in the Topopah Spring Member were estimated to vary between 8.6 MPa (1,246 psi) and 11.3 MPa (1,638 psi) and to have a ratio of 0.96 for horizontal to vertical stress based on established in situ stress models available at that time (Haimson, 1978; Brown and Hoek, 1978). In the far-field analyses, the in situ vertical stress was assumed to be equal to the weight of the overburden. The in situ horizontal stress was estimated using an average of the horizontal to vertical stress ratio functions developed by Haimson (1978) and Brown and Hoek (1978).

Repository Area Boundaries

It is important to distinguish between the boundaries of the geologic structural blocks and the boundaries of the underground workings. The underground design shown on preliminary layouts (Subsection 2.5.1) is smaller than the total area available for the underground workings, and there is no performance requirement that restricts the location of the disposal area to a single geologic block. The geologic characterization of Yucca Mountain that has taken place to date has identified a preferred disposal area within the central structural block. This determination does not imply, however, that areas adjacent to the central block are unsuitable for waste disposal. Around the central block and within Yucca Mountain, there is a large area that may meet performance requirements. The underground workings will be laid out to conform to the natural features of the central structural block and adjacent blocks, taking maximum advantage of natural barriers (e.g., overburden and distance above the water table). Identification of areas adjacent to the central structural block that meet performance constraints will provide flexibility to allow the boundaries of the underground workings to be extended to compensate for any unforeseen adverse geologic conditions (e.g., major faults or rubble zones) located in the central structural block.

The process of determining the boundary of the underground workings will start with the consideration of the central structural block and move to the surrounding geologic blocks (see Figure 1-3, p. 1-8). The following guidelines will be used in locating the underground facility.

- The first choice for the underground facility is the densely welded devitrified portion of the Topopah Spring Member.

- All points within the underground workings must have at least 200 m (656 ft) of overburden.

- A significant thickness of the Calico Hills Unit between the underground workings and the water table would be desirable to provide a significant radionuclide retardation barrier between the underground facility and the water table.

- The host rock must meet mineability requirements. A study is currently under way to assess the effects of faults surrounding the central structural block on mineability and ground support requirements (Dravo, in review).

- The thermal and mechanical properties (e.g., strength and thermal conductivity) of the rock must be satisfactory so that thermal constraints will be met and long-term stability of openings can be maintained.

A preliminary underground repository area study based on these constraints is being prepared for the central structural block and adjacent areas (Mansure and Ortiz, in review) to define a preliminary conceptual plane for the underground workings. The plane dips 1° to the north and 5° to the east. The underground workings can be placed in this plane and meet the above constraints while keeping drift grades to less than 10%. The preliminary plane has more than the minimum area required for the underground workings, but limiting the conceptual design to this plane would not optimize repository performance or allow for a large degree of flexibility in design or construction. Therefore, the underground area study is continuing.

Hydrologic Description of Yucca Mountain

The hydrologic conditions of a repository site and the perturbations of the hydrology induced by introducing a repository may require site-specific measures to control groundwater movement, radionuclide migration, and hydrothermal effects on underground openings and rockmass stability. No requirements for design features to mitigate hydrologic effects of a repository at Yucca Mountain other than the measures that are under consideration for repository closure discussed in Section 4 have been identified in analyses and experiments conducted to date (Scott et al., 1983; Mondy et al., 1983).

Mean annual precipitation at Yucca Mountain is about 15 cm/yr (6 in./yr) (Winograd and Thordarson, 1975; Rush, 1970). At least 97% of this amount is lost to evapotranspiration and runoff. Less than 1.0 mm/yr (0.04 in./yr) probably infiltrates the subsurface (DOE, in preparation, b). In the unsaturated zone beneath Drillhole Wash, a vertical flux of about 1.0 to 10.0 mm/yr (0.04 to 0.4 in./yr) has been estimated on the basis of heat flow studies (Sass and Lachenbruch, 1983). Estimates of recharge based on regional mass-balance water budgets suggest that no recharge is needed at Yucca Mountain to explain regional flow patterns (Waddell, 1982). In situ moisture contents and negative hydraulic pressures indicate that flux through the disposal horizon is less than 0.5 mm/yr (0.22 in/yr.) (Sinnock et al., in review).

The areal distribution of precipitation over Yucca Mountain is probably not uniform, nor is the distribution of precipitation throughout a given year uniform. The infiltration rates are affected by both the areal and temporal distributions, but variation in rates is largely a function of differences in topography, surficial materials, and intensity of precipitation.

A.2.3 Future Work

Ongoing and future work to improve the physical model of Yucca Mountain includes (1) gathering additional stratigraphic and structural data from borehole and shaft testing within the central structural block; (2) improving characterization of fault strikes, dips, and offset so that predicted geologic surfaces within the central structural block can be extended to outlying blocks; (3) gathering exploratory borehole data outside the central structural block to verify the location of stratigraphic units; and (4) gathering hydrologic data from borehole and shaft testing.

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APPENDIX B

ENGINEERING STUDIES FOR THE DESIGN CRITERIA

This appendix summarizes the engineering studies that are being conducted to define in greater detail the design criteria presented in Section 1. The primary purpose of the design criteria is to ensure the radiological health and safety of the general public and repository personnel. The engineering studies described in this appendix also provide additional data and calculations to support the conceptual design phase.

Design criteria are requirements placed on specific repository systems, structures, and components that are derived from policy and regulations issued by various government agencies to implement the Nuclear Waste Policy Act (NWPA) of 1982. Design criteria are also derived from national codes and standards developed for design and construction of buildings and mines. These criteria can be divided into three categories: (1) design criteria for surface facilities, (2) design criteria for underground facilities, and (3) general design criteria applicable to the entire repository.

The engineering studies that further define the design criteria for surface facilities are summarized below.

The site selection study described in Appendix B.1 applies Department of Energy (DOE) siting guidelines (DOE, 1983) to the selection of a site for the Nevada Nuclear Waste Storage Investigations (NNWSI) repository surface facilities. Nuclear Regulatory Commission (NRC) (1983a, 1983b) and Environmental Protection Agency (EPA) regulations (1982) are also being applied.

The radiological release studies discussed in Appendix B.2 postulate accident scenarios that result in radiological releases from the surface facilities during the operating period of the repository. The dose limits defined for the general public (NRC, 1983b) and for operating personnel (NRC, 1983a) are then used to determine the adequacy of the site boundary and the repository safety systems.

Appendix B.3 describes a repository safeguard study that provides a preliminary assessment of the administrative and record-keeping requirements for the administrative and physical security systems of the repository. The preliminary design criteria for the repository safeguards systems are derived from 10 CFR 60, (NRC, 1983b) and DOE Order 5632.2 (DOE, 1979).

The engineering studies that further define the design criteria for underground facilities include studies of retrievability, performance constraints and acceptable areal power density, waste emplacement configurations, and thermal/mechanical calculations.

The design criterion for retrievability described in Appendix B.4 is derived from 10 CFR 60 (NRC, 1983b). This study examines the effects of the retrievability requirement on the design of the underground facilities and on the waste emplacement and retrieval equipment.

Appendix B.5 describes the preliminary technical constraints used in repository design. These constraints, derived from National Waste Terminal Storage (NWTS) Program guidance (Battelle, 1981) and on an NNWSI Working Group document (Johnstone and Gnirk, 1982), are the design criteria that were used in the selection of the waste emplacement horizon. The preliminary technical constraints are also being used to determine the manner in which the waste will be distributed underground.

As described in Appendix B.6, two different waste emplacement configurations--vertical and horizontal--are currently being studied for waste emplacement. Because these two configurations involve different geometries, different design criteria have been developed. Examples of these criteria, which are derived from current mining practices, include acceptable drift dimensions, pillar factors of safety, and ventilation system sizing.

The thermal/mechanical calculations performed to support the conceptual design phase are described in Appendix B.7. The calculations, which include both scoping calculations and detailed analyses, established design parameters, evaluated margins of safety, and indicated whether the preliminary concepts for the underground area meet the performance constraints.

The engineering studies that further define the design criteria for the entire repository include studies of worker radiation exposure, handling of waste generated onsite, and equipment development.

The worker radiation exposure studies discussed in Appendix B.8 address the design criteria for worker exposures under normal operating conditions. These criteria have been derived from a DOE regulation (DOE Order 5480.1A; DOE, 1981).

The study that addresses the design criteria for the handling of waste generated onsite as the result of repository operations is described in Appendix B.9. These criteria are derived from current nuclear industry practices for similar waste forms.

The equipment development study is described in Appendix B.10. This study identifies the special equipment required for repository operations and construction, the tasks that equipment will perform, and the design criteria needed for equipment development. These criteria will be derived from DOE guidelines for worker exposures to radiation (DOE Order 5480.1A; DOE, 1981) and from the equipment requirements dictated by the overall repository design.

B.1 Site Selection Study

B.1.1 Background

The selection of a site for the surface facilities will follow DOE siting guidelines that address the preclosure period (10 CFR 960.5; DOE, 1983). These guidelines address the regulatory aspects of 10 CFR 20 (NRC, 1983a), 10 CFR 60 (NRC, 1983b), and draft 40 CFR 191, Subpart A (EPA, 1982).

The rationale for locating the surface facilities will be based, in order of importance, on

- short-term radiological safety;

- environmental quality, socioeconomic impacts, and transportation; and
- ease and cost of construction, operation, and closure.

B.1.2 Status

The determination of site acceptability will be based on a methodology that reflects these levels of significance. Factors to be weighed in the evaluation include population density and distribution, site ownership and control, meteorology, offsite installations and operations, environmental quality, socioeconomic impacts, transportation, surface characteristics, rock characteristics, hydrology, and tectonics.

The preliminary concepts contemplate a site for surface facilities on the more level areas east of Yucca Mountain. Specific technical requirements determine the relative suitability of possible sites within a selected area. Siting guidelines are being established so that evaluative criteria can be weighed. Those criteria that are critical to health and safety will indicate which portions of the area being considered should be disqualified. The latter judgment will be based on accident scenarios developed for use in a preliminary safety determinations study (Jackson and Gram, in preparation).

B.1.3 Future Work

Some locations for the surface facilities within the area shown on Figure 2-1 are known to be marginal because they lie in flood plains or on faults. A decision on each technical factor will be made, and these decisions will be taken into account in the final site recommendation. Some information, such as alluvial thickness,and fault location, must be obtained before comparative evaluations can be made. These data are being gathered by the U.S. Geological Survey (USGS) and Sandia National Laboratories, Albuquerque (SNLA). The results of the comparative evaluations are being prepared (Neal et al., in preparation).

B.2 Radiological Releases

B.2.1 Background

Several factors have been considered in assessing the potential effects of accidental radionuclide releases from the repository on the public and on operations personnel. Potential scenarios that cause releases and their probabilities have been identified (Jackson and Gram, in preparation). These scenarios have been grouped in three categories: (1) natural phenomena, (2) external man-made events, and (3) internal accidents during operations. These scenarios are listed in Tables B-1 and B-2. The source and potential amount of radioactive material that could be released have been determined, and the pathways by which the released material might reach the public and operating personnel have been characterized. Finally, the estimated doses have been calculated for (1) the maximum individual at the postulated exclusion boundary, (2) the general public within a 50-mi radius of the repository, and (3) operations personnel. The results of this study will be used to recommend design changes (if any) that might mitigate or eliminate the effects of the postulated releases. Modifications in operating procedures that might accomplish the same result will also be recommended.

B.2.2 Status

The calculated dose commitments for operations personnel for all the scenarios are summarized in Table B-1. The single worker dose limit established in 10 CFR 20 (NRC, 1983a) is 5 rem/yr or 3 rem/quarter. Except in the scenarios that occur as the result of (1) the aircraft impact, (2) the fire in the access ramp, and (3) the fire in the emplacement drift, the single worker dose is below the limits set by the NRC. The primary factors that contribute to the higher doses in these three scenarios are fire and severe mechanical shock. The elevated temperatures volatilize the halogens, volatile solids, and some of the heavy radionuclides.

The calculated dose commitments for the maximum individual and for the general population are summarized in Table B-2. All exposures are less than

TABLE B-1

PRELIMINARY WORKER DOSE COMMITMENTS FROM POSTULATED ACCIDENTS

Scenario[a]	Probability of Event (event/yr)	Single Worker Whole-Body[b] Equivalent Dose (rem)	Workers Exposed (number)	Whole-Body[b] Equivalent Dose (man-rem)	Comments
Exposure limit 10 CFR 20		5.0 rem/yr 3.0 rem/quarter			
Background		9.00×10^{-2} rem/yr	414[c] 434[c]	3.73×10^{-1} 3.91×10^{-1}	
Natural Phenomena					
Flood	1.0×10^{-2}	1.80×10^{-11}	87	1.57×10^{-9}	Only waste-handling facility workers are assumed to be exposed.
Earthquake	$<1.3 \times 10^{-3}$	5.71×10^{-1}	87	4.97×10^{1}	
Tornado	$<9.1 \times 10^{-11}$	5.71×10^{-1}	87	4.97×10^{1}	
Man-Made External Events					
Underground nuclear explosive test	1.0×10^{-3}	5.71×10^{-1}	87	4.97×10^{1}	
Aircraft impact	$<2.0 \times 10^{-10}$	6.16×10^{0}	327[c] 347[c]	2.01×10^{3} 2.14×10^{3}	All waste-handling facility workers are assumed killed. Other surface and subsurface personnel are assumed to be exposed as a consequence of the accident.
Operational Accidents					
Fuel assembly drop in hot cell	$<1.0 \times 10^{-1}$	1.25×10^{-2}	414[c]	5.18×10^{0}	All surface and subsurface personnel are assumed to be exposed equally as a consequence of the accident.
Transportation accident and fire at loading dock			434[c]	5.43×10^{0}	
Spent fuel	$<1.0 \times 10^{-7}$	4.00×10^{0} 1.01×10^{-2}	17 397[c] 417[c]	6.80×10^{1} 4.01×10^{0} 4.21×10^{0}	Workers at the waste-handling facility loading dock receive the maximum dose; remaining personnel receive the smaller dose.
CHLW	$<1.0 \times 10^{-7}$	6.90×10^{-1} 1.75×10^{-3}	17 397[c] 417[c]	1.17×10^{1} 6.95×10^{-1} 7.29×10^{-1}	
Transportation accident and fire on waste-handling ramp	$<1.0 \times 10^{-7}$	7.23×10^{1}	6	4.34×10^{2}	Workers in the waste-handling ramp area receive the maximum dose.
		4.98×10^{1} 1.28×10^{1} 7.50×10^{-2}	40[c] 60[c] 368	2.00×10^{3} 7.68×10^{2} 2.76×10^{1}	Waste emplacement workers receive a smaller dose than workers in the ramp area. Remaining personnel aboveground receive the smallest dose.
Transportation accident and fire in repository emplacement drift	$<1.0 \times 10^{-7}$	1.86×10^{2} 1.57×10^{1} 7.50×10^{-2}	40[c] 60[c] 374	7.44×10^{3} 9.42×10^{2} 2.81×10^{1}	Waste emplacement workers receive a greater dose than aboveground operations personnel.

a. Except for the transportation accident and fire at the loading dock where both spent fuel and CHLW are evaluated, all scenarios involve spent fuel.

b. Each of the calculated dose commitments reported in this study is made up of an acute component and a chronic component. Depending on the radionuclides involved, chronic exposure can be received primarily in the first year after the accident, as from Ru-106 or be distributed more equally over the 50 yr for which that dose is calculated, as from Pu-241.

c. Horizontal emplacement of waste canisters requires an estimated 40 subsurface workers; vertical emplacement requires an estimated 60 subsurface workers.

TABLE B-2

PRELIMINARY POPULATION DOSE COMMITMENTS FROM POSTULATED ACCIDENTS

Scenario[a]	Probability of Event (event/yr)	Maximum Individual Whole-Body Equivalent Dose (rem)	General Population: Population Exposed (number)	General Population: Whole-Body Equivalent Dose (man-rem)	Range of Health Effects (Cancer Deaths)
Exposure limit 10 CFR 60		0.50 rem/yr			
Background		9.00×10^{-2} rem/yr	19,908	1.79×10^{3}	
Natural Phenomena					
Flood	1.0×10^{-2}	1.59×10^{-5}	29[b]	4.61×10^{-4}	9.55×10^{-9} to 2.93×10^{-8}
Earthquake	$<1.3 \times 10^{-3}$	2.34×10^{-4}	19,908	3.07×10^{-3}	2.31×10^{-7} to 7.07×10^{-7}
Tornado	$<9.1 \times 10^{-11}$	2.34×10^{-4}	19,908	3.07×10^{-3}	2.31×10^{-7} to 7.07×10^{-7}
External Man-Made Events					
Underground nuclear explosive test	1.0×10^{-3}	2.34×10^{-4}	19,908	3.07×10^{-3}	2.31×10^{-7} to 7.07×10^{-7}
Aircraft impact	$<2.0 \times 10^{-10}$	3.28×10^{-1}	19,908	1.21×10^{2}	9.04×10^{-3} to 2.77×10^{-2}
Operational Accidents					
Fuel assembly drop in hot cell	$<1.0 \times 10^{-1}$	5.14×10^{-6}	19,908	8.21×10^{-5}	6.16×10^{-9} to 1.89×10^{-8}
Transportation accident and fire at loading dock					
Spent fuel	$<1.0 \times 10^{-7}$	2.42×10^{-4}	19,908	4.04×10^{-3}	3.03×10^{-7} to 9.30×10^{-7}
CHLW	$<1.0 \times 10^{-7}$	4.35×10^{-5}	19,908	4.76×10^{-4}	3.57×10^{-8} to 1.09×10^{-7}
Transportation accident and fire on waste-handling ramp	$<1.0 \times 10^{-7}$	9.64×10^{-9}	19,908	1.32×10^{-7}	4.17×10^{-6} to 1.28×10^{-5}
Transportation accident and fire in emplacement drift	$<1.0 \times 10^{-7}$	9.64×10^{-9}	19,908	1.32×10^{-7}	4.17×10^{-6} to 1.28×10^{-5}

a. Except for the transportation accident outside the facility where both spent fuel and CHLW are evaluated, all scenarios are based on spent fuel.

b. Only the population in the zone directly south of Drill Hole Wash is exposed.

0.5 rem/accident, the limit set in 10 CFR 60 (NRC, 1983b). The greatest single exposure (0.328 rem) is to the maximum individual in the aircraft impact scenario. A postulated exclusion boundary enclosing an area 32,000,000 m^2 (7,900 acres), which places the maximum individual about 4 km (2.5 mi) from the facility, appears adequate to meet the radiation exposure limit set in 10 CFR 60.

B.2.3 Future Work

The detailed results of dose calculations will be published in a preliminary safety assessment study (Jackson and Gram, in preparation). In addition, more refined calculations to be performed during the conceptual design phase will be published later.

B.3 Repository Safeguards

B.3.1 Background

NRC (1983b) and DOE (1979) regulations and International Atomic Energy Agency (IAEA) practices (IAEA, 1968; IAEA, 1975) have been reviewed and adapted for use at the repository. Administrative and record-keeping requirements, along with design criteria for a physical security system, have been developed for the protection of the repository itself and for the radioactive material it will contain. Details of this assessment are provided in a preliminary safeguards assessment document (Jackson and Tomasko, in review). This document is designated "Unclassified Controlled Nuclear Information" and will be released only to those who have a need to know.

B.3.2 Status

Administrative and Recordkeeping Requirements

The NRC permits the DOE to develop and certify its own safeguards for the repository [10 CFR 60.21(b)(3); NRC, 1983b]. The primary source for the development of administrative and record-keeping requirements and for the development of the physical protection system is DOE Order 5632.2, "Physical Protection of Nuclear Materials" (DOE, 1979).

The principal administrative and record-keeping requirements for the repository include the preparation of a safeguards and security plan developed by DOE and submitted to the NRC as part of the application for construction authorization. The training and qualification programs for the guard force at the repository will be similar to those existing for the Nevada Test Site (NTS) guard force at the time of repository construction. All repository operations personnel should have DOE-approved accesses or clearances. The precedent for this requirement has already been established for personnel currently involved in nonweapons areas at NTS [e.g., Engine Maintenance and Disassembly Facility (E-MAD)]. Clearances will not be required for mining and construction workers, who will instead be granted a name approval form of access. This procedure is also in keeping with current NTS practice.

Personnel records, including access rosters and visitors' registers, should be kept. A nuclear materials accounting and control system that uses numbered waste canisters and borehole locations should be implemented. Such a system would not only aid repository safeguards but would also aid waste operations (by indicating, for example, which boreholes have been filled and which boreholes can accept more waste). This system would also aid retrievability of all or part of the waste, should retrieval be deemed necessary.

If the U.S. government should decide to place the repository on the list of nuclear facilities subject to IAEA inspection, the administrative and record-keeping requirements would be contained in a site-specific facility attachment to the US/IAEA agreement (NRC, 1983c). The attachment would contain details about what the IAEA would be allowed to inspect, when the inspections would take place, and what types of records would be required for documentation purposes. Although the IAEA requires annual physical inventories of special nuclear material (SNM), such inventories would be impractical in a repository. Instead, seals could be placed over the boreholes, and inventory of these seals could be used in lieu of physical inventories in the underground facilities (Jackson and Tomasko, in review).

Design Criteria for the Physical Security System

The physical protection system should be equivalent to that afforded a Category IIIA (DOE, 1979) amount of SNM. Such a system includes perimeter fencing and lighting sufficient for closed-circuit TV assessment, guarded entry points, doors equipped with alarms, and patrols during nonworking hours. Details of the physical protection system design criteria will be disclosed only to those who have a need to know (Jackson and Tomasko, in review).

B.3.3 Future Work

No further safeguards work is planned during the conceptual design phase.

B.4 Retrievability

Retrievability of the waste placed in a geologic repository is a planned contingency mandated by the NWPA, by NRC requirements (10 CFR 60; NRC, 1983b), and by DOE policy. It is therefore a principal design criterion for the underground facilities. Initiation of waste retrieval must be possible starting at any time up to 50 yr after the first waste has been emplaced, and it is anticipated that the time required to retrieve the waste will be comparable to the time required for emplacement. This retrievability study will identify the effects of the retrieval requirement on the design and operations of the facility.

B.4.1 Background

The following constraints form the basis for the entire study.

- The emplacement and retrieval concepts selected must not compromise the ability of the site to contain and isolate the radionuclides present in the waste.
- The proposed waste retrieval concept must be founded on good engineering analysis and must be credible when subjected to a peer review.
- The emplacement and retrieval concepts and equipment must be demonstrated before a construction license is granted.

- The emplacement and retrieval concepts selected must address both vertical and horizontal waste emplacement configurations, possible backfilling of the access drifts, and capital and operating costs.

The study will produce the following:

- descriptions of waste emplacement and retrieval procedures,

- identification of adverse conditions that may arise during retrieval operations and proposed solutions to these conditions,

- design requirements and criteria for surface and underground facilities and systems to accommodate the retrieval design criteria,

- design criteria for emplacement and retrieval equipment, and

- schedule and resource requirements to demonstrate retrievability.

B.4.2 Status

The results, to date, include the following.

- Use of the vertical emplacement configuration as the reference concept for emplacement and retrieval. Vertical waste emplacement and retrieval concepts have been demonstrated for short periods of time at near ambient rock temperature at Project Salt Vault (Lyons, Kansas) (Bradshaw and McClain, 1971) and Climax Spent Fuel Demonstration (Nevada Test Site) (Heuze, 1981).

- A preliminary emplacement and retrieval concept based on (1) long horizontal emplacement holes (Foster-Miller, Inc., in review), (2) a feasibility study for an emplacement drill (Robbins, 1984), and (3) preliminary concepts for emplacement and retrieval equipment (Young et al., 1983).

- Heat transfer studies on temperature buildup in the drifts and on the effects of thermal stress on the rock (Wilson et al., in preparation; Flanagan, in preparation).

B.4.3 Future Work

Current and future activities are concentrating on the refinement of emplacement and retrieval methods, equipment concepts, development and demonstration schedule, and resource requirements.

B.5 Preliminary Technical Constraints and Acceptable Areal Power Density

B.5.1 Background

The underground portion of the repository will be designed in accordance with certain technical constraints derived from DOE NWTS guidance (Battelle, 1981) and an NNWSI working group document (Johnstone and Gnirk, 1982). These technical constraints are the design criteria that were used in the selection of the waste emplacement horizon and that are being used to determine the manner in which the waste will be distributed underground.

The preliminary technical constraints specify conditions for design features in the near field (the underground facility and adjacent rock) and in the far field (the overlying and nearby rockmass). The technical constraints for the near field are specified for the operational period and address operational serviceability and safety. Technical constraints for the far field address minimizing any impact on the containment and isolation provided by the waste package and the site and include limiting (1) rock temperature [to less than 200°C (390°F) to preclude mineral dehydration or alteration in the rock]; (2) stresses (to preclude modification of the hydrologic system; e.g., by establishing or greatly opening fracture systems); and (3) deformation [limiting surface uplift or subsidence to levels below natural analogs (see Table B-3)].

These preliminary technical constraints affect the manner in which the waste is distributed underground. Canisters that contain waste of different

TABLE B-3

PRELIMINARY TECHNICAL CONSTRAINTS[a]

System Component	Operational Constraints[b]	Containment Constraints[b]	Isolation Constraints[b]
Near Field[c]			
Roof, Drift, Floor	Operational serviceability[d]	No constraint	No constraint
Environment	Operational serviceability[d]	No constraint	No constraint
Shafts	Operational serviceability;[d]	No constraint	
Seals: Shaft and Borehole		Similar performance to that of the tuff[d,e]	
Pillars	Safety factor >1.5[d]	No constraint	No constraint
Mineral Dehydration/ Alteration	T<200°C (390°F)[d, f]	No constraint	No constraint
Engineered System	No radionuclide release at repository boundary[g]	No radionuclide release at repository boundary[g]	$<10^{-5}$ per nuclide per year[g]
Far Field[h]			
Rockmass: Mechanical Behavior		No new fractures[d, e]	
Mineral Dehydration/ Alteration		T<200°C (390°F)[d, f]	
Surface Uplift and Subsidence		<Natural analogs[d]	
Surface Temperature Increase		ΔT<6°C (comparable[d] to natural variations)	
Thermally Perturbed Groundwater Flow		Travel time to accessible environment >1,000 yr[g]	

a. Based on Johnstone et al., 1984.

b. Operational constraints apply to the operating period of the repository. Containment contraints apply to the period between closure of the repository and 1,000 yr after the first waste has been emplaced. Isolation contraints apply to the time period beyond 1,000 yr after the first waste has been emplaced.

c. Pertaining to the repository system geometry and repository-induced effects; that space within the disposal horizon.

d. These technical constraints are called "performance constraints" in the preliminary system description.

e. This constraint applies to the center 70% of the vertical distance from the surface to the disposal horizon.

f. The temperature for mineral dehydration/alteration is taken to be T<200°C (390°F). Johnstone et al. (1984) assumed T<150°C (300°F).

g. These technical constraints are called performance objectives in 10 CFR 60.113 (NRC, 1983b).

h. Pertaining to the repository system geometry and repository-induced effects; that space outside the disposal horizon that extends in all directions to a distance equivalent to the depth of the underground workings.

types and ages have different thermal power outputs. The results of the areal energy deposition calculations shown in Figure B-1 indicate that, for a fixed initial areal power density (IAPD), areal energy deposition is substantially higher for older waste and lower for younger waste than it is for 10-yr-old waste. For a fixed emplacement array, areal energy deposition varies only marginally from the value for 10-yr-old waste over the range of waste ages considered (after 50,000 yr, 1% higher for 5-yr-old waste, 2% lower for 20-yr-old waste, and 4% lower for 40-yr-old waste). Therefore, if a plan for the spatial distribution of 10-yr-old waste can be developed that minimizes the area required for waste disposal and yet satisfies all the near- and far-field technical constraints (see Table B-3), then the same plan using older waste would result in the deposition of approximately the same total energy but would be conservative with respect to the peak temperatures in the early years. The same plan could also be used for younger waste as long as peak temperature constraints are not exceeded.

The preliminary technical constraints were developed before the need for a system description was recognized. Many of the preliminary technical constraints shown in Table B-3 have been subsequently incorporated in the System Description and renamed "performance constraints". These performance constraints are indicated in Table B-3. Similarly, certain preliminary technical constraints are called "performance objectives" by the NRC (July, 1983b). These performance objectives are also indicated in Table B-3. For consistency with the original work done by Johnstone and Gnirk (1982), the original nomenclature "preliminary technical constraints" has been retained in this document.

B.5.2 Approach

The goal of this study is to maximize the acceptable areal power density (APD) within the given preliminary technical constraints in order to minimize repository cost. The first step in developing a distribution plan is to assume a set of dimensions for the underground layout. The waste characteristics and layout dimensions of the borehole spacing, standoff distance, and emplacement drift are then used in structural, heat transfer, and thermal/structural analyses to ensure that the effects of the waste heat fall within

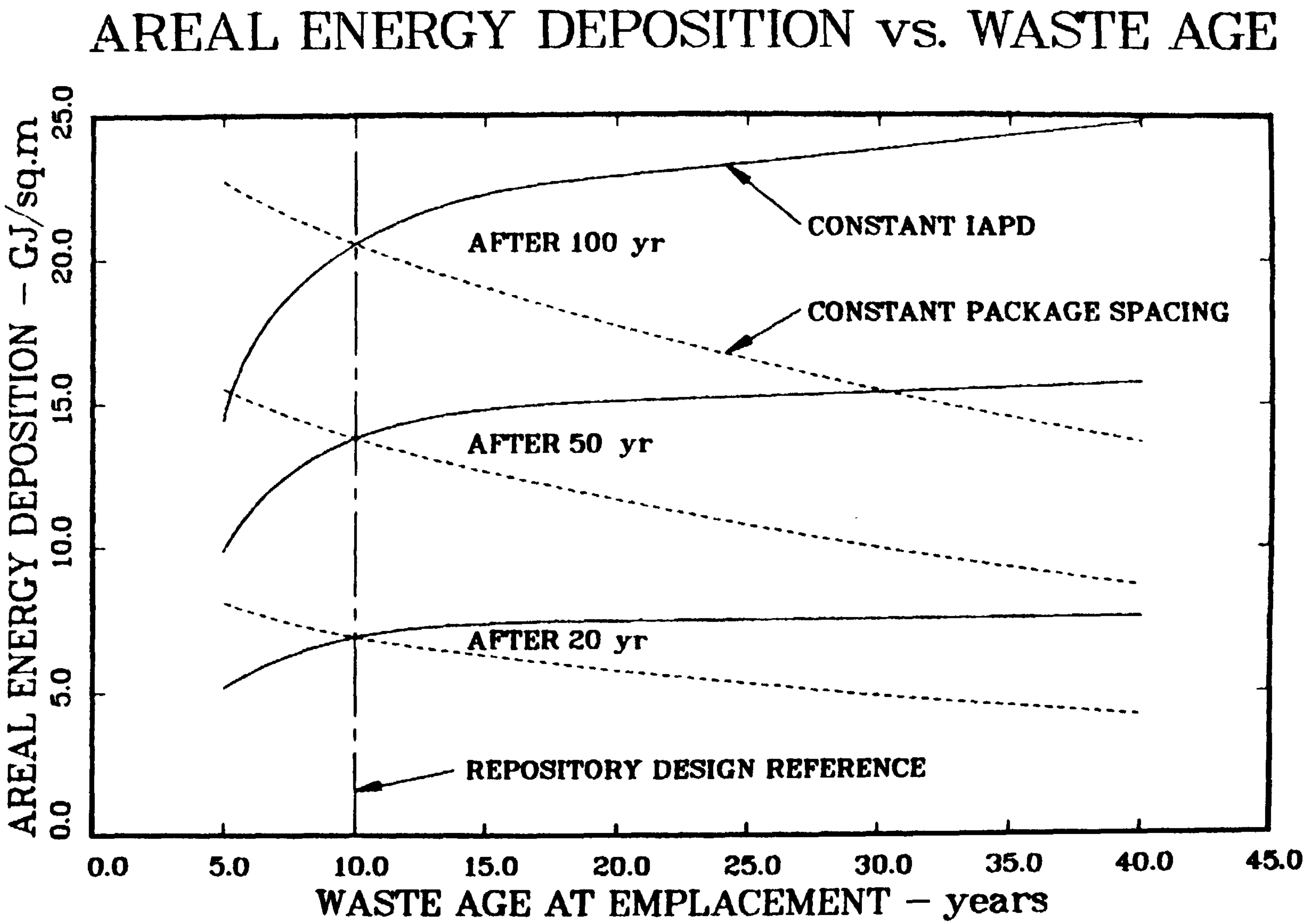

Figure B-1. Areal Energy Deposition as a Function of Waste Age at the Time of Emplacement in a Repository

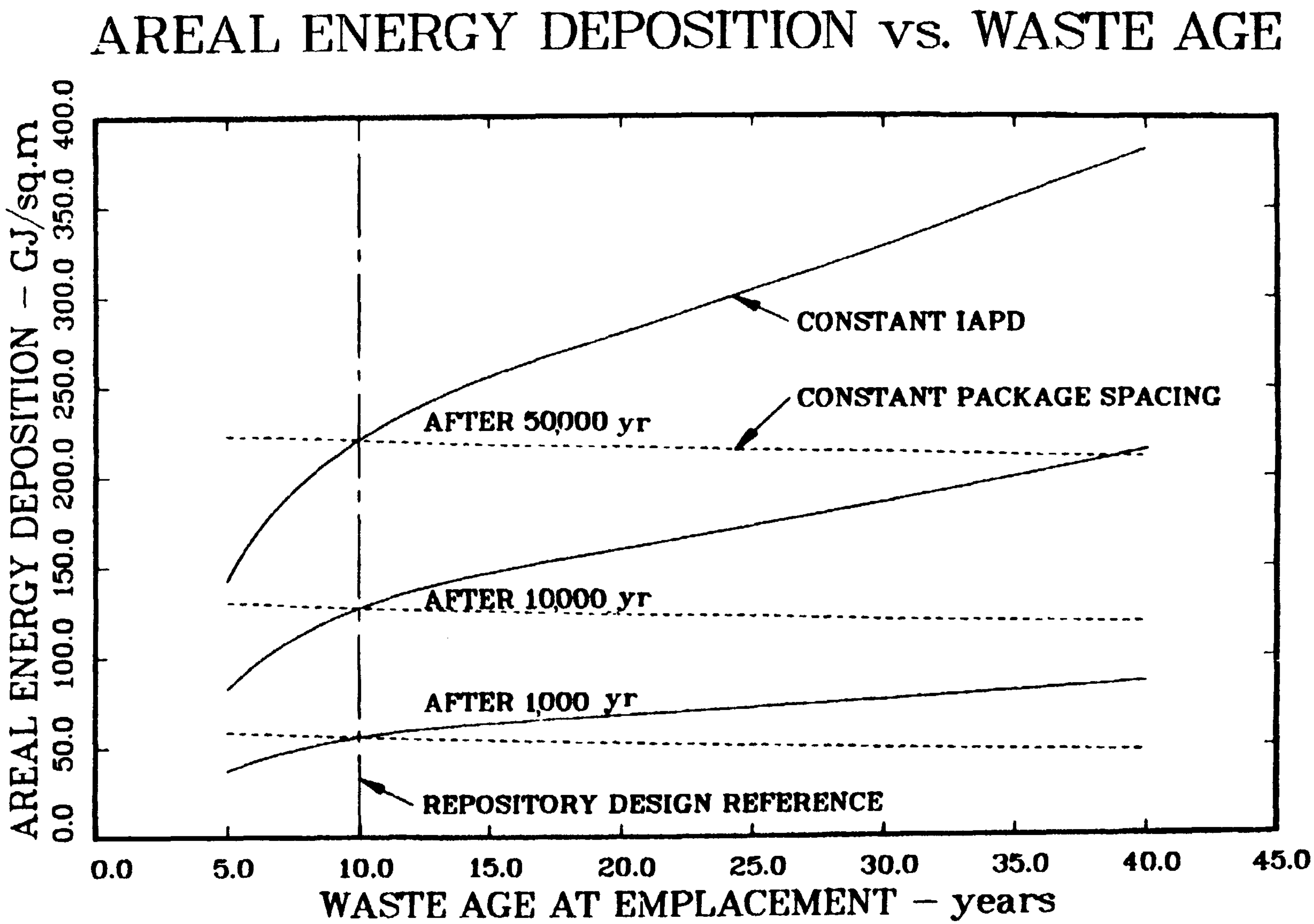

Figure B-1. Areal Energy Deposition as a Function of Waste Age at the Time of Emplacement in a Repository (concluded) the near-field performance constraints and operating requirements listed in Table B-3. At the same time, the dimensions for a series of boreholes, emplacement drifts, access drifts, alcoves, and ventilation drifts, along with the waste characteristics, are used to establish an APD. This APD, together with the information contained in the repository site design basis, is then used to assess the effects of the waste heat in the far field.

In the far field, the differences between the effects of vertical and horizontal emplacement are indistinguishable. The far-field effects are compared to the far-field technical constraints to determine compliance (see Table B-3). Current constraints permit no degradation (i.e., no new fractures) of the center 70% of the vertical distance from the surface to the disposal horizon. If the comparison shows that either the near-field or far-field constraints are violated, the proposed layout dimensions must be changed and rechecked. An alternative to this procedure is to re-examine the validity of the preliminary technical constraints. In some cases, the violation of a constraint may not produce an undesirable effect, and the constraint can be relaxed. This relaxation must be examined carefully to ensure that no adverse impact results.

B.5.3 <u>Status</u>

The emplacement horizon selection study (Johnstone et al., 1984) indicates that for spent fuel 10 yr out-of-reactor, 14.1 W/m^2 (57 kW/acre) is an acceptable APD when compared to the set of preliminary technical constraints imposed (see Table B-3).

The current layout dimensions for both vertical and horizontal configurations are being reviewed with the intent of increasing the APD value as much as possible. A preliminary bounding calculation for spent fuel 10 yr out-of-reactor indicates that an APD of 22.2 W/m^2 (90 kW/acre) or more violates the far-field constraints and is unsuitable (Svalstad, 1983).

A near-field calculation for spent fuel 10 yr out-of-reactor indicates that an APD of 18.8 W/m^2 (76 kW/acre) or less is acceptable. The far-field ects must now be established and compared to the far-field constraints. The effects in both the near and far field at the 14.1-W/m^2 (57-kW/acre) value fall within acceptable preliminary technical constraints (Johnstone et al., 1984).

B.5.4 Future Work

Analyses will continue using the most recent values for waste characteristics, rock properties, and preliminary technical constraints. The goal will be to establish upper bounds on the APD in the far field and to establish borehole spacings and loadings in the near field in order to obtain maximum flexibility in repository layout and to accommodate variability in rock properties.

B.6 Waste Emplacement Configurations

B.6.1 Background

Both the vertical and horizontal configurations are currently being studied for waste emplacement. Because these two configurations involve different geometries, different design criteria have been developed. Examples of these criteria, which are derived from current mining practices, include acceptable drift dimensions, pillar factors of safety, and ventilation system sizing support. This study will further define these criteria and provide additional data and calculations to support the conceptual design phase.

The preliminary concepts for the vertical and horizontal emplacement boreholes are shown in Figure B-2. The diameter and length of the emplacement borehole depend on the dimensions of the various waste canisters and the waste package design. Canisters range from 0.31 m (12 in.) to 0.62 m (24 in.) in diameter and 3.08 m (10 ft) to 4.62 m (15 ft) in length. A cross section of the configuration for vertical emplacement is provided in Figure B-3 and for horizontal emplacement in Figure B-4. A complete list of dimensions is given in a reference waste emplacement geometries memo ully, 1983).

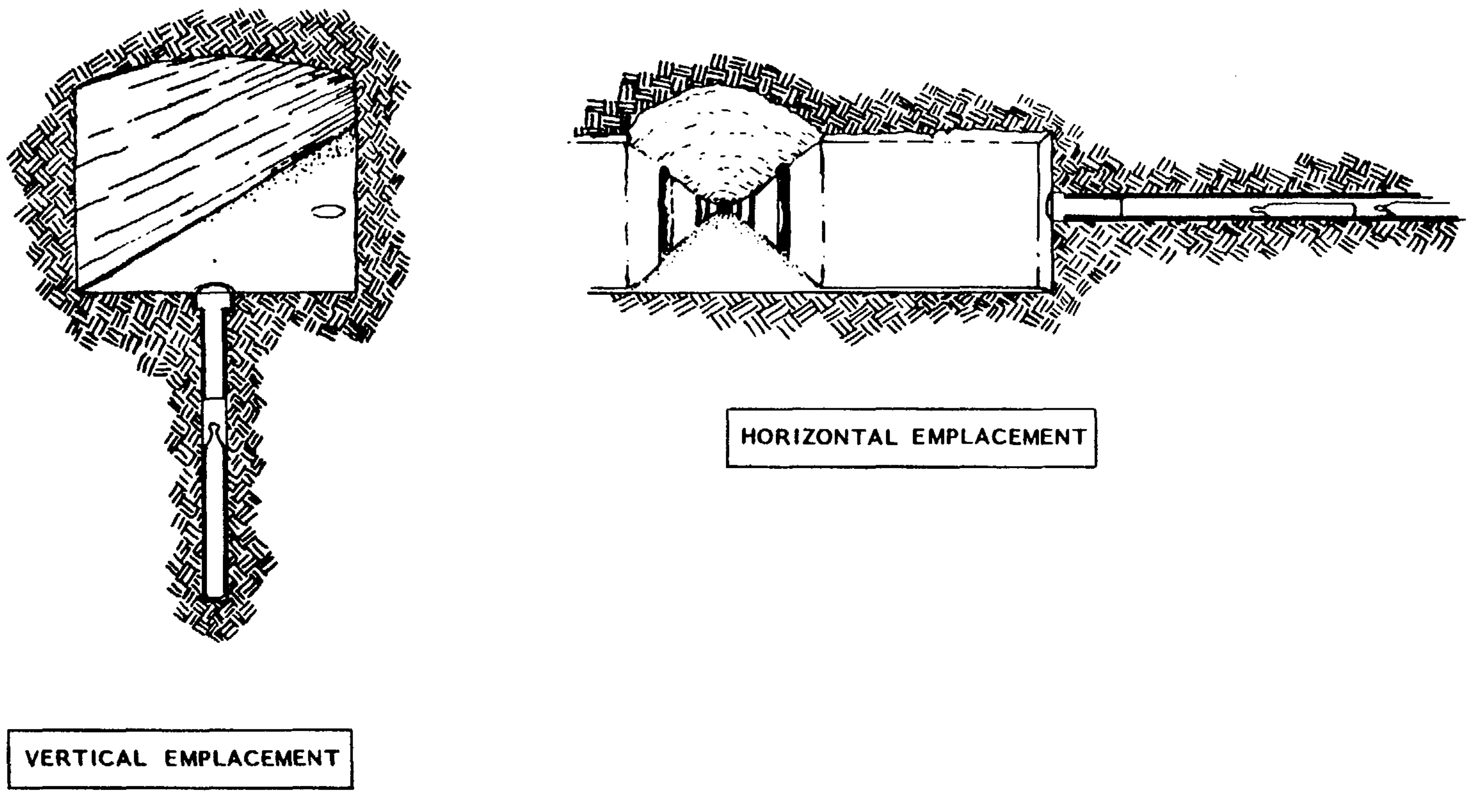

Figure B-2. Horizontal and Vertical Waste Emplacement Configurations

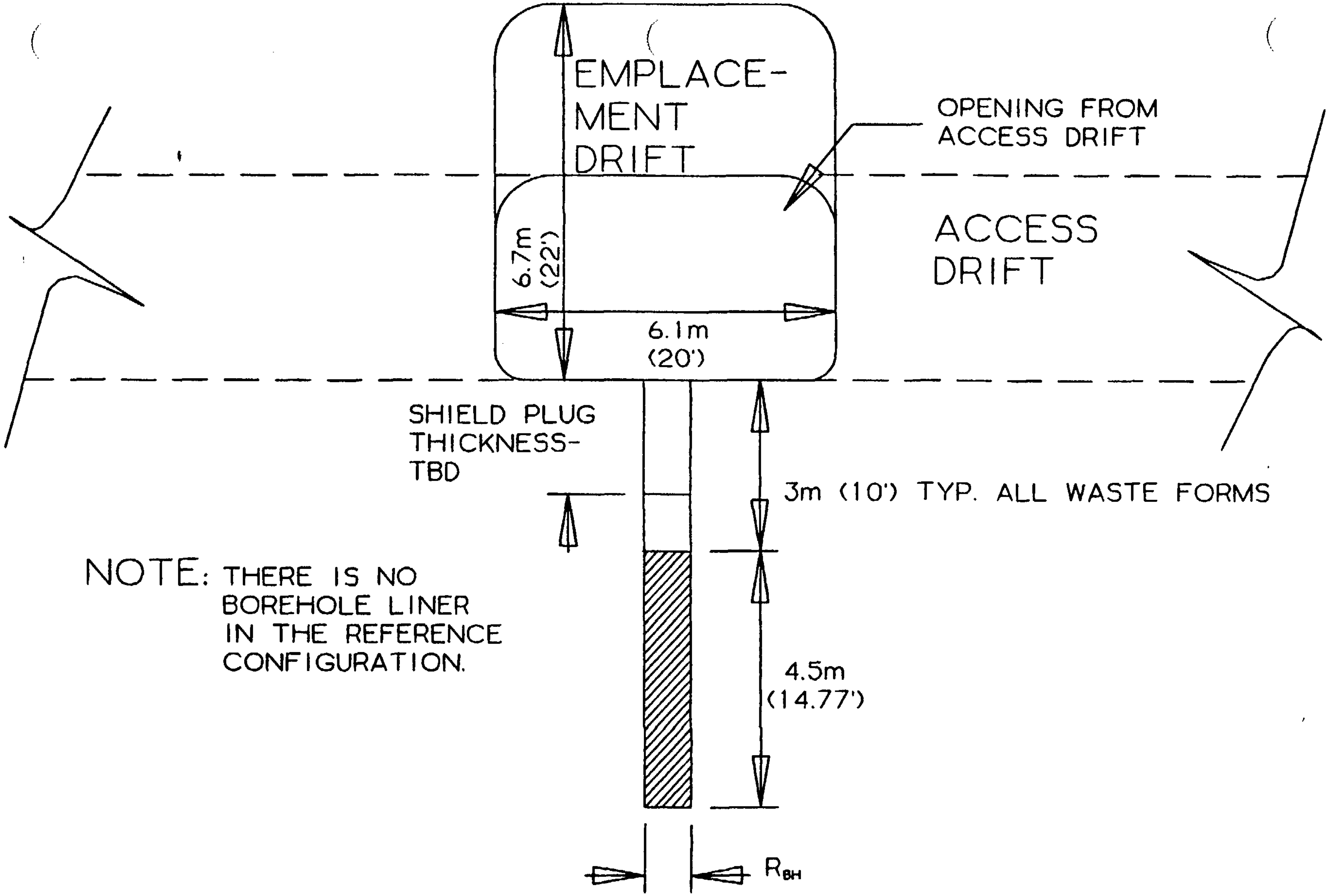

Figure B-3. Cross-Sectional View of the Reference Vertical Emplacement Drift and Borehole Geometry

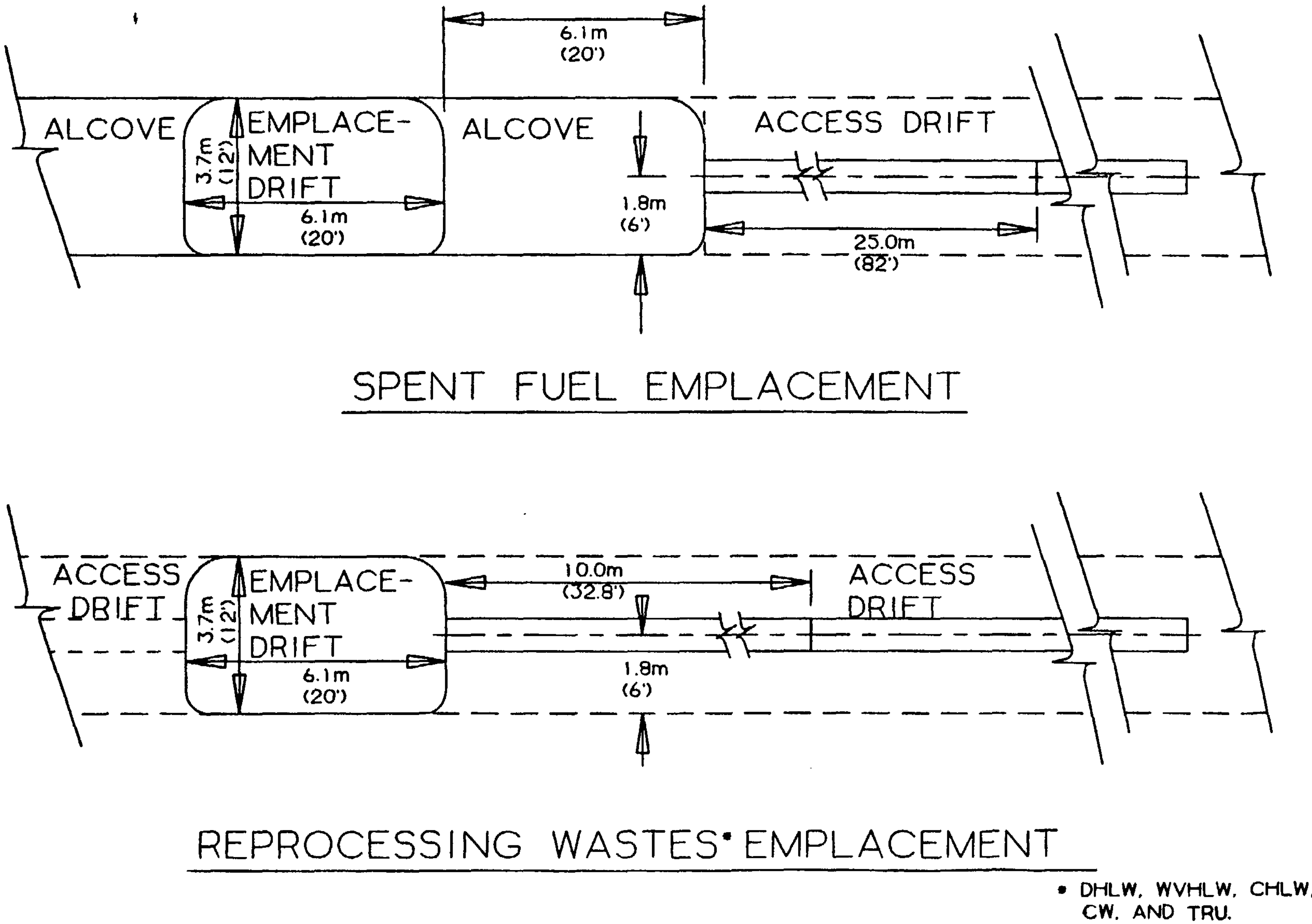

Figure B-4. Cross-Sectional View of the Reference Horizontal Emplacement Drift and Borehole Geometry

B.6.2 Status

The two configurations require different emplacement drift layouts. Borehole spacing depends on the thermal power generated by the radioactive decay of the waste and therefore on the type and age of the waste emplaced. Current concepts allow an APD of 14.1 W/m^2 (57 kW/acre) for spent fuel 10 yr out-of-reactor. For consolidated spent fuel rods, which emit 3.4 kW/canister, the borehole spacing is 8.0 m (26.25 ft) for vertical emplacement and 36.0 m (118.11 ft) for horizontal emplacement. Figure B-5 shows a typical plan view of a vertical emplacement drift, and Figure B-6 shows a typical plan view of a horizontal emplacement drift.

Figures B-3 through B-6 show the different drift configurations required by different emplacement methods. To emplace 1,000 canisters of spent fuel in horizontal boreholes would require the mining of approximately 21,200 m^3 (27,000 yd^3) of tuff, and vertical emplacement would require the mining of 500,000 m^3 (635,000 yd^3). To emplace 1,000 canisters of spent fuel in horizontal boreholes would require the drilling of 5,606 m (18,220 ft) of borehole, while vertical emplacement would require 7,692 m (25,000 ft) of borehole.

The emplacement method selected depends on a number of factors. The greatest differences between the two methods are in the mining, hole drilling, operations, and thermal/structural effects. These factors will be reflected in differences in cost and in environmental and health effects. Mining and drilling costs for vertical emplacement are estimated to be as much as three times the cost of horizontal emplacement (Scully et al., in review).

The larger amount of mined material resulting from vertical emplacement would lead to additional environmental impacts due to the much larger muck pile. These effects have not been quantified. Additional mining accidents may also occur because of the increased mining.

Emplacement and retrieval operations would also be more expensive for vertical emplacement (Scully et al., in review). The cost differential is

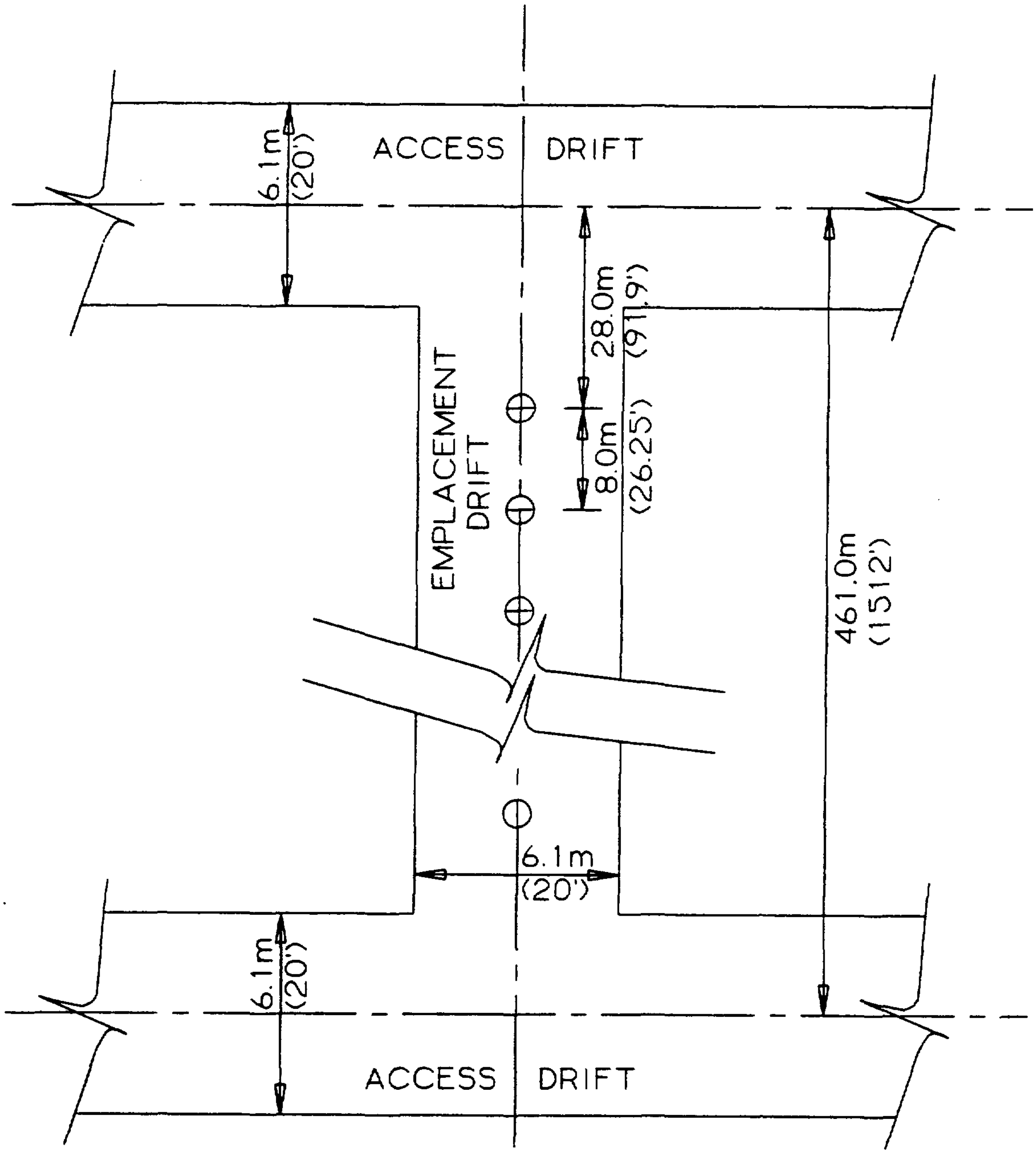

Figure B-5. Plan View of the Reference Drift and Borehole Geometry for Vertical Emplacement of Spent Fuel

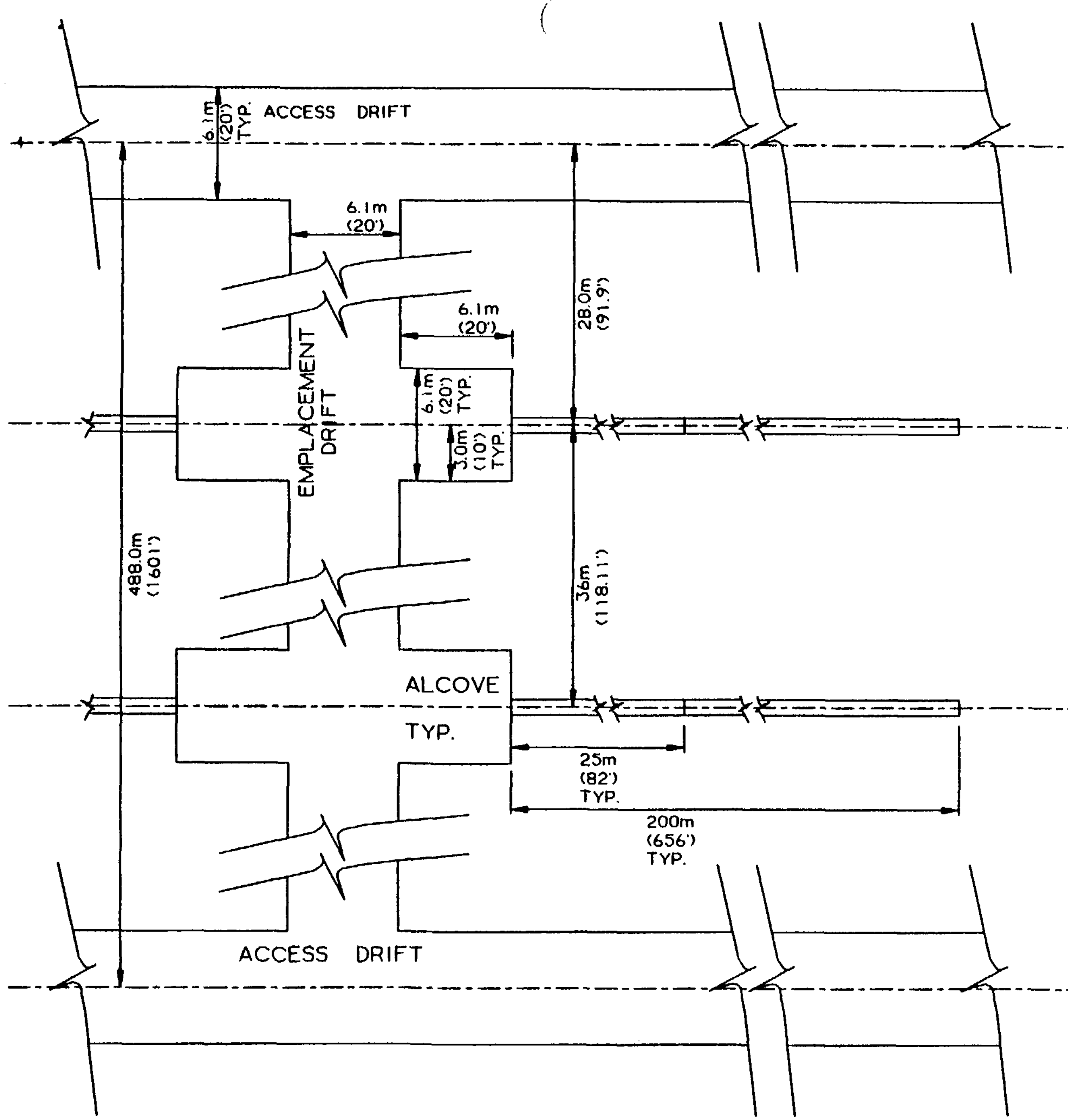

Figure B-6. Plan View of the Reference Drift and Borehole Geometry for Horizontal Emplacement of Spent Fuel estimated to be a factor of three. By leaving vacant a 25-m (82-ft) portion of the horizontal emplacement hole adjacent to the drift, drift temperatures can be kept below 50°C (122°F) without ventilation during the retrieval period. Temperatures in the vertical emplacement drifts rise very quickly, and, without ventilation, would exceed 60°C to 70°C (140°F to 158°F) within 10 to 20 yr, depending on waste type and canister loading (Dravo, in review; Hickox, 1983). The temperatures are based on an assumed APD of 12.4 W/m^2 (50 kW/acre) (see Appendix B.5). The higher temperatures would present problems for maintenance and retrieval operations without continuous cooling of the drifts by the ventilation system.

B.6.3 Future Work

As details of the waste characterization become firm (Appendix A.1) and the results of the waste distribution plan (Appendix B.5) evolve, the emplacement configurations will be updated. Other input parameters include drift stability, drift temperatures, and ventilation air flows.

B.7 Thermal/Mechanical Calculations

B.7.1 Background

Both near-field and far-field thermal and rock mechanics calculations have been performed to support the repository conceptual design. These calculations, which include both scoping calculations and detailed analyses, establish design parameters, evaluate margins of safety, and indicate whether the preliminary concepts meet the preliminary technical constraints (see Table B-3).

B.7.2 Status

Far-field thermal and rock mechanics calculations are important to repository design. The parameters required to establish far-field effects are waste characteristics, APD, disposal area size, and disposal area location, including orientation. The thermal and mechanical responses of the rock in the far field at Yucca Mountain have been shown to be insensitive to the details of the repository design (Brandshaug, 1983). These calculations establish the value for APD for a given waste type and a given disposal area geometry that cannot be exceeded in determining the appropriate borehole and drift spacings.

Near-field thermal and thermal/hydrological calculations have been performed to determine the temperatures of the waste form, rockmass, and drifts and the amount of moisture entering the drifts (Peters, 1982; Langkopf, 1980; Sundberg and Eaton, 1981; Sisson, 1982; Flanagan and Subia, 1983a). These analyses, together with ventilation studies by Dravo (in review) and Hickox (1983), have established the near-field thermal environment that will be considered during the repository design phase.

Near-field analyses of rock mechanics have been performed to evaluate the long-term stability of excavations in the conceptual design (Flanagan and Subia, 1983a; Flanagan and Subia, 1983b; Melo, 1983; Agbabian, in review).

Calculation Methodologies

The calculations performed to date have used a wide range of techniques and approaches, including engineering judgment, simple analytic calculations, numerical evaluation of closed form solutions, boundary element calculations, and finite element methods. The general approach has been to use simple methods for scoping calculations and parameter sensitivity studies, and then to verify the results using more sophisticated calculations. The thermal and rock mechanics analyses have progressed through the scoping phase to the extent necessary to establish the conceptual design values of the relevant parameters (e.g., drift width). Sophisticated models (finite element) have been developed and tested using preliminary parameter values and will be used to evaluate the repository conceptual design.

B.7.3 Results of Thermal/Mechanical Calculations

The objectives of most of the calculations performed to date have been to identify the most suitable geologic unit for waste emplacement (Johnstone et al., 1984; Melo, 1983) and to compare the horizontal and vertical waste emplacement methods (Flanagan and Subia, 1983a). Only preliminary values, chosen for comparative purposes, have been used for design parameters. The conclusions from these studies provide the basis for evaluating the conceptual design. The conclusions of the thermal and ventilation studies are

- The heat from the radioactive waste will not cause moisture to migrate to the drifts in quantities sufficient to cause an accumulation of liquid on the drift walls (Mondy et al., 1983).

- In the horizontal emplacement method, a standoff distance between the emplacement drift wall and the first waste canister will be sufficient to keep the drift temperature from exceeding 50°C (122°F) during the first 50 yr without ventilation.

- In the vertical emplacement method, drift temperatures will reach 100°C (212°F) during the first 50 yr unless the drift is ventilated (Melo, 1983).

- Normal mine ventilation velocities of 18.3 m/min (60 ft/min) should be sufficient to keep both vertical and horizontal emplacement drift temperatures below 50°C (122°F) during the operations period (Hickox, 1983).

- Thermal constraints on waste temperature and rockmass temperature will result in spacing of drifts and boreholes consistent with good mining practice (acceptable extraction ratios) (Scully, 1983; Mansure, in preparation).

- It will take approximately 6 mo to reestablish acceptable working conditions in a vertical emplacement drift using blast cooling (Svalstad and Brandshaug, 1983).

Thermal/Mechanical Design

Thermal/mechanical design relies on both empirical methods and computer calculations. Empirical methods are used primarily to determine extraction ratios that will ensure drift stability and to establish the drift dimensions to be used in computer calculations.

Empirical and mining engineering methods used in preparing the preliminary thermal/mechanical designs include:

- evaluating the ratio of unconfined compressive strength to overburden stress;

- evaluating the pillar factor of safety by the use of empirical relationships, including geometric dimensions, unconfined compressive strength, in situ stress modified by excavation, and a scale factor to account for the difference in rock strength measurements obtained from small rock samples rather than from the actual rockmass;

- evaluating the drift factor of safety by taking into account integrated stress concentration factors, in situ stress, and unconfined compressive strength; and

- evaluating rockmass classification by use of the Norwegian Geotechnical Institute (NGI) Tunneling Quality Index (Barton et al., 1974; Barton, 1976) and South African Council for Scientific and Industrial Research (CSIR) Geomechanics Classification of Jointed Rock Masses (Bieniawski, 1976).

The first three methods give safety factor information. The fourth method, rockmass classification, gives two additional pieces of information: the NGI Tunneling Quality Index gives estimates of the maximum unsupported drift span or drift height that can be constructed safely without ground support; the CSIR Geomechanics Classification of Jointed Rock Masses gives an estimate of the maximum time an unsupported span will stand. The underground mine design is based on these data.

The computer calculations progress through an iterative process, starting with thermal calculations that use the ARRAYF code to determine appropriate canister spacings. In this approach, canister spacings are varied until the arrangement is found that has the maximum APD and that meets performance constraints for temperature (see Table B-3). The emplacement arrangement is used to establish a unit cell for finite-element near-field thermal/mechanical calculations. The APD is then used in far-field calculations. The primary finite-element codes used were ADINA and SPECTROM 11. These codes use a continuum elastic/plastic stress analysis containing ubiquitous vertical joints to determine construction and thermally generated stresses.

B.7.4 Future Work

Additional thermal/mechanical calculations will be performed during the conceptual design phase. An internal planning document in the form of an analyses matrix is being prepared for these additional calculations.

B.8 Worker Radiation Exposure Study

B.8.1 Background

Radiation exposure regulations prepared by the DOE, NRC, and EPA have been reviewed to determine their applicability to the design of the repository at the NTS. The most specific regulations are contained in DOE Order 5480.1A (DOE, 1981). DOE Order 5480.1A states:

> " . . . exposure rates in work areas should be reduced as low as reasonably achievable by proper facility design and equipment layout. Design factors to consider are: occupancy time, source terms, spacing, processes, equipment, and shielding. On-site personnel exposure levels less than one-fifth of the permissible dose equivalent limits prescribed in this chapter should be used as a design objective . . ."

The dose equivalent limit set by DOE Order 5480.1A is 5 rem/yr; hence, the design criterion is less than 1 rem/yr.

Both NRC and EPA regulations are being revised; thus, the design criterion may be changed when the revised regulations are promulgated.

B.8.2 Status

The waste-handling facilities will be designed to limit the maximum individual worker exposure to 0.5 mrem/hr under normal operating conditions. Further, the facilities will be designed to reduce the annual exposure to individual workers and to the total repository work force to the lowest level reasonably achievable. The basis for deciding what is reasonably achievable will be the incremental cost of dose reduction (NRC, 1983a).

A preliminary plan for waste-handling operations has been prepared (Dennis et al., 1984a). This operations plan served as the basis for operator exposure calculations set forth in a subsequent report (Dennis et al., 1984b). These preliminary operator exposure calculations, along with earlier generic analyses (Shirley, 1983), have been used to identify operations for which operator radiation protection beyond that contemplated to date is required to meet conceptual design guidelines (Scully et al., in preparation).

Engineering studies are now under way to identify those operations for which it is cost-effective to provide the operator with a shielded cab or work station and those operations for which it is cost-effective to use remote-handling and automated-handling equipment. To ensure that exposure guidelines are met, all areas that are intended for continuous occupancy will be designed to limit maximum worker exposure to 0.5 mrem/hr. This maximum dose rate would result in an annual exposure of less than 1 rem to workers, when time off for vacations and holidays is taken into account.

A design that will allow the contractor who operates the repository to reduce worker radiation exposure to the lowest levels reasonably achievable is the goal of this study. The basis for deciding what is reasonably achievable will be the incremental cost of dose reduction as discussed in an International Commission on Radiation Protection publication (ICRP, 1977) and DOE guidance (1975). As a minimum, the conceptual design of the repository must allow the operating contractor to meet the radiation exposure guidelines set for the repository in DOE Order 5480.1A.

B.8.3 Future Work

This study will continue through all phases of the repository design process.

B.9 Processing of Waste Generated Onsite

B.9.1 Background

This study discusses the design criteria for handling waste generated onsite as a result of repository operations. This waste is produced during the preparation of waste packages for underground disposal. These wastes, in both solid and liquid form, will be treated onsite and disposed in the low-level transuranic (TRU) waste disposal area. The volume of waste generated onsite will be very small compared to the volume of under-200-mrem/hr waste received from outside sources.

B.9.2 Status

The design criteria for handling waste generated onsite are divided in two classes: (1) criteria for handling solid wastes and (2) criteria for handling liquid wastes.

Solid waste is divided into low-density and high-density categories. Low-density waste consists primarily of anticontamination clothing, rubber gloves, and celluosic materials from decontamination operations. These wastes are shredded, compacted, and put in boxes for disposal. High-density solid waste includes contaminated tools and discarded equipment from hot cell operations. Large items are disassembled or cut up in the hot cells and packaged in 208-ℓ (55-gal) drums, boxes, or, when necessary, in special containers designed to fit a particular piece of equipment. These criteria for packaging solid wastes are derived from current nuclear industry practices.

Liquid waste will consist largely of aqueous decontamination solutions that result from carrier washdown, cask decontamination, and other activities. These wastes will either be filtered or centrifuged to remove suspended solids and will then be collected and sampled for level of radioactivity.

Additional treatment, such as ion exchange, may be used to reduce the level of radioactivity, and the treated effluent will be processed in a multiple-stage evaporator and spray dryer. All distillate will be collected and recycled. The criteria for handling liquid wastes are also derived from current nuclear industry practice.

B.9.3 Future Work

Facilities for processing waste generated onsite will be further defined during the conceptual design phase.

B.10 Equipment Development

B.10.1 Background

Spent fuel rod bundles and spent fuel shipping casks have been handled successfully in many facilities for years. The transport of radioactive materials and the transfer of waste from surface storage to the transporter and from the transporter to a disposal location have been successfully accomplished. Underground drilling operations in some size ranges are routine and use off-the-shelf equipment. Repository operations involve a scale that, in some cases, renders previously tried methods unacceptable due either to the frequency of the operation or to the overall economics of the operations. New techniques and equipment must be developed and demonstrated before an application for a construction authorization can be submitted.

B.10.2 Status of Equipment Development

Shipping Cask Receipt and Preparation

The preliminary analysis of cask receipt and preparation tasks indicates that automation is necessary to keep operator exposure within acceptable levels. Because cask receipt is a frequent occurrence at a repository, the required worker exposure levels cannot be maintained using conventional contact methods. Procedures that require development include remote-handling methods to accomplish cask inspection, cask handling, and preparation of casks for unloading.

Future activities will identify the specific tasks that require automated equipment and the hardware that requires redesign or for which new designs must be prepared. Specifications and design criteria will be developed. State-of-the-art techniques and existing robotic-type equipment will be surveyed to determine their suitability for use in a repository. Where existing technology can be adopted or applied to produce the desired results, equipment development activity will be left to commercial vendors to produce at the appropriate time. A program will be undertaken to develop special equipment that is not commercially available.

Spent Fuel Consolidation Equipment

Intact spent fuel assemblies will be received at the repository. It may be cost-effective to remove the individual fuel rods from the fuel assemblies and to package the fuel rods and assembly hardware separately for disposal. This process, disassembling the fuel bundles and packaging the components separately, is called "fuel consolidation."

Prototype fuel consolidation equipment is being used at reactors to reduce the space required for the storage of spent fuel. The cost effectiveness of fuel consolidation at the NNWSI repository is being investigated and will be determined as part of the repository conceptual design effort. If fuel consolidation at the repository proves to be cost-effective, design criteria for fuel consolidation equipment and facilities will be developed.

Waste Transporters

Two waste transporters for the vertical waste emplacement method have been built and demonstrated in Project Salt Vault (Lyons, Kansas) (Bradshaw and McClain, 1971) and in the Climax Spent Fuel Demonstration (Nevada Test Site) (Heuze, 1981). While neither of these transporters was totally prototypical of a vehicle that is suitable for use in a repository, the technology has been demonstrated. A transporter for the horizontal emplacement method has not been developed; therefore, equipment development efforts will focus on the development and demonstration of this transporter.

The approach will first establish the feasibility of horizontal emplacement. Assuming that horizontal emplacement is feasible, transporter concepts will be developed. The more promising concepts will be explored using surface mockups. The final steps will be design, fabrication, and loading to full nonradioactive demonstration of a prototype unit.

The results to date include a feasibility study for the horizontal transporter (Foster-Miller, Inc., in review). The study indicates that the concept presented is feasible. An expansion of this study into other concepts is under way as are planning and scheduling for the design, fabrication, and testing phases.

Waste Emplacement and Retrieval Equipment

Emplacement and retrieval in the vertical emplacement method have been demonstrated (Bradshaw and McClain, 1971). Emplacement in long horizontal boreholes has not been demonstrated. Efforts will concentrate on the development of equipment to emplace and retrieve canistered waste from long 183-m (600-ft) to 213-m (700-ft) horizontal boreholes. The approach to this task will be similar to that used for the waste transporter and will include feasibility determination, conceptual design and testing, and prototype design, development, and testing, followed by full nonradioactive demonstration.

The results to date are encouraging and are included in a feasibility study for emplacement and normal retrieval (i.e., boreholes with intact liners) (Foster-Miller, Inc., in review). Expansion of the study to include additional concepts is in progress. Planning and scheduling for the design, fabrication, and testing phases are also under way. A feasibility study for overcoring a full canister of waste 0.9 m (3 ft) in diameter and 4.6 m (15 ft) long has been accomplished (Robbins, in preparation). Assuming that drilling is confined only to the grout surrounding a canister in an intact borehole, the proposed core barrel appears feasible; however, considerable development would be required before a high level of confidence in the overcoring technique could be achieved.

Emplacement Borehole Drilling Equipment

The drilling of both the vertical and horizontal emplacement holes requires development of equipment that does not currently exist. The drilling equipment required for shallow vertical boreholes is very close to off-the-shelf hardware; therefore, an immediate effort to develop drilling equipment for the vertical method is not required. Drilling equipment for long horizontal boreholes is less well developed. Cutter technology has been developed and demonstrated in hard rock by tunnel-boring machines; therefore, guidance systems can be adapted from existing tunnel-boring technology. Also, considerable data exist on motors, gearboxes, thrust cylinders, and other major components, and for chip removal systems. There is considerable experience with tunnel-boring hardware capable of boring holes 1.8 m (6 ft) in diameter.

Efforts to develop equipment for drilling long horizontal boreholes will concentrate on scaling down existing hardware to develop a drilling system that can drill a hole in the range of 0.6 m (2 ft) to 1.2 m (4 ft) in diameter, 182 m (600 ft) to 213 m (700 ft) long, and that can concurrently or subsequently line the hole with steel casing. The development approach will be to explore (1) conventional pilot hole drilling, using rotating drill pipe to bore into a parallel drift and subsequently back-reaming to the required size, and (2) boring, using nonrotating drill pipe and a down-hole cutter drive and steering system. To assess the viability of conventional drilling techniques, the accuracy of state-of-the-art pilot hole drilling equipment will be determined, and the equipment may be field tested. Feasibility studies, followed by conceptual design and testing, prototype design, and fabrication, testing, and field demonstrations of full systems will be the development sequence.

The results to date include a report (Robbins, 1984) on the feasibility of boring a system of holes 0.6 m (2 ft) to 1.2 m (4 ft) in diameter and 183 m (600 ft) to 213 m (700 ft) long. In the next phase, the feasibility of emplacing a steel liner directly behind the cutterhead as the hole is being drilled will be explored. An accuracy survey of pilot holes is also being initiated to establish the maximum borehole length that can be achieved by back-reaming.

Future activities will lead to the field demonstration of either rotating drill pipe or rotating cutterhead equipment for the emplacement holes.

Mechanical Miner

The construction of the underground openings can be accomplished by conventional drill and blast techniques. However, if a mechanical miner can be used, several advantages will accrue. First, eliminating the use of explosives will improve safety. Second, the surface finish of road beds and drift walls will be much smoother than that of a blasted surface, which will facilitate bolting shield doors and installing ventilation barriers. Third, assuming estimated production rates can be achieved, the use of mechanical miners is much less labor-intensive and will require less overbreak (extra rock) removal. Therefore, the mechanical miner could be more cost-effective.

The approach will be to establish the cutting characteristics of the Topopah Spring Member and to determine whether commercial mechanical miners operate effectively in this medium. A new mining machine is undergoing final development at one manufacturer. A prototype of the concept has already been demonstrated in rock comparable to welded tuff. As this equipment is developed, it will be monitored, and, as appropriate, a demonstration to verify applicability will be arranged.

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GLOSSARY

Access drift - A drift in the disposal area that connects the parallel emplacement drifts. Access drifts serve as passageways for waste transporters and are used as haulageways for muck, materials, and equipment.

Accessible environment - The atmosphere, the land surface, surface water, oceans, and the portion of the lithosphere outside the controlled area of the repository.

Actinides - Radioactive elements with an atomic number larger than 88.

Activation - The process of making a material radioactive by bombardment with neutrons, protons, or other nuclear particles.

Activity - A measure of the rate at which radioactive material is decaying and emitting radiation; usually given in terms of the number of nuclear disintegrations occurring in a given quantity of material over a unit of time. The special unit of activity is the curie.

ADINA - A finite element computer code for thermoelastic/plastic stress analysis that includes a capability for considering ubiquitous joints or fractures in a rockmass.

ALARA - As low as reasonably achievable. ALARA refers to limiting radioactive releases and radiation exposures.

Apron feeder - A machine consisting of a series of overlapping metal plates (aprons) that run in an endless chain. The machine is used for transferring materials (such as muck) at a constant feed rate.

Areal energy density (or deposition) - The total amount of thermal energy deposited in the host rock, averaged over the area of an emplacement panel, during the period that the waste is emplaced. Units are gigajoules per square meter.

Areal power density (APD) - The total amount of thermal power produced by emplaced waste, averaged over the area of an emplacement panel, expressed in watts per square meter or in kilowatts per acre. The initial value (IAPD) at the time the waste is emplaced is a design input parameter used in far-field thermal and thermomechanical response calculations.

Argillic (argillaceous) - Containing or pertaining to clay or clay mixed with minerals.

ARRAYF - A computer code for calculating temperature profiles around an array of emplaced waste that uses numerical integration and superposition of closed-form heat transfer solutions.

Articulating boom - An arm or lever extending from a fixed machine (usually hydraulic), which, through the use of two to three joints, can be oriented in any direction.

Atomic number - The number of protons within an atomic nucleus.

Backfill - The material used to refill an excavation. This material is often the original excavated material.

Barrier - Any material or structures that prevent or substantially delay movement of the emplaced wastes toward the accessible environment. A barrier may be a natural barrier (the geologic medium in which the waste is emplaced) or a manmade (engineered) barrier such as a concrete wall that seals off a portion of the repository.

Blast cooling - A method of cooling an emplacement drift by forcing a large quantity of cooler air through the drift.

Boiling water reactor (BWR) - A reactor that uses boiling water in the primary cooling system. Primary cooling system steam turns turbines to generate electricity.

Borehole liner - A metallic or ceramic sleeve placed in a vertical or horizontal borehole to prevent sloughed rock from interfering with waste package emplacement or retrieval operations.

Borosilicate glass - A silicate glass containing at least 5% boric acid. This glass is one of several materials used as a matrix in which radioactive waste is incorporated in order to reduce the leachability and dispersibility of the waste.

Brow - The intersection of a shaft wall and the top of a horizontal opening. A brow usually requires special support.

Bulkhead - A tight partition of masonry, steel, or concrete used to control ventilation and to separate construction activities from waste emplacement activities.

Burnup - A measure of nuclear fuel consumption in a reactor, expressed as the total amount of heat released per unit weight of fuel (megawatt-days per metric ton of initial heavy metal).

Canister - As used in this document, a metal container for solid radioactive waste. A canister provides physical containment but no shielding against penetrating gamma radiation. During transfer from work station to work station, shielding is provided by a cask.

Cask - A container that holds one or more canisters and provides shielding for highly radioactive materials during transportation. (See "facility cask" and "shipping cask.")

Cladding - Stainless steel or Zircaloy metal tubing in which fuel pellets are encased. Pellets enclosed in the cladding by end caps comprise a fuel rod.

Cladding waste (hulls) - Pieces of fuel rod tubing that remain after the spent fuel has been chopped up and the fuel material has dissolved into the liquid feed stream of the uranium and plutonium recovery processes at a reprocessing plant.

Collar - The junction of a mine shaft and the ground surface.

Commercial high-level waste (CHLW) - Products from solidification of high-level liquid wastes generated from reprocessing spent nuclear reactor fuel from commercial electric power plants.

Conceptual design - Defined as that design which thoroughly establishes the scope of a project and provides a basis for a reliable budget estimate. The types of construction, utilities, power, services, equipment, shielding, processes, instrument requirements, and space allocations are all established.

Consolidation - As used in this document, consolidation refers to the process whereby fuel rods removed from either BWR or PWR assemblies are repackaged in a more compact package for waste disposal.

Constraint - See "performance constraints".

Construction authorization - Permit issued by the NRC to construct a nuclear facility.

Construction liner (shaft liner) - A steel, brick, or concrete structure fixed around a shaft to support the walls. In modern shafts, a concrete lining is generally used as a permanent shaft liner.

Containment (confinement) - The confinement of radioactive wastes within designated boundaries, e.g., within a waste package.

Contamination - Undesired radioactive material on the outside surface; does not pertain to radioactivity that penetrates the walls of a waste package.

Controlled area - A surface location to be marked by suitable monuments extending horizontally no more than 10 kilometers in any direction from the outer boundary of the underlying waste disposal area from which incompatible activities will be restricted following permanent closure.

Curie (Ci) - A special unit of activity that equals 3.7×10^{10} spontaneous nuclear disintegrations per second.

Decay period - The amount of time a fuel assembly spends in a nuclear reactor during which the reactor is shut down.

Decommissioning - Preparations taken for retiring nuclear facilities from active service, accompanied by the execution of a program to reduce or stabilize radioactive contamination. The objective of decommissioning is to place the facility in a condition that ensures that future risk to the public safety is within acceptable bounds.

Decontamination - The selective removal of radioactive material from a surface or from within another material.

Defense high-level waste (DHLW) - Products from the solidification of high-level liquid wastes that have been generated by the reprocessing of spent fuel produced by nuclear reactors used in federal defense programs.

Design basis - A principal determinant that establishes the overall repository design. There are two bases for the repository design: (1) the waste to be disposed and (2) the geologic characteristics of the site.

Design criteria - Rules, regulations, codes, standards, and design-dependent constraints that govern the design of the repository. These criteria have been developed to ensure that facility design, construction, and performance objectives will be met.

Dip - The angle at which a bed, stratum, vein, or any other planar geologic feature is inclined from a horizontal position. The dip is measured in a vertical plane that is perpendicular to the strike of the geologic feature.

Disposal - The permanent emplacement of high-level radioactive waste, spent nuclear fuel, or other highly radioactive material in a repository. The repository will be designed to allow the retrieval of the waste, if necessary.

Dose - A term, generally having the same meaning as the more rigorous term "dose equivalent," that expresses radiation exposure as a quantity of biological damage in units of rem.

Drift - Horizontal, or nearly horizontal, mined passageway. In this document, the term "access drift" is used to describe the tunnels that provide access to the emplacement drifts.

Electrohydraulic drill jumbo - An electrically powered, hydraulically controlled drilling machine consisting of a carriage or mobile platform on which the drills are mounted.

Emplacement drift - Drift in which radioactive waste packages are disposed in either horizontal or vertical boreholes.

En echelon - Pertaining to geologic features that overlap or are staggered.

Engineered barriers - Man-made components of a disposal system designed to prevent the release of radionuclides into the geologic emplacement medium; includes any cladding or matrix that surrounds high-level waste, canisters for high-level radioactive waste, and other materials placed over and around these canisters.

Exploratory shaft (ES) - A vertical shaft sunk through the candidate emplacement horizon to allow in situ characterization of the underground environment. In the first phase, access will be provided to the candidate horizon to verify its suitability and to demonstrate the effectiveness of shaft design and construction methods. The second phase will include in situ testing as a means of resolving issues concerning the suitability of the site for a repository.

Extraction ratio - Ratio of mined area to total area.

Facility cask - A specially designed container that provides shielding and containment for waste disposal packages during transfer from the surface facility to the disposal locations underground.

Fan-and-filter train - Ventilation system component consisting of a series of graduated particulate air filters and a fan to compensate for the pressure drop across the filters.

Far field - The zone extending from the near field outward in all directions to a distance equal to the depth of the disposal area. The far field includes the rockmass, the groundwater regime, and the shafts, ramps, and drill holes.

Fault - A fracture or fracture zone within a rock formation along which vertical, horizontal, or transverse slippage occurs.

Fault block - A crustal unit either completely or partly bounded by faults.

Feeder/breaker - A component of the muck-handling system that is fed by load-haul-dump (LHD) vehicles and that breaks up the mined rock and feeds it to the main conveyor.

Finite element calculations - An approximation method for studying continuous physical systems; the physical system under study is divided into discrete elements interconnected at discrete node points.

Fission (nuclear) - The splitting of a nucleus into two or (rarely) more fragments; usually limited to heavier nuclei such as isotopes of uranium, plutonium, and thorium.

Fission product - Any radioactive or stable nuclide produced by fission, including both primary fission fragments and their radioactive decay products.

Fissionable material - Actinides capable of undergoing fission by interaction with neutrons of all energies.

Geohydrology - The science that relates to the character, source, and mode of occurrence of the water of the earth.

Geologic setting - The spatially distributed geologic, hydrologic, and geochemical systems at and around a geographic site.

Glove box - A sealed compartment that has a protective liner and holes to which gloves are attached and sealed for use in handling radioactive materials inside the compartment.

Ground support (or control) - Methods by which underground openings are artificially supported to provide long-term stability; e.g., rockbolts, steel sets, shotcrete.

roundwater - Water that exists or flows within a zone of saturation beneath the land surface.

Half-life - (a) Physical--the time required for a quantity of a radioactive substance to decay to one-half of its original quantity. (b) Biological--time required for half of an ingested or inhaled substance to be eliminated from the body by natural process. (c) Effective--time required for half of an ingested or inhaled radioactive substance to be eliminated from the body by a combination of radioactive decay and natural processes; mathematically equal to the product of the physical and biological half-lives divided by the sum of the physical and biological half-lives.

Head frame - The steel frame at the top of a shaft that carries the sheave or pulley for the hoisting rope, skip-dumping gear, or cage-unloading facilities.

Heater test - An experiment involving the placement of heaters in openings in a rockmass to observe structural, thermal, hydrologic, and/or geochemical responses.

High-efficiency particulate air (HEPA) filter - An air filter capable of removing from an air stream at least 99.97% of particulate material as small as 0.3 micron in diameter.

High-level waste - (a) The highly radioactive material that results from the reprocessing of spent nuclear fuel, including liquid waste produced directly from reprocessing and any solid material derived from this liquid waste that contains concentrated fission products; (b) other highly radioactive material that the NRC, in compliance with existing law, determines by rule requires permanent isolation.

Hoist house - The building containing the hoist or hoists used for raising or lowering men and/or materials in a shaft; usually located on the surface near the headframe.

Hot cell - A heavily shielded containment structure, usually constructed of concrete and equipped to permit remote viewing and handling of highly radioactive material. It is used during the removal of waste from the shipping cask, repackaging, and transferring the waste to the waste transporter.

Hydraulic gradient - The change in static head per unit of lateral distance in a given direction.

Hydrostatic pressure - The pressure exerted by the water at any given point in a body of water at rest.

In-hole powered roller system - A conveyor installed in a horizontal borehole that moves waste disposal packages to or from their positions inside the borehole.

In situ - In the natural or original position or condition.

In situ stress - The magnitude and state of ground stress in a rockmass before any excavation or other man-made disturbance.

Ion exchange - Process for selectively removing a solute from a waste stream by reversibly transferring ions between an insoluble solid and a solute in the waste stream; the exchange medium can then be washed to collect the waste or taken directly to disposal.

Irradiation - Exposure of an object, material, or organism to radiation.

Irradiation period - The amount of time a fuel assembly spends in a nuclear reactor during which the reactor is operating.

Isolation - As defined in 10 CFR 60, the inhibition of the transport of radioactive material from the repository so that amounts and concentrations entering the accessible environment will be kept within prescribed radiological limits.

Lagging - Material used to secure the roof and sides of an underground opening behind the main steel supports. This material is usually short lengths of steel or timber.

Licensing - The process of obtaining the authorizations from the NRC to site, construct, operate, and decommission a repository for radioactive waste prior to commencement of these activities. Licensing is conducted in accordance with 10 CFR 60.

Lithophysae - Hollow, bubble-like voids or filled-void structures that are found in certain volcanic rocks and are composed of concentric shells of fine crystalline minerals.

Low-level waste - (a) Radioactive material that is not high-level radioactive waste, spent nuclear fuel, transuranic waste, or byproduct material as defined in Section 11e(z) of the Atomic Energy Act of 1954 [42 U.S.C. 2014 (e)(z)], and (b) radioactive material that the NRC, in compliance with existing law, classifies as low-level radioactive waste.

Man-rem - Unit of the radiation dose received by a population group.

Maximum individual - A term used in radiological impact assessment for a hypothetical person whose assumed or estimated location and habits maximize the radiation exposure calculated for that individual.

Medium - A surrounding or enveloping substance; the geologic medium for radioactive waste disposal is the formation (host rock) in which the waste is emplaced. Several media are being considered: salt, basalt, crystalline rock, and tuff.

Megapascal (MPa) - A unit of pressure equal to the pressure resulting from a force of one million newtons acting uniformly over an area of one square meter. One megapascal equals 144.9 pounds per square inch.

Mined geologic disposal system (MGDS) - A licensed system for disposing of commercial spent fuel and high-level and transuranic waste in mined excavations in a geologic formation. The system is composed of three major subsystems: the geologic setting, the repository, and the waste disposal package.

xed-oxide fuel - Nuclear reactor fuel containing both uranium and plutonium oxides.

Model - A conceptual description and associated mathematical representation of a system, subsystem, component, or condition that is used to predict changes from a baseline state as a function of internal and/or external stimuli and as a function of time and space.

Monitoring - Routine measuring of the quantity and type of discharge or migration of radioactive waste from a waste management facility. Monitoring also measures changes in physical, chemical, or biological characteristics of the site and the surrounding area.

MTHM (MTIHM) - Metric tons of heavy metal (metric tons of initial heavy metal); refers to the heavy metal (usually uranium and/or plutonium) fuel material loaded into fresh reactor fuel; sometimes MTU (metric tons of uranium) is used to describe reactor fuel loaded with uranium only.

Muck - Ore or rock broken and removed during excavation operations.

Natural barrier - The physical, mechanical, chemical, and hydrologic characteristics of the geologic environment that individually or collectively act to minimize or preclude radionuclide transport.

Near field - Pertains to the repository system geometry and repository-induced effects; that space within the engineered barrier system.

Neutron - An elementary atomic particle with no charge and a mass approximately equal to that of a proton that is emitted by certain nuclear transformations.

Nevada Test Site (NTS) - An area of 3,367 square kilometers (1,300 square miles) in Clark and Nye counties in southern Nevada dedicated to U.S. Department of Energy programs.

Normalized thermal power - The thermal power of radioactive waste expressed as the ratio of the power at a given time to the power at a specific time. For example, if the power is x kilowatts at the time of emplacement in the repository and 0.5 x kilowatts after the waste has been emplaced for 50 years, then the normalized thermal power at the time of emplacement is 1.0 and 50 years after emplacement is 0.5.

Nuclide (radionuclide) - A species of atom characterized by the number of protons and neutrons in its nucleus and by the energy content of its nucleus. These factors determine the properties of an element, including its radioactivity. Radioactive nuclides are called radionuclides.

Offgas - Gas released by a material undergoing a chemical, thermal, or other process.

ORIGEN2 - An improved version of a computer code (ORIGEN) that calculates the buildup and decay of radionuclide inventories, thermal power, and other characteristics of reactor fuel as it undergoes processes in nuclear reactors and reprocessing plants. Both ORIGEN and ORIGEN2 were developed by Oak Ridge National Laboratory.

Overburden - Soil, sand, gravel, and other materials that lie above bedrock.

Overtravel - The extra distance provided at a mine shaft collar and at the underground station at the bottom of a shaft for stopping a conveyance for men and/or materials.

Panel - A usually rectangular section of the underground layout sized to accommodate a certain amount of waste and used in planning, scheduling, and design analyses.

Perched groundwater - Water in the unsaturated zone (above the deepest water table) having pressure greater than atmospheric.

Performance constraints - Quantitative limits within which a repository must be designed so that the performance objectives of protecting the public and the environment from radiological hazards can be met.

Permeability - Capacity of a substance to transmit a fluid

Pillar - A column of rock left after excavation of the surrounding rock to provide support for the overlying strata.

Plug - A combination of materials used to close off a shaft; these materials may include crushed tuff, sand, grout, and concrete.

Porosity - That capacity of a rock or soil to contain water in voids or interstices; usually expressed as a percentage or as a ratio of void volume to total volume.

Portal - The aboveground entrance to a ramp.

Pressurized water reactor (PWR) - A reactor system that uses pressurized water in its primary cooling system. Steam produced in a secondary cooling system is used to turn turbines to generate electricity.

Quality assurance (QA) - All those planned and systematic actions necessary to provide adequate confidence that the geologic repository and its subsystems or components will perform satisfactorily in service. Quality assurance includes quality control, which provides a process for ensuring that the quality of a material, structure, component, or system meets predetermined requirements.

Radiation - Particles and electromagnetic energy emitted by nuclear transformation that are capable of producing ions when interacting with matter; gamma rays and alpha and beta particles are primary examples.

Radioactive decay - The spontaneous transformation of one nuclide into one or more different nuclides, accompanied by the emission of radiation.

Raise drilling - A large-diameter hole drilled upward from the bottom.

Ramp - An inclined opening that leads from the surface to the underground facility. Ramp access is planned for waste emplacement activities.

Regenerative braking - A braking system, which uses electric motors, in which electricity is generated as well as consumed.

Rem - A unit of radiation dose equivalent that is numerically equal to an absorbed dose of 100 ergs/gram (deposited by 250-kVP X rays) multiplied by a quality factor, a distribution factor, and any other necessary modifying factors that translate the absorbed dose into an equivalent quantity of biological damage.

Remote handling - The manipulation of radioactive waste by using specially designed equipment that allows operators to move waste with minimal exposure to radiation.

Repository - Any system licensed by the NRC that is intended to be used for the permanent deep geologic disposal of high-level radioactive waste and spent nuclear fuel, whether or not the system is designed to permit the recovery, for a limited period during initial operation, of any materials placed in the system. This term includes both surface and subsurface areas in which waste-handling activities are conducted.

Reprocessing - Chemical processing of spent nuclear reactor fuel to recover fissionable materials.

Retrievability - Capability of removing waste from its place of isolation using planned engineering procedures.

Retrieval - The act of intentionally removing radioactive waste from the underground location at which the waste had been previously emplaced for disposal.

Retrieval period - The period after the waste has been emplaced in the repository during which retrievability is maintained.

Risk (mathematical) - The product of the consequences and the probability of an event's occurrence.

Rockbolt - A bar, usually fabricated of steel, inserted into predrilled holes in rock and secured. Rockbolts are used in combination with wire mesh to prevent pieces of rock from falling into underground excavations.

Saturated zone - That part of the earth's crust beneath the deepest water table in which all voids, large and small, are theoretically filled with water under pressure greater than atmospheric.

Scaling - Removal of loose rock from the excavation roof, walls, or drilling surface for safety purposes.

Sealing - Those activities associated with the permanent closure of the underground facility, shafts, ramps, and boreholes. Materials used in sealing may include crushed tuff, grout, and concrete.

Seismicity - The phenomenon of earth movements.

Shaft - A vertical excavation, commonly made from the surface. Compared to its depth, it has a small cross-section area. A shaft may be used for lowering and hoisting men and materials, for draining water, or for ventilation.

Shaft-and-drift access - A method of gaining access to an underground point not directly beneath the surface entry. A vertical shaft is sunk to the desired underground elevation, and a horizontal drift is driven to intersect the shaft at the desired location. Used as an alternative to a ramp.

Shield plug - A thick cylinder, usually concrete, used to permanently plug boreholes and reduce radiation exposure levels in the drift after waste has been emplaced in the borehole.

Shielded fork-lift truck - A conventional fork-lift truck to which shielding has been added in order to control radiation exposure to the operator from radioactive loads.

Shielding - A material interposed between a source of radiation and personnel for protection against the danger of radiation. Commonly used shielding materials are concrete, water, lead, and steel.

Shielding closure - A massive temporary fixture placed over a vertical or horizontal borehole to provide protection from radiation during waste emplacement and retrieval.

Shipping cask - A specially designed and certified, massive metal container that provides shielding and containment in accordance with federal and/or international radiological safety rules and regulations for safe transportation of radioactive materials through the public domain.

Shotcrete - Portland cement, mortar, or Gunite pneumatically applied to scaled surfaces of underground excavations to prevent erosion by air and moisture in order to provide a smooth surface that reduces drag on ventilation flow and to provide some ground support.

Site - The rectangular area surrounding the repository as shown in Figures 1-1 and 1-3.

Skid-steered vehicle - A vehicle whose steering is accomplished by braking the wheels on one side of the vehicle while powering the wheels on the other side.

Skip - A self-dumping type of bucket used in a shaft for hoisting ore or rock.

Specific power - The total heat produced by a reactor core or component of the core (e.g., a fuel assembly) divided by the total mass of fissionable material in the core or component.

SPECTROM 11 - A finite element computer code for thermoelastic/plastic stress analysis that includes a capability for considering ubiquitous joints or fractures in a rockmass.

Spent fuel (nuclear) - Fuel that has been withdrawn from a nuclear reactor following irradiation, the constituent elements of which have not been separated by reprocessing.

Standoff (distance) - A variable distance between the drift wall or floor and the radioactive waste in a horizontal or vertical borehole. The standoff distance aids in controlling temperatures and radiation exposure levels in the drift.

Storage - Retention of high-level radioactive waste, spent nuclear fuel, or transuranic waste with the intent of recovering this waste or fuel for subsequent use, processing, or disposal.

Strain - Deformation resulting from applied stress; strain is proportional to stress.

Stratigraphic unit - A bed or layer of rock, or a body of layers classified as a unit on the basis of character, property, or attribute.

Stress - The force per unit area in a solid material found by dividing the total force by the area to which the force is applied.

Strike - The direction or bearing of a horizontal line in an inclined plane, such as a bed, vein, or other planar geologic feature.

Structural block - A fault block or blocks that behave as a unified structural entity.

Surface dose rate - The radiation exposure rate measured at the surface of an object such as a container of radioactive waste.

Surge storage - Temporary storage required because of logistical variations or operational requirements.

Suspect storage - An area in which waste shipments or packages that may be damaged or defective are stored until appropriate measures can be taken.

Switchgear room - A room containing the aggregate of switching devices for an electric power or transformer station.

Tectonic - Of, pertaining to, or designating the processes causing, and the rock structures resulting from, deformation of the earth's crust.

Testing - The determination or verification of the capability of an item to meet specified requirements by subjecting the item to a set of physical, chemical, environmental, or operating conditions. Testing may also be exploratory in nature for the purpose of determining physical parameters and may be conducted in situ as part of a field program or performed in a laboratory on materials acquired at this site or on materials representative of those at the site.

Title I Design - A more detailed design than the repository conceptual design containing more particulars on all topics and the completion of the various trade-off studies. Additionally, the outline of specifications for equipment and construction, a rough construction package breakdown, and cost estimates of ±10% for construction and operations will be provided. A large number of drawings will accompany this document.

Title II Design - The final design document from which the repository will actually be constructed. This document will contain construction drawings and bid packages as well as detailed specifications for all repository equipment, buildings, and underground workings.

Transportation package - A transportation packaging and its radioactive contents.

Transportation packaging - One or more receptacles and wrappers and their contents, excluding fissile material and other radioactive material, but including absorbent material, spacing structures, thermal insulation, radiation shielding, devices for cooling and for absorbing mechanical shock, external fittings, neutron moderators, nonfissile neutron absorbers, and other supplementary equipment. These packagings are specially designed and certified in accordance with federal and/or international radiological safety rules and regulations for safe transportation of radioactive materials through the public domain.

Ubiquitous vertical joints - Frequent small joints uniformly distributed through a rockmass.

Unconfined compressive strength - The load that a rock can withstand without breaking when it is compressed in one direction without confinement from other directions.

Unsaturated zone - That part of the earth's crust in which not all of the voids are filled with water.

Ventilation drift - A mined drift used exclusively as a conduit for ventilation air.

Vitric - Glassy.

Vitrification - Any act or process, whether geological or man-made, of forming a glassy material.

Waste (radioactive) - Radioactive material emplaced in the repository.

Waste disposal package - The primary container that holds, and is in contact with, solidified high-level radioactive waste, spent nuclear fuel, or other radioactive materials, and any overpacks that are emplaced at a repository.

Waste disposal system - The configuration of man-made and natural features that provides for the handling, disposal, and isolation of radioactive wastes. This system includes waste packages, the repository, the site, and those portions of the geologic setting that provide for isolation of the wastes.

aste form - Radioactive waste and any encapsulating or stabilizing matrix.

Waste management - The planning, execution, and surveillance of essential functions related to the control of radioactive (and nonradioactive) waste, including treatment, transportation, storage, surveillance, and isolation.

Water table - The upper surface of the zone of water saturation at which the pressure is equal to atmospheric pressure; the upper surface of an unconfined aquifer.

Welded tuff - Tuff that has been hardened by heat retained in the material and in associated gases.

West Valley high-level waste (WVHLW) - Products from solidification of high-level liquid waste currently stored at the West Valley Nuclear Fuel Services facility in West Valley, New York. The high-level liquid wastes were generated from reprocessing spent nuclear reactor fuel.

X ray - Penetrating electromagnetic radiation produced by electron energy transitions.

Yieldable steel arches - Steel arches installed in underground openings as the ground is removed. These arches are used to support loads caused by changing ground movement or faulted and fractured rock. They are designed so that when the the ground load exceeds the design load of the arch as installed, yielding takes place in the joint of the arch, permitting the overburden to settle into a natural arch of its own and thus tending to bring all forces into equilibrium.

Zeolite - A group of hydrous aluminosilicate minerals with ion-exchangeable large cations and loosely held water molecules permitting reversible hydration.

Zircaloy - An alloy of zirconium and small quantities of iron, tin, chromium, and nickel used for encasing nuclear fuel pellets.

LIST OF ABBREVIATIONS AND ACRONYMS

AGNS	-	Allied General Nuclear Services
ANSI	-	American National Standards Institute
APD	-	Areal power density
BWR	-	Boiling water reactor
CDR	-	Conceptual Design Report
CFR	-	Code of Federal Regulations
CHLW	-	Commercial high-level waste
CSIR	-	Council for Scientific and Industrial Research (South Africa)
DHLW	-	Defense high-level waste
DOE	-	Department of Energy
DOT	-	Department of Transportation
DWPF	-	Defense Waste Processing Facility (Savannah River)
EA	-	Environmental assessment
E-MAD	-	Engine Maintenance, Assembly, and Disassembly Facility
EPA	-	Environmental Protection Agency
ES	-	Exploratory shaft
HEPA	-	High-efficiency particulate air (filter)
HVAC	-	Heating, ventilation, and air conditioning
IAEA	-	International Atomic Energy Agency
IAPD	-	Initial areal power density
ICRP	-	International Commission on Radiation Protection
IEEE	-	Institute of Electrical and Electronics Engineers
LLNL	-	Lawrence Livermore National Laboratory
LHD	-	Load/haul/dump unit
LWT	-	Legal-weight truck
MGDS	-	Mined geologic disposal system
MPa	-	Megapascal
MOX	-	Mixed uranium and plutonium oxides
MTIHM	-	Metric ton of initial heavy metal
MTHM	-	Metric ton of heavy metal
MTU	-	Metric ton of uranium
MWd	-	Megawatt day
MW(t)	-	Megawatt (thermal)
NA	-	Not applicable
NAFR	-	Nellis Air Force Range

NFC	-	National Fire Code
NGI	-	Norwegian Geotechnical Institute (Oslo)
NNWSI	-	Nevada Nuclear Waste Storage Investigations (Project)
NRC	-	Nuclear Regulatory Commission
NTS	-	Nevada Test Site
NWPA	-	Nuclear Waste Policy Act of 1982
NWTS	-	National Waste Terminal Storage (Program)
OD	-	Outside diameter
PRCR	-	Preliminary Repository Concepts Report
PWR	-	Pressurized water reactor
SNLA	-	Sandia National Laboratories, Albuquerque
SNM	-	Special nuclear materials
TBD	-	To be determined
TRU	-	Transuranic waste
TTC	-	Transportation Technology Center (Sandia National Laboratories)
UPS	-	Uninterrupted power supply system
USGS	-	U.S. Geological Survey
WBS	-	Work breakdown structure
WIPP	-	Waste Isolation Pilot Plant
WVHLW	-	West Valley high-level waste
x-y	-	Used to describe a crane that moves in two dimensions

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