# 5.0 CLOSURE AND DECOMMISSIONING

Permanent closure of the repository involves sealing the shafts, the ramps, underground facility, and exploratory boreholes as required to achieve the performance goals for the sealing subsystem (Section 2.4.1.3). Associated activities include removing equipment from the underground facility, backfilling the underground facility, and decommissioning the surface facilities. Closure of the underground facility will not be initiated until the performance confirmation program has satisfactorily demonstrated that the repository can meet long-term performance objectives for containment and isolation. Thus, as described in Section 3.2, closure of the underground facility may not be initiated until approximately 50 yr after the first waste has been emplaced.

This chapter describes the activities involved in closure and decommissioning of the repository, including closure of the underground facilities (i.e., removing equipment and sealing or backfilling the drifts), sealing the shafts and ramps, sealing the boreholes, and decommissioning the surface facilities. This chapter also presents the conceptual designs for seal components.

## 5.1 Closure of the Underground Facilities

Consistent with the definitions in 10 CFR 60 (NRC, 1986), the underground facility includes the emplacement panels, maintenance shops and service areas, all drifts, and the seals and backfill in the drifts; however, it excludes the shafts, ramps, and boreholes and their seals. The seals and backfill contribute to containment and isolation by controlling water flow entering the underground facility and by deterring human entry, as described in the Systems Requirements and Subsystems Design Requirements documents (Appendix P).

This section discusses closure of the underground facility, including removal of operating equipment, backfilling of the underground facility, and emplacement of seals in the underground facility.

### 5.1.1 Removal of Operating Equipment

At the end of the waste emplacement period, mining and transportation equipment, conveyors, maintenance equipment, and waste emplacement equipment will still be underground. It is currently proposed that salvageable material be removed through the ramps before closure.

Rock support will be left in place, except in local zones where it may be necessary to achieve a tight bond between the sealing material and the rock. Roadways may be removed or broken up in some portions of the underground facility to promote vertical infiltration of ground water through the floors and thereby limit lateral flow along the floor. The necessity for removing ventilation control bulkheads will be addressed during design studies.

### 5.1.2 Backfilling of Underground Openings

#### 5.1.2.1 Functions

Fernandez and Freshley (1984) have shown in a preliminary evaluation that, from a hydrologic viewpoint, backfilling an underground facility in an unsaturated tuff environment is not essential. In addition, as described in Section 3.3.1, the drifts are designed to be stable through decommissioning (Section 5.4).

Backfill may be beneficial in local areas that have a potential for ground-water inflow through faults or fracture zones. In the event of a sudden inflow, the backfill will dissipate the flow and encourage vertical drainage through the floor instead of lateral flow along the floor. If the backfill is tightly emplaced, it could also divert some of the inflow around the perimeter of the drift. Other functions that backfilling could serve include controlling long-term subsidence and deterring human entry into the underground facility.

#### 5.1.2.2 Design Concepts

The selection of suitable backfilling materials and emplacement methods will be based on the intended function of the backfill as well as on practical considerations. If the material is intended to direct flow to another part of the repository, a coarse, relatively permeable material is appropriate and it will not be necessary to backfill tightly against the roof. If the function is to delay lateral movement of water, a compacted backfill of low permeability may be necessary; if the function is to divert flow around a drift or retain water within a specific location of the underground facility, it will be necessary to tightly compact a low-permeability material against the roof. To counteract any settlement in the backfill and formation of a gap at the interface of the backfill and rock, it may be necessary to add a swelling clay (such as bentonite) to the backfill. If the backfill is to prevent major roof collapse, it may not be necessary to tightly pack the fill, but some degree of compaction will be appropriate to limit settlement. Additional studies addressing the technical need to backfill a portion or all of the underground facility will be conducted as part of the advanced conceptual design (ACD).

The following paragraphs describe the backfilling methods that could be used. Essentially the same concepts, materials, and placement methods can be used to fill either a single drift or the entire underground facility. Moreover, the same concepts can be used to produce either a free-draining or low-permeability fill. In either case, the backfill could be the crushed tuff mined from the emplacement area. This material is readily available and is geochemically compatible with the host rock. The pieces of crushed tuff will have a maximum size of about 8 in. If the backfill is to be emplaced mechanically, it can be emplaced without further crushing or screening. If a low-permeability fill is required, it can be produced by mixing tuff fines or clay with the crushed tuff. Water introduced during backfilling operations to control dust and/or improve compaction will be used in limited quantities. Excess water, if present, will be removed in the same way as water introduced during development activities.

Backfill can be emplaced using either mechanical or pneumatic methods. If mechanical methods are selected, the crushed tuff is transported by conveyor and emplaced by load/haul/dump vehicles and bulldozers (Figure 5-1a). The material can be compacted as necessary with smooth drum rollers, hand-held tampers, or vibratory compactors, and by repeated passes of the emplacement equipment (Hilf, 1975). Sand and gravel have been effectively compacted using 5- to 15-ton vibratory rollers (Terzaghi and Peck, 1967). The material is spread in layers 12 to 14 in. thick, and 2 to 4 passes of the roller are used. Moisture control is not necessary. In limited areas, self-propelled, hand-operated, vibratory compactors have been found to be useful for effectively compacting layers of 4 to 8 in.

Because mechanical emplacement and compaction are difficult within about 5 to 6 ft of the roof, it may be necessary to use pneumatic emplacement for the zone near the roof and perhaps for the entire drift (Figure 5-1b). Pneumatic emplacement can handle material up to 3 in. in size, which can be transported directly from the surface. Methods used for pneumatic backfilling of abandoned mines are discussed by Eby (1981). For reasons of health and safety, it is generally necessary to control dust, which is accomplished by sprinkling.

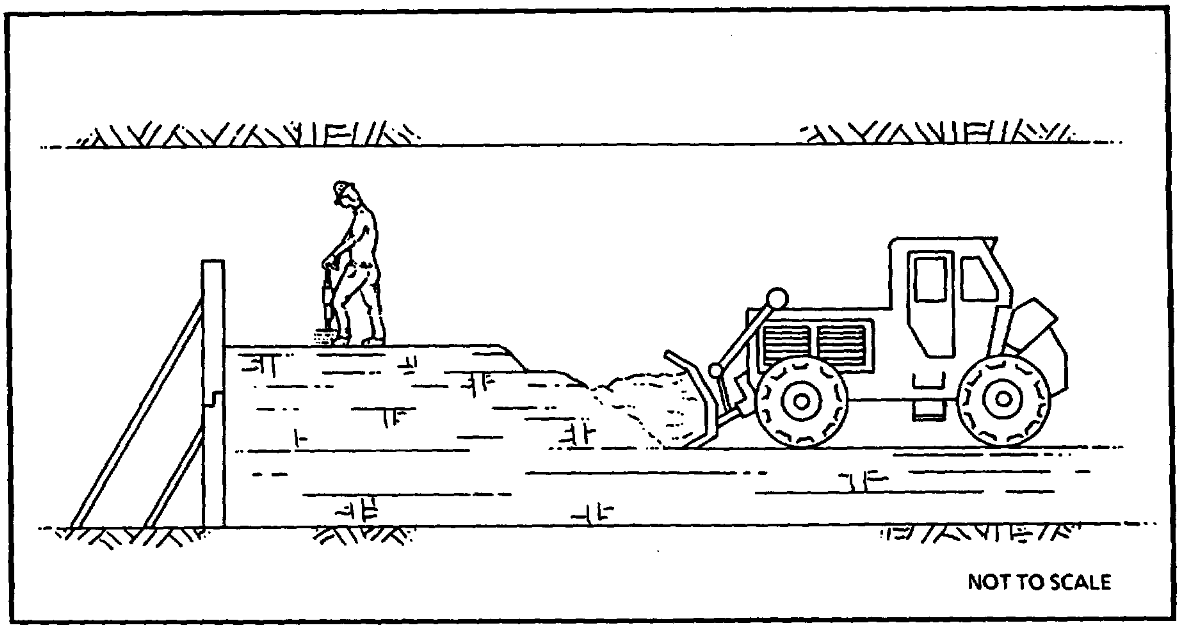
The degree of compaction achieved in a cohesionless backfill (i.e., a material containing little or no clay) depends on the gradation, placement, and compaction methods but is not affected significantly by moisture content during the compaction process (Hilf, 1975). Higher density and lower porosity are achieved by using materials that contain a wide range of grain sizes. Crushed rock obtained from the mining is expected to have a maximum size of about 8 in. and would be moderately well graded (coefficient of uniformity 4) with few fines. The range of dry bulk density for well-graded quartz gravels is from about 109 to 147 lb/ft$^3$ [void ratio 0.52 to 0.13 (Hilf, 1975)]. For a crushed tuff, which has a lower grain density, a range of dry bulk density can be computed using a formula from Hilf (1975):

$$\gamma_t = \frac{G_s \gamma_w}{1 + e} ,$$

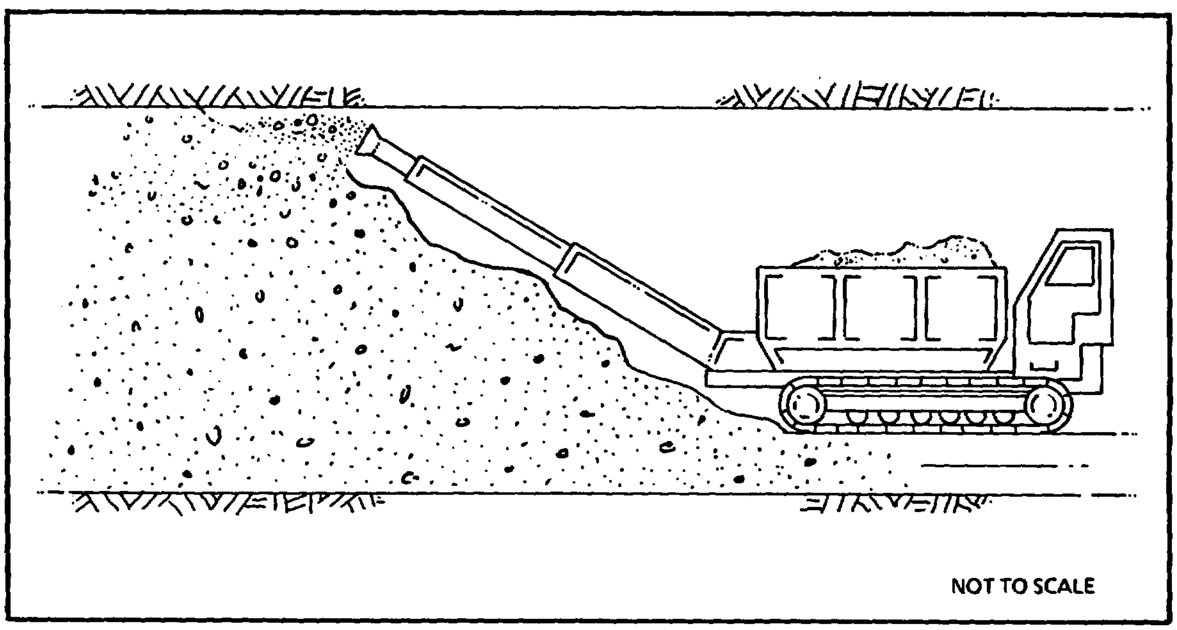
where

$\gamma_t$ = dry bulk density of the compacted tuff,
$G_s$ = specific gravity of tuff grains,
$\gamma_w$ = density of water, and
$e$ = void ratio.

The minimum and maximum void ratios, 0.13 and 0.52 (Hilf, 1975), can be used in the formula above to obtain the range of dry bulk densities for compacted tuff. Compacting this material from its loosest to densest state would have little effect on permeability but more effect on compressibility and the degree of settlement that could occur over time. A fill placed in a 21-ft-high drift at minimum density might settle about 5 ft. Compacting the same material by a combination of mechanical and pneumatic methods could limit the settlement to 1 to 2 ft. The choice between mechanical and pneumatic emplacement methods will be made during the development of the ACD.




5-1a. Emplacement by Mechanical Compaction




5-1b. Emplacement by Pneumatic Backfilling

Figure 5-1. Backfill Emplacement Methods (Figure prepared for the SCP-CDR.)

### 5.1.3 <u>Sealing of Underground Facilities</u>

#### 5.1.3.1 <u>General Requirements</u>

Numerous faults with small displacements and small lateral continuity occur throughout the proposed location for the underground facility (Scott and Bonk, 1984). However, only the Ghost Dance Fault appears potentially significant with respect to its extent (Section 2.2.3.2). If such a fault is both continuous and permeable from the surface down to the emplacement horizon, there is a possibility that localized, periodic water flow from the surface will enter the emplacement areas. Consequently, various sealing and diversion concepts for the drifts have been proposed. The intent is to encourage vertical infiltration in the region in which the inflow occurs or to direct water to specific areas in the underground facility.

The concepts introduced by Fernandez and Freshley (1984) are presented as alternatives, some or all of which may be applied, depending on the site conditions encountered. It is expected that the conditions encountered will require relatively simple seals, barriers, or drains to divert or impound periodic, minor inflow. If no water-producing faults are encountered, it may not be necessary to use seals anywhere in the underground facility. At the other extreme, it may be necessary to isolate some fault zones by means of seals to divert water to nonemplacement drifts or to abandon an emplacement drift or borehole. Because the prospective underground facility is located in the unsaturated zone, large inflows, either continuous or periodic, are not anticipated.

#### 5.1.3.2 <u>Design Concepts</u>

##### 5.1.3.2.1 <u>Sumps and Drains</u>

Sumps or drains are the simplest means for controlling water that enters a drift. They can be used both to increase the drainage capacity of the floor and to provide some storage capacity. Figure 5-2 shows a cross section through a drainage system excavated below a source of water inflow in an emplacement drift. The drain consists of a sump excavated in the floor and backfilled with coarsely crushed tuff. Holes could be drilled in the bottom of the sump and filled with gravel to increase the drainage capacity.

##### 5.1.3.2.2 <u>Dams</u>

When the inflows are greater than the storage or drainage capacity of the sump, a single dam or bulkhead could be constructed on an inclined drift to retain a large amount of water. Figure 5-3 illustrates this design option. A trench could be constructed downgrade to collect leakage through the dam or bulkhead. This trench could then be connected to an access drift or a sump. Dams could also be placed on both sides of an inflow zone to form a water collection and drainage area. The water-retention capacity would depend on the height and spacing of the dams and the grade and width of the drift.

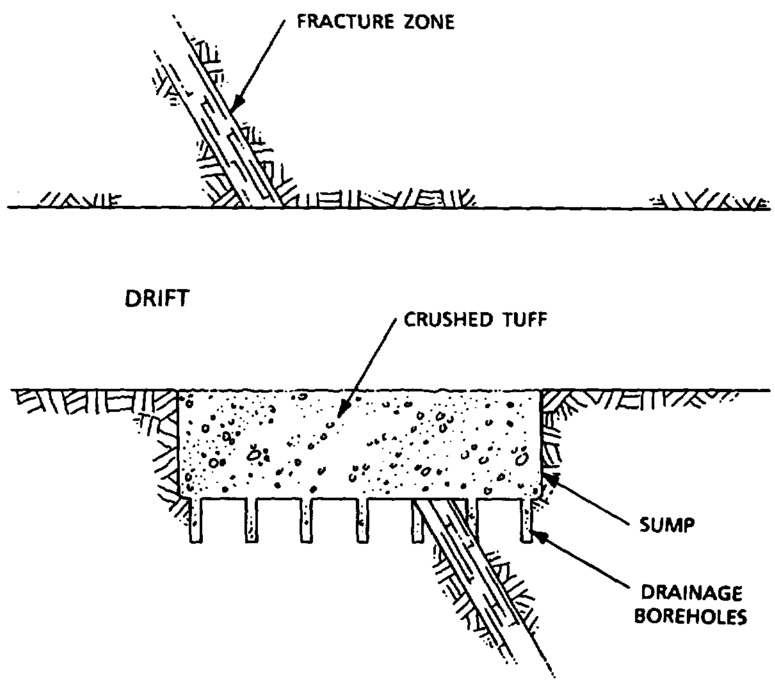



Figure 5-2. Concept for Using Sumps and Drains to Impound and Divert Water Inflow (Fernandez and Freshley, 1984.)

Materials for construction of the dams include a mixture of crushed tuff and clay and/or concrete. Initial studies have been completed at Pennsylvania State University to develop mortars based on Portland cement and grouts that are chemically compatible with the tuff at elevated temperatures. Concretes can be developed from these materials by the addition of tuff or quartz aggregate. If concrete is used, the dams will be constructed using conventional methods. Compacted clay or mixtures of clay and rock can be designed to have very low hydraulic conductivity (Section 5.2.2.2) (Fernandez et al., 1987). The earthen material or clay chosen for use should be compatible with an environment characterized by silica-rich rock and ground water containing sodium (or mixed sodium and calcium) (DOE, 1986). Preferred clays include sodium, calcium montmorillonite (commercial bentonite), or illite.

5.1.3.2.3 <u>Grouting</u>

Grouting is a process conventionally used in underground construction to reduce water inflows. The success of grouting operations in fractured rock depends on factors such as the aperture, continuity, and tortuosity of the fractures, all of which influence the penetrability of a grout of a given particle size. Cement grouts can be used successfully in fractured rock with a bulk hydraulic conductivity of $10^{-2}$ to $10^{-4}$ cm/s, whereas finer-grained cementitious or chemical grouts are commonly used in rocks with lower conductivity (Kelsall et al., 1982).

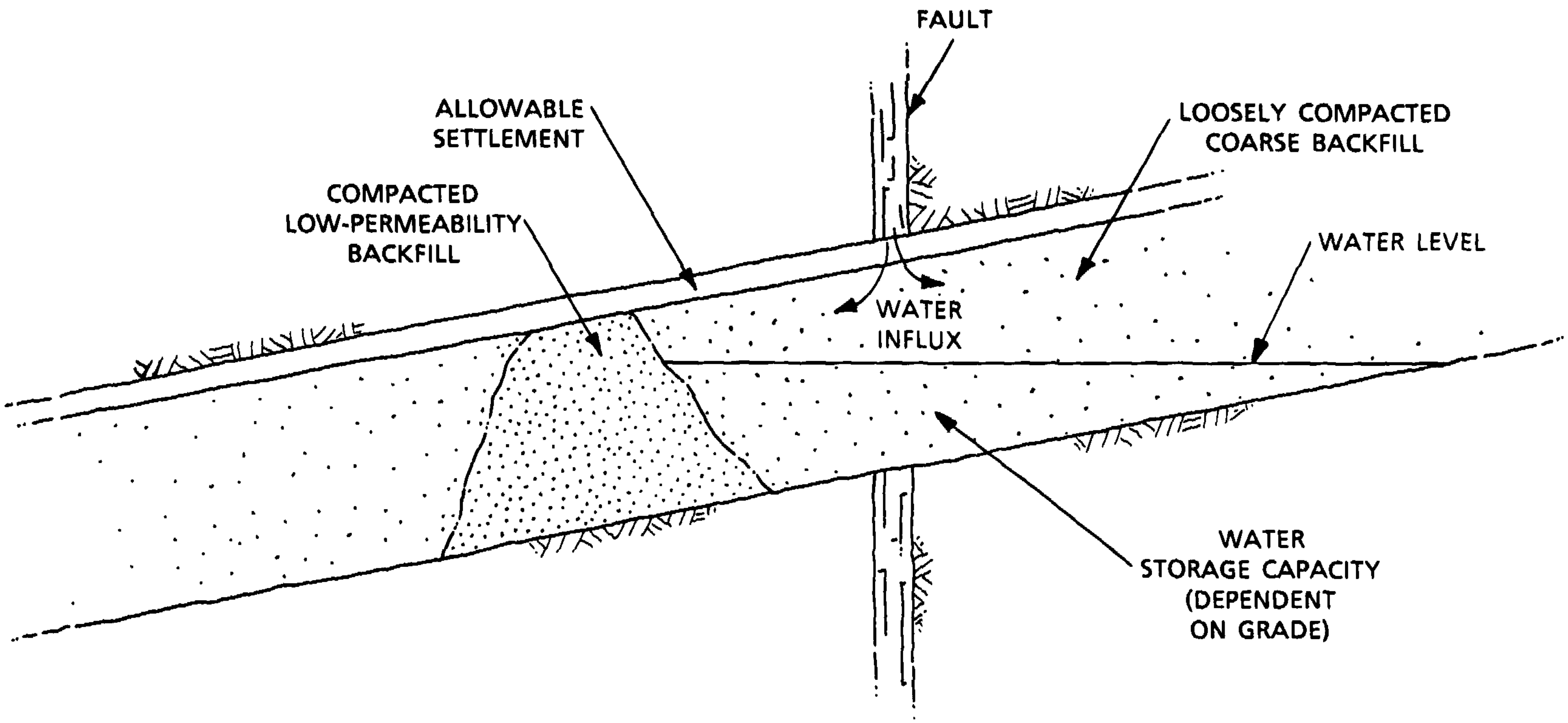



Figure 5-3. Single Dam (Figure prepared for the SCP-CDR.)

The expected range of bulk hydraulic conductivity for fractured welded tuff is $10^{-2}$ to $10^{-5}$ cm/s (Scott et al., 1983). Cement grouting should largely reduce hydraulic conductivity in rock with this range of conductivity, particularly toward the upper end of the range. Theoretically, a reduction of several orders of magnitude could be achieved, given that the hydraulic conductivity of the rock matrix is approximately $10^{-9}$ cm/s (Sinnock et al., 1984) and that the permeability of cement grouts developed for sealing applications in a repository (Roy et al., 1985) is typically less than $10^{-6}$ darcy (equivalent to $10^{-9}$ cm/s). In practice, the reduction may be less because not all fractures may be completely filled, but a reduction of at least two orders of magnitude should be reasonably achievable.

The grout is injected through a series of holes drilled into the roof and sidewalls of the drift to intercept the fault or fracture zone. The intention is to form a low-conductivity, grouted zone that envelops the drift, forcing the bulk of any water flow around the drift. Grouting in this manner reduces but does not necessarily eliminate the potential inflow because some of the flow might be diverted into other fractures that intersect a drift. Grouting may be used as the sole means to control an inflow, or it may be used in combination with other barriers such as dams or plugs (Figure 5-4). In any grouting operation, injection pressures would be monitored carefully to avoid hydrofracturing.

5.1.3.2.4 Bulkheads

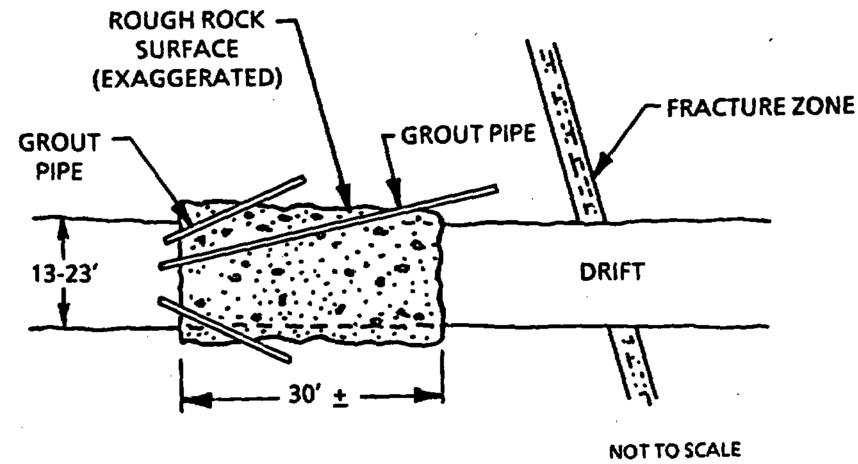
Bulkheads may be constructed to seal off a drift on either side of an inflow zone. This option will be considered only for major continuous flows that cannot be handled by simpler measures such as drains and dams. Abandonment of a portion of the emplacement drift is also possible if bulkhead construction is complicated in some way.

Figure 5-4 illustrates the concepts for bulkheads. Plugs in mines are normally constructed of concrete, and the interface between the concrete and the rock, together with the damaged zone surrounding the drift, is pressure-grouted with cement grout (Garrett and Campbell Pitt, 1961; Auld, 1983).

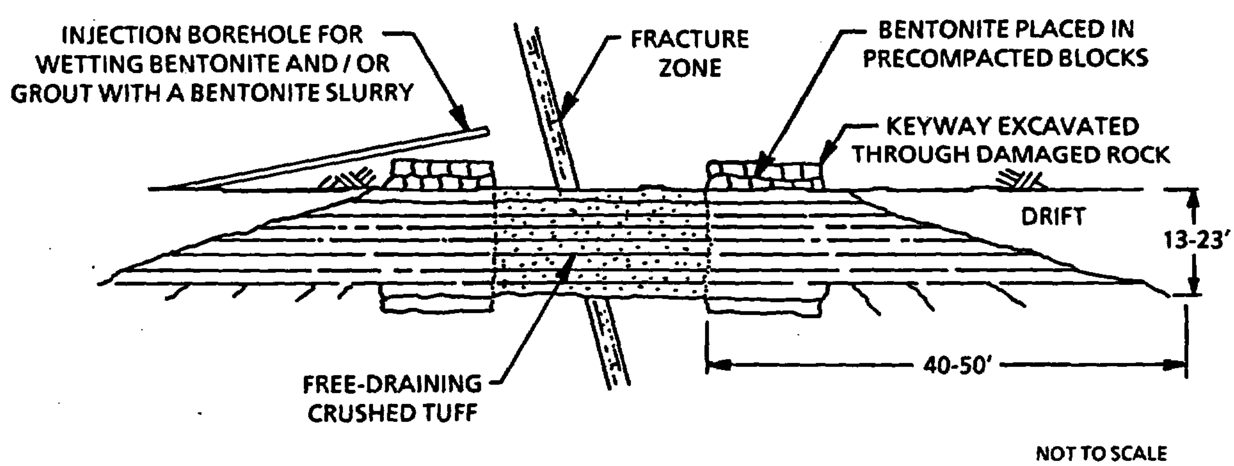
The primary material considered for construction of plugs is concrete. Although this concrete is expansive to counteract shrinkage, it may still be necessary to grout an interface and damaged zone with cement grout. The concrete may be placed as a mass or may be used to grout preplaced aggregate.

As shown in Figure 5-4a, the bulkhead may be keyed into the host rock both to remove rock damaged by blasting and to provide a more circuitous interface. The keyway (an interlocking channel or groove) would also increase resistance to shearing, although adequate resistance may be achieved by a rough rock surface. If necessary, the keyway will be excavated by machine to avoid further damage to the rock. An entryway can be incorporated in the bulkhead if needed to facilitate construction.

For the purposes of the conceptual design, the necessary length of a bulkhead is estimated (based on engineering judgment) to be approximately




5-4a. Cementitious Bulkhead




5-4b. Earthen Materials (or Clay) Bulkhead

Figure 5-4. Concepts for Drift Bulkheads Used to Isolate Major Inflows (Figure prepared for the SCP-CDR.)

two times its height. If it is determined that bulkheads are to be used, their length will be determined as part of the ACD studies. The length will be selected to minimize end-shear effects and leakage. Analyses may also be required to evaluate thermal and mechanical interaction between the bulkhead and the rock. These analyses will address static rock loads, hydrostatic head applied to one end of the bulkhead, hydration effects during curing, thermal effects following waste emplacement, and seismic loading.

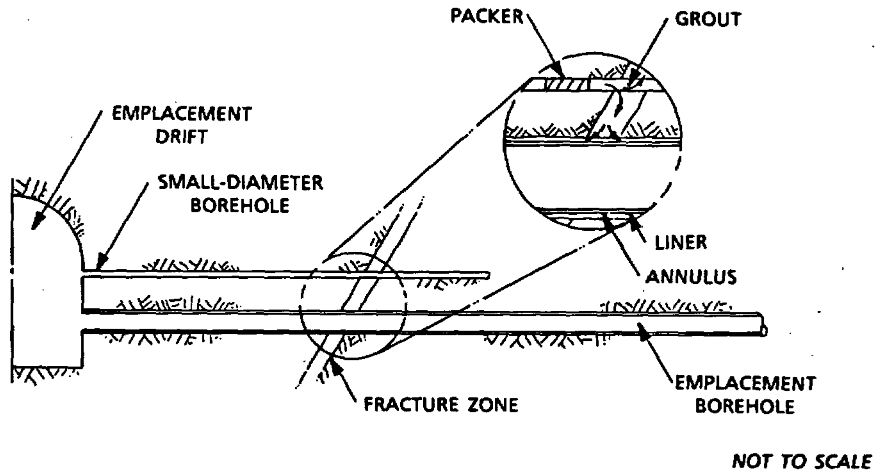
Figure 5-4b shows an alternative concept for a crushed tuff, earthen, or clay bulkhead. Clay might be a preferred material if geochemical studies should show that concrete unacceptably degrades in the repository environment. Conceptually, low-permeability bulkheads can be constructed using pure bentonite or a mixture of rock and bentonite. The bentonite would be placed in precompacted granular or block form, and water would be added to cause the clay to swell against the rock interface. The damaged zone could be treated by removal of blast-damaged rock in a keyway and, possibly, by grouting. The designs presented in Figure 5-4 are meant to be schematic, and, if bulkheads are proposed, the details in Figure 5-4 may be modified.

#### 5.1.3.2.5 Sealing in the Vicinity of Waste Containers

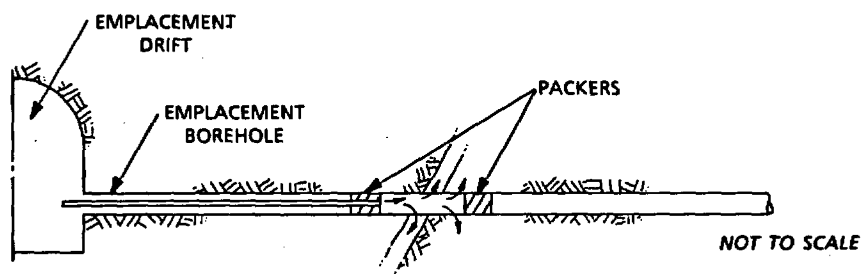
In the horizontal emplacement configuration, there is a possibility of encountering previously undetected water-bearing zones in an emplacement borehole. In such cases, it may be possible to grout the permeable zone, to install a plug so that some of the borehole can be used for waste emplacement, or to abandon the emplacement borehole. Grouting could be performed through small-diameter boreholes drilled parallel to and above the emplacement borehole (Figure 5-5a). In this case, the borehole would be grouted after the liner had been installed. The grout would be forced through the fracture zone into the annulus around the liner. A second method of sealing the water-producing zone would involve filling the hole with grout and redrilling the borehole before installing the liner (Figure 5-5b).

An additional concept involves isolating the fracture zone by means of a grout plug placed before installing the liner (Figure 5-5c). The plug would be placed on the drift side of the potential inflow zone by injecting grout between packers or bridge plugs. This approach involves abandoning the borehole beyond the plug and would only be considered if the fracture zone occurred near the far end of the borehole. A final alternative would be to abandon any boreholes in which a significant water inflow is encountered at the time of drilling and is observed to continue at an unacceptable inflow rate for some period following drilling. The duration of observation would depend on the nature of the water-producing zone.

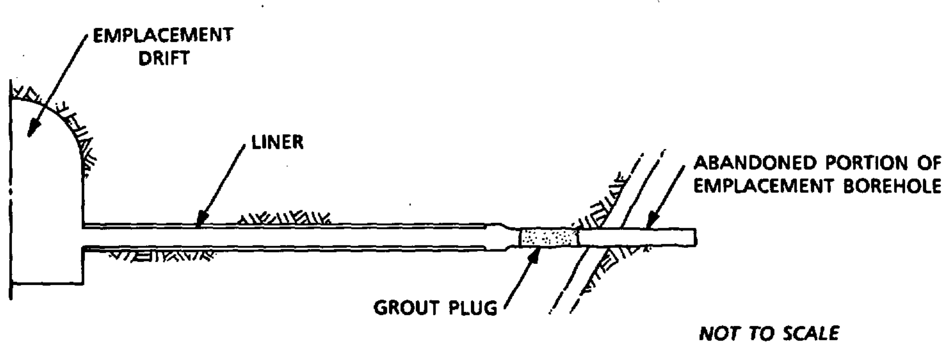
In the horizontal configuration, emplacement boreholes are drilled halfway between the floor and roof of the drifts; therefore, it probably will not be necessary to install postclosure seals in the emplacement drifts. Any periodic inflow through the boreholes could drain along the drift floors without threatening emplaced waste if the borehole is inclined toward the drift.




5-5a. Grouting Through a Small-Diameter Borehole




5-5b. Grouting Between Packers in a Horizontal Emplacement Borehole




5-5c. Installing a Grout Plug Adjacent to the Rock

Figure 5-5. Alternative Concepts for Sealing Zones in Water-Producing Emplacement Boreholes (Fernandez and Freshley, 1984.)

## 5.2 Sealing of Shafts and Ramps

The design of the repository includes four vertical shafts and two ramps. The locations of the shafts and ramps relative to the subsurface workings are shown in Figures ES-3 and 4-5. Dimensions, grades, total depths, excavation methods, and linings are summarized in Table 5-1. Figure 4-27 shows the elevations and cross sections of the four shafts.

### 5.2.1 Functions of Seals

The main functions of seals placed in the shafts and ramps are to reduce the volume of water that could enter the waste emplacement area from the surface, or from ground water encountered in the shafts or ramps, and to deter human intrusion into the emplacement area.

The shafts are located near the mouths of steep-sided washes. These washes are normally dry, but flash floods can occur briefly during heavy rainfall. During the operation of the repository, flood control structures will prevent surface water from entering the shafts. However, over the long term (i.e., 10,000 yr), the flood control features cannot be relied upon to control water flow over the shaft entry points. Sealing components that restrict the amount of water entering the shaft may be needed as the flood control features deteriorate. The potential for surface water flow into ramps is considered low because of the location of the ramp portals with respect to the location of nearby washes.

Perched water can occur at contacts between stratigraphic units if the contrast in properties between adjacent stratigraphic units forms either a permeability or capillary barrier (Montazer and Wilson, 1984). A potential scenario is that heavy rainfall saturates the alluvium and infiltrates down to bedrock. Perched water could form at the contact of the alluvium and bedrock or at a lower contact between welded and non-welded tuffs. Lateral flow toward a shaft or ramp could then occur. However, there is no conclusive evidence that perched water currently exists at Yucca Mountain.

The shafts are not expected to intersect major faults; however, the ramps cross several fault zones at relatively shallow depths. Faults that underlie washes, such as the fault inferred in Drill Hole Wash, could be recharged by rainfall and flooding in the wash.

The discussion above points to the possibility of periodic ground-water flow into the shafts and ramps. If it is necessary (1) to limit the amount of water entering the emplacement area to meet the performance goals for the sealing subsystem or (2) to control settlement of the shaft fill, it may be necessary to place seals either in the shafts and ramps or at the points at which the shafts and ramps enter the underground facility. The ground-water inflows to the shaft, if any, will be characterized as part of the exploratory shaft facility studies.

### 5.2.2 Design Concepts for Shaft Seals

Figure 5-6 shows the general arrangement of components that may be included in the shaft sealing system. These components, the surface

## TABLE 5-1

### SUMMARY OF CONSTRUCTION PARAMETERS FOR SHAFTS AND RAMPS[a]

| Designation | Grade | Excavated Diameter (ft) | Finished Diameter (ft) | Total Depth (ft) | Length (ft) | Excavation Method | Lining |
|---|---|---|---|---|---|---|---|
| Exploratory Shaft 1 (ES-1) | Vertical | 14.5 | 12 | 1,480 | NA[b] | Conventional | 12-in. concrete |
| Exploratory Shaft 2 (ES-2) | Vertical | 8.0 | 6 | 1,020 | NA | Raise bore | Steel |
| Men-and-Materials Shaft | Vertical | 22.5 | 20 | 1,090 | NA | Conventional | 15-in. concrete |
| Emplacement Area Exhaust Shaft | Vertical | 22.5 | 20 | 1,030 | NA | Conventional | 15-in. concrete |
| Tuff Ramp | 17.9% | 25.0 | 24 | NA | 4,627 | Tunnel-boring machine (TBM) | Rock bolts, wire mesh, shotcrete |
| Waste Ramp (vertical) | 8.9% | 23.0 | 21 | NA | 6,603 | TBM | Rock bolts, wire mesh, shotcrete |

a. Sections 4.3 and 4.4.
b. NA--Not applicable.

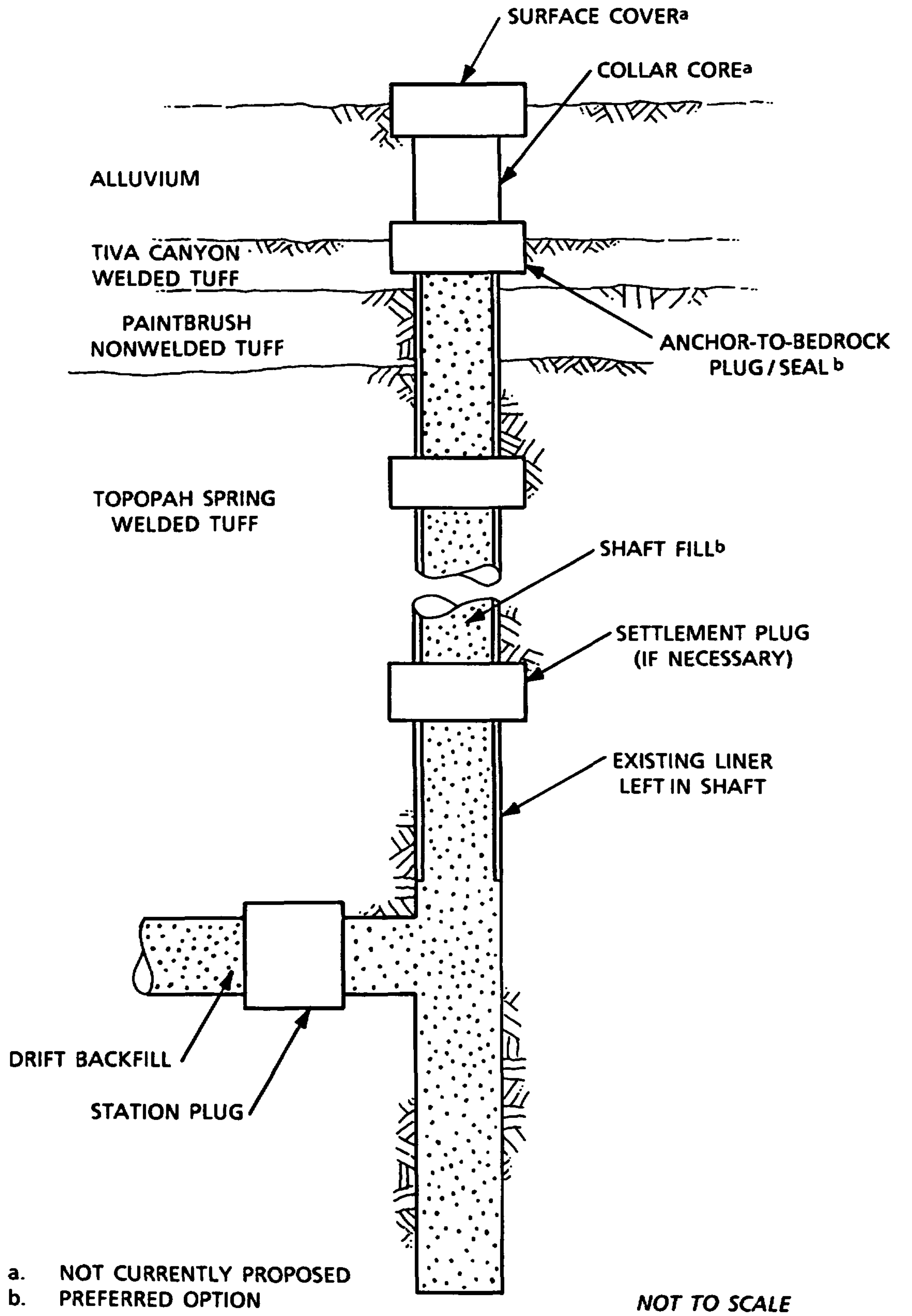



Figure 5-6. General Arrangement for Shaft Seals (Fernandez and Freshley, 1984.)

barrier, the shaft fill, the settlement plug, and the station plug, are described in the following sections. It is intended that most of the shaft liner shown in Figure 5-6 will be left in place; however, the portion of the liner beneath the intersection of the shaft and drift will be removed.

#### 5.2.2.1 Surface Barrier

In the development of the sealing concepts, the surface barrier comprises a surface cover, a collar core, and an anchor-to-bedrock plug/seal (Fernandez and Freshley, 1984). However, marking a shaft location with a prominent, durable monument could be inconsistent with the goal of deterring human entry (Fernandez and Freshley, 1984) because the monument would draw attention to the location of the access points. The position adopted in the sealing program for the repository in tuff is that it is not necessary to mark the surface location of the shaft. Rather, it is preferable to restore the surface location to its original condition to hide the shaft locations. The only sealing component of the surface barrier would therefore be an anchor-to-bedrock plug/seal.

The main functions of the anchor-to-bedrock plug/seal are to reduce surface-water entry into the upper portion of the shaft and to discourage human intrusion. Accordingly, the barrier should have low permeability and a moderate to high strength to prevent casual or accidental access.

Figure 5-7 shows a design concept for restoring the upper portion of the shaft. The major component of the design is a dense plug or bulkhead keyed into the surface of the bedrock. The bedrock plug serves both to reduce the flow of water into the shaft at the interface of the bedrock and the alluvium and to deter human entry. The construction sequence for restoration of the upper portion of the shaft (Figure 5-7) is given below.

- Fill or seal the shaft up to the lower portion of the anchor-to-bedrock plug/seal (Section 5.2.2.2).
- Remove headframe, outfitting, and all surface facilities.
- Perform first-stage grouting in the vicinity of where the anchor-to-bedrock plug/seal is to be installed.
- Remove a portion of the shaft liner where the plug is to be installed and excavate the key for the bedrock plug.
- Clean the rock surface where the anchor-to-bedrock plug/seal is to be installed.
- Construct the anchor-to-bedrock plug/seal.
- Perform second-stage grouting after plug construction.
- Place compacted alluvial fill (or other material) above the anchor-to-bedrock plug.
- Place riprap over the surface cover (optional).

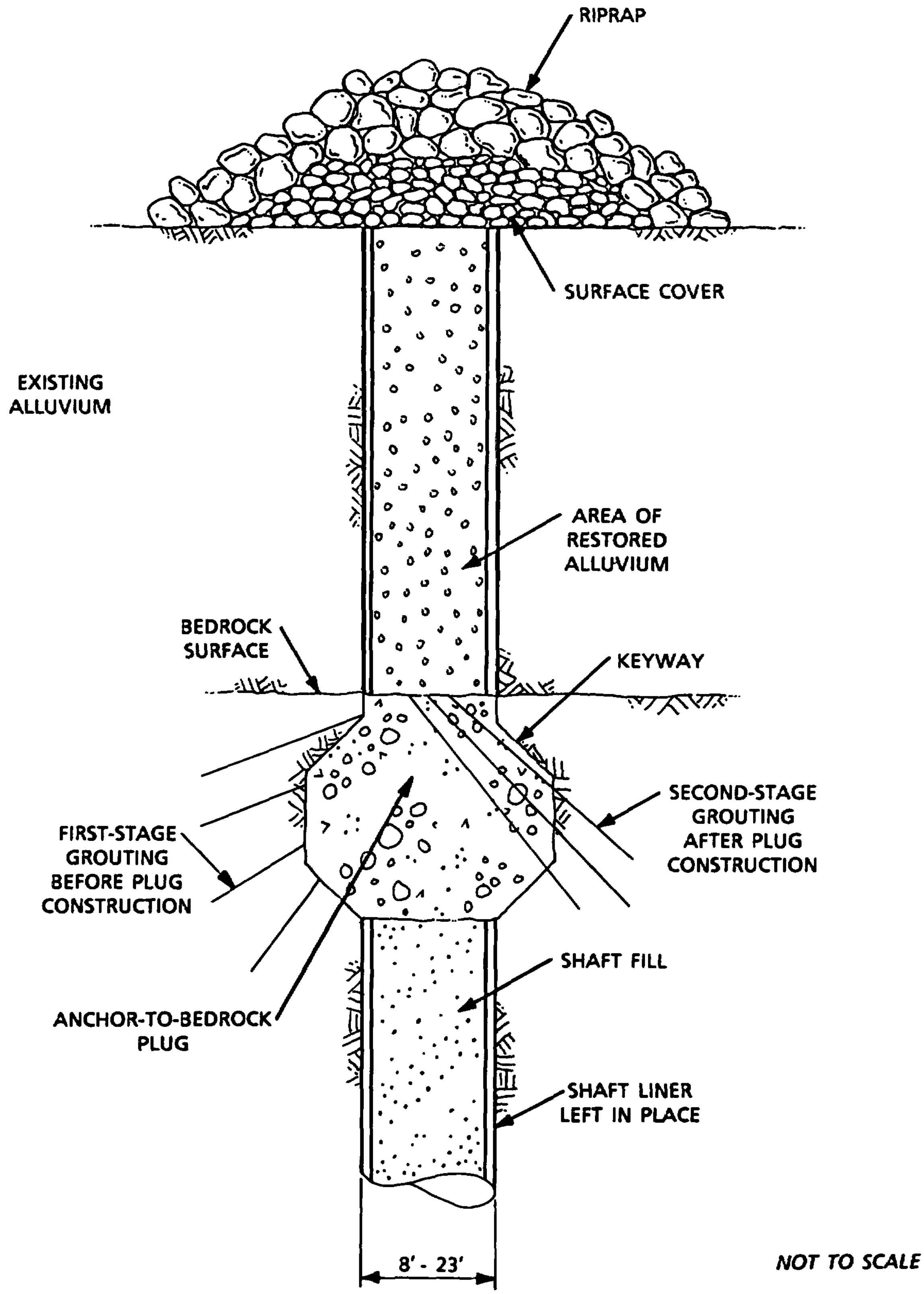



Figure 5-7. Conceptual Design for Shaft Surface Barrier (Fernandez and Freshley, 1984.)

The primary material proposed for the anchor-to-bedrock plug/seal is concrete (Fernandez et al., 1987). The principal design requirements for the material are low permeability (less than $10^{-5}$ cm/s), moderate to high strength, and durability in the near-surface desert environment. Suitable riprap in the form of blocks of welded tuff or basalt may be found near the site.

#### 5.2.2.2 Shaft Fill

Two concepts are being considered for the function of the shaft fill placed below the surface barrier. As currently proposed, the shaft fill has moderate porosity and high permeability to allow free drainage. Large volumes of water are prevented from entering the emplacement area through the shaft station by the surface barrier and possibly by a plug placed at the intersection of the shaft and the drift leading into the underground facility (Section 5.2.2.4). The fill is graded and compacted to reduce settlement. If found to be necessary after detailed analysis, "settlement plugs" could be placed at intervals in the shaft to further reduce settlement.

The alternative concept is to place a lower-permeability fill that creates a barrier to water infiltration. Placement of a low-permeability fill could preclude the need for a station plug. Settlement in a highly compacted, uniformly graded, and fine-grained fill is less than in one that is looser and poorly graded. The sumps below the shaft station can be filled with a coarse, free-draining material, and a suitable filter can be placed between the two fills in the zone immediately above the shaft station.

The material used for both alternatives is an earth fill. A high-permeability fill consists of crushed tuff screened (and possibly graded) from the tuff excavated from the emplacement area. Hydraulic conductivity depends primarily on gradation [which can vary from greater than 10 cm/s for coarse gravel to $10^{-2}$ to $10^{-4}$ cm/s for fine sands (Terzaghi and Peck, 1967)] and, to a lesser degree, on compaction. Lower-permeability fills could be produced by adding finely ground (silt-size) tuff or clay. In mixtures of clay and sand or gravel, the hydraulic conductivity depends on the type and amount of clay and on the degree of compaction. For example, hydraulic conductivities lower than $10^{-9}$ cm/s can be achieved in compacted mixtures of sand and bentonite that contain 20 to 30% bentonite (Wheelwright et al., 1981). Studies are in progress to determine the consolidation and permeability characteristics of crushed tuff (Fernandez, 1985).

The fill can be placed in the shaft by a bucket and compacted. Sands and gravels are compacted using vibratory equipment, whereas clay-bearing mixes are compacted by tamping. Water content is adjusted to achieve optimum density. In the current plans, the shaft lining is left in place down to the intersection of the shaft and drift. The lining could be removed or perforated in the sump below the station.

#### 5.2.2.3 Settlement Plugs

Plugs may be needed to limit the settlement of the shaft fill. Settlement plugs might be needed with either high- or low-permeability shaft fill. In the former case, the plugs would be designed to drain water; however, in the latter case, the plugs could be designed to be water barriers.

Figure 5-8 shows a design concept for a settlement plug. To provide additional support, the shaft lining is removed in the zone of the plug, and the plug is keyed into the rock walls of the shaft. For a low-permeability plug, grouting at the interface and within the damaged zone may be needed. Such a plug could be constructed using concrete. For a free-draining plug, grouting is not considered, except as necessary to provide adequate resistance to shearing. Drainage through the plug is provided by using tubes filled with aggregate or possibly by using a no-fines concrete (Fernandez and Freshley, 1984).

The effect of temperature on the settlement plugs is expected to be a relatively benign factor because the plugs are protected from variations in the surface temperature and are relatively far removed from the heat-generating waste.

#### 5.2.2.4 Station Plug

The shaft station is the area where one or more drifts are connected to the shaft. A plug placed in this area would retain the shaft fill within the shaft. A second function might be to limit ground-water flow from the shaft into the drifts.

Figure 5-9 shows the design concept for a station plug in a horizontal drift adjoining a shaft. Similar plugs could be placed in each drift that joins the emplacement area to the shafts, including the ramps that connect with the perimeter drift.

The plug shown in Figure 5-9 is intended to be a water barrier as well as a retaining wall for the shaft fill. Accordingly, the plug is keyed into the rock both to increase shear resistance (to withstand a water head, if one were to build up in the shaft) and to intersect undisturbed rock beyond the damage zone. The plug is also separated from the shaft to avoid stress concentrations at the intersection of the shaft and drift. The space between the plug and the shaft is filled with concrete or compacted fill, and the surrounding rock may be grouted if highly fractured. The concrete used in the plug could be the same as that proposed for shaft settlement plugs (Section 5.2.2.3) or fault seals. The need for the specific construction details given in Figure 5-9 will be evaluated as part of the ACD effort.

### 5.2.3 Design Concepts for Ramp Seals

The types of components proposed for ramp seals (Figure 5-10) are similar to those proposed for shaft seals. The major component is the anchor-to-bedrock plug/seal that prevents inflow of surface water and deters human entry. The remainder of the ramp is backfilled with a relatively permeable, coarsely crushed tuff. Depending on the expected ground-water inflow from faults and fractures, which will be determined by future hydrogeologic investigations, it may be necessary to place low-permeability barriers at intervals in the backfill downgrade from the

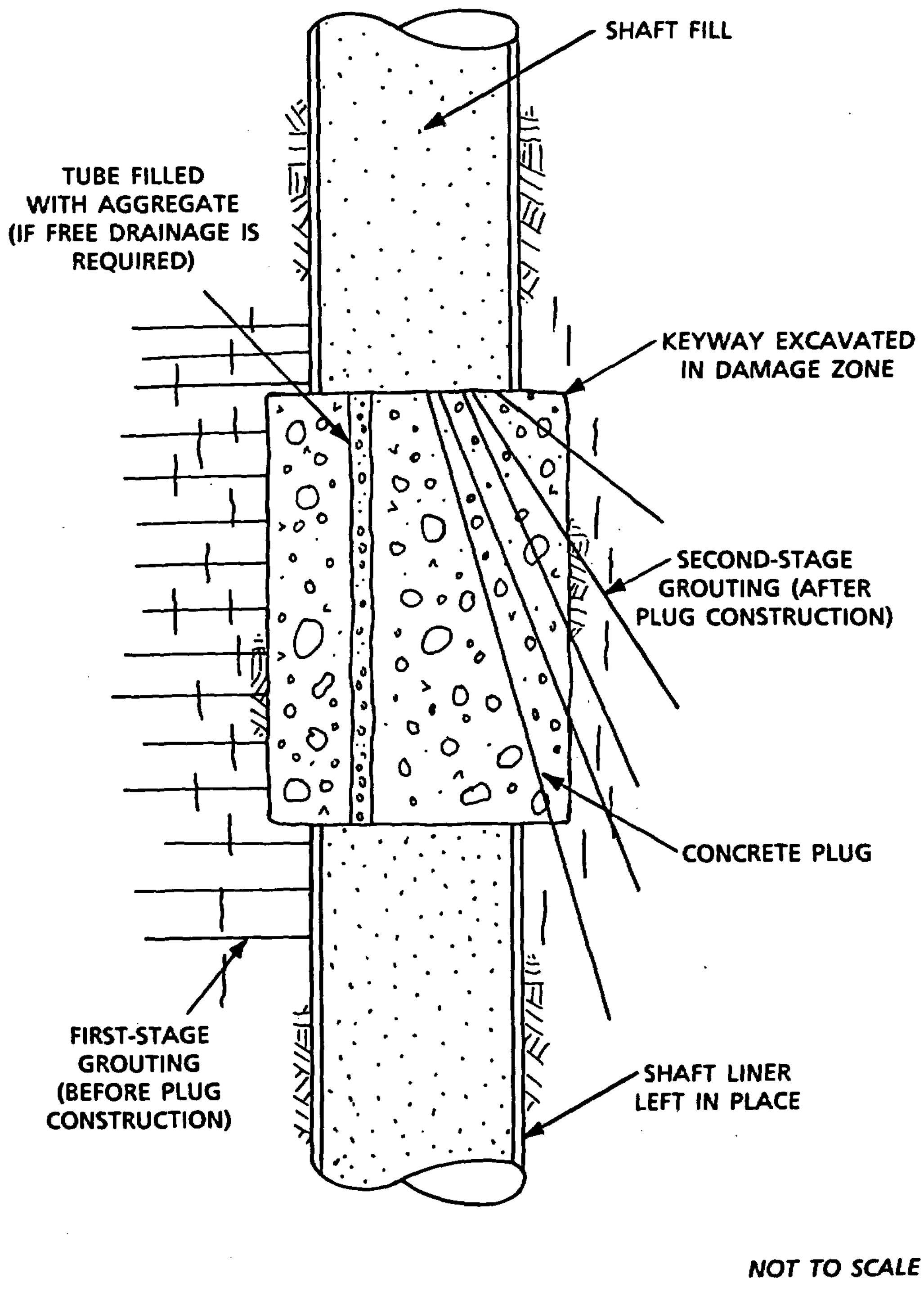



Figure 5-8. Conceptual Design for Settlement Plug in Shaft (Fernandez and Freshley, 1984.)

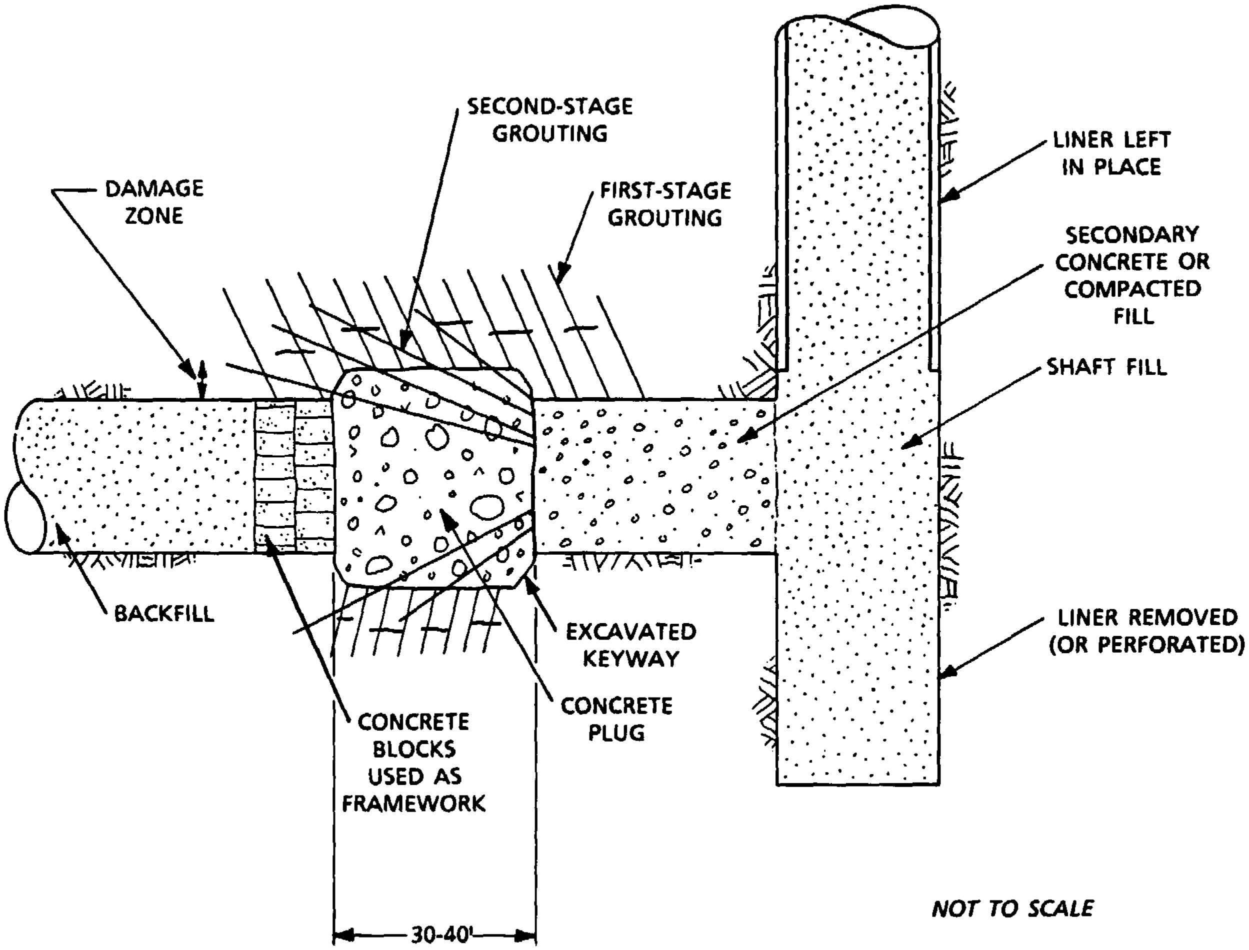



Figure 5-9. Conceptual Design for Station Plug (Fernandez and Freshley, 1984.)

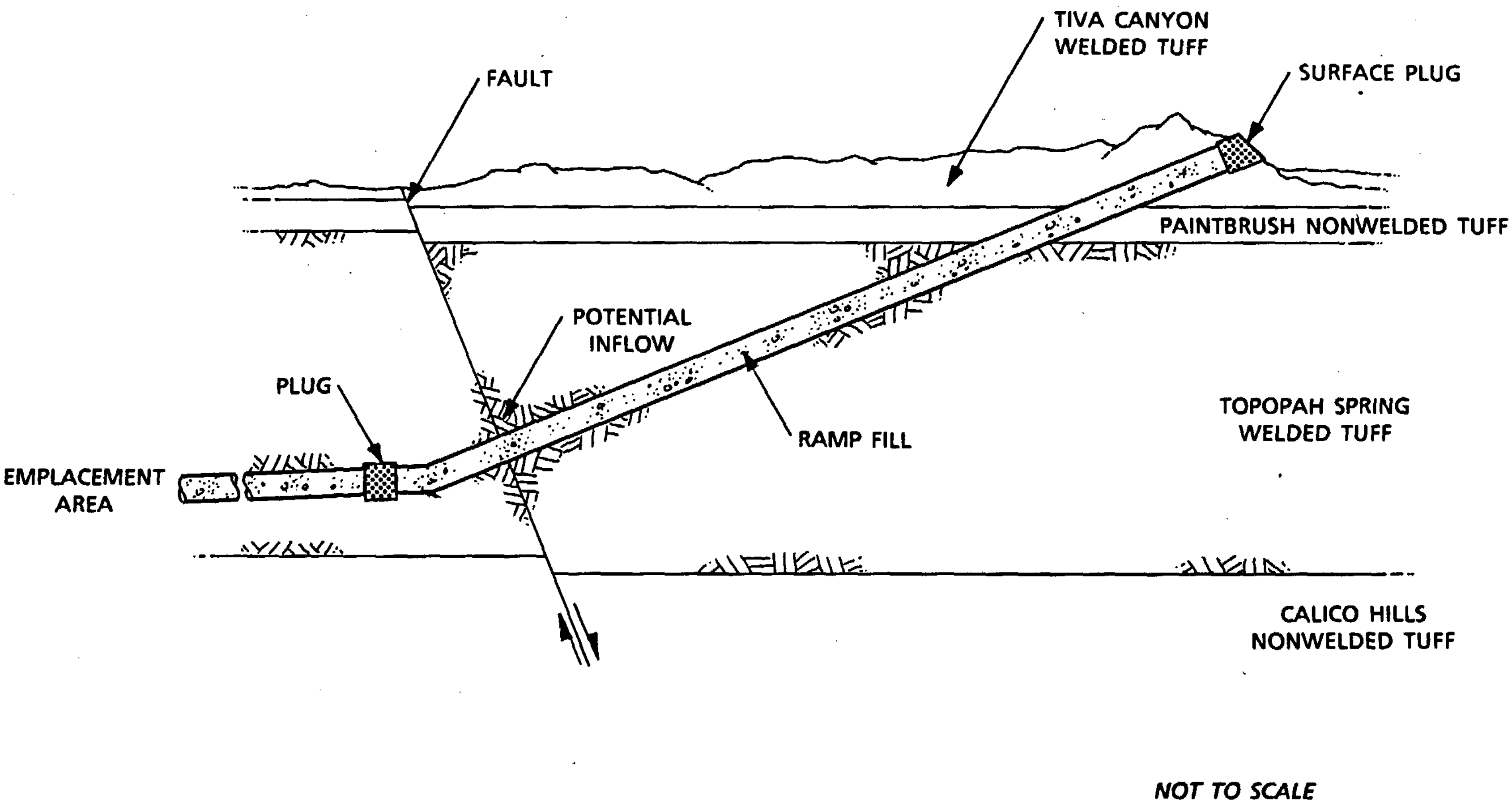



Figure 5-10. General Arrangement for Ramp Seals (Fernandez and Freshley, 1984.)

expected inflows. These barriers could be concrete plugs similar to the fault seals or station plugs described above, or they could be sections of compacted, clay-rich backfill. If drainage upgrade from these barriers is desired, it will be necessary to remove the ramp floor and recondition the tuff to obtain the appropriate drainage.

The design concept for the surface barrier (Figure 5-11) includes riprap overlying compacted fill at the ramp portal and a concrete plug. The plug is placed in the ramp, in good rock, away from any near-surface, weathered, or fractured zone. The concrete is the same as that developed for the anchor-to-bedrock plug in the shafts.

The backfill in the ramp is crushed tuff, placed mechanically or pneumatically (Section 5.1.2.2). Low-permeability sections, if needed, may consist of crushed tuff mixed with 20 to 30% bentonite. The low-permeability material is placed and compacted mechanically as close to the roof as possible, and then the remaining void is filled pneumatically.

## 5.3 Sealing of Exploratory Boreholes

Figure 5-12 shows the locations of exploratory boreholes drilled or planned in and adjacent to the underground facility at 1-km intervals from the perimeter of the underground facility.

### 5.3.1 Functions

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

- any exploratory boreholes within the perimeter of the underground facility that penetrate to the water table, and
- boreholes that penetrate to the water table downdip from the emplacement horizon; these boreholes could provide a preferred pathway for contaminated ground water that drains vertically from the emplacement area through the rock mass and then flows downdip along a capillary or permeability barrier to intersect the boreholes.

Criteria that relate methods of sealing to various types of boreholes will be developed further during the ACD studies. These criteria will take into account proximity to the boundaries of the underground facility, depth of penetration, and location with respect to hydrologic gradients, as well as State of Nevada regulations for plugging and abandoning wells.

### 5.3.2 Design Concepts

Borehole seals will be designed to impede flow via the borehole through the nonwelded tuffs of the Calico Hills to the water table. The simplest concept for borehole sealing involves filling the boreholes with cement grout (Figure 5-13). Grouts suitable for use at the Yucca Mountain site are being developed by Pennsylvania State University (Fernandez,

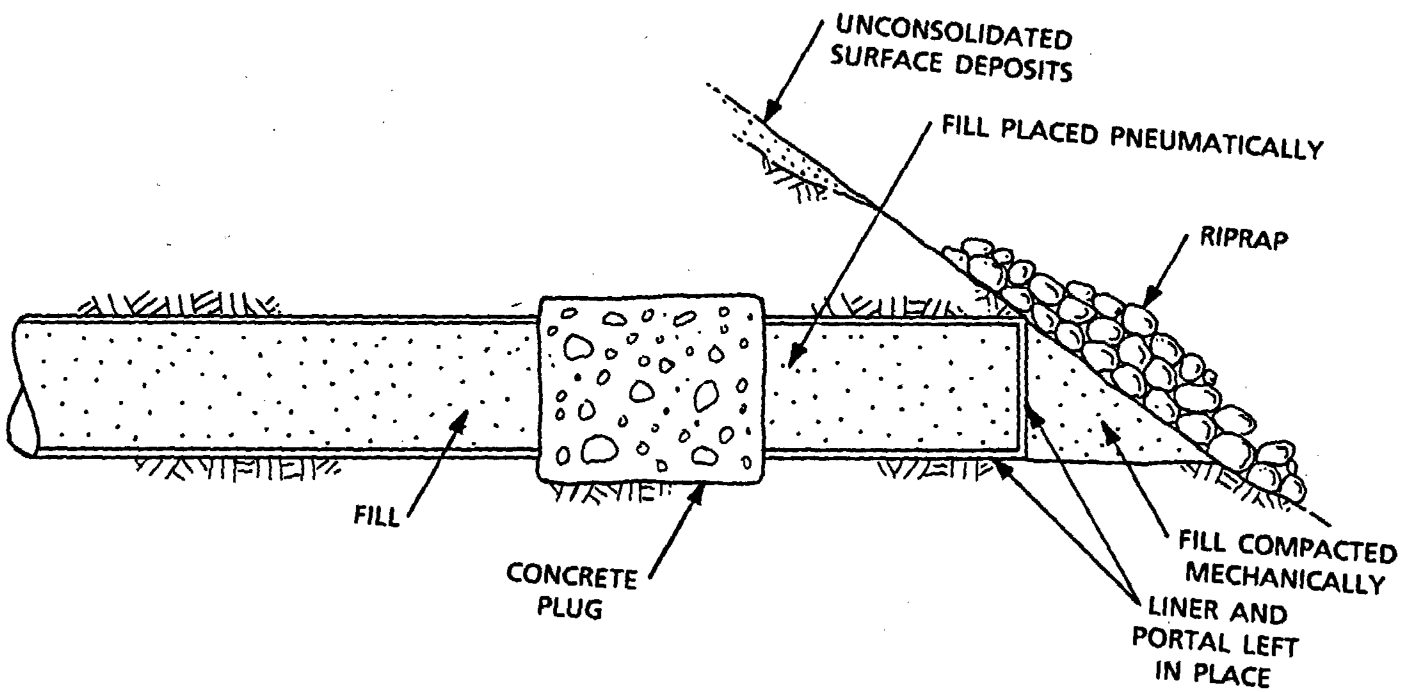



Figure 5-11. Conceptual Design for Surface Barrier for Ramps (Figure prepared for the SCP-CDR.)

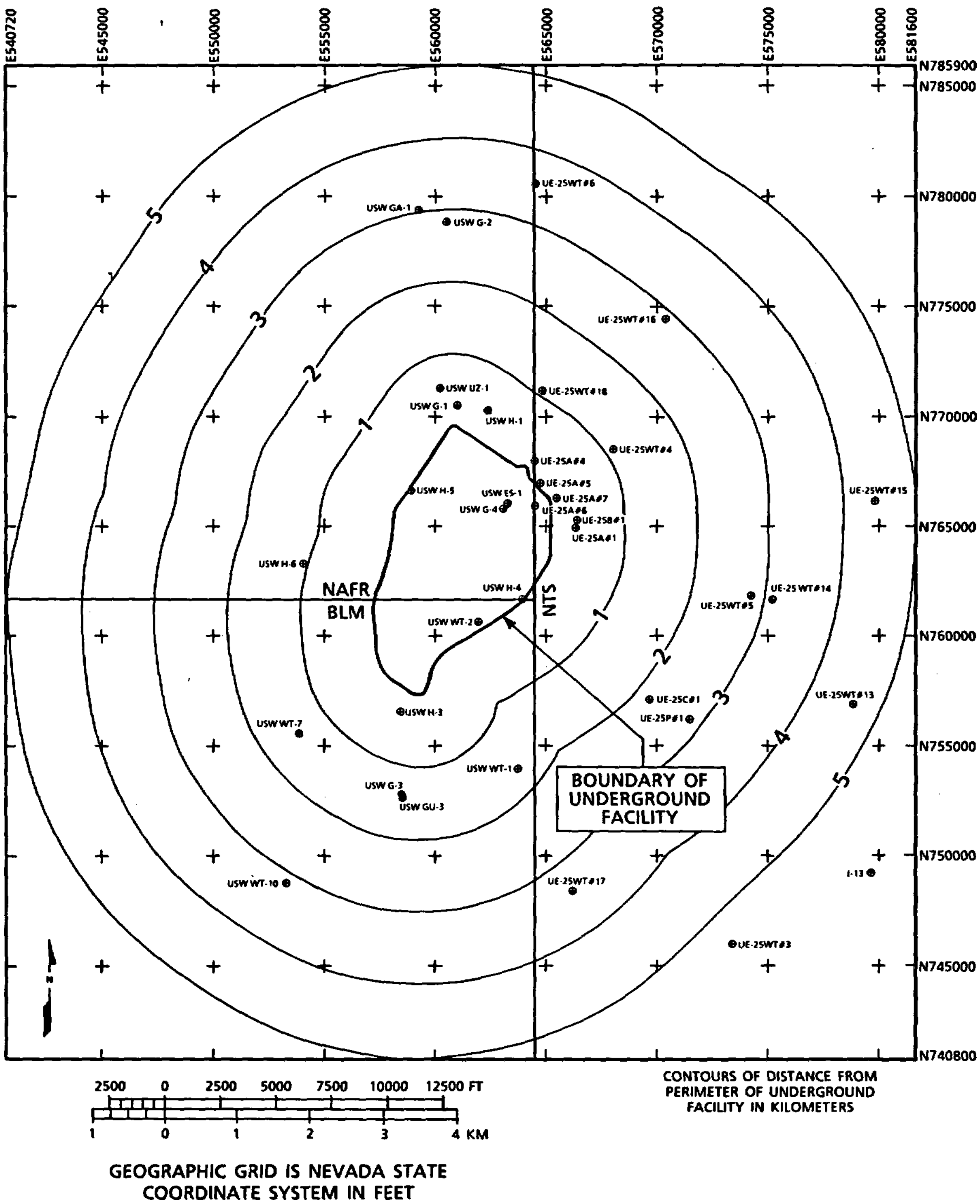



Figure 5-12. Location of Exploratory Boreholes (SNL, CAD-IGIS Data Base, CAL0096)

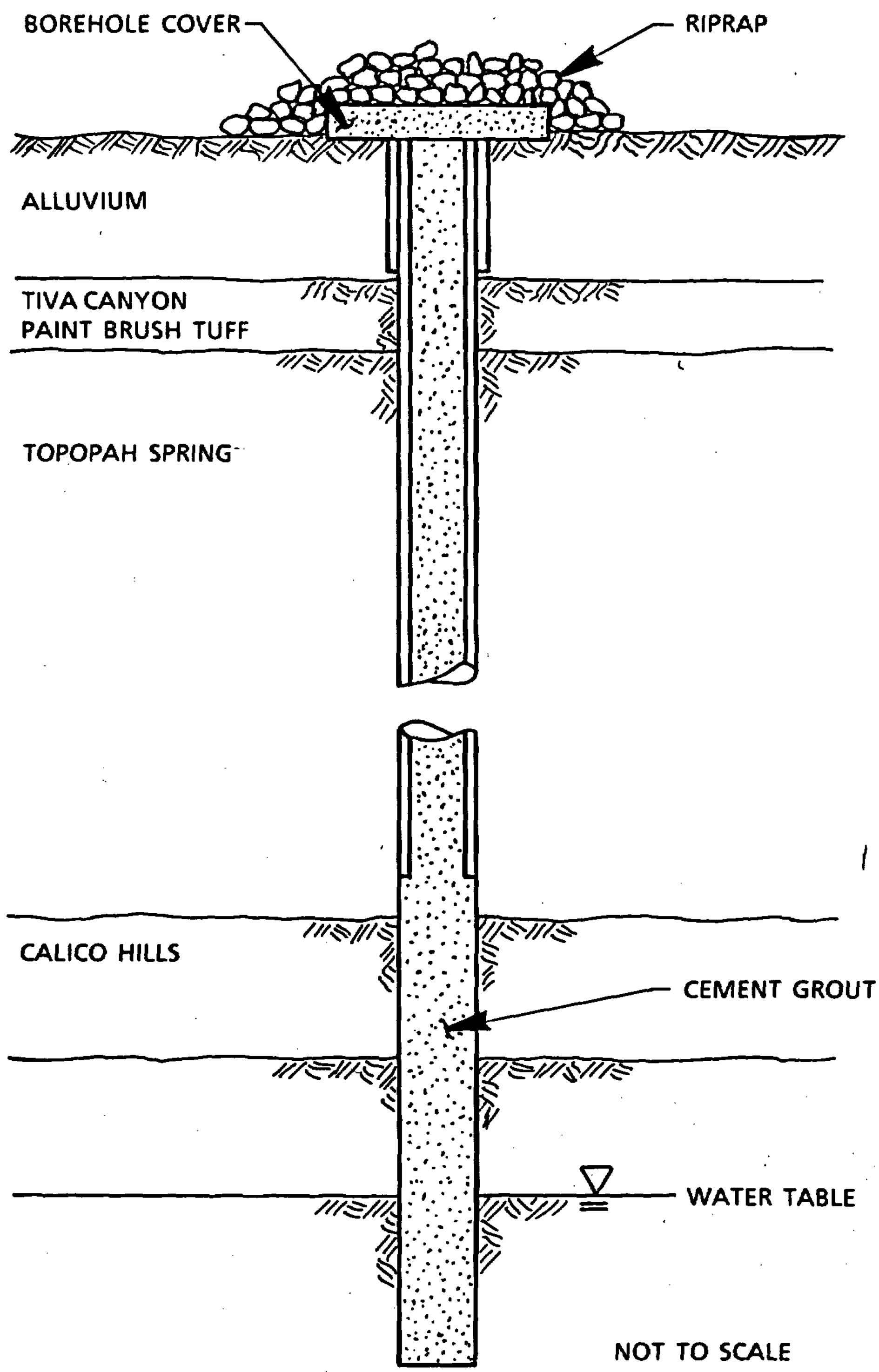



Figure 5-13. Concept for Sealing Boreholes (Fernandez and Freshley, 1984.)

1985). These grouts have low internal and interface permeability and are chemically compatible with the tuff environment.

It is currently proposed to seal the zone in the nonwelded unit of the Calico Hills between the base of the Topopah Spring Member and the water table, if necessary. The borehole casing in this zone may be removed to allow a good bond between the cement and the rock and to avoid a double interface (an interface on either side of the casing). Procedures for plugging abandoned wells have been well developed by the oil industry (Herndon and Smith, 1976; D'Appolonia, 1979). These procedures may prove suitable for sealing boreholes in and adjacent to the underground facility, provided that strict quality assurance procedures are adopted for placing the grout in key zones to ensure a uniform, dense material.

The following steps are involved in sealing boreholes.

- Characterize the borehole using available records or by running geophysical logs. Particular attention should be paid to zones in which circulation has been lost during drilling and to the condition of the borehole in the Calico Hills section.

- If the borehole is cased through the Calico Hills, remove casing from a section 50 to 100 ft long in the Calico Hills above the water table. A variety of milling and cutting tools is available for this purpose.

- Pressure-grout any zones in which circulation lost during drilling in the Calico Hills. It should not be necessary to grout zones in other formations in which circulation has been lost, provided that inflow from these zones does not impede other sealing operations (such as flushing the borehole).

- Drill out the borehole and flush, using water or mud to remove casing fragments and other debris.

- Clean and condition the borehole wall in the Calico Hills, using wall scratchers to remove mud cake. (If necessary, the borehole can be enlarged by using underreamers to form a keyway.)

- Place cement by pumping through tubing or by pouring from a dump bailer, as described by Herndon and Smith (1976).

Different sealing materials or placement methods could be used in other sections of the boreholes or in boreholes located in noncritical areas. For example, a borehole could be filled with sand in the zones below the water table and above the emplacement horizon. It may be simpler, however, to fill the entire borehole with the same material, i.e., cement grout.

A surface cover is placed on all boreholes to prevent access and to mark the location. The cover consists of a concrete pad covered by rocks as a protection against weathering. A marker is placed on the pad to designate the borehole and to list its purpose.

## 5.4 Decommissioning of the Surface Facilities

At the end of the caretaker period (or at the end of the retrieval period, if retrieval should be necessary), the surface facilities, including contaminated surface facilities and components needing decontamination, will be dismantled or removed from service. It is planned to restore the site to as near to its prerepository condition as possible by razing all surface facilities and regrading and planting as necessary.

The purpose of decontamination is to ensure that residual contamination is within permissible levels for unrestricted use. Limits to residual radioactivity have been provided as guidance in Regulatory Guide 1.86 (AEC, 1974).

Plans for decommissioning activities are required as part of the license application (LA) to the Nuclear Regulatory Commission (NRC) and must be updated before applying for the license amendment for permanent closure [10 CFR 60.46(a)]. The decommissioning concepts in the current conceptual design reflect early consideration of requirements. A decommissioning plan, to be developed during ACD, will include the following information:

- methods to be used for decommissioning,
- methods for identification of facilities and components requiring decontamination for decommissioning,
- methods for disposal of radioactive waste generated during decommissioning,
- methods for protection of occupational and public health and safety,
- a plan for final radiological survey, and
- estimated costs of decommissioning.

Decommissioning studies will continue as the design matures and will be consistent with the more detailed designs developed during the ACD and license application design (LAD). Decommissioning will be completed in accordance with the decommissioning plan presented in the LA and later amendments.

### 5.4.1 Current Decommissioning Concepts

The repository must be designed so that components, buildings, structures, and other features can easily be decontaminated and dismantled to meet the requirements of 10 CFR 60.132. The general criteria used in selecting design features include the potential for (1) ensuring occupational health and safety, (2) limiting site-generated radioactive waste, (3) facilitating decommissioning activities, (4) reducing total decommissioning time, and (5) limiting decommissioning costs.

Initially, decommissioning will involve surveying and characterizing the extent of contamination of the surface facilities so that appropriate methods for decontamination and dismantlement may be selected. Most radioactive contamination will have been removed early in the caretaker phase; however, the facilities used for performance confirmation may still be contaminated at the end of the caretaker phase.

Dismantlement is defined as the dismemberment, distribution, or removal from the site of facility systems, in whole or in part, for the purposes of salvage, interim storage, mothballing, use at another location, or safety. Complete dismantlement of the surface facilities is required. All equipment that can be reused will be salvaged. Because dismantlement may involve the use of very large equipment or explosives, facility layout and spacing must be considered during the design. The buildings will be demolished, rubble and debris will be removed, and the structures and buildings will be razed to a depth 2 ft below the level of the restored finish grade. The surface will be regraded and restored as nearly as possible to its original condition and will be revegetated.

Radioactive waste generated during decommissioning will be treated and packaged in the waste treatment building, which will be the last building to be decommissioned. Disposal of site-generated waste is not permitted on the site; hence, other licensed disposal sites will be used.

A final radiological survey of the site will be performed, and institutional barriers and controls will be established, such as installation of permanent markers or monuments to identify the controlled area and the geologic repository operations area and establishment of public records and archives. These measures will alert future generations to the presence of radioactive waste underground. An application for termination of the operating license will be forwarded to the NRC for completion of the decommissioning process.

### 5.4.2 Design of Major Surface Facilities Requiring Decommissioning

At this stage of the design, the principal impact of the decommissioning requirements is the specification that, insofar as is practicable, facilities in which radioactive waste is handled will be designed to simplify decontamination and ultimate decommissioning. These facilities include Waste-Handling Building 1, Waste-Handling Building 2, the waste treatment building, the decontamination building, the performance confirmation building, and any other potentially contaminated areas. To simplify eventual decommissioning, the designs will include the following features, as appropriate:

- stainless steel liners on walls and floors of hot cells, where contamination is expected;
- special coatings in potentially contaminated areas to facilitate decontamination;
- sealing or elimination of cracks, crevices, and joints to prevent accumulation and spread of contamination;
- ventilation and contamination barriers to prevent or reduce the spread of contamination;
- modular equipment to facilitate removal of equipment from contaminated areas;
- location of ventilation exhaust filters at or near major sources of airborne contamination to reduce contamination of long sections of exhaust ductwork and downstream exhaust equipment;
- minimization of the length of embedded or buried piping used for contaminated liquids; and

- reduction of contaminated components into segments of a size that permits disposal of the segment intact, thereby greatly reducing the risk of exposure during segmenting operations.

### 5.4.3 Surface Facilities Requiring Decontamination

#### 5.4.3.1 Waste-Handling Buildings

The hot cells and other waste-handling areas, heating, ventilating, and air-conditioning (HVAC) system, and high-efficiency particulate air (HEPA) filters in both waste-handling buildings will be decontaminated. Equipment will be decontaminated by chemical, mechanical, electropolishing, and ultrasonic means. Structures will be decontaminated and demolished using water cannons, grinding techniques, scarifiers, drills and spalls, hammers and chisels, and paving breakers. Building rubble will be removed, and the site will be restored.

The hot cells will be designed so that penetrations, crevices, and exposed concrete surfaces are limited. The hot cells will also have continuous wall liners, strippable wall coatings, and built-in provisions for decontamination and dismantling and will be designed so that equipment can easily be removed. Equipment surfaces will be pretreated to facilitate decontamination.

Hot cell systems will be designed with an intracell decontamination system and remote decontamination capability. The hot cells will also be compartmentalized according to levels of radioactivity. Areas of contamination will be designed so that the contamination is restricted to a localized zone.

The HVAC system will be provided with filters to prevent escape of particulate contamination from the hot cell, and the design will permit easy access for decontamination and removal of contaminated ducting.

In radioactive waste treatment systems, the length of pipe runs will be limited, and holding tank liners will be pretreated. The design will ensure that the holding tanks are accessible. The features of other structures and equipment in the radioactive waste treatment system will be similar to those of the hot cell.

#### 5.4.3.2 Waste Treatment Building

The waste treatment building will be used to treat site-generated radioactive waste during repository operations. It will also treat the radioactive waste from decommissioning the waste-handling buildings, performance confirmation building, decontamination building, and other contaminated facilities. The waste treatment building will be decommissioned after other buildings have been decommissioned.

The waste treatment building includes waste-processing areas and storage areas for site-generated waste but contains no hot cell. The equipment in the liquid- and solid-waste-processing areas includes tanks, pumps, piping, and solidification modules. This equipment, along with any other potentially contaminated equipment, will be decontaminated by flushing with water or, if necessary, by treating with chemicals. The equipment will be surveyed, dismantled, and removed.

The building areas for waste processing and storage are normally uncontaminated, except that accidental spills may occur during operations. Should an accidental spill occur, localized areas will be cleaned and decontaminated. During decommissioning, any localized area that has been contaminated will be decontaminated; then the building will be demolished.

#### 5.4.3.3 Performance Confirmation Building

The performance confirmation building contains a hot cell and waste-handling and support facilities. The hot cell could have as high a level of radioactive contamination as the cask-unloading hot cell or the consolidation hot cells in WHB-2. Pending further development of the performance confirmation concept and equipment requirements, it is assumed that the facility's features and the contamination in the performance confirmation building are similar to those of WHB-2. Therefore, the decommissioning process for the performance confirmation building will be similar to that for WHB-2.

#### 5.4.3.4 Decontamination Building

The decontamination building is used to decontaminate off-normal casks or equipment. It is not expected to be used frequently. After each recovery operation from off-normal conditions, the building and equipment, including ultrasonic bath, electropolishers, chemical baths, and spray booths, will be decontaminated, if necessary. The contamination level in the building will be low. During decommissioning, any areas with localized contamination will be decontaminated. The equipment will be removed and the building will be demolished.

#### 5.4.3.5 Emplacement Area Exhaust Building

Under normal operating conditions, the ventilation system of the emplacement area exhaust building will not become contaminated; however, the system has been designed so that, if a radioactive release occurs in the emplacement area, the portion of the ventilation system that had become contaminated would be decontaminated as part of the decommissioning process. Decontamination would be necessary in the uppermost portion of the exhaust shaft, the inlet plenum, HEPA filter duct work, and possibly the HEPA filter room of the emplacement area exhaust building. These and other details will be developed during ACD.

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# 6.0 PERFORMANCE OBJECTIVES

The information presented in this chapter is an evaluation of the repository design features and operating procedures that will be used to ensure compliance with a subset of the performance objectives identified in 10 CFR 60 (NRC, 1986b), which are related to operations releases, waste retrieval, waste isolation, and performance confirmation. The information needed to address these performance objectives is contained in the design portions of this document (Chapters 3, 4, and 5) and the analyses presented in Chapter 7 (Design Analysis), in Chapter 8 (Design Issues and Data Needs), and in supporting appendices of this report.

A critical component of the regulatory requirements imposed on the design process is the implementation of a quality assurance program to be applied "to all systems, structures, and components important to safety, to design and characterization of barriers important to waste isolation, and to activities related thereto" [10 CFR 60, Subpart 6 (NRC, 1986b)].

The evaluation of the repository design and related analyses with respect to specific performance objectives provides design information used in determining the items important to safety and barriers important to waste isolation, which forms a list called the "Q-List" (Section 7.4). In addition, site information required to identify Q-List items is presented in detail in the Site Characterization Plan (SCP) (DOE, in preparation). In particular, the analyses of the site information are presented in SCP Sections 6.4 and 8.3. The material presented in those sections uses the Issues Hierarchy (DOE, 1986c) as an organizing principle (Section 1.5 of this report).

The lists of items potentially important to safety and of items and activities important to waste isolation are needed to support the resolution of two key issues relating to preclosure and postclosure of the repository. The information necessary to develop these lists is shown schematically in Figure 6-1, which also identifies the sections of the Site Characterization Plan Conceptual Design Report (SCP-CDR) that contain this information. A full discussion of the development of the Q-List is contained in Sections 2.7 (which provides definitions), 7.4 (which discusses methodology), and 4.6 (which lists items potentially important to safety and items and activities important to waste isolation). As indicated in Figure 6-1, the Q-List was developed using information from the design, design analyses, and supporting appendices of this report.

## 6.1 Radioactive Releases During Normal Operations

The repository facilities are designed to limit both radiation exposures in, and releases of radioactive materials to, the restricted and unrestricted areas during normal operations in compliance with the guidelines established by the Nuclear Regulatory Commission (NRC) and Environmental Protection Agency (EPA) (Section 2.5). Occupational exposures will be reduced to as low as reasonably achievable (ALARA), using programs similar to those in Regulatory Guide 8.8 (NRC, 1978) and in "A Guide to Reducing Radiation Exposure to As Low As Reasonably Achievable (ALARA)"

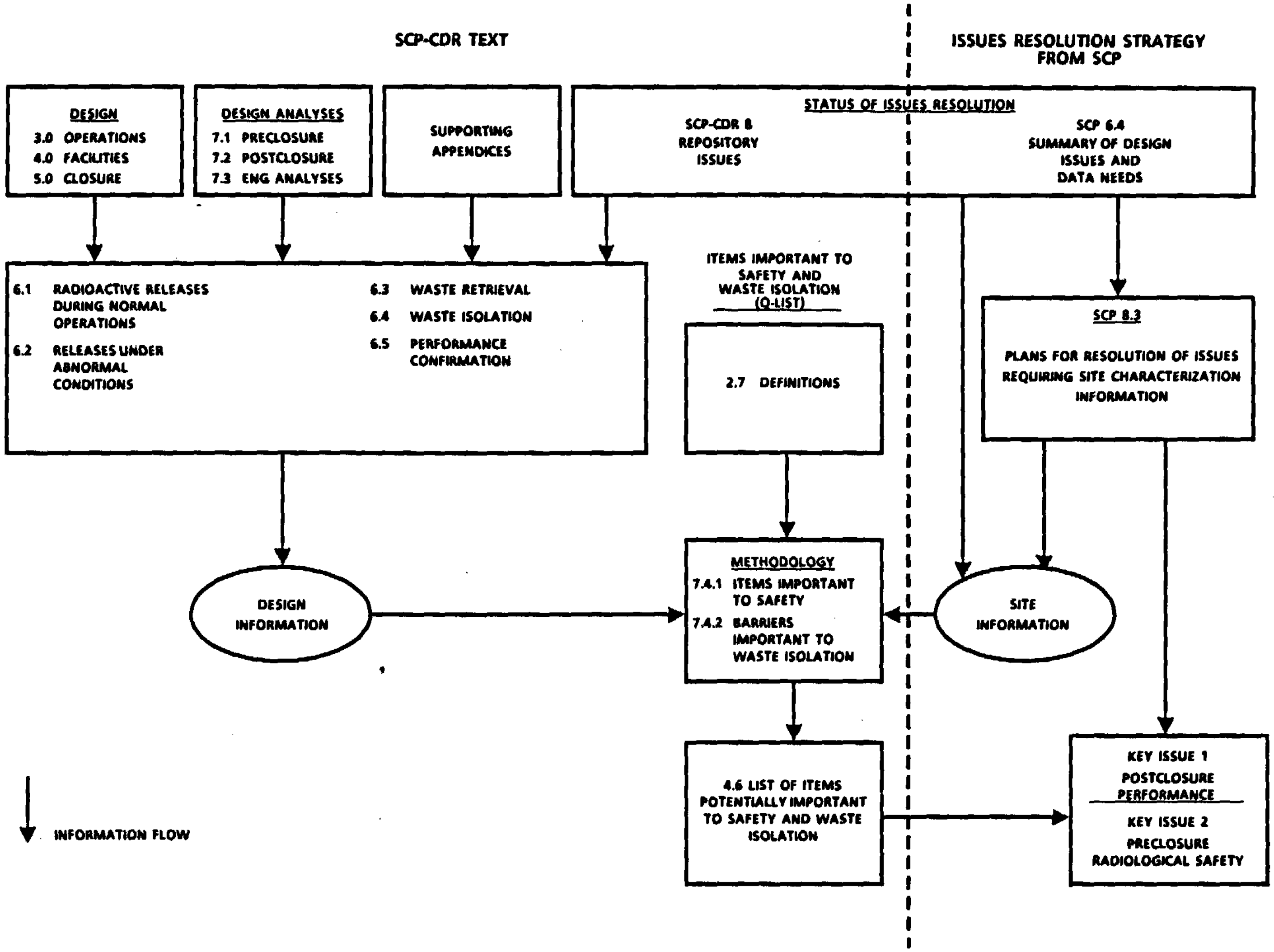


Figure 6-1. Relationship of this Report to the Issues Resolution Strategy (Figure prepared for the SCP-CDR.)

(Kathren et al., 1980). Releases can occur in the form of liquids, solids, and gases via the air and water pathways. All air and water effluents from the repository will be monitored to demonstrate compliance with regulatory limits and to verify the operation of any design features that prevent or mitigate the potential release of radioactive materials during normal operations.

The fundamental design approach to controlling release of radioactive materials to the restricted and unrestricted areas is to limit discharges to the air and water pathways. Collecting, monitoring, sampling, solidifying, and disposing of liquids are the design means used to prevent releases through water pathways. Monitoring and filtering the air before release to the environment are the primary design means to control releases of airborne contamination. Solid wastes can be collected, monitored, treated, packaged, and sent to an offsite disposal area to prevent releases of contaminated solids to the environment. The integrated collection, monitoring, treatment, and disposal of liquid, solid, and gaseous effluents is referred to as the waste treatment system. The design of this waste treatment system will comply with all applicable state and federal regulations.

This section is separated into four subsections: (1) liquid effluents, (2) solid wastes, (3) gaseous wastes, and (4) site monitoring. The first three subsections discuss the design concepts and approaches for the collection, monitoring, treatment, and disposal of liquid and solid wastes generated onsite, and monitoring and filtration of gaseous wastes. The site-monitoring subsection discusses monitoring requirements and the philosophy of the monitoring program used to ensure that radioactive releases to the environment are within applicable limits.

### 6.1.1 Liquid Effluents

#### 6.1.1.1 Sources and Quantities

The major sources of chemical liquid wastes include decontamination solutions, vehicle washdowns, laundry drains, and spent resin slurries. Decontamination solutions are generated by using water, detergents, or chemical solutions to remove radioactive contamination from equipment, tools, and casks. Maintenance activities are major contributors to these liquid wastes.

Vehicle washdown solutions include detergents, oils, salts, and road dirt. These solutions are recycled at the washdown station and are normally released to the sanitary drain unless determined by monitoring and/or sampling to be radioactively contaminated.

The liquids in laboratory drains contain chemical wastes and other solutions with varying amounts of solubles, insoluble solids, detergents, organic compounds, and concentrations of radioactive materials. Contaminated liquids from the laundry drains are included in this category.

Wastes from spent resin slurries are generated by the purification system for recyclable liquids in the waste treatment building (Section 4.2.4.2.1). These slurries are periodically transferred to the cement solidification system for processing. In addition to these chemical wastes, floor drains, interior flushing of shipping casks, and exterior rinsing of shipping casks are major sources of liquids that must be collected, monitored, and treated.

Estimates of the quantities of liquid wastes were calculated using the analytical methods discussed by Engelhard and Jardine (1985). Curie content was estimated based on literature, operating plant experience, and engineering judgment. Table 6-1 summarizes these estimates for the chemical and recyclable liquids. These quantities are the design bases for the liquid waste treatment system in the waste treatment building. At this design stage, no liquid wastes from the underground emplacement areas are included in Table 6-1; they will be determined during the advanced conceptual design (ACD). All initial estimates of liquid waste sources and quantities will be reviewed and refined during ACD.

TABLE 6-1

SUMMARY OF LIQUID WASTES GENERATED ON THE SURFACE

| Chemical Liquids* | Gal/yr | Ci/yr |
|---|---|---|
| Decontamination Solutions | 22,400 | 4.5 |
| Vehicle Washdowns | 5,800 | 0.06 |
| Laundry Drains | 5,700 | 0.002 |
| Spent Resin Slurry (cask flushes) | 2,600 | 80 |
| SUBTOTAL | 36,500 | 85 |
| **Recyclable Liquids** | | |
| Decontamination Rinses and Floor Drains | 18,000 | 4 |
| Cask Interior Flushes | 212,400 | 750 |
| Cask Exterior Flushes | 149,600 | 15 |
| SUBTOTAL | 380,000 | 769 |

*Only the chemical liquids are treated by a solidification process. The recyclable liquids are reused, not solidified.

### 6.1.1.2 Treatment and Operations

A conceptual flow diagram for treatment of liquid radioactive wastes is shown in Figure 3-10. The flow diagram shows the estimated waste quantities and sources and the equipment needed to collect, monitor, treat, and solidify the liquid wastes. Monitoring and sampling are used extensively to establish which liquids must be routed to the waste treatment building.

Facilities containing radioactive materials will be designed to permit the segregation of liquid wastes into chemical liquids and recyclable liquids as described below. Chemical liquids, including liquids from laundry drains and other liquids not suitable for processing by ion exchange, are collected, monitored, and solidified with cement in 55-gal drums. Two waste storage tanks, in which the pH of the liquids is controlled chemically, are used to collect these chemical wastes. Tank mixers and waste recirculation pumps agitate the liquids to keep solids in suspension. The waste is then mixed with cement and solidified in 55-gal drums, which produces about 1,200 drums/yr.

Recyclable liquids are those generated by nonchemical decontamination processes or those collected from contaminated equipment drains. These liquids are suitable for reuse after processing by ion exchange. These relatively large volumes of liquid are collected in tanks separate from those used for the collection of chemical liquids. The liquids to be recycled are then directed through cartridge filters and ion exchangers to remove radioactive particulates and to purify the water. Purified water is recycled for use in decontaminating and preparing shipping casks. Spent resins are periodically slurried from the ion exchangers of the purification system to the chemical liquid tanks for solidification.

#### 6.1.1.3 Waste Disposal

After contaminated liquid wastes that cannot be purified for recycling have been solidified, the 55-gal drums are transported to an offsite, near-surface disposal area.

### 6.1.2 Solid Waste

#### 6.1.2.1 Sources and Quantities

Compactible and noncompactible solid wastes are generated by the receipt, preparation, storage, emplacement, maintenance, and waste-handling operations in the waste-handling buildings, decontamination building, underground emplacement areas, and the waste treatment building. All suspect materials are collected and monitored to determine whether further treatment and special disposal are necessary.

Compactible wastes are materials that can be processed mechanically (other than by supercompacting) to increase package density. Noncompactible wastes are those at or near maximum density before any waste treatment. Hazardous materials are not included in the categories for compaction.

Solid wastes can be further subclassified based on materials and/or compositional properties. A set of subclassifications has been adapted from information developed by Deltete et al. (1984) to categorize solid wastes expected to be generated at a repository.

Based on these subclassifications, the various types of compactible waste include

- plastic, consisting of nonhalogenated plastics (e.g., coveralls, protective suits, lab coats, boots, gloves, sponges, hats, raincoats, sheets, bags, containers, and bottles);
- polyvinyl chloride, consisting of halogenated plastics (e.g., protective suits, coveralls, lab coats, boots, gloves, hoses, containers, and bottles);
- paper, including coveralls, lab coats, absorbent paper, wrappings, and cartons;
- materials used to absorb fluids (e.g., vermiculite and bentonite);
- cloth, including coveralls, lab coats, rags, mops, and gloves;
- rubber, including boots, hoses, gloves, and sheets;
- metal, including items that can be compacted, such as empty cans;
- filters, including high-efficiency particulate air (HEPA) filters, prefilters, and respirator canisters; and
- miscellaneous items.

The various types of noncompactible waste include

- wood, including construction lumber, plywood, and packing;
- conduit, including tubing, cable, wire, and electrical fittings;
- pipe, tubing, valves, and pipe fittings;
- filters, including cartridge-type filters and canisters;
- wooden or metal frames that surround HEPA filters;
- concrete, including the debris from scarifying and demolishing concrete shields, structures, and supports, or large concrete pieces;
- tools, generally consisting of hand tools, although some power-driven tools can be included;
- dirt, including dust, floor sweepings, and similar small particulates, or large quantities of contaminated soil or sand;
- glass, including bottles, laboratory glassware, instrument tubing, and face plates;
- lead used as a shielding material in any configuration; and
- miscellaneous items.

Estimates of the quantities of these solid wastes have been made based on the methods described by Engelhard and Jardine (1985). Table 6-2 summarizes these estimates for compactible wastes, noncompactible wastes, and various solid filter media needing treatment. The waste treatment systems are primarily located in the waste treatment building described in Section 4.2.4.2.1. Portions of the waste-handling buildings are also used to treat HEPA filters and spent cartridge filters, which may contain high levels of radioactivity and require remote handling. At this stage of the design, no solid wastes from the underground emplacement areas have been included in Table 6-2; quantities will be estimated during ACD.

TABLE 6-2

ESTIMATED QUANTITIES OF SOLID WASTES GENERATED IN THE SURFACE FACILITIES

| Waste Type | Quantity ($ft^3$/yr) Untreated | Treated | Ci/yr |
|---|---|---|---|
| Compactible | 46,550 | 9,310 | 130 |
| Noncompactible | 2,650 | 2,650 | 5 |
| HEPA Filters | 2,640 | 1,060 | 900 |
| Cartridge Filters from Shipping Cask Flush* | 425 | 3,075 | 6,800 |
| Cartridge Filters from Purification of Recyclable Liquids* | 45 | 325 | 690 |
| TOTAL | 52,310 | 16,420 | 8,525 |

*It is assumed that most of the waste from these types is treated.

### 6.1.2.2 Treatment Operations

A conceptual flow diagram for treatment of solid radioactive wastes is shown in Figure 3-11. The flow diagram shows the estimated waste quantities and the equipment needed to collect, monitor, and treat the solid wastes.

Solid wastes generated during health physics surveys, decontamination activities, and maintenance are placed in plastic bags and are collected in drums or boxes in the areas where they are generated. These containers are monitored periodically for any radiological leaking and are then transferred to the waste treatment building.

These wastes are separated into compactible and noncompactible wastes. Compactible wastes are placed in a compactor that reduces the volume and packages the material in 100-$ft^3$ boxes. Some noncompactible wastes may be combined with compactible wastes before compaction. Other noncompactible wastes are packaged in similar boxes. After packaging, the boxes are moved to an interim holding area to await transport offsite for disposal.

Solid wastes containing high concentrations of radioactivity must be handled remotely. Air filters from the hot cells in the waste-handling buildings are replaced periodically, using master/slave manipulators and remotely operated cranes and manipulators. The spent filters are placed in a device that separates the filter media from the frames. The filter media are compacted, the frames are shredded, and both are packaged in 55-gal drums. The drums are then placed in canisters that are sealed and handled in a manner similar to that used for containers of spent fuel and high-level waste.

Spent cartridge filters are placed in cement-lined 55-gal drums with adsorbent material to eliminate free liquids in the package. These operations are performed remotely, using master/slave manipulators and the overhead bridge crane in the waste treatment building. The packaged drums of cartridge filters are transferred to Waste-Handling Building 2 (WHB-2) (Figure 3-11) for loading into canisters, which allows remote handling in a manner similar to that used for drums of air filters from the hot cells.

#### 6.1.2.3 Disposal Options for Site-Generated Waste

It is currently planned to dispose of site-generated waste offsite at an authorized commercial facility. Radioactive wastes containing less than specified concentrations of certain radionuclides may be buried in an offsite, near-surface disposal site licensed by the NRC or an agreement state in accordance with 10 CFR 61 (NRC, 1986c). The maximum concentration of alpha-emitting, transuranic nuclides allowed for commercial low-level waste to be buried in near-surface disposal sites is 100 nCi/g.

Alpha-emitting, transuranic nuclides may be introduced into site-generated waste streams because of accidental release of fuel materials from spent fuel assemblies. The larger pieces or particles of spent fuel will be retrieved and packaged in spent fuel containers using specialized equipment (yet to be designed) and will not be treated as site-generated waste. However, dust and small particles of such fuel materials not easily retrieved will be collected on ventilation exhaust air filters and from wastes generated by decontamination activities.

The waste treatment systems for radioactive waste generated at the repository are being designed to produce waste forms and packages that are acceptable for burial at commercial, near-surface disposal sites, and these wastes are not expected to contain concentrations of transuranic nuclides in excess of 100 nCi/g. However, further study of this question will be needed in future design phases. All wastes generated at the repository are expected to meet the definition of low-level radioactive waste in 10 CFR 61.

The waste treatment system and the quantities to be disposed of are summarized schematically in Figure 6-2. Appendix D of this report provides a list of the major equipment associated with the waste treatment

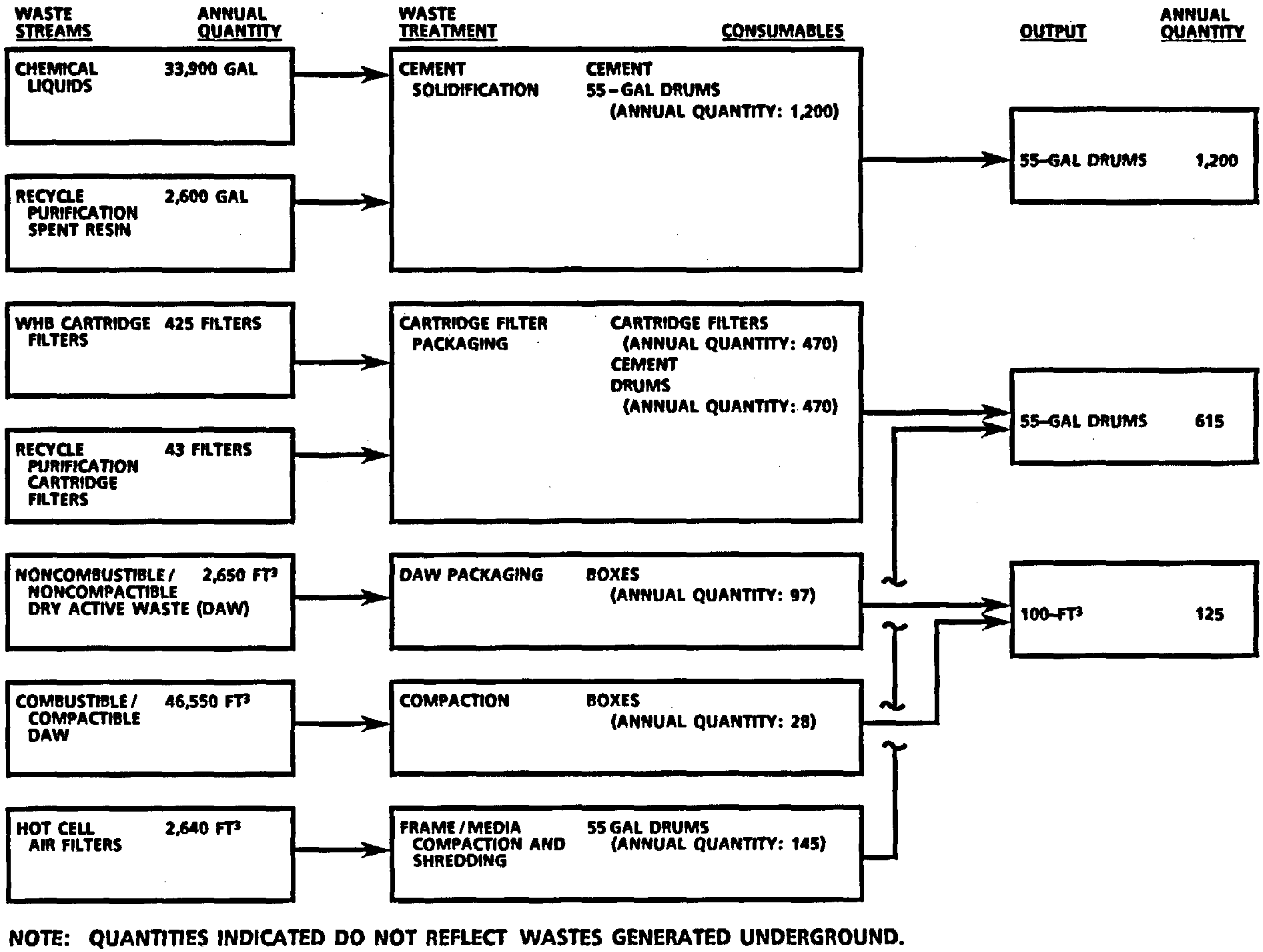


Figure 6-2. Summary of Reference Waste Treatment Process (Figure prepared for the SCP-CDR.)

systems. The arrangement and description of the waste treatment building are presented in Section 4.2.4.2.1.

### 6.1.3 Gaseous Waste

Releases of radioactive materials as airborne particulates or gaseous releases in the exhaust air system are controlled and prevented by confinement and ventilation systems. Monitoring and effluent sampling are used to verify the efficacy of design features for preventing releases to the environment and to demonstrate that the effluents comply with allowable release limits.

#### 6.1.3.1 Particulate Releases

Any airborne radioactive particulates released to the atmosphere must be below the concentration limits specified in 10 CFR 20, Appendix B, and must be low enough to meet the radiation dose limits in 40 CFR 191. To ensure that these limits are not exceeded and to reduce the amount of radioactivity released to the environment, HEPA filters and various other filtering media will be provided in the ventilation exhaust systems of all contaminated and potentially contaminated areas of the surface and subsurface facilities. Such areas include space provided for cask unloading, cask preparation, fuel unloading, fuel consolidation, waste packaging, surface storage, decontamination, solid and liquid waste treatment, and underground emplacement operations. A discussion of the ventilation and filtering system is contained in Section 6.1.3.3.

#### 6.1.3.2 Gaseous Releases

Gases, such as krypton, tritium, iodine, and carbon-14; volatile radioactive compounds, such as cesium iodides; and radioactive fission-product gases may be released in small quantities from spent fuel through defects in the cladding or from the accidental rupture of fuel rods during fuel consolidation or fuel-handling operations. Measurements of defective spent fuel rods by Peehs et al. (1986) indicate that releases of radioactive iodine and cesium result in an extremely-small-to-negligible quantity of these radionuclides at dry storage temperatures of 150 to 400°C. These preliminary results from Peehs et al. (1986) suggest that special offgas systems for the treatment of volatiles, such as iodine and cesium, will probably not be needed in facilities that handle spent fuel under dry storage conditions.

Small releases of tritium as tritiated water were observed in the study by Peehs et al. (1986). The measured curie content of the tritium releases were between the releases for iodine and krypton. The potential for releases of tritium from spent fuel needs more analysis before it can be concluded that special collection systems to prevent tritium releases are not needed. Preliminary calculations indicate that tritium releases are of more concern in onsite, restricted areas than in offsite, unrestricted areas.

Calculations of dose consequences for krypton releases from broken spent fuel rods in a repository have been reported by Donahue and Jardine (1986). These results show that even in fuel consolidation operations, where an increased number of cladding failures is expected, design of special collection and treatment systems for all krypton releases is not likely to be necessary. The ALARA considerations for krypton releases require further study, particularly cost/benefit analyses.

Studies will continue during ACD to characterize the types and quantities of radioactive gases likely to be released from normal repository operations, including the waste treatment processes. At this stage of the design, no special offgas collection and treatment systems for gases and volatile radionuclides have been included in the facility designs. Standard, modular offgas treatment systems used by the nuclear industry are included with the liquid and solid waste treatment systems and hot cell decontamination systems. When modifications are made to the current waste treatment systems (such as adding an incinerator or an evaporator) or when future studies identify any special offgas requirements, the appropriate waste treatment systems will be incorporated in the facility designs. Operations requiring more analyses and supporting data about releases of gaseous and volatile radionuclides from spent fuel include cask preparation (i.e., cask venting), fuel consolidation, handling of dry spent fuel, and container closure.

#### 6.1.3.3 General Surface Ventilation Systems

Separate heating, ventilating, and air-conditioning (HVAC) systems are provided for the various waste-handling areas, the surface storage vault, and personnel areas. In general, two types of ventilation systems are provided: once-through systems and recirculation systems. Once-through systems rely completely on outdoor air to meet indoor ventilation requirements and are used in areas where the potential for radioactive contamination exists. All air from these systems is directed through exhaust filters before release to the atmosphere. Recirculation systems recirculate ventilated air to reduce heating and cooling load requirements.

Radioactive gases and airborne particulates are contained and controlled by maintaining increasingly negative pressure zones in buildings containing radioactive materials. The pressures in zones of potentially higher contamination are lower than those in zones of potentially lower contamination. All pressure zones in buildings containing radioactive materials will be maintained at a pressure lower than atmospheric pressure to prevent leakage to the outside environment. Table 4-3 shows the pressure ranges in each zone, together with a description of the zones. Figures 4-15 and 4-16 illustrate those pressure zones in the two waste-handling buildings (WHB-1 and WHB-2).

All air released to the atmosphere from buildings containing radioactive materials is directed through one or more banks of HEPA filters to prevent release of radioactive particulates. In both waste-handling buildings, ventilation air is exhausted above roof levels. Tornado dampers are currently provided on all ventilation intake and exhaust systems for areas in which radioactive material is present.

In potentially contaminated areas, ventilation exhaust filter assemblies and associated fans are provided with sufficient redundancy to allow continuous ventilation exhaust while filters are replaced, components are maintained, or when filter failure occurs.

The surface storage vaults in both waste-handling buildings are ventilated by forced-air convection. The exhaust air is normally unfiltered but is continuously monitored. If an off-normal event in a vault results in the detection of airborne contaminants in the vault's airstream, exhaust air from the vault is automatically diverted through two HEPA filters before release.

In the underground facility, ventilation air from the waste emplacement areas is normally exhausted directly to the outside environment without filtration. Potentially contaminated areas and the emplacement area exhaust shaft are continuously monitored for airborne radioactivity. If concentrations of radioactivity that are higher than normal are detected, the ventilation exhaust from the waste emplacement area is automatically diverted through HEPA filters, and the flow rate is automatically reduced.

### 6.1.4 Site Monitoring

Site-monitoring requirements are classified in this section as either radiological protection or environmental monitoring. The monitoring requirements for radiological protection, which are designed to protect the health and safety of the public and workers, have been derived from 10 CFR 60.131. Environmental monitoring requirements are not specified in 10 CFR 60. Initial environmental monitoring is used to determine concentrations of naturally occurring radionuclides in the environment as a baseline for measuring the impact of repository operations on the environment. Subsequent monitoring of the environment will verify the accuracy of site monitoring for radiological protection of the public. This section discusses both types of site-monitoring requirements.

#### 6.1.4.1 Radiological Protection Monitoring

Based on the general design requirements in 10 CFR 60.131, the geologic repository operations area will be designed to limit radiation doses, radiation levels, and concentrations of radioactive materials in air in the restricted area to those limits specified in 10 CFR 20. The same requirements can be used to establish a basis for site-monitoring requirements during normal repository operations to prevent or limit releases of radioactivity.

Beyond the basis for monitoring specified in 10 CFR 20, the specific design requirements in 10 CFR 60.131(a) include

- the means to limit the concentration of radioactive material in the air;

- the means to limit the time needed to perform work in the vicinity of radioactive materials, including, as appropriate, designing equipment for ease of repair and replacement and providing adequate space for operation;

- suitable shielding;

- the means to monitor and control the dispersal of radioactive contamination;

- the means to control access to areas of high radiation or areas of airborne radioactivity; and

- a radiation alarm system to warn of significant increases in radiation levels, concentrations of radioactive material in the air, and increased radioactivity release in effluents; the alarm system will be designed with provisions for calibration and for testing its operability.

Achievement of these six design requirements will necessitate site-monitoring instrumentation, which will be incorporated in a health physics program.

Effluent-monitoring and sampling systems will measure the amounts and concentrations of radionuclides in all liquid effluents and exhaust air with enough precision to determine whether releases conform to the stipulations of 10 CFR 20.106, which governs radioactive materials in liquid and air released to unrestricted areas. Monitoring equipment and components will be designed according to the recommendations of ANSI N42.18 (ANSI, 1980). All potentially contaminated liquids generated at the repository will be collected in sumps or tanks to allow monitoring, sampling, and analysis before disposal. Liquids containing quantities of radionuclides that exceed any NRC or EPA limits for discharge will be directed to the waste treatment building for treatment and processing. Liquids that have been properly characterized by monitoring and that meet discharge limits will be diverted to the sanitary drain system for conventional discharge.

All ventilation exhaust from potentially contaminated areas will be continuously monitored for airborne radioactivity to determine concentrations. In each building, as appropriate, the exhaust streams will be combined in one common exhaust header that is isokinetically sampled in accordance with ANSI N13.1 (ANSI, 1969). The exhaust-monitoring systems will include remote readout and preset alarm capabilities. All data received from the effluent monitors will be logged by the repository computer system.

A meteorological tower will be provided in the central surface facilities area to establish site-specific meteorological monitoring data for use in assessment of the radiological impacts of airborne effluents. Offsite concentrations of any airborne radioactivity released from the repository will be estimated based on these meteorological data.

To ensure that radiation exposures comply with 10 CFR 20, all individuals entering the waste operations area will be monitored by dosimeters for radiation exposure. Only properly authorized and monitored personnel will be allowed to enter areas where potential radiation levels exceed background levels. The specific type of personnel dosimetry has not yet been selected. Monitoring devices will be provided in the facilities to supplement personnel dosimetry. Stationary radiological monitoring systems will measure radiation levels and concentrations of airborne radioactivity. These monitoring systems will also provide alarms when measurements indicate above-normal levels. Area radiation monitors will be provided in accessible areas throughout the waste operations area to continuously monitor radiation levels. Continuous air monitors and fixed-filter air samplers will be provided in potentially contaminated areas to monitor the concentrations of airborne radioactivity. The health physics program will include area surveys to periodically verify radiation levels.

Alarms will be provided in surface and subsurface facilities to warn operators when airborne radiation levels exceed normal ranges so that affected areas can be evacuated, if necessary, and corrective action can be taken. The alarms will also be recorded and monitored by a computer at a central location. Criticality alarms will be provided where necessary. All entries or exits from the waste operations area will be equipped with portal monitors. Change rooms and various areas throughout the waste operations area will be equipped with hand and foot monitors and portable survey instruments.

Studies will be conducted during ACD and site characterization to establish whether any special considerations for monitoring radon are necessary. No special provisions are currently provided. Continuous-air and fixed-air-sampler monitors are used to detect radiation or airborne contamination underground. When contamination is detected, a signal is generated that automatically causes exhaust air from the emplacement area to be diverted through HEPA filters located in the emplacement area exhaust filter building. Operating difficulties that might result from dust, and the need to detect extremely low-level radioactivity in large volumes of underground exhaust effluents, will be studied during ACD, and any appropriate design modifications will be incorporated in future designs. Various portable hand and foot monitors will also be used in the underground emplacement areas.

#### 6.1.4.2 Environmental Monitoring

Environmental monitoring establishes the levels of radionuclides in the environment and generates baseline data against which the impacts of repository operation are assessed. This monitoring is done during site characterization and operations and as part of initial postclosure monitoring. An outline of an environmental monitoring program has been developed and is discussed below.

The environmental monitoring program will obtain samples and measure radiation levels at locations surrounding the repository to confirm that effluents are not adversely affecting the environment and are in compliance with the limits for radiation exposures to the public specified in 40 CFR 191. An area within a 50-mi radius of the prospective Yucca Mountain site will be covered by the monitoring program. Air monitoring will be conducted using continuous air samplers (i.e., collection of particulates on filter media and reactive gases on charcoal), thermoluminescent dosimeters (for measurement of external radiation exposures), and pressurized ion chambers (for measurement of gamma exposure rates). Samples of soil, ground water, produce, milk, and biota will be periodically collected and analyzed. In addition, a program to monitor human exposure will be conducted that includes whole-body radiation measurements and urine analyses, which is currently required by the Department of Energy (DOE) at the Nevada Test Site (NTS).

Population exposure will be determined by continuous air sampling for particulates, reactive gases, noble gases, and tritiated water vapor. External, whole-body, gamma exposures will be measured by using highly sensitive gamma-rate recorders at the larger population centers and by integrated measurements with thermoluminescent dosimeters at both populated and unpopulated locations. To assess radionuclide migration and potential population exposure, ground water will be monitored frequently at nearby locations. If onsite monitors fail to detect any evidence of a release, the impacts on soil, biota, and food crops will be assessed only once a year.

During the operating period, monitoring data will be collected routinely (monthly) at unpopulated locations to detect any radionuclides transported through the atmosphere. For this sampling, all types of air samples will be collected, as described above, at pre-established locations. Soil and biota serve as media that integrate radionuclide deposition over time and will be sampled on a quarterly basis. Water sampling, comprehensive atmospheric sampling at populated locations, and external gamma measurements will also be made during the operations phase.

## 6.2 Releases Under Abnormal Conditions

Section 6.2.1 outlines the philosophy and approach being developed to identify design-basis accidents (DBA) for the Yucca Mountain repository. Section 6.2.2 outlines the philosophy of design analysis being developed to identify and design systems, structures, and components used to mitigate offsite releases from postulated DBAs. Because the current repository design is conceptual and details have not been developed, specific design features have not been identified. Section 6.2.3 provides a directory to sections of this report in which additional information on accidental releases and their prevention is located.

### 6.2.1 Design-Basis Accidents

Design-basis accidents aid in identifying those systems, structures, and components (engineered safety features) that must withstand the effects of those accidents without allowing excessive release of radioactive material. By specifying acceptable releases in the design requirements for the DBAs and by incorporating those specifications in the design, safe design is achieved. The DBAs are used to evaluate public safety but will not be used to evaluate any other criteria, such as worker safety, loss of production schedules, or economic losses.

#### 6.2.1.1 Methods for Identifying Design-Basis Accidents

Design-basis accidents are defined as those credible events that could impose a severe strain on the capacity of engineered safety systems to perform their safety functions. The methods used to develop a set of DBAs must include the systematic identification, development, and screening of initiating events and accident scenarios. Information and experience from prior development of DBAs for similar facilities can be used to some degree. If information from similar facilities is used, it must be rigorously examined to ensure that any significant differences between facilities have not been overlooked.

Two basic methods for developing DBAs--deterministic and probabilistic--are available. Both methods have their value. The deterministic method has been used in the Nevada Nuclear Waste Storage Investigations (NNWSI) Project (Jackson et al., 1984) to establish bounding accidents for the purpose of determining the magnitude of any release to offsite areas. This deterministic approach indicates that no major problem concerning offsite doses would exist at the repository.

More recent work has used the probabilistic approach outlined in Appendix L-1. The work, documented in Appendices F and L-1, supports and agrees with earlier deterministic results. The calculations and analyses have not identified any accidents that produce an offsite exposure above the 0.5-rem threshold for identifying items important to safety (10 CFR 60). However, it is still possible and reasonable to establish a set of DBAs against which to test the design. Because the 0.5-rem threshold is not considered to be a limit for DBAs, an acceptable limit will be established for use during ACD studies.

Design-basis accidents are assigned to one of three major categories: in-plant events, severe natural phenomena, and offsite, man-made events. Though not comprehensive, the following list includes representative events:

- in-plant events, which include accidental collisions of materials-handling equipment and systems, escape of radioactive materials, and equipment failures;

- severe natural phenomena, which consist of earthquakes, extreme winds or precipitation, flooding, sandstorms, and tornado-generated missiles; and

- offsite man-made events, which include airplane crashes, explosions in industrial facilities, underground nuclear explosions at the NTS, releases of hazardous materials, and collisions of vehicles transporting radioactive waste.

#### 6.2.1.2 Initial Set of Potential Design-Basis Accidents

A set of potential accidents being considered for inclusion as DBAs is presented in Table 6-3. These accidents represent an initial compilation for use in this SCP-CDR. This set is based on engineering judgment and experience with the designs of licensed nuclear facilities. The left column of Table 6-3 lists initiating events under each of the three categories. The right column of Table 6-3 lists some events that could result from any of the initiating events in the left column. Design analyses of facility responses and analyses of offsite release consequences for these potential DBAs have not yet been started. An initial set of DBAs will be developed during the ACD that will include evaluations of the facilities' response to DBAs and offsite dose consequences. During the ACD, the results of DBA analyses will provide the basis for setting design parameters and criteria for the license application design (LAD).

TABLE 6-3

SUMMARY OF POTENTIAL ACCIDENTS BEING CONSIDERED AS FUTURE DESIGN-BASIS ACCIDENTS

| Initiating Events | Events in the Facility That May Result from the Initiating Event* |
|---|---|
| **Natural Phenomena** | • Cask drop in receiving bay or cask preparation area |
| Earthquake<br>Flood<br>Extreme Wind<br>Tornado (including missiles) | • Fuel assembly drop in cask-unloading hot cell or consolidation hot cell |
| | • Runaway transporter in ramp |
| **Offsite Man-Made Events** | • Loss of HVAC in such locations as ducts, vault, and storage racks |
| Loss of Offsite Electrical Power<br>Aircraft Crash<br>Underground Nuclear Explosions | • Detonation of mining explosives |
| **In-Plant Failures** | • Fires in areas containing combustible materials<br>- fire in waste-handling building, waste treatment building, and waste emplacement area;<br>- fire in contaminated air filtration system;<br>- diesel oil fire; and<br>- criticality (possibly). |
| Structure<br>Equipment<br>Operator | |

*Any one of these events may be caused by several of the initiating events. A one-to-one correlation across the table is not implied.

### 6.2.2 Design of Mitigating Features

#### 6.2.2.1 Introduction

Neither the identification nor the analyses of the DBAs needed to identify mitigating features has been completed. Identification of an initial set of mitigating features is scheduled for the ACD. This section discusses the methods planned for identifying and establishing the design requirements of features needed to prevent or mitigate releases to the accessible environment.

#### 6.2.2.2 Methods for Identifying Mitigating Features

The process envisioned to determine the design features necessary for the prevention or mitigation of offsite releases is summarized in Figure 6-3. The objective is to identify, by performing analyses of all

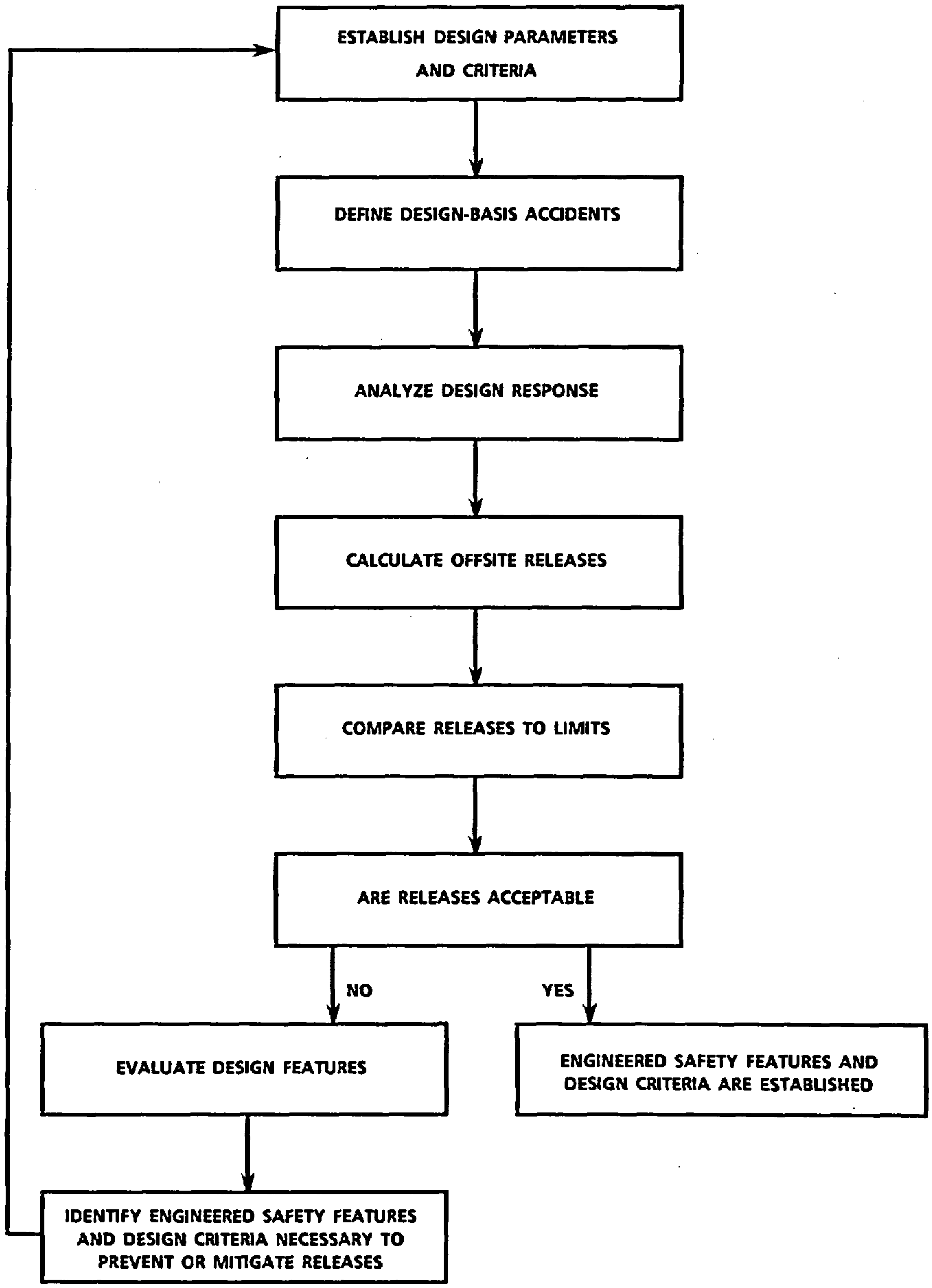


Figure 6-3. Illustration of Design Analysis Process Used to Determine Engineered Safety Features (Figure prepared for the SCP-CDR.)

the DBAs, the engineered features needed to prevent or mitigate offsite dose consequences resulting from these DBAs. This process is iterative; design analyses are repeated for each DBA until all necessary engineered safety features have been defined. Any design features required to prevent or mitigate consequences (such as worker safety, economic impacts, investment protection, interruption of the production schedule, etc.) that do not result in offsite doses are not within the scope of the design analyses given in Figure 6-3.

The first step in Figure 6-3 involves establishing a set of design parameters and criteria within which DBAs are defined. Second, design analyses of the responses of the structures, systems, and components to DBA conditions are performed to establish areas where radioactive material releases could be initiated. Because each area and design feature can be affected differently by DBA conditions, multiple, repetitive response analyses must be conducted to determine the responses of the structures, systems, and components and to identify any associated damage that could result in an offsite release. The postulated offsite releases are calculated and compared with the offsite release limits for DBAs.

If the releases are above DBA limits (these limits have not yet been established by regulation), the appropriate design features must be evaluated in more detail; if the releases are below DBA limits, no further analysis is needed. Offsite releases are initially evaluated without taking any credit for the preventive or mitigating capabilities of the engineered features. However, once systems, structures, or components have been identified as necessary to prevent or mitigate a DBA's offsite consequences, they must be designed so that they do not fail under DBA conditions. The selection of design features to prevent or mitigate offsite releases (if multiple alternatives exist) will take the costs of these features into account.

As shown in Figure 6-3, there is an iteration that leads back to the first step in which the DBAs are reevaluated. This iteration ensures that the design parameters and criteria used for the facility design and the engineered safety features are consistent and will produce an acceptable response to the DBA. The entire design analysis is then repeated for the revised set of design criteria to verify that a facility's response to the DBA and resulting releases of radioactive material are acceptable.

During the evaluation of each DBA, some evaluations and review of the design parameters are made for effects on, and consistency with, previously analyzed DBAs. A comprehensive analysis of all DBAs is a difficult task to implement because the relationship between parameters is generally complex and subtle. After the design analyses have been completed for all DBAs and the design requirements and parameters for the engineered safety features have been established, a licensable facility design and design bases will be available for presentation to the NRC.

6.2.2.3 <u>Mitigating Features</u>

The determination of DBAs and the development of design details have not progressed to a point at which quantitative analysis can be performed to identify mitigating features. However, through experience and engineering judgment, several items have been incorporated in the current design. Examples of the items included are (1) zoned ventilation systems in the waste-handling buildings, (2) HEPA filters on all potentially contaminated ventilation systems, (3) the location of the surface facilities, (4) seismic considerations for surface facility design, (5) separate underground ventilation systems for the development and waste emplacement areas, and (6) radiation-monitoring systems. The philosophy used throughout the design has been that the simpler the operations and the fewer the movements and operations, the fewer accidents are likely to occur.

### 6.2.3 Directory to Additional Data

Discussions pertaining to preventing or mitigating offsite releases from abnormal events appear throughout this report. Table 6-4 lists the sections where more detailed information can be found.

## 6.3 Waste Retrieval

Design requirements for retrieval follow the DOE's position paper on retrievability and retrieval (DOE, 1986b, Appendix D). The following design activities ensure that the design of the repository includes the option to retrieve emplaced waste: (1) prediction of the conditions at the time of retrieval, (2) retrieval demonstrations for equipment and methods not previously demonstrated, and (3) development of reference designs that ensure that the ability to retrieve all of the emplaced waste (full retrieval) is not precluded.

### 6.3.1 Expected Conditions

The conditions of the underground portion of the geologic repository operations area during the 50-yr retrievability period are expected to be good with respect to opening stability, ambient air conditions, and operator safety. These conditions are not expected to compromise the capability of retrieving the waste. The rock properties, design parameters, etc., used to predict conditions underground that result from the current design were chosen to encompass some of the extreme conditions that could be present. Qualitatively, based on preliminary evaluations completed to date, the following conditions are expected for most retrieval operations.

- The access ramp and drifts will be dry and stable throughout the retrievability period.
- Acceptable air quality will be maintained in the underground area.
- The ventilation system will be fully operable.
- Acceptable temperature will either be maintained or achieved by forced ventilation and cooling.
- Acceptable radiologic conditions will exist.
- The emplacement boreholes will be stable and will provide acceptable access to the waste containers.
- The waste containers will be intact.

TABLE 6-4

DIRECTORY OF DISCUSSIONS RELATED TO RADIOACTIVE RELEASES UNDER ABNORMAL CONDITIONS

| Topic | Section |
|---|---|
| Radiological Exposures to the Public | 2.4.3 |
| Radiation Protection | 2.5 |
| Federal Regulations | 2.6.2 |
| Classification of Systems, Structures, and Components Important to Safety and Waste Isolation | 2.7 |
| Ventilation | 3.4 |
| Heating, Ventilating, and Air-Conditioning Systems for the Waste-Handling Buildings | 4.2.4.1.3 |
| Underground Ventilation Control System | 4.4.3.1 |
| Items Important to Safety | 4.6.1 |
| Releases Under Abnormal Conditions | 6.2 |
| Resolution of Issue 2.3, Accidental Radiological Releases | 8.3.3 |
| Preliminary Preclosure Radiation Safety Analysis | Appendix F |
| Design-Basis Criteria | |
| Probable Maximum Flood | Appendix H-1 |
| Seismic | Appendix H-2 |
| Wind and Tornado | Appendix H-3 |
| Fire Water | Appendix H-4 |
| Standby Power | Appendix H-5 |
| Monitoring | Appendix H-6 |
| Items Important to Safety at the Yucca Mountain Repository | Appendix L-1 |

The emplacement area is located several hundred feet above the water table. This location, combined with the effects of the heat from the waste, will aid in keeping the drifts dry. The 50 yr/50°C retrieval design criterion (Section 2.4.4.3), combined with the requirement for periodic ventilation, inspection, and maintenance of access and emplacement drifts, will aid in maintaining acceptable air quality, temperature conditions, and the operability of the ventilation system. [Appendices A and

J and Flores (1986) give projected temperature/time curves for drifts and boreholes.] The predicted thermal stresses around the drifts are well below the anticipated rock strength values, and the induced stress in the borehole liners that results from predicted rock fall is acceptably low (Appendix B). (Appendix O gives recommended properties, and Section 8.3.7.2.6 and Appendix N give the thermomechanical analyses.) The dry environment will retard potential corrosion of the liner.

A preliminary list of off-normal retrieval conditions has been identified, and an initial assessment of the probabilities of their occurrence has been performed (Appendix L-2). These qualitative assessments will be re-examined in future studies in an attempt to quantify the probability of occurrence from the high, medium, low, and negligible categories to categories of greater than $10^{-1}$, $10^{-1}$ to $10^{-3}$, $10^{-3}$ to $10^{-5}$, or less than $10^{-5}$ (Section 2.4.4). The initial assessment identified only a few conditions of medium probability but many low-probability conditions (Appendix L-2) relative to completing the overall retrieval operations in the alloted time. However, several specialized operations were identified that may require equipment development and demonstration. None of the conditions resulted in a significant consequence (Appendix L-2). The list of retrieval conditions under consideration is contained in Appendix J.

### 6.3.2 Retrieval Demonstrations

Two categories of retrieval demonstrations are planned: proof-of-principle demonstrations and development of prototypical equipment. Retrieval equipment and methods involving the use of nonstandard equipment (not commercially available) or the use of standard equipment in unusual circumstances require proof-of-principle demonstrations. According to current plans, proof-of-principle demonstrations will be complete by the time of license application (LA). Where design questions remain, prototypical equipment will be developed during review of the LA and repository construction (DOE, 1986b, Appendix D).

#### 6.3.2.1 Proof-of-Principle Demonstrations

For proof-of-principle demonstrations, two types of demonstrations are involved: component demonstrations and mockup demonstrations. Component demonstrations will be performed for equipment components that (1) are critical to retrieval and are not commercially available, (2) are extrapolations from current technology, or (3) require new technology. The current list of components for the horizontal emplacement configuration that might require proof-of-principle demonstrations includes the borehole drill and liner installation equipment, the borehole shielding closure, the container dolly, the container retrieval system for both normal and off-normal operations, and the transporter/cask alignment system (Appendix D of this report). The current list of components for vertical emplacement that might require proof-of-principle demonstrations includes the shielding closure, the waste container removal system, and the transporter/cask alignment system.

Mockup demonstrations test the larger systems along with some aspects of the retrieval environment. These mockup demonstrations evaluate the integration of components and subsystems already demonstrated. The demonstrations will be planned to include the necessary portions of design-basis off-normal conditions (Figure 2-11) to develop confidence in system performance. It is expected that mockup demonstrations will not include noncritical components or subsystems; hence, fabrication of a complete set of retrieval equipment is not considered necessary, nor is it planned for proof-of-principle demonstrations.

#### 6.3.2.2 Development of Prototypes

At the time of LA, remaining questions about the performance of retrieval equipment under normal and expected off-normal conditions (Figure 2-11) will be addressed by the development and testing of prototypical equipment. Prototypical equipment is developed to verify its performance and methods of retrieval under normal and expected off-normal conditions. Most of the data on prototype testing can be obtained more accurately and efficiently by using mockups rather than by testing in the emplacement area because the test environment can be controlled. Prototypical development will also be used to refine the design. These refinements will include evaluations of human interfaces, system integration, environment, time and motion studies, development of drawings and specifications for production equipment, and development of operator training program.

### 6.3.3 Full Repository Retrieval

Retrievability is to be designed into the repository as a planned contingency; therefore, the capability for full retrieval need not be provided or even designed at the time of repository construction, provided that it can be designed later with no adverse impact. The design of all retrieval concepts, methods, and equipment must be completed, but it need not be integrated in a design for full retrieval. For example, long-term stability of underground openings will be addressed during initial design and construction, but the complete design of all surface facilities in which retrieved waste containers are cleaned or repackaged for shipment offsite may not be necessary and can probably be performed later with no adverse effect. The ventilation system should be designed to allow routine cooling and maintenance of emplacement drifts and to allow for retrieval of emplaced waste. This ventilation system should also accommodate full retrieval, in case retrieval is required. The retrieval system and individual items of equipment must be designed to meet performance criteria that provide for full retrieval within the specified time period (34 yr). However, only enough equipment should be fabricated to demonstrate that performance criteria for unit rates are met; a full complement of equipment and facilities to empty the entire repository need not be provided.

The design criteria that ensure that retrieval capability is maintained are found in Section 2.4.4.3 and are summarized below.

- Liners will be used in the emplacement boreholes: partial liners for vertical boreholes and full liners for horizontal boreholes.

- The transporter is designed to operate in both an emplacement and retrieval mode.

- The repository will not be backfilled during the preclosure period.

- Drift temperatures will be limited to 50°C for 50 yr (Section 3.2.1).

- A dolly will be used in the horizontal emplacement configuration to avoid damaging the waste container during emplacement or retrieval.

- The ventilation system will be designed to cool the emplacement drifts and to supply adequate ventilation air during waste removal operations.

- The ramps and drifts are being designed for long-term stability.

- Retrieval equipment is being designed to function under normal and off-normal retrieval conditions.

Should partial or full retrieval be mandated either for economic reasons or to ensure public safety, it is not expected that any problems needing major development of new technology will be encountered (Appendix L-2); rather, some unique applications of existing technology are anticipated. In the case of vertical emplacement, forced ventilation for cooling drifts before re-entry appears to be the most demanding problem. However, the equipment will be in place, and the operating procedures will have been established during the continuing cooling, inspection, and maintenance program. If horizontal emplacement is chosen, it is thought that the retrieval problems will be different from and more complex than those of the vertical emplacement configuration but that they could be solved by using current engineering technology (Appendix L-2). For selected off-normal conditions, it may be necessary to develop specialized equipment, which will result in unique applications of available technology. For the emplacement concept selected, the retrieval equipment will have been fully developed and demonstrated before operations begin and will be demonstrated further during the recovery of waste packages for performance confirmation.

Existing site data, such as rock matrix properties and fracture orientation and frequency, are expected to be confirmed by in situ measurements in the exploratory shaft facility (ESF). Existing data obtained from core samples have been used in the design process, and few, if any, changes are expected. Substantial additional information is expected from ESF observations regarding the frequency and potential severity of off-normal conditions to be encountered underground.

The repository design is constrained by the need to maintain long-term access to the emplacement drifts and the waste containers in the boreholes. It is not thought that this constraint will impose additional design requirements or increase overall repository costs.

### 6.3.4 Directory to Additional Data

Those sections where retrieval is discussed in this report are listed in Table 6-5. This list does not include specific supportive information, such as the requirements for long-term drift stability and periodic maintenance programs.

TABLE 6-5

DIRECTORY OF DISCUSSIONS RELATED TO RETRIEVAL

| Topic | Section |
|---|---|
| Retrievability Requirements | 2.4.4.1 |
| Development of Design Criteria | 2.4.4.3 |
| Waste Retrieval | 3.2 |
| Retrieval Philosophy | 3.2.1 |
| Waste Retrieval Operations | 3.2.2 |
| Maximum Ventilation Requirements for the Waste Emplacement Area | 3.4.2.2 |
| Air-Cooling Requirements | 3.4.3.3 |
| Waste Removal Operations for Performance Confirmation | 4.5.4 |
| Waste Retrieval | 6.3 |
| Issue 2.4: Waste Retrievability | 8.3.5 |
| Expected Temperatures for Borehole Walls and Drifts after Spent Fuel Emplacement | Appendix A |
| Preliminary Liner Stress Analyses | Appendix B |
| Ventilation and Cooling Analyses | Appendix C |
| Equipment for Surface Support and Waste Handling, Underground Development, and Waste Transportation, Emplacement, and Retrieval | Appendix D |
| An Assessment of the Feasibility of Disposing of Nuclear Waste in the Horizontal Configuration | Appendix E |
| Waste Retrieval | Appendix J |
| Items Important to Retrievability at the Yucca Mountain Repository | Appendix L-2 |
| Thermomechanical Analyses | Appendix N |

## 6.4 Waste Isolation

This section addresses the design features and measures taken during operations to reduce adverse effects on both waste isolation and containment. Each subsection addresses a specific requirement of 10 CFR 60: opening stability, underground layout, rock excavation, thermal loads, and shaft and borehole seals.

Key Issue 1 (Chapter 8 explains the Issues Hierarchy) requires the mined geologic disposal system (MGDS) to isolate the radioactive waste from the accessible environment in accordance with regulatory requirements. Issue 1.1, Total System Performance; Issue 1.4, Waste Package Containment; and Issue 1.5, Engineered Barrier System Release Rates are responsible for demonstrating that these requirements are met. The design issues [Issue 1.11, Configuration of Underground Facilities (Postclosure) and Issue 1.12, Seal Characteristics] are responsible for ensuring that design, construction, operation, and closure of the subsurface facilities do not adversely affect waste containment or isolation. The discussion in this section is based on these two design issues. SCP Sections 8.2 and 8.3.5 provide a detailed discussion of how the MGDS will meet the waste isolation and containment requirements of Key Issue 1.

Issue 1.11, Configuration of Underground Facilities (Postclosure), provides an interface for the design with various other issues under Key Issue 1 (Figure 6-4). The performance issues (e.g., Issue 1.1, Total System Performance; Issue 1.4, Waste Package Containment; and Issue 1.5, Engineered Barrier System Release Rates) have performance goals that Issue 1.11, Configuration of Underground Facilities (Postclosure), and Issue 1.12, Seal Characteristics, convert to design requirements, which are incorporated in the design by Issue 4.4, Preclosure Design and Technical Feasibility. This perspective of how performance is incorporated in design forms the basis for the following sections. The following sections are organized by topic rather than by issue. Discussions organized on an issue basis for Issue 1.11, Configuration of Underground Facilities (Postclosure), and Issue 1.12, Seal Characteristics, can be found in SCP Sections 8.3.2.2 and 8.3.3.2.

It is necessary to ensure that the design, construction, operation, and closure of the subsurface facilities do not adversely affect waste containment and isolation. Postclosure performance goals governing the design of the subsurface facilities have been established by Issues 1.11 and 1.12 through the performance allocation process described in SCP Sections 8.3.2.2 and 8.3.3.2. The relationship between the design features of the subsurface facilities and postclosure performance is discussed, in part, in Sections 6.4.1 through 6.4.5 below. Although waste containment and isolation are postclosure issues, many aspects of preclosure construction and operations can influence postclosure performance. Thus, resolution of postclosure design issues places constraints on preclosure construction and operation of the subsurface facilities. For example, the types of construction materials and amounts of water used, operation of the ventilation system, and blasting will be controlled so that these operations do not adversely affect waste containment and isolation. Although measures taken during operations to reduce adverse effects on waste

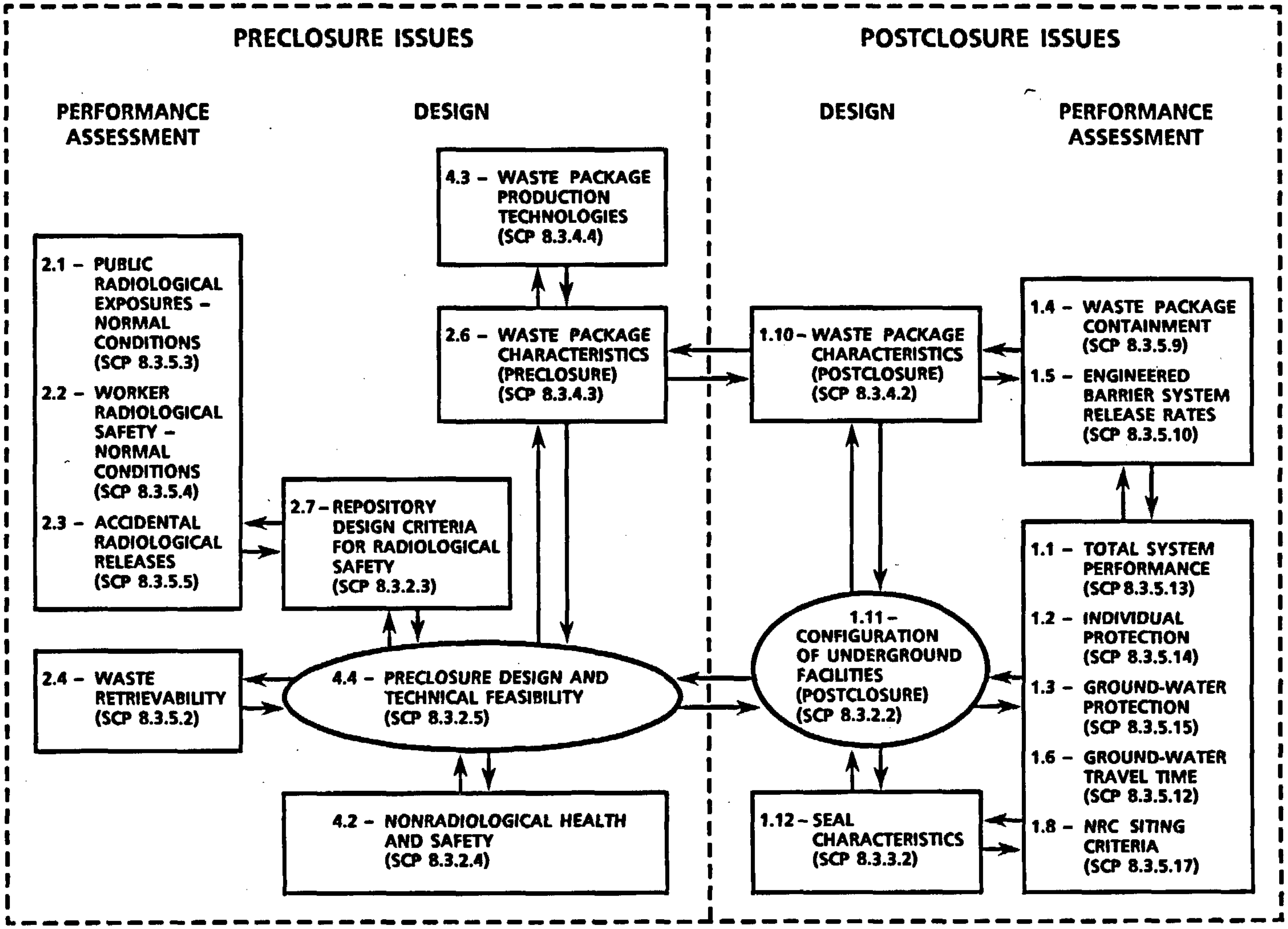


Figure 6-4. Relationship Among Design- and Performance-Related Issues Used Directly in Performance Allocation (Figure prepared for the SCP-CDR.)

containment and isolation are not discussed as such in the subsections below, they are part of the postclosure design goals established in SCP Sections 8.3.2.2 and 8.3.3.2.

6.4.1 Opening Stability [10 CFR 60.133(e)]

In this discussion, the stability of the openings in the underground facility is considered important only to the extent that it affects waste containment and isolation. The waste package provides waste containment; therefore, the stability of an opening is relevant to containment only if instability of the opening could damage the waste package sufficiently to affect its ability to contain the waste. The waste is isolated from the accessible environment to the extent that the site prevents or limits the transport of radionuclides. Thus, the stability of an opening is relevant to isolation only if instability of the opening could alter site characteristics sufficiently to damage the site's ability to isolate the waste.

The openings in the subsurface facilities include ramps and shafts, shops and underground support facilities, main and access drifts, emplacement drifts, and emplacement boreholes. Descriptions of these openings, including location, function, size, and shape, are given in Sections 4.3 and 4.4.

6.4.1.1. Contribution of Opening Stability to Containment

Rock movement deleterious to containment is movement that can damage the waste packages enough to interfere with their function. The containment requirement in 10 CFR 60 can be satisfied either by stable openings or rock movement that results in no significant consequences. The latter occurrence necessitates developing criteria for waste package performance and for the openings.

Analysis of opening stability is based, in part, on experience gained by the mining industry. The usefulness of empirical rock-mass classification systems (Hoek and Brown, 1980) that have been used to analyze the host rock at Yucca Mountain (Section 8.3.7.2.6) (Dravo, 1984; Langkopf and Gnirk, 1986) is limited by the relatively short time mines have operated, compared with the 300- to 1,000-yr performance period for substantially complete containment of the radionuclides in spent fuel or high-level waste within the waste packages. These empirical rating systems lead to the projection that an unsupported span the size of a drift in even the best rock will have a maximum unsupported standup time of 20 yr. The fundamental lack of experience in predicting long-term stability of openings using the rating systems leads to the conclusion that long-term containment within the waste packages should not depend on opening stability. Rather, the waste packages and the openings immediately surrounding the waste packages must be designed so that local rock instabilities will not compromise waste package performance.

Only rock in the immediate vicinity of a waste package has the potential to physically damage the waste package's ability to perform its containment function. Openings far removed from the waste package (shafts and ramps) will not affect containment. Thus, only the stability of emplacement boreholes (and, possibly, the stability of the emplacement drift in the vertical configuration) is potentially important to containment. A summary of borehole stability calculations made to date is given in Section 8.3.7. These calculations have been made using both elastic and compliant-joint constitutive models. The latter models predict stresses high enough to fracture the rock in the immediate vicinity of the boreholes. These calculations do not indicate the potential for large-scale failure, which would be detrimental to containment, but they do indicate that there may be local instability around the boreholes. The design of the waste packages must take this instability into account.

#### 6.4.1.2 Contribution of Opening Stability to Waste Isolation

The openings of the subsurface facilities can affect waste isolation if they create preferential pathways for radionuclide transport to the accessible environment or if they affect the site's ability to prevent or limit radionuclide transport. The shafts and ramps create potential pathways to the accessible environment. Section 6.4.5 discusses the means of ensuring that these openings do not adversely affect waste isolation. The openings of the shops and underground support facilities are separate from the waste emplacement areas and are not direct connections to the accessible environment. (Figure 4-34 shows the layout of these facilities.) Instability of these openings is not expected to adversely affect waste isolation. The main drifts, access and emplacement drifts, and emplacement boreholes constitute the remainder of the underground openings. Because of the extent of these openings and the volume of extracted rock, the potential effect of the openings on waste isolation must be assessed.

Waste isolation and opening stability are addressed in 10 CFR 60 by the requirement that "...the underground facility...be designed to reduce the potential for deleterious rock movement or fracturing of overlying or surrounding rock" [Section 133(e)(2)] and that "...the underground facility...be designed so that the performance objectives will be met" [Section 133(1)]. Thus, the regulations do not require that openings be stable but rather that the design reduce the potential for adverse effects on waste containment and isolation resulting from instability of openings. The application of these requirements to the design process occurs through the performance allocation goals set by Issue 1.11, Configuration of Underground Facilities (Postclosure) (SCP Section 8.3.2.2). The regulations and several generic technical positions drafted by the NRC recognize that rock movement may not necessarily be detrimental to waste isolation. The design satisfies the requirement "...shall be designed to reduce the potential for..." by incorporating opening shapes, sizes, extraction ratios, and thermal loadings that enhance stability and by specifying backfill to mitigate the consequences of any drift instability.

Waste isolation in geologic formations below the water table is affected by several factors, including (1) permeability of the host rock matrix and existing hydraulic gradient, (2) frequency and connectivity of fractures in the host rock, and (3) alteration of the integrity of the host rock by construction of the underground facility and the presence of thermally induced stresses. In recognition of these facts, 10 CFR 60 includes in Section 133(e)(2) the requirement cited above on deleterious rock movement and fracturing of the host rock.

These factors do not influence waste isolation in the partially saturated zone in the same way they influence it below the water table. The Yucca Mountain tuffs do have a very low matrix permeability, but the waste isolation capability of the site is not dependent on the sparsity of natural or thermally induced fractures. For a hard, fractured rock, such as the Topopah Spring Member, there will always be the potential for rock movement, especially the opening or closure of existing joints as a result of thermal expansion of the rock. Current data indicate that capillary effects tend to draw the ground water into the rock matrix; thus, water movement should occur in the rock matrix rather than in the fractures (DOE, 1986a, Section 6.3.1.1). Hence, slight, thermally induced fracture movement is not necessarily deleterious to waste isolation. Future site characterization activities will determine whether this interpretation of the hydrologic mechanisms at the Yucca Mountain site is correct. As a result of this interpretation of the hydrologic mechanisms, the major concern regarding waste isolation is maintaining the partially saturated state rather than avoiding changes in fracture permeability or preventing direct connection to an aquifer.

#### 6.4.1.3 Other Factors Affecting Opening Stability

During licensing, the ground support system for the drifts and the borehole liners will not be credited as design features that reduce the potential for adverse effects on waste containment and isolation. Predictive methods are probably not adequate for demonstrating the long-term stability of underground openings (including the effects of the ground support system and liners) but can be used to bound the amount of rockfall on the waste package. Drift and borehole stability and ground support systems and liners are of concern in the preclosure period. Analysis of the current designs during the preclosure period is presented in Section 7.1.3. The designs are influenced by operating requirements, equipment designs, in situ stress, thermal loads, rock properties, and extraction ratios. The effect of extraction ratios and thermal loads on waste isolation and containment is discussed in Sections 6.4.2 and 6.4.4.

The current conceptual design calls for backfilling drifts before closure (Section 5.2). Although backfill cannot prevent the instability of openings, it can, in some cases, mitigate the consequences of instability by reducing the extent of additional fracturing around an opening. However, the major deleterious effect of instability around emplacement boreholes is loading of the waste package. Backfill in the boreholes, rather than mitigating the effects of instability, might transfer a greater load to the waste packages. Thus, backfill of emplacement boreholes is not contemplated. Backfill in the drifts and other underground openings will limit potential collapse of the openings during the postclosure period.

### 6.4.2 Underground Layout

To contribute to waste containment and isolation, the design of the underground layout will take into account site-specific conditions and provide sufficient flexibility to accommodate localized variations in those conditions [10 CFR 60.133(a)(1) and (b)]. Specific site characteristics evaluated in developing the design include the thermal and mechanical properties of the host rock, in situ stress, hydrology, topography, stratigraphy, location of faults, and presence of joints and fractures.

The overall layout of the underground facility, which is essentially the same in both the vertical and horizontal emplacement configurations, is discussed in Section 4.4.2 and shown on Figures 3-20 and 4-30. The underground facility layout has been developed progressively through the following steps:

- select the primary (preferred) area for the underground facility,
- select the emplacement horizon,
- determine the usable portion of the primary area (usable area),
- determine the area needed (size) for the underground facility,
- delineate the boundaries of the conceptual layout of the underground facility,
- locate points of underground access to the layout,
- establish the elevation of entry into the emplacement horizon,
- locate unique facilities (shops, etc.),
- select the orientation and layout of panels and drifts,
- establish opening sizes and spacings, and
- establish the grade for all drifts.

Screening the Nevada Research and Development Area of the NTS and nearby areas for favorable locations for the permanent disposal of radioactive waste in a mined repository resulted in the selection of Yucca Mountain (Sinnock and Fernandez, 1982). The primary area for locating the underground facility (Figure 6-5) was designated, taking site characteristics into account (Mansure and Ortiz, 1984; DOE, 1986a, Section 6.3.3.2.3). The boundaries of this area are approximate.

The presence of faults was a major factor in delineating the primary area (Figure 6-5). As explained in Section 2.2.3.2, the boundaries of the primary area include faults with large displacements (as great as 500 m) and densely faulted zones with minor displacements. As stated in Section 6.3.1.3.3 of the Environmental Assessment (EA), (DOE, 1986a), the interior of the primary area contains relatively few faults, with only minor offsets (20 m or less) and rare breccia (Scott and Bonk, 1984).

Faults can be boundaries of the primary area if they terminate the continuity or suitability of the host rock for emplacement of waste. For example, the emplacement horizon is significantly displaced across Solitario Canyon Fault, which forms the western boundary of the primary area. The layout of the underground facility has generally been located to avoid major faults. Minor faults cannot be avoided entirely and will have to be crossed. With proper ground support, faults can be traversed and do not limit development of the underground facility (Dravo, 1984). Rock characteristics that have adverse effects on waste isolation could be associated with faults. If such conditions are encountered, a contingency plan will be followed to ensure isolation of the waste from the accessible environment (SCP Section 8.3.2.2.3). A typical response, as required by such a contingency plan, might be to skip and isolate an unsuitable area.

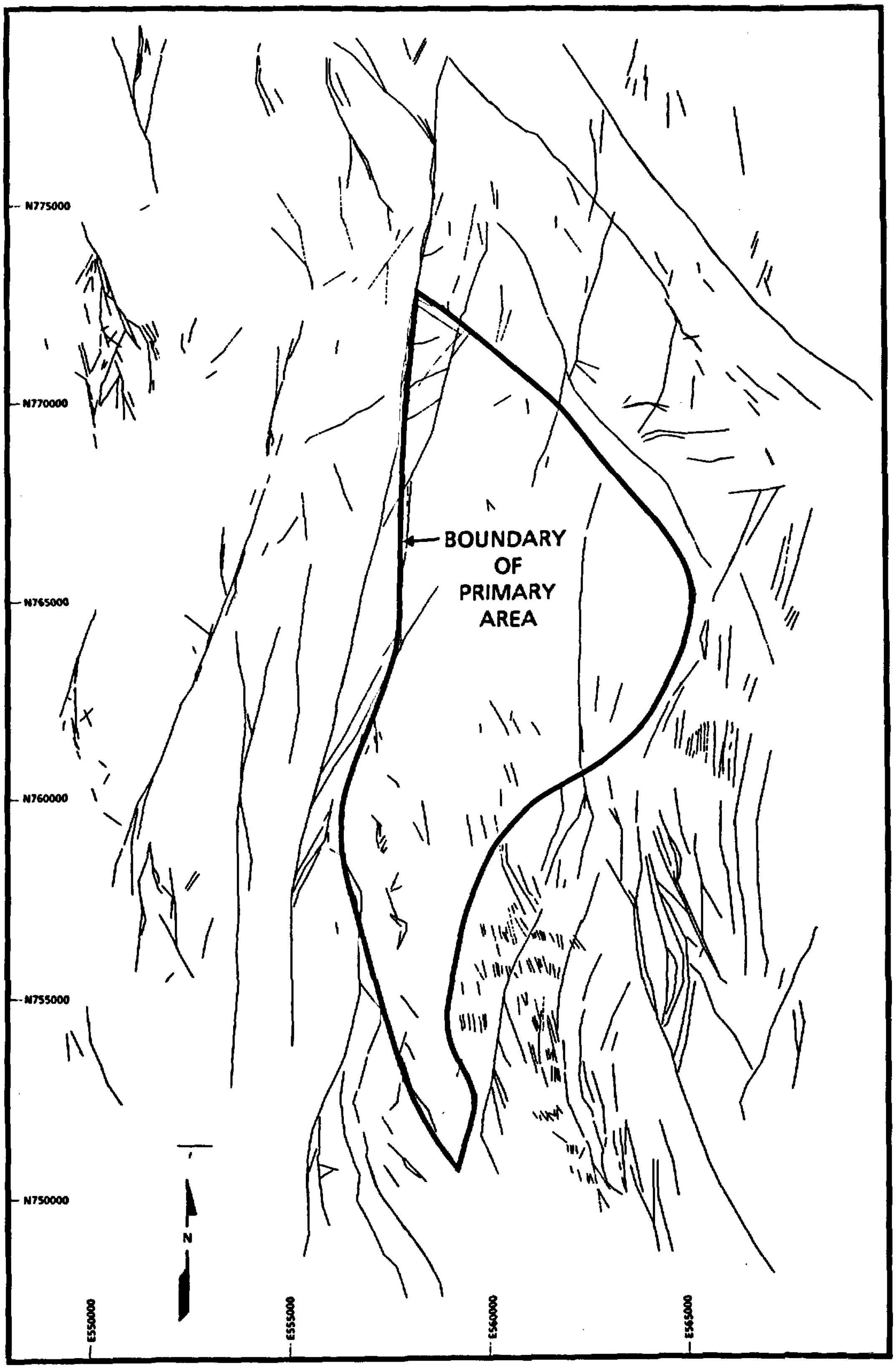


Figure 6-5. Relationship of Primary Area to Faulting at Yucca Mountain (SNL, CAD-IGIS Data Base, CAL141.)

The orientation of drifts and boreholes in the primary area was determined primarily by preclosure criteria, including location of the surface facilities, sizes and shapes of the openings, functional requirements, efficiency of development and emplacement operations, and ventilation requirements. The preferred layout was then evaluated against postclosure performance goals to ensure that the design would not adversely affect waste isolation and containment.

The in situ stress state at Yucca Mountain is anisotropic (Table 2-10). This anisotropy could cause the initial stability of the openings in the underground facility to be dependent on the orientation of the openings. Calculations indicate that, from the time of closure to well beyond the containment period (300 to 1,000 yr), the average temperature increase will be large enough so that the thermally induced horizontal stresses will be larger than the in situ stress. The thermal stresses should not have any significant horizontal anisotropy; therefore, postclosure opening stability (and, hence, waste containment and isolation) should not be adversely affected by horizontal stress anisotropy. For this reason, the anisotropy of horizontal in situ stress has not been an overriding factor in designing the layout of the underground facility.

The approach to resolving Issue 1.11 [Configuration of Underground Facilities (Postclosure) (Section 8.2.2)] does not include taking credit for demonstrating drift stability after closure, even though the calculations indicate that the drifts will be stable. However, the approach does seek reasonable assurance that instabilities of boreholes will not adversely affect the containment function of the waste package. The orientation of vertical emplacement boreholes is not affected by the orientation of the drifts; whereas, the orientation of horizontal emplacement boreholes changes as the drift orientation changes. Therefore, the relative orientation of the opening versus fracture direction is a postclosure consideration for boreholes only in the horizontal emplacement configuration.

Given a single joint (or larger feature, such as a fault), the preferred orientation of an underground structure is directly perpendicular to the feature, and the least desirable orientation is parallel to the feature. When more than one joint is involved, the problem is more complex. For two joint sets, the optimum orientation should be close to the bisector of the larger angle between the directions of the two joint sets. The fracture or joint directions at Yucca Mountain are described in Section 2.3.1.4 and Figure 2-9. For analysis of the design, it has been assumed that this joint pattern can be described as two joint sets--one at N12°W and the other at N34°E. The layout (Figure 4-30) for horizontal emplacement determined by the design approach discussed above orients the horizontal emplacement boreholes S56°E. This orientation is not parallel to either joint direction and lies close to the bisector of the larger angle between the joint sets assumed above.

The extraction ratio is one of the design goals used to limit the potential for subsidence. The extraction ratio is calculated based on the plan view, considering only the drifts. Consistent with common mining engineering practice, the emplacement boreholes are not considered in calculating the extraction ratio because boreholes are considerably smaller than drifts and because, in addition to the extraction ratio, the opening size and volume of mined rock influence the potential for subsidence.

The goals established for the extraction ratio of emplacement panels are that the ratio be less than 30% for vertical emplacement and less than 10% for horizontal emplacement (SCP Section 8.3.2.2). The conceptual design, as shown on Figures 3-20, 4-30, 4-37, and 4-38, results in the extraction ratios given in Table 6-6. These extraction ratios are low compared with those commonly used in hard rock mining (50 to 80%), and, although low extraction ratios do not guarantee absence of subsidence, they do enhance stability and confidence that there will be limited subsidence. Thermomechanical codes will be used to determine any potential for opening instabilities that could contribute to subsidence as part of the issue resolution process for Information Need 1.11.6, Thermomechanical Effects on Postclosure Design (SCP Section 8.3.2.2.6).

TABLE 6-6

EXTRACTION RATIOS USED IN THE CONCEPTUAL DESIGN

| Underground Facility Opening | Extraction Ratio: Vertical Emplacement Configuration (%) | Extraction Ratio: Horizontal Emplacement Configuration (%) | Acreage for Both Emplacement Configurations[a] |
|---|---|---|---|
| Shops and Support Facilities | 33[b] | 33[b] | 40 |
| Mains[c] | 22 | 22 | 110 |
| Access Drifts[c] | 18 | 18 | d |
| Emplacement Panels | | | 1,250 |
| Typical | 16 | 5 | |
| Maximum | 30[e] | 5 | |

a. For equal areal power densities (APD), the overall layout is the same for the vertical and horizontal emplacement configurations.
b. Average extraction ratio for shop and support facilities areas.
c. Calculation of the extraction ratio includes pillars around mains and access drifts.
d. Access drifts are part of the panel, and, therefore, their acreage is not reported separately. They occupy about 17% of the emplacement panel. Their extraction ratio is reported separately because they are areas of increased extraction in the panel.
e. Unconsolidated and low-burnup fuel will probably need to be emplaced at the design limit; i.e., the goal established in SCP Section 8.3.2.2.

The conceptual design for development of the underground facility is described in Section 3.3.1.4. Development and subsequent waste emplacement are accomplished in the following phases.

- Accessways to the emplacement level are constructed.

- Underground support facilities are developed.

- The three mains and the perimeter drift are developed to a point approximately two panel widths beyond the panel in which waste is being emplaced. This development will begin in the northeast quadrant and proceed in a clockwise direction.

- The emplacement panels are developed by first driving the access drifts from the mains to the perimeter drifts. The emplacement drifts are then constructed between the access drifts. When construction of an emplacement drift has been completed, the waste emplacement boreholes are drilled.

The development sequence described above limits the potential impact of mining operations on waste emplacement operations. In addition, development and waste emplacement operations are separated by at least one full panel and are served by separate ventilation systems.

During the ACD, the sequence for development will be reviewed to determine what sequence best satisfies performance goals and most efficiently uses the available space. For example, consideration will be given to an alternate development sequence in which the mains are developed; then the access drifts are driven out to confirm the rock conditions of the site; and, finally, the perimeter drifts are driven to connect with the ends of the access drifts. In this sequence, should the access drifts encounter undesirable conditions, portions of the access drifts could be sealed off as necessary and the perimeter drifts would be driven in acceptable rock.

The design of panel layout and borehole spacings, as shown in Figures 4-37 and 4-38, assumes waste characteristics appropriate to the year 2011 (Section 2.1), which is taken as a median year with respect to thermal output of the waste. This "typical" year is used for the ventilation analysis and conceptual design of development operations. However, there are many other combinations of waste package characteristics and drift and borehole spacings that satisfy the design criteria for allowable areal power density (APD) in the far-field and near-field performance goals (temperature and stability).

In the ideal repository design, the waste package design and borehole and drift spacings would vary, depending on waste characteristics and rock properties. However, it is not practical to vary these design parameters for each waste package. A reasonable approach to the design process is to establish a constant waste package design and a limited number of spacings, which will accommodate a range of waste characteristics. Thus, the method used to establish the waste package design and borehole and drift spacings is licensed rather than licensing the parameters of a single waste package or design of an emplacement panel.

### 6.4.3 Rock Excavation [10 CFR 60.133(f)]

Section 133(f) of 10 CFR 60 requires that the design of the underground facility incorporate excavation methods that limit the potential for creating a preferred pathway to the accessible environment. In SCP Section 8.3.2.2.5, under Information Need 1.11.5, this regulation has been interpreted to be satisfied by limiting excavation-induced changes in rock-mass permeability. Selection of actual excavation methods has involved consideration of possible ground-water movement, the potential impact of rock fracturing in the particular geologic and hydrologic setting at Yucca Mountain, and the potential impact of excavation methods on stability (Section 6.4.1).

Selection of the rock excavation method is also addressed indirectly in Section 133(i) of 10 CFR 60, which requires that the facility be designed to meet performance objectives. This aspect is addressed in SCP Section 8.3.2.2.4 under Information Need 1.11.4, which considers potential modifications of the chemistry and degree of saturation of the host environment during repository construction. The excavation method has been identified as a primary concern in controlling both such changes because of the use of water, drilling fluid, and other materials during construction.

A consequence of disposal in a partially saturated host rock is that the creation of new fractures in the rock mass and resultant increase in permeability may not directly influence waste isolation. Current data indicate (1) that capillary effects tend to draw the ground water into the rock matrix and, thus, water movement should occur in the rock matrix rather than in the fractures and (2) that the flow is substantially vertical (DOE, 1986a, Section 6.3.1.1). As a result of these interpretations of hydrologic mechanisms at the site, the major concern is maintaining the partially saturated state rather than avoiding changes in permeability, creating hydraulic interconnection of the underground facility openings, or establishing direct connection to an aquifer.

Verification of site performance, including any design-induced changes, is based on assumptions regarding the geochemical environment. The excavation method chosen and the controls placed on the related activities should limit the potential for changes, especially potentially adverse changes, in the geochemical environment.

The methods selected for constructing emplacement boreholes, secondary access and emplacement drifts, primary access drifts, and shafts and ramps are given in Sections 3.3.1 and 3.3.2. The bases for each selection are discussed below. The excavation processes for each of these openings will result in varying but small amounts of damage to the host rock.

#### 6.4.3.1 Emplacement Boreholes

The emplacement boreholes, whether vertical or horizontal, will be drilled. This excavation method decreases the potential for collateral damage. Loosening of the rock mass, including raveling of small blocks of rock defined by preexisting fractures, will be minimized in the horizontal borehole by the installation of a liner immediately behind the drill bit.

Potential changes in the degree of saturation and in the geochemistry have been a major concern in the design of equipment for drilling emplacement boreholes. The current design uses an air-flush method for removing drill cuttings from the borehole. This method limits, though does not completely eliminate, the need for water or other drilling fluids. Final approval of the nature and quantity of drilling fluids and any other materials used during preparation of the emplacement boreholes will be based on performance assessment analyses that consider changes in saturation throughout the preclosure and postclosure periods and chemical interactions between the host rock, the waste container, and chemical species introduced during the preclosure period.

#### 6.4.3.2 Secondary Access and Emplacement Drifts

The dimension and shape of the emplacement drifts are largely determined by the design of the waste containers and the waste transporter and a desire to limit the excavation in the waste emplacement panels (Section 6.4.2). It is possible that mechanized mining methods will be used, but conventional drill-and-blast mining has been selected because it provides maximum flexibility and control. Use of this method will result in a small but controllable amount of damage to the host rock. This damage is considered inconsequential because damage to the host rock surrounding the drift, if any, (1) is not likely to extend far enough to affect the stability of the emplacement borehole in the vicinity of the waste packages (i.e., waste containment will not be affected) and (2) will not extend far enough to affect the boundary of the disturbed zone (i.e., waste isolation will not be affected).

The extent of damage to rock around unrelieved blastholes (blastholes for which there is no free surface to break to) has been investigated for a number of different rock types, including tuffaceous rocks (Dowding, 1985). Damage is a function of the energy density per unit length of borehole and has been related to peak strain and particle velocity. Typically, the extent of damage around an unrelieved blasthole may be expected to extend some 20 to 30 borehole radii from the blasthole, which implies a damaged zone around a typical blasthole (100 mm in diameter) of approximately 1 m. This zone of damage will be substantially reduced for relieved blastholes (i.e., when breaking to a free surface) and can be essentially eliminated, if necessary, through the use of smooth-wall blasting techniques if the peak particle velocity around the trim holes for the drift is reduced to below 700 mm/s.

Indirect damage to the rock mass around underground openings as a consequence of nearby blasts has been investigated in a number of field tests (Dowding, 1985). These tests indicate that loosening along preexisting fractures may occur when particle velocities exceed approximately 500 mm/s and that new cracks around an unlined opening may be observed if the particle velocity exceeds 900 mm/s. These values are considerably in excess of those that would occur in the vicinity of a carefully designed blast in which delayed detonations and smooth-wall blasting are used. Hence, both direct and indirect damage to the host rock as a consequence of the careful use of drill-and-blast methods is not considered significant.

#### 6.4.3.3 Primary Access Drifts

The primary access drifts include the mains and perimeter drifts. Based on economic and scheduling considerations, full-face tunnel-boring equipment and conventional mining (Section 3.3.1) have been selected for excavation of these openings. As with the equipment used for drilling the emplacement boreholes, mechanical damage to the rock mass resulting from use of a tunnel-boring machine (TBM) will be minimal. Similarly, conventional mining of the primary access drift will result in minimal damage to the rock mass (Section 6.4.3.2). Moreover, except for dust suppression, there is no need for a flushing medium that may adversely affect the saturation or chemistry of the rock mass.

#### 6.4.3.4 Shafts and Ramps

Shafts and ramps will be excavated by conventional mining, raise boring, or TBM. Section 3.3.1 describes the approach used to excavate each shaft or ramp. As with the excavation of drifts, damage to the host rock is expected to be minimal; however, shafts and ramps must be excavated according to criteria established by considering the needs of the sealing program (SCP Section 8.3.5.11). Procedures for sealing shafts and ramps are discussed in Section 5.2.

### 6.4.4 Thermal Loads [10 CFR 60.133(i)]

Section 133(i) of 10 CFR 60 requires that the thermal loading of the underground facility be selected so that performance objectives are met while taking into account the predicted thermal and thermomechanical response of the host rock. This requirement, as addressed by Information Need 1.11.6 (SCP Section 8.3.2.2), results in the need to (1) select the allowable far-field APD and (2) design the distribution of waste and the configuration of the underground openings to meet near-field constraints and to be consistent with the far-field APD.

The design of the layout of the underground facility could begin from either near- or far-field criteria (Section 7.2.2). The latter were selected as the starting point in the design process because the allowable far-field APD and associated concept of equivalent energy density (Appendix G) provide a single design parameter that can be used to ensure that the layout meets all far-field goals; i.e., as long as the waste is emplaced at less than the allowable far-field APD, there will be reasonable assurance that the far-field goals are met and that the design meets the requirements of the applicable parts of 10 CFR 60.133.

For the near field, no single design parameter (APD or other) is known that can be used to ensure that all near-field goals are met. The thermomechanical response must be analyzed to determine whether the near-field goals are met each time the near-field design changes (waste type, borehole spacing, waste age, burnup, etc.). Furthermore, it is unlikely that a single worst case can be established and analyzed (young waste has a higher initial output, but older waste decays more slowly). Thus, for a given APD in the near field, it is possible to either meet or violate a given goal.

#### 6.4.4.1 Areal Power Density

Preliminary, far-field, thermomechanical performance goals have been established through the performance allocation process by Issue 1.11 (SCP Section 8.3.2.2). These goals are

- limiting temperature changes in selected barriers,
- limiting the potential for deleterious rock movement or creation of preferential pathways for radionuclide migration, and
- limiting the impact on the surface environment.

The last of these goals has no direct bearing on isolation and will not be discussed further.

Thermally driven dehydration or irreversible chemical changes in the host rock, although not likely to have a significant effect on total system performance, could, in principle, be either beneficial or detrimental to waste isolation and ground-water travel time. During the performance allocation process, it was decided to limit the potential for such changes rather than to investigate the effects of such changes (SCP Section 8.3.2.2). The site was chosen because of its existing favorable chemical, mineralogical, and hydrologic characteristics. It was decided to limit the potential for changes in those characteristics during development so that postclosure performance of the site will not deviate unnecessarily from conditions or processes identified during site characterization. Tentative limits on temperature changes in the Calico Hills and the vitrophyre at the base of the Topopah Spring Member have been set and will be used during the selection of the APD.

The potential effect of thermally induced stresses on postclosure performance is still being assessed because flow mechanisms in the partially saturated host rock at Yucca Mountain are still being characterized. This uncertainty in the hydrologic mechanisms is mitigated by the fact that the level of stress in the host rock is generally increased by thermal expansion, which results in a decrease in permeability in most of the host rock. The stress increase is most pronounced for horizontal stresses near the underground facility and will result in closure of the predominantly vertical joints. Elastic analyses indicate that small compensating reductions in horizontal stress may cause small increases in the permeability of vertical joints near the ground surface above the underground facility and at some depth below the underground facility. These effects and similar ones affecting vertical stress beyond the perimeter of the underground facility are less than the stress increases and permeability changes in the immediate vicinity of the underground facility.

The generally compressive nature of the induced stress field around the emplacement area ensures that permeability, and fracture permeability in particular, will be decreased in the immediate vicinity of the underground facility unless new fractures or extensive regions of joint slippage or joint activation develop. As discussed in Section 6.4.1, neither of these events is likely to adversely affect total system performance; however, during the performance allocation process, it was decided to limit these effects rather than rely on demonstrating a lack of adverse consequences. These effects could arise if the thermally induced stresses are high relative to the strength of the rock matrix, joints, or faults. Accordingly, thermomechanical analyses of typical cross sections of the repository will be performed to identify any potential for development of new fractures, widespread joint activation, or fault activation.

#### 6.4.4.2 Waste Emplacement Configuration

Selection of an APD that satisfies all far-field performance criteria merely defines the allowable APD of the repository. The design-basis APD is some value equal to or less than the allowable APD. During repository design, the design-basis APD must be used to establish waste container spacing, borehole spacing, and allowable container thermal output so that near-field criteria are satisfied. As in the case of the far field, the postclosure criteria for the near field are concerned with temperature changes and the nature and extent of any mechanical damage to the host rock.

The temperature criteria, identified in SCP Section 8.3.2.2, relate to (1) stabilizing the waste form, (2) minimizing the region of irreversible chemical changes, and (3) contributing to maintaining a dry environment (possibly for at least 300 yr). This last criterion, which is intended to limit the corrosion of the container, is the only criterion for which increasing the APD may be an advantage. However, other site characteristics and economic considerations may also encourage selection of a relatively high APD.

The design of the waste emplacement configuration will be determined primarily by practical considerations for the preclosure period. These considerations include worker health and safety, maintenance of the waste retrieval option, equipment constraints, and cost. Once a feasible design for emplacement of the waste at the specified design-basis APD has been developed, the design will be analyzed to establish whether the design criteria for near-field temperature will be met. If these criteria cannot be met, the design can be modified by changing the distribution of the waste or by revising the design-basis APD, provided that the far-field criteria are satisfied. The process will be iterative and, at the outset, will involve heat-transfer calculations. Eventual verification of the design will rely on more detailed two- and three-dimensional thermal analyses that adequately model heat transfer in the partially saturated tuff and that may consider the possible effects of ventilation during the preclosure period.

Finally, the design must be checked to ensure that the extent of rock movement that results from thermally induced loads is within an acceptable range. For the emplacement boreholes, it is necessary to evaluate the load that would be exerted on the waste package in the event that the emplacement borehole liner is crushed or corrodes some years after the conclusion of the retrieval period. This load must be consistent with the design criteria for the waste package. Thermal and mechanical analyses, using generally conservative assumptions regarding the properties of the rock around the emplacement boreholes, will provide a basis for estimating the extent of loosening of blocks of rock and any loads on the waste package if the liner is completely corroded. A similar approach will be used to evaluate the potential for progressive loosening of rock around the other openings of the underground facility once any ground support has corroded. If the calculations suggest a potential for extensive loosening that would be deleterious to isolation or would result in surface subsidence, the underground facility design will be modified to mitigate such effects.

### 6.4.5 Shaft and Borehole Seals (10 CFR 60.134)

Penetrations, such as shafts and boreholes, can become preferential pathways to the accessible environment. To ensure that the overall system performance objective for the MGDS is met, it is necessary to evaluate the potential for shafts and boreholes to serve as preferential pathways that would compromise performance. If this objective is jeopardized, measures must be taken to seal the shaft and boreholes to ensure adequate performance.

Several completed studies have contributed to the seal design information presented in Sections 5.1, 5.2, and 5.3. The studies include the development of sealing concepts (Fernandez and Freshley, 1984). These concepts were developed by considering the geologic nature of the unsaturated tuffs at Yucca Mountain, especially the highly fractured Topopah Spring Member welded tuff. Using these concepts, a detailed plan (Fernandez, 1985) was developed to focus on future studies that will provide a design acceptable for LA. Further refinement of this plan is presented in SCP Sections 6.4.3 and 8.3.5 and in Section 8.2.2 of this report. Discussions of completed work are given in SCP Section 6.4.3.2 and Section 8.2.2.2 of this report.

In SCP Section 8.3.3, the approach used to resolve Issue 1.12 involves several steps that result in the preparation of design requirements and constraints and in the identification of information that must be defined to resolve the issue. These requirements, constraints, and information are then transmitted to Issue 1.11, which partly defines the reference postclosure design. To determine whether the performance goals for the sealing system elements can be met, analysis of the reference postclosure design in conjunction with selected site and test data from the Reference Information Base (RIB) is necessary. This process is performed for each design phase using the steps summarized below.

- Identify the repository elements to which this issue applies. In what follows, the term "sealing component" is synonymous with "sealing system element."
- Define the licensing approach, i.e., the function that each selected sealing component is to perform and the process that must be considered in assessing the component's ability to perform its function.
- Identify the performance measure that shows how well the sealing component performs its intended function.
- Establish the performance goals and level of confidence needed to reach the goal.
- Define the parameters, the range of values, and the level of confidence needed in the parameter range to achieve the performance goal.
- Develop the design requirements that apply to sealing options and identify the design constraints that are imposed on nonsealing system elements by the sealing system.

- Identify information needed to resolve Issue 1.12.

A recently completed report (Fernandez et al., 1987) establishes performance standards for the seals in the underground facility, shafts and ramps, and boreholes. It also proposes the technical basis for seal performance allocation, the design requirements for specific design options, and the materials to be used for these design options. The study has been used to refine the sealing concepts and to provide an additional basis for the design illustrated in Sections 5.1, 5.2, and 5.3.

Section 5.1 of this report discusses the closure of the underground facility and describes removal of operating equipment, backfilling of underground openings, and sealing of discrete, water-producing zones. Section 5.2 discusses the sealing of shafts and ramps. Sealing components in the shafts and ramps fall into two general categories: shaft fill and discrete sealing components. The construction sequence for emplacing sealing components, including the restoration of rock surfaces before emplacing seals at the entry points of the shafts and ramps, is presented in Section 5.2.2.1. Because the shafts and ramps are in the unsaturated zone and do not penetrate into or through aquifers, no sealing of aquifers is necessary. Section 5.3 discusses the steps involved in sealing exploratory boreholes. The selection of sealing materials, the reworking of drillholes, and the removal of casings are included in the discussion.

The second general concern pertaining to sealing is the pretreatment of rock surfaces before emplacing the seals. During the initial construction of the exploratory shafts (or any other shafts), no permanent seals will be emplaced. If seals are needed at selected locations in the shafts, a section of the liner will be removed (a part of the decommissioning process) and the rock surfaces may be treated if necessary to achieve the desired level of seal performance. This treatment could include removal of loose rock at the shaft or borehole walls, chemical treatment of the rock surface, or restoration of the modified permeability zone to some desired level of performance. Additional details associated with the installation of shaft and borehole seals, the selection of sealing materials, reworking of drillholes, and removal of casings are given in Sections 5.2 and 5.3.

### 6.4.6 Directory to Additional Data

Discussions pertaining to waste isolation appear throughout this report. Table 6-7 lists the sections where more detailed information may be found.

## 6.5 Performance Confirmation

This section describes the general scope, function, and content of the performance confirmation program that will be conducted by the DOE, including descriptions of the general regulatory basis for the program, the required elements of the complete program plan as interpreted by the DOE, and preliminary plans for the performance confirmation program that have been developed, specifically as they relate to the conceptual design of the repository proposed for the Yucca Mountain site.

TABLE 6-7

DIRECTORY OF DISCUSSIONS RELATED TO WASTE ISOLATION

| Topic | Section |
|---|---|
| Functional Design Requirements for the Repository Facilities | 2.4.2 |
| Design Requirements: Waste Isolation | 2.4.5 |
| Classification of Systems, Structures, and Components Important to Safety and Waste Isolation | 2.7 |
| Items Important to Waste Isolation | 2.7.2 |
| Systems, Structures, and Components Important to Safety or Waste Isolation | 4.6 |
| Items Important to Waste Isolation | 4.6.2 |
| Waste Isolation | 6.4 |
| Effect of Site Characteristics on the Layout of the Underground Facility | 7.3.1.2 |
| Long-Term Waste Isolation Performance | 7.3.4.1 |
| Barriers Important to Waste Isolation | 7.4.2 |
| Barriers Important to Waste Isolation: Analysis Conclusions | 7.5 |
| Configuration of Underground Facilities (Postclosure) | 8.2.1 |
| Seal Characteristics | 8.2.2 |
| Repository Design Criteria for Radiological Safety | 8.3.4 |

The performance confirmation program is an integral part of the licensing process for a geologic repository, as required by the NRC licensing rule, 10 CFR 60, Subpart F (Parts 60.140 through 60.143). The rule presents the NRC requirements for the complete performance confirmation program. These requirements form the basis for a program plan that must be submitted to the NRC at the time of LA. At the time the SCP is issued, however, the performance confirmation plan can be addressed only in a general way, based on the requirements of Subpart F and preliminary assessments to date. Details of the performance confirmation plan will be developed concurrently with the site characterization activities. Both the general and specific requirements of the program are addressed in Section 6.5.1 below.

The scope of the performance confirmation program required by NRC is defined in 10 CFR 60.2 as "the program of tests, experiments, and analyses which is conducted to evaluate the accuracy and adequacy of the information used to determine with reasonable assurance that the performance objectives for the period after permanent closure will be met." Although these tests, experiments, and analyses will be conducted before permanent closure, the objective under this definition is clearly that of confirming postclosure performance (DOE, 1987). Thus, even though the performance confirmation program described here is conducted during the preclosure period, it does not include the confirmation of preclosure performance objectives.

The duration of the performance confirmation program is defined in 10 CFR 60.140(b): "The program shall have been started during site characterization and it will continue until permanent closure." The performance confirmation program is broken into two phases: a baseline phase and a confirmation phase.

The general objective of the performance confirmation program, as described in the following sections, is to (1) acquire data, (2) use such data in assessments to ensure that the MGDS is functioning as intended and anticipated and is within limits assumed during licensing review, and (3) support the application to amend the license for permanent closure.

### 6.5.1 Program Plan

This section presents the regulatory basis for the performance confirmation program, including the general requirements and specific program elements and implementation. The DOE's issue resolution approach to comply with the regulatory requirements is also summarized here. Finally, with the performance assessment program separated into the baseline and confirmation phases, elements of the program in both of these phases are outlined and described to the degree that they are developed at this time.

#### 6.5.1.1 General Requirements

The DOE has developed an issues hierarchy based on the four key issues found in the Mission Plan (DOE, 1985). The key issues concern waste containment and isolation, radiological safety, environmental safety, and engineering feasibility and cost. These four key issues form the top level of the issues hierarchy. Issues constitute the next level of the hierarchy, and the issues under each key issue are divided into groups consisting of performance and design issues. Information needs are subsumed under each issue and form the third level of the hierarchy.

Regulatory and functional requirements are embodied in the issues hierarchy. The complete issues hierarchy for the NNWSI Project is found in SCP Section 8.2. That section also describes the general approach to issue resolution and the manner in which the issues hierarchy serves as the organizing basis for DOE activities related to licensing, designing, constructing, operating, and closing the MGDS. In general, the resolution of design issues supports the resolution of performance assessment issues. The resolution of issues during the site characterization phase is achieved by gathering sufficient information through the Site Program

(SCP Section 8.3.1) to select a site, by developing a suitable design, and by making defensible performance assessments for the LA. In particular, LA is the culmination of the issue resolution process for the site characterization phase of the MGDS program. Plans for resolution of the issues for LA are presented in SCP Section 8.3, Planned Tests, Studies, and Analyses.

In keeping with this issues-based approach, regulatory and functional requirements for performance confirmation are embodied in Issue 1.7, Performance Confirmation. SCP Section 8.3.5.16 describes plans for the "resolution" of Issue 1.7 for LA as they exist at this time. The resolution of Issue 1.7 for LA principally comprises the development of a plan for evaluating the performance of the MGDS during the construction, operations, caretaker, and postclosure periods to confirm that the performance is within the limits assumed during licensing review. Implementation of the plan will occur after LA.

The scope, duration, and general objective of the performance confirmation program are described in this section. Further general requirements of the program include

- providing data that indicate, where practicable, whether actual subsurface conditions encountered and changes in these conditions during construction and waste emplacement operations are within the limits assumed during licensing review [10 CFR 60.140(a)(1)] and

- providing data that indicate, where practicable, whether natural and engineered systems and components required for repository operation, or which are designed or assumed to operate as barriers after permanent closure, are functioning as intended and anticipated [10 CFR 60.140(a)(2)].

Pursuant to 10 CFR 60.140(c) and (d), performance confirmation will include in situ monitoring, laboratory and field testing, and in situ experiments. The program will be implemented so that it does not affect the ability of the natural and engineered elements of the geologic repository to meet the performance objectives. Further, the program will

- provide baseline geologic information and analyses of that information on those parameters and natural processes pertaining to the geologic setting that may be changed by site characterization, construction, and operations and

- monitor and analyze changes from the baseline condition of parameters that could affect the performance of a geologic repository, provide feedback and analysis of data, and implement appropriate action.

#### 6.5.1.2 Phases of the Performance Confirmation Program

The performance confirmation program is divided into a baseline phase and a confirmation phase, separated by docketing of the LA. Table 6-8

TABLE 6-8

RELATIONSHIP OF PHASES OF THE PERFORMANCE CONFIRMATION PROGRAM TO STAGES OF THE LICENSING PROCESS[a]

| Phases of Performance Confirmation Program | | Stages of Licensing Process | Significant Components of Performance Confirmation to Be Delivered During This Stage of the Licensing Process |
|---|---|---|---|
| BASELINE PHASE | | Site characterization | Plans for collecting baseline site data<br>Plans for designing engineered facilities<br>Plans for predicting changes in baseline conditions<br>Plans for validating performance models<br>Plans for assessing performance |
| BASELINE PHASE | | License application | Definition and predictions of baseline conditions<br>Predictions of changes in baseline conditions<br>Performance assessments for LA<br>Performance confirmation program plan |
| CONFIRMATION PHASE | INTERIM PERIOD | Construction application | Requirements from NRC on the reporting requirements for results of confirmation studies relative to deficiencies in design or observed data not consistent with predictions |
| CONFIRMATION PHASE | CONSTRUCTION, OPERATIONS & CARETAKER PERIODS | Amendment of construction application (if needed) | Revised plans for the performance confirmation program based on results of performance confirmation testing during license review and construction |
| CONFIRMATION PHASE | CONSTRUCTION, OPERATIONS & CARETAKER PERIODS | License application update(s) | Results of construction phase testing relevant to baseline conditions |
| CONFIRMATION PHASE | CONSTRUCTION, OPERATIONS & CARETAKER PERIODS | License to operate | Any changes in reporting or further testing requirements mandated by NRC |
| CONFIRMATION PHASE | CONSTRUCTION, OPERATIONS & CARETAKER PERIODS | License amendment for closure | Results of testing backfill and seals<br>Results of performance confirmation testing<br>Data and results to resolve any open issues<br>Performance assessments supporting permanent closure |

a. This table is taken in part from a draft DOE position paper on performance confirmation (DOE, 1987a).

b. Delivery of components is the responsibility of the DOE, except where noted.

shows how the performance confirmation program spans the stages of the licensing process and lists components of the performance confirmation program applicable to each stage.

The baseline phase corresponds to the site characterization period, during which the body of site data, the design, and performance predictions are assembled for support of LA. This data base constitutes the baseline information for performance confirmation as suggested by 10 CFR 60.140(d)(2).

The confirmation phase is further divided into an interim period and the principal segment, which consists of the construction, operation, and caretaker periods. The interim period begins with docketing of the LA and concludes at the start of construction. During the interim period, the DOE may continue confirmation testing started during the site characterization period. Once construction and operations begin, the geologic conditions encountered and predicted changes in conditions can be confirmed by the testing and monitoring program.

During the baseline phase, the following objectives for the performance confirmation program are to be achieved.

- The conditions important to postclosure performance will be established.

- Changes in those conditions resulting from repository construction and operation that would affect postclosure performance will be predicted.

- The assessments necessary to demonstrate that repository performance is expected to meet the NRC postclosure performance objectives will be produced.

- A plan will be produced for the evaluation and confirmation of predicted conditions and performance, for feedback of results to the NRC, for defining any needed modifications in the design or construction methods, and for reporting such recommended changes to the NRC. The plan will be implemented during the confirmation phase.

- Performance confirmation testing will begin, as appropriate.

During the confirmation phase, the objectives of the interim period are to

- continue appropriate testing of the thermomechanical properties and response of the host rock, refine predictions of the effects of the repository, and confirm predictions to the extent possible;

- continue appropriate hydrologic testing in the underground test facility to confirm preconstruction conditions; and

- continue model validation work not completed during the baseline phase.

The objectives of the construction, operation, and caretaker periods of the confirmation phase are to

- complete the validation of models not completed during earlier phases of the program and

- collect data and perform analyses to confirm that performance is within the limits established during the baseline phase.

#### 6.5.1.3 Preliminary Plans for Performance Confirmation

Development of plans for the performance confirmation program is preliminary at this stage before site characterization. The performance assessments and sensitivity studies available at this stage are essentially those conducted to support the EA (DOE, 1986a). The designs for the underground facilities and waste containers are conceptual, as explained in this document and in the SCP. Available information about the site conditions is also limited at this stage before site characterization, as are the predictions for changes in conditions as a result of site characterization, repository construction, and operations.

Nevertheless, many details of the plan have been developed, both for the baseline phase and for the confirmation phase. The plans respond to the requirements included in 10 CFR 60.141, Confirmation of Geotechnical and Design Parameters; 60.142, Design Testing; and 60.143, Monitoring and Testing Waste Packages.

##### 6.5.1.3.1 Plans for the Baseline Phase

Performance confirmation testing expected to begin during site characterization includes the following tests.

- A large-scale heated room test would be made to confirm the response of the rock mass to added heat for a period of time longer than that available during site characterization and to show the effect on the stability of mined openings from that same heat. This test would be conducted in the ESF.

- Selected site characterization tests continuing beyond the site characterization phase would be made to provide increased confidence in data and models. Candidate site characterization tests for continuation into the confirmation phase include ground-water flow rate tests and others to be selected as a result of the site characterization activities. These tests will also be conducted in the ESF.

##### 6.5.1.3.2 Plans for the Confirmation Phase

During repository construction and operations, the DOE will conduct a program of surveillance, measurement, testing, and geologic mapping to ensure that geotechnical and design parameters are within the limits established during the baseline phase for LA.

- Underground geotechnical conditions encountered during the construction and operation periods will be monitored and evaluated against the baseline conditions. Monitoring and testing techniques will be selected from the tests conducted during site characterization or will be developed as a result of facts learned during site characterization. Candidate conditions to be monitored include, but are not limited to

  - saturation level of the host rock,
  - at-depth locations and conditions of faults encountered,
  - fracture frequency in the host rock,
  - locations and rates of water inflow into the underground emplacement area, and
  - lithophysal content of the host rock.

- Changes in underground geotechnical conditions that result from construction and operations will be monitored and evaluated to confirm that the conditions encountered are within the limits of predicted performance contained in the baseline. As a minimum, measurements will be made of the following parameters for use in evaluating the changes in conditions:

  - rock deformations and displacements;
  - changes in rock stresses and strains;
  - changes in locations and rates of water inflow into underground areas;
  - changes in rock saturation levels and pore water pressure, including changes along fractures and joints; and
  - thermal and thermomechanical response of the rock as a result of development and operations of the repository.

- The DOE will conduct in situ monitoring of the thermomechanical response of the underground facility until permanent closure to ensure that the performance of the natural and engineered features is within design limits.

- Waste container performance confirmation monitoring and testing will be conducted beginning as soon as practicable after first emplacement of waste. Both in situ and laboratory tests will be conducted.

  - Monitoring of in situ conditions of waste containers will employ waste containers that are representative of those emplaced in the underground facility.

  - The in situ environment selected for the waste container confirmation program will be representative of that in which the wastes are to be emplaced.

  - Laboratory tests will focus on the internal condition of the waste containers and will duplicate, to the extent practical, the environment experienced by the emplaced waste containers in the underground facility.

- Waste container performance confirmation tests will begin as soon as practicable after start of emplacement operations. The planning basis is that removal of waste containers from the underground facility for testing and monitoring will begin 5 yr after first emplacement and proceed at a rate not to exceed one container per month and not less than one container per year. Testing and evaluation of the waste containers will be done in the performance confirmation building, a part of the surface facilities described in Section 6.5.3 below. The scope of testing has not been developed at this time; however, it is expected to be developed during ACD.

- The waste-container-monitoring program will continue as long as practical up to the time of permanent closure.

• Measurements of the response of the host rock and waste containers will be concentrated in dedicated performance confirmation testing areas (Section 6.5.3, Performance Confirmation Facilities). In addition, measurements may also be made at selected locations throughout the repository.

  - Dedicated performance confirmation test areas are planned for a minimum of three locations in the emplacement areas of the underground facility. Emplacement of candidate containers in the first of these test areas will commence as soon as practicable after the beginning of emplacement operations to permit interpretation of thermal and related effects as early as possible.

• In situ tests of certain features of the design will be conducted as part of the performance confirmation program. This program will begin as early as practicable, probably during the early or developmental stages of construction. Design features to be tested include the following.

  - <u>Borehole, Shaft, and Ramp Seals</u> Before full-scale operation proceeds to seal boreholes and shafts, test sections will be established to evaluate the effectiveness of borehole, shaft, and ramp seals at full scale.

  - <u>Backfill</u> Before permanent backfill placement is begun, a backfill test section will be constructed to evaluate the effectiveness of backfill placement and compaction procedures against design requirements.

  - The degree of thermal interaction effects on the waste containers, backfill, rock, and ground water that occur as the result of the design will be assessed.

• All measurements and observations will be compared to the original design bases and assumptions (i.e., the baseline information). If there are significant differences between the measurements and observations and the baseline information, the

DOE will determine the need to modify the design or construction methods. The DOE will report any differences and recommended changes to the NRC.

### 6.5.2 Development and Verification of Codes

The performance confirmation program will use computer codes to evaluate the performance of the MGDS against the performance baseline. The computer codes used in the performance confirmation program are those used to calculate the values of the performance measures for design and performance issues and to predict long-term performance in support of LA. Validation of these codes will have been completed for use by the time of LA; however, validation may continue until permanent closure to improve confidence in the codes. Any codes changed or developed to meet the specific needs of performance confirmation must undergo the complete verification and validation process. (SCP Sections 8.3.5.20 and 8.3.5.21 provide a description of this process.)

The process of verification and validation of computer codes is described in SPC Section 8.3.2.1 for codes related to the repository design, Section 8.3.3.1 for codes related to the design of seals, and Sections 8.3.5.20 and 8.3.5.21 for performance assessment codes. The approach to specifying the appropriate data for use in the validation process is also described.

Computer codes planned for use in resolution of design and performance issues are listed in the discussion of appropriate issues in SCP Section 8.3. The computer codes that have been used for design analyses and performance assessments already completed for the conceptual design process are discussed in Chapter 8 of this document.

### 6.5.3 Performance Confirmation Facilities

This section describes the facilities to be used for performance confirmation to the extent that they are defined at this time. Features of the facilities are highlighted by reference to the appropriate design sections of this document. The facilities described include

- dedicated underground performance confirmation test areas,
- the performance confirmation building located on the surface, and
- facilities for housing the personnel who carry out the performance confirmation program.

Dedicated areas for performance confirmation testing are planned for a minimum of three locations within the emplacement areas of the underground facility. The first area selected is adjacent to the ESF, comprises nominally 10 acres, and is shown and briefly discussed in Section 4.4.2.1. This location will be representative of site conditions to the same extent as the ESF. Early access to this area will permit development of the monitoring and testing program at a relatively early time in the operating life of the repository, thus yielding data on the response of the representative waste containers and host rock as long as possible before amendment for permanent closure. It is planned to locate two other areas of similar size in outlying representative emplacement panels, which will be selected later.

The dedicated test areas will be equipped with sensors and a monitoring system to monitor the response of both the waste containers and the surrounding rock mass. Equipment of this type may also be installed at selected locations throughout the underground facility as the facility expands so that the response of specific features of the site to the construction and operation of the repository can be monitored.

A performance confirmation building is planned for the surface, as shown and briefly discussed in Section 4.2.4.2.2. This facility will be used to test and evaluate waste containers and their contents, as well as to conduct materials properties tests on rock samples removed from the underground facility. The building comprises approximately 25,000 $ft^2$ and contains all the facilities necessary for dismantling waste containers to inspect and test internal components. A design basis of one waste container per month has been used for scaling the operational facilities of this building.

Provisions are included in the general administration building for housing the personnel and data analysis equipment required for the performance confirmation program. A staff of 25 to 40 people is expected to be necessary. Computer facilities for storing and accessing the baseline information, as well as for analyzing and evaluating the performance confirmation information, are included in the conceptual design described in Section 4.2.

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# 7.0 DESIGN ANALYSIS

## 7.1 Preclosure Design Analysis

The process of design involves establishing basic objectives and requirements for the repository, investigating site characteristics, and performing analyses to support selection of design features that satisfy the overall facility requirements and that are compatible with site conditions. Many of the basic objectives and requirements for the repository are established by state and federal regulations and other codes and standards.

To develop facility designs that are consistent with the basic objectives and criteria, certain design features or design parameters, such as the size and capacity of structures, systems, and components, are analyzed. Varying the design parameters and estimating their effects on the overall performance permits selection of the values that affect the desired performance. If more than one approach proves satisfactory, the alternatives are compared through tradeoff studies to select the most cost-effective approach.

Some conceptual design analyses are described in the following sections. These studies are included in the appendices, except for the soils and foundations report (Ho et al., 1986) listed in the references for this chapter.

### 7.1.1 Approach to the Analysis

Section 2.4 describes the general design approach specified by the Department of Energy (DOE) at the program level; the design approach described in this chapter is more specific to the design of the repository in tuff.

The design and subsequent analyses of the repository follow a pattern typical of all design problems. This pattern is characterized by (1) development of the design and functional criteria; (2) setting of design and functional constraints; (3) development of performance criteria; (4) compilation of data available for use in the performance of design and functional analyses; (5) preparation of the design; and (6) analysis of the design to verify compliance with design and functional constraints, to optimize the design (tradeoff studies), and to determine the quality of data needed (sensitivity studies).

During the development of design and functional criteria, the documents that govern the design and function of the repository were identified. The applicable requirements have been extracted and summarized in design control documents, such as the "Subsystems Design Requirements to Support the Conceptual Design Studies for the Yucca Mountain Mined Geologic Disposal System" (SDR) and the "Yucca Mountain Mined Geologic Disposal System Requirements" (SR). (Both documents are contained in Appendix P.) State and federal legislation, regulations, and other directives provide the statutory and regulatory criteria for the design of the repository. Specific design and functional criteria needed for the detailed design of a repository have been developed by the repository designers. Functional criteria are not necessarily static because they are subject to changing guidance by DOE. These specific criteria consider the characteristics of the site and the effect that these characteristics may have on the design and function of the repository.

Postclosure requirements are major constraints on the design. For example, the ability of the repository to provide long-term isolation must not be jeopardized by the techniques and materials used in the construction of the repository.

Performance criteria are statements of how well a given subsystem of the mined geologic disposal system (MGDS) must perform to meet programmatic, legislative, and regulatory requirements. In design, performance criteria are used to generate repository designs and operations procedures and to measure the adequacy of these designs and procedures. These criteria are developed from the design and functional criteria and constraints. The throughput rate, which is a basic performance criterion for the repository, is used to establish the size of the waste-handling facilities and the equipment and personnel requirements for both the surface and subsurface facilities.

The data used to design and evaluate the repository for compliance with the performance criteria are derived from investigations, tests, and measurements made on the site and from laboratory tests conducted on samples of soil or rock from the site. Additional data have been obtained from literature and by analogy to similar geologic settings or facilities in other locations.

The analyses that verify compliance with the criteria use the available data to demonstrate that the repository meets design and functional requirements. This demonstration is accomplished in two steps. The first step consists of the analyses that verify the feasibility of the repository design based on preliminary site data and current repository functional requirements. The second step comprises the analyses performed to support the design that accompanies the license application (LA) for the repository. These analyses will use more extensive site data, which will be obtained during site characterization, and the more advanced analytical techniques that will be available at that time.

Specific analyses that evaluate the preclosure performance of the conceptual designs of underground openings are described in detail in Section 7.1.3. First, an empirical approach based on the historical performance of openings in various categories of rock was used to predict opening stability during the operational life of the repository and to design the supplemental rock support installed in the opening during construction. Then, selected analytical techniques were applied to different models that are representative of the geologic conditions in the emplacement horizon. This approach substantiates the results obtained using empirical techniques and assesses the effects of temperature increases in the rock, which result from the emplaced waste.

Tradeoff studies will be performed during all repository design phases to refine the design and procedures based on criteria such as safety, functional ability, efficiency, and costs. Alternative designs and procedures will be compared during the tradeoff studies. The conceptual design described in Chapters 3, 4, and 5 reflects the results of numerous tradeoff studies, such as those performed to select the means of access to and egress from the underground facility, the methods to be used for excavation, and the location of the surface facilities (Neal, 1985).

Sensitivity studies are used to determine and justify the degree of precision needed for the data to be used in the design. The analyses are performed by using a range of values for a particular parameter to determine the effect of varying the parameter. If results change only slightly with a large change in the parameter, that particular parameter need not be measured with a high degree of precision. Sensitivity studies are also performed to evaluate design alternatives, such as the study regarding the length of the horizontal borehole (Stinebaugh and Robb, 1987). In that study, the cost per waste container in the horizontal borehole was determined for a range of borehole lengths. It was concluded that borehole lengths beyond approximately 300 ft do not result in significant cost savings.

### 7.1.2 Surface Elements

#### 7.1.2.1 Soils and Foundations

The near-surface soils and rock at the proposed repository have been assessed and found satisfactory for the foundations of the surface facilities (Section 2.2.5). The study included limited field and laboratory testing at the alternative sites considered for the surface facilities. These sites are located on an alluvial plain east of Yucca Mountain (Figure 4-7). The results of soils testing in 1983 by Holmes & Narver have also been considered. The testing program was developed by Sandia National Laboratories (SNL) and Bechtel National, Inc. (BNI); the actual field excavation and laboratory testing were performed by Holmes & Narver under the direction of SNL and BNI (Neal, 1985).

Field exploration was conducted in May 1984. Test pits approximately 12 ft deep were excavated at four of the locations considered as potential surface facility sites. The geologic characteristics of each test pit were logged, in situ density tests were performed whenever feasible, and samples were collected for laboratory testing. The laboratory tests included soil classification; analysis of natural moisture content; measurements of gradation, specific gravity, and absorption; and compaction tests.

The soils at all four test pits are similar. The top 1 to 2 ft are composed of loose, fine-grained sandy soil, which will be removed during construction and stockpiled for topsoil. Beneath the topsoil lies approximately 6 ft of alluvial material that is partly to wholly cemented with calcite (caliche). This material is typical of very old soils and can be excavated using ripping equipment. Exploratory borings drilled under the direction of SNL in 1983 and 1984 indicated a 35- to 150-ft-thick layer of very dense, gravelly sand alluvium below the caliche. The gravelly soil has a high content of sand with some silt and numerous cobble- and boulder-size rocks. There is a general lack of distinct bedding and an absence of rounded particles. These soil characteristics are all consistent with deposition by flash floods. Soils deposited by flash floods may be unstable, but the high values of relative density found for these soils indicate that the soils are not unstable. Bedrock of ash-flow tuff lies beneath the alluvium.

Table 2-3 lists the physical and engineering properties of the site soils. The physical properties and compaction curves are based on field and laboratory tests. Engineering properties have been evaluated indirectly from field observation and from knowledge of soil deposition processes, degree of cementation, and other physical properties. The engineering properties listed in Table 2-3 are for the dense, gravelly sand alluvium underlying the caliche layer. Because these soils are dense to very dense with slight to moderate cementation, settlement of the surface facilities foundations is expected to be small. The allowable bearing pressure of 6,000 $lb/ft^2$ selected for the surface facilities is based on a 4-ft-wide footing, 2 ft below grade. Should the footing be greater than 4 ft wide or deeper than 2 ft below grade, the allowable bearing pressure would be greater. However, for very large foundations, allowable settlement, rather than allowable bearing pressure, may control the design.

The waste-handling buildings are expected to be founded on soil approximately 30 ft below the existing grade, a depth considerably greater than the depth of the test pit. However, judging from exploratory borings, the uncemented soils encountered at the greater depths are expected to be similar to those encountered in the test pits.

The soil properties adopted for the conceptual design must be verified, and site-specific conditions must be better defined for subsequent stages of design by additional site exploration.

7.1.2.2 Probable Maximum Flood at the Men-and-Materials Shaft

A preliminary analysis of the probable maximum flood (PMF) has been performed for the men-and-materials shaft area because the local terrain is rugged and the confluence of two washes that discharge into Drill Hole Wash is nearby. This analysis evaluated the feasibility of locating the shaft and its supporting facilities in such an area. The PMF flows and elevations of surface water were estimated by assuming that provisions for flood protection are incorporated in the design. From this analysis, it was determined that the men-and-materials shaft may be adequately protected from PMF levels at its proposed location; however, this preliminary conclusion will be reevaluated during later stages of the design. This study is summarized in a memo report included as Appendix H-1. The current plot plan, shown in Figure 4-8, differs in arrangement from the layout used in the flood study but alters neither the drainage design, the analysis, nor the conclusions. The methods used in the preliminary analysis are briefly described below.

The surface topography was evaluated from a U.S. Geological Survey (USGS) 7-1/2-min quadrangle topographic map with contour intervals of 20 ft. A probable maximum precipitation (PMP) of 14.1 in. for a 6-hr storm was estimated from National Weather Service information (Section 2.3.2.2.3). The hydrographs for the PMF for drainage areas tributary to the ditches north and south of the men-and-materials shaft area and for Drill Hole Wash were developed for the PMP using a method suggested by the U.S. Department of Agriculture (1968). A computer program (HEC-1) developed by the U.S. Army Corps of Engineers (1981b) was used to synthesize the flood hydrographs and to establish peak flows of the PMF. The results are given in Table 7-1.

TABLE 7-1

PEAK DISCHARGES OF THE PROBABLE MAXIMUM FLOOD

| Drainage Basin | Area ($mi^2$) | PMF Peak Flows (cfs) |
|---|---|---|
| North Ditch | 0.28 | 4,700 |
| South Ditch | 0.10 | 1,700 |
| Drill Hole Wash | 2.00 | 17,400 |

Drainage ditches were sized to accommodate the flood flows using an iterative process, and a second Corps of Engineers computer program (HEC-2) (U.S. Army Corps of Engineers, 1981a) was used to perform hydraulic computations and to determine water surface profiles in the ditches and in Drill Hole Wash. The analysis showed that the depth of the flood flow in the north ditch would be 5.6 ft and that a hydraulic jump (a sudden transition from rapid to more tranquil flow) would form upstream from its junction with Drill Hole Wash. Downstream from the hydraulic jump, the depth of flow would increase from that in the upstream section; however, the hydraulic jump would be located far enough downstream to have no impact on the men-and-materials shaft area.

For the south ditch, it was assumed that the culverts beneath the access road would be plugged during the PMF and that flood waters would flow over the road. Under these conditions, it was determined that the PMF water level in the south ditch would be about 1.4 ft below the grade level at the shaft location.

Debris produced by the PMP in the north and south ditches and Drill Hole Wash was estimated, but the cumulative effects of events having greater frequency were not considered. The cumulative effects of storm debris produced and deposited in the drainage channels should be analyzed further.

Additional study using refined topographic data will more precisely determine hydraulic characteristics downstream of the men-and-materials shaft site and high-water profiles of flood flows in the drainage ditches. Also, a PMF study must be conducted for other major surface facility locations, including the central surface facilities area, exploratory shafts, emplacement area exhaust shaft, and tuff ramp portal.

#### 7.1.2.3 Seismic Design

The design of the surface facilities is affected by the seismicity of the site and the method selected to analyze the systems, structures, and components. An evaluation of the seismicity of the site and its surrounding region is essential to ensure that the repository design will not produce undue risk to the health and safety of the public as the result of seismic events. Preliminary geologic information pertaining to seismicity has been formulated (URS/Blume, 1986; URS/Blume, 1987). More detailed information will be obtained from continuing field exploration directed toward evaluating faulting, which will include surface geologic mapping, subsurface investigations (including trenching), and various geophysical surveys.

Seismic design requirements for the surface facilities have been established as part of a study included as Appendix H-2. The design approaches to accommodate earthquakes and underground nuclear explosions (UNE) during testing at the Nevada Test Site (NTS) are addressed in this document. The two URS/Blume reports define design-basis earthquakes (DBE), and the resulting design response spectra are to be used as the seismic input in the analysis of surface facility structures. Mathematical modeling techniques and methods of structural analysis to be used for the design of structures are established in the seismic design basis.

The dimensions of the hot cell walls in the waste-handling buildings are based on shielding requirements and engineering judgment. It is assumed (based on engineering experience obtained with other structures) in the current conceptual design that the walls are adequate to withstand current estimates of seismic and UNE ground accelerations (Section 2.3.3.1.). Structural analysis and design appropriate for ground motion will be done during the advanced conceptual design (ACD).

Waste-Handling Building 2 has been divided into sectors by seismic joints. The maximum length of each building sector in any direction is limited to approximately 200 ft. The locations of the seismic joints have been selected to limit potential torsional effects in each individual sector. In addition, the surface storage vault is isolated from the remainder of the waste-handling building.

The development of an approach to resolve seismic and tectonic issues [consistent with the requirements of 40 CFR 191 (EPA, 1986), 10 CFR 60 (NRC, 1986), and 10 CFR 960 (DOE, 1986a)] is addressed in the Site Characterization Plan (SCP) (DOE, in preparation), Section 8.3.1. The methods used to evaluate seismic and tectonic hazards, to assess the performance of repository facilities, and to demonstrate compliance with applicable regulations are also discussed in SCP Section 8.3.1.

#### 7.1.2.4 Wind and Tornado

Design requirements to provide tornado protection for structures, systems, and components important to safety are described in the design basis for wind and tornadoes (Appendix H-3). That design basis defines the characteristics of extreme wind and tornadoes and establishes the physical properties and impact velocities of tornado-generated missiles.

The methods to be used to transform design wind speed, tornado characteristics, and impacts of tornado-generated missiles into an equivalent static load on structures are addressed in Appendix H-3.

Long-term records of winds were obtained from the climatological station of the National Oceanic and Atmospheric Administration at Las Vegas, Nevada (Appendix H-3). The fastest wind speed determined from those records does not exceed the basic wind speed recommended by the American National Standards Institute (ANSI) (1982) for a 100-yr recurrence interval. A basic wind speed of 80 mph recommended by ANSI (1982) is used for the design of all surface structures. Three sources of data on the wind speeds of the design-basis tornado were considered in establishing the characteristics of the design-basis tornado. Fujita (1981) investigated 24 tornadoes occurring in the area surrounding the NTS from 1916 through 1979. Other sources included Regulatory Guide 1.76 (AEC, 1974) and ANSI (1983). The maximum tornado wind speed chosen for design is 180 mph in accordance with the recommendations of ANSI (1983). The characteristics of tornadoes and tornado-generated missiles to be used for the design are shown in Tables 2-13 and 2-14.

7.1.2.5 Water Storage and Distribution

A study (Appendix H-4) has been prepared to evaluate different methods for storing and distributing domestic and fire water to the central surface facilities. A gravity system, a booster pump distribution system, and a combination system were analyzed in that study. The gravity distribution system is recommended, based on cost and operating considerations.

In the gravity system, storage tanks are located on the hill above the central surface facilities so that sufficient pressure (approximately 65 psi) is provided in the water distribution networks. Two separate water distribution networks are used: one network supplies domestic water in the facilities and the other supplies the fire hydrants and sprinkler systems. The advantages of the gravity distribution method are (1) reliability (because there are no pumps in most of the system), (2) minor maintenance requirements, and (3) minimal leakage (because low pressure is maintained in the system). The water storage tanks and distribution network systems for the surface facilities are described in Section 4.2.5.5.

The storage requirements, including daily demand and fire demand, have been estimated for each stage of repository life. Maximum quantities obtained during the operating stage of the project have been used for sizing the permanent water system for the repository. Approximately 800,000 gal of storage capacity is provided for the surface facilities and 420,000 gal for the subsurface facilities.

7.1.2.6 Preliminary Operations Analysis

Waste throughput rates have been determined to permit design of the features necessary to accommodate the required waste-handling and processing rates. The design-basis waste receipt rates described in Chapter 2 were used to determine the rates of cask, fuel assembly, and other waste unit throughputs. The results of this analysis are shown in Table 3-2.

Specific operating steps for functions associated with the shipping casks and wastes were then identified. Time requirements for each step were estimated, and a time-line diagram was prepared to show the sequence of steps for handling the casks and wastes. Based on the time requirements, the quantity and capacity of the equipment and facilities necessary for handling or processing the waste at the required throughput rates could be determined.

#### 7.1.2.7 Site-Generated Waste

In this analysis, potential sources of site-generated radioactive waste were identified, and the volumes and characteristics of each major stream were estimated so that systems and design features could be provided to collect and treat these wastes. The design of waste treatment systems for site-generated wastes was based on the types, volumes, frequency of production, and radioactivity levels associated with the wastes.

The amounts and characteristics of liquid and solid radioactive wastes generated at the repository were estimated from literature pertaining to nuclear power plant operations and from information and experience with spent fuel storage facilities (Sections 6.1.1.1 and 6.1.2.1).

Each major area where radioactive materials are handled was evaluated to identify all activities that generate solid and liquid wastes. Estimates of radioactive wastes were developed for each activity, and the total volume of each type of waste was then determined by adding the results for each major area. The results of the above analyses are described in Section 6.1.

#### 7.1.2.8 Normal and Standby Electrical Power

Electrical power requirements for the repository were evaluated to determine the necessary capacities of various distribution systems. Requirements for 13.8-kV, 4.16-kV, 2.4-kV, and 480-V normal power distribution systems were determined by estimating the electrical loads at the repository.

Standby power supply requirements were determined from estimates of critical functions for which the supply of electricity would have to be maintained in the event of loss of normal power. Diesel generators will supply standby power.

Uninterruptible power supply requirements were also determined from evaluations of equipment needing continuous electrical power. All computers and monitoring equipment that provide essential data or that perform vital functions have uninterruptible power.

Additional information from these analyses is included in Appendix H-5.

#### 7.1.2.9 Monitoring Systems

The primary functions of the monitoring systems include monitoring the safety conditions for workers and the public and supporting performance confirmation.

Various monitoring requirements have been addressed, including radiological, safeguards and security, fire and smoke, environmental, and other facility and equipment monitoring. Additional information on these analyses is included in Appendix H-6.

### 7.1.3 Underground Elements

Four types of underground analyses are discussed individually in the sections below: thermomechanical, seismic, hydrologic, and ventilation. This section provides a summary of the detailed material presented in Chapter 8 and, where necessary, provides additional description of the underground elements. Section 8.3.7 details the thermomechanical, seismic, and ventilation calculations summarized in this chapter.

Consistent with the format of Section 8.3.7, the sections below address the analysis approach, data requirements, results, and requirements for future work. The approach discussed in Section 7.1.1 is generic, whereas the approach presented in each section below is specific to the category of analyses being presented.

#### 7.1.3.1 Stability of Underground Openings

This section describes briefly the approach used to develop the design of the underground openings. Section 8.3.2.5 of the SCP describes in detail the methods and data required to ensure that the underground openings can be developed and will remain usable with reasonable maintenance throughout the operating life of the repository. The design emphasizes that the technology used in the construction and operations phases is available or can be demonstrated to be effective before the final phases of repository design.

##### 7.1.3.1.1 Approach

Although numerical modeling has been used predominantly to predict the thermomechanical response of the underground excavations to overburden stress and thermal loading, some empirical techniques have also been used. The empirical approach relies on rock-mass classification methods. In particular, the Norwegian Geotechnical Institute (NGI) Tunnel Quality Index (Barton et al., 1974) and the South African Council for Scientific and Industrial Research Classification System (CSIR) (Bieniawski, 1974) have been applied to the rock-mass characteristics of the emplacement horizon, the Topopah Spring Member (Langkopf and Gnirk, 1986). Because these rock-mass classification methods do not include thermally induced loads on the underground excavations, their use is limited to time-independent analysis of the drifts. After waste emplacement, the thermally induced loads are expected to be several times greater than the overburden loads; therefore, it is necessary to use thermomechanical models (i.e., numerical methods) to estimate the forces applied to the underground excavations. The thermomechanical models include both in situ stresses and thermal loads.

Three basic numerical methods have been used to analyze some of the time-dependent effects on the underground excavations--finite-element, boundary-element, and analytic methods. The specific computer codes used in the analyses are listed in Table 8-6. That table provides the code name, author, ownership, and description of the code. For the finite-element calculations, two codes have been used to calculate the thermal and mechanical effects. First, the temperature distributions around an underground excavation are determined by use of a heat-transfer code. The temperature history from the thermal calculations is then used as input into a mechanical code that calculates the stress field around the excavation. The boundary-element calculations incorporate the thermal and mechanical calculations in the same code.

A mesh is required for both finite-element and boundary-element calculations. Finite-element meshes generally extend over the entire domain of the problem, whereas boundary-element meshes are generally limited to subdivision of the excavation boundary only. Boundary-element methods offer the advantage of a faster solution; finite-element methods are advantageous because codes have been developed that readily incorporate inhomogeneities and alternative constitutive models (i.e., elastic and inelastic joint models).

To a much lesser extent, analytic and semianalytic solutions in coded form have also been used to analyze the thermal and/or mechanical effects underground. These solutions have been limited mainly to scoping calculations whose purpose was to guide the formulation of finite- and boundary-element calculations. Analytic solutions have also been used to verify the performance of the codes.

To ensure the correct performance and predictive capabilities of the empirical and numerical approaches, it is necessary to verify (show that the code operates as specified in the model) and validate (demonstrate that the model represents the intended physical system or process) the codes or procedures that address the two approaches. Although some assessment of the applicability of the empirical approaches is planned, the major effort is tied to verification and validation of the codes being used because the empirical approaches are generally founded on large data bases that relate geometric and geologic characteristics to opening stability. Verification is done by comparing the numerics generated by both the equation-solver and material model of the code to closed-form analytic solutions and to benchmarked problems run on similar software. Codes are validated by comparing code results with laboratory and field experiments.

#### 7.1.3.1.2 Data Requirements

The site-specific geologic data needed for the thermomechanical analyses of the underground openings are defined in Chapter 2. Properties of the intact rock, rock mass, and joints are presented, along with the probable or expected range in their values. The rock mass is considered a composite of joints and intact rock. Which properties are used in a particular analysis depends on the model being used. Rock-mass properties are used in elastic models that do not explicitly account for the presence of joints. Intact rock and joint properties are used in models that directly account for jointing. In addition, the specific data used in a particular thermomechanical analysis have differed--not only because of the model being used but because the values have changed as more data are collected and analyzed.

Because the understanding of the rock properties has changed as the data base expanded, there are some differences in the properties used to obtain the results given below. For that reason, the results present both historical and current estimates of the thermomechanical behavior of the underground openings.

7.1.3.1.3 Results

This section presents the results of thermomechanical analyses of the underground openings according to the type of opening analyzed--drifts, waste emplacement boreholes, and shafts and ramps--and reviews the status of verification and validation activities. Specific analyses are discussed in Appendix N, where references for specific predicted values are given. In this section, a general discussion of the predicted values obtained in the analyses is provided.

Finite-element, boundary-element, analytic, and rock-mass classification techniques have been used to analyze the expected conditions of the drifts. The emplacement and access drifts have been analyzed using elastic and inelastic (joint) material models with linear and nonlinear thermal models for up to 100 yr following waste emplacement. Sensitivity studies of geometric parameters (drift shape, orientation, and depth) and geologic properties (thermal and mechanical) have been conducted.

The results of particular interest are the temperatures, displacements, and stresses at the drift boundary. Maximum drift temperatures for unventilated horizontal and vertical emplacement drifts for up to 100 yr are 60 and 110°C, respectively. The maximum boundary stresses were 35 and 55 MPa for the horizontal and vertical emplacement drifts. Both of these stress levels are sufficiently below the expected rock-mass strength of 75 MPa to alleviate concerns that excessive stress might cause drift failure. Values of the predicted stresses that are of concern are generally substantially reduced at locations removed from the opening boundary; hence, the openings are generally much more stable than indicated by a comparison of the boundary stresses to rock-mass strength. It is predicted that the drift opening will contract less than 1 in.; therefore, the likelihood that the drift will not provide adequate clearance for equipment is slight.

Sensitivity studies have shown that the drifts are capable of withstanding greater variations in geologic properties than are expected. This conclusion was made using thermoelastic models of the emplacement drifts that varied thermal, mechanical, and thermomechanical properties over their expected range. The properties were varied both independently and jointly in models that simulated conditions at the time of waste emplacement and up to 100 yr later. Other parametric studies have demonstrated drift stability after modeling alternative drift shapes, depth, standoff distances, and areal power density (APD).

Similar results are obtained when the sensitivity of the input parameters to the empirical approaches of drift analyses is considered. These results apply to the condition of the drift before waste is emplaced. Variation of the geologic characteristics (strength, rock quality designation, joint spacing, condition, and orientation) used in the CSIR rock-mass classification system resulted in a rating of "fair to very good" for the host rock, which is consistent with the sensitivity results from numerical analyses. The average or expected rock-mass description given by both the NGI and CSIR rock-mass classification systems is "good" (Langkopf and Gnirk, 1986).

Elastic and inelastic (joint model) calculations have been performed using finite- and boundary-element methods to analyze the waste emplacement boreholes in the horizontal configuration. The expected geologic and material properties have been used in the analysis of the thermomechanical response of the borehole. In general, the thermomechanical response of the waste emplacement borehole is sensitive to the material model being used. Inelastic modeling of the borehole generally results in a level of stress approximately twice that predicted by elastic modeling. The differences between the results of elastic and inelastic modeling occur mainly on the borehole wall. Differences between the results of the elastic and inelastic models quickly dissipate at distances only slightly removed from the borehole wall. The results of the thermal and inelastic mechanical modeling of the horizontal borehole show a maximum borehole wall temperature of 160°C and a maximum stress concentration of 96 MPa. The temperatures and stress levels are expected to be similar for the vertical waste emplacement borehole. The high stress levels of the host rock may indicate the need for a borehole liner. Stress analyses of the 0.5-in.-thick steel borehole liner show that the loading caused by possible rockfall on the liner is acceptable.

Elastic finite-element and boundary-element calculations have been performed for the ramps, shafts, and shaft liners, as well as for the exploratory shaft facility (ESF) to determine the adequacy of the openings and structures. Stress profiles taken for various cross sections along the ramp reveal maximum stress levels slightly less than those of the horizontal emplacement drifts. A maximum stress of 30 MPa has been noted in the ramp crown 100 yr after waste emplacement. The predicted stresses in the rock surrounding the shafts are approximately equal to those resulting from the ramp analyses. Ramps and lined shafts are therefore expected to be usable for the life of the repository, although some work should be done to evaluate in more detail the effects of thermally induced loads.

The approach to the verification and validation of codes and models used to predict thermomechanical behavior has been developed, and initial work in this area has been completed. Several comparisons of code and model predictions with field and laboratory observations have been documented. In particular, the results of finite-element codes that incorporate compliant and ubiquitous-joint models of G-Tunnel drifts (located in Rainier Mesa on the NTS) imply drift stability, a condition substantiated by observation. The NGI and CSIR rock-mass classification techniques (empirical approach) also predict stability in G-Tunnel drifts. There is general agreement between models and approaches in predicting the actual or field conditions of the drifts at G-Tunnel.

On a smaller scale, observations were made at G-Tunnel in a small-diameter heated borehole that agreed with heat-transfer code predictions. The finite-element code predicted the structural integrity of boreholes in both welded and nonwelded tuff before and after thermal cycling. On a large scale, the predicted in situ stresses were validated by the close agreement between measurements made at Rainier Mesa and finite-element model predictions.

Code results have been compared with laboratory measurements and field observations. The stress/strain relationships obtained by code results agree closely with the behavior of thermally fractured granite measured in the laboratory. The above activities demonstrate the type of work needed to validate the codes. Site-specific verification and validation activities using results from ESF and laboratory experiments on Topopah Spring tuff are planned as a basis for licensing.

#### 7.1.3.1.4 Future Work

Planned work includes tradeoff and design sensitivity studies, reference calculations on the underground design, and analyses to verify and validate codes. The tradeoff and sensitivity studies are aimed at understanding how the design responds to variations in geologic, geometric, and load parameters. This understanding may lead to an improved design or may support the existing design. Concurrently with sensitivity studies and after design maturity, reference calculations on the design, using deterministic or average properties, will establish expected conditions. The credibility of these predictions is based on the qualifications of the empirical or numerical approach being used. The empirical approach (rock-mass classification methods) will be qualified through further studies of case histories similar to repository conditions, by demonstrations in the ESF, and by comparison of empirical and numerical predictions. The numerical approach will be qualified with respect to method, model, and code. Selected codes, based mainly on the finite-element method, will be verified and validated.

### 7.1.3.2 Design Analyses Based on Seismic and Weapons Test Loads

#### 7.1.3.2.1 Approach

The response of the underground facility and structures to the dynamic loads resulting from natural seismicity or UNEs conducted at the NTS will be analyzed in three steps.

The first step is to define the DBE and the design-basis loads resulting from UNEs. This definition must include the maximum accelerations, velocities, displacements, and other defining characteristics, such as frequency, content, and duration. The second step is to determine the attenuation ratios that are to be applied to the predicted surface accelerations, velocities, and displacements for appropriate design input to the analysis of the underground facility and structures. The third step is to evaluate the response of the surface and underground facilities and structures to the DBE and UNE input. This evaluation will include an analytical approach and, for the subsurface facilities, a comparison of the facilities with existing, analogous, subsurface facilities that have been subjected to similar seismic loadings.

7.1.3.2.2 Data Requirements

The data needed to establish the design-basis seismic event are presented in Section 2.3.3.1. As described in that section, both the characteristics of the faults and the history of seismic events in the area surrounding Yucca Mountain are needed to establish the design-basis seismic event for the Yucca Mountain site. The characteristics of faults needed are (1) the activity of the fault and (2) the history of movement and rate of slippage along its length. The history of seismic events is used to develop the seismogenic zoning for the site.

Knowledge of the geologic properties of the site is needed to determine the appropriate attenuation ratios. The geologic properties needed include the stratigraphic and material characteristics. A complete description of the site characteristics needed is given in SCP Section 8.3.2.5.1

7.1.3.2.3 Results of Analyses

Significant progress has been made in two of the three steps indicated in Section 7.1.3.2.1. In particular, DBEs and attenuation ratios have been developed. In the analysis, work completed includes evaluating the underground facility by comparing it with other underground structures. Detailed analyses will be performed in future design stages, as needed.

Results of Analyses Performed to Determine the Design-Basis Seismic Event

Preliminary estimates of the peak ground accelerations produced by the design-basis seismic event and by UNEs are given in Table 2-12. The methods by which these estimates were obtained are described in Sections 2.3.3.1 and 8.3.7. These methods are reported in detail by URS/Blume (1986); other work pertinent to the determination of the design-basis seismic event at the site is reported in the following documents.

"Prediction of Ground Motion from Nuclear Weapons Tests at NTS" (Vortman, 1979).

"Prediction of Ground Motion from Underground Nuclear Weapons Tests as It Relates to Siting of a Nuclear Waste Storage Facility at NTS and Compatibility with the Weapons Test Program" (Vortman, 1980).

"Comparison of Ground Motion from Earthquakes and Underground Nuclear Weapons Tests at NTS" (Vortman, 1982a).

"Ground Motion from Earthquakes and Underground Nuclear Weapons Tests: A Comparison as It Relates to Siting a Nuclear Waste Storage Facility at NTS" (Vortman, 1982b).

"Proceedings of the Conference on DOE Ground Motion and Seismic Programs On, Around, and Beyond the NTS" (SNL, 1984a).

"Ground Motion Produced at Yucca Mountain from Pahute Mesa Underground Nuclear Explosions" (Vortman, 1986).

Determination of Seismic Attenuation Factors for Underground Design

At the depth of the underground facility, it is estimated that the peak accelerations are half of those predicted at the surface (URS/Blume, 1986). The following documents were used in the determination of this estimate.

"The Technology of High-Level Nuclear Waste Disposal" (du Pont, 1981).

"Seismic Effects on Underground Openings" (Marine et al., 1982).

"Effects of Repository Depth on Ground Motion--The Pahute Mesa Data" (Vortman and Long, 1982a).

"Effects of Ground Motion on Repository Depth--The Yucca Flat Data" (Vortman and Long, 1982b).

"Prediction of Downhole Waveforms" (Long et al., 1983).

Evaluation of the Response of Underground Facilities and Structures to Seismic Loading

In the following discussion, "facilities" are defined as the mined openings of the repository and "structures" are the constructed, engineered features of the design (concrete bulkheads, ventilation control doors, partitions, shaft linings, etc.).

The technologies for analyzing and designing the seismic stability of an opening in rock are not yet developed, particularly for openings that are not circular in cross section. Most of the techniques used to date are empirical, although there are computer-based, finite-element (or similar) methods available for possible use. Most of the work completed to substantiate the feasibility of maintaining the underground openings is comparative. The comparative approach relies on the historical performance of underground facilities subjected to seismic loadings. Considerable information supports and gives credibility to this approach. A report that identifies, compiles, and summarizes numerous measurements and observations made in underground facilities is "Effects of Earthquakes on Underground Facilities: Literature Review and Discussion," (Carpenter and Chung, 1986).

The analysis of structural performance is generally straightforward, provided that the characteristics of the seismic waves affecting the structure are well defined. With an adequate description of this seismic input, either static or dynamic analysis of the structures' response can be performed. The choice of a particular analytic approach depends both on the response of the structure to vibration and on the frequency distribution of the seismic loading function.

Thus far, the review of reports [such as the one by Carpenter and Chung (1986)] and observations of actual underground openings subjected to ground motion indicate that it is feasible to design and construct the subsurface facilities to withstand a credible seismic event.

#### 7.1.3.2.4 Future Work

The following additional work needs to be completed to support the design of the subsurface facilities for the repository at Yucca Mountain:

- confirm the DBE and the loadings resulting from UNEs used for the design basis;
- establish analytical techniques to be used at Yucca Mountain; and
- continue to apply the comparative method of design evaluation through identification and historical evaluation of other underground facilities that are similar in geology, depth, and dimensions to the proposed repository.

### 7.1.3.3 Control of Water in Drifts

This section identifies potential hydrologic problems in the drifts before closure, design or procedural solutions to these potential problems, and assessments of the probability of occurrence. The following hydrologic sources are considered: natural occurrences of ground water (regional water table, perched water, fault flows), surface water (runoff and flooding), and water from operations (water lines and condensation from ventilation airflow).

Natural occurrences of ground water include the water table, perched water, and fault flows. Yucca Mountain is located in a desert environment in which the mean rainfall is less than 8 in. annually and the regional water table is 200 to 400 m below the waste emplacement horizon. Thus, ground water is not expected to infiltrate the emplacement drifts in significant quantities. Potential sources of ground water above the water table include perched water and water associated with fault zones.

Perched water may be present as the result of localized differences in permeability. At Yucca Mountain, no saturated zones above the water table definitely identified as perched water have been encountered during exploratory drilling, and the current design is based on the inference that no major perched water zones will be encountered.

Some localized zones of saturation may exist within fault zones or beneath areas of high infiltration of surface-water runoff. Following drift excavation, ground water flowed from fractures at G-Tunnel and other tunnels in Rainier Mesa, but the flow ceased or decreased substantially within a matter of days. Because the geology is similar at Yucca Mountain, localized flow from faults could occur in the emplacement horizon. Were such inflows to occur, the water could be collected in a sump area, pumped to the surface, and disposed of. Water from a fault zone intersecting a drift and producing continuing inflow could potentially be diverted using grouting, drainage holes in the drift floor, or other techniques to prevent the water from moving through the drifts and spreading laterally in the emplacement horizon. Therefore, the technology is probably available for controlling expected flow of water into the subsurface facilities at Yucca Mountain. Because it is not certain whether measurable inflow would occur, techniques for controlling significant amounts of inflow are not part of the reference design but would be considered in contingency planning. The hydrologic regime, including infiltration (water flow into the soil at the ground surface), percolation (water flux through the rock units below the ground surface), and hydraulic conductivity (rate of water movement through the rock under unit hydraulic gradient), is discussed more thoroughly in Section 2.2.4.

Surface runoff is a natural occurrence that can lead to flooding. Section 2.2.6 presents the results of analyses for the 100- and 500-yr floods and the regional maximum flood. It was concluded that flood flows of all three magnitudes at Yucca Wash would remain within stream channels. Diversion and drainage structures have been designed to provide flood protection in the vicinity of shaft collars and ramp portals (Figure 4-9).

More important than the regional flood analyses is the PMF analysis. The PMF is site-specific and more stringent than the regional flood analyses. PMF levels and flows will be quantified when more definitive topographic maps and other information become available. In general, the underground entries will be protected from the PMF by channels or dikes that divert upland runoff and by setting the finished grades at elevations above the adjacent PMF levels.

In addition to naturally occurring water, water is introduced in the underground facilities as part of repository operations. For example, waterlines are used to supply water to suppress dust generated during development. An undetected rupture of a waterline could result in localized flooding of the underground facility, but detailed design features in the water distribution system will limit the amount and rate of flow in the waterline.

Condensation occurs in the ventilation airstream as a result of changes in the capacity of the air to hold water as the air courses through the underground facility. The ventilation air is heated as it passes through the waste emplacement drifts, and it cools before or after entering the exhaust shaft, possibly condensing water. The air temperature and the length of the ventilation route determine the amount of condensed water. The ventilation air also removes water from the host rock as it passes through the drifts.

The potential for condensation in the ventilation flow is a time-dependent problem that may be mitigated by the design. The drifts are designed so that any water, whether from operations or ground-water sources, is diverted away from the waste emplacement area during the operating period. After development has been completed, all emplacement areas will slope in the direction of a sump at the base of the emplacement area exhaust shaft, the lowest point in the underground facility. Therefore, condensation occurring near the emplacement area exhaust shaft should not increase the amount of water coming in contact with the waste packages. The drainage plan for the underground facility is described in Section 4.4.2.

No design analyses have addressed the effects of sealing or backfilling during preclosure for the following reasons: (1) it is not expected that seals will be used during the operating period of the repository because the host rock at the Yucca Mountain site is unsaturated, and (2) it is not planned to use backfilling for structural support during the preclosure period. The current design calls for backfill as part of the decommissioning process.

#### 7.1.3.4 Underground Ventilation

This section summarizes the ventilation discussion presented in Chapter 8; specifically, Section 8.3.7 (Technical Feasibility) synopsizes the ventilation calculations for the development and waste emplacement areas and the drift-cooling calculations. Chapter 3 presents the airflow requirements, routes, and general system configuration, and Chapter 4 gives the shapes and sizes of the underground openings that are used as input to the ventilation analyses.

##### 7.1.3.4.1 Approach

As required by the SR and the SDR (Appendix P), the ventilation systems to support construction and waste-handling operations must be completely independent. This requirement necessitates two sets of analyses: one for the development area and the other for the waste emplacement area.

Analyses for the design of the ventilation system and evaluation of its performance during repository construction have been performed for the conditions expected during construction. The analyses performed to design and evaluate the ventilation system supporting waste handling and emplacement are to be done for the conditions that exist (1) during emplacement operations and (2) several years after emplacement has been completed. The postemplacement analyses evaluate the system's capability to provide sufficient quantity and quality of air to cool the drifts so that personnel can enter for inspection, maintenance, or retrieval.

After all analyses have been completed, it is necessary to verify that the pressure differentials at the boundaries between the two systems ensure that any leakage between these systems flows to the waste emplacement side. This difference in pressure is achieved by designing the waste emplacement ventilation system as a "pulling" system, in which the suction fans are located at the exhaust point, and by designing the ventilation system for the development area as a "pushing" system, in which the fans are located at the air intake point. These pressure differentials are also input into load calculations for the barriers that separate the two systems so that the structural adequacy of the barriers can be assessed.

##### 7.1.3.4.2 Data

Design and analyses of the underground ventilation systems require a knowledge of the repository layout and development sequence (Section 3.3), the shapes and sizes of the underground openings (Section 4.4), airflow requirements (Section 3.4.2.1), and environmental parameters (Section 2.3). Airflow requirements are expressed in terms of both quantity and quality. The air quantity requirements are taken from regulations specifying (1) dilution of diesel exhaust fumes, (2) minimum air velocities for each work area, and (3) minimum quantity of air per worker. Based on regulatory requirements, the design basis used for the quantity of air is

45,000 cfm for each active emplacement drift (the calculation is located in Appendix C). A more detailed evaluation of future design phases will consider requirements related to radon, concentration of respirable dust, and personnel comfort. In waste emplacement areas in which maintenance of drifts or retrieval of waste is occurring, the design basis is that the air-cooling power (ACP) must be greater than 500 $W/m^2$ and the dry-bulb temperature less than 40°C. For inspection of drifts containing waste, the design assumed a needed ACP of at least 300 $W/m^2$ and a dry-bulb temperature no greater than 45°C. This design basis was established in an attempt to provide substantially more air than would be required to meet regulatory requirements so that flexibility could be provided to compensate for changes in both design requirements and philosophy and to provide for errors in estimating parameters.

The environmental parameters for which site-specific data must be obtained include radon emission rates, quantities of respirable particulates, rates of moisture release from the host rock, temperatures of the host rock, diurnal and seasonal variations in air temperature, meteorological conditions, and drift characteristics (e.g., surface roughness).

#### 7.1.3.4.3 Results

The results of the ventilation calculations that support the design presented in this report are discussed in Section 3.4. Several conclusions or observations can be drawn from these calculations.

- The total air quantities required in both emplacement configurations are well within the capabilities of available mine ventilation equipment and are typical of the quantities required by conventional mines.

- For the vertical emplacement configuration, cooled inlet air will be needed in all cases to facilitate cooling the drifts so that they can be inspected and maintained or so that waste can be removed for performance confirmation. Cooled air may be needed if cooldown in 70 days is not acceptable.

- Maximum airflow requirements for layout and development of the horizontal configuration are less than 70% of those required for the vertical configuration.

#### 7.1.3.4.4 Future Work

Future design phases will concentrate on more refined analyses of the ventilation design. Questions regarding fan reversibility and concentrations of radon and respirable dust will receive more detailed attention, as will specific operations needed for retrieval. The planning of these investigations is presented in Section 8.3.7.

## 7.2 Postclosure Design Analysis

This section discusses the analytical methods used to confirm that the conceptual design meets the postclosure design requirements of 10 CFR 60 and establishes design requirements placed on the design process, as controlled by Issue 4.4 (Section 8.3.7).

Chapter 8 of this document and SCP Chapter 6 are organized based on the issues hierarchy and the products required to resolve the issues. Analytical methods are summarized in those discussions as part of the approach to developing a product and resolving an issue. In contrast, this section is organized to provide a detailed discussion of analytical methods. The results of studies (products) are summarized as examples of the application of an analytical method.

### 7.2.1 Approach to the Analysis

The postclosure design analyses are guided by the rationale described in Sections 6.4.1 and 6.4.4 to ensure that the design contributes to waste isolation and containment. The region near the borehole (the near field) must be analyzed to determine the contribution of the underground facility to containment. The far field (a region assumed to extend from the underground facility to the surface of the earth or to a distance where the rock mass is unaffected by the thermal load) must be analyzed to ensure that waste isolation is not compromised by thermal or mechanical perturbations of the host rock resulting from the heat produced by the waste.

Analyses of the effects of the design on waste isolation and containment after closure of the repository are complicated by several circumstances.

- Uncertainties exist about the thermal and mechanical properties of the host rock.
- The analyses must predict responses over long periods of time.
- The far-field region is heterogeneous.
- The constitutive relationships applying to tuffaceous rocks and jointed rocks are still being developed.

Each of these circumstances indicates the need for an approach in which the results of several analytical techniques are compared to provide a consistent understanding of the expected response of the host rock.

The analysis is also guided by engineering judgments regarding appropriate analytical tools, constitutive models, and levels of simplification. Some design tradeoff studies are adequately addressed using simplified models; more sophisticated models are used for analyses in which specific geometries and physical phenomena affect the results in detail.

#### 7.2.1.1 Coupling of Heat-Transfer and Mechanical Responses

Only a one-way coupling between the heat-transfer and mechanical responses was considered. A typical thermomechanical analysis was conducted by first calculating the transient temperature distribution at a series of times during the thermal decay of the waste. The temperature fields were then used to calculate thermally induced strains and the resulting mechanical response of the host rock.

#### 7.2.1.2 Heat-Transfer Mechanisms

Design calculations to date have assumed heat transfer by conduction. The techniques and models for heat transfer by conduction, combined with convection in a partially saturated flow system, are currently under development. It is not expected that the inclusion of convection will change the calculated temperature significantly enough to change the design of the underground facility; however, this assumption has not yet been adequately demonstrated.

Experiments at the NTS (Johnstone and Hadley, 1980) have demonstrated that vaporization of pore water can potentially influence the heat transfer in partially saturated tuff. Temperature-dependent thermal properties have been used in the heat-transfer analyses to account for this vaporization. Two simplified models have been used. In some cases under analysis, boiling (vaporizing) temperatures will never be approached; therefore, one of the simplified models is a "no-boiling" model in which no pore water vaporization or other drying processes are taken into account. The other simplified model is the "boiling" model approximation based on an approach described by Morgan et al. (1978). This approximation assumes that the pore water vaporizes (boils) when the temperature increases sufficiently. The boiling phenomenon is simulated over a specific temperature range.

The boiling model differentiates between increasing and decreasing temperatures. As temperatures increase, the thermal conductivity and volumetric heat capacity change twice. First, these properties change when the temperature reaches the onset of boiling. The second change occurs when the temperature increases beyond the range of boiling. As the temperatures decrease, the thermal conductivity and volumetric heat capacity change only once. This change occurs at the onset of boiling temperature, which now becomes the onset of resaturation. The model implies that the energy consumed during the process of boiling (dehydration of the rock) does not return upon resaturation of the rock. It is assumed that this energy is lost to the system.

#### 7.2.1.3 Continuum Mechanics

The approach to the analyses of the tuff rock mass at Yucca Mountain is based on continuum mechanics. Equivalent continuum models have been developed to describe the gross response of a rock mass that includes numerous discontinuities, such as fractures, joints, and faults. Morland (1974) described the approach to deriving a constitutive relationship for the gross response that averages the effects of individual joints over a representative volume. The approach is necessary and appropriate for analyses in which the fractures are closely spaced relative to the length scales of interest. The derivations of the equivalent continuum models assume that a representative volume element includes several joints and that the element is small compared with the length scale of the boundary loads or the dimensions of the openings. Another assumption is that the apertures and the relative displacements of the joints are small compared with the joint spacing.

A rationale for analyzing the discontinuous rock mass using continuum mechanics is based on the observations of experiments (e.g., those reported by Price et al., 1984) that show that, like most rocks, tuff deforms in a brittle or ductile manner (depending on the confining pressure). Continuum mechanics concepts, such as elasticity and plasticity, are typically invoked to describe constitutive relations for brittle and ductile rock.

7.2.1.4 Computer Codes

Several computer codes are used for analyzing the influence of the design on the postclosure containment and isolation capabilities of the tuff rock mass. Table 8-1 identifies the source and describes the capability of each code.

7.2.1.5 Constitutive Relationships

The relationship between stress and strain, called a "constitutive relationship," is a relationship involving parameters that are developed from laboratory and field tests. The constitutive laws selected to describe mechanical deformation of the jointed tuff rock mass at Yucca Mountain include linear elastic, elastic/plastic, and nonlinear elastic (compliant joint).

Linear elastic constitutive laws can be applied to a jointed rock mass when scale, pressure, and temperature conditions are such that the rock mass generally responds as an elastic solid (i.e., the strain is recoverable) and the strain varies in proportion to the applied stress. SCP Chapter 2, Geoengineering, presents mechanical properties of both intact rock and the rock mass that indicate that tuff behaves as a linear elastic solid, provided that the stress does not exceed approximately two-thirds of the short-term breaking strength. Field measurements of rock-mass response in densely welded tuff indicate that an elastic constitutive model can be used to adequately represent deformation of the fractured rock mass over the small (less than 10 MPa) stress ranges applied in experiments (Zimmerman et al., 1986). Hence, linear elastic constitutive relationships have been assumed for some of the analyses. This same material response has been considered appropriate in many mining applications (Hoek and Brown, 1980).

The tuff rock mass at Yucca Mountain is fractured (Spengler and Chornack, 1984). For large stress changes, the normal and shear response of fractures is inelastic and nonlinear (Goodman, 1980). Elastic/plastic constitutive laws are used for those analyses in which the stress exceeds the elastic limit (the stress magnitude at which the strain is not recoverable). Up to that limiting stress value, elastic behavior is prescribed, and, beyond it, plasticity theory applies. The mathematics governing the incremental theory of plasticity are independent of the deformation mechanism. Material behavior can be simulated by (1) an initial yield condition that defines the domains of elastic and plastic behavior; (2) a flow rule that defines plastic strain increments based on current stresses and previous plastic strains; and (3) a hardening rule that describes how the size, shape, and orientation of the yield surface (the boundary separating elastic and elastic/plastic behavior) changes during the deformation.

Both isotropic and anisotropic elastic/plastic analyses have been used by the Nevada Nuclear Waste Storage Investigations (NNWSI) Project. Of these, the anisotropic model appears to be a better approximation of the tuffs at Yucca Mountain because field studies have indicated a preponderance of vertical fractures. Extensive field and drillhole data from Yucca Mountain (Scott et al., 1983) suggest that the constitutive model should assess the mechanical response of both the intact rock (matrix) and fractures. The anisotropic models (Thomas, 1980) were developed for the ADINA code and for the SPECTROM-11 code. Because joints are characterized as parallel planes of weakness throughout a continuum, the model has been called "the ubiquitous-joint model." The model allows consideration of slippage on pre-existing fractures and prediction of newly created fractures.

The compliant-joint constitutive model (Thomas, 1982; Labreche, 1985; Chen, 1987) is a further extension and improvement of the elastic/plastic approximation to the response of jointed rock masses. The compliant-joint model combines the response of the matrix rock and the joint into a composite continuum response. The matrix rock is treated as linear elastic. The joint closure is treated as nonlinear elastic. The model incorporated in the JAC code treats the shear response of the joint as plastic deformation, whereas the SPECTROM-11 version restricts the shear displacement along the joint to the elastic regime.

The mechanical properties of both the matrix and the fractures are needed as input for the compliant-joint model. It is assumed that the matrix is isotropic and linearly elastic. The necessary elastic constants are available from laboratory testing (Appendix O). Each material point can have as many as four joint sets, each described by a different orientation and an average spacing between fracture planes. The shear behavior of the joints was approximated from laboratory experiments on fractures (Teufel, 1981; Olsson, 1987) to be elastic/perfectly plastic. The elastic shear response of the joints is described by a joint shear stiffness. In elastic/plastic analyses, the onset of plastic deformation is determined by a linear slippage criterion described by a friction coefficient and the cohesion. The response normal to the fracture is nonlinear elastic in accordance with observed laboratory results (Goodman, 1980; Olsson, 1987). The relationship between stress normal to the fracture and closure of the fracture is described by a hyperbolic function that requires two material constants: the half-closure stress and the unstressed aperture. These parameters can be measured in laboratory experiments. The compliant-joint model describes matrix and fracture responses that contribute to mechanical deformation in a rock mass.

The JEM model is a more detailed constitutive model for jointed rock masses. This model is based on the assumption that the rock matrix is linearly elastic and isotropic and is characterized by two elastic constants. In general, the deformation in a jointed rock mass that is subjected to both normal and shear stress results from compressive and shear strain in the rock between joints and from interfacial normal and shear displacements in joints. Because the focus is on a rock mass with joints that are periodically spaced, a basic unit consisting of a single thickness of rock and a single joint is considered. This approach closely parallels the work of Goodman (1976) and Amadei (1983), who have written extensively on the relationship between jointed rock masses and anisotropic elastic modeling. The joint response in the JEM model is based on an empirical description of experimental joint response given by Barton (1982). Barton's treatment is quite comprehensive, having been derived from observations over a wide range of joints and loading conditions.

#### 7.2.2 Far-Field Effects

##### 7.2.2.1 Conceptual Model for Thermal Analysis

The conceptual thermal model (Figure 7-1) is a two-dimensional (x-y) model with the following boundary conditions.

- The two vertical boundaries are adiabatic.
- The lower horizontal boundary is a constant-flux boundary.
- The ground surface is a convective boundary.

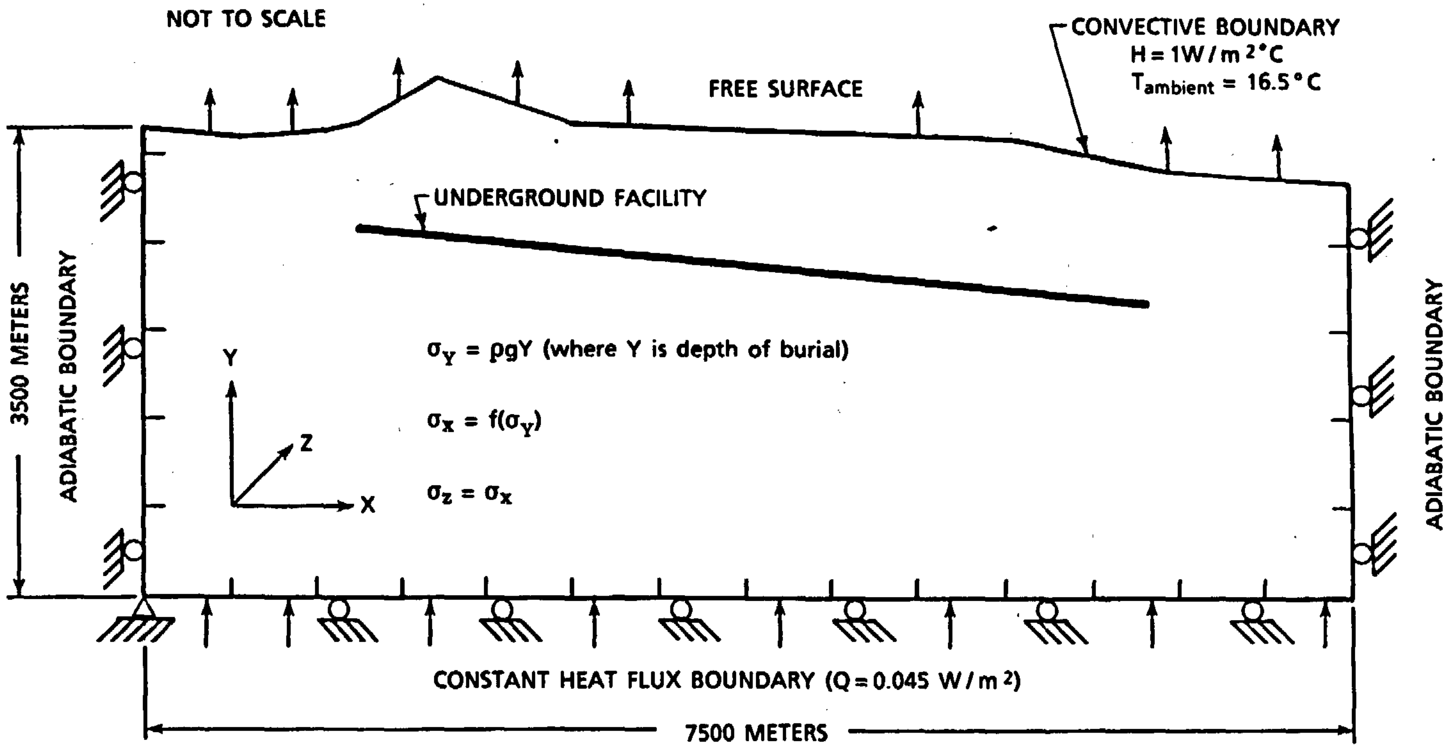
The convective heat-transfer coefficient used at the ground surface is 1 $W/m^2 \cdot °C$, and the air temperature used is 16.5°C (Appendix P). The flux along the lower horizontal boundary is 0.045 $W/m^2$ and was determined in a manner that matched the initial temperatures of the model to those measured at the site. The initial rock temperatures of the thermal model used for the far field are based on temperature measurements from Drillholes USW H-4, USW H-5, and USW G-4 at Yucca Mountain (Sass et al., 1983).

The underground facility is modeled as a 4-m-thick heat-generating plate. The plate thickness is approximately equal to the length of a waste container. This smearing out of the heat sources is considered valid for the far field (i.e., at distances greater than the spacing between boreholes and drifts) but does not give accurate temperatures for the near-field region. The underground facility is modeled as infinitely long in the out-of-plane direction (normal to the paper), a consequence inherent in the two-dimensional model. In this model, it is assumed that all the waste is emplaced instantaneously. This assumption is generally conservative because it will result in predicted rock temperatures slightly higher than those resulting from sequential emplacement of waste.

The underground facility is located above the water table. It has been assumed that the rock above the water table is 80% saturated. If the rock is heated to temperatures above 100°C (assuming atmospheric conditions), the pore water in the rock may boil. The simulation of boiling has been included in the model.

##### 7.2.2.2 Conceptual Model for Mechanical Analyses

The conceptual model for mechanical analyses of the far-field region at Yucca Mountain (Figure 7-2) is a two-dimensional plane-strain model that maintains the complex stratigraphic definition at Yucca Mountain in terms of element geometry and definition of the material properties of each stratigraphic unit. The rock is characterized by using elastic, elastic/plastic, or jointed rock models.




NOTES: a. MODEL ASSUMES VERTICAL JOINTING

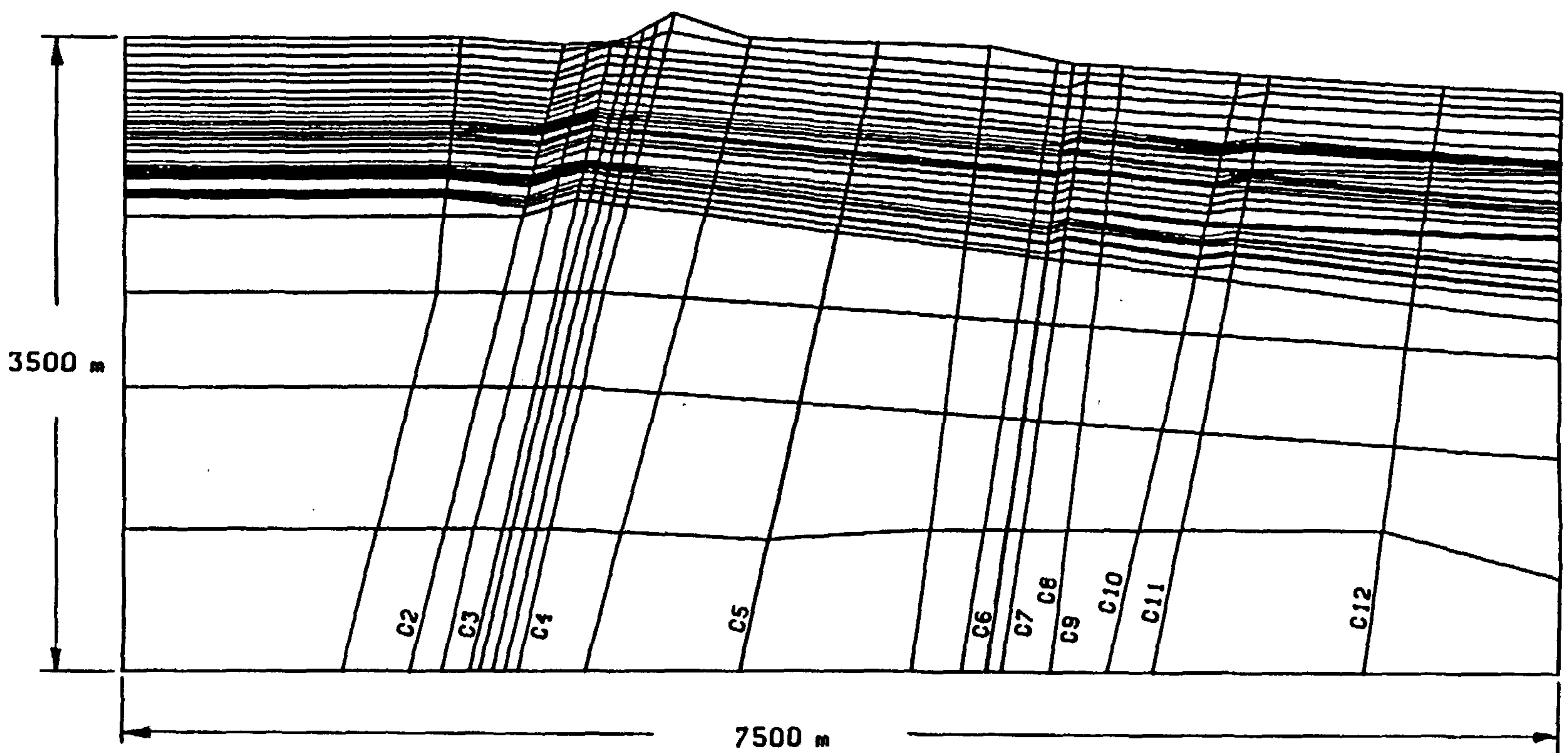
b. $\sigma_Y$ = IN SITU STRESS IN THE Y DIRECTION

c. VERTICAL SURFACES CONSTRAINED HORIZONTALLY, FREE TO MOVE VERTICALLY ( )

d. HORIZONTAL SURFACE CONSTRAINED VERTICALLY, FREE TO MOVE HORIZONTALLY ( )

e. FIXED PIVOT ( )

Figure 7-1. Conceptual Model for Far-Field Calculations at Yucca Mountain (Johnstone et al., 1984.)




NOTE: FAULTS ARE LABELED $C_2$, $C_3$, $C_4$, ETC.

Figure 7-2. Finite Mesh in Far-Field Thermal/Mechanical Calculations (Johnstone et al., 1984.)

The displacement boundary conditions used are illustrated in Figure 7-1 and are described below.

- The two vertical boundaries are restrained from horizontal movement.
- The lower horizontal boundary is restrained from vertical movement.
- The ground surface is unrestrained (free of stress).

The locations of existing faults (e.g., C2, C3, C4 in Figure 7-2) were idealized as offsets of the thermal/mechanical units. The finite-element idealization provides a refined mesh near the faults to facilitate fault simulations. The detailed response of displacement along faults has not been included in analyses to date.

Stresses in the model were initialized to match as closely as possible the estimated in situ stresses at Yucca Mountain. The far-field calculations reported by Johnstone et al. (1984) assumed that the in situ stresses at the NTS varied with depth. The ratio ($k_o$) of the average horizontal stress to the average vertical stress varied inversely with depth according to a functional form that is consistent with stress measurements in the continental United States (Haimson, 1978; Brown and Hoek, 1978). The function representing the average of the values measured by these workers is

$k_o$ = the lesser of (0.55 + 150/z) or 2.4,

where z is depth in meters. At the depth of the underground facility, this function predicts a nearly hydrostatic state of stress ($k_o \simeq 1$).

Subsequent studies (Bauer et al., 1985; Stock et al., 1984) suggested that the stress ratio in Yucca Mountain is between 0.3 and 0.8. The sensitivity of the results of the far-field analysis to the in situ stress state will be the subject of further study.

The numerical techniques for analyzing the far-field region require the specification of a pre-existing stress state that corresponds to an in situ stress field over the geologic problem domain. The standard approach of simply initializing by subjecting an unstressed state to gravitational body forces is not satisfactory for problems that include topographic relief and stratigraphic units (Figure 7-2).

The techniques for establishing the initial equilibrium stress state for stress analyses of large geologic domains are being evaluated to ensure that the in situ stress state matches as closely as possible the estimates of the in situ stress state at Yucca Mountain. The stress state has been initialized by first initializing the geologic problem domain to a pre-existing stress state that approximates the effects of topography, stratigraphy, and geologic structures and then subjecting the domain to gravitational body forces to compute equilibrium initial conditions.

#### 7.2.2.3 Finite-Element Idealization

The finite-element idealization of the far-field region (Figure 7-2) defines the geometric boundaries of the far-field domain. The idealization is based on the stratigraphic data base maintained for Yucca Mountain (Ortiz et al., 1985). The boundaries were extended horizontally and vertically beyond the region of Yucca Mountain shown in Figure 7-1. This extension was necessary to avoid violating the boundary conditions used in the thermal and mechanical models.

The mesh closely matches the topography, thermal/mechanical stratigraphy, location of the emplacement area, and location of faults. The mesh was refined in the regions of the far field most likely to be affected by the underground facility and in regions where the rate of change of temperature and displacements was expected to be high.

#### 7.2.2.4 Studies Completed

Three studies of far-field effects can be cited at this time. Johnstone et al. (1984) used a far-field thermal/mechanical analysis to evaluate each of four units that were under consideration for the underground facility at Yucca Mountain. Brandshaug and Svalstad (1984) compared the results of far-field analyses that included two-dimensional and three-dimensional effects. Blanford (1985) examined the distribution of maximum temperatures in the far-field region surrounding the underground facility.

##### 7.2.2.4.1 Unit Evaluation at Yucca Mountain

A thermal/mechanical analysis of the far field was conducted as part of the unit evaluation study (Johnstone et al., 1984) to confirm that each of the stratigraphic horizons under consideration for site characterization would contribute to waste containment and isolation. The calculations were based on the finite-element method as it was implemented in the finite-element computer code SPECTROM-11 (Table 8-1). The conceptual models and the finite-element idealization were designed to reflect the thermal/mechanical functional stratigraphy at Yucca Mountain. The constitutive model was elastic/plastic, simulating the effects of ubiquitous vertical joints.

In an attempt to bound the results, two sets of calculations were completed. One calculation used the best estimates of the average values of thermal and mechanical properties of the thermal/mechanical units; the other calculation used limiting values of the thermal and mechanical properties. The limiting values were generally plus or minus two standard deviations from the average values. The positive or negative variations were chosen to obtain a "worst-case" set of values.

The far-field analyses conducted for the unit evaluation study provided the following conclusions, which have been used as guidance in the design of the underground facility.

- An APD of 57 kW/acre results in an acceptable far-field response of the host rock to effects of the thermal load (Johnstone et al., 1984).

- Design calculations could rely on constant-temperature boundary conditions to simulate the convective heat-transfer mechanism at the surface of the earth.

- The variations in the material properties provided insight into the sensitivity of the far-field response to some of the design parameters and site characteristics as shown in the following examples.

  - The APD is the most sensitive design parameter.

  - Changing the material properties over the wide ranges considered in the study did not significantly influence the far-field response. This conclusion was inferred from comparisons of analyses of four horizons and the two calculations (average and limit values for properties) conducted for each.

- The location of the underground facility, the thermal properties of the rock, and the APD chosen ensure that temperature changes near the ground surface will be acceptable (substantially less than the 6°C rise allowed in the study).

- Further analysis is needed to evaluate the sensitivity of the response to the constitutive relation for jointed-rock models. The ubiquitous-joint model used in the unit evaluation study provided conservative results. The model assumed vertical, planar, parallel, nonintersecting joints, much like a deck of cards. The mitigating effects of joint orientation, dispersion, intersecting joints, aperture changes, dilation, and joint slippage are under investigation.

- The sensitivity of the far-field response to in situ stress also needs further analysis. The unit evaluation analyses revealed the need to understand the in situ stress at Yucca Mountain and to develop techniques for initializing the stress for the analysis.

#### 7.2.2.4.2 Application of Far-Field Models to the Disposal of Radioactive Waste in Geologic Formations

Brandshaug and Svalstad (1984) provide information about the validity of using a two-dimensional approximation for the thermal response of the far-field region. The results of three-dimensional heat-transfer analyses (SPECTROM-349) were used to calculate thermal expansion and stresses under the assumption of plane strain, using the finite-element technique (SPECTROM-31). The rock was characterized as elastic/plastic. A Mohr-Coulomb criterion was used to assess the onset of plastic response. The ubiquitous-joint model was used to predict whether joints slipped or opened. These analyses provided information in the following areas.

- Analyses of the two-dimensional heat transfer and deformation along a representative section perpendicular to the long dimension of a repository provide an adequate understanding for designing a repository that contributes to the containment and isolation of waste in the far field.

- The similarity of the inelastic responses and surface uplifts of two different APDs (57 kW/acre for spent fuel and 100 kW/acre for commercial high-level waste) show that these responses are not sensitive to the selected value of APD. This effect is probably attributable to the fact that the two fuel types (spent fuel and commercial high-level waste) delivered similar magnitudes of total energy to the rock.

- The effects of emplacing waste types having different initial APDs and decay characteristics in separate parts of the repository were insignificant in the far field.

#### 7.2.2.4.3 Determination of Maximum Temperature as a Function of Distance from a Repository

Blanford (1985) used a simplified analytic three-dimensional thermal model of a repository to construct profiles of the maximum temperatures in the far field. The rock mass was modeled as a homogeneous half space. The heat-transfer mechanism was assumed to be linear heat conduction. The thermal properties were representative of the Topopah Spring Member of Yucca Mountain. Two generic repository configurations were considered: 1,260 acres of spent fuel at 57 kW/acre and 645 acres of commercial high-level waste at 100 kW/acre. The repository was simulated as a heat-generating rectangular plate embedded in a semi-infinite half-space representing the rock mass. Figure 7-3 shows the maximum far-field temperatures of the host rock for spent fuel emplaced at 57 kW/acre. These analyses provided the following information.

- The APD is the design parameter that most significantly influences the maximum temperatures in the far field.

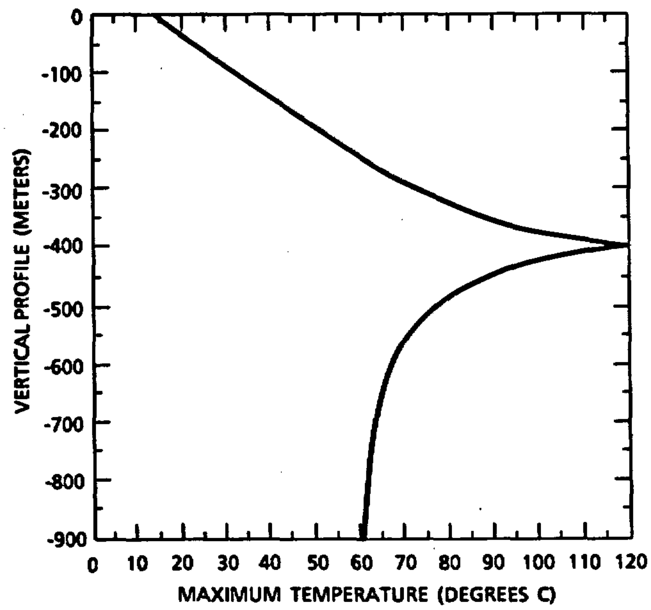
- Most of the heat is transferred vertically rather than laterally. The volume of rock above the emplacement area reaches and sustains higher temperatures for longer periods of time than the volume of rock peripheral to the emplacement area.

### 7.2.3 Near-Field Effects

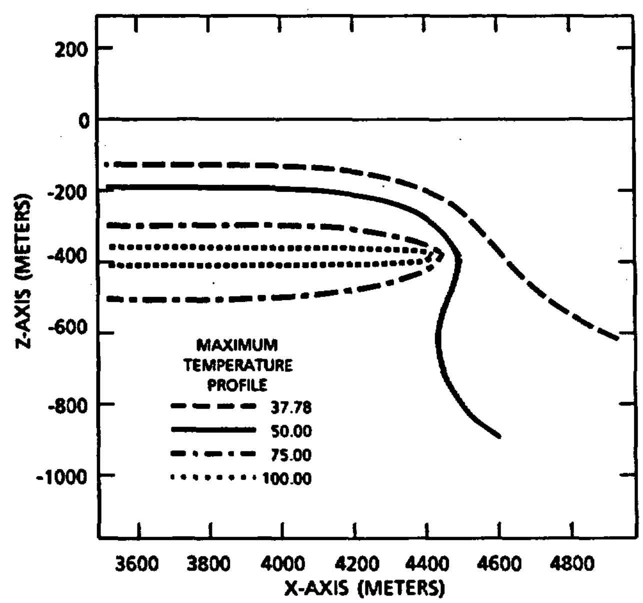
Section 6.4.4 provides a discussion of the approach being taken to select the thermal loading of the underground facility. That approach involves performing thermal and thermomechanical analyses to determine whether near-field postclosure design criteria are satisfied. The near-field criteria are tentatively identified in SCP Section 8.3.2.2 as

- a borehole wall temperature of less than 275°C,
- a rock-mass temperature at 1 m from the borehole wall of less than 200°C,
- the majority of borehole wall temperatures above boiling for more than 300 yr,
- no unacceptable loads on the container, and
- no deleterious movements of host rock around underground openings.

To date, near-field analyses of the proposed underground facility have largely focused on its behavior during the preclosure period. Many of




7-3a. Vertical Profile of Maximum Temperature Through the Center of the Underground Facility




7-3b. Contours of Maximum Temperature on a Vertical Plane Through the Underground Facility

Figure 7-3. Maximum Far-Field Temperatures for a Repository for Spent Fuel with an Areal Power Density of 57 kW/acre (Modified from Blanford, 1985.)

those analyses are discussed in Section 8.3.7, which pertains to preclosure conditions. Despite the focus on behavior during the preclosure period, several of these studies provide useful information on the postclosure period. Because those analyses have been performed over a period of several years, during which time the site data and conceptual design have been progressively refined, the bases for the calculations have varied. The following summaries identify the assumptions and constitutive relationships used in each study. The results of these studies are presented in Section 8.3.7.

The results of the analytical studies summarized below suggest that the near-field, postclosure criteria identified in SCP Section 8.3.2.2 will be met using either of the current emplacement concepts. This finding is based primarily on the results of the reference calculations for the emplacement drifts in both configurations and for the horizontal emplacement boreholes. At present, no comparable set of calculations that uses current estimates of the rock properties has been made for the vertical emplacement borehole.

<u>Reference Thermal and Thermal/Mechanical Analyses of Drifts for Vertical and Horizontal Emplacement of Nuclear Waste in a Repository in Tuff</u> (St. John, 1987)

Reference calculations of the conceptual designs for horizontal and vertical emplacement of 8.55-yr-old spent fuel were performed using the HEFF boundary-element (Brady, 1980), DOT (ONWI, 1983a), and VISCOT (ONWI, 1983b) finite-element codes. The material properties used for those analyses were the same as those given in the Reference Information Base (Appendix Q) for the NNWSI Project, with the exception that the values of joint cohesion and joint coefficient of friction current at the time the calculations were performed were those of Nimick, Bauer, and Tillerson (Attachment to Appendix O) and that no adjustments were made for changes as the rock mass dehydrates.

In these analyses, the response of the rock mass to development of the drifts and to subsequent thermal loading indicates that no failure of the rock matrix is expected and movement on nearby vertical joints will be restricted to localized regions in the side walls of the drifts. Limited data were presented for the first 200 yr following waste emplacement. Those data indicated that the stresses around the drifts peak within the first 100 yr and that the results of assessment of stability during the preclosure phase may provide a conservative estimate of what might occur subsequently. These results indicate minimal potential for subsidence at the site unless mechanisms are operating that cause substantial changes in the properties of the rock.

<u>Analysis of Horizontal Waste Emplacement Boreholes of a Nuclear Waste Repository in Tuff</u> (Arulmoli and St. John, 1987)

Thermal analyses of the conceptual design of boreholes for horizontal emplacement of 8.55-yr-old spent fuel were performed using the DOT code. The resulting temperature histories were subsequently used in a series of analyses using the VISCOT and JAC codes and several different constitutive descriptions of the tuff rock mass. In the simplest case, the rock-mass properties were used in linear elastic analyses, and the results were postprocessed to predict regions of matrix overstress or joint activation. Other cases used the ubiquitous-joint model of ADINA and the single and orthogonal compliant-joint models of JAC to investigate how regions of overstress might extend.

The results of the analyses indicate that the peak temperature of the borehole wall occurs about 35 yr after emplacement, that the peak temperature is approximately 155°C, and that the temperature of the borehole wall remains above 100°C for the first 300 yr after waste emplacement. At that same time, the temperature 1 m into the rock is approximately 135°C. The actual conditions will differ somewhat from these predictions because the waste containers will not be distributed continuously along the length of the emplacement boreholes.

The results of postprocessing data from the analyses for which linear elastic properties were assumed indicate that very limited regions of activation of vertical joints are expected for the first 300 yr after waste emplacement. Analyses using single-joint models of ADINA and JAC indicate that this region of activation is potentially self-stabilizing and never extends significantly beyond that predicted by the elastic calculations. Further analysis using joint properties at the low end of the measured range resulted in a similar finding. When the compliant-joint model of JAC was used, high stresses were found at the top and bottom of the borehole. This phenomenon, which was very localized, was attributed to the fact that the rock-mass modulus approached that of the intact rock as the joints closed.

Unit Evaluation at Yucca Mountain, Nevada Test Site: Summary Report and Recommendation (Johnstone et al., 1984)

As part of the unit evaluation performed during the selection of the candidate horizon at Yucca Mountain, a series of thermomechanical analyses of the drifts for waste emplacement was performed. The case analyzed was vertical emplacement of 10-yr-old spent fuel in drifts with dimensions similar to those of the vertical emplacement drifts in the current conceptual design. Analyses were performed using the ADINA and JAC codes; the constitutive models for a rock mass contained a single set of vertical joints.

The purpose of analyzing the drifts for unit evaluation was to provide a basis for selecting the APD for each unit. The design-basis criterion for the selection was that the drift floor temperature should not exceed 100°C during the operating period of the repository (a constraint assumed at that time to enhance retrieval). Another near-field criterion considered was that the factor of safety of the pillars between drifts should exceed 1.5. However, the drift floor temperature criterion was the governing criterion and resulted in the selection of an APD of 57 kW/acre.

This study considered several different units and a range of properties. Although the design and properties used in this study are not current, it is important to note that the results of the study were not significantly affected by the variations.

## 7.3 Engineering Analysis of Design

This section discusses the impact of certain alternatives on the repository. The alternatives include (1) site characteristics affecting design, (2) effect of construction techniques, (3) comparison of horizontal and vertical emplacement, and (4) effect of the ESF.

### 7.3.1 Site Characteristics Affecting Design

A three-dimensional graphic model of Yucca Mountain (Nimick and Williams, 1984) has been developed using an Interactive Graphics Information System. The model is a collection of three-dimensional surfaces based on interpolation between data points. The model describes the stratigraphy (strike, dip, thickness, and lateral extent of the units), the structure (locations, offsets, strike, and dip of faults), and hydrology (position of the water table). Faulting of the surfaces is not automated but is included in the model output interactively. A complete discription of the model has been published (Ortiz et al., 1985).

The three-dimensional graphic analysis of Yucca Mountain has been used to identify areas for waste emplacement and to ensure that the underground facility meets the following design goals: (1) the underground facility should be in the low-lithophysae portion of the Topopah Spring Member, (2) all portions of the underground facility must be at least 200 m below the ground surface directly overlying the underground facility, (3) the underground facility should be significantly above the water table (SCP Section 8.3.2.2), and (4) the dip of the underground facility should be less than 10%.

A preliminary evaluation of possible waste emplacement areas, which takes into account the thickness and lateral extent, dip, lateral and vertical continuity, and faulting of the host rock, has (1) identified a primary (or preferred) area for waste emplacement, (2) determined the usable portion of the primary area, and (3) located a slab within the usable area that maximizes the usable area while minimizing the dip of the slab (Mansure and Ortiz, 1984). Figure 7-4 shows how this slab is positioned in the low-lithophysae portion of the Topopah Spring Member.

Design options or decisions regarding the facility as a whole, which may affect waste containment and isolation, include

- selecting an APD for the underground facility and, as a result, determining the size of the underground facility;
- locating the accesses to the underground facility;
- locating the best position (depth and grade) for the underground facility and matching its shape to the usable portion of the primary area;
- establishing the orientation of the drifts and boreholes; and
- deciding how the development of the underground facility will accommodate specific site conditions.

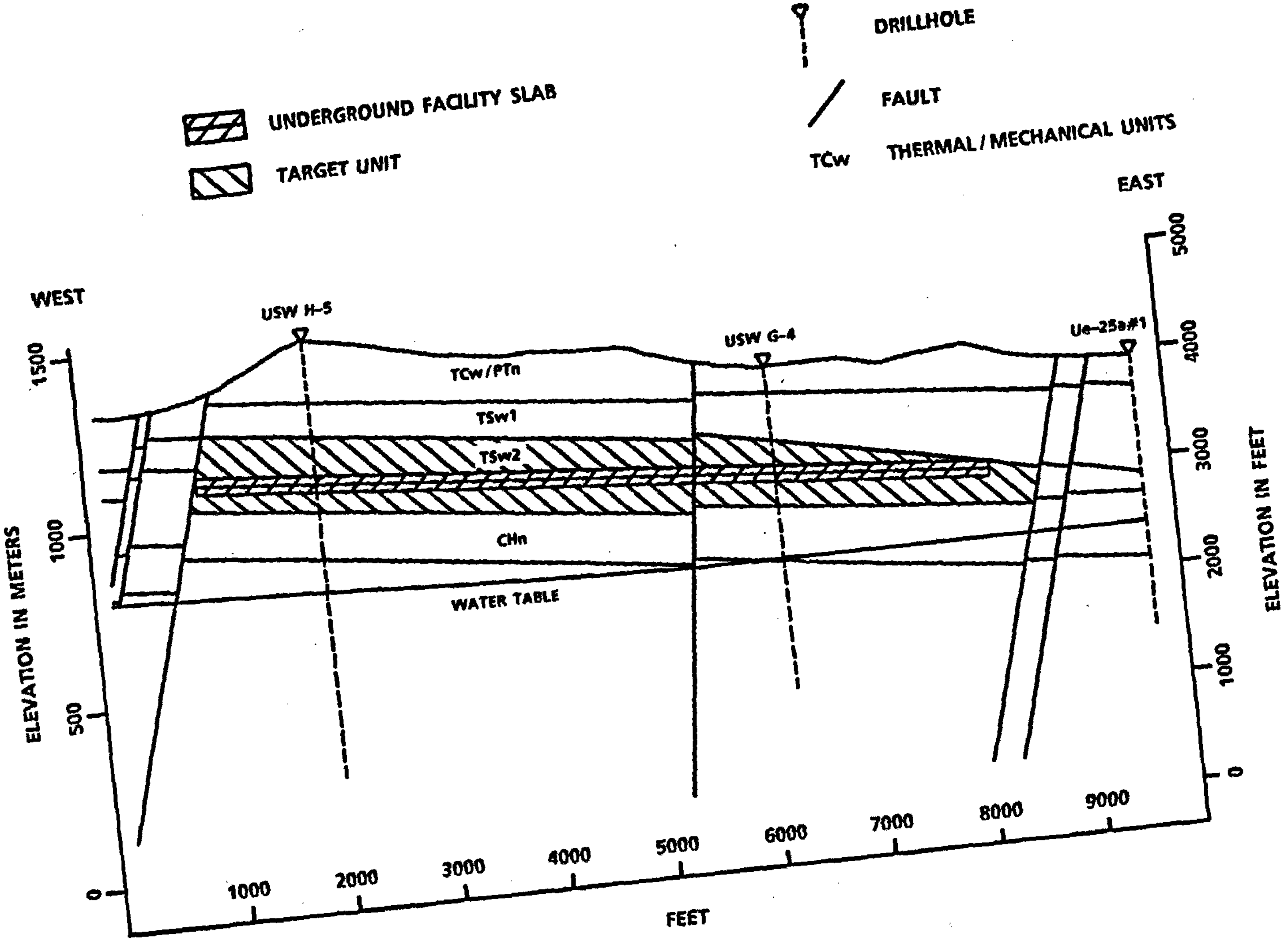



Figure 7-4. Cross Section of Yucca Mountain Showing Position of Slab (Modified from Ortiz et al., 1985.)

The second, third, and fifth items depend on large-scale site characteristics (thickness and lateral extent of the host rock, depth of the host rock, lateral and vertical continuity of the host rock, faulting, breccia, and spatial variability of rock-mass properties). The effect of site data on the first item (APD) is given in Section 6.4.4 and SCP Section 6.4.2, and the effect of site data on the fourth item is discussed in Section 6.4.2. The need for additional site data for these items is discussed in SCP Section 8.3.2.2.

#### 7.3.1.1 Effect of Site Characteristics on Location of Accesses

Section 4.3 gives the description and functions of the accesses to the underground facility. The locations of the accesses to the underground facility are shown on Figure 4-5. The selection of these locations was based on the same factors considered in the selection of the site for the general surface facility (Neal, 1985).

The locations of the collar of the men-and-materials shaft and the emplacement area exhaust shaft were selected following an evaluation of surface topography and site accessibility, known and inferred geologic structures, compatibility with the overall repository layout and operations, and surface flooding potential.

The siting of the the collars of the two exploratory shafts will be established by the ESF and sealing program (SCP Sections 8.1.2 and 8.3.3.2). Although the exact location of these facilities may change slightly, any changes should not significantly affect the overall layout of the underground facility. The design of the subsurface facilities assumes that both shafts are available for use as intake ventilation airways following the completion of site characterization work. Thus, the location of these accesses is a constraint on the design of the underground facility.

The location and alignment of the portals for the waste ramp and tuff ramp were selected after evaluation of known and inferred fault intercepts, machinery and transporter grade limitations, surface-flooding potential, and site conditions affecting portal constructibility.

Alignment of the tuff ramp and its portal location is based on the ramp slope, minimum excavation of alluvial material near the portal, surface flooding potential, and proximity to the tuff pile. The alignment of the waste ramp is constrained by the relative locations of the surface and subsurface facilities and by the maximum allowable slope for the waste transporter. The waste ramp portal is located on the east side of Exile Hill, which is in an area of little or no alluvial cover.

To minimize the length of the ramps through potentially faulted ground, both the tuff ramp and waste ramp are aligned nearly perpendicular to the strike of the Drill Hole Wash Fault at the point where these ramps intersect the fault. The waste ramp also runs perpendicular to the north/south-trending faults mapped west of the surface facility site. The waste ramp alignments generally cut across the principal strike direction of the fractures.

### 7.3.1.2 Effect of Site Characteristics on the Layout of the Underground Facility

It is important that the arrangement of repository features be flexible to accommodate unexpected geologic conditions. The layout of the subsurface facility is expected to be flexible enough to accommodate such conditions as minor faults. Breccia associated with such faults is not expected to cause adverse effects. Additionally, rock support systems capable of handling a wide range of potential site conditions have been proposed. However, site characterization is needed to confirm these expectations and to investigate the effects of uncertainty in geologic characteristics. The frequency and extent of anomalous zones needs to be estimated. These studies will require additional exploratory boreholes and subsurface field tests or observations in the ESF. The site programs necessary to quantify the effects of uncertainty in geologic data are described in SCP Sections 8.3.1.2, 8.3.1.4, 8.3.1.8, 8.3.1.15, 8.3.1.16, and 8.3.1.17.

Analysis of a three-dimensional computer graphics model of Yucca Mountain (Nimick and Williams, 1984) indicates that the primary area contains approximately 2,200 acres. Minor faults and breccia and blocks rotated to steep dips may occupy some of the area. Although these features have not been shown to create waste isolation problems in an unsaturated environment, flexibility will allow waste emplacement in locations where characteristics are known to be more favorable. These site characteristics have been considered when determining how much bigger (for flexibility) the usable area should be than the area needed. Available site data indicate that approximately 5,000 additional acres of rock with acceptable characteristics may be present outside the primary area (Mansure and Ortiz, 1984; Sinnock and Fernandez, 1982). Appendix M shows the capacity of Yucca Mountain in terms of area available in comparison with the area needed. The need for additional site data is discussed in SCP Section 8.3.2.2.

Basic requirements for the thickness of the potential host rock are (1) the presence of sufficient overburden to ensure a low probability that erosion will uncover the waste and (2) sufficient thickness of suitable host rock to provide the volume of rock required for construction of the underground facility. Mansure and Ortiz (1984) show that the approximate thickness of the preferred host rock is about 100 to 175 m within the primary area. This thickness is about three times that of the underground facility envelope (45 m) and is more than 15 times the height of the drifts. The overburden thickness (distance from the surface to the underground facility) at Yucca Mountain is more than 300 m over approximately 50% of the primary area and is over 200 m everywhere above the usable portion of the primary area (DOE, 1986b, Section 6.3.1.3.3). Thus, exploration of the primary area to date has revealed sufficient thickness of potential host rock for flexibility in design of the underground facility.

To date, a value of less than 15 to 20% for lithophysal content has been used to establish the preferred horizon. At low percentages, lithophysae have little effect on physical properties. High percentages (probably near 30%) of lithophysae may change the thermomechanical properties (Price et al., 1985) to the point that ground support requirements and stability are affected. Laboratory testing is planned to quantify the thermomechanical properties of tuff that contains the higher percentages of lithophysae. Although the preferred horizon is expected to have less than 15 to 20% lithophysae, this expectation does not imply that the underground facility must be placed in host rock with less than 15 to 20% lithophysae but only that host rock with a lower lithophysal content may be preferable. Although there are no plans at this time to emplace waste in sections that contain high percentages of lithophysae, there is no known waste isolation problem inherent in emplacing waste in such areas. Should such areas be encountered during construction, they will be evaluated for emplacement suitability.

Figure 7-4 shows a cross section of Yucca Mountain and the possible location of the underground facility. The figure shows that a single slab potentially exists that should satisfy all current design criteria. The most efficient layout for the underground facility would be on a horizontal plane. However, the Topopah Spring Member dips to the east at an angle of 5 to 8°; thus, the layout must also dip to stay within the desired rock unit.

### 7.3.2 The Effect of Construction Techniques

The design criteria specified by 10 CFR 60 for the underground facility require that the openings (1) ensure operational safety [10 CFR 60.133(e)(1)], (2) reduce the potential for deleterious rock movement or fracturing of the overlying or surrounding rock [10 CFR 60.133(e)(2)], and (3) be constructed by methods that will limit the potential for creating a preferential pathway for ground water or migration of radioactive waste to the accessible environment [10 CFR 60.133(f)]. These are the criteria against which the construction methods are judged for potential impact on the repository.

The construction methods presented in this conceptual design are believed to comply with the requirements above. Construction techniques considered should be flexible to accommodate possible changes in design parameters and conditions encountered during construction. These methods are not believed to jeopardize postclosure performance or the performance of the shaft and borehole seals.

The method planned for the construction of the underground drifts is drill-and-blast mining. This method was chosen because (1) it is applicable to all rock types expected in the construction of the repository, (2) it is adaptable to all shapes of opening cross sections, and (3) there is no mechanical mining system currently in use that can produce the opening shapes desired in rock as strong as that in the emplacement horizon. The ramps used for access to the underground facility, the waste main, and the perimeter drift will be constructed by tunnel-boring machine (TBM). TBMs can be used for these openings because the excavated openings can be circular in cross section and have long runs with large radii of curvature that can be negotiated by a TBM.

#### 7.3.2.1 Approach to Selecting the Construction Methods for the Repository

The approach for evaluating the impact of construction methods on the three areas of concern or criteria identified by 10 CFR 60 is described below.

7.3.2.1.1 Operational Safety

There are two major concerns in the safe design of an underground opening. The first concern is to design the underground opening to prevent a general failure that could block access and ventilation flow. The second concern is the potential for local rockfall, which presents a hazard to workers. The following steps in the design process ensure that the underground openings will be safe.

The first step uses empirical design techniques to determine the maximum size of an opening that will be stable, based on the mechanical properties of the rock. Once the maximum opening size has been determined, analytical methods are used to verify the designs. This design process and the results of work completed are described in Section 8.2.1.2. The only impact of the construction method considered in this step is the potential increase in the size of the opening (overbreak) created by the construction method.

The second step is to design support to prevent the fall of rocks from the back (ceiling) of the opening. Candidate support systems include rock bolts, rock bolts and wire mesh, structural steel, concrete, and shotcrete, either individually or in combination. The selection of the support system is determined using empirical, experience-based methods. These methods, and the data required for their application, are presented in Section 8.3.7.2.6. Based on this approach, it has been concluded that the most appropriate ground support for most of the underground facility is rock bolts and wire mesh.

7.3.2.1.2 Deleterious Rock Movement

Deleterious rock movement is a pre- and postclosure concern. Whether deleterious rock movement will be produced by the construction methods is determined by a combination of observation and testing. Inspection of the surfaces of the exposed rock reveals whether there is a change in the characteristics and frequency of fractures in the rock. Part of this inspection can include comparing the fractures in cored samples taken radially outward from the opening to fractures exposed in the opening; this technique will aid in assessing rock movement as a function of the distance from the constructed surface.

Testing techniques to determine whether deleterious rock movement has resulted from construction are based on permeability measurements. One testing approach measures the bulk permeability in boreholes that will be intersected by the opening. These measurements are repeated in these same boreholes at the same locations after the opening has been driven. The comparison of the pre- and postconstruction permeability is a measure of the disturbance of the rock created by construction.

Construction criteria applied in the design of the repository directed at limiting the potential for deleterious rock movement include (1) limiting extraction ratios, (2) constructing emplacement boreholes by drilling to limit perturbation of the rock close to the waste, and (3) backfilling the underground openings at closure.

7.3.2.1.3 Preferential Pathway

It is unlikely that the construction methods chosen for Yucca Mountain will create a preferential pathway for migration of water and radionuclides. This conclusion is supported by published reports that quantify the extent of the damage created in the rock surrounding an opening as less than 2 m when drill-and-blast construction is used. Several reports (Montazer et al., 1982; Kelsall et al., 1982; King et al., 1984; Miller et al., 1974; Case and Kelsall, 1987) document the extent of rock damage resulting from drill-and-blast mining.

The sensitivity of the repository to the potential for the creation of a preferential pathway by a construction method, however slight, is reduced by the design features of the repository listed below.

- Shaft depths are limited to the minimum depths necessary to accomplish testing. This feature reduces the disturbance of the natural barrier between the underground facility, the underlying formations, and the water table. Ground-water inflow, if any, and sealing of shafts and ramps are discussed in Section 5.2.

- Underground openings are not developed in the vicinity of the exploratory boreholes, which communicate with the surface or the water table. The allowable distance from construction to any existing borehole has been estimated to be 15 m.

- The present conceptual design of the underground layout is limited by having precluded areas that contain known geological structures, e.g., the Drill Hole Wash structures and the imbricate normal faults to the northeast. The final boundary will be based on the location and characteristics of these structures at the depth of the emplacement horizon as determined by site characterization. (The Ghost Dance Fault is an exception; this fault is within the boundary of the underground layout. The exact position of the underground facility in relationship to this fault has not yet been determined; the eventual position will depend on the characteristics of the fault as determined by site characterization.)

The potential of the construction method to create a preferential pathway will be evaluated by the empirical, observational, and testing techniques identified above. In addition to the potential of the construction method to cause structural damage, the materials used for construction must be evaluated to ensure that they are compatible with the host rock and do not contribute to the creation of a preferential pathway.

7.3.2.2 Data Requirements

The data required to assess the effect of construction techniques are identified in Section 8.2.1.1 and in SCP Section 8.3.

7.3.2.3 Results of Analysis

To this point, the analyses performed on the underground openings consist mainly of calculations to verify general stability and to determine the types of rock support required. These analyses consider the construction methods only to the extent that they affect the opening size and create a zone of loosened rock (blast-damaged zone), which must be stabilized by the rock support system.

7.3.2.4 Future Work

Future work to fully assess the effect of the construction method on safety, deleterious rock movement, and the creation of a preferential pathway consists of

- analysis to determine at what point blast damage can potentially affect the ability of the repository to meet the requirements of 10 CFR 60.133 and

- measurements to confirm assumptions made regarding the extent of the blast-damaged zone.

7.3.3 The Effect of the Exploratory Shaft Facility

Certain elements of the ESF are incorporated in the underground facility, namely the two exploratory shafts and the drifts that connect them to the facility during operation. Because these features will be used in the repository, a quality assurance (QA) program similar to the one intended for use during repository construction will be imposed on these elements. This action will help ensure that these elements function as required for the operating life of the repository.

The possible interactions between the ESF, the site, and the repository are discussed under the following topics: (1) the effects of the ESF on the repository site and repository, (2) the layout of the ESF, (3) the functions of the ESF during operation, and (4) the impact of construction and operational seals.

7.3.3.1 The Effects of the Exploratory Shaft Facility on the Repository Site

An underlying goal in the design of the ESF is that the design not compromise the repository site during either the preclosure or postclosure period. Two concerns are mechanical damage and chemical additions to or changes in the site.

Figure 7-5 shows the design of the ESF used in the development of the conceptual design. The extraction ratio for the design shown is less than 20%. In rock the strength of the Topopah Spring Member, an extraction ratio of less than 20% should not result in subsidence and subsequent fracturing of the overlying rock. This conclusion is substantiated by Hill (1985) and by St. John (1985). In the latter document, calculations predict repository stability for the design-basis thermal load of 57 kW/acre. Further discussions are given in Section 8.3.7.

Mechanical damage to the rock will be limited by use of controlled drilling and blasting and by a low extraction ratio. Chemical changes at the site will be reduced by monitoring and controlling the introduction

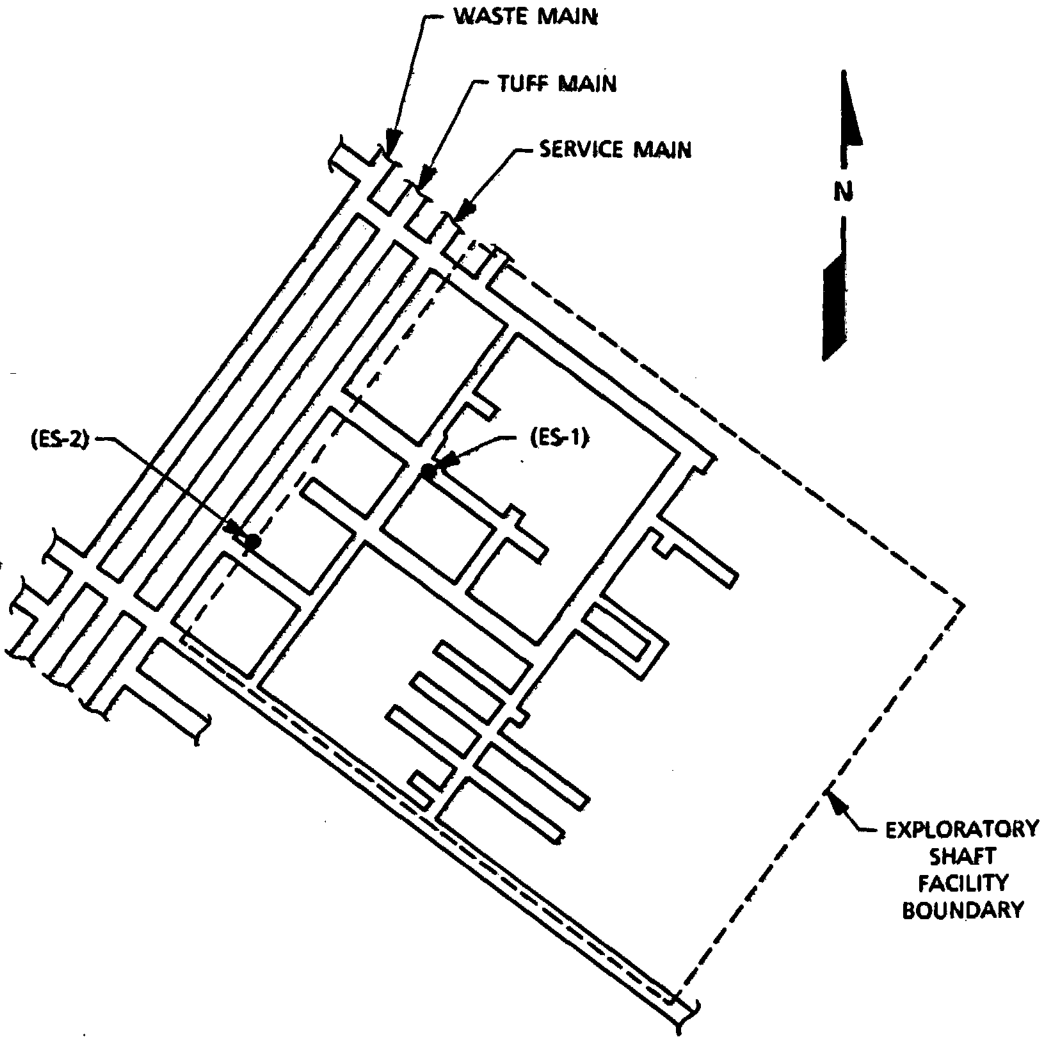



Figure 7-5. Exploratory Shaft Facility Concept (Modified from Parsons Drawing R07028.)

of water and chemicals and by careful selection of construction materials. The types and quantities of materials to be used, as well as those expected to be "lost" during construction and operation, must be noted and analyzed with respect to their long-term impact.

As described in Section 5.2.2, seals will be emplaced in all shafts as part of the closure of the underground facility. These seals will be designed to impede the entry of water near the surface and to promote the free drainage of any water that does enter. Surface diversion structures prevent entry of surface water during the operations period. The portions of shafts that extend below the emplacement horizon are intended to be backfilled with permeable material during repository closure to encourage drainage. Analyses will be performed before closure to determine whether it is necessary to remove selected portions of shaft liners to promote drainage. It is intended that any water that may enter the exploratory shafts above the emplacement horizon be diverted away from emplaced waste by being allowed to drain into the formation directly below the shaft.

#### 7.3.3.2 The Effects of the Exploratory Shaft Facility on the Full Repository

To limit the effect of the ESF on the repository, the ESF has been designed and located to limit operational and physical connection to the remainder of the underground facility. The following features illustrate this independence.

- It is not planned to use the hoist used in the ESF during the operations phase of the repository.

- The utilities for the ESF are separate from the utility system that supports the remainder of the underground facility.

- It is not planned to use the surface facilities of the ESF as part of the repository.

- The number of connections between the ESF and the remainder of the underground facility is the minimum necessary to permit the eventual use of the exploratory shafts for supplying ventilation air to the underground facility.

- As shown in Figure 7-5, the separation of the ESF from the repository drifts varies but is generally greater than 100 ft. This separation ensures that there will be little or no structural interaction between the ESF and the repository, as substantiated by the calculations summarized in Section 8.3.7.

In addition, the interfaces between the ESF and the remainder of the underground facility are monitored in the NNWSI Project by a group that considers and reviews the physical interfaces between the ESF and the repository. The purposes of this group are to identify, define, and document these interfaces and to alert all participants of any changes that might occur. Interface areas of particular interest to the review group are the design of ground support, design of openings, choice of construction materials, and selection of construction methods. The group also reviews proposed operational procedures in the two facilities to ensure that they do not adversely affect either facility.

#### 7.3.3.3 Layouts Considered for the Exploratory Shaft Facility

Numerous variations in design have been, and continue to be, developed for the ESF. In the configuration used in the conceptual design, two shafts provide access for personnel, utilities, and ventilation to the ESF. The primary shaft, Exploratory Shaft 1 (ES-1), is 12 ft in diameter and is equipped with a hoist for men, materials, and the handling of mined tuff. This shaft is used during ESF operation for routing utilities, ventilation supply, and exhaust ducts. The second shaft, Exploratory Shaft 2 (ES-2), is a 6-ft-diameter shaft used during ESF operation primarily for emergency egress. A study of the shaft sizes used for the ESF is documented by SNL (1984b).

The design of the ESF must be flexible to accommodate changes in experiments and to accommodate additional experiments that may be needed as development of the ESF proceeds.

#### 7.3.3.4 Functions of the Exploratory Shaft Facility During Operation of the Repository

During repository operations, ES-1 will provide a portion of the air required by waste emplacement operations. The hoist fittings installed in the shaft during site characterization will be removed when the shaft is converted to support the repository.

During repository operations, ES-2 will supply ventilation air to the support shops in the waste emplacement area. It will probably not be necessary to reconfigure this shaft for use in the repository; therefore, it can still serve as a means of emergency egress during the operating life of the repository. The reconfiguration of the exploratory shafts will be designed and scheduled to avoid significant impact on ongoing experiments.

#### 7.3.3.5 Sealing the Exploratory Shafts

No construction or operational seals are planned for the exploratory shafts; thus, there is no potential impact on the preclosure performance of the repository as the result of the emplacement of seal materials during construction of the exploratory shafts.

### 7.3.4 Effects of the Emplacement Configurations

Both vertical and horizontal emplacement configurations are being considered for the Yucca Mountain repository. Before the repository and equipment designs are completed, the emplacement configuration will be selected. Factors that will be considered in making this decision and that have been examined to date include

- long-term waste isolation performance,
- thermal and mechanical effects on the underground facility and surrounding rock,

- safety of operating personnel and the general public,
- retrievability, and
- technical feasibility and costs.

This section discusses the effects of the vertical and horizontal configurations on these factors.

#### 7.3.4.1 Long-Term Waste Isolation Performance

To determine the capability of the two emplacement configurations to provide long-term waste isolation, the effects of borehole orientation, standoff distance, and materials used in the boreholes need to be considered.

Horizontal and vertical emplacement present different physical configurations to be modeled and analyzed. For example, the area of the waste container as seen in plan view is several times greater for the horizontal configuration than for the vertical configuration. Without extensive and detailed modeling and analysis, it is not possible to predict that one configuration will be superior to the other; however, bounding and probabilistic analyses, using conservative assumptions, have been done to assess the magnitude of potential releases (Sinnock et al., 1984; Lin, 1985; Lin et al., 1986). These results indicate that there is little probability of a significant difference in release related to the emplacement configuration.

In the unlikely event that a drift is flooded with water, flood waters would have to reach higher levels in a drift in the horizontal emplacement configuration than in the vertical configuration to enter the emplacement boreholes and contact the waste containers.

Because of the increased standoff between the emplacement drift and the waste containers, the waste containers in horizontal boreholes are more isolated from features such as borehole collars and drift support systems in which materials such as concrete and grout may have been used. As a result, the potential for chemical modification of ground water that could come in contact with the waste containers is lower in horizontal boreholes than in vertical boreholes. Both emplacement configurations include at least partial steel liners in the boreholes; as a result, the potential for chemical changes in the ground water caused by the liner is similar in both configurations.

Construction blast overbreak (propagation of fractures into the surrounding rock during drift-blasting operations) has a greater potential for creating a preferential pathway for ground-water movement past the waste containers in the vertical configuration because the containers would be placed closer to and directly under the drift.

#### 7.3.4.2 Thermal and Mechanical Effects on the Repository

##### 7.3.4.2.1 Mining Volumes and Extraction Ratio

Figures 3-20 and 4-37 show the underground layout and a typical emplacement panel for the vertical emplacement configuration. Figures 4-38 and 4-30 show the underground layout for horizontal emplacement. Comparison of these figures shows a large difference in the total length of drifts that must be constructed in each configuration. In the vertical configuration, the total drift length is 610,740 ft, and a total of 14.4 million tons of material is mined. In the horizontal configuration, the total drift length is 245,870 ft, and 5.3 million tons is mined. The amount of rock extracted for mining in the horizontal configuration is therefore 37% of that in the vertical configuration, which results in less potential subsidence and, hence, less disturbance of the natural state of the host rock formation.

7.3.4.2.2 <u>Drift Temperatures</u>

The temperatures expected in the emplacement drifts after waste emplacement are much higher in the vertical configuration than those in the horizontal configuration (Appendix J). As a result, thermal stresses in the host rock surrounding the drifts will be lower in the horizontal configuration, possibly resulting in more stable drifts. Furthermore, lower temperatures allow repository personnel access to the emplacement drifts for the purposes of inspection, instrument observation, maintenance, and other tasks, with only minimal ventilation for cooling the drifts.

7.3.4.2.3 <u>Drift Shapes</u>

The emplacement drifts for the vertical configuration are 22 ft high and 16 ft wide. In the horizontal configuration, the emplacement drifts are 14 ft high and 21 ft wide. Because thermal loading in the drifts is lower in the horizontal configuration (because the standoffs are longer), it is predicted that the drifts in the horizontal configuration will be more stable than those in the vertical configuration when heated (St. John, 1987) although the excavation-induced loading is potentially of more concern in the horizontal configuration.

7.3.4.2.4 <u>Ventilation</u>

The ventilation schematics for vertical and horizontal emplacement shown in Figures 3-32 and 3-34, respectively, demonstrate the simplification obtained by using horizontal emplacement. The number of ventilation stoppings, airlocks, regulators, and other air control features is significantly reduced in the horizontal configuration.

7.3.4.3 <u>Safety of Operating Personnel and the General Public</u>

The amount of mining needed in the horizontal configuration is considerably less than it is in the vertical configuration. The size of the mining crew needed to construct the underground facility is 83 in the horizontal configuration and 305 in the vertical configuration. In the horizontal configuration, the difference in crew size implies a reduction in the total exposure of personnel to the hazards associated with mining.

Because up to 18 waste containers will be placed in each horizontal borehole and only one waste container will be placed in each vertical borehole, there will be up to 18 times as many boreholes and closures to prepare in the vertical configuration as in the horizontal configuration. The smaller number of borehole operations needed for horizontal emplacement implies a potential for a smaller radiation dose to underground workers. Furthermore, radiation levels in the drifts should be lower in the horizontal configuration because of the greater standoff between the waste containers and the drift, and, therefore, radiological safety for the workers should be improved.

No significant differences between vertical and horizontal emplacement are expected with respect to the safety of the general public.

#### 7.3.4.4 Retrievability

Under normal conditions, temperatures in the emplacement drifts after waste emplacement will be significantly higher in the vertical configuration than in the horizontal configuration. As a result, the vertical configuration will require more extensive cooling of the emplacement drifts for retrieval operations.

Under normal conditions, procedures for removing waste from the repository, after the repository has been prepared for retrieval and the emplacement drift has been cooled, are similar to emplacement operations. The equipment used for emplacement is also used in waste removal operations. In the case of the horizontal configuration, additional equipment and operations may be required to position waste containers in the borehole entry region for subsequent removal, thereby increasing potential safety concerns.

Under off-normal conditions, retrieval will probably be significantly more complex in the horizontal configuration than in the vertical configuration because of the greater standoff distances between the emplacement drifts and the emplaced waste containers. The concepts presented in this report for operations to remove blocked or bound containers from horizontal boreholes are more complex than those for vertical boreholes. These concepts were developed for a wide range of off-normal conditions without regard to how often (or if) those conditions would occur. Further analysis is necessary for both the vertical and horizontal configurations to determine which off-normal conditions are credible, which credible conditions have significant impacts on retrievability, and which equipment systems must be developed to deal with those conditions. This analysis must be completed before a more definitive comparison of retrievability under off-normal conditions can be made between the two configurations. A preliminary attempt at identifying off-normal conditions is contained in Appendix L-2. Additional analysis is planned for the ACD.

#### 7.3.4.5 Technical Feasibility and Cost

Although questions remain concerning the performance of equipment at operating rates expected for repository operations, the feasibility of developing emplacement equipment for vertical emplacement has been demonstrated in Project Salt Vault (ORNL, 1971) and in the Climax facility (Patrick, 1985). Further analysis and design development are needed to prove the feasibility of horizontal emplacement and the equipment needed for that configuration; however, individual components of the necessary equipment have been assessed and judged feasible (Appendix E).

The technical feasibility of off-normal retrieval equipment must be determined for both configurations through further analysis and design development. The additional studies needed to establish the most desirable combination of emplacement borehole length, number of packages per borehole, standoff distance, emplacement drift temperatures, emplacement and retrieval equipment techniques, etc., are currently being planned.

Development and demonstration costs will be higher for horizontal emplacement and retrieval equipment because of the additional mechanical components required. The facility for horizontal equipment demonstration will also be more extensive and costly because of the size needed to replicate the horizontal emplacement borehole. Finally, the ability to drill and line long, horizontal boreholes has not yet been demonstrated, although a development prototype boring machine has been designed and may be fabricated and tested.

## 7.4 Systems, Structures, and Components Important to Safety and Waste Isolation

### 7.4.1 Systems, Structures, and Components Important to Safety

#### 7.4.1.1 Introduction

Items important to safety are defined in 10 CFR 60.2 as "those engineered structures, systems, and components essential to the prevention or mitigation of an accident that could result in a radiation dose to the whole body, or any organ, of 0.5 rem or greater at or beyond the nearest boundary of the unrestricted area at any time until the completion of permanent closure." The Nuclear Regulatory Commission (NRC) and DOE have advocated the use of probabilistic risk assessment (PRA) techniques to determine those items important to safety. A method has been developed, and, based on a preliminary radiological safety analysis (PRSA) of the conceptual design of the Yucca Mountain repository (Appendix F), which used a PRA approach, a preliminary list of items potentially important to safety has been compiled. A detailed report of the study to identify items important to safety is contained in Appendix L-1 and is summarized below.

#### 7.4.1.2 Summary of Method for Determining Items Important to Safety

The determination of items important to safety (Q-List items) is based on a PRSA (Appendix F). The method used in the PRSA follows the NRC method for a simplified and streamlined Level 3 PRA described in the PRA procedures guide (NRC, 1983). A Level 1 PRA involves only systems modeling and generation of accident scenarios. A Level 2 PRA consists of a Level 1 PRA and an analysis of releases. A Level 3 PRA consists of Level 1 and Level 2 PRAs and consequence analyses. The level of detail of the PRSA varies at each step, depending on the data and design information currently available. Because the primary objective of the PRSA was to provide a numerical basis for selecting a preliminary list of items important to safety, only accident scenarios resulting in public exposures have been considered in detail.

Initiating events, both internal and external, were first identified and screened on the basis of their potential to contribute to a significant offsite release of radioactive materials. The event-tree technique (an inductive process involving the graphical depiction of the sequence of events that follow an initiating event) developed accident scenarios for those initiating events that survived the first screening process. The key to developing an event tree for each surviving initiating event was the selection and definition of intermediate events. Event trees were not constructed in any more detail than that necessary to adequately characterize the accident. Lacking data and design details, development and analysis of fault trees (a deductive process involving the graphical depiction of the possible component failures that might lead to an intermediate event on an event tree) were not complete. However, variations of a conventional fault tree or fault diagrams were developed for most intermediate events. Fault diagrams provide important insight into the probabilities of intermediate events.

After the event trees had been developed, the average frequency of occurrence of each initiating event and each intermediate event was evaluated. The consequences of the accident scenarios were evaluated at the same time. These frequencies were estimated from historical data and the judgment of a panel of engineers with extensive experience in the nuclear industry. Consequence analyses involved the development of models and estimates of radionuclide releases, dispersion, and transport into the environment, as well as dose calculations. The results of the probability and consequence analyses were used to quantify the event trees by assigning probabilities to each intermediate event.

Based on the results of the event tree quantifications, all accident scenarios were classified as either a Q-Scenario, a Potential-Q-Scenario (PQ-Scenario), or a Non-Q-Scenario (NQ-Scenario). Q-Scenarios are those scenarios whose dose consequences are greater than or equal to 0.5 rem and whose average frequency of occurrence is greater than $1 \times 10^{-5}$/yr (Section 2.7.1). Q-Scenarios are further evaluated to determine which of the systems, structures, and components involved in the scenarios are important to safety. PQ-Scenarios are those scenarios whose dose consequences and probabilities of occurrence do not exceed the thresholds mentioned above but are judged to have a reasonable possibility of becoming a Q-Scenario as more data are collected and the repository design matures. PQ-Scenarios are further evaluated to determine which systems, structures, and components are potentially important to safety. NQ-Scenarios are those scenarios whose dose consequences and average frequency of occurrence do not exceed the thresholds mentioned above and are judged to have no chance of becoming a Q-Scenario in the future. NQ-Scenarios need no further evaluation.

#### 7.4.1.3 Method of Identifying Items Important to Safety

The methods described in this section include more details than presented above. These methods are basically the same as those described for preclosure radiological safety performance assessment in SCP Section 8.3.5.1, Strategy for Preclosure Performance Assessment. The process is illustrated in Figure 7-6.

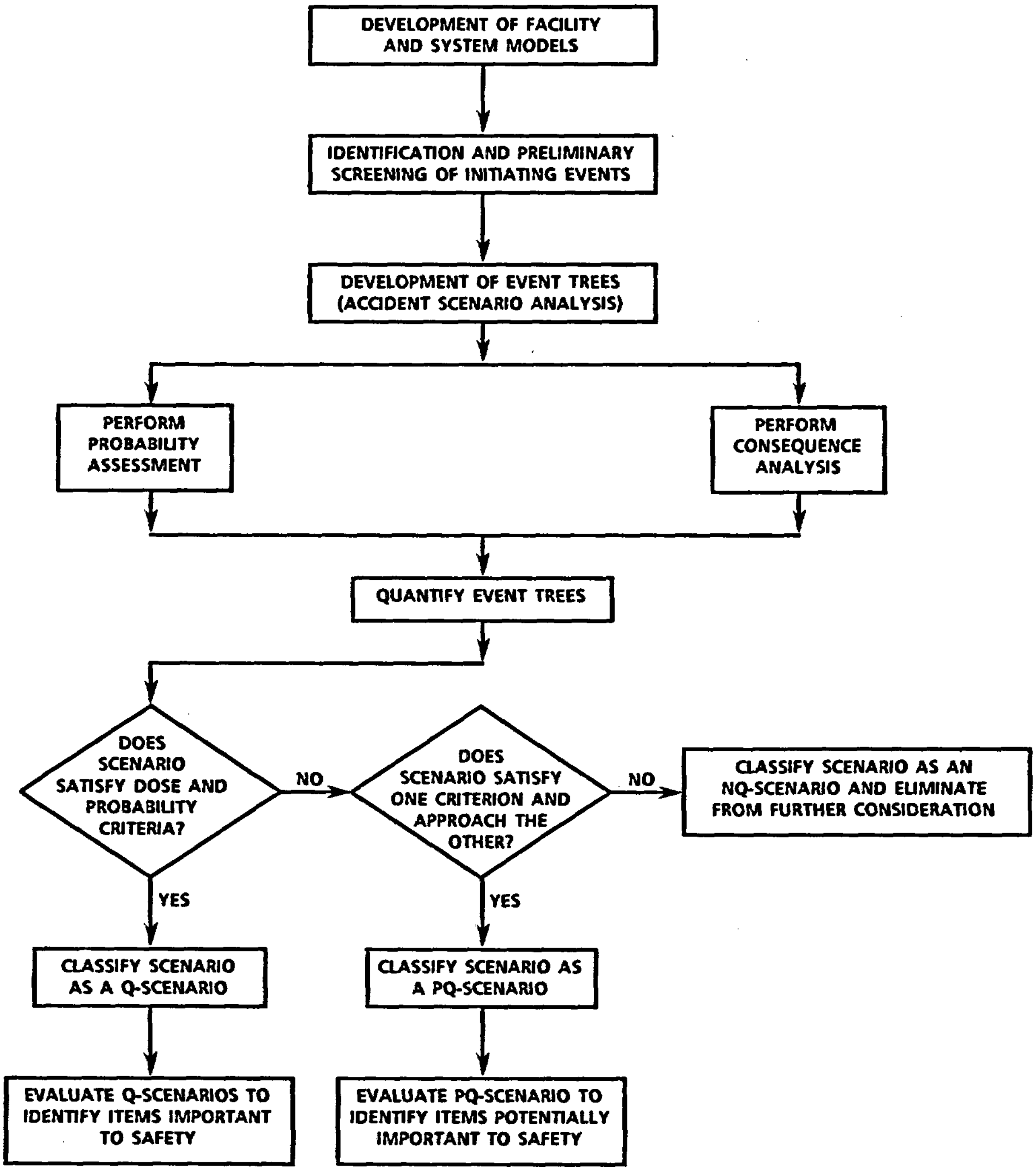



Figure 7-6. Q-List Methods for Determining Items Important to Safety (Figure prepared for the SCP-CDR.)

#### 7.4.1.3.1 Facility and Systems Modeling

To facilitate the preclosure safety analysis used as the basis for determining items important to safety, the structures, systems, and components of the reference design were grouped into three general areas: Area I, which includes the access, waste-receiving and inspection, and the surface and subsurface portions of the waste operations area; Area II, the general support area; and Area III, the development area. These areas are shown in Figure 2-2 of Appendix F. There are no waste receipt, handling, preparation, or emplacement operations performed in Areas II and III. All of these functions are performed in Area I; therefore, significant offsite releases will not be initiated in Area II or Area III.

Area I was further subdivided into nine system areas: (1) the access area (for the purposes of this analysis, the access area includes the bridge over Fortymile Wash), (2) the receiving and inspection area for offsite carriers, (3) the cask-receiving and inspection area, (4) the cask-unloading hot cells, (5) the transfer tunnels, (6) the consolidation hot cells, (7) the waste-packaging hot cells, (8) the surface storage vault, and (9) the underground emplacement areas. These areas are illustrated in Figures 2-2, 2-3, and 2-4 of Appendix F. The waste types in these nine system areas are grouped in three general classes characterized by different levels of resistance to dispersion of radioactive materials during an accident. These classes are shown in Table 7-2.

In Table 7-3, the waste types and their associated degree of resistance to dispersion are assigned to each of the nine system areas. This information is used to develop and evaluate accident scenarios.

#### 7.4.1.3.2 Identification and Screening of Initiating Events

##### Internal Initiating Events

A set of internal initiating events that could cause significant radiological releases to the environment was identified and screened, using two different methods to ensure that a comprehensive set of site-specific and facility-design-specific initiating events was obtained. The screening methods included the judgment of an engineering panel and systematic evaluations using interaction matrices. The results of the two methods were then compared, compiled, and analyzed to develop a comprehensive and representative set of internal events for event tree development.

In the first screening method, a survey form was developed for describing accident scenarios in a standardized manner. This form, along with the facility drawings, was distributed to the engineering panel so that panel members could evaluate the reference facility design. The survey form is illustrated in Figure 3-1 of Appendix F. The members of the panel studied the site plans, building layouts, waste-handling operations, and material block flow diagrams and then completed the survey form. Review of the completed survey forms revealed that two general categories of accidents could lead to significant offsite releases: (1) accidents that occur during transport of the waste around the site and (2) waste-handling accidents that occur in the waste-handling buildings.

TABLE 7-2

WASTE TYPES CATEGORIZED ACCORDING TO LEVEL OF RESISTANCE TO DISPERSION

| Waste Type* | Dispersion Resistance |
|---|---|
| Bare Fuel Assemblies and Bare Fuel Rods | Low |
| Spent Fuel and Defense High-Level Waste (DHLW) in Containers | Medium |
| Spent Fuel and DHLW in Shipping Casks | High |

*DHLW includes both DHLW and West Valley high-level waste (WVHLW).

Ramp access for waste emplacement operations, when compared to shaft access, substantially reduces the number of accident scenarios that need to be considered. The ramp access to the underground facility allows the use of a single transporter cask permanently mounted on a waste transporter to

- collect the waste container from the surface storage vault using the collection/emplacement mechanism inside the transporter cask;
- transport the waste container to the underground facility by way of the access ramp;
- transport the waste container to the waste emplacement borehole by way of the main entry, panel access, and emplacement drifts; and
- emplace the waste container in the emplacement borehole using the collection/emplacement mechanism inside the transporter cask.

Using the ramp thus eliminates two waste container transfer operations normally associated with shaft access to the underground facility:

- transfer of the waste container from the surface storage vault into the shaft transfer cask and
- transfer of the waste container from the shaft transfer cask into the waste transporter.

Ten reference scenarios associated with waste emplacement operations have been identified that might lead to a release of radioactive materials from the repository. These scenarios are shown in Table 7-4.

The PRA analysis for these accident scenarios is presented in Appendix F. Several of the scenarios could result in a dose consequence

TABLE 7-3

THE NINE SYSTEM AREAS IN AREA 1

| | System Area[a] | Radioactive Materials[b,c] | Dispersion Resistance |
|---|---|---|---|
| 1. | Access Area (outside yard) | Fuel assemblies in cask | High |
| | | DHLW canisters in cask | High |
| 2. | Receiving and Inspection Areas (outside yard) | Fuel assemblies in cask | High |
| | | DHLW canisters in cask | High |
| 3. | Cask-Receiving and Preparation Area (waste-handling buildings) | Fuel assemblies in cask | High |
| | | Fuel assemblies in cask with inner lid unbolted | Medium |
| 4. | Cask-Unloading Hot Cells (waste-handling buildings) | Bare fuel assemblies | Low |
| | | DHLW canisters before overpacking | Medium |
| 5. | Transfer Tunnels (waste-handling buildings) | Bare fuel assemblies | Low |
| | | DHLW canisters and containers | Medium |
| 6. | Consolidation Hot Cells (waste-handling buildings) | Bare fuel rods | Low |
| | | Bare fuel assemblies | Low |
| 7. | Waste-Packaging Hot Cell (waste-handling building) | Bare fuel rods in open containers | Low |
| | | Bare fuel assemblies in open containers | Low |
| 8. | Surface Storage Vault (waste-handling buildings) | Fuel assemblies or rods in sealed containers | Medium |
| | | DHLW canisters in sealed containers | Medium |
| 9. | Emplacement Areas (underground facility) | Fuel assemblies or rods in sealed containers in casks | High |
| | | DHLW canisters in sealed containers in casks | High |

a. The location of the system is indicated in parentheses to clarify the definition.
b. DHLW includes both DHLW and WVHLW.
c. Only the waste classification or configuration most vulnerable to dispersion in each system area is listed.

TABLE 7-4

SCENARIOS ASSOCIATED WITH WASTE EMPLACEMENT OPERATIONS
THAT MIGHT LEAD TO RADIOACTIVE RELEASES

| Event | Description |
|---|---|
| **Surface Storage Vault** | |
| Container Transfer Machine (CTM) Fails. | During transfer, an equipment failure occurs and the container is dropped, possibly causing a breach. All waste forms are considered in this scenario. |
| Shielded Underground Transporter Collides. | The transporter accidentally hits the CTM or runs into the facility wall. The CTM or transporter is carrying a container, and a breach occurs. |
| Shielded Underground Transporter Moves. | A transporter accidentally moves during waste loading and a container breach occurs because of shearing. |
| **Underground and Emplacement Area** | |
| Waste Transporter Coasts Down Ramp (runaway transporter). | Mechanical failure causes a transporter to coast from the top of the ramp and strike the ramp wall, which is a particular hazard near the bottom where the ramp is curved. A cask breach and/or fuel ignition in the transporter are possible. |
| Transporters Collide on Ramp. | A transporter is driven by mistake up the ramp while a second transporter is going down, resulting in a head-on collision and a fire and/or an explosion. A breach of a cask is possible. |
| Container Drops into Emplacement Borehole (vertical emplacement configuration). | A transporter grapple or a container pintle fails during emplacement. |
| Transporter Moves Unexpectedly. | A transporter moves unexpectedly during emplacement, resulting in a shearing force and container breach. |
| A Second Vehicle Collides with Loaded Transporter. | A small secondary vehicle collides with a transporter during an emplacement operation, resulting in possible container breach and secondary fire in the transporter. |

TABLE 7-4

SCENARIOS ASSOCIATED WITH WASTE EMPLACEMENT OPERATIONS THAT MIGHT LEAD TO RADIOACTIVE RELEASES (concluded)

| Event | Description |
|---|---|
| Underground and Emplacement Area (concluded) | |
| Exhaust Filter Building Ignites. | A fire occurs because of an electrical short or a worker accident, and high-efficiency particulate air (HEPA) filters and/or equipment for ventilation are damaged. |
| HEPA Filter System Fails. | The radiation monitor may not activate the HEPA bypass system or equipment failure may occur, causing normal releases or accidental releases given a common mode of coincidence failure. |

greater than 0.05 rem at the site boundary or have a probability of occurrence greater than $10^{-9}$/yr. These values were selected as screening criteria for the scenarios described in Appendix F.

In the second method for screening initiating events, interaction matrices were produced for each of the nine system areas of the repository. The interaction matrices are shown in Figures 3-2 through 3-10 of Appendix F. These matrices identified the major structures, systems, and components in each area. Each row in the matrix was then analyzed on a column-by-column basis to identify possible interactions between items. Interactions that obviously would not result in a radiological release were excluded from further scenario development.

The results of these methods were compared and compiled to form a reference set of internal initiating events for the site-specific design of the Yucca Mountain repository. This list is shown in Table 3-2 of Appendix F.

To select internal initiating events for further analyses (i.e., event tree development and quantification), two screening criteria were applied to the reference set of internal initiating events: (1) an internal initiating event in a system area was selected for further analyses if it was judged likely to produce scenarios that would result in bounding offsite releases of radioactive materials and (2) two or more internal initiating events in a system were selected if they involved different waste types or radiological releases.

Based on the above screening criteria and the results listed in Table 3-4 of Appendix F, the internal initiating events shown in Table 7-5 were chosen for further event tree development and quantification.

TABLE 7-5

INTERNAL INITIATING EVENTS CHOSEN FOR FURTHER EVENT TREE DEVELOPMENT AND QUANTIFICATION

| System Area | Internal Initiating Event |
|---|---|
| Access Area | Train falls off bridge. |
| Cask-Receiving and Inspection Area | Train collides with an obstacle. |
| Cask-Receiving and Preparation Area | Crane drops cask. |
| Cask-Unloading Hot Cell | Crane drops fuel assembly. |
| Cask-Unloading Hot Cell | Crane drops DHLW canister. |
| Waste-Packaging Hot Cell | Container-cutting machine malfunctions. |
| Consolidation Hot Cell | Consolidation system malfunctions. |
| Transfer Tunnel (in the surface facilities) | Transfer/storage cart is involved in accident. |

## External Initiating Events

External events that could cause significant radiological releases to the environment have been identified and screened using the following methods. First, a comprehensive checklist of external events, which included both natural and human-induced phenomena, was compiled, based on literature surveys of previous safety analyses and PRAs for nuclear facilities (NRC, 1983; ONWI, 1981). This checklist (Table 3-3 of Appendix F) was circulated to the engineering panel to eliminate events that were neither applicable to the region near Yucca Mountain nor significant for an offsite radiological release.

A set of screening criteria consistent with NRC's PRA procedures guide (NRC, 1983) was developed and used by the engineering panel to screen the potential external events for subsequent analysis. These screening criteria are shown in Table 7-6.

These screening criteria were applied to each of the external events listed in Table 3-3 of Appendix F. The results indicate that it is not necessary to analyze most of the external events at this stage of design and PRA. A consensus of the engineering panel for the external events listed in Table 3-3 of Appendix F is shown in Table 3-4 of Appendix F. The external events selected for further analyses are flood, earthquake, extreme wind, sandstorm, accident or activities at the military facility, and loss of offsite power.

TABLE 7-6

SCREENING CRITERIA FOR EXTERNAL EVENTS

| Exclusion Code | General Criterion |
|---|---|
| a | The external event is not applicable to the Yucca Mountain site region (e.g., coastal erosion, hurricanes). |
| b | The external event is irrelevant to preclosure operations (e.g., inadvertent human intrusion, such as archaeological exhumation). |
| c | It is not considered very likely that the event (e.g., drought, frost) will cause any significant radiological releases to the environment. |
| d | The event has an extremely low frequency of occurrence; therefore, it does not need to be considered in the design of a nuclear facility (e.g., the probability of an impact by a meteorite heavier than 2 lb is $10^{-9}$/yr and is therefore not considered). |
| e | The impact of the external event is well within the plant design basis (e.g., subsidence, thermal loading, interaction of the waste and rock). Certain events, such as earthquake, flood, and extreme wind, are not subject to this criterion because their magnitude may exceed the design basis. |

#### 7.4.1.3.3 Development of Event Tree and Accident Scenario Analysis

Event trees present a logical and systematic depiction of the various accident scenarios developed through the occurrences of intermediate events following a single initiating event. This method has been used extensively in PRAs for nuclear power plants. Because the repository design is still in the conceptual design phase, development of detailed event and fault trees, such as those used in as-built or fully designed nuclear facilities, is not possible; however, event trees have been developed for each internal and external initiating event chosen for further analysis.

The major considerations used in developing the events trees and intermediate events were

- radioactive release barriers (i.e., cask, cladding, container, canister);

- mitigative measures for radioactive releases [i.e., heating, ventilating and air-conditioning (HVAC) filtration systems, monitoring systems and controls]; and

- sources of radioactive release (i.e., fires).

Because of the general nature of the initiating events and the intermediate event considerations used in the event trees, fault diagrams were used for more detailed description of the various interpretations of the events. The fault diagrams were similar to conventional PRA fault trees in that a deductive, logical thought process was used; however, the fault diagrams were not quantified because of the lack of design details for this stage of the design. The fault diagrams provided important insight into the mechanisms at work in the accident scenario. The resulting event trees and fault diagrams can be seen in Appendix F of this report.

Probability Assessment

A frequency analysis of an event tree requires evaluating the probability of occurrence of each event and the average frequency of occurrence of each accident scenario in the event tree. The frequency of all events has been assessed by one of two methods: (1) conducting a literature search of previously published data and (2) surveying a panel of experienced engineers to obtain their opinions based on engineering judgment. In the current phase of design, the systems, structures, and components that could be involved in accident scenarios have not yet been designed in detail. As a result, estimates of event frequencies from the published literature would not be accurate; however, frequency assessments were assigned to some items regarded as similar to systems or components of existing facilities. The engineers' judgment was based largely on their insight as to what a structure, system, or component will be designed to do in the future and what components will eventually compose the system being evaluated for its failure frequency. As a result, some of the estimated frequencies obtained from the panel may not always be consistent with current design drawings.

The literature search involved a review of previous studies and reports in open literature pertaining to the failure rate of systems and the frequencies of occurrence of internal events. From these studies and reports, a list of frequencies was developed for events involving systems that matched or appeared to be very similar to the system designs for the Yucca Mountain repository. The categories of internal events sought in the literature included (1) transportation accidents for trucks and trains, (2) failures of electrical components or systems, (3) failures of mechanical components or systems, and (4) failures of material-handling equipment.

The survey of the panel of engineers for judgments of frequencies involved supplying a list of initiating and intermediate events and compiling the engineers' judgments. The list of initiating and intermediate events included events for which data were also found in the literature. A comparison of published data and engineering judgments was used wherever possible to calibrate the level of conservatism in the engineering judgment of the panel. The range of results from the panel was assessed, and a single representative value was determined. Engineering judgment was used wherever no published (or applicable) data were found.

The panel assigned one of four categories to an event: (1) anticipated, (2) unlikely, (3) very unlikely, and (4) not credible. "Anticipated" was interpreted as something that is going to happen in the range of once a year to once in 10 yr. "Unlikely" was used to indicate an occurrence between once in 10 yr and once in the lifetime of the facility (i.e., 10 to 50 yr). "Very unlikely" was used to indicate that the event will probably not occur in the lifetime of the facility but cannot be disregarded, and, therefore, the event must be treated explicitly in the facility design. "Not credible" was used to indicate that the expected frequency is so low (i.e., about $10^{-6}$/yr, or lower) that it is considered not to occur, and, therefore, does not need to be explicitly considered in the facility design. Table 4-4 of Appendix F is a list of these categories, their references, alternative definitions, and range of expected occurrences as used in the development of event frequencies. Uncertainties associated with the average frequencies of events were also estimated.

## Consequence Analysis

To assess the dose received by a member of the public or other results of a release of radioactivity, the types and quantities of radioactive materials available for release and transport to the environment must be known (Appendix F). This section presents a brief description of the methods used to calculate (1) the quantities of radioactive materials that, given a radioactive material release at a particular point, are transported through the environment at the repository site and (2) the resulting dose consequences to an individual subjected to maximum exposure at the boundary of the repository site.

During an accident that could lead to an offsite release of radioactivity, certain pathways are more important than others. The airborne pathway is the most important for the postulated accidents at the Yucca Mountain repository. If radioactive materials in the form of suspended particulates and gases escape from hot cells, containers, canisters, spent fuel cladding, or shipping casks, these materials could be transported offsite by the prevailing winds. Transport of radionuclides is affected by factors such as buoyancy, changes in wind velocity, presence or lack of precipitation, building wake effects, and dry deposition.

Once the inventory of radioactivity potentially released to the environment has been estimated, the dose to a member of the public, assumed to be located at the site boundary for the duration of the release, can be calculated for the airborne pathway using a dispersion model. The doses have been calculated for an individual exposed under or near the passing plume. The doses were calculated for both external exposures from a passing cloud and for internal exposures from inhalation of radionuclides in the cloud. Because each accident scenario or pathway through an event tree has a unique set of assumptions and release fractions, it was decided that it would be more efficient to develop a set of generic unnormalized dose consequence curves for spent fuel and DHLW. To determine the dose consequence for each scenario, adjustments and scaling of the two unnormalized dose consequence curves were made.

The Q-List method requires that the calculated dose consequences resulting from accident scenarios include estimates of uncertainties. A detailed discussion of uncertainty estimation and the results of the dose consequence analysis are presented in Appendix F.

#### 7.4.1.3.4 Event Tree Quantification

Event trees are quantified by assigning probabilities to each intermediate event. Release fractions for the radioactive materials present in the scenario are also assigned according to the system, structure, or component being evaluated. A detailed discussion of the development of these release fractions is provided in Appendix F. The expected frequency of individual accident scenarios was calculated as the product of the average frequency probabilities of the initiating event and the probability of intermediate events that form the accident scenario. This method is based on the assumption that the common-cause contribution to the failure of internal and intermediate events is insignificant compared to the contribution of independent causes. It is also assumed that probabilities determined for all intermediate events initiated by earthquakes are conditional probabilities. The dose consequences were assessed as described above.

#### 7.4.1.3.5 Q-List Screening

Scenario Screening

Accident scenarios that could lead to significant offsite releases of radioactive material and dose consequences were developed using the method described above (Appendix F). Two criteria--dose and probability--were used to screen the accident scenarios for those scenarios that could identify items important to safety. Using the dose criterion, an accident scenario could lead to the identification of items important to safety if the calculated offsite public dose was greater than or equal to 0.5 rem; otherwise, the accident scenario was not significant with respect to items important to safety. Using the frequency criterion, an accident scenario could lead to the identification of items important to safety if the expected frequency of scenario occurrence was greater than or equal to $10^{-5}$/yr; otherwise, the scenario was not significant with respect to items important to safety.

During screening, the expected frequency, including its uncertainty, and the calculated offsite public dose, including its uncertainty, were compared with the above criteria. If and only if an accident scenario passed both screening criteria, the accident scenario was classified as a Q-Scenario. The Q-Scenarios were then further analyzed to determine which of the systems, structures, or components involved in the scenario are important to safety. Systems, structures, or components are important to safety if they are essential to either the prevention of the scenario or the mitigation of the scenario's dose consequence.

Scenarios not significant with respect to items important to safety are classified as either an NQ-Scenario or a PQ-Scenario. All NQ-Scenarios are eliminated from further consideration in identifying items important to safety.

Any scenario that is not identified as a Q-Scenario but which, as further study and design take place, is judged to have a reasonable potential to be upgraded to a Q-Scenario, is classified as a PQ-Scenario. Systems, structures, and components involved in PQ-Scenarios need further analysis to determine which items should be placed on a "potentially important-to-safety list." These items will be assigned a QA level appropriate to their importance to safety. A potentially important-to-safety list is consistent with DOE guidance (DOE, 1986c). No specific criteria exist by which to identify PQ-Scenarios; therefore, engineering judgment was used to identify all PQ-Scenarios. If the engineering panel felt that the scenario was not a Q-Scenario, a PQ judgment was based on the opinion that further analyses are needed to establish for a broader technical audience that the scenario is not a Q-Scenario.

Screening of Systems, Structures, and Components (Items)

Once a scenario has been classified as a Q-Scenario or a PQ-Scenario, that scenario is further analyzed to determine which of the items involved in the scenario should be placed on the list of items important to safety or potentially important to safety. These systems, structures, and components are evaluated further to determine the role each item plays in the scenario. Items whose failure causes the loss of consequence mitigation processes or whose failure directly causes the release of radioactive materials are classified as important to safety or potentially important to safety, depending on which type of scenario is being evaluated. No Q-Scenarios were identified; therefore, no Q-List items were identified. However, several PQ-Scenarios were identified.

#### 7.4.1.4 Preliminary PQ-List (Items Potentially Important to Safety)

The preliminary PQ-List is presented in Table 7-7, Appendices F and L-1 provide a complete discussion of the methods and analyses used in classifying the items listed in Table 7-7. The work reported in these appendices includes the effects of mitigative features (i.e., radiation alarms and filtration systems) in some of the accident scenarios. Since the time these analyses were conducted, a decision has been made to not use mitigative features in the Q-List analyses. As a result, the analyses presented in the two appendices have been re-examined to remove any reductions in radiological dose consequence or frequency of occurrence that accrued from the mitigative features. The re-examination has resulted in the PQ-List given in Table 7-7. No Q-List items resulted from the re-examination.

### 7.4.2 Barriers Important to Waste Isolation

Barriers important to waste isolation are defined (Section 2.7.2) as the barriers, structures, systems, and components that are relied on to achieve the postclosure performance objectives in 10 CFR 60, Subpart E. The engineered barriers that meet this definition are placed on a Q-List. The natural barriers that meet this definition are not placed on the Q-List because they cannot be designed. Instead, their ability to isolate the waste is given special protection through an "activities list." This list contains all the activities that might adversely affect that ability and for which design criteria are not meaningful. Additional discussions can be found in SCP Section 8.6.

TABLE 7-7

ITEMS POTENTIALLY IMPORTANT TO SAFETY

| Items | Locations | Initiating Events |
|---|---|---|
| Crane, Shipping Cask | Cask-receiving and preparation area | Crane drops a shipping cask. |
| Hot Cell Structure | Waste-packaging hot cell | Earthquake causes failure of hot cell structure. |
| Crane | Cask-unloading hot cell<br>Consolidation hot cell<br>Waste-packaging hot cell | Earthquake causes crane to drop on fuel assemblies. |
| Vehicle Stop | Cask-receiving and preparation area | Vehicle with cask falls into cask preparation pit (detailed analysis not performed). |
| Fire Protection System | Waste-handling buildings | Fire involving radioactive material is a dispersion promoter (detailed analysis not performed). |
| Cask Transfer Machine | Surface storage vault | CTM drops container with consolidated fuel rods. |
| Transporter Cask | Underground facility and ramp | Transporter coasts down the waste ramp and strikes the wall of the ramp or main access drift. |

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

The first performance objective (10 CFR 60.112) deals with the allowable release of radioactivity from the repository to the accessible environment. SCP Section 8.3.5.13, which treats this performance objective as Issue 1.1, describes the plans for demonstrating that this performance objective will be met. In the performance allocation derived there, primary reliance is placed on natural barriers; the table in SCP Section 8.3.5.13 that summarizes the allocation names the saturated zone and the unsaturated rock units below the emplacement area. The principal unsaturated rock units in this allocation are the Calico Hills nonwelded zeolitic unit and the Calico Hills nonwelded vitric unit. Only for releases of gaseous radionuclides is an engineered system, the waste container, relied on. Other allocations in SCP Section 8.3.5.13 are made as backup allocations and do not designate barriers on which the DOE expects to place primary reliance. From these allocations, therefore, the waste container is proposed for inclusion on the preliminary Q-List of items important to waste isolation. The preliminary activities list includes the activities that have a potential for adversely affecting the waste isolation capabilities of the saturated zone, the Calico Hills nonwelded zeolitic unit, and the Calico Hills nonwelded vitric unit.

The second performance objective (10 CFR 60.113) deals with the time during which the waste package must provide substantially complete containment of high-level waste. SCP Section 8.3.5.9, which treats this performance objective as Issue 1.4, allocates performance to the emplacement environment of the waste package, which is the Topopah Spring welded unit in the immediate vicinity of the emplaced waste; to the waste container; and to the waste form inside the container. This allocation suggests that the waste container be placed on the Q-List of items important to waste isolation; although the waste form receives some allocation, it does not appear on the preliminary Q-List because it will not be engineered as part of the repository design. Activities that have the potential for adversely affecting the waste isolation capabilities of the Topopah Spring welded unit are placed on the preliminary activities list.

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

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

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

### 7.5 Analysis Conclusions

The design of a repository for disposal of spent fuel or high-level waste is an iterative process, consistent with conventional engineering practice. The steps in this process consist of

- development of design criteria, including functional and regulatory requirements, design constraints, and performance objectives;

- development of a preliminary design;

- analysis of the design against design criteria;

- modification of the design and/or criteria, as required; and

- continued analysis and modification of the design until a satisfactory solution is obtained.

The analysis of the design is thus an integral part of the overall design process. The individual analyses vary from using simple engineering judgment, such as preferred design features, to performing extensive numerical calculations regarding repository performance.

Analysis of the design considers the preclosure and postclosure periods separately. Preclosure concerns are primarily related to worker and public safety and retrievability. Postclosure concerns relate to the waste isolation and containment objectives of the repository design. Analyses completed to date are generally preliminary in nature, are based upon conceptual (not final) design, and rely upon limited site data. Conclusions drawn from those analyses should not, therefore, be considered final; rather, those conclusions represent an attempt to obtain insight into selected areas of concern as a guide to defining and setting priorities for future studies.

Standard engineering approaches have been used in designing the surface facilities. Some features of the design rely on experience gained through construction of comparable features at reactors or other nuclear facilities. No site characteristics have been identified that resulted in design features beyond reasonably available technology. Seismic considerations are of greatest concern, but the present DBE can be readily accommodated by the conceptual design. Substantial additional site data and evaluations are needed. Flooding and extreme winds are of less concern, and protection from these phenomena is easily provided. The characteristics of the target horizon for waste emplacement (thickness, thermal and mechanical properties, jointing and faulting, etc.) are believed to be readily accommodated by the proposed conceptual design.

The design of the subsurface facilities is based in part on experience in construction of drifts at the NTS and extensive mining at other locations. Classical analytical methods applied to the proposed design and anticipated site conditions indicate that the construction and operation of the subsurface facilities are within the capabilities of standard technology. Shaft, ramp, and drift excavation will use available equipment or methods. Equipment for drilling emplacement boreholes, particularly in the horizontal configuration, requires development but is based on existing technology. Normal ground support methods are expected to provide the required safety during operations. Ventilation requirements are similarly within existing capabilities and do not impose unacceptable constraints on the design.

The analysis of the effects of the emplaced waste considers the thermal and mechanical stresses imposed by the heat released from the waste as the result of radioactive decay. These stresses are of concern in both the preclosure and postclosure periods. The technology for simulation and analysis of thermomechanical effects in partially saturated geologic media is still being developed; thus, the overall approach to the analysis, at present, uses both bounding calculations and sensitivity analysis. This approach allows determination of the site parameters and processes most important to repository performance.

Far-field effects resulting from waste emplacement are the potential surface uplift caused by thermal expansion and temperature increase at the ground surface. Both effects are currently judged to be well within acceptable limits, and neither is overly sensitive to the expected range of site conditions.

Near-field effects include the temperature of the emplacement borehole wall and surrounding rock mass and the stresses in the rock surrounding the borehole. The analyses indicate that these effects are within established constraints for both the horizontal and vertical configurations. The design presented in Section 4.4, which incorporates commingling of DHLW, WVHLW, and spent fuel, will generally maintain an envelope of desaturated rock around most of the waste for at least 300 yr, significantly reducing potential container corrosion rates. Evaluation of the thermal and mechanical effects in potentially anomalous zones needs to be completed as more site data become available.

The location and layout of the underground facility reflect desirable thermal and mechanical rock properties, required minimum depths below the surface, vertical distance to the regional water table, thickness, fault offsets, dips of the target horizon, and area needed to provide adequate waste disposal capacity within the constraints of established APD. A primary area that satisfies all constraints and adjacent areas with additional capacity were identified. Preliminary evaluations generally lead to the belief that construction of the underground facility using standard methods is not expected to significantly affect the isolation or containment capabilities of the site. Evaluation of allowable quantities of fluids and materials will be made during ACD.

Plans for the design and construction of the ESF are reviewed by an interface control group to ensure that any interactions between the ESF and the remainder of the underground facility have been properly evaluated. In the current conceptual design, construction of the underground facility for the repository does not rely on the ESF, although the ESF will eventually provide ventilation air intakes for the emplacement areas. However, the design of the exploratory shafts allows for the possibility of their use in repository construction if this use should prove advantageous in future design studies. Construction of the ESF is not expected to detract from the waste isolation capability of the site. All shafts will be designed to divert any water entering the shafts away from the emplaced waste and therefore will not be expected to adversely affect the potential for water movement in the vicinity of the emplaced waste. If necessary, selected portions of shaft liners placed during construction of the shafts could be removed before closure of the subsurface facilities to enhance free drainage through the bottom of the shafts.

The reference design is based on vertical emplacement of a single waste package in each vertical borehole. Emplacement in the vertical configuration is restricted to a single package because of the thickness of the target emplacement horizon. The primary advantages of vertical emplacement are that several aspects of the concept have been demonstrated and that the emplacement and retrieval operations are mechanically simpler. The primary disadvantages of the vertical configuration are the high drift temperatures that occur after waste emplacement and the large volume of mining required. Emplacement of multiple waste containers in long horizontal boreholes, an alternative concept, has advantages, including

- reduced impact of drift excavation on the properties of the rock adjacent to the waste;
- greater drift stability (upon heating) as the result of lower extraction ratios;
- lower preclosure drift temperatures, facilitating operations and enhancing drift stability;
- generally greater radiological and nonradiological safety; and
- significant cost savings.

The principal disadvantages of the horizontal emplacement configuration are related to the increased mechanical complexity of operations and the associated increase in the required demonstrations of feasibility. The technology for drilling and lining horizontal boreholes is under development. Complete evaluation of the horizontal emplacement configuration will require feasibility demonstrations of emplacement and retrieval capabilities.

A preliminary list of items important to safety and a list of items and activities important to waste isolation have been generated. There are no items clearly judged important to safety in the proposed repository design. Several features of the surface facility and transporter cask are potentially important to safety and will be among the items more rigorously evaluated before LA. Based on an evaluation of the postclosure performance objectives, the waste container is the only engineered item considered important to waste isolation. The proposed list of activities important to waste isolation would include those that have the potential for adversely affecting the isolation capabilities of selected natural barriers, including and below the emplacement horizon.

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# 8.0 SUMMARY OF DESIGN ISSUES AND DATA NEEDS

## 8.1 PURPOSE AND ORGANIZATION

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

The NNWSI Project issues hierarchy is described in detail in Section 8.2 of the site characterization plan (SCP) (DOE, in preparation) and summarized by shortened titles in Figure 8-1. Briefly, the highest level of the hierarchy consists of four key issues, which were first defined in the DOE Mission Plan (DOE, 1985) and 10 CFR Part 960. Issues form the second level of the hierarchy and are grouped as performance assessment and design issues under each key issue. Regulatory and functional requirements imposed on the MGDS are embodied in the issues.

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

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

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

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

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

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

KEY ISSUE 1 POSTCLOSURE PERFORMANCE

PERFORMANCE ISSUES

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

DESIGN ISSUES

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

KEY ISSUE 2 PRECLOSURE RADIOLOGICAL SAFETY

PERFORMANCE ISSUES

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

DESIGN ISSUES

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

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

KEY ISSUE 4 PRECLOSURE PERFORMANCE

PERFORMANCE ISSUE

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

DESIGN ISSUES

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

Figure 8-1. Nevada Nuclear Waste Storage Investigations (NNWSI) Project issues hierarchy.

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

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

Several of the issues found in SCP Section 8.3.2, Repository program, Section 8.3.3, Seals program, and Section 8.3.5, Performance assessment program, are directly related to the design of the surface and subsurface MGDS facilities, the subject of SCP Chapter 6. While SCP Section 8.3 gives the specific plans for resolving each of these issues, Sections 8.2.1 through 8.11 of this chapter give the status of work already completed relative to these issues. This relationship is shown below.

| SCP-CDR Chapter 8.0 | Issue Number | Short Title of the Issue | Related Part of SCP Section 8.3 |
|---|---|---|---|
| 8.2.1 | 1.11 | Configuration of underground facilities (postclosure) | 8.3.2.2 |
| 8.2.2 | 1.12 | Seal characteristics | 8.3.3.2 |
| 8.3.1 | 2.1 | Public radiological exposures--normal conditions | 8.3.5.3 |
| 8.3.2 | 2.2 | Worker radiological safety--normal conditions | 8.3.5.4 |
| 8.3.3 | 2.3 | Accidental radiological releases | 8.3.5.5 |
| 8.3.4 | 2.7 | Repository design criteria for radiological safety | 8.3.2.3 |
| 8.3.5 | 2.4 | Waste retrievability | 8.3.5.2 |
| 8.3.6 | 4.2 | Nonradiological health and safety | 8.3.2.4 |
| 8.3.7 | 4.4 | Preclosure design and technical feasibility | 8.3.2.5 |
| 8.3.8 | 4.5 | Repository system cost effectiveness | ------- |

## 8.2 POSTCLOSURE

### 8.2.1 ISSUE 1.11: CONFIGURATION OF UNDERGROUND FACILITIES (POSTCLOSURE)

8.2.1.1 Introduction

The question asked by Issue 1.11 is

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

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

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

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

133(b) Flexibility of design.

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

133(e)(2) Underground openings.

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

133(f) Rock excavation.

> The design of the underground facility shall incorporate excavation methods that will limit the potential for creating a preferential pathway for ground water or radioactive waste migration to the accessible environment.

133(h) Engineered barriers.

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

133(i) Thermal loads.

> The underground facility shall be designed so that the performance objectives will be met taking into account the predicted thermal and thermomechanical response of the host rock, and surrounding strata, ground-water system.

The proposed strategy for resolution of this issue is presented in SCP Section 8.3.2.2. In that section, the issue resolution strategy for Issue 1.11 is presented and interrelationships between Issue 1.11 and other issues are addressed. Readers unfamiliar with the issue resolution strategy for this issue should review the contents of SCP Section 8.3.2.2 before continuing. In this Section 8.2.1, the current status of resolution of the issue is reported.

Summary information describing the computer codes used in the analyses supporting the work completed is contained in Table 8-1.

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

1. Contribute to containment and isolation.

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

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

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

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

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

<u>Information Need 1.11.1</u> Site characterization information needed for design (SCP Section 8.3.2.2.1).

Table 8-1

Codes Used to Support Work Completed for Information Need 1.11.6 of Issue 1.11 (page 1 of 2)

| Product number | Code name | Author | Ownership[a] | Design parameter | Analysis description |
|---|---|---|---|---|---|
| 1 | ADINAT | K. J. Bathe | MIT | Areal power density. Determine if thermal loading meets near- and far-field constraints. | A finite-element heat transfer program. 2-D, 3-D; for automatic dynamic nonlinear heat conduction; convective and adiabatic boundaries; constant or decaying heat source. |
| 1 | ADINA | K. J. Bathe | MIT | Areal power density. Determine if thermal-induced stresses meet near- and far-field constraints. | A finite-element, stress analysis program, 2-D, 3-D; elastic, elastic/plastic ubiquitous joint model; accepts precalculated temperature history. |
| 1 | SPECTROM-41 | D. K. Svalstad, RE/SPEC Albuquerque, NM | RE/SPEC | Areal power density. Determine if thermal loading meets near- and far-field constraints. | Finite-element, heat transfer program. Nonlinear heat conduction; convection and adiabatic boundaries; constant or decaying heat sources. |
| 1 | SPECTROM-11 | RE/SPEC Albuquerque, NM | RE/SPEC No documentation available | Areal power density. Determine if thermal-induced stresses meet near- and far-field constraints. | Finite-element stress analysis program. Elastic, elastic/plastic ubiquitous joint model; accepts precalculated temperature history. |
| 1 | SPECTROM-349 | D. K. Svalstad RE/SPEC Albuquerque, NM | RE/SPEC | Far-field temperature distribution, design of underground facility. | A linear superposition program. For three-dimensional heat conduction solutions for constant or decaying heat source from parallelepiped in a semi-infinite homogeneous medium. |
| 1 | ARRAYF | R. D. Klett | SNL | Borehole spacing strategy. Determine if thermal loading meets near-field constraints. | A linear superposition. For three-dimensional heat conduction solutions for a constant or decaying cylindrical heat source. |
| 2 | SIM | Ahmad Badie | Raymond Kaiser Engineering, Parsons Brinckerhoff, San Francisco, CA | Borehole spacing strategy. Determine if thermal loading meets near-field constraints. | A linear superposition for three-dimensional heat conduction solutions with constant or decaying line heat sources. |

Table 8-1

Codes Used to Support Work Completed for Information Need 1.11.6 of Issue 1.11 (page 2 of 2)

| Product number | Code name | Author | Ownership[a] | Design parameter | Analysis description |
|---|---|---|---|---|---|
| 2 | HEFF | B. H. G. Brady, University of Minnesota | Public domain | Stresses around a borehole, emplacement drift, or repository. | A boundary-element stress analysis program. 2-D, thermoelastic analysis of constant or decaying thermal load. |
| 2 | STRES3D | C. St. John M. Christianson University of Minnesota | Public domain | Stresses around a borehole, emplacement drift, or repository. | Computer program for determining temperatures, stresses, and displacements around single or arrays of constant or decaying heat sources. Based on closed form solution. |
| 2 | DOT | Polivka, Wilson | University of California | Temperature distribution around a borehole or emplacement drift. | A general purpose heat transfer program. Linear and nonlinear steady-state or transient-heat transfer. Input for VISCOT. |
| 2 | VISCOT | ONWI/OWID | Public domain | Stresses around a borehole, or emplacement drift. | Finite-element stress analysis or program. Thermoviscoelastic, thermoviscoplastic; accepts pre-calculated temperature history. |

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

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

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

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

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

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

| Number | Description |
|---|---|
| 1.11.3-1 | The area-needed determination will establish the required area for the underground portion of the MGDS at the Yucca Mountain site. |
| 1.11.3-2 | The usable area and flexibility evaluation will (1) establish the boundaries of the area available for the MGDS underground facility at the Yucca Mountain site and (2) evaluate the flexibility of the site based on a comparison of the design for the MGDS underground facility layout and the area available for these facilities as determined by using a 3-D graphics model of the geologic structure of Yucca Mountain. |
| 1.11.3-3 | The vertical or horizontal emplacement orientation decision will document the decision and supporting logic for either (1) emplacing a single waste container in vertical boreholes in the |

floor of the drifts (current reference emplacement orientation) or (2) emplacing one or more waste containers in horizontal boreholes in the walls of the drifts.

1.11.3-4 The drainage and moisture control plan will present a plan for limiting the amount of water in contact with the containers to provide a favorable containment and isolation environment by promoting the migration of water away from the waste containers.

1.11.3-5 The criteria for contingency plan will provide (1) the criteria that can be used to identify underground emplacement areas that have geologic and hydrologic characteristics, conditions, or both within the ranges anticipated in licensing, and (2) criteria for modification of the MGDS underground facility baseline design based on the geologic characteristics encountered.

Information Need 1.11.4 Design constraints to limit water usage and potential chemical changes (SCP Section 8.3.2.2.4).

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

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

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

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

| Number | Description |
|---|---|
| 1.11.6-1 | The allowable areal power density chosen as a criteria on the layout of the MGDS underground facility and the logic supporting this choice will be documented. |

1.11.6-2 The borehole spacing strategy will establish a plan for how to distribute the waste containers so that the allowable areal power density constraint and temperature criteria are met, considering the thermal characteristics of the waste.

1.11.6-3 The sensitivity studies will evaluate and document the effects of uncertainty in the description of the waste type and the geologic setting on the MGDS underground facility design and the thermal and thermomechanical response of the host rock.

1.11.6-4 The strategy for containment enhancement will document work done to evaluate alternative ways of distributing the waste containers so as to increase the number of containers that remain dry and the time the containers remain dry.

1.11.6-5 The reference calculations will (1) predict thermal and thermomechanical responses of the host rock on a container, drift, and far-field scale and (2) document the results of these calculations for use by other issues.

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

| Number | Description |
|---|---|
| 1.11.7-1 | The reference postclosure design will document the reference design of the repository and will form the basis for post-closure performance assessment of the MGDS facilities. |
| 1.11.7-2 | The documentation of compliance will document the compliance of the postclosure design with the requirements of 10 CFR 60.133. |

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

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

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

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

### 8.2.1.2 Work completed

Twenty products have been identified in SCP Section 8.3.2.2 as important to the resolution of Issue 1.11 (see Section 8.2.1.1 for a complete listing of the products). Significant results have been reported to date for the following six products:

- 1.11.1-2 Reference thermal/mechanical stratigraphy
- 1.11.1-3 Reference thermomechanical rock properties document
- 1.11.3-1 Area-needed determination
- 1.11.3-2 Usable area and flexibility evaluation
- 1.11.6-1 Allowable areal power density
- 1.11.6-2 Borehole spacing strategy

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

#### 1.11.1-2 Reference thermal/mechanical stratigraphy

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

Analytical approach

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

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

Data

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

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

Results

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

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

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

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

1.11.1-3 Reference thermomechanical rock properties document

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

Analytical approach

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

Data

Rock properties are derived from laboratory measurements of thermal and mechanical rock properties. Current rock mass properties are given in Section 2.3.1 (reference design data base). These data are derived from the site data given in SCP Chapter 2, (Geoengineering).

Results

A consistent set of reference properties (physical, mechanical, and thermal properties and in situ conditions) for the thermal and mechanical stratigraphy at the Yucca Mountain site has been established. These reference properties have been derived from analyses of laboratory and field data (i.e., both intact rock data and rock mass data) currently existing for the site. These reference properties are contained in Section 2.3.1, in SCP Chapter 2 and are included in the NNWSI Project Reference Information Base (Appendix Q). References for the sources of the laboratory and field data are cited in SCP Chapter 2 and Section 2.3.1.

Analyses of the data have resulted in the derivation of methods to better understand and extrapolate both field and laboratory data. For example, a method for relating porosity to mechanical and strength data has been derived (Price and Bauer, 1985). Zimmerman et al. (1986a) show the relationship between laboratory and field determinations of the thermal, mechanical, and thermomechanical response of rock.

1.11.3-1 Area-needed determination

The area-needed determination will establish the required area for the underground facility at Yucca Mountain.

Analytical approach

Mansure (1985) gives a complete description of how the area needed was determined. Basically, the area for high-heat-producing waste has been determined by dividing the thermal output of the waste by the design basis areal power density (APD). The area for low-heat-producing waste was determined on the basis of operational and safety constraints. The area needed for the shops and other support facilities has been added to the areas needed for waste emplacement. The area needed is an important input into the usable area and flexibility evaluation discussed for the next product (1.11.3-2).

Data

The area-needed determination depends on the allowable APD. The APD, in turn, depends on site data. For the site data related to APD, refer to the discussion of that product in 1.11.6-1. The nonsite-related data required to determine the area needed include (1) the waste inventory, (2) the space for shops and support facilities, and (3) the size and spacing of the drifts.

Results

A preliminary determination of the area needed for a 70,000 metric tons uranium (MTU) underground facility has been completed. The results of this study have been used for (1) the planning of the site characterization program and (2) the preliminary evaluation of compliance with 10 CFR Part 960 as given in the environmental assessment (DOE, 1986c). Both of these uses of the area needed depend on comparing the area needed to the thickness and lateral extent of the host rock. The current value of the area needed is based on the layout of the underground facility presented in Section 4.4.2.

The current layout occupies 1,420 acres (Section 4.4.2). This is based on an inventory of 62,000 MTU of spent fuel and 8,000 MTU of defense high-level waste (DHLW) and West Valley high-level waste (WVHLW), of an APD of 57 kW/acre. This is less than the area-needed given in the Environmental Assessment because the acreage reported there was for an all-spent-fuel repository. The uncertainty in the area-needed is judged to be ± 210 acres, based on uncertainty in the final basis APD of 40 to 80 kW/acre (Appendix M).

The analyses to determine the area-needed assume that the waste is emplaced at the equivalent energy density of the design basis APD. These analyses (Mansure, 1985) have resulted in two significant conclusions: (1) commingling (the placement of DHLW and WVHLW with spent fuel in the same emplacement panel) will not significantly (less than 10 percent difference) change the area needed, and (2) horizontal and vertical waste emplacement options do not require signficantly different areas (less than 50 acres difference).

1.11.3-2 Usable area and flexibility evaluation

The usable area and flexibility evaluation will (1) establish the boundaries of the area available for the underground facility and (2) evaluate the flexibility of the site by comparing the layout with the area available for these facilities.

Analytical approach

The usable area and flexibility evaluation began with the selection of the primary and adjacent areas. Once these areas were selected, the preferred horizon for waste emplacement was chosen. A computer graphics model (CAD/CAM-like system) was used to display a three-dimensional picture of Yucca Mountain and compare underground facility location to constraints (required overburden, etc.). This approach is described in reports by Nimick and Williams (1984) and Mansure and Ortiz (1984).

## Data

The data base used by the IGIS for this study was reported by Ortiz et al. (1985). The three-dimensional model of Yucca Mountain is based on geologic data from surface mapping of outcrops and faults and from unit contacts determined using core and cuttings taken from wells drilled at the site.

## Results

Screening of the Nevada Research and Development Area of the Nevada Test Site and nearby areas for favorable locations for the permanent disposal of radioactive waste in a mined geologic disposal system (MGDS) resulted in the selection of Yucca Mountain as the primary area for location of the underground facility (Sinnock and Fernandez, 1982). Four geologic units at Yucca Mountain were compared--the Topopah Spring Member, the tuffaceous beds of Calico Hills, the Bullfrog Member, and the Tram Member. The portion of the Topopah Spring Member containing relatively few lithophysae was recommended (Johnstone et al., 1984). Subsequent evaluations of usable area and flexibility have been limited to the relatively low lithophysae portion of the Topopah Spring Member. Although the preferred horizon is expected to have low lithophysae content, this does not imply that the underground facility must be placed in low lithophysae host rock but only that host rock with lower lithophysae content may be preferable (Section 6.3.3.2.3 of DOE, 1986c).

Analysis (Mansure and Ortiz, 1984) of the output from a three-dimensional computer graphics model of Yucca Mountain prepared by Nimick and Williams (1984) indicates that Area 1, identified as the primary area and shown in Figure 8-2, contains approximately 2,200 acres. Approximately 1,850 acres of Area 1 are potentially usable on the basis of the disqualifying condition for erosion, which requires a 200-m overburden (DOE, 1986c).

Area 1 contains relatively few faults and rare fault breccias (Scott and Bonk, 1984). The surface and subsurface geologic exploration of Yucca Mountain has concentrated in this area and in the immediately surrounding area that has a relatively low fault density. Available site data indicate that rock with acceptable characteristics may be present within areas 2 through 6, and perhaps even outside these areas (Mansure and Ortiz, 1984; Sinnock and Fernandez, 1982).

If one considers only the primary area, the usable area (1,850 ± 140 acres) is more than the area-needed (1,420 ± 210 acres). Because of the irregularities of the shapes and the uncertainty in the size of the area needed and the area available, there is limited lateral flexibility. The other areas identified outside the primary area may contain over 5,000 acres (areas 2 to 6 on Figure 8-2); however, at this time, there are insufficient data to qualify most of these areas. Current understanding of design concepts and conclusions about offsets from site features suggest that there may be a need for as much as 300 additional acres to ensure adequate flexibility (Appendix M). Figure 8-3 shows two proposed expansions to the reduced primary area: (1) 2 EA and 2 EB and (2) SE. These areas could add at least an additional 750 acres. Note that the narrow,

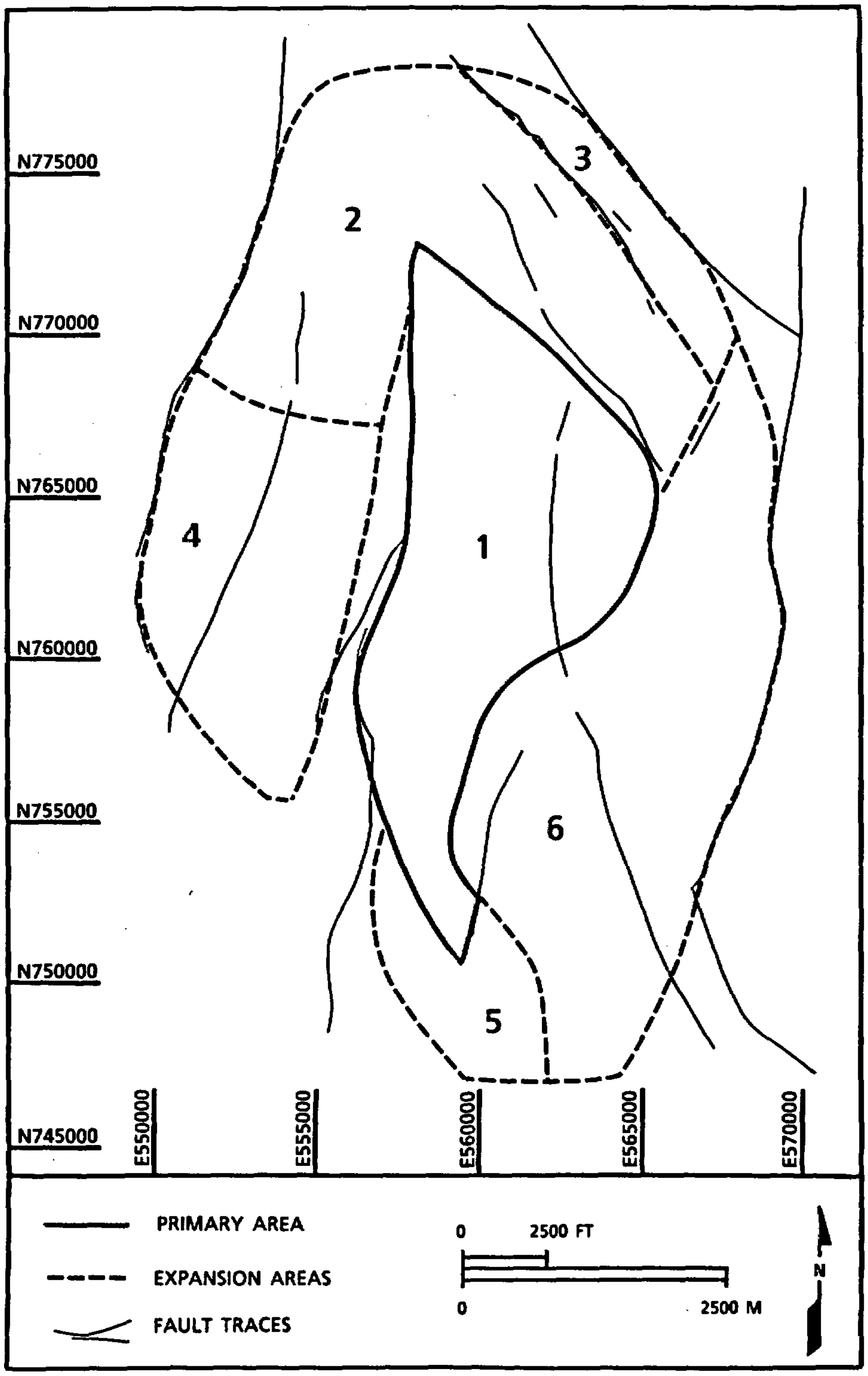


Figure 8-2. Primary area (area 1) for the underground repository and potential expansion areas (areas 2 through 6). (Modified from Mansure and Ortiz, 1984.)

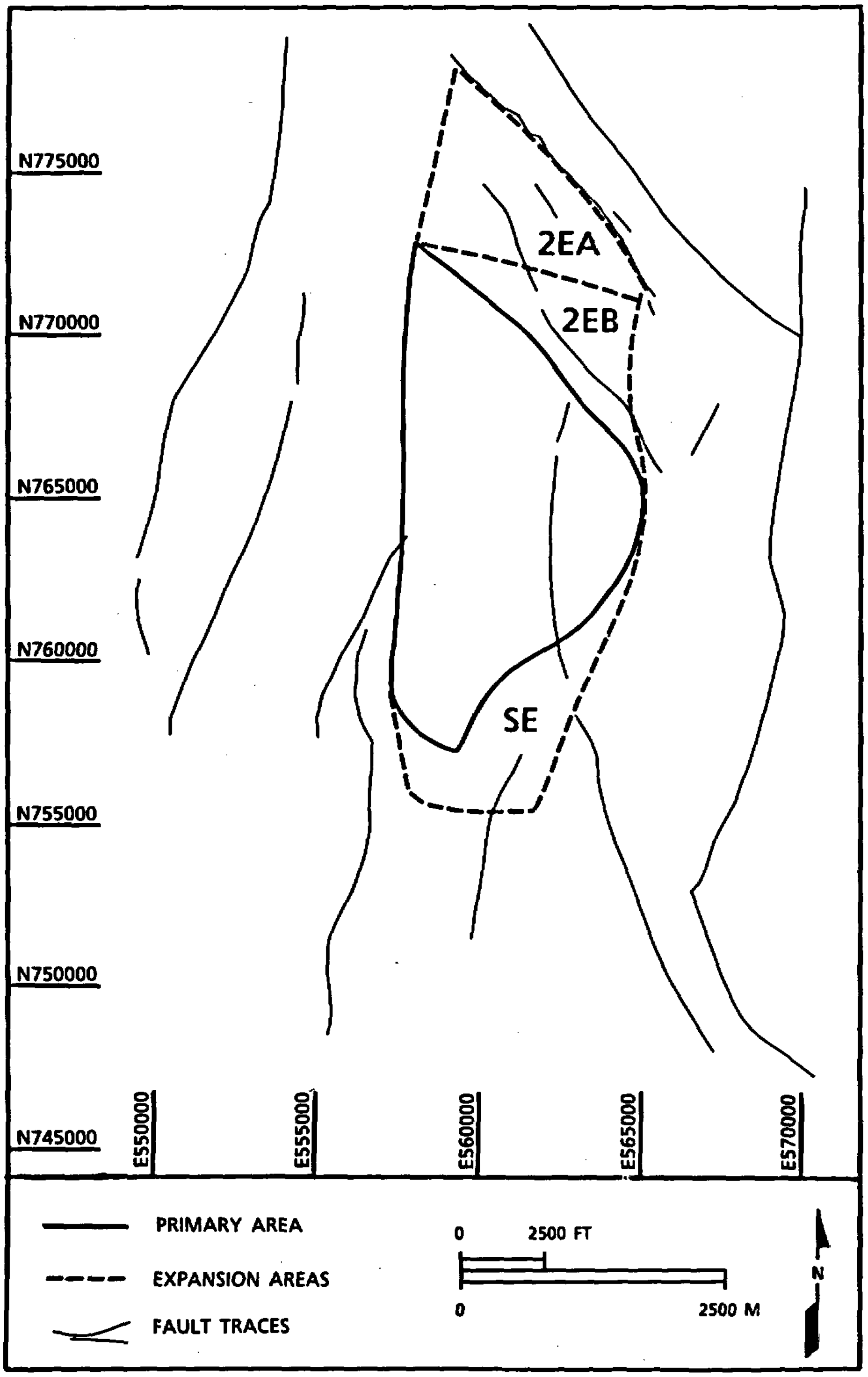


Figure 8-3. Revised usable portion of the primary area and the expansion areas. (Modified from Mansure and Ortiz, 1984.)

southern portion of the primary area, area 1 (Figure 8-2), is not included in the revised, usable portion of the primary area shown in Figure 8-3 because it cannot be efficiently developed as part of the underground facility. The proposed site characterization program (SCP Sections 8.3.2.2.1 and 8.3.2.2.3) includes plans to gather the data necessary to qualify these expansions.

Basic requirements for the thickness of the potential host rock are (1) the presence of sufficient overburden to ensure a low probability of uncovering the waste by erosion and (2) sufficient thickness of suitable host rock to provide the volume of rock required for construction of the underground facility. Mansure and Ortiz (1984) show that the approximate thickness of the preferred host rock is about 100 to 175 m within the primary area or about three times the thickness of the 45-m slab assumed for the underground facility envelope or more than 15 times the height of the drifts. The overburden at Yucca Mountain is more than 300 m thick over about 50 percent of the primary area and is over 200 m everywhere above the usable portion of the primary area. Thus, to date, exploration of the primary area has revealed sufficient thickness of potential host rock for flexibility in design of the underground facility.

1.11.6-1 Allowable areal power density

The APD (kW/acre) is a criterion placed on the design of the underground facility layout to ensure that the thermomechanical effects of the heat released by the waste meet performance allocation goals. This criterion is applied on a per panel basis; i.e., average output of a panel is divided by size of the panel.

<u>Analytical approach</u>

The approach used to determine the current design basis APD (Johnstone et al., 1984) was first to find the APD that resulted in a 100°C floor temperature and then to determine if that loading meets near- and far-field constraints. The determination of whether the loading meets near- and far-field constraints was done with the thermomechanical codes given in Table 8-1 (Section 8.2.1.1).

<u>Data</u>

Data used in this study include in situ initial conditions (temperature and stress), thermal and mechanical properties of the rock, the stratigraphy, and the thermal output of the waste. The initial in situ conditions and rock thermal and mechanical properties used in this study were reported by Tillerson and Nimick (1984). Stratigraphy used is given in Nimick and Williams (1984). The APD determined by the unit evaluation study (Johnstone et al., 1984) has been adopted as the current design basis. That study considered a range of parameter values sufficient to include the expected values of the site properties given in Section 2.3.1. The Reference design data base, Section 2.3.1, contains values that are different from those used by Johnstone et al. (1984). The design basis APD will be revised before the advanced conceptual design and license application design to be consistent with the RIB data.

Results

The unit evaluation study (Johnstone et al., 1984) determined the value of 57 kW/acre for the thermal loading of the underground facility in the Topopah Spring Member. This value was computed using average waste age and burnup characteristics. This value has been the design basis used for developing the layouts reported in Section 4.4 of this report. As noted in the analytical approach section previously, this loading was based on a maximum floor temperature for vertical emplacement of 100°C (Johnstone et al., 1984). This is a constraint that was assumed in the evaluation studies. Changes in ventilation system concepts have resulted in the issue resolution process replacing this constraint with a design goal of 50°C at 50 years (see SCP Section 8.3.2.5, for an explanation of where and how the 50/50 constraint is applied). With the change to this constraint, the allowable thermal loading could increase above the current design basis of 57 kW/acre.

In establishing the allowable APD for the advanced conceptual design, a tradeoff study will be performed and an allowable APD higher than the current design basis may be adopted if it meets all criteria. Note that higher loadings are not necessarily detrimental to performance. A higher APD may make it possible to keep the waste containers dry for a longer period of time and, thus, assist in meeting the requirements of Issue 1.10, Waste package characteristics (postclosure). A higher APD also will reduce the area needed for the underground facility and, thus, increase lateral flexibility. On the other hand, a higher APD may have undesirable performance effects such as higher stresses and temperatures.

A procedure has been developed (Appendix G) based on the equivalent energy density concept (O'Brien and Shirley, 1984) to apply the design basis loading (57 kW/acre) to other than average waste ages and burnups. This procedure allows the design of the underground facility to accommodate the variability in thermal output of wastes of different ages and burnup rates.

1.11.6-2 Borehole spacing strategy

The borehole spacing strategy will establish a plan to distribute the waste containers such that the allowable APD constraint and temperature criteria are met, considering the thermal characteristics of the waste.

Analytical approach

The typical panel design, reported in Section 4.4.2 of this report, distributes the waste to meet thermal constraints given in SCP Section 8.3.2.2.6 (thermomechanical effects). This typical panel design is the first step in developing a borehole spacing strategy. The approach was to use actual drift and borehole dimensions to establish the standoff distances, which are used to control drift temperatures. Then, the borehole (and drift for vertical emplacement) spacings were varied to simulate emplacement of the waste at the design basis (57 kW/acre) loading, while limiting the extraction ratio to no more than 30 percent and meeting the temperature constraints described in this section. Various typical panel layouts were analyzed using the heat conduction code SIM (Table 8-1, Section 8.2.1.1.). Professional judgment was used to pick the most practical panel layout.

Data

Data for these calculations were taken from reference properties (Appendix O). These data are consistent with the design data given in Section 2.3.1. Data required included rock thermal and mechanical properties and initial in situ conditions.

Results

The typical panel design presented in Section 4.4.2 is the first step in the borehole spacing study. Future work will determine practical development strategies based on sensitivity studies that consider waste type, age, and burnup. The current typical panel design contributes to the development strategies by demonstrating the design steps necessary to ensure that all criteria and design goals are met. That is, calculational procedures were developed to lay out a typical panel that met constraints. Thus, the typical panel demonstrates that reasonable waste distributions exist that meet all criteria and design goals. The typical panel presented includes commingling of waste types and should be sufficiently flexible to incorporate expected variations and uncertainty in the waste characteristics, inventory, and receipts.

The process developed results in a typical panel, reported in Section 4.4.2, that does the following:

1. Uses the design basis APD.

2. Incorporates standoffs of the waste packages from drift walls to control drift wall temperatures.

3. Uses drift dimensions consistent with equipment, ventilation, mining, operation, and retrieval systems requirements.

4. Meets borehole and rock mass thermal constraints.

Further, the design of the typical panel considers the goal (SCP Section 8.3.2.2.6, thermomechanical effects) of enhancing containment of the waste by maintaining the temperature around the container above the boiling point of water for 300 yr. Thus, in determining the waste distribution, peak temperatures were held below constraints on the temperature of the waste package while consideration was given to maintaining the temperature of the rock surrounding the waste container above the boiling point of water for as long as possible.

In addition to the above six products where significant progress has been documented in published reports, progress has been made on understanding several of the other products.

1.11.1-1 Data requirements list

The current data requirements list is given in Section 8.3.2.2.1 (Site characteristics needed for design). The list will be updated based on additional studies, changes to waste package characteristics, changes in design or design basis, or any changes to the goals of Issue 1.11.

1.11.2-1 Waste package characteristics for design of the underground facility

The current waste package characteristics for design of the underground facility are given in SCP Section 8.3.2.2.2. Those characteristics will be updated based on additional studies, any changes in the goals of Issue 1.10 (SCP Section 8.3.4.2), or changes in design or design basis.

1.11.3-3 Vertical or horizontal emplacement orientation decision

The initial evaluations of horizontal and vertical emplacement are given in Appendix E. Potential discriminating factors in the decision process are containment, waste isolation, retrievability, work radiologic safety, hydrologic character, and underground facility cost. Preliminary results based on normal operations indicate that the preclosure performance of the two emplacement options will be essentially the same except for worker radiologic safety and underground facility cost. The horizontal emplacement option appears to offer both lower worker exposure to penetrating radiation and lower underground facility costs. More equipment development and demonstration for retrievability would be required prior to license application for the horizontal emplacement configuration. However, both emplacement options are judged to perform in an acceptable manner; further investigations will be conducted to assess the effects of off-normal conditions.

1.11.3-4 Drainage and moisture control plan

A plan for drainage control has been incorporated in the design presented in Section 4.4. This plan precedes both performance allocation and establishing goals on drainage. Future work on drainage will include establishment of performance and sealing requirements to limit the amount of water reaching emplacement areas during the postclosure period.

1.11.3-5 Criteria for contingency plan

Detailed work on the contingency plan will be part of the advanced conceptual design activities. However, some concepts on how to accommodate site-specific conditions have been incorporated in the current design. Specifically, the current design provides for a different ground support system to accommodate changes in underground conditions. During development, unexpected conditions like small zones of perched water, localized heavily fractured zones, water recharge pathways, or localized lithophysae-rich zones may be encountered. The contingency plan will provide the means to accommodate such regions.

Development of the contingency plan will begin with the assumption that all of the target area will be considered acceptable (except for possible local regions identified during the site characterization phase as being unacceptable). If local conditions are not consistent with performance objectives and regulatory requirements using the baseline design, then design modifications would be required. The procedures for implementing such design modifications would be licensed as part of the contingency plan, implemented by the performance confirmation program, and reported to and reviewed with the NRC. These procedures might include the following:

1. Continued development with design revisions like increased ground support and reduced thermal loading.

2. Skipping and isolating an area unfavorable for development.

SCP Section 8.3.2.2.3, Underground facility orientation and layout, has a more detailed discussion of contingency plan concepts.

1.11.5-1 Excavation methods criteria

The excavation method design bases are (1) for emplacement drifts, conventional mining with controlled blasting techniques and controlled water usage, and (2) for boreholes, drill with vacuum chip removal and incorporating moisture for dust control only. These methods are documented in Section 3.3 and Section 6.4.3, the subsystem design requirements document (Appendix P), and Section 8.3.2.2.5 (excavation methods for construction). These methods should result in excavations that meet performance goals (SCP Section 8.3.2.2). The conventional mining of welded tuff has been demonstrated with blast control in G-Tunnel at the NTS (Section 7.3.2 of this report) as discussed in Zimmerman and Finley (1987). Demonstration of the drilling equipment for the emplacement boreholes is currently planned for G-Tunnel (SCP Section 8.3.2.5, preclosure design and technical feasibility).

1.11.5-2 Long-term subsidence control strategy

The long-term subsidence control strategy is to limit the extraction ratio and thermal load. The extraction ratio is to be less than 10 percent for horizontal emplacement and less than 30 percent for vertical emplacement (Section 8.3.2.2.5). Current design (Section 4.4 and Section 6.4.2) falls within this guideline for the emplacement areas. Stablility at the design basis thermal loading of 57 kW/acre has been demonstrated analytically by thermomechanical calculations (St. John, 1987). The calculations performed to assess long-term drift stability did not indicate any potential for appreciable subsidence. The design basis presented in Section 4.4 calls for backfill to be installed in all openings at the end of the retrievability period.

1.11.6-3 Sensitivity studies

The far-field unit evaluation study (Johnstone et al., 1984) considered the Topopah Spring Member, the tuffaceous beds of Calico Hills, the Bullfrog Member, and the Tram Member. Each unit is at a different depth; two are saturated and two are unsaturated, three are welded tuffs and one is a nonwelded tuff. This evaluation addressed a range of values for almost all parameters except horizontal to vertical in situ stress ratio. Results of the unit evaluation study did not show significant differences in the system response to the parameter variations. As a result, it is expected that the postclosure design will not be very sensitive to uncertainties in site data. Additional work will be needed to confirm this conclusion if the in situ stress ratio is substantially different from that assumed in the analysis done by Johnstone et al (1984). This conclusion will be evaluated in future studies (SCP Section 8.3.2.2, configuration of underground facilities--postclosure).

1.11.6-4 Strategy for containment enhancement

Issue 1.10, waste package design--postclosure, (SCP Section 8.3.4.2) incorporates a goal to enhance containment by keeping the container dry. Issue 1.11 has established a design goal of maintaining the majority of the waste containers at temperatures above the boiling point of water for 300 yr. Calculations of how long the containers remain above this temperature (Appendix K) have shown the (1) need for using the explicit geometry of waste distribution including the effects of the finite size of the underground facility (i.e., boundary effects) and (2) difference between local area power density and areal power density. The time duration that the containers remain above this temperature was shown to be very sensitive to thermal loading and position within the underground facility.

1.11.7-1 Reference postclosure repository design

The postclosure aspects of the conceptual design are summarized in SCP Section 6.1.1.8 and given in detail in Section 6.4. This conceptual design will be used to evaluate MGDS performance and site characterization plans. The future versions of the Reference Information Base will contain reference postclosure repository design and will be updated periodically using NNWSI Project change control procedures.

Work has not begun yet on four of the products identified in SCP Section 8.3.2.2 for Issue 1.11. These are 1.11.4-1 (material inventory criteria); 1.11.4-2 (water usage criteria) 1.11.6-5 (reference calculations--for postclosure design); and 1.11.7-2 (documentation of compliance).

## 8.2.1.3 Future Work

### 8.2.1.3.1 Analysis needs

The logic used in identifying the analyses required to resolve Issue 1.11 is presented in the SCP in Section 8.3.2.2 and Sections 8.3.2.2.3 through 8.3.2.2.6 (information needs corresponding to issue resolution functions). The analyses are the approaches or methods described in those sections that will be used to calculate or otherwise establish that the anticipated or actual performance will meet the performance goals stated in SCP Section 8.3.2.2. In general, the analyses are organized into activities to produce the products of the issue. For more information about these products and the analysis needs, see Sections 8.3.2.2.3 through 8.3.2.2.6 of the SCP.

8.2.1.3.2 Development needs

The reader is referred to Section 8.3.2.2 of the SCP for discussions of future work on the products. In general, development needs do not exist for the products of this issue except the following:

1.11.3-4 Drainage-moisture control plan
1.11.3-5 Criteria for contingency plan
1.11.6-5 Reference calculations

8.2.1.3.3 Site information needs

The logic used in identifying the data important to resolution of Issue 1.11 is presented in SCP Sections 8.3.2.2.3 through 8.3.2.2.6 (information needs corresponding to issue resolution functions). SCP Section 8.3.2.2.1 (Information Need 1.11.1) lists in detail the site data needed to resolve this issue. It also defines how well the data need to be known to resolve the issue, and provides the link to the site characterization issues under which the test plans for obtaining the data will be discussed. The data required include rock properties data, summarized in SCP Section 8.3.2.2, the geologic data necessary to develop the three-dimensional graphics model of Yucca Mountain, and the effects of mining on the rock mass. However, for the reasons noted previously in the Section 8.2.1.3.2, Development needs, additional data may be required to support establishing standoffs from unfavorable areas and to quantify the amount of water in contact with the container.

8.2.2 ISSUE 1.12: SEAL CHARACTERISTICS

8.2.2.1 Introduction

The question asked by Issue 1.12 is

> Have the characteristics and configurations of the shaft and borehole seals been adequately established to (a) show compliance with the postclosure design criteria of 10 CFR 60.134 and (b) provide information to support resolution of the performance issues?

The regulatory basis for Issue 1.12, the postclosure design criteria of 10 CFR 60.134, requires that

1. Seals for the shafts and boreholes shall be designed so that following permanent closure, they do not become permanent pathways that compromise the geologic repository's ability to meet the performance objectives for the period following closure.

2. Materials and placement methods for seals shall be selected to reduce, to the extent practicable, the potential (1) for creating a preferential pathway for ground water to contact the waste packages, or (2) for radionuclide migration through existing pathways.

A brief summary of the plan for assessing the performance of the seal system is described in SCP Section 8.3.5.11. The complete discussion of the proposed strategy for resolution of this issue is presented in SCP Section 8.3.3 (seal systems). Readers unfamiliar with the issue resolution strategy for this issue should review the contents of SCP Section 8.3.3 before continuing. Issue 1.12 has been subdivided into four information needs and the completed work has been identified under the associated information need. The completed work is numbered in a manner that corresponds with the information need numbering system. For example, 1.12.4-1 is the completed work identified under the fourth information need of Issue 1.12. The information needs are as follows:

Information Need 1.12.1 Site, waste package, and underground facility information needed for design of seals and their placement methods.

This information need consists of the review and compilation of information associated with the site, the waste package, and the underground facility design. This work is ongoing and is not completed. The site characterization information needed for seal design is identified in Section 8.3.3.2.1 of the SCP.

Information Need 1.12.2 Materials and characteristics for seals for shafts, drifts, and boreholes.

This information need consists of the review, compilation, and development of information associated with the material and characteristics of seals for shafts, drifts, and boreholes. This work is ongoing. The site characterization information needed for seal design is identified in SCP Section 8.3.3.2.2.

Information Need 1.12.3 Placement methods for seals for shafts, drifts, and boreholes.

The development of placement methods for seals has not begun; this information need is discussed in SCP Section 8.3.3.2.3.

Information Need 1.12.4 Reference design of seals for shafts, drifts, and boreholes.

| Number | Description |
|---|---|
| 1.12.4-1 | In the repository sealing concepts (hydrologic analysis 1), the concepts for sealing a nuclear waste repository in unsaturated tuff are presented. These concepts provide the basis for all future design activities in the NNWSI Project repository sealing program. As part of the development of these concepts, shaft and drift drainage calculations are performed. |
| 1.12.4-2 | In the modification of rock mass permeability in the zone surrounding a shaft (hydrologic analysis 2), analyses were performed to assess how the rock mass permeability around a vertical shaft excavated in a densely welded, highly fractured tuff might change. The modification of the rock mass permeability is due to the effects of stress distribution and blasting. From these analyses, a modified permeability zone model is presented. |

1.12.4-3 In the hydrologic calculations to evaluate backfill of shafts and drifts (hydrologic analysis 3), hydrologic calculations were performed to assess the need for and extent of sealing the drifts and shafts.

1.12.4-4 In the numerical analysis to evaluate backfilling repository drifts (hydrologic analysis 4), hydrologic calculations evaluating the influence of backfilled drifts on flow through the surrounding unsaturated tuff matrix are presented.

1.12.4-5 In the vadose water flow around a backfilled drift (hydrologic analysis 5), the magnitude and direction of the ground-water flow in the vicinity of a vertically emplaced waste container were calculated. The waste container was situated in an unsaturated tuff environment.

Additional information on Information Need 1.12.4 is presented in SCP Section 8.3.3.2.4.

Summary information describing the computer codes used in the analyses supporting the completed work, just identified is contained in Table 8-2.

<u>Summary of status of issue resolution</u>

A brief summary of the status of issue resolution for sealing is presented below. This will aid in establishing a perspective for how the results of the individual analyses and evaluations completed to date (SCP Section 6.4.3.2) contribute to the definition of planned future activities.

Sealing of a potential repository at Yucca Mountain involves emplacement of sealing elements in the shafts, ramps, boreholes, and underground facility. Design development of sealing elements first required establishing sealing concepts. Sealing concepts were developed with an understanding of the hydrogeology at the site and selected numerical calculations.

The following site conditions guided the concept development as well as the types of calculations to be performed.

1. The repository would be located in the unsaturated zone, 200 to 400 m above the water table.

2. The repository would be located in the Topopah Spring Member, which is a highly fractured, welded tuff unit.

3. Water flow at the repository horizon could occur within the matrix or discrete, water-producing zones.

The NNWSI Project repository sealing program is currently using these concepts to develop more specific sealing designs. Because specific seal designs have not been identified, it can be concluded that additional work is necessary to resolve this issue. Additional work will fall into the following categories:

TABLE 8-2

CODES USED FOR ANALYSES ADDRESSING ISSUE 1.12

| Code Name | Author | Code location(s) | Design parameter | Analysis description |
|---|---|---|---|---|
| TRUST | A. E. Riesenauer<br>K. T. Key<br>T. N. Narasimhan<br>R. W. Nelson<br>(NRC, 1982b)<br>NUREG/CR-2360 | Pacific Northwest Laboratory, Battelle Memorial Institute | Shaft drainage potential-performance evaluation of sealing components. | Finite difference; determines fluid flow past sealing elements in variably saturated porous media. |
| SAGUARO | R. R. Eaton<br>D. K. Gartling<br>D. E. Larson<br>SAND 82-2772 | Sandia National Laboratories | Shaft drainage potential-performance evaluation of sealing components. | Finite difference; determines fluid flow past sealing elements in variably saturated porous media. |

1. Develop a complete design for the sealing subsystem. Design includes not only selection of the appropriate geometries for seals but also selection of materials and development of an appropriate emplacement strategy. Currently, the efforts within the NNWSI Project repository sealing program are focused on establishing the need for sealing and the appropriate design requirements. Both of these efforts will help to establish the suitable characteristics of sealing elements in shafts, ramps, boreholes, and the underground facility. These characteristics then will support the development of the configuration of sealing elements. First, selection of the appropriate design option will be made as part of the advanced conceptual design.

2. Document the hydrologic conditions encountered while excavating the exploratory shaft and the exploratory shaft facility. This information is necessary because the sealing concepts are based on the current understanding of the hydrologic conditions. This information will be obtained by participants involved with the testing in the exploratory shaft facility.

3. Assess the performance of select sealing designs to confirm acceptable performance and to arrive at preferred designs through design tradeoff studies. These tradeoff analyses will include performance, cost, and environmental concerns.

The resolution of this issue is believed (based upon preliminary evaluations completed to date) to be possible because of the following:

1. Conceptual designs have been defined as presented in Chapter 5. These conceptual designs were developed assuming reasonably available technology would be used to construct these designs. Further, these designs form the basis for the site data needed.

2. Performance goals have been developed (SCP Section 8.3.3) that can be used to evaluate the suitability of seal designs.

3. Preliminary calculations indicate that even if more water than anticipated is encountered at the repository horizon, these waters can effectively be isolated and drained through the repository drift floors.

However, before demonstrating the resolution of this issue, a total seal system design will have to be proposed and its performance evaluated. This includes the effects of environmental conditions on the performance of sealing materials. Currently, the design requirements are being developed and potentially suitable materials are being selected. The information obtained from this effort will support development of the ACD.

### 8.2.2.2 Work completed

Significant results have been reported to date for the work under Information Need 1.12.4. The approach used, data utilized, and the results obtained are summarized in the following section.

### 1.12.4-1 Repository sealing concepts (hydrologic analysis 1)

Analytical approach

Calculations evaluating shaft and drift drainage were presented in Fernandez and Freshley (1984). The purpose of these calculations was to determine if water entering the shafts or drifts can be drained at those locations. The possibility of using a shaft for drainage below the underground facilities was investigated using methods proposed by the U.S. Bureau of Reclamation (USBR) for boreholes and was summarized and critiqued by Stephens and Neuman (1982a, 1982b). Two of the steady-state methods summarized by Stephens and Neuman (i.e., the methods by Glover and by Nasberg-Terletskata) were used directly in evaluating the shaft drainage potential. Flow into a drift floor was evaluated to determine the extent of the floor used to dissipate water from a discrete fault or fracture zone. Flow was computed using the equation for parallel plate analogy for flow in fractures.

Data

Drainage through highly fractured, welded tuff was computed in this analysis. Two locations of welded tuff were considered: drift floor and the base of shafts. To compute drainage, the effective hydraulic conductivity was required. Values for fracture aperture width, hydraulic conductivity of fractures, and fracture frequency were used to compute the effective hydraulic conductivity.

From Zimmerman and Vollendorf (1982), two sets of values were selected for hydraulic conductivity and aperture width. One set represented the lowest measured hydraulic conductivity with an associated aperture width. The second set represented an arithmetic mean of 12 hydraulic conductivities with an associated mean aperture width. A conservatively low value for fracture frequency was assumed based on information discussed by Scott et al. (1983). Fracture frequencies presented by Scott et al. represented fracture frequencies of cores and outcroppings of densely welded tuff in the vicinity of Yucca Mountain.

Results

The performance of two sealing system elements (SCP Section 8.3.3.2) was evaluated in this hydrologic analysis. The sealing system elements evaluated were the unsaturated Topopah Spring Member (TSw2) at the base of shafts (shaft drainage analysis following) and the drift floor within the Topopah Spring Member to accommodate net flow from faults (drift drainage analysis below).

From the results of the shaft drainage analysis, it was concluded that an estimated inflow of approximately 100 to 150 $m^3$/yr can be effectively drained through the bottom of the shaft, even when considering conservative values of fracture spacing and permeability. A geologic unit having bulk rock hydraulic conductivity of $5 \times 10^{-6}$ cm/s could potentially drain 150 $m^3$/yr for a 8-m (22-ft)-diameter shaft and 120 $m^3$/yr for a 4-m-diameter shaft. Both conditions assume a modest buildup of water (i.e., about 15 m) at the base of a shaft. Because of the conservative nature of the calculations presented for drainage at the base of shafts (Fernandez and Freshley, 1984) and because the expected value for bulk rock hydraulic conductivity of welded tuff is likely to be higher than $5 \times 10^{-6}$ cm/s, yearly inflows of water (100 to 150 $m^3$/yr) into shafts are expected to drain through the bottom of shafts.

From the drift drainage calculations, it was concluded that considering the possible effects of fracture permeability, an inflow of 0.4 $m^3$/wk into a drift can be drained through a 6-m length of drift floor.

The ability to achieve the performance goals for the underground facility will depend on the frequency of water occurrences in the underground facility and the design options available to reduce or control water flow into the waste disposal rooms. Tradeoff analyses performed as part of advanced conceptual design and license application design will be performed to select the preferred design option.

1.12.4-2 Modification of rock mass permeability in the zone surrounding a shaft (hydrologic analysis 2)

Analytical approach

An analysis was performed to determine the modification in rock mass permeability resulting from stress redistribution and blast damage around a vertical shaft excavated through fractured, welded tuff (Case and Kelsall, 1987). To assess the permeability changes due to stress redistribution, elastic and elastoplastic stress analyses were performed to estimate the stress distributions after excavations for a wide range of rock properties and in situ stress conditions. Changes in stress are related to changes in rock mass permeability using stress-permeability relations for fractures obtained from laboratory and field testing. Coupling the information from the stress analysis with the relationship established between stress and permeability, the permeability enhancement due to stress redistribution was calculated.

The second half of this analysis involved performing an assessment of the increased permeability due to blast damage adjacent to the wall of the shaft. Both case histories and theoretical relationships between explosive charge weight and the particle velocity required to produce fracturing were evaluated to determine the potential extent of damage. This assessment of blast damage together with the analysis of stress redistribution effects on permeability were combined to develop the modified permeability zone model.

Data

The purpose of this analysis was to determine the changes in permeability around a shaft excavated in fractured, welded tuff. These changes were caused by stress redistribution in the area surrounding the excavation and by damage to this area due to blasting. The result of this analysis was the development of a modified permeability zone model. The data used to develop the model included the following:

1. Compressive strength of welded tuff (Price, 1983).

2. Tensile strength of welded tuff (Nimick et al., 1985).

3. Rock mass rating values (Langkopf and Gnirk, 1986).

4. Laboratory investigations of the influence of effective confining stress on fracture permeability (Peters et al., 1984).

5. Field data associated with G-Tunnel heated block test, specifically, permeability versus effective normal stress from a single fracture (Zimmerman et al., 1985).

6. Theoretical relationship between the charge weight and particle velocity required to produce fracturing (Holmberg and Persson, 1979).

Results

The modified permeability zone model was developed so that the performance of the shafts and drifts, as excavated, could be evaluated. This model then could be used in addressing the need for sealing. If it is determined that sealing is needed or desired, this model could be used in developing specified designs to achieve a desired performance.

The assumptions and data used in this analysis were varied to address potentially varying field conditions. Because of this variation in input parameters, multiple results were obtained. Two models were developed: one for a 100-m-depth location in welded tuff and the second for a 310-m-depth location in welded tuff. Expected conditions and upper bound changes also were evaluated. Finally, three conditions concerning blast damage were evaluated: no blast damage, a 0.5-m blast damage zone, and a 1-m blast damage zone from the shaft wall.

To compare the relative changes in rock mass permeability, the permeability was averaged over an annulus 1 radius wide around a 4.4-m (14.5-ft) diameter shaft. By performing this averaging, it was shown that permeability changes could range from 15 to 80 times the undisturbed rock mass averaged over an annulus 1 radius wide from the shaft wall. This model will be used in future analyses to determine the performance of the overall sealing system.

1.12.4-3 Hydrologic calculations to evaluate backfill of shafts and drifts (hydrologic analysis 3)

Analytical approach

Hydrologic calculations were performed to assess the need for and extent of sealing shafts and drifts. Two geometries were evaluated using the computer code TRUST (NRC, 1982):

1. A drift with vertical emplacement of waste packages to determine water flow near the waste package and through the drift.

2. A shaft penetrating a slightly inclined contact between welded and nonwelded tuff units to determine the water flow into the shaft.

TRUST (NRC, 1982), an integrated, finite difference code for unsaturated ground-water flow, was used for the drift and shaft analyses. Individual subanalyses were evaluated for each geometry. For the drift geometry, four subanalyses were performed. All subanalyses assumed that a drift was located in a welded tuff unit. The drift backfill, either clay or sand, and the saturated permeability values for the welded tuff unit were varied. Five subanalyses were evaluated for the shaft analysis. All drift subanalyses assumed that the shaft penetrated an inclined, welded-nonwelded tuff contact. It was assumed that the shaft was backfilled with either a clay or a sand material. The relative positions of the nonwelded and welded tuff units were varied together with the saturated permeability values. Additional details of the subanalyses evaluated are given in Freshley et al. (1985a) and in Fernandez and Freshley (1984).

Data

As indicated under the approach section for this analysis, water flow under unsaturated conditions was evaluated for two geometries. The first geometry involved a drift located in an unsaturated, welded tuff. The second geometry involved a shaft penetrating unsaturated welded and nonwelded units. Both of these geometries assumed that the drift or shaft was backfilled with a sand or clay. To assess water flow in the vicinity of the shaft or drift, it was necessary to obtain hydrologic properties of the materials used in the analysis. The permeability versus pressure-head relationships for sand, clay, and the welded and nonwelded tuff units were of primary concern. Knowledge of porosity of the materials also was required. The hydrologic properties and porosity of sand (Crab Creek sand) and clay (Chino clay) were taken from Mualem (1976). The hydraulic properties of selected welded and nonwelded units were determined from core taken from well USW GU-3. Under some instances, the permeability versus pressure-head curves were scaled up or down to provide a broad range of input parameters. All the data used in this analysis are included in Freshley et al. (1985a). The only other datum used in this analysis was the assumed input flux of 0.4 cm/yr.

Results

This analysis addressed the performance of two sealing system elements, shaft fill and drift backfill. The function of the shaft fill and drift backfill is to reduce the amount of water entering the waste disposal rooms. The analysis goes further to determine if the type of backfill can significantly influence the flow past waste packages for the drift backfill portion of the analysis. The conclusions given below are taken from Fernandez and Freshley (1984) and Freshley et al. (1985a).

The following conclusions were derived from the drift analysis:

1. From a hydrologic perspective, backfilling of the repository drifts is not essential. This conclusion is based on the observation that varying the backfill in drifts does not significantly influence the flow rates in the vicinity of the waste packages.

2. Water flow past horizontally emplaced waste packages cannot be altered by varying drift backfill. The standoff zone (i.e., the zone between the drift and the first waste package) is sufficiently large to negate the effect backfill materials have on ground-water flow past the waste packages.

3. If backfilling is necessary, coarse, rather than fine, materials are more satisfactory because of their capacity to drain and act as a capillary barrier.

4. Greater flow of water into drifts may occur when saturation in the surrounding rock formation is high (98 to 99 percent). However, this level of saturation is unlikely to occur in the horizon being considered for the repository (Topopah Spring Member).

The conclusions from the shaft analyses were

1. From a hydrologic viewpoint, assuming porous matrix flow, backfilling the shafts is not essential. This conclusion is based on the prediction that the amount of water entering the shafts will be insignificant.

2. If backfilling is required for other reasons, the shaft should be filled with a material that behaves hydrologically like a sand.

The conclusions from the drift analysis stated above suggest that where free-flowing water from discrete, water-producing zones is not encountered, backfilling is not essential. Therefore, if sealing is required in the underground facility, emphasis will be placed on controlling water that enters the underground facility. In the current conceptual design, drainage paths exist from the emplacement drifts to the access drifts, then into the mains and finally to the base of the emplacement exhaust shaft. The ability to achieve the performance goals established for the underground facility will be evaluated, considering the alternative sealing components that could be emplaced in the underground facility.

Based on the shaft backfilling evaluation, assuming porous matrix flow, it was concluded that backfilling is not essential for hydrologic reasons, however, for safety reasons, backfilling of shafts will occur. In determining how the performance goals for shaft sealing components can be met, shaft backfill, the modified permeability zone, and other shaft sealing components will be evaluated.

### 1.12.4-4 Numerical analysis to evaluate backfilling repository drifts (hydrologic analysis 4)

Analytical approach

Additional hydrologic calculations evaluating the influence of backfilled repository drifts in a welded tuff unit were performed following the completion of the hydrologic calculations described under: hydrologic analysis 3. The TRUST code (NRC, 1982) was used in this analysis. Both fine- and coarse-grained materials were assumed as the backfill material in the drift. The primary difference between this calculation and the hydrologic analysis #3 was the selection of a different permeability versus pressure-head relationship for the welded tuff unit. Details are given in Freshley et al. (1985b).

Data

This analysis evaluated the water flow, under unsaturated conditions, in the vicinity of a drift that was backfilled with a sand or clay material. This analysis (Freshley et al., 1985b) differed from that presented in Freshley et al. (1985a), by the selection of the hydraulic properties of the welded tuff unit modeled and by the flux imposed at the upper boundary. This analysis used data on the hydraulic properties of welded tuff that were considered more representative of the Topopah Spring Member than that used by other analyses. The data used are included in Peters et al. (1984). The moisture retention characteristics and unsaturated permeabilities from sample G4-6 were used in this analysis. Data obtained from sample G4-6 were used because the porosity and permeability of sample G4-6 are lower than for sample S-19 presented by Freshley et al. (1985a), and are more representative of the prospective host rock than data from other samples. Further, sample G4-6 is a densely welded tuff from the Topopah Spring Member. The flux used in this analysis was 0.01 cm/yr.

Results

This analysis evaluated the role of drift backfill on flow past a vertically emplaced waste package. Two moisture retention characteristic curves for the host rock formation were selected to perform the analysis. This analysis differs from hydrologic analysis 3 in that a second sample characteristic curve (sample G4-6) was input into the model. This second characteristic curve was more representative of the host rock formation. The conclusions from this analysis were similar to the conclusions presented in the hydrologic analysis 3. Thus, the conclusions from hydrologic analysis 3 were substantiated.

1.12.4-5 Vadose water flow around a backfilled drift (hydrologic analysis 5)

Analytical approach

Hydrologic analyses (Mondy et al., 1985), similar to those described in hydrologic analyses 3 and 4, were performed using the computer code SAGUARO (Eaton et al., 1982). SAGUARO is a finite-difference code developed to model the flow of vadose water. In this analysis, the magnitude and direction of flow were determined in the vicinity of a vertically emplaced waste package below a drift backfilled with various materials. Sand and clay, representing the potential backfilled materials, were selected because of their significantly different hydrologic properties.

Data

The data used in this analysis were identical to the data used to perform hydrologic analysis 3. The hydrologic properties and porosity for sand and clay were taken from Mualem (1976). The hydrologic properties of the welded tuff unit were taken from preliminary hydrologic analyses of selected welded tuff samples from USW G-3.

Results

The sealing system element evaluated in this analysis was the drift backfill associated with the underground facility. The purpose of this analysis was to evaluate the flow past vertically emplaced waste packages using the same geometry as used in hydrologic analysis 3. However, this analysis was performed using a different computer code than that used in analysis 3 (TRUST) (NRC, 1982). In this sense, corroboration of the results obtained in hydrologic analysis 3 would be possible. The following conclusions were drawn from the study reported in Mondy et al. (1985).

1. With the drift simulated as being backfilled with clay, the predicted water flow past a waste package is not significantly different from that predicted in areas relatively far removed from the drifts. Similarly, the analysis in which the drift was simulated as being backfilled with sand predicted that the flow near the waste package would be reduced by only 10 percent compared to that predicted when simulating clay-filled drifts. Hence, the water flow past a vertically emplaced waste package is not very sensitive to the hydrologic properties of the backfill material for the conditions simulated in this preliminary analysis.

2. The vertical water flow is diverted only one to two drift widths to the side of the drift by the drift backfill. This limited diversion implies that the drift backfill would not influence flow past a horizontally emplaced waste package if a stand-off distance of more than two drift widths is included in the design.

The conclusions from this analysis suggest, as did hydrologic analyses #3 and #4, that if sealing is required in the underground facility, emphasis will be placed on designing sealing components that will control water from discrete, water-producing zones.

### 8.2.2.3 Future Work

#### 8.2.2.3.1 Analysis needs

Because of the structure of this report, the analysis needs are discussed here and in SCP Sections 8.3.3.1.3 (seal design), 8.3.3.1.4 (seal modeling), 8.3.3.2.1 (information needed for seal design under Information Need 1.12.1), and 8.3.5.11 (plans to assess seal system performance). The intent of this section is to summarize these identified sections.

The strategy used in developing seal designs is (1) to establish the need for seals through the use of analytical solutions describing unsaturated and saturated flow and (2) to account for the thermal effects of waste emplacement on the environmental conditions expected in the underground facilities, shafts, and ramps. Depending on the extent of the data base, sensitivity studies will be performed to establish a broad range of responses. Analyses will be performed on sealing elements to determine if the assigned performance goals can be achieved. This analytical effort may include the use of simple analytical solutions or complex computer codes.

8.2.2.3.2 Developmental needs

Numerical codes may be used to assess performance of sealing components, and can be used to more accurately define response of sealing components or subsystems. Responses can include hydrologic and thermomechanical behavior.

No new flow codes will be developed as part of the sealing program. Only existing codes will be used to assess the performance of sealing designs. Validation of the codes will be performed as part of the testing program associated with the exploratory shaft facility, and the strategy for this validation is described in the discussion of the ground-water travel time issue (Issue 1.6, SCP Section 8.3.5.12).

8.2.2.3.3 Site information needs

This section presents the site characterization parameter needs to resolve Issue 1.12 (seal characteristics). The information needed to confirm design assumptions is included in tables in SCP Section 8.3.3.2.1. Information such as the saturated hydraulic conductivity, gravitational analyses, compressibility of shaft fill, borehole construction, and geologic logs associated with specific boreholes, will support the design process in the selection of the appropriate methods to emplace sealing components. Site information needed to validate analytical methods may include hydrologic characterization of the Topopah Spring Member (TSw2). Specific properties are unsaturated matrix properties and the drainage capacity of the TSw2 unit. The prevalence of water-producing zones, if any, and the hydrologic nature of the Ghost Dance fault, the area underlying Drill Hole Wash, and the rock matrix will all be important site information needs in selecting the most appropriate sealing designs.

# 8.3 PRECLOSURE

## 8.3.1 ISSUE 2.1 PUBLIC RADIOLOGICAL EXPOSURES--NORMAL CONDITIONS

### 8.3.1.1 Introduction

The question asked by Issue 2.1 is

> During repository operation and closure, (a) will the expected average radiation dose to members of the public within any highly populated area be less than a small fraction of the allowable limits, and (b) will the expected radiation dose received by any member of the public in an unrestricted area be less than the allowable limits, as required by 10 CFR 60.111, 40 CFR Part 191 Subpart A, and 10 CFR Part 20?

The complete discussion of the proposed strategies for resolution of this issue is presented in SCP Section 8.3.5.3 (public radiological exposures--normal conditions). Readers unfamiliar with the issue resolution strategy for this issue should review the contents of SCP Section 8.3.5.3 before continuing.

Issue 2.1 has been subdivided into three information needs, and the completed work has been identified under the associated information need. The completed work is numbered in a manner that corresponds with the information need numbering system. For example, Section 2.1.2-1 is the first completed work identified under the second information need of Issue 2.1. Work that is similar to that required by this issue is discussed in Section 8.3.2 (radiological safety of workers--normal conditions) and in Section 8.3.3 (accidental radiological releases).

The Issue 2.1 information needs are as follows:

Information Need 2.1.1 Site and design information needed to assess preclosure radiological safety.

This information need consists of the review and compilation of information associated with the site; waste forms; surface and subsurface facility design; waste receiving, preparation, storage, and emplacement procedures; waste retrieval, storage, preparation, and shipping procedures; site-generated waste handling, preparation, and shipping procedures, repository caretaking procedures; and repository closure procedures. This work is ongoing. The site characterization information needed for resolution of this issue is identified in SCP Section 8.3.5.3.1.

Information Need 2.1.2 Determination of projected releases of radioactive material from the repository to restricted and unrestricted areas under normal conditions.

| Number | Description |
|---|---|
| 2.1.2-1 | The radioactive releases during normal operations for the surface facilities under normal operating conditions were addressed and reported in Section 6.1 of this report. |

Information Need 2.1.3 Determination that public radiation exposure resulting from the release of radioactive material from the repository combined with exposures from offsite installations and operations meets applicable requirements.

Methodology similar to that used to obtain projections of public radiation exposure, resulting from the release of radioactive material under accident conditions, Section 8.3.3, will be used to forecast public exposures under normal conditions.

8.3.1.2 Work completed

The following work has been completed for Issue 2.1.

2.1.2-1 Radioactive releases during normal operations

Section 6.1, Radioactive releases during normal operations, addresses the releases that are expected to occur as a result of the waste receiving, preparation, storage, and emplacement activities. Releases of naturally occurring radiation (e.g., radon-222 and radon daughters released as a result of mining activities or released from the mined materials stored on the surface) and radiation releases from sources other than the site (e.g., radiation releases from the Nevada Test Site) have not been addressed by Section 6.1. This section is separated into four subsections: (1) liquid effluents, (2) solid wastes, (3) gaseous secondary wastes, and (4) site monitoring. In the first three subsections, the design concepts and approaches for collecting, monitoring, treating, and disposing of liquid, solid, and gaseous wastes are discussed. These discussions include identification of the sources, types, quantities, method of treatment, and method of disposal of these wastes. The releases of radioactive materials from the repository to the restricted and unrestricted areas under normal conditions are estimated. The fourth subsection discusses the requirements and philosophy of the site monitoring program. The site monitoring program will ensure that radioactive releases to the restricted and unrestricted areas under normal conditions are within the limits established in the regulations addressed by this issue.

8.3.1.3 Future work

Preliminary investigations are planned as part of the advanced conceptual design activities and more detailed analyses are planned as part of the license application design and licensing activities for the mined geologic disposal system.

Some of the site characteristics which have been identified in SCP Section 8.3.5.3 as site information that should be obtained by the site characterization program are:

1. Meteorology of the Yucca Mountain site and adjacent areas.

2. Radon-222 and radon daughter emanation rate from the host rock at ambient and elevated temperatures.

8.3.2 ISSUE 2.2 WORKER RADIOLOGICAL SAFETY--NORMAL CONDITIONS

8.3.2.1 Introduction

The question asked by Issue 2.2 is

> Can the repository be designed, constructed, operated, closed, and decommissioned in a manner that ensures the radiological safety of workers under normal operations, as required by 10 CFR 60.111 and 10 CFR Part 20?

The regulatory requirement addressed by this issue is 10 CFR 60.111(a). The wording of 10 CFR 60.111(a) invokes 10 CFR Part 20.

The performance objective stated in 10 CFR 60.111(a) (performance of the geologic repository operations area through permanent closure) is as follows:

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

The complete discussion of the proposed strategies for resolution of this issue is presented in SCP Section 8.3.5.4 (radiological safety of workers--normal conditions). Readers unfamiliar with the issue resolution strategy for this issue should review the contents of SCP Section 8.3.5.4 before continuing.

Issue 2.2 has been subdivided into two information needs, and the completed work has been identified under the associated information need. The completed work is numbered in a manner that corresponds to the information need numbering system. For example, 2.2.2-1 is the first completed work identified under the second information need of Issue 2.2. The information needs are as follows:

Information Need 2.2.1 Determination of radiation environment in surface and subsurface facilities due to natural radioactivity.

> As part of the site characterization program, the natural radioactivity of the site will be characterized. The natural radioactivity of the site will be used in the determination of the expected annual and repository lifetime exposures of workers to natural radioactivity. No work on this information need, other than the identification of the required site characteristics, has been completed. This work, identification of site characteristics needed for determination of natural radiation environments, is described in Section 8.3.5.4.1 of the SCP.

Information Need 2.2.2 Determination that projected worker exposures and exposure conditions meet applicable requirements.

| Number | Description |
|---|---|
| 2.2.2-1 | Worker exposures under normal operating conditions have been estimated and these estimates have been used in both the design and evaluation of the repository facilities. |

8.3.2.2 Work completed

The completed work for Issue 2.3 is described in the following section.

2.2.2-1 Worker exposures under normal conditions

Two investigations have been conducted to forecast the expected exposures of workers to penetrating radiation during repository operations under normal operating conditions. The results of these investigations are reported in Dennis et al. (1984a) and in Stinebaugh and Frostenson (1986).

The reports by Dennis, et al. (1984a) and Stinebaugh and Frostenson (1987) were prepared for use by the repository architect-engineer in the conceptual design of the waste-handling facilities and equipment. These reports list the repository operations and the estimated worker radiation exposures. All forecast annual exposures were below the 5 rem/yr permissible dose equivalent limit. However, eight worker positions were identified where the forecast exposures exceed the 1 rem/yr design objective (DOE, 1986a, Chapter 11). Future design efforts will focus on reducing the exposure at these eight positions, as well as reducing general worker exposure to levels as low as reasonably achievable.

Stinebaugh and Frostenson (1987) was prepared after Dennis et al. (1984a) and it addresses the expected worker exposure under current expected conditions during the emplacement and retrieval of spent fuel when the vertical emplacement mode is used (Section 3.1.2 and Section 6.3 of this report). Emplacement and retrieval operations and the estimated worker radiation exposures are listed. All worker exposures were found to be below the 5 rem/yr exposure limit. Only one worker position exceeded the DOE design objective of 1 rem/yr. Future design efforts will focus on reduction of exposure at this position, as well as reduction of general worker exposure to levels as low as reasonably achievable.

8.3.2.3 Future work

8.3.2.3.1 Analysis needs

Worker exposures resulting from the natural radioactivity of the host rock will be investigated as site information becomes available. During each subsequent design phase (advanced conceptual design, license application design, and final procurement and construction design), the expected exposure of workers under normal conditions will be forecast. The forecast will become more detailed as the supporting design, waste characterization, and site information become more detailed.

8.3.2.3.2 Site data needs

As discussed in SCP Section 8.3.5.4 (radiological safety of workers--normal conditions), certain site data are needed to determine the radiation environment in the surface and subsurface facilities as a result of natural radioactivity. The main contribution to worker exposure from natural radioactivity is due to radon-222 and its daughter isotopes. There are other contributions from other naturally occurring radionuclides; however, these are not significant when compared with the contribution due to radon-222 and its daughters. Some of the site data needed to determine worker exposure as a result of natural radioactivity are as follows:

1. Radon-222 and radon daughter emission rates from the host rock.

2. Meteorological and environmental data.

Certain other site data are needed to estimate worker exposure from operations. These also are discussed in SCP Section 8.3.5.4. These site data are the characteristics of the host rock required to determine the shielding properties of the host rock. Other than these site data, no further site data have been identified as necessary to determine the expected radiation exposure of the workers under normal repository conditions.

## 8.3.3 ISSUE 2.3: ACCIDENTAL RADIOLOGICAL RELEASES

### 8.3.3.1 Introduction

The question asked by Issue 2.3 is

> Can the repository be designed, constructed, operated, closed, and decommissioned in such a way that credible accidents do not result in projected radiological exposures of the general public at the nearest boundary of the unrestricted area, or of workers in the restricted area, in excess of applicable limiting values?

The complete discussion of the proposed strategy for resolution of this issue is presented in SCP Section 8.3.5.5 (accidental radiological releases). Readers unfamiliar with the issue resolution strategy for this issue, should review SCP Section 8.3.5.5 before continuing.

Under this issue a list of structures, systems, and components important to safety will be developed. This list and a list of structures, systems, and components important to waste isolation combine to form the Q-List.

Issue 2.3 has been subdivided into the following four information needs:

Information Need 2.3.1 Determination of credible accidents applicable to the repository.

Information Need 2.3.2 Determination of projected releases of radioactive material from the repository to restricted areas under accident conditions.

Information Need 2.3.3 Determination that projected worker exposures and exposure conditions meet applicable requirements.

Information Need 2.3.4 Determination that projected public exposures and exposure conditions under accident conditions meet applicable requirements.

These four information needs indicate the various steps (accident definition, projected releases, and predicted exposures) conducted in completing safety analyses for accident conditions. These steps have been taken in the two preliminary safety analyses completed to date for the proposed Yucca Mountain repository. The discussion for resolving the status of this issue is organized to show the progression made in moving from the analysis based on preliminary repository design concepts (Jackson, 1984) to that based on the conceptual design.

Table 8-3 contains summary information describing computer codes used in the analyses supporting the completed work discussed here.

8.3.3.2 Work completed

This section discusses the work that has been performed to date to support resolution of this Issue. The work has been documented in three reports:

1. Jackson, J. L., H. F. Gram, K. J. Hong, H. S. Ng, and A. M. Pendergrass, "Preliminary Safety Assessment Study for the Conceptual Design of a Repository in Tuff at Yucca Mountain," SAND83-1504, Sandia National Laboratories, Albuquerque, NM, December 1984. (Jackson et al., 1984)

2. "Preliminary Preclosure Radiological Safety Analysis," prepared by Bechtel National, Inc., for Sandia National Laboratories, Albuquerque, New Mexico, Appendix F of this report.

3. "Items Important to Safety and Retrievability for the Yucca Mountain Repository," prepared by Bechtel National, Inc., for Sandia National Laboratories, Albuquerque, New Mexico, Appendix L of this report.

The first report, by Jackson et al. (1984) is of a scoping nature and based on preliminary repository concepts. Nevertheless, this work represents a significant contribution to the resolution of this issue. The second and third reports are Appendices F and L, respectively. The second report is based on a more advanced and more complete design (although still conceptual in nature) of the repository than the Jackson et al. (1984) study and, therefore, enhances and updates some of the results of that earlier report. Also, the Jackson et al. (1984) report presented preliminary estimates of worst-case radioactive releases resulting from postulated accidents, while Appendix F estimates radioactive releases for accidents developed using a probabilistic risk assessment (PRA) approach. Appendix L discusses the results of Appendix F and uses the results to make a preliminary identification of items important to safety. The Jackson et al. (1984) report is discussed first, followed by an integrated discussion of Appendices F and L.

Summary of the Jackson et al. (1984) report

As just mentioned above, the Jackson et al. (1984) report presented preliminary estimates of worst-case releases resulting from postulated accidents for the repository based on preliminary repository concepts. Following is a discussion of the approach used by the Jackson et al. (1984) report and the results of that report.

Table 8-3. Codes used in analyses addressing Issue 2.3

| Code name | Author | Code location | Design parameter | Analysis description |
|---|---|---|---|---|
| AIRDOS-EPA | R. E. Moore<br>C. F. Baes III<br>L. M. McDowell-Boyer<br>A. P. Watson<br>F. O. Hoffman<br>J. C. Pleasant<br>C. W. Miller | U.S. Environmental Protection Agency | Accident scenario. Atmospheric transport of radioactive plume. First-year and 50-yr dose commitments to maximum individual and repository personnel calculated using ALLDOS dose conversion factors. | Radionuclide releases modeled as Gaussian distributed short-duration plumes dispersed during average climatic conditions. |
| ORIGEN 2 | A. G. Croff | Oak Ridge National Laboratory | Radionuclide source terms and release fractions (Jackson et al., 1984) 83-1504. Dose rate map extrapolation. | Calculates the radionuclide inventories for the various waste forms. |

The potential causes of accidental releases from repository operations that would expose the general public and repository personnel were divided into three main categories: (1) natural phenomena, (2) external manmade events, and (3) operational accidents. Three accidents were developed for the natural phenomena category: (1) flooding, (2) tornado or high winds, and (3) earthquake. Aircraft crash and ground motion resulting from underground nuclear explosion (UNE) tests were the two manmade events developed. Finally, for the operational accidents category, five accidents were developed: (1) a fuel assembly drop in a hot cell, (2) a transportation accident and fire at the loading dock that involves spent fuel, (3) a transportation accident and fire at the loading dock that involves commercial high-level waste (CHLW), (4) a transportation accident and fire in the waste-handling ramp that leads from the surface facilities to the disposal horizon, and (5) a transportation accident and fire in a waste emplacement drift in the horizontal waste emplacement concept.

Source terms for each accident were derived from the radionuclide inventory involved, the waste form, and the postulated accident. Radionuclide inventories were based on spent fuel from pressurized water reactors that had been out of reactor for 10 years, on CHLW derived from reprocessing this spent fuel, and on West Valley high-level waste (WVHLW).

The principal exposure pathway in the scenarios analyzed was the atmospheric transport of a radioactive plume. Exposures resulted from (1) radiation reflected from the plume (cloud shine), (2) radiation from fallout on the ground (ground shine), (3) direct contact (air immersion), (4) inhalation of radionuclides from the plume, and (5) ingestion of foodstuffs contaminated by radioactive fallout. In the flooding scenario, direct contact with contaminated flood water was the exposure mechanism for repository personnel.

The source terms and pathways were used to calculate the 50-yr dose commitments to the general public and the first-yr and 50-yr dose commitments to the maximum individual and repository personnel in each of the 10 scenarios. Dose commitments to the public were calculated using the AIRDOS-EPA computer code. Releases were modeled as Gaussian-distributed, short-duration plumes dispersed during averaged climatic conditions. Dose commitments to the maximum individual and to repository personnel were calculated using the ALLDOS dose conversion factors. The release plume was postulated to pass directly over the maximum individual at average wind velocity.

Dose commitments reported in this study were made up of an acute dose and a chronic dose commitment. These doses were received via external and internal exposure pathways. The acute dose was received within hours or minutes following the accidental release and was a result of external exposure. The chronic doses were received as a result of continuous exposure to radionuclides incorporated in the body after inhalation or ingestion. The calculated dose commitments were converted to health effects (excess cancer deaths), in accordance with the methodology for determining dose and health-effect relationships described in the BEIR III report (BEIR III, 1980).

The Jackson et al. (1984) report presents the results of the analysis in terms of (1) doses to the repository workers, (2) doses to the maximum individual, and (3) doses to the general public. The results of the report also included the identification of accident scenarios and estimates of the probabilities of these accidents.

The Jackson et al. (1984) report analyzed ten accident scenarios. These were divided into three categories: (1) natural phenomena, (2) manmade external events, and (3) operational accidents. The natural phenomena analyzed included a flood, a 0.4g horizontal acceleration earthquake, and a tornado. The probability of these events was estimated to be $1.0 \times 10^{-2}$ per yr, less than $1.3 \times 10^{-3}$ per yr, and less than $9.1 \times 10^{-11}$ per yr, respectively. Because of the low probability of the tornado, this event might not be considered credible. Accidents involving underground nuclear event (UNE) test and aircraft impact were the two manmade events analyzed. The probability of the UNE causing a radioactive release was estimated to be less than $1.0 \times 10^{-3}$ for any one event. There were no data to estimate the event frequency. The probability of an aircraft impact was estimated to be $2.0 \times 10^{-10}$ per year. Again, because of the low probability of the aircraft impact, this event might not be considered credible. There were five operational accidents analyzed: (1) a fuel assembly drop in a hot cell, (2) two transportation accidents and fires at the loading dock involving two different waste types, (3) a transportation accident and fire in the waste-handling ramp, and (4) a transportation accident and fire in an emplacement drift. The probabilities of these events were estimated to be $1.0 \times 10^{-7}$/yr for the transportation accidents. The transportation accidents were on the edge of what might be considered credible, taking into account the uncertainties of the estimates. A transportation accident with a fire can be avoided by using electric transporters and eliminating the fuel for the fire. This possibility is being considered.

The calculated first-year commitments for repository workers are below the occupational exposure limits (there is no specific accident-related exposure limit for workers) set by the NRC in 10 CFR Part 20 of 5.0 rem/yr and 3.0 rem/qtr for all accidents except for the transportation accident and fire in an emplacement drift. The dose commitment for this accident is 6.8 rem to workers in the emplacement drift. This accident was identified as being nearly credible. A major contributing factor to the dose, however, was the volatization of radionuclides caused by the fire. Since as noted earlier, all-electric transporters would remove the fuel for the fire, this accident can be eliminated or at least the consequences reduced considerably.

The calculated first-year and 50-yr dose commitments for the maximum offsite individual were all less than the important-to-safety threshold established by the NRC (10 CFR 60.2) of 0.5 rem whole-body per accident. The greatest single first-year dose commitment for the maximum individual was calculated to be 0.055 rem and occurred in the aircraft impact scenario (recall this scenario has an extremely low probability). It should be noted that actual Air Force flight data were not used in the Jackson et al. (1984) report but are being factored into current evaluations. Similar results were calculated for the general public except that doses for the general public are always lower than for the maximum individual.

The greatest single exposure to the population was calculated to be 110 man-rem (for a population of 19,908) and, again, occurred during the aircraft impact scenario. The results of this study are preliminary. Future work is expected to produce differing results based on new and more accurate data.

Summary of Appendices F and L

The previous discussion of the Jackson et al. (1984) report presented results that were based on worst-case radioactive releases. The following discussion of Appendices F and L presents a probabilistic-risk-assessment (PRA) approach to estimating radioactive releases from credible accidents. The methodology is related to determining items important to safety and is depicted in Figure 8-4. The complete reports are contained in Appendices F and L while the methodology and results are summarized in the following. (This information was given earlier in Sections 7.4.1 and 4.6.1 but is repeated here for reader convenience.)

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

After developing the facility and system model initiating events both internal and external were identified and screened by a panel of experienced design and safety analysis engineers. The basis for the screening was the potential of the events to contribute to a significant offsite release of radioactive materials. Using the event-tree technique, accident scenarios then were developed for those initiating events surviving the first screening process. Event trees are graphical depictions of the sequence of events that occur following an initiating event. The construction of an event tree is an inductive process in that one goes from the specific--the initiating event--to the general, all the possible results of the initiating event. The key factor for developing an event tree for each surviving initiating event was the selection and definition of the intermediate events. Event trees were constructed in detail appropriate to the level of design detail available and as necessary to adequately characterize the accident. Because of lack of data and design details, fault trees were not completely developed and analyzed; however, variations of conventional fault tree or fault diagrams were developed for most intermediate events. Fault trees are graphic depictions of the possible events that might lead to an intermediate event on an event tree. Constructing a fault tree is a deductive process in that one goes from the general--all possible ways for the intermediate event to come about--to the specific, the intermediate event. The use of fault diagrams provides important insight into the probabilities of intermediate events.

After event trees were developed, the probability of each initiating event and each intermediate event was evaluated, as were the consequences of accident scenarios. The probability and consequence analyses were

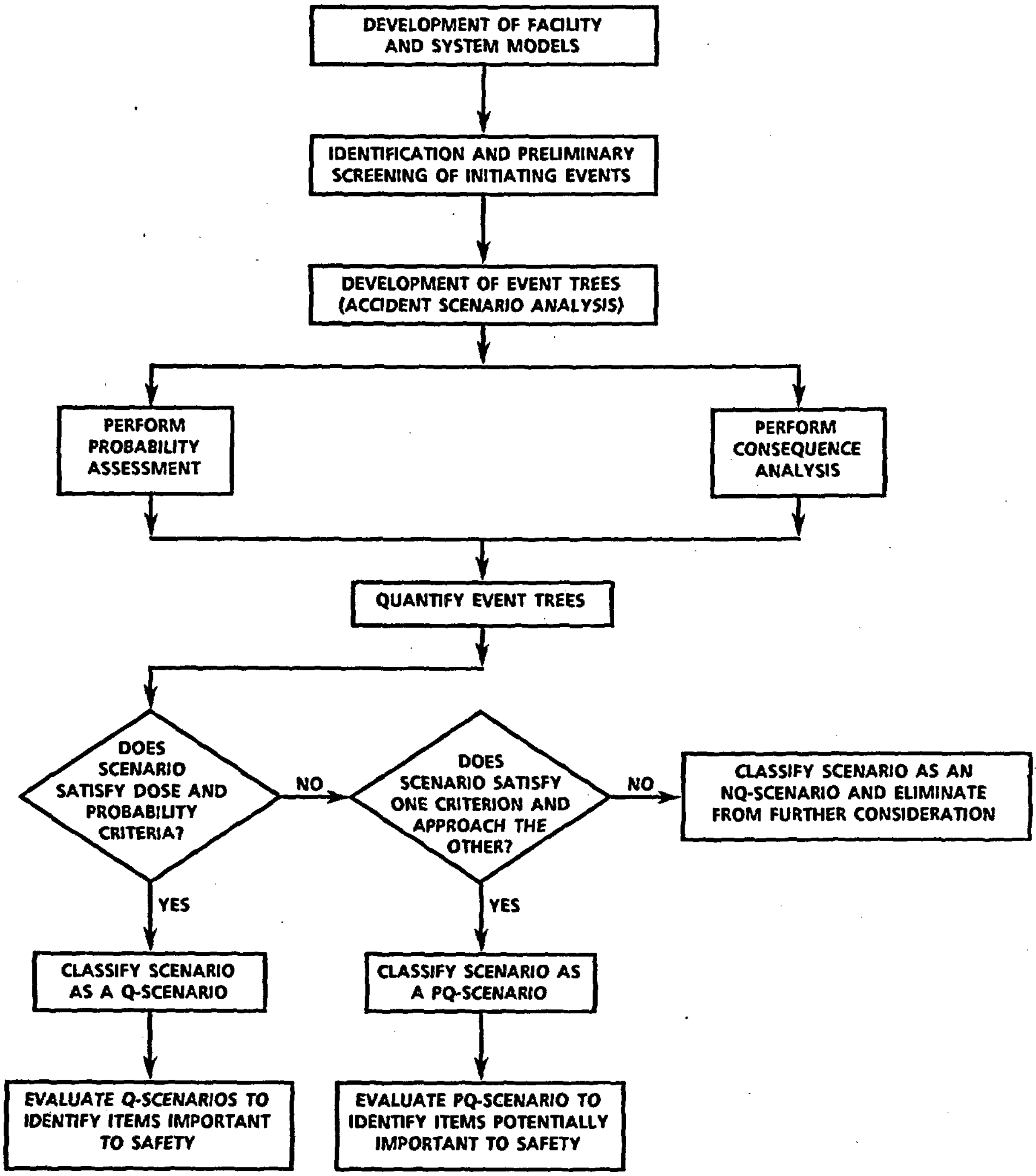


Figure 8-4. Q-List methodology for items important to safety (original figure).

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

On the basis of the results of the event tree quantifications, all accident scenarios that resulted in either dose consequences of more than 0.05 rem at the site boundary and probabilities of more than $1 \times 10^{-9}$ per yr were selected as reference accident scenarios. The reference accident scenarios were identified by simplifying, or pruning, the event trees of all the accident scenarios that did not fall within the limitations established for the dose consequences and probability criteria. The initial list of items important to safety was derived from the reference scenarios and the numerical results of the analyses.

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

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

2. Probability criterion: An accident scenario could potentially lead to the identification of items important to safety if the probability of occurrence of the scenario is greater than $1 \times 10^{-5}$ per yr; otherwise, the scenario is not considered significant with respect to items important to safety.

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

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

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

Once a scenario is classified as a Q-scenario or a PQ-scenario, that scenario is further analyzed to determine which of the items involved in the scenario should be placed on the list of items important to safety or potentially important to safety. Further analysis of the scenario involves the evaluation of the systems, structures, and components involved in the scenario to determine what role the item plays in the scenario. Items that have a failure that causes the loss of consequence mitigation processes or have failure that directly causes the release of radioactive materials are classified as important to safety or potentially important to safety and placed on the Q-list or PQ-list, depending on which type of scenario is being evaluated. Current plans will make these items (PQ-items), as well as items important to safety, subject to a QA level I program that satisfies the requirements of Title 10 CFR 60, Subpart G. A potentially important-to-safety list is consistent with DOE guidance (DOE, 1986).

The results to date have not identified any Q-scenarios, or consequently, any Q-list items; however, this result is based on incomplete and preliminary data and design. For example, an airplane-crash event did not have available actual data and will have to be reexamined. Consequently, all items that have been classified as potential Q-list will be treated as if they were Q-list during future design, until the design detail and available data support a definitive analysis and conclusion. The preliminary list of potential items important to safety (Q-list), as developed in Appendix L and through technical review of this appendix is presented in Table 8-4.

In addition, as the design is developed, i.e., the reference configuration of the license application design and additional data become available, the complete sequence of the Q-list method will be implemented again to refine, correct, and validate the initial results.

A detailed discussion of the methods used in determining items important to safety, is given in Appendix F. A complete discussion of the results of the analysis to determine items important to safety, is given in Appendix L.

Table 8-4. Potential Q-list for items important to safety at the Yucca Mountain Repository

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

### 8.3.3.3 Future work

#### 8.3.3.3.1 Analysis needs

During each subsequent design phase (advanced conceptual design, license application design), these analyses, described previously will be repeated. As site information becomes available and the repository design matures, these analyses will rely more on data and calculations and less on engineering judgment. The final set of analyses will be used to support the license application.

8.3.3.3.2 Site data needs

Immediate site data needs are meteorological data. These data include such items as wind and precipitation patterns, atmosphericstability class, and site-boundary location. These data are used to calculate the transport of radionuclides in the atmosphere and are described in SCP Section 8.3.1.12. Other data used by this issue are described in SCP Sections 8.3.1.10, 8.3.1.11, and 8.3.1.13.

## 8.3.4 ISSUE 2.7: REPOSITORY DESIGN CRITERIA FOR RADIOLOGICAL SAFETY

### 8.3.4.1 Introduction

The question asked by Issue 2.7 is

> Have the characteristics and configurations of the repository been adequately established to (a) show compliance with the preclosure design criteria of 10 CFR 60.131 through 10 CFR 60.133, and (b) provide information for the resolution of the performance issues?

The general design criteria for the geologic repository operations area (10 CFR 60.131), the additional design criteria for the surface facilities in the geologic repository operations area (10 CFR 60.132), and the additional design criteria for the underground facility (10 CFR 60.133) are presented in Table 8-5. The responsibility for meeting the criteria stated in 10 CFR 60.131 through 60.133 is divided among several issues.

To define the role and responsibilities currently assigned under this issue, an understanding of other issues is necessary. Issues 2.1 (public radiological exposures--normal conditions), 2.2 (worker radiological safety--normal conditions), and 2.3 (accidental radiological releases) address the compliance of the repository system with allowable releases of radioactive materials during preclosure. Under Issue 2.4 (waste retrievability) the retrieval option is maintained, and under Issue 1.11 (configuration of underground facilities--postclosure) the compliance with the postclosure design criteria of 10 CFR 60.133 is ensured with the exception of criteria related to sealing the repository that are addressed under the seal characteristics issue (Issue 1.12).

Issue 4.4 (preclosure design and technical feasibility) is the central or focusing issue that describes the development of the repository designs related to preclosure concerns.

With this understanding of the other issues, a detailed evaluation (Table 8-5) of the criteria specified in 10 CFR 60.131 through 10 CFR 60.133 reveals clearly the role of this issue (Issue 2.7). Under Issue 2.7 radiological-safety-related design criteria are developed and specified. The related design work will be done in Issue 4.4 since other issues specify requirements that must be met by the system design, e.g., the ventilation system design must meet criteria related to radiological safety (Issue 2.7), retrievability (Issue 2.4), and nonradiological health and safety (Issue 4.2).

Table 8-5. Design criteria for the geologic repository operations (page 1 of 8)

| Design Criteria of 10 CFR Part 60 | Issue that addresses the criterion | Are site data needed to address the criterion? |
|---|---|---|
| 60.131 General design criteria for the geologic repository operations area. | | |
| (a) Radiological protection. The geologic repository operations area shall be designed to maintain radiation doses, levels, and concentrations of radioactive material in air in restricted areas within the limits specified in Part 20 of this chapter. Design shall include | | |
| (1) Means to limit concentrations of radioactive material in air; | 2.7 | Yes |
| (2) Means to limit the time required to perform work in the vicinity of radioactive materials, including, as appropriate, designing equipment for ease of repair and replacement and providing adequate space for ease of operation; | 2.7 | No |
| (3) Suitable shielding; | 2.7 | Yes |
| (4) Means to monitor and control the dispersal of radioactive contamination; | 2.7 | Yes |
| (5) Means to control access to high radiation areas or airborne radioactivity areas; and | 2.7 | No |
| (6) A radiation alarm system to warn of significant increases in radiation levels, concentrations of radioactive material in air, and of increased radioactivity released in effluents. The alarm system shall be designed with provisions for calibration and for testing its operability. | 2.7 | Yes |
| (b) Structures, systems, and components important to safety. | | |
| (1) Protection against natural phenomena and environmental conditions. | 2.7 | Yes |
| The structures, systems, and components important to safety shall be designed so that natural phenomena and environmental conditions anticipated at the geologic repository operations area will not interfere with necessary safety functions. | | |

Table 8-5. Design criteria for the geologic repository operations (page 2 of 8)

| Design Criteria of 10 CFR Part 60 | Issue that addresses the criterion | Are site data needed to address the criterion? |
|---|---|---|
| (2) Protection against dynamic effects of equipment failure and similar events. | 2.7 | No |
| The structures, systems, and components important to safety shall be designed to withstand dynamic effects, such as missile impacts, that could result from equipment failure, and similar events and conditions that could lead to loss of their safety functions. | | |
| (3) Protection against fires and explosions. | | |
| (i) The structures, systems, and components important to safety shall be designed to perform their safety functions during and after credible fires or explosions in the geologic repository operations area. | 2.7 | Yes |
| (ii) To the extent practicable, the geologic repository operations area shall be designed to incorporate the use of non-combustible and heat resistant materials. | 4.2 | No |
| (iii) The geologic repository operations area shall be designed to include explosion and fire detection alarm systems and appropriate suppression systems with sufficient capacity and capability to reduce the adverse effects of fires and explosions on structures, systems, and components important to safety. | 2.7 | Yes |
| (iv) The geologic repository operations area shall be designed to include means to protect systems, structures, and components important to safety against the adverse effects of either the operation or failure of the fire suppression systems. | 2.7 | No |
| (4) Emergency capability. | | |
| (i) The structures, systems, and components important to safety shall be designed to maintain control of radioactive waste and radioactive effluents, and permit prompt termination of operations and evacuation of personnel during an emergency. | 2.7 | No |

Table 8-5. Design criteria for the geologic repository operations (page 3 of 8)

| Design Criteria of 10 CFR Part 60 | Issue that addresses the criterion | Are site data needed to address the criterion? |
|---|---|---|
| (ii) The geologic repository operations area shall be designed to include onsite facilities and services that ensure a safe and timely response to emergency conditions and that facilitate the use of available offsite services (such as fire, police, medical, and ambulance service) that may aid in recovery from emergencies. | 4.2 | No |
| (5) Utility services. | | |
| (i) Each utility service system that is important to safety shall be designed so that essential safety functions can be performed under both normal and accident conditions. | 2.7 | Yes |
| (ii) The utility services important to safety shall include redundant systems to the extent necessary to maintain, with adequate capacity, the ability to perform their safety functions. | 2.7 | No |
| (iii) Provisions shall be made so that, if there is a loss of the primary electric power source or circuit, reliable and timely emergency power can be provided to instruments, utility service systems, and operating systems, including alarm systems, important to safety. | 2.7 | No |
| (6) Inspection, testing, and maintenance. | 2.7 | No |
| The structures, systems, and components important to safety shall be designed to permit periodic inspection, testing, and maintenance, as necessary, to ensure their continued functioning and readiness. | | |
| (7) Criticality control. | 2.7 | Yes |
| All systems for processing, transporting, handling, storage, retrieval, emplacement, and isolation of radioactive waste shall be designed to ensure that a nuclear criticality accident is not possible unless at least two unlikely, independent, and concurrent or sequential changes have occurred in the conditions essential to nuclear criticality safety. Each system shall be designed for criticality safety under | | |

Table 8-5. Design criteria for the geologic repository operations (page 4 of 8)

| Design Criteria of 10 CFR Part 60 | Issue that addresses the criterion | Are site data needed to address the criterion? |
|---|---|---|
| normal and accident conditions. The calculated effective multiplication factor ($k_{eff}$) must be sufficiently below unity to show at least a 5% margin, after allowance for the bias in the method of calculation and the uncertainty in the experiments used to validate the method of calculation. | | |
| (8) Instrumentation and control systems. | 2.7 | No |
| The design shall include provisions for instrumentation and control systems to monitor and control the behavior of systems important to safety over anticipated ranges for normal operation and for accident conditions. | | |
| (9) Compliance with mining regulations. | 2.7 | No |
| To the extent that DOE is not subject to the Federal Mine Safety and Health Act of 1977, as to the construction and operation of the geologic repository operations area, the design of the geologic repository operations area shall nevertheless include such provisions for worker protection as may be necessary to provide reasonable assurance that all structures, systems, and components important to safety can perform their intended functions. Any deviation from relevant design requirements in 30 CFR, Chapter 1, Subchapters D, E, and N will give rise to a rebuttable presumption that this requirement has not been met. | | |
| (10) Shaft conveyances used in radioactive waste handling. | All waste will be transported underground in the ramp.[a] | NA |
| (i) Hoists important to safety shall be designed to preclude cage free fall. | | |
| (ii) Hoists important to safety shall be designed with a reliable cage location system. | | |
| (iii) Loading and unloading systems for hoists important to safety shall be designed with a reliable system of interlocks that will fail safely upon malfunction. | | |

Table 8-5. Design criteria for the geologic repository operations (page 5 of 8)

| Design Criteria of 10 CFR Part 60 | Issue that addresses the criterion | Are site data needed to address the criterion? |
|---|---|---|
| (iv) Hoists important to safety shall be designed to include two independent indicators to indicate when waste packages are in place and ready for transfer. | | |
| 60.132 Additional design criteria for surface facilities in the geologic repository operations area. | | |
| (a) Facilities for receipt and retrieval of waste. | 2.7 | Yes |
| Surface facilities in the geologic repository operations area shall be designed to allow safe handling and storage of wastes at the geologic repository operations area, whether these wastes are on the surface before emplacement or as a result of retrieval from the underground facility. | | |
| (b) Surface facility ventilation. | 2.7 | Yes |
| Surface facility ventilation systems supporting waste transfer, inspection, decontamination, processing, or packaging shall be designed to provide protection against radiation exposures and offsite releases as provided in 60.111(a). | | |
| (c) Radiation control and monitoring. | | |
| (1) Effluent control. | 2.7 | Yes |
| The surface facilities shall be designed to control the release of radioactive materials in effluents during normal operations so as to meet the performance objectives of 60.111(a). | | |
| (2) Effluent monitoring. | 2.7 | No |
| The effluent monitoring systems shall be designed to measure the amount and concentration of radionuclides in any effluent with sufficient precision to determine whether releases conform to the design requirement for effluent control. The monitoring systems shall be designed to include alarms that can be periodically tested. | | |

Table 8-5. Design criteria for the geologic repository operations (page 6 of 8)

| Design Criteria of 10 CFR Part 60 | Issue that addresses the criterion | Are site data needed to address the criterion? |
|---|---|---|
| (d) Waste treatment. | 2.7 | No |
| Radioactive waste treatment facilities shall be designed to process any radioactive wastes generated at the geologic repository operations area into a form suitable to permit safe disposal at the geologic repository operations area or to permit safe transportation and conversion to a form suitable for disposal at an alternative site in accordance with any regulations that are applicable. | | |
| (e) Consideration of decommissioning. | 4.4 | No |
| The surface facility shall be designed to facilitate decontamination or dismantlement to the same extent as would be required, under other parts of this chapter, with respect to equivalent activities licensed thereunder. | | |
| 60.133 Additional design criteria for the underground facility. | | |
| (a) General criteria for the underground facility. | | |
| (1) The orientation, geometry, layout, and depth of the underground facility, and the design of any engineered barriers that are part of the underground facility shall contribute to the containment and isolation of radionuclides. | 1.11 | Yes |
| (2) The underground facility shall be designed so that the effects of credible disruptive events during the period of operations, such as flooding, fires and explosions, will not spread through the facility. | 4.4 | No |
| (b) Flexibility of design. | 1.11 | Yes |
| The underground facility shall be designed with sufficient flexibility to allow adjustments where necessary to accommodate specific site conditions identified through in situ monitoring, testing, or excavation. | | |
| (c) Retrieval of waste. | 2.4, 4.4 | Yes |
| The underground facility shall be designed to permit retrieval of waste in accordance with the performance objectives of 60.111. | | |

Table 8-5. Design criteria for the geologic repository operations (page 7 of 8)

| Design Criteria of 10 CFR Part 60 | Issue that addresses the criterion | Are site data needed to address the criterion? |
|---|---|---|
| (d) Control of water and gas. | 4.4 | Yes |
| The design of the underground facility shall provide for control of water or gas intrusion. | | |
| (e) Underground openings. | | |
| (i) Openings in the underground facility shall be designed so that operations can be carried out safely and the retrievability option maintained. | 2.4, 4.2, 4.4 | Yes |
| (ii) Openings in the underground facility shall be designed to reduce the potential for deleterious rock movement or fracturing of overlying or surrounding rock. | 1.11 | Yes |
| (f) Rock excavation | 1.11 | Yes |
| The design of the underground facility shall incorporate excavation methods that will limit the potential for creating a preferential pathway for ground water or radioactive waste migration to the accessible environment. | | |
| (g) Underground facility ventilation. | | |
| The ventilation system shall be designed to | | |
| (i) Control the transport of radioactive particulates and gases within and releases from the underground facility in accordance with the performance objectives of 60.111(a). | 2.7 | Yes |
| (ii) Assure continued function during normal operations and under accident conditions. | 2.7, 4.2, 4.4 | Yes |
| (iii) Separate the ventilation of excavation and waste emplacement areas. | 2.7, 4.4 | No |

Table 8-5. Design criteria for the geologic repository operations (page 8 of 8)

| Design Criteria of 10 CFR Part 60 | Issue that addresses the criterion | Are site data needed to address the criterion? |
|---|---|---|
| (h) Engineered barriers. | 1.11 | Yes |
| Engineered barriers shall be designed to assist the geologic setting in meeting the performance objectives for the period following permanent closure. | | |
| (i) Thermal loads. | 1.11 | Yes |
| The underground facility shall be designed so that the performance objectives will be met taking into account the predicted thermal and thermomechanical response of the host rock, and surrounding strata, ground-water system. | | |

[a]The repository design for the Yucca Mountain site uses a ramp (instead of a shaft and hoist) through which waste is transported underground by transporters.

The proposed issue resolution strategy for this issue is presented in SCP Section 8.3.2.3 (repository design criteria for radiological safety). Readers unfamiliar with the issue resolution strategy for this issue should review the contents of SCP Section 8.3.2.3 before continuing.

The information needs for Issue 2.7 are as follows:

Information Need 2.7.1 Determination that the design criteria in 10 CFR 60.131 through 60.133 and any appropriate additional design objectives pertaining to radiological protection have been met.

Information Need 2.7.2 Determination that the design criteria in 10 CFR 60.131 through 60.133 and any appropriate additional design objectives pertaining to the design and protection of structures, systems, and components important to safety have been met.

Information Need 2.7.3 Determination that the design criteria in 10 CFR 60.131 through 60.133 and any appropriate additional design objectives pertaining to criticality control have been met.

Information Need 2.7.4 Determination that the design criteria in 10 CFR 60.131 through 60.133 and any appropriate additional design objectives pertaining to compliance with mining regulations have been met.

Information Need 2.7.5 Determination that the design criteria in 10 CFR 60.131 through 60.133 and any appropriate additional design objectives pertaining to waste treatment have been met.

The information needs indicate that the development of the design criteria applicable for radiological safety require (1) interfaces with site, waste package, and repository designs, (2) understanding potential conditions that may exist in surface and underground facilities, and (3) establishing means of controlling releases. The discussions below will focus on the work completed to date related to criteria development and to the means for controlling releases that are part of the current design.

### 8.3.4.2 Work completed

The work completed in support of this issue consists of design criteria established for the use in the conceptual design presented in this report, and in criteria prepared to support the advanced conceptual design activities. Repository design guidelines were issued in advance of this report. As part of the development of this report, these guidelines were expanded by establishing additional means of limiting exposures and by more clearly defining planned operations. These refinements are part of the Subsystem design requirements (Appendix P).

Design criteria have been obtained from both regulatory guidance and from DOE Orders. The regulatory guidance is principally from 10 CFR 60.131, 132, and 133 while the DOE guidance is principally from DOE Orders 5480.1B (DOE, 1986b), 6410.1 (DOE, 1983b), and 6430.1 (DOE, 1983a). This guidance is translated into several specific points of design philosophy for the NNWSI Project work. Some of the more important points are as follows:

1. Design basis will be 20 percent of allowable release.

2. No administrative controls will be used to meet worker dosage criteria.

3. Separate underground ventilation systems will be used for excavation and waste emplacement areas.

4. Redundancy of systems and equipment will be provided.

5. Systems for mitigating disruptive events will be provided.

6. Design will consider decommissioning requirements.

7. Maintainability will be considered in facilities and equipment design.

The development of the conceptual design has led to identifying numerous means of limiting releases. For the surface facilities, these include the compartmentalization of surface facility operations, design of hot cells for negative-pressure operation, shielding of selected operations, and development of zoned ventilation systems in the surface buildings. In addition, filtration systems for gaseous effluents, strippable wall coatings in selected areas, removable liners from selected equipment, and automated systems, where possible, are used in the current design. Placement of the waste-handling building and its effluent exhaust systems is influenced by the prevailing wind direction as a means of limiting contamination of other surface facilities. Access control is also provided for the surface facilities. Collection and treatment of site-generated waste is reflected in the current design, as are specified areas for decontamination activities.

Means of limiting releases in the underground facilities rely primarily on decisions made relative to the ventilation systems and to equipment design. In the ventilation system, filters are provided on the underground exhaust building, a positive-pressure differential will exist between the development and waste emplacement areas to allow leakage to always be toward the emplacement side. For the equipment program, means of shielding are reflected in the transporter cask, transporter cab, and shield plugs designed for the waste emplacement boreholes. Additionally, speed limitations and braking criteria have been established for the transporter as a means of limiting the consequences of potential accidents. Access control is provided.

Means of limiting releases are inherent in many of the planned operations for the repository. For example, operations are sequenced so that workers are not expected to be consistently downstream from waste emplacement operations. Similarly, airflow related to muck removal from the development area will be exhausted along the tuff ramp thereby having minimal potential for ingestion by workers. Extensive inspections are planned for waste upon arrival and during processing. Maintenance operations are being designed, where possible, to be conducted outside the hot cells although obviously some maintenance will require remote systems.

8.3.4.3 Future work

As described in the previous paragraphs and reflected throughout this report, applicable criteria have been identified as the basis for establishing means of controlling releases of radioactive materials from the repository.

The future work related to this issue consists primarily of identifying progressively more detailed design criteria for advanced conceptual design and license application design activities. This work is described in more detail in Section 8.3.2.3 (repository design criteria for radiological safety).

## 8.3.5 ISSUE 2.4: WASTE RETRIEVABILITY

### 8.3.5.1 Introduction

The question asked by Issue 2.4 is

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

In general, 10 CFR 60.111(b)(1) requires that the emplaced waste must be retrievable on a reasonable schedule until the completion of the performance confirmation program and NRC review. In addition, Section 5-1(a)(3) of 10 CFR Part 960 includes a requirement that the repository siting, construction, operation, and closure will be demonstrated to be technically feasible on the basis of reasonably available technology. These regulatory requirements form the basis for Issue 2.4. The resolution of this issue follows the issue resolution strategy (IRS) presented in SCP Section 8.3.5.2. Readers unfamiliar with the IRS for this issue should review SCP Section 8.3.5.2 before continuing.

The object of this issue is to ensure that the repository preserves the option of waste retrieval. To ensure that the retrieval option is maintained, this issue

1. Establishes a strategy for resolution through performance allocation.

2. Defines retrievability-related design criteria.

3. Establishes normal and off-normal conditions anticipated for retrieval operations. [Note that in this section the term off-normal is used to identify conditions which are anticipated to occur infrequently. In future documents the term off-normal will be replaced with the term abnormal.]

4. Identifies information (analyses, demonstrations, etc.) required from other issues to ensure compliance with retrievability requirements.

5. Assesses compliance with the regulatory requirements for retrievability.

These responsibilities assigned under Issue 2.4 are depicted in Figure 8-5, which details the strategy to be used for retrievability evaluation. The significance of Issue 4.4, (preclosure design and technical feasibility), also is evident in the figure. Under Issue 4.4 the design for facilities and equipment is developed, analyses of the design are conducted, needed tests and demonstrations are conducted, and an operations plan is developed.

In developing the strategy for resolving this issue, it was determined that the ability to perform retrieval operations is based on the ability to perform the following four functions:

1. Provide access to the emplacement boreholes.
2. Provide access to the waste containers.
3. Remove waste containers from the emplacement boreholes.
4. Transport and deliver the waste to the surface facilities.

To ensure that the design will include the ability to perform these functions under normal and off-normal conditions, it will be necessary to document the following:

1. Retrieval strategy and planning.

2. Retrieval conditions.

3. Retrievability input to repository design requirements (RDR) document.

4. Facility and equipment designs, demonstrations and design analyses.

5. Retrievability compliance analyses.

The designs, demonstrations, and supporting analyses will be documented in reports produced under Issue 4.4 (SCP Section 8.3.2.5). Hence, discussions of the status of the retrievability issue will be focused on documentation produced to date regarding items 1, 2, 3, and 5 of the previous list.

Section 8.3.5.2 presents the work completed to date. The future work to be performed on these products is summarized in Section 8.3.5.3.

## 8.3.5.2 Work completed

### 8.3.5.2.1 Retrieval strategy and planning documents

The approach to development of a strategy for retrievability has been to develop a guidance paper to ensure consistency of planning assumptions concurrently with development of a strategy paper to adapt this guidance for NNWSI Project specific applications. The documents that address strategy and planning are as follows:

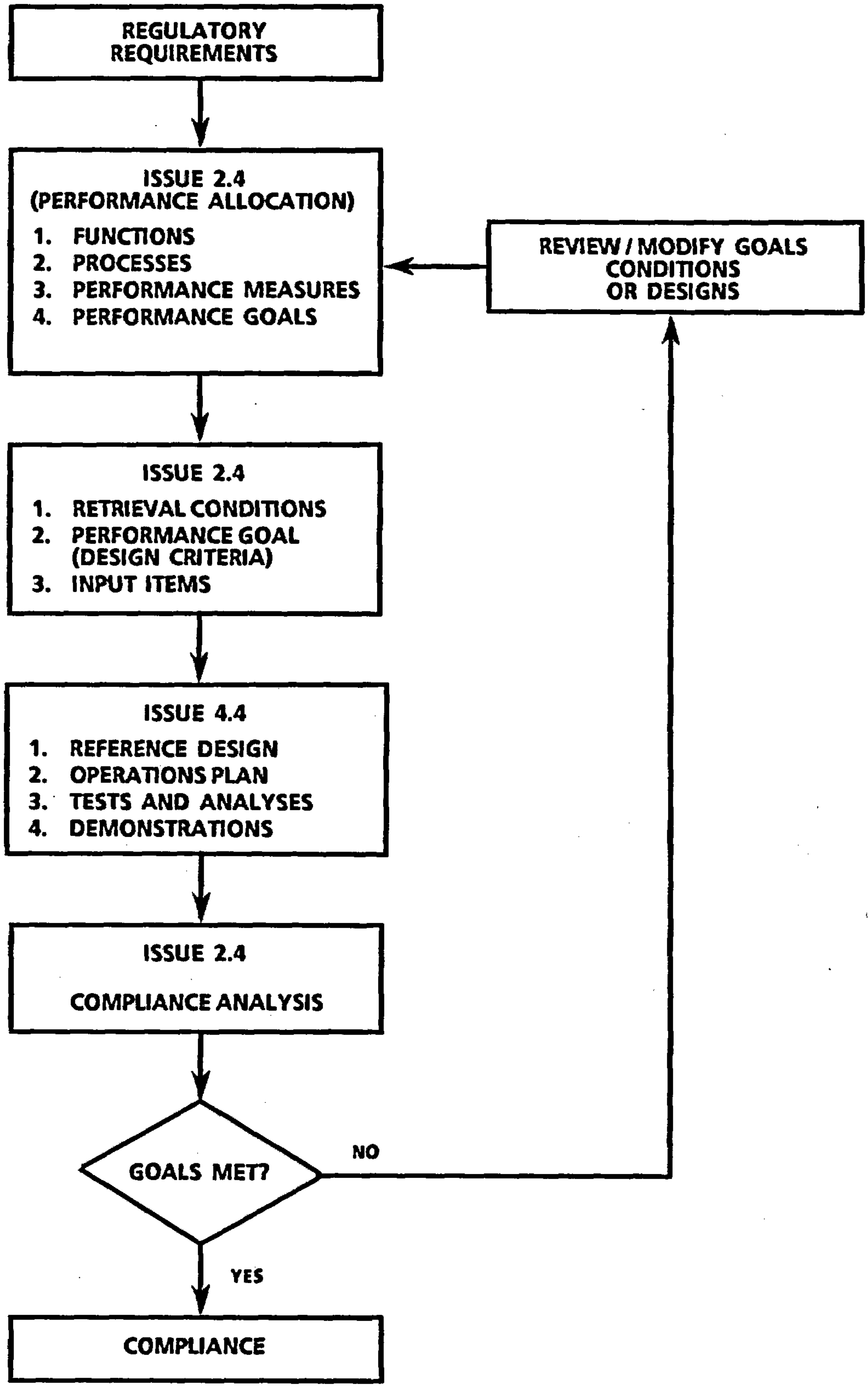


Figure 8-5. Strategy to be used for retrieval evaluation (original figure).

1. "Department of Energy Generic Requirements for a Mined Geologic Disposal Site" (DOE, 1986d).

2. "Retrievability: Strategy for Compliance Demonstration," SAND84-2242 (Flores, 1986).

The basis (or data) used to develop this strategy included the regulatory requirements, the Generic Requirements (GR) document (DOE, 1984), and the Mission Plan (DOE, 1985). These reports address (1) the identification and evaluation of the regulatory requirements for retrievability, (2) the establishment of a design basis for evaluating the ability to retrieve, (3) the identification of the expected repository conditions at the time of retrieval, (4) the development of the methodology for defining normal conditions and identifying off-normal conditions, and (5) the identification of the timing for design and demonstration activities that are needed to ensure that the ability to retrieve is maintained throughout the retrievability period.

These two reports will be used to form the basis for more detailed definition of the demonstrations, analyses, operations, equipment development, and anticipated conditions. Consistency in these detailed definitions requires an expansion of the strategy documented to date. This proposed strategy or approach is described in Appendix J. This approach relies on the use of a probabilistic approach as a means for segregating conditions that require consideration from those that do not, Figure 8-6. A further segregation is identified to classify the conditions as normal and off-normal. This classification of conditions will form the basis for the segregation of items in the design approach, demonstration plans, and anticipated degree of readiness for various conditions. It is recognized that substantial engineering judgment will be necessary to implement this approach and that uncertainty will exist with regard to the exact probability of occurrence of many of the postulated conditions; nevertheless, it is planned to apply this, or a similar framework, in advanced conceptual design studies.

8.3.5.2.2 Retrieval conditions

Estimates of the repository conditions at the time of retrieval are important for use as input to the design basis and demonstration plans. The retrieval conditions are divided into two categories: normal and off-normal. Normal conditions are those conditions under which the retrieval process can be performed using standard (essentially, the emplacement equipment) equipment and procedures. Off-normal conditions exist when nonstandard equipment and procedures are required.

The basic approach to the development of the normal conditions involves the following: (1) the identification of the repository systems important to the performance of the retrieval process (2) the prediction of the condition of those systems at the time of retrieval. The repository systems were identified by evaluating the ability to perform the four major functions for retrieval using the SCP-CD concepts as a basis. The prediction of the condition of these systems was accomplished using current design information, completed analyses, and engineering judgment.

| PROBABILITY | | $10^{-1}$ | $10^{-3}$ | $10^{-5}$ |
| --- | --- | --- | --- | --- |
| CONDITION CLASSIFICATION | NORMAL | EXPECTED OFF-NORMAL | CREDIBLE OFF-NORMAL | NOT CREDIBLE |
| DESIGN APPROACH | DESIGN BASIS | | CONTINGENCY | NOT INCLUDED |
| DEGREE OF READINESS | ESTABLISHED EQUIPMENT ESTABLISHED OPERATIONS | | EQUIPMENT CONCEPTS OPERATIONS CONCEPTS | DEVELOP CONDITION SPECIFIC PLAN |
| DEMONSTRATION PLANS | PROOF-OF-PRINCIPLE DEMONSTRATIONS AND (AS NEEDED) PROTOTYPE DEMONSTRATIONS | | PROOF-OF-PRINCIPLE DEMONSTRATIONS (IF NEEDED) | NONE |

Figure 8-6. Classification of retrieval conditions on the basis of probability (original figure).

The off-normal conditions were identified using the approach discussed in Appendix L. As shown in Appendix L, a short list of potentially credible processes and events was developed by screening approximately 75 events and processes contained in the master list. To identify potential off-normal conditions, the short list of processes and events were evaluated relative to the ability to perform the four retrieval functions. The potential off-normal conditions were screened on a probability basis, resulting in the determination of potentially credible off-normal conditions.

The basis for the identification of normal and off-normal conditions was the regulatory requirements, results from technical analyses, results of literature reviews, the SCP-CD and engineering judgment.

Normal retrieval conditions

As mentioned previously, normal conditions are those conditions under which the retrieval process can be performed using standard equipment and procedures. The system elements whose performance and, as a result, condition could affect the ability to retrieve include ramp and drifts, emplacement boreholes, ventilation system, including the shafts, waste-handling building, retrieval equipment, and the waste container. A complete discussion of current normal conditions for retrieval is presented in Appendix J. In this section, a brief discussion on the normal conditions for these elements is presented.

Ramps and drifts

The normal conditions within the ramps and drifts are characterized in terms of (1) rock temperature in the drifts, (2) condition of the opening, (3) radiation levels, and (4) air quality.

The basis for retrievability planning is tied to the current conceptual design results as follows:

1. The anticipated temperatures for the floor of the emplacement drifts and the wall of the access drifts for vertical emplacement and for the emplacement drift floor for horizontal emplacement are addressed in SCP Section 8.3.5.2. As shown in Appendix J, the goal to limit the temperature to 50°C at 50 yr in the access drifts for vertical emplacement and in the emplacement drifts for horizontal emplacement is met.

2. Under normal conditions, current design calculations suggest that the ramp and drifts are expected to remain stable. It is anticipated that small pieces of rock will fall through the holes in the wire mesh. This will be managed with light maintenance. It is also expected that in local, more highly fractured areas, more extensive and frequent maintenance may be required.

3. For normal conditions, personal radiation protection will be the same during retrieval as that required for emplacement operations (Dennis et al., 1984a). The radiological environments for worker safety are addressed under Issue 2.2 while the design for radiological safety is addressed under Issue 2.7.

4. Acceptable air quality will be maintained in all operational areas during retrieval operations. In the ramp, service areas, and access drifts, acceptable air quality will be maintained until repository closure, through the use of continuous ventilation. However, there are no plans to ventilate the emplacement drifts during the caretaker period. Therefore, ventilation will be reestablished to ensure that an acceptable air quality exists before reentry for initiation of retrieval operations will be allowed.

Emplacement boreholes

The conditions within the emplacement boreholes are characterized in terms of (1) rock temperature, (2) condition of the opening, (3) radiation levels, and (4) condition of the borehole liner.

The basis for retrievability planning under normal conditions is tied to the current conceptual design as follows:

1. The predicted temperature histories for the emplacement boreholes for the vertical and horizontal emplacement concepts are shown in Appendix J. The temperature remains above 100°C throughout the retrievability period, therefore, a dry environment is expected.

2. For the vertical emplacement concept, the borehole will be stable with negligible amounts of rockfall into the emplacement borehole under normal conditions. For the horizontal concept, minor rockfall against the liner is anticipated. In addition, as noted previously, a dry environment, as a result of high temperatures, is expected.

3. At the time of emplacement, order-of-magnitude estimates of the waste container surface radiation dose rates for spent fuel are $10^5$ rem/h for gamma and $10^2$ rem/h for neutron radiation (O'Brien, 1985). These surface radiation levels are used as the worst-case levels for shielding design.

4. Under normal conditions, the liner will be intact and provide acceptable access to the emplaced waste containers throughout the design basis 84-yr period.

Ventilation system

The ventilation system equipment (fans, regulators, chillers, etc.) will continue providing ventilation to the ramp and access drifts throughout the caretaker period. In addition, the distribution and regulation system to the emplacement drifts will be used on a periodic basis for inspection and maintenance of the emplacement drifts. As a result, the emplacement ventilation system including the shafts and ramps will be maintained in a fully operational condition throughout the caretaker period.

Waste-handling building

If waste emplacement operations are in progress, it is expected that the waste-handling building, and the equipment contained within it, will be in operable condition. However, it is anticipated that extensive modifications and additional construction would be necessary to accommodate the retrieval operations. During the caretaker period, it is assumed that maintenance and repair will have been performed only to maintain the structure; therefore, repair and maintenance may be required to bring the waste-handling equipment within the building to an operational state.

Retrieval equipment

If waste emplacement operations are in progress, the equipment required for waste removal under normal conditions (the emplacement equipment) will be in an operational condition. During the caretaker phase, it is anticipated that two sets of retrieval equipment will remain operational in support of the performance confirmation program. For full-repository retrieval initiated during the caretaker phase, it is anticipated that maintenance and repair will be required to achieve an operational condition for the other two sets of retrieval equipment, assuming the current design basis that four sets will be required. In addition, training of additional operators probably will be required.

For the horizontal concept, under normal conditions, the dolly and the dolly hook, described in Section 4.5 of this report, are not expected to fail during retrieval operations. The current planning basis for the dolly roller system under normal conditions is that it will be operable during retrieval operations; however, sliding friction, not rolling friction is assumed in establishing design loads for the emplacement or retrieval mechanism in the transporter.

Waste container condition

Under normal conditions, the waste container is expected to remain intact throughout the retrievability period and the removal process.

Off-normal retrieval conditions

As mentioned previously, off-normal conditions exist when the retrieval process must be performed using nonstandard equipment or procedures. The current development of off-normal retrieval conditions was part of the retrievability evaluation presented in Appendix L. As shown in Figure 8-7, the first step was to develop a comprehensive list of processes and events that could potentially lead to a delay in retrieval operations. These events and processes were categorized as naturally occurring, human-induced, and repository-induced. Input for this master list was obtained from literature surveys, engineers involved in developing retrieval equipment and operations, working sessions with engineering professionals, and peer and management reviews of the master list. The resulting master list of approximately 75 events and processes is shown in Table 4-1 of Appendix L. This master list then was screened using the set of criteria shown in Table 4-2 of Appendix L to eliminate from further consideration those events and processes that, under current

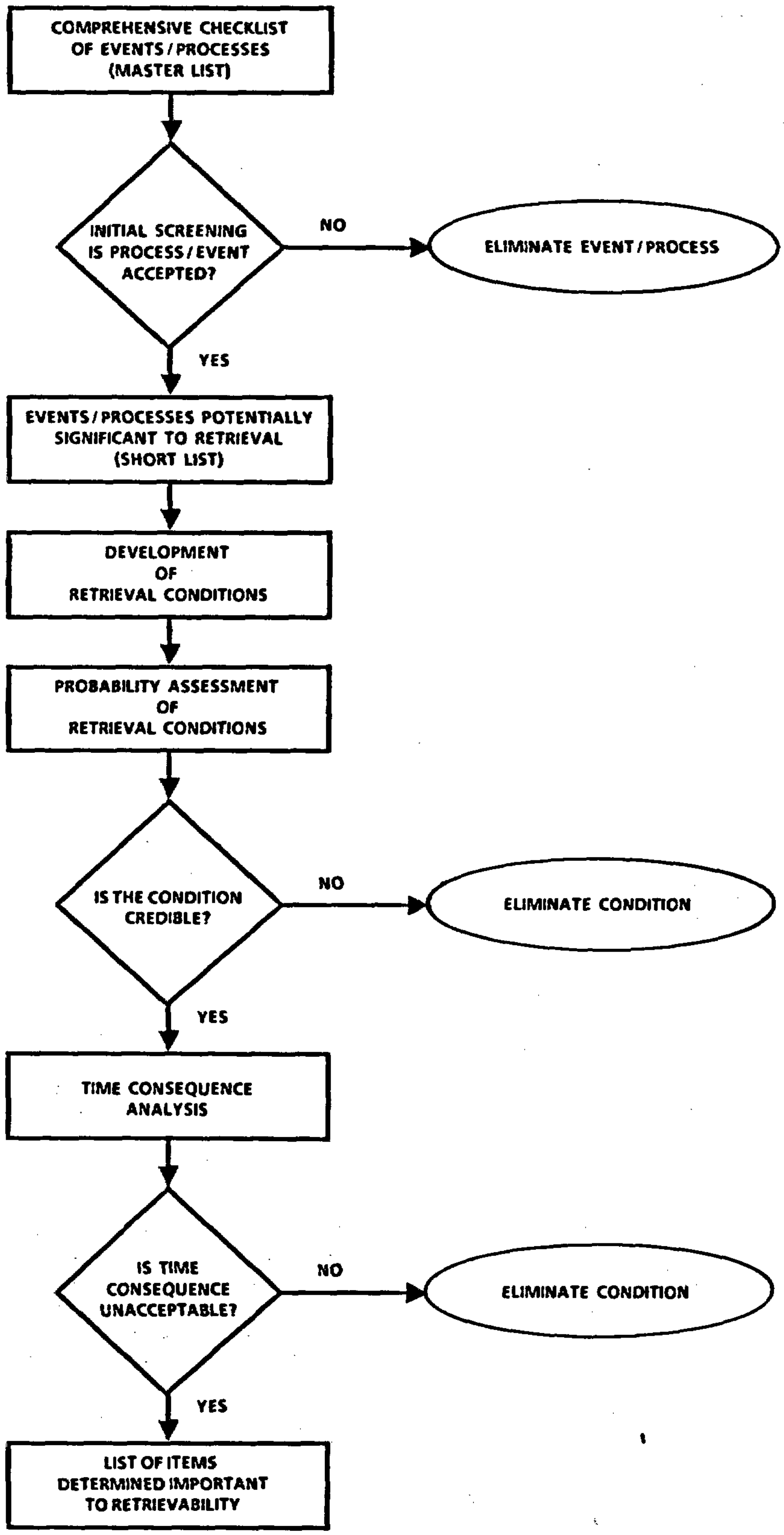


Figure 8-7. Methodology used to determine items important to retrievability (original figure).

design concepts and understanding of site processes, either were not applicable to the Yucca Mountain site or obviously resulted in an insignificant time delay in retrieval operations. This screening resulted in the short list of processes and events that could potentially lead to a significant time delay in performing retrieval operations. The events and processes on the short list are as follows:

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

Consequences of these events and processes (e.g., waste package failure) are addressed in more detail of Appendix L. The next step involved identifying retrieval conditions that result from the events and processes identified in the short list. These conditions were developed by examining the effects of these events and processes on the ability to perform the following four retrieval functions: (1) access to the emplacement boreholes, (2) access to the waste containers, (3) ability to remove waste containers, and (4) return waste containers to the surface. Using engineering judgment and the SCP-CDR as a basis, a list of approximately 110 potential off-normal conditions was developed. These conditions are presented in Table 4-5 of Appendix L-2. These conditions were then assigned a probability of occurrence using engineering judgment. These estimates of probability were assigned using qualitative descriptions of high, medium, low, and negligible. Negligible was considered to be less than $10^{-5}$/yr. Conditions that were judged to have a negligible probability of occurrence were removed from further consideration. Retrieval conditions judged to have a medium or low probability of occurrence were classified as off-normal. A list of the 43 identified off-normal conditions is contained in Table 3-1 of Appendix J. Retrieval conditions judged to have a high probability of occurrence were classified as normal conditions and, if not already included in the design basis for retrieval, will be added. A time consequence analysis was performed to estimate the delay in total time for performing the retrieval operations for the repository resulting from the identified off-normal conditions. The following six conditions were judged to have a potential time consequence of six months or greater:

1. Ventilation equipment failure as the result of a tectonic (ground motion) event.

2. Emplacement borehole rockfall as the result of a tectonic (ground motion) event (vertical only).

3. Waste container "tilt" as the result of a tectonic (ground motion) event (vertical only).

4. Shield plug jam as the result of a tectonic (ground motion) event.

5. Ventilation system failure as the result of a human error related to maintenance.

6. Transporter collision with the ramp as the result of an operator error.

The off-normal conditions presented in Appendix J have been used to guide the development of off-normal retrieval operations and equipment needs. In the future, Table 3-9 of Appendix L will be used as a starting point for the application of probability evaluations shown in Figure 8-7. The application of these concepts will result in the development of more detailed design and operational criteria for equipment and facilities, more accurate guidance for equipment development requirements and demonstration needs, and a firm basis for deciding what equipment will be on hand at the repository.

8.3.5.2.3 Retrievability input to repository design requirements

The development of retrievability-related design criteria began during early design stages and has become more specific as the design has evolved. The current set of design criteria was refined as a result of the performance allocation process described in SCP Section 8.3.5.2. In the future, this set of design criteria will be refined using the concept shown in Figure 8-6 and discussed in Appendix J.

The basis or data used in the development of the design criteria include the regulations concerning retrievability (Section 2.6.1 of this report), the SCP-CDR design, Appendix D of the Generic Requirements (GR) document (DOE, 1986d) and the Mission Plan (DOE, 1985).

The early designs that reflected the inclusion of retrievability-related design criteria were the Repository Design Concepts Report (Jackson, 1984) and the Two-Stage Repository Report (SNL, 1986).

8.3.5.2.4 Retrievability compliance analysis

Under Issue 2.4 the reference design and the results of analyses, tests, and demonstrations performed under Issue 4.4 are evaluated to determine if the goals for retrievability are met. This is accomplished during the compliance assessment activity shown in Figure 8-5. To effectively communicate between Issues 2.4 and 4.4, the concept of an input item is used. As shown in Figure 8-5, a list of input items is generated under Issue 2.4 to identify the information required from other issues to perform the retrievability compliance analysis. The current list of approximately 20 input items was developed in SCP Section 8.3.5.2. For example, to ensure that the design will provide usable openings, a need is generated to provide opening and support system designs, perform analyses to predict their performance, develop contingency plans for off-normal conditions, and provide supporting evidence that the design will be satisfactory (i.e., the performance goals are met), which would be performed under Issue 4.4. A complete discussion of these input items is included in SCP Sections 8.3.5.2.2 through 8.3.5.2.6.

Work toward providing these input items has been completed in the following areas: (1) underground opening design, (2) ventilation system design, (3) radiological protection, and (4) equipment development.

Underground opening design

Information on the stability of the underground openings is required both to perform the first retrieval function (i.e., to ensure that the access and drifts will be usable throughout the retrievability period) and to provide information concerning emplacement borehole stability for the second function--access to the waste container.

Evaluations of the thermal and mechanical effects on stability of shafts, ramps, drifts, and boreholes have been the focus of about 15 reports or studies synopsized in Section 8.3.7.2 and are not repeated here. These analyses have used a variety of numerical and empirical approaches as follows: (1) finite-element methods, (2) boundary-element methods, and (3) tunnel-indexing methods. Similarly, different constitutive models were used as follows: (1) elastic models, (2) ubiquitous-joint models, (3) compliant-joint models, and (4) elastic-plastic models. Other items that have been varied in some of the analyses include: (1) opening sizes and shapes, (2) depths, (3) thermal and mechanical properties, and (4) fracture properties and in situ conditions. The common preliminary conclusions drawn from the approaches used to date are as follows:

1. Drifts, shafts, and ramps, as currently designed, are predicted to remain stable during preclosure.

2. Waste emplacement boreholes are predicted to remain stable during preclosure, although some potential exists for negligible amounts of rock to fall on the liner planned for use in horizontal emplacement holes.

3. Excavation-induced response of openings in Topopah Spring tuff should be expected to be similar to those in the Grouse Canyon tuff in G-Tunnel.

Ventilation system design

Evaluations of the ventilation system design are required to determine the feasibility of providing a safe working environment for retrieval operations. The status of these evaluations is presented in Section 3.4 of this report. Detailed analyses are documented in Appendix C. The principal results related to retrievability are synopsized in the following text.

The design of the ventilation system has considered three different sets of operations conditions: (1) for construction and emplacement operations, (2) for reentry for inspection, and (3) for maintenance and retrieval operations. Preliminary ventilation system design analyses have been completed for both the vertical and horizontal emplacement orientations. For construction and emplacement operations, maximum velocity constraints are met and requirements to provide acceptable airflow to the ramp, drifts, and service areas are met using currently available equipment.

To ensure that continued access to the emplacement boreholes is maintained, reentry for inspection purposes is planned. The criteria for an acceptable inspection environment was defined as an air cooling power greater than 300 $W/m^2$ and a dry bulb temperature less than 45°C. As shown in Section 3.4, using ambient air, it would take 168 d and 14 d to cool the vertical and horizontal emplacement drifts, respectively. Using chillers, it would take 21 d and 5 d to cool the vertical and horizontal emplacement drifts, respectively. This is based on a 708-kW cooling load for vertical emplacement and a 490-kW cooling load for horizontal emplacement.

For reentry for maintenance or retrieval purposes, the criteria for an acceptable environment is defined as an air cooling power greater than 500 $W/m^2$ and a dry bulb temperature less than 40°C. As shown in Section 3.4, more than 560 d are required to cool the vertical emplacement drifts using ambient air. The horizontal emplacement drifts would require 70 d for cooling using ambient air. Assuming a 708-kW cooling load, the vertical emplacement drift can be cooled in approximately 37 d. For the horizontal concept, the emplacement drifts can be cooled within 11 d using a 490-kW cooling load.

The results of these preliminary analyses indicate that the requirements for providing adequate ventilation can be met for inspection and retrieval operations using currently available equipment. Future work will focus on refinement of these analyses with specific attention paid to the following items:

1. Particulates (burden and type).
2. Temperature.
3. Humidity.
4. Airborn radioactive contaminants.
5. Gaseous pollutants.

<u>Radiologic protection</u>

The basic approach to ensuring radiological protection is as follows: (1) identify radiation sources under normal and accident conditions, (2) establish the radiation levels for these sources, and (3) develop designs and operations plans that result in the ability to perform retrieval under an acceptable radiological environment.

The reports that address radiological concerns include the following:

1. "Reference Nuclear Waste Description for a Geologic Repository at Yucca Mountain, Nevada," SAND84-1848

2. "Preliminary Safety Assessment Study for the Conceptual Design of a Repository in Tuff at Yucca Mountain," SAND83-1504

3. "NNWSI Repository Worker Radiation Exposure Volume I, Spent Fuel and High-Level Waste Operations in a Geologic Repository in Tuff," SAND83-7436/1

4. "Worker Radiation Dose During Vertical Emplacement and Retrieval of Spent Fuel at the Tuff Repository," SAND84-2275

5. "Preliminary Preclosure Radiological Safety Analysis," prepared by Bechtel National, Inc., for Sandia National Laboratories, Albuquerque, New Mexico, Appendix F of this report

6. "Items Important to Safety and Retrievability for the Yucca Mountain Repository," prepared by Bechtel National, Inc., for Sandia National Laboratories, Albuquerque, New Mexico, Appendix L of this report

Radiation sources in the repository are categorized as follows: (1) waste generated and (2) naturally occurring. Estimates of the source term for the waste containers are reported in O'Brien, 1985. These estimates will be used as a basis for radiation shield designs for retrieval equipment. Worker dose estimates are contained in Jackson et al. (1984), Dennis et al. (1984a), and Stinebaugh and Frostenson (1986). These studies indicate that radiation doses of less than 1 rem/yr are possible through modifications in operations or equipment. Preliminary results of studies to identify accidents during retrieval operations, which result in radioactive releases are discussed in Appendices F and L.

Future work will include refinement of public and worker dose-rate estimates, detailed equipment shielding designs, and refinement of accident analyses. The principal concern for naturally occurring radiation sources is the potential contamination from radon-222 and radon daughters. No work in this area has yet been completed. Current work is focused on estimation of the emanation rate for radon-222 and its potential effect on repository operations. This work will include G-Tunnel tests and tests at the exploratory shaft facility (SCP Section 8.3.1.15, rock characteristics program).

Equipment development

The development of equipment is achieved in the following phases:

1. Development of equipment concepts.
2. Conceptual design.
3. Interim design phases (proof-of-principle, prototype, etc.).
4. Final design.

Retrieval equipment development is performed under Issue 4.4 (preclosure design and technical feasibility). Work on equipment development is progressing in two areas: (1) the development of equipment for emplacement and retrieval of wastes and (2) the development of equipment to accurately drill and line long horizontal emplacement boreholes. The equipment related to drilling and lining horizontal emplacement boreholes is included here since the requirement to line the boreholes is principally related to ensuring access to the waste containers for possible retrieval. The concepts for equipment for emplacement and retrieval of waste have been developed and are presented in the following documents:

1. "Conceptual Engineering Studies and Design for Three Different Machines for Nuclear Waste Transporting, Emplacement, and Retrieval," SAND83-7089 (Fisk et al., 1985).

2. "Disposal of Radioactive Waste Packages in Vertical Boreholes--A Description of the Operations and Equipment for Emplacement and Retrieval," SAND84-1010, May 1986, (Stinebaugh and Frostenson, 1986).

3. "Disposal of Radioactive Waste Packages in Horizontal Boreholes--A Description of the Operations and Equipment for Emplacement and Retrieval," SAND84-2640, May 1986, (Stinebaugh et al., 1986).

4. "One-Twelfth-Scale Model of the Horizontal Emplacement and Retrieval Equipment for Radioactive Waste Packages at the Proposed Repository in Tuff," SAND86-7135, (White et al., 1986).

Preliminary conceptual designs for retrieval equipment are presented in Stinebaugh and Frostenson (1986), Stinebaugh et al. (1986), and Appendix E. In addition, a one-twelfth-scale model of the waste emplacement and retrieval equipment for horizontal emplacement has been completed (White et al., 1986). This model is being used to gain perspective on design features that need modification. Future work will focus on developing design concepts that allow retrieval under off-normal conditions and completing conceptual designs of retrieval equipment for normal conditions during advanced conceptual design.

The work that has been completed on the development of drilling and lining equipment for the horizontal boreholes is presented in the following documents:

1. "Small Diameter Horizontal Hole Drilling--State of Technology," SAND84-7103 (Robbins Company, 1984b).

2. "Feasibility Studies and Conceptual Design for Placing Steel Liner in Long, Horizontal Boreholes for a Prospective Nuclear Waste Repository in Tuff," SAND84-7209 (Robbins Company, 1985).

3. "Installation of Steel Liner in Blind Hole Study," SAND85-7111 (Kenny Construction Company, 1987).

4. "Design of a Machine to Bore and Line a Long Horizontal Hole in Tuff," SAND86-7004 (Robbins Company, 1987).

A detailed design for the drill and lining system has been completed. Current work involves fabrication and testing of a prototype of the drill, which will be followed by additional testing in G-Tunnel at the Nevada Test Site. This work is being performed under Issue 4.4 (preclosure design and technical feasibility).

#### 8.3.5.3 Future work

The future work that is planned under Issue 2.4 will focus on (1) further development of tactics and corresponding schedules that ensure that the work required to support resolution of Issue 2.4 is clearly identified and is completed on a schedule consistent with that for the NNWSI

Project; (2) refinement of retrieval conditions, both normal and off-normal; (3) refinement of design criteria; (4) continued review of the results from Issue 4.4 for the defined input items to ensure that the established performance goals are met; and (5) development of a report that assesses compliance concerns relative to retrievability.

Retrieval planning and strategy documents

Before development of the advanced conceptual design, the strategy for meeting the regulatory requirements and for implementing the requirements contained in the DOE position on retrieval and retrievability, will be described in a future NNWSI retrieval strategy document.

During advanced conceptual design, the tactics for implementation of the retrieval philosophy outlined in Section 2.4.4 will be defined in more detail and presented in the retrieval implementation plan. This plan will address requirements for design development, equipment development, demonstrations, retrieval condition evaluation, and supportive studies.

Retrieval conditions

In the future, the classification of retrieval conditions will use the probability-based approach presented in Figure 8-6. Additional development of design detail for equipment, especially for off-normal operations, and additional evaluation of potential conditions is required during ACD. (In future documents, including the ACD report, the term off-normal will be replaced with the term abnormal.) This will allow classification of potential conditions as normal, abnormal (expected and credible), or not credible. The classification of these retrieval conditions will use an identification concept similar to the one used to date for identifying items important to retrievability (Appendix L). The results of future work will be presented in two reports describing retrieval conditions. The first report will be generated during advanced conceptual design; a second report is planned in support of the license application design.

Retrievability input to subsystem design requirements

The repository design requirement (RDR) report will be periodically updated as additional or modified requirements are developed. Most of the retrievability-related changes are expected to result from additional definition of equipment concepts and retrieval conditions. The resulting modifications to the retrievability-related design criteria will be forwarded to the RDR authors for review and publication in periodic updates.

Retrievability compliance analysis

A preliminary report addressing the status of compliance with the retrievability requirement will be issued at the completion of advanced conceptual design. An additional report on compliance will be completed as part of the license application design.

## 8.3.6 ISSUE 4.2: NONRADIOLOGICAL HEALTH AND SAFETY

### 8.3.6.1 Introduction

The question asked by Issue 4.2 is

> Are the repository design and operating procedures developed to ensure nonradiological health and safety of workers adequately established for the resolution of the performance issue?

The complete discussion of the proposed strategy for the resolution of this issue is presented in SCP Section 8.3.2.4 (nonradiological health and safety). Readers unfamiliar with the issue resolution strategy for this issue should review the contents of SCP Section 8.3.2.4 before continuing.

Issue 4.2 has been subdivided into three information needs, and the completed work has been identified under the associated information need. The completed work is numbered in a manner that corresponds with the information need numbering system. For example, 4.2.3-1 is the first completed work identified under the third information need of Issue 4.2. The information needs are the following:

Information Need 4.2.1 Site and performance information needed for design

This informaion need consists of (1) compiling the site characterization and performance assessment information identified in the other information needs under Issue 4.2 into a single integrated list and (2) reviewing the proposed site characterization program and performance assessment program to ensure that the actions required to obtain the site characterization information and to provide the required performance assessment information are incorporated in these programs. Work completed to date has focused on the safety aspects of excavation stability. The site characterization and performance assessment information needed for design is identified in SCP Section 8.3.2.4.1.

Information Need 4.2.2 Potential nonradiological hazards to personnel

The repository design and operating procedures will be reviewed to determine nonradiological hazards to personnel. The risk to personnel from a given nonradiological hazard then will be determined by (1) calculating the probability of occurrence of the event identified as a personnel hazard, (2) determining the consequences of the event, and (3) multiplying the probability of an event occurrence and the consequences of the event. If the risk is determined to be unacceptable, a change will be incorporated in the repository design and the repository operating procedures. The work completed to date for this informaton need has focused primarily on the identification of events that could have hazards associated with excavation stability.

Information Need 4.2.3 Design measures for avoiding or mitigating hazards to personnel

| Number | Description |
|---|---|
| 4.2.3-1 | The design analysis work describes the approach being used in the design of the underground openings and the underground ventilation system. |
| 4.2.3-2 | Other work describes the approach being used to develop design criteria that address worker nonradiological health and safety concerns. |

Section 8.3.6.2 summarizes the completed work that is pertinent to the resolution of Issue 4.2. Section 8.3.6.3 identifies future work that will provide additional information for use in the enhancement of worker nonradiological health and safety.

### 8.3.6.2 Work completed

#### 8.3.6.2.1 Design analysis work

Work has been completed in the following areas.

Underground openings

The concern in the design of the underground openings is that they are stable and usable for the life of the repository. For personnel safety, stability implies that (1) no localized rock fall of a size sufficient to cause serious personnel injuries will occur, and (2) no catastrophic failure of the openings that could block personnel access and egress will occur.

The analyses that are being made to assure that the design results in underground openings that are stable and, thus, safe, is the same work that is done to support the conclusion that the openings can be designed, constructed, and used for the life of the repository using currently available technology. This work is presented in Sections 8.3.7.2, Technical Feasibility--Work Completed and SCP Section 8.3.2.5.7, Design analysis. The data required to do these calculations are specified in SCP Section 8.3.2.5.1, Site Information needed for design. The conclusion drawn from this work is that the underground openings will be stable and usable for the life of the repository; this conclusion translates further into the conclusion that the drifts will be safe for repository workers. The results of these calculations are discussed in detail in Section 8.3.7.2 of this report.

Potential hazards to excavation workers

To evaluate the potential hazards to excavation workers at Yucca Mountain, excavation experience in the welded and nonwelded tuffs at the NTS that have been used for weapons-effect testing has been examined. The safety records show that in the past such excavations have been carried out with minimum adverse effects on worker safety. To assess the relative level of safety for tunneling operations at the NTS, the incidence rates for NTS operations can be compared with injury incidence rates for similar mining operations. Such a comparison was presented in Figure 6-27 of the environmental assessment for the Yucca Mountain site (DOE, 1986c). The industry category that is most similar to excavation conditions in the tuffs at NTS is the category of hard-rock metal mining. The data presented in the environmental assessment are based upon industry average data compiled by the National Safety Council and data for NTS operations compiled by Reynolds Electric and Engineering Co. (REECo), the DOE contractor for excavation operations. The data presented clearly indicate a significantly better safety record for NTS tunneling operations than is typical of industry practice. While the industry average incidence rate is lower now than it was 20 yr ago by a factor of about two, NTS operational safety record is still lower than the industry average by a factor of about three.

Specific excavation experience in G-Tunnel at the NTS is of interest because part of the G-Tunnel experience involves a welded tuff, the Grouse Canyon Member. Engineers and geologists familiar with excavation in the welded Grouse Canyon Member have expressed the opinion that the ground support that will be required in the Topopah Spring Member at Yucca Mountain is likely to be similar to that required in the welded Grouse Canyon Member. None of the accidents identified in a search of tunnel records could be considered to be caused by unstable ground, faulting, or other such geologically related conditions. This was observed to be consistent with the period between approximately 1965 and 1985 for NTS operational experience. The one accident that involved the falling of a piece of rock was the result of an oversight in barring down loose rock before support installation. The accident report in question indicates that this accident probably would not have occurred if the correct NTS mining practice had been followed (DOE, 1986c).

Faults and shear zones that could compromise the safety of repository personnel because of construction problems or water inflow are not expected in the primary repository area at Yucca Mountain. The design and layout of the underground facility is planned to minimize contact with portions of the host rock where minor faults and shear zones are identified. There is to date no indication that pressurized brine pockets, evidence of dissolution, or significant accumulations of water or toxic gases are present in the repository horizon.

Underground ventilation system

Other significant physical or chemical phenomena known to be associated with rock characteristics are related to ventilation-system design and worker safety. The temperature increases resulting from the emplaced waste are important in designing ventilation systems and in selecting the standoff distance between the drift and the emplaced waste. Excavations at the NTS show that explosive or other hazardous gases are not to be expected. Thus, the ventilation system will primarily control dust. Hazards associated with dust and hazards associated with naturally occurring radon released during rock excavation will be mitigated by supplying adequate flow volumes to meet safety requirements. Techniques already implemented in the uranium mining industry will be considered. The proper design and operation of a ventilation system based on current technology should readily mitigate dust and radiation concerns.

The results obtained from the analyses performed to verify that the ventilation of the underground repository facility could be accomplished using reasonably available technology are applicable in the resolution of Issue 4.2. These results are given in Section 8.3.7.2. The goal imposed on the design of the underground ventilation system is that adequate air must be supplied to the workers under the most extreme operational conditions. The analyses indicate that this goal can be achieved.

#### 8.3.6.2.2 Other work supporting the conceptual design

The work, other than analyses, that has been completed consists primarily of identifying legislative and regulatory requirements governing worker safety. These requirements have been incorporated in the subsystems design requirements document (Appendix P), the design criteria for the repository. These requirements are summarized in SCP Section 8.3.2.5.4 (repository design requirements). The operational plan, SCP Section 8.3.2.5.3 (plan for repository operations), also is influenced by these legislative and regulatory requirements.

### 8.3.6.3 Future work

Underground opening stability

Basically, two things need to be done in relation to the design of the underground openings:

1. Further work needs to be done with the rock mass classification methods. This work should be directed at obtaining additional data from comparable underground facilities to increase the data base on which projections of stability and the design of the support systems can be based.

2. Additional work needs to be done to verify the codes used to analyze the performance of the underground openings. This verification work can be accomplished in two ways: (a) by monitoring demonstration openings driven in the exploratory shaft facility, and (b) by applying the analyses techniques to previously driven openings and comparing the analytical results with the observed results.

Underground ventilation systems

Additional work needs to be done to quantify the potential radon gas burden on the ventilation system. The particulates generated during construction and operation need to be qualified and quantified.

The required efforts identified here are discussed in more detail in Section 8.3.7.3.1.

## 8.3.7 ISSUE 4.4: PRECLOSURE DESIGN AND TECHNICAL FEASIBILITY

### 8.3.7.1 Introduction

The question asked by Issue 4.4 is

Are the technologies for repository construction, operation, closure, and decommissioning adequately established for resolution of the performance issues?

The complete discussion of the proposed strategy for resolution of this issue is presented in SCP Section 8.3.2.5 (preclosure design technical feasibility). Readers unfamiliar with the issue resolution strategy for this issue should review the contents of SCP Section 8.3.2.5 before continuing.

Issue 4.4 has been subdivided into 10 information needs. Several of the information needs address the concept of reasonably available technology. Evaluations of whether satisfaction of an information need can be achieved using reasonably available technology will be based upon the 10 CFR Part 960 definition: Reasonably available technology means technology which exists and has been demonstrated or for which the results of any requisite development, demonstration, or confirmatory testing efforts will be available before license application.

The completed work has been identified under the associated information need. The complete work elements are numbered in a manner that corresponds with the information need numbering system. For example, 4.4.2-1 is the first completed work identified under the second information need of Issue 4.4. The information needs and completed work are the following:

Information Need 4.4.1 Site and performance assessment information needed for design.

This information need consists of (1) compilation of the site characterization and performance assessment information identified in the remaining Issue 4.4 information needs into a single integrated list and (2) the review of the proposed site characterization program and performance assessment program to ensure that the actions required to obtain the site characterization information and to provide the required performance assessment information are incorporated in these programs. This work has not been completed; the site characterization and performance assessment information needed for design is identified in SCP Section 8.3.2.5.1.

Information Need 4.4.2 Characteristics and quantities of waste and waste packages needed for design.

| Number | Description |
|---|---|
| 4.4.2-1 | The preliminary reference waste descriptions document (O'Brien, 1984) contains a description of the waste type and waste containers. |
| 4.4.2-2 | The reference nuclear waste descriptions document (O'Brien, 1985) contains a description of the waste being considered for disposal at the mined geological disposal system (MGDS) site. |
| 4.4.2-3 | Section 2.1 (waste form and package) contains a summary description of the waste form and waste package used as a basis for conceptual design of surface and subsurface facilities. |

Additional information on Information Need 4.4.2 is presented in SCP Section 8.3.2.5.2.

Information Need 4.4.3 Plan for repository operations during construction, operations, closure, and decommissioning.

| Number | Description |
|---|---|
| 4.4.3-1 | The operational procedures for receiving, packaging, emplacing, and retrieving waste describe these operations as they were understood at the beginning of the conceptual design phase. |
| 4.4.3-2 | Chapter 3 of this report provides an overview of the principal operations and functions that will be performed in the repository. |

Additional information on Information Need 4.4.3 is presented in SCP Section 8.3.2.5.3.

Information Need 4.4.4 Repository design requirements for construction, operations, closure, and decommissioning.

| Number | Description |
|---|---|
| 4.4.4-1 | Chapter 2 of this report (bases for the SCP conceptual design) contains a documentation of the reference values and design assumptions used in the conceptual design of the MGDS facilities. |

Additional information on Information Need 4.4.4 is presented in SCP Section 8.3.2.5.4.

Information Need 4.4.5 Reference preclosure repository design.

| Number | Description |
|---|---|
| 4.4.5-1 | The repository reference designs that formed the basis for the repository conceptual design are addressed. |
| 4.4.5-2 | Chapter 4 of this report presents a description and discussion of the conceptual design. |

Additional information on Information Need 4.4.5 is presented in SCP Section 8.3.2.5.5.

Information Need 4.4.6 Development and demonstration of required equipment.

| Number | Description |
|---|---|
| 4.4.6-1 | The conceptual designs for the waste receiving and preparation equipment address the equipment necessary to receive the waste and prepare the waste for emplacement. |

4.4.6-2 The conceptual designs for the waste emplacement and retrieval equipment address equipment necessary to transport the waste underground; emplace the waste; and, if directed, retrieve the waste.

4.4.6-3 The conceptual designs for the waste emplacement hole boring equipment are addressed.

Additional information on Information Need 4.4.6 is presented in SCP Section 8.3.2.5.6.

Information Need 4.4.7 Design analyses, including those addressing impacts of surface conditions, rock characteristics, hydrology, and tectonic activity.

| Number | Description |
|---|---|
| 4.4.7-1 | Structural, thermal, and thermomechanical analyses are addressed. |
| 4.4.7-2 | Ventilation analyses are addressed. |
| 4.4.7-3 | Hydrologic analyses are addressed. |
| 4.4.7-4 | Tectonic and seismic analyses are addressed. |

Additional information on Information Need 4.4.7 is presented in SCP Section 8.3.2.5.7.

Information Need 4.4.8 Identification of technologies for surface facility construction, operation, closure, and decommissioning.

This information need will review Information Needs 4.4.3 through 4.4.6 to determine if the technology used in the surface facilities design can be considered reasonably available technology.

Additional information on Information Need 4.4.8 is presented in SCP Section 8.3.2.5.8.

Information Need 4.4.9 Identification of technologies for underground facility construction, operation, closure, and decommissioning.

This information need will review Information Needs 4.4.3 through 4.4.6 to determine if the technology used in the underground facilities design can be considered reasonably available technology.

Additional information on Information Need 4.4.9 is presented in SCP Section 8.3.2.5.9.

Information Need 4.4.10 Identification of technologies for emplacement of seals for accesses, drifts, and boreholes.

This information need will review Information Needs 1.12.3 and 1.12.4 to determine if the technology used in the design and placement of seals can be considered reasonably available technology.

Additional information on Information Need 4.4.10 is presented in SCP Section 8.3.2.5.10.

Summary information describing the computer codes used in the analyses supporting the completed work elements previously identified is contained in Table 8-6.

8.3.7.2 <u>Work completed</u>

The following sections summarize the completed work for Issue 4.4.

8.3.7.2.1 Characteristics and quantities of waste and waste containers

4.4.2-1 Preliminary reference waste description

In the preliminary reference waste descriptions report, O'Brien (1984) describes the reference waste forms and containers for the early stages of conceptual design of a radioactive waste repository being considered for location in the tuff formations at Yucca Mountain. An assessment of the effects of nonreference waste characteristics on repository design is included.

4.4.2-2 Reference nuclear waste description

In the reference nuclear waste description document, O'Brien (1985) describes the reference wastes to be used as a basis for the conceptual design of a geologic repository being considered for location in the tuff formations at Yucca Mountain. Waste characteristics and production rates are taken from a DOE guidance document (DOE, 1984). This information is recast as waste receipt and emplacement schedules to be used in the design of repository facilities and equipment and as input to the timetable for repository development.

4.4.2-3 Characteristics and quantities of waste form and waste container

For the waste form and container, Section 2.1 of this report summarizes the characteristics and quantities of the wastes and waste packages that were used as a basis for the conceptual design of a geologic repository being considered for location in the tuff formations at Yucca Mountain.

8.3.7.2.2 Plans for repository operations

4.4.3-1 Operational procedures

For operational procedures for receiving, packaging, emplacing, and retrieving waste, Dennis et al., (1984c), was prepared for use by the designers of the surface and underground waste-handling facilities and equipment. This report describes the radioactive waste expected at the repository; the shipping casks and the facility casks; and the waste receiving, handling, packaging, transfer, and emplacement operations. Potential waste retrieval operations also are discussed.

Table 8-6. Computer codes used in analyses for Issue 4.4[a] (page 1 of 3)

| Code name | Author | Code location | Design parameter | Analysis description |
|---|---|---|---|---|
| VNETPC | J. McPherson | Mining Ventilation Services, Oakland, CA | Ambient mine ventilation requirements. | Simulates underground airflow distribution and calculates fan requirements and pressure loss. |
| CLIMSIM 2.0 | J. McPherson | Mining Ventilation Services, Oakland, CA | Drift cooling requirements. | Given wet- and dry-bulb temperatures of inlet air, the code simulates the psychrometric and environmental conditions in the airways. |
| ASHSD | Ghosh, Wilson | University of California at Berkeley, CA | Seismic analysis of structure-soil system. | Finite-element model. |
| PORFLOW-R | A.K. Runchal | ACRI, Los Angeles, CA | 2-D analysis of vertical emplacement drift. Thermal modeling | Finite-element heat transfer for 2-D nonlinear heat convection and conduction in a porous medium. |
| THERM3D | A.K. Runchal | ACRI, Los Angeles, CA No documentation available. | Thermal modeling and 3-D analysis of vertical emplacement drift. | Finite-element heat transfer for 3-D analysis. |
| TEMP3D | M. Christianson University of Minnesota | Public domain | Thermal modeling and 3-D analysis of vertical emplacement drift. | Computer program for determining temperatures around single or arrays of constant or decaying heat sources. Based in closed form solution. |
| ABAQUS | Hibbit, Karlsson, and Sorenson, Inc. | Hibbit, Karlsson, and Sorenson, Inc. | Displacements and stresses about underground openings. | Finite-element program for linear and nonlinear structural analysis. |
| SANCHO | C.M. Stone R.D. Kreig Z.E. Beisinger | Public domain | Displacements and stresses around underground openings. | Finite-element program to compute quasistatic, large deformation, inelastic response of planar or axisymmetric solids. |
| ADINAT | K.J. Bathe | MIT | Temperature surrounding underground openings, used in conjunction with ADINA. | Finite-element heat-transfer program. 2-D, 3-D; for automatic dynamic nonlinear heat conduction; convective and adiabatic boundaries; constant or decaying heat source. |
| HEFF | B.G.H. Brady University of Minnesota | Public domain | Effects of parameter uncertainty on drift stability. | Boundary-element stress analysis for 2-D thermoelastic analysis of a rock mass subject to constant or decaying thermal loading. |

Table 8-6. *Computer codes used in analyses for Issue 4.4*[a] (page 2 of 3)

| Code name | Author | Code location | Design parameter | Analysis description |
|---|---|---|---|---|
| ADINA | K.J. Bathe | MIT | Displacements and stresses about underground openings. | Finite-element stress analysis program. 2-D, 3-D; elastic elastic/plastic ubiquitous joint model; accepts precalculated temperature history. |
| STRESS3D | C. St.John<br>M.C. Christianson | University of Minnesota | Stress distribution for evaluation of usable emplacement area. | Computer program for determining temperatures, stresses, and displacements around single or arrays of constant or decaying heat sources. |
| LINED | C. St.John<br>J.F.T. Agapito and associates | Public domain | Linear integrity due to surrounding stress. | Static analysis of a tunnel with liner or damaged annulus. |
| BMINES | U.S. Bureau of Mines | Public domain | Rock bolt performance. | Computer program of analytic modeling of rock/structure interaction. |
| VISCOT | ONWI | Public domain | Displacements and stresses around underground openings. | Finite-element stress analysis program. Thermoviscoelastic, thermoviscoplastic; accepts precalculated temperature history. |
| DOT | University of California | Public domain | Used in conjunction with VISCOT. Time/temperature history (input for other stress codes). | General purpose heat conduction code for both linear and nonlinear steady-state or transient heat analysis. |
| SPECTROM-11 | RE/SPEC Albuquerque, NM | RE/SPEC No documentation available. | Displacements and stresses about underground openings. | Finite-element stress analysis program. Elastic, elastic/plastic, ubiquitous joint model; accepts precalculated temperature history. |
| SIM | Parsons Brinckerhoff Quade & Douglas, San Francisco, CA | PBQ&D - Parsons Brinckerhoff Quade & Douglas, | Rock temperature around borehole comparison with thermal limit of canister. | A linear superposition program for three dimensional heat conduction solutions with constant or decaying line heat sources. |
| COYOTE | D.K. Gartling Sandia National Laboratories | Public domain | Temperature around underground openings input for other stress codes. | Finite element computer program for nonlinear heat conduction problems. |

Table 8-6. Computer codes used in analyses for Issue 4.4[a] (page 3 of 3)

| Code name | Author | Code location | Design parameter | Analysis description |
|---|---|---|---|---|
| SPECTROM-41 | D.K. Svalstad RE/SPEC for ONWI Albuquerque, NM | RE/SPEC | Temperature surrounding an underground opening. | Finite-element heat transfer program. Nonlinear heat conduction; convective and adiabatic boundaries; constant or decaying heat source. |
| SPECTROM-31 | D.A. Labreche S.V. Petney RE/SPEC for SNL Albuquerque, NM | RE/SPEC | Displacements and stresses around underground openings. | Finite-element stress analysis program. Large deformation, static and quasi-static response of planar and axisymmetric solids; thermoelastic/plastic, ubiquitous joint model, compliant joint model; accepts precalculated temperature history. |
| JAC | J.H. Biffle Sandia National Laboratories | Public domain | Displacements and stresses around an underground opening. | Finite-element stress analysis program. Nonlinear quasi-static response of solids with the conjugate gradient method; elastic/plastic, ubiquitous joint model, compliant joint model; accepts precalculated temperature history. |
| FLUSH | J. Lysmer T. Udada C. Tsai H.B. Seed University of California at Berkeley, CA | J. Lysmer | Soil-structure interaction, license-application design. | 2-D finite-element soil/structure interaction program. |
| CLASSI | Luco and Wong University of California at San Diego, CA | Luco and Wong No documentation available. | Soil-structure interaction, license-application design. | 3-D soil/structure interaction analyses using frequency-dependent impedance functions. |

[a]ACRI = analytic and computational Research, Inc.; MIT = Massachussetts Institute of Technology; ONWI = Office of Nuclear Waste Isolation.

4.4.3-2 Principal operations and functions

Chapter 3 of this report provides an overview of the principal operations and functions that will be performed at the repository. These operations and functions include waste handling and emplacement, waste retrieval, mining, ventilation, and the equipment needed to perform these operations. Equipment and concepts requiring development are identified.

8.3.7.2.3 Repository design requirements

4.4.4-1 Reference values and design assumptions for conceptual design

Chapter 2 of this report documents the reference values and design assumptions used by the architect-engineer in the completion of the SCP conceptual design. Presented are the technical requirements and assumptions that are the bases for the repository design; the site constraints, assumptions, and data that affect the repository design or the approach to the design; and the reference geologic data used in the design.

8.3.7.2.4 Reference preclosure repository design

4.4.5-1 Repository reference designs forming basis of conceptual design

Repository reference designs are the basis for performance analyses, operational plans, costs estimates, and schedules. There have been two reference designs completed and documented prior to the third, as presented in this report for the proposed repository at Yucca Mountain:

1. Jackson, J. L., (compiler), 1984. "Nevada Nuclear Waste Storage Investigations Preliminary Repository Concepts Report," SAND83-1877, Sandia National Laboratories, Albuquerque, New Mexico.

2. SNL (Sandia National Laboratories), 1986. "Two-Stage Repository Development at Yucca Mountain: An Engineering Feasibility Study," SAND84-1351 Rev. 1, H. R. MacDougall, (compiler), Sandia National Laboratories, Albuquerque, New Mexico.

There is only one reference design for the repository at any one time. The current reference design for the proposed repository at Yucca Mountain is this report. The other two designs just identified have been superseded by this design and are no longer used as a basis for supporting calculations, operational plans, or cost estimates. The two obsolete designs are identified here as a part of the chronological record of the design evolution for the repository. In addition, studies supporting these two designs are often referenced in this report. Additional information on the philosophy for reference repository designs is given in SCP Section 8.3.2.5.5.

4.4.5-2 Conceptual design description

The design description is in Chapter 4 of this report, which describes the conceptual design of the repository, with emphasis on the excavations, facilities, systems, and equipment needed to perform the operations described in Chapter 3 of this report.

### 8.3.7.2.5 Development and demonstration of required equipment

#### 4.4.6-1 Waste receiving and preparation equipment

For waste receiving and preparation, the equipment that must be developed is primarily the remote manipulation equipment required for unloading, packaging, welding, inspection, and decontamination. This equipment is not unique in that essentially all the required components have been built and demonstrated in other applications. The design task for the repository at Yucca Mountain is to (1) configure this equipment to perform the required tasks in a safe and effective manner and (2) determine that the resulting equipment set will be capable of accommodating the projected waste throughputs. The work completed to this time relative to the receiving and preparation activity is the development of conceptual designs and the analysis of worker environments. This work is documented in the following reports:

1. Dennis, A. W., 1983. "Design Considerations for Occupational Exposure for a Potential Repository at Yucca Mountain, High-Level Waste Handling Operations," SAND83-0247C, Sandia National Laboratories, Albuquerque, New Mexico.

2. Dennis, A. W., R. Mulkin, and J. C. Frostenson, 1984b. "Operational Procedures for Receiving, Packaging, Emplacing, and Retrieving High-Level and Transuranic Wastes in a Geologic Repository in Tuff," SAND83-1982C, Sandia National Laboratories, Albuquerque, New Mexico.

3. Dennis, A. W., P. D. O'Brien, R. Mulkin, and J. C. Frostenson, 1984c. "NNWSI Repository Operational Procedures for Receiving, Packaging, Emplacing, and Retrieving High-Level and Transuranic Waste," SAND83-1166, Sandia National Laboratories, Albuquerque, New Mexico.

4. Dennis, A. W., J. C. Frostenson, and K. J. Hong, 1984a. "NNWSI Repository Worker Radiation Exposure, Volume 1, Spent Fuel and High-Level Waste Operations in a Geologic Repository in Tuff," SAND83-7436/1, Sandia National Laboratories, Albuquerque, New Mexico.

Current information supports a conclusion that the receiving and preparation tasks at the repository can be accomplished using reasonably available technology. The relevant considerations are the following:

1. The equipment design and operational procedures presented in the listed documents are based on commercially available equipment, such as manipulators, remote welders, and remote operated and programmable position cranes.

2. Operations are based on demonstrated procedures for handling of radioactive materials; such procedures include using shielding, placing operators in locations remote from the material being handled, and providing for remote replacement, repair, and maintenance of cell equipment.

3. The operations to be performed in receiving and preparing of the waste at the repository closely parallel the task of refueling nuclear power reactors; thus, the experience and the equipment developed to support refueling can be incorporated in the designs for receiving and preparation equipment.

4.4.6-2 Waste emplacement and retrieval equipment

For waste emplacement and retrieval, equipment is required for loading the waste at the surface facility, transporting the waste underground, emplacing the waste in the emplacement borehole, and retrieving the waste. The concepts for the equipment required to perform these activities are based on currently available technology (e.g., the waste transporter is based on the use of a commercially available mine haulage system that has been thoroughly tested in mining applications). Requirements imposed on the design of this equipment include the incorporation of backup actuators, provision for easy access to replace key components, and simplicity. These requirements are imposed to improve the reliability of the equipment for waste emplacement and retrieval and to minimize operational malfunctions from which recovery would be difficult and hazardous to personnel. The reports that document the work completed in support of the equipment development are as follows:

1. Stinebaugh, R. E., and J. C. Frostenson, 1987. "Worker Radiation Doses During Vertical Emplacement and Retrieval of Spent Fuel at the Tuff Repository," SAND84-2275, Sandia National Laboratories, Albuquerque, New Mexico.

2. Fisk, A. T., P. de Bakker, B. J. Doherty, J. P. Pokorski, and J. Spector, 1985. "Conceptual Engineering Studies and Design for Three Different Machines for Nuclear Waste Transporting, Emplacement, and Retrieval," SAND83-7089, prepared by Foster-Miller, Inc., Waltham, Massachusetts, for Sandia National Laboratories, Albuquerque, New Mexico.

3. Flores, R. J., 1986. "Retrievability: Strategy for Compliance Demonstration," SAND84-2242, Sandia National Laboratories, Albuquerque, New Mexico.

4. Stinebaugh, R. E., and J. C. Frostenson, 1986. "Disposal of Radioactive Waste Packages in Vertical Boreholes--A Description of the Operations and Equipment for Emplacement and Retrieval," SAND84-1010, Sandia National Laboratories, Albuquerque, New Mexico.

5. Stinebaugh, R. E., I. B. White, and J. C. Frostenson, 1986. "Disposal of Radioactive Waste Packages in Horizontal Boreholes--A Description of the Operations and Equipment for Emplacement and Retrieval," SAND84-2640, Sandia National Laboratories, Albuquerque, New Mexico.

The conclusion from the work completed to this point is that the equipment required to emplace and retrieve waste at the Yucca Mountain mined geologic repository can be designed and developed by integrating available technology. Development will be required to ensure that the integration of the available technology performs as required under the conditions for emplacement and retrieval.

4.4.6-3 Waste emplacement hole boring equipment

For waste emplacement and retrieval, the vertical emplacement boreholes can be bored using existing, commercially available drills with minor modifications. This conclusion is documented in a report by The Robbins Company (1984a). The boring of the holes for horizontal emplacement will require the development of a new drill. This drill, as it is currently designed, is based on technology used in tunnel boring machines (TBMs). The boreholes required for the horizontal emplacement concept are much smaller in diameter than the drifts produced by a TBM. Thus, it is necessary to scale down the components used for TBMs to build the waste emplacement hole drill. The horizontal emplacement hole drill, because of its smaller size and the desire to drill dry, has potentially unique problems such as cuttings removal, maintenance, and control. On the larger TBMs, personnel have direct access to the machine to correct problems occurring during boring.

The work that has been completed to this time in support of the design, development, fabrication, and testing of the horizontal hole drill is summarized by the following reports:

1. Robbins Company, 1984b. "Small Diameter Horizontal Hole Drilling--State of Technology," SAND84-7103, prepared for Sandia National Laboratories, Albuquerque, New Mexico.

2. Robbins Company, 1985. "Feasibility Studies and Conceptual Design for Placing Steel Liner in Long, Horizontal Boreholes for a Prospective Nuclear Waste Repository in Tuff," SAND84-7209, prepared for Sandia National Laboratories, Albuquerque, New Mexico.

3. Kenny Construction, Inc., 1987. "Installation of Steel Liner in Blind Hole Study," SAND85-7111, prepared for Sandia National Laboratories, Albuquerque, NM.

4. Robbins Company, 1987. "Design of a Machine to Bore and Line a Long Horizontal Hole in Tuff," SAND86-7004, prepared for Sandia National Laboratories, Albuquerque, New Mexico.

These reports document results of drill equipment market surveys, feasibility studies for liner installation methods, and preliminary retrieval techniques.

All work completed indicates that the drilling of the emplacement holes for waste at the Yucca Mountain repository can be performed with existing drilling systems or with adaptations of existing drill systems. The verification of this conclusion will require development tests in site-specific geology.

8.3.7.2.6 Design analysis

4.4.7-1 Structural, thermal, and mechanical analyses

The results from the structural, thermal and thermomechanical analyses, that relate to evaluating the stability of underground openings and required ground support for the mined geologic disposal system (MGDS) are synopsized in this section. The required ground support conditions identified by these analyses were determined to be well within the capabilities of available mine support systems. Results are presented from analyses using both computer codes and empirical approaches. The published reports that document the analyses discussed are the following:

1. Hustrulid, W., 1984a. "Lining Considerations for a Circular Vertical Shaft in Generic Tuff," SAND83-7068, Sandia National Laboratories, Albuquerque, New Mexico.

2. Hustrulid, W., 1984b. "Preliminary Stability Analysis for the Exploratory Shaft," SAND83-7069, Sandia National Laboratories, Albuquerque, New Mexico.

3. Hill, J., 1985. "Structural Analysis of the NNWSI Exploratory Shaft," SAND84-2354, Sandia National Laboratories, Albuquerque, New Mexico.

4. St. John, C. M., 1987a. "Interaction of Nuclear Waste Panels with Shafts and Access Ramps for a Potential Repository at Yucca Mountain," SAND84-7213, prepared by Agbabian Associates for Sandia National Laboratories, Albuquerque, New Mexico.

5. St. John, C. M., 1987b. "Investigative Study of the Underground Excavations for a Nuclear Waste Repository in Tuff," SAND83-7451, prepared by Agbabian Associates, Inc., for Sandia National Laboratories, Albuquerque, New Mexico.

6. Johnson, R. L., 1981. "Thermo-Mechanical Scoping Calculations for a High Level Nuclear Waste Repository in Tuff," SAND81-0629, Sandia National Laboratories, Albuquerque, New Mexico.

7. Thomas, R. K., 1987. "Near Field Mechanical Calculations Using a Continuum Jointed Rock Model in the JAC Code," SAND83-0070, Sandia National Laboratories, Albuquerque, New Mexico.

8. Johnstone, J. K., R. R. Peters, and P. F. Gnirk, 1984. "Unit Evaluation at Yucca Mountain, Nevada Test Site: Summary Report and Recommendation," SAND83-0372, Sandia National Laboratories, Albuquerque, New Mexico.

9. Svalstad, D. K., and T. Brandshaug, 1983. "Forced Ventilation Analysis of a Commercial High-Level Nuclear Waste Repository in Tuff," SAND81-7206, Sandia National Laboratories, Albuquerque, New Mexico.

10. St. John, C. M., 1987d. "Thermomechanical Analysis of Underground Excavations in the Vicinity of a Nuclear Waste Isolation Panel," SAND84-7208, prepared by Agbabian Associates for Sandia National Laboratories, Albuquerque, New Mexico.

11. St. John, C. M., 1987a. "Reference Thermal and Thermal/Mechanical Analyses of the Drifts for Vertical and Horizontal Emplacement of Nuclear Waste in a Repository in Tuff," SAND86-7005, prepared by J. F. T. Agapito and Associates, Inc., for Sandia National Laboratories, Albuquerque, New Mexico.

12. St. John, C. M. and S. J. Mitchell, 1987. "Investigation of Excavation Stability in a Finite Repository," SAND86-7011, prepared by J. F. T. Agapito and Associates, Inc., for Sandia National Laboratories, Albuquerque, New Mexico.

13. Ehgartner, B. L., 1987. "Sensitivity Analyses of Underground Drift Temperature, Stresses, and Safety Factors to Variation in the Rock Mass Properties of Tuff for a Nuclear Waste Repository Located at Yucca Mountain, Nevada," SAND86-1250, Sandia National Laboratories, Albuquerque, New Mexico.

14. Langkopf, B. S., and P. F. Gnirk, 1986. "Rock-Mass Classification of Candidate Repository Units at Yucca Mountain, Nye County, Nevada," SAND82-2034, Sandia National Laboratories, Albuquerque, New Mexico.

15. Arulmoli, K., and C. M. St. John, 1987. "Analysis of Horizontal Waste Emplacement Boreholes of a Nuclear Waste Repository in Tuff," SAND86-7133, Sandia National Laboratories, Albuquerque, New Mexico.

16. St. John, C. M., 1985. "Thermal Analysis of Spent Fuel Disposal in Vertical Emplacement Boreholes in a Welded Tuff Repository," SAND84-7207, prepared by Agbabian Associates for Sandia National Laboratories, Albuquerque, New Mexico.

17. Dravo Engineers, Inc., 1984. "Effect of Variations in the Geologic Data Base on Mining at Yucca Mountain for NNWSI," SAND84-7125, Sandia National Laboratories, Albuquerque, New Mexico.

18. Zimmerman, R. M., M. L. Blanford, J. F. Holland, R. L. Schuch, and W. H. Barrett, 1986b. "Final Report G-Tunnel Small-Diameter Heater Experiments," SAND84-2621, Sandia National Laboratories, Albuquerque, New Mexico.

19. Zimmerman, R. M., R. L. Schuch, D. S. Mason, M. L. Wilson, M. E. Hall, M. P. Board, R. P. Bellman, and M. L. Blanford, 1986. "Final Report: G-Tunnel Heated Block Experiment," SAND84-2620, Sandia National Laboratories, Albuquerque, New Mexico.

20. Zimmerman, R. M., 1983. "First Phase of Small Diameter Heater Experiments in Tuff," Proc. 24th U.S. Symposium on Rock Mechanics, College Station, Texas.

21. Zimmerman, R. M., M. L. Wilson, M. P. Board, M. E. Hall, and R. L. Schuch, 1985. "Thermal-Cycle Testing of the G-Tunnel Heated Block," Proc. 26th U.S. Symposium on Rock Mechanics, Rapid City, South Dakota.

22. Chen, E. P., 1987. "A Computational Model for Jointed Media with Orthogonal Sets of Joints," SAND86-1122, Sandia National Laboratories, Albuquerque, New Mexico.

23. Labreche, D. A., and S. V. Petney, 1987. "The SPECTROM-31 Compliant Joint Model: A Preliminary Description and Feasibility Study," SAND85-7100, Sandia National Laboratories, Albuquerque, New Mexico.

24. Bauer, S. J., R. K. Thomas, and L. M. Ford, 1985b. "Measurement and Calculation of the Mechanical Response of a Highly Fractured Rock," Proc. 26th U.S. Symposium on Rock Mechanics, Rapid City, South Dakota.

25. Labreche, D. A., 1985. "Calculation of Laboratory Stress-Strain Behavior Using a Compliant Joint Model," Proc. 26th U.S. Symposium on Rock Mechanics, Rapid City, South Dakota.

26. Thomas, R. K., 1982. "A Continuum Description for Jointed Media," SAND81-2615, Sandia National Laboratories, Albuquerque, New Mexico.

Relevant information from these reports is summarized in the following paragraphs grouped according to structural features of repository.

Emplacement drifts

St. John (1987) reports the results of two-dimensional finite- and boundary-element calculations for the emplacement drifts that include thermal effects out to 100 yr. The calculations are based on reference design information using currently available information about the rock and site characteristics. The thermomechanical properties are presented in Section 2.3.1 of this report. The thermal analyses were performed using the finite-element code DOT, and a second analysis used the boundary-element code HEFF. The HEFF code resulted in temperatures of within $\pm 1$°C of those predicted by DOT. Both codes used constant thermal and elastic properties. A mixture of 60 percent PWR and 40 percent BWR waste was modeled at an areal power density of 57 kW/acre. Because the analyses were two-dimensional with cross sections through the drifts, the heat sources (i.e., waste containers) were not explicitly represented along the axis of the drift. Rather, the heat sources were equivalently represented by a plane extending into and out of the modeled drift cross sections. Both vertical and horizontal emplacement drifts were analyzed using continuously ventilated and unventilated drift conditions. The intention was to bound the problem, realizing that actual effects of drift ventilation would fall somewhere between the two ventilation extremes modeled. Drift temperatures, although not directly related to drift stability, are important for assessing environmental conditions to which personnel may be subjected if cooling is not used. Maximum drift temperatures of 58 and 109°C resulted for the unventilated condition of the horizontal and vertical emplacement drifts, respectively. The maximum drift temperatures occurred at 100 yr after waste emplacement. The large difference in drift temperature for the unventilated horizontal and vertical emplacement is a result of the difference in standoff distance of the waste from the drift. The standoff distance for horizontal emplacement was simulated as 33 m. The standoff distance for vertical emplacement was simulated as 3.1 m. The ventilated condition placed the drift temperature at 30°C for both emplacement drifts analyzed over the 100-yr period. This is an estimate based on the 23°C in situ temperature and the likely inability of ventilation to maintain the drift at that temperature once the waste is emplaced. The actual drift temperature will likely fall within the broad range of the continuously ventilated and unventilated conditions.

Thermal results for two- and three-dimensional calculations of the vertical drift are documented by St. John (1985). The two-dimensional analyses were performed by the finite-element code PORFLOW, and the three-dimensional analyses were performed by the finite-element code THERM3D and the analytic solutions contained in the TEMP3D code. Nonlinear thermal effects were not modeled; the thermal decay of the waste was modeled and all other model input parameters were held constant throughout the 100-yr period analyzed. BWR containers at 3 kW each were spaced 4.0 m apart along the drift, 3.05 m below the floor. The analyses used a rectangular drift shape, and properties differed slightly from those of the reference information base. The temperatures resulting from the two-dimensional and three-dimensional codes differed little except in the immediate vicinity of the container, and the agreement between the analytic solutions and finite-volume codes was excellent. Unventilated drift conditions resulted in a maximum temperature of 133°C at approximately 50 yr after waste emplacement. The drift temperature at 100 yr was only 4°C less than that at 50 yr. These results differ slightly from those presented by St. John (1987a). The differences are mainly because of differences in the decay characteristics of the waste used and the emplacement density along the drift. The initial source strength along the vertical emplacement drift in this analysis is 28 percent higher than that used in the analyses by St. John (1987a). The ventilated drift condition assumed the drift to be maintained at 30°C as did the St. John (1987a) analyses.

The thermal modeling discussed by Johnstone et al. (1984) for drift-scale analyses was used to establish the maximum areal power density (APD) for waste emplacement such that the drift floor temperature did not exceed 100°C for times up to 110 yr after waste emplacement. This criterion sets the maximum expected temperature and is used to design the cooling system necessary to prepare the drifts for reentry for purposes of inspection, repair, or retrieval. Note that this criterion has been superseded in this report by temperature criteria established for access drift temperature in the vertical emplacement mode (Section 8.2.1). The analyses are based on the unventilated vertical emplacement drift. St. John (1987a) shows the unventilated drift exhibiting higher temperatures than the ventilated drift and the vertical emplacement drifts higher temperatures than the horizontal emplacement drifts. Therefore, the maximum temperature criteria, if applied to the horizontal emplacement of waste result, would result in a higher allowable APD. The nonlinear thermal analyses were performed using ADINAT and SPECTROM-41. The APD of the repository was established as 57 kW/acre for the Topopah Spring tuff.

The stress results reported in St. John (1987a) were obtained from the finite-element code VISCOT, using an elastic constitutive model. The stress analyses were performed at emplacement time and 100 yr later for the horizontal and vertical emplacement drifts, assuming both ventilated and unventilated drift conditions. The temperature results are reported in the previous paragraph. VISCOT uses the thermal field generated by DOT code analyses of temperature to calculate the induced thermal loading. The induced thermal stresses and in situ stresses are combined, and the stresses around the drift are computed. Knowledge of the stress state enabled the factors of safety against localized rock failure and activation of existing vertical joints to be assessed. The highest stresses were noted at the drift crown 100 yr after waste emplacement. The magnitudes of the principal stress in the drift crown ranged from 31 to 36 MPa for the horizontal emplacement drift, depending on the drift ventilation assumed. Higher stresses occurred for the unventilated drift condition. The vertical emplacement drift had crown stresses ranging from 13 to 54 MPa for the ventilated and unventilated conditions, respectively. The effect of ventilation is much more pronounced for the vertical emplacement option, where the waste packages are located much closer to the drift. The maximum stress magnitudes are well below the average unconfined compressive strength of 150.8 MPa measured in the laboratory. If a 50 percent reduction factor is applied to the average laboratory value of strength to account for scale effects (Appendix O), the minimum safety factor for the vertical emplacement drifts is 1.4. In this cluster analysis, the minimum safety factor calculated for the horizontal emplacement drift was 2.1. These safety factors are minimal because they are based on stresses at a point on the drift boundary. Stress magnitudes in this elastic analysis decrease for locations removed from the drift. This is illustrated in Figures 8-8 and 8-9, which plot the principal stress magnitudes and their directions for the vertical and horizontal waste emplacement drifts at excavation time and 100 yr later. The ventilated and unventilated drifts are shown in the figures. The safety factors corresponding to the stress levels plotted in Figures 8-8 and 8-9 are contoured in Figures 8-10 and 8-11, respectively. The safety factor contours show an increase in magnitude as distance from the drift crown increases. The mass of rock making up the crown area of the drift has an average safety factor much higher than the boundary values at the crown. The safety factor for the drift can be obtained by integrating or averaging the safety factor values over the crown region. The crown region is chosen because it has the lowest safety factor. Interpretation of Figures 8-12 and 8-13 result in an average safety factor for the crown region of the drifts which is greater than or equal to 3.0. This safety factor is considered conservative for the drift because the crown area will contain ground support such as rockbolts, a feature not modeled in the numerical analyses by St. John (1987a).

Johnstone et al. (1984) documents the results of inelastic vertical emplacemnt drift calculations using the ubiquitous-joint model for times out to 110 yr. These calculations are coupled to the thermal analyses performed by ADINAT and SPECTROM-41, as previously reported. No matrix fracturing occurred around the Topopah Spring drift for either the average

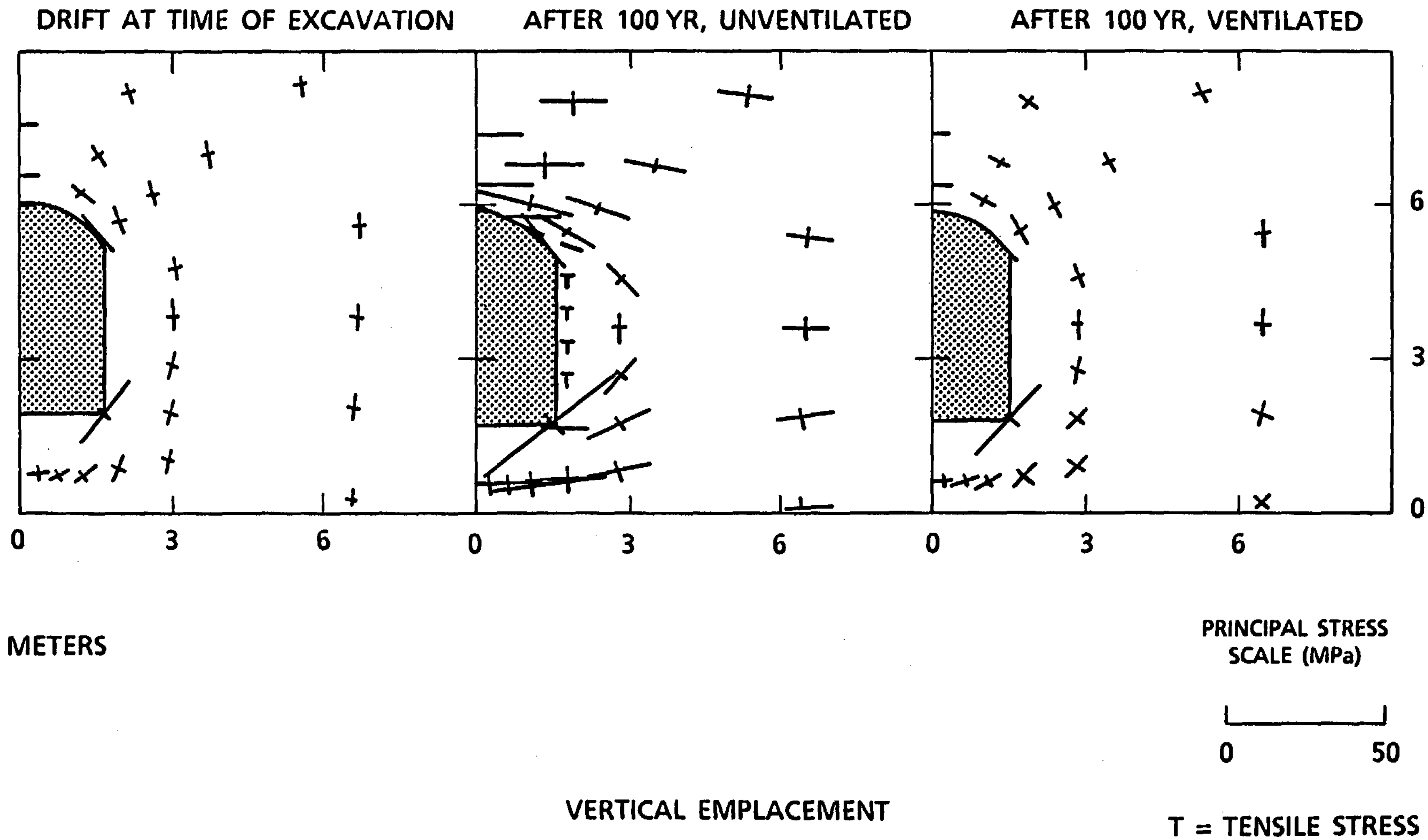


Figure 8-8. Finite-element predictions of the principal stresses in the vicinity of the vertical emplacement drift (St. John, 1987a).

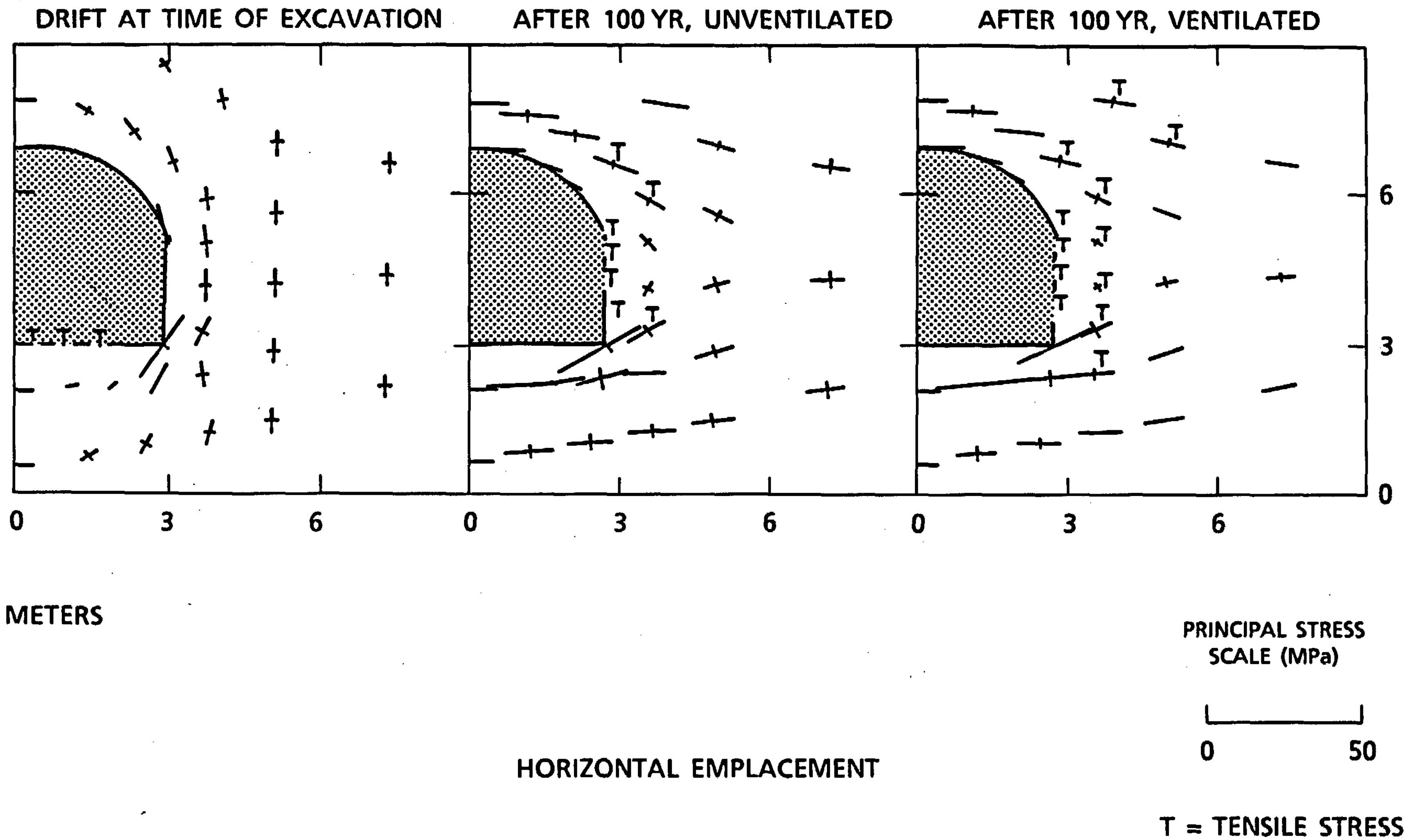


Figure 8-9. Finite-element predictions of the principal stresses in the vicinity of the horizontal emplacement drift (St. John, 1987a).

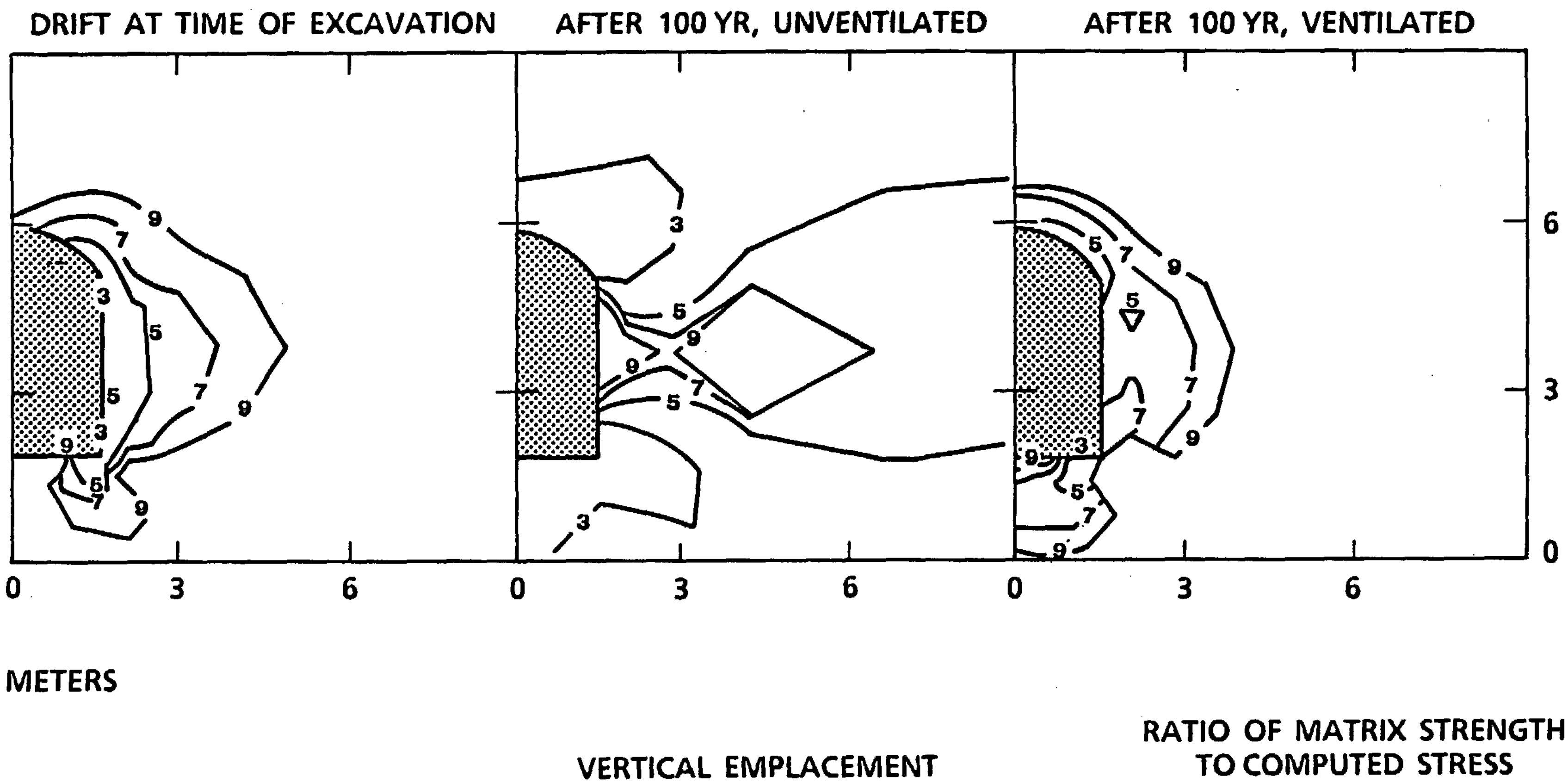


Figure 8-10. Finite-element predictions of the ratio between matrix strength and stress around the vertical emplacement drift. The numbers on the plots are ratios (St. John, 1987a).

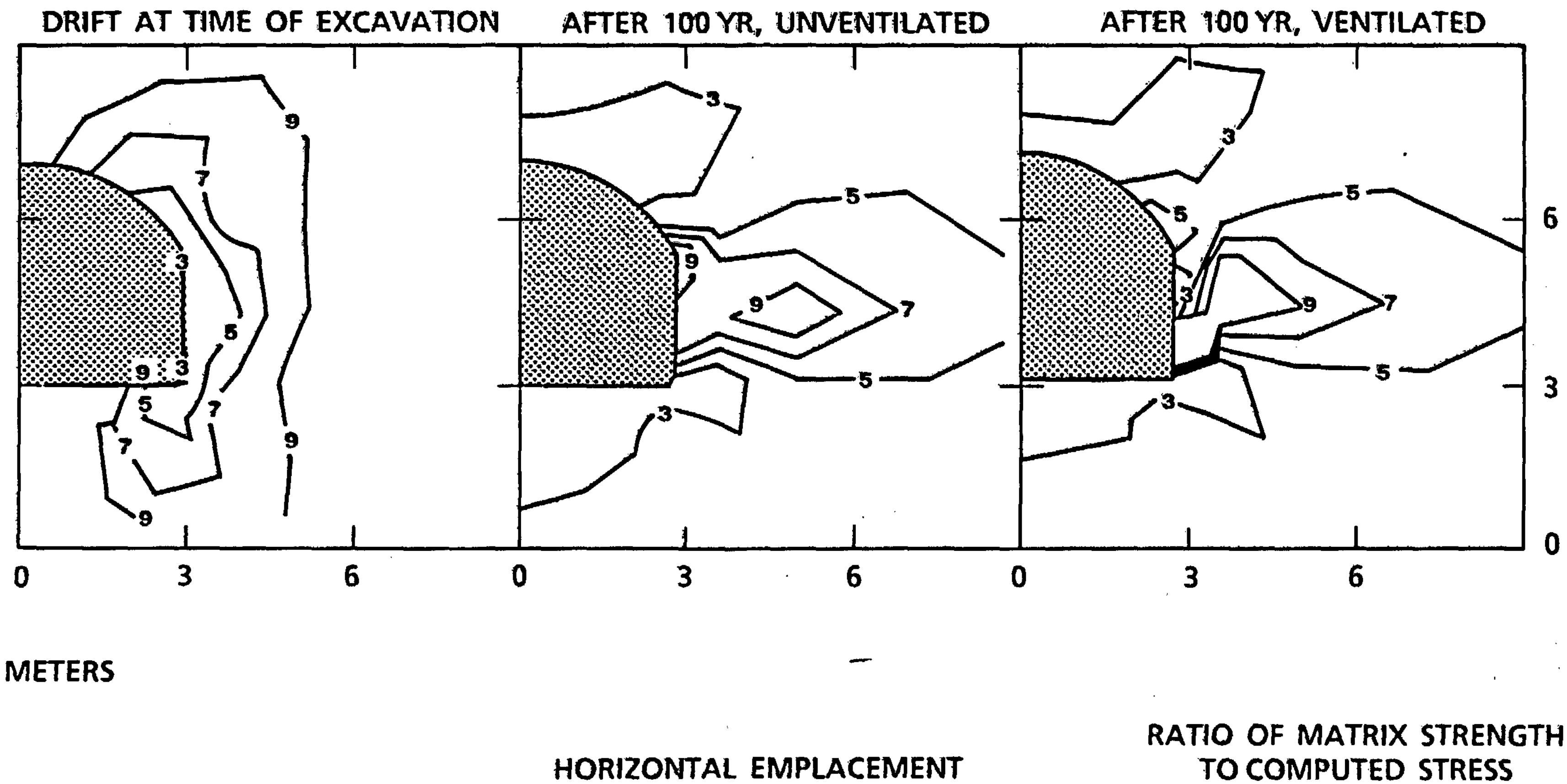


Figure 8-11. Finite-element predictions of the ratio between matrix strength and stress around the horizontal emplacement drift. The numbers on the plots are ratios (St. John and Mitchell, 1987).

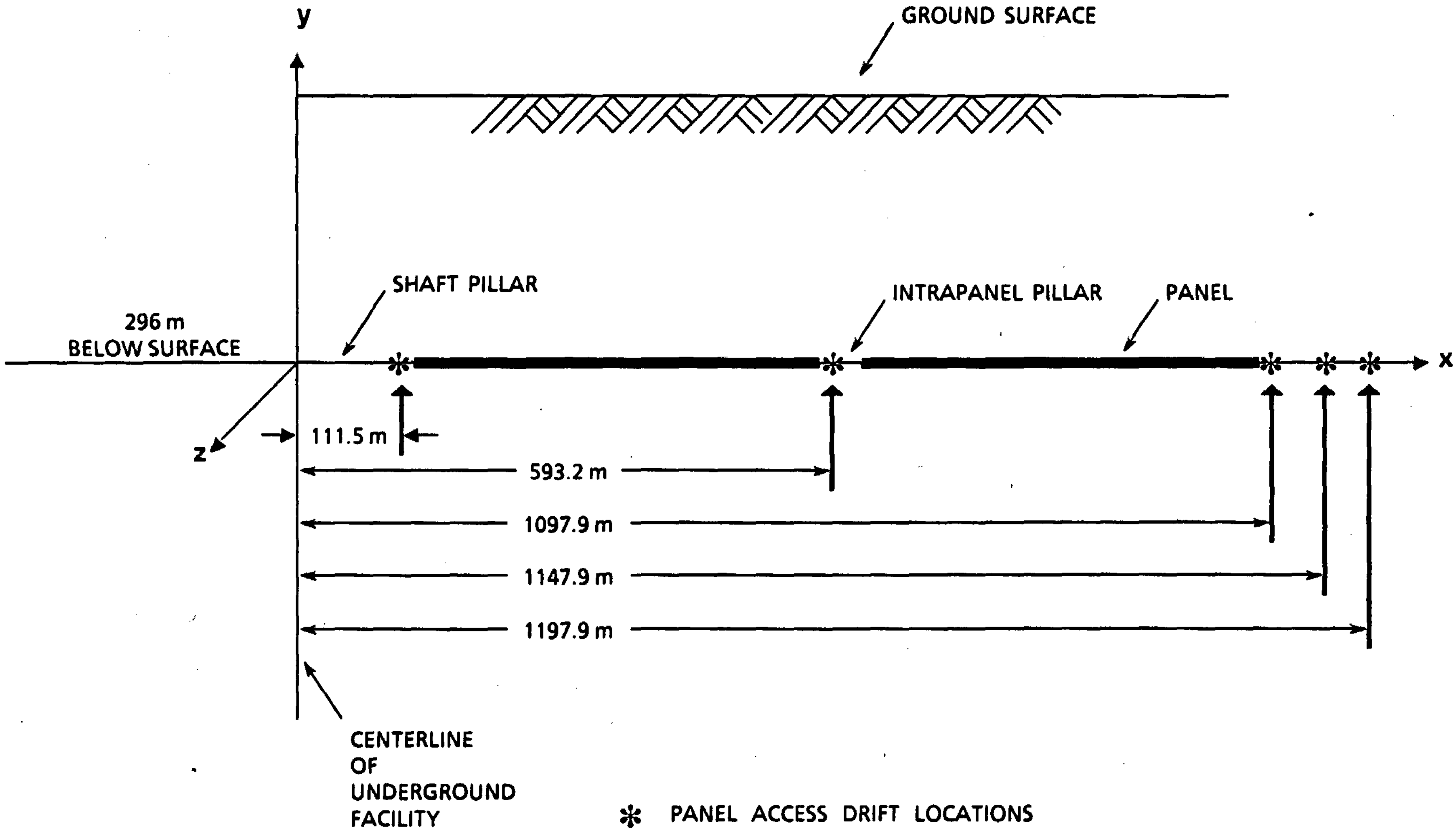


Figure 8-12. Repository cross section showing access drift locations considered (St. John and Mitchell, 1987).

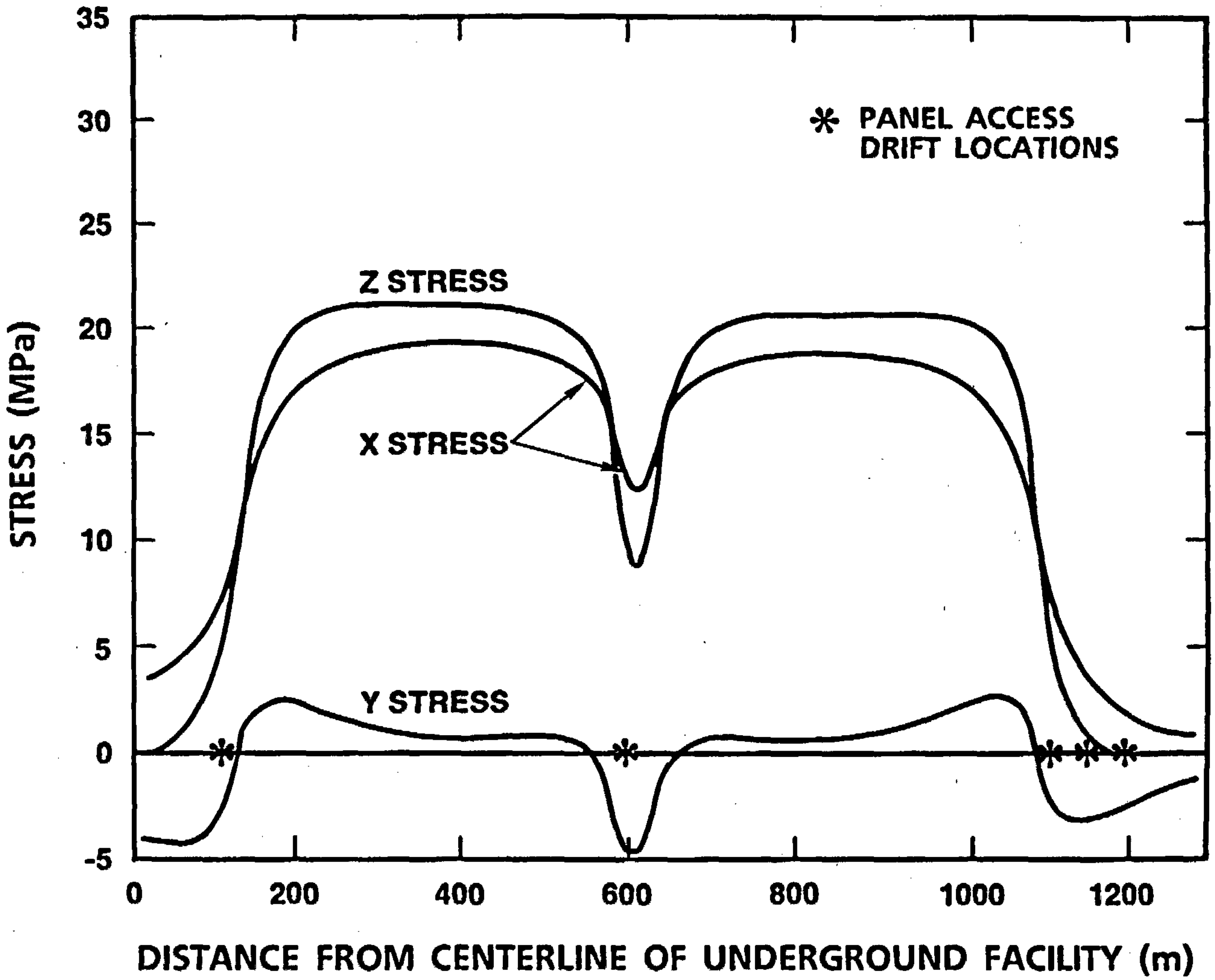


Figure 8-13. Induced stress profile on repository horizon 50 yr after waste emplacement (St. John and Mitchell, 1987).

or limiting property case. The limiting properties were taken as either plus or minus two standard deviations from average values, the sign being chosen on a worse-case basis. The elastic calculations presented by St. John (1987a) recognized the vertical emplacement drift as experiencing higher horizontal stresses than the horizontal emplacement drift for unventilated conditions. As such, the rock surrounding the horizontal drift should also remain intact when analyzed using the ubiquitous-joint model. The corresponding minimum safety factors were approximately 1.5 and 3 for the limiting and average case, respectively. Both the average and limiting safety factors indicate acceptable drift stability. Minor amounts of joint slip were noted; however, it is expected to have no consequence on drift stability--a conclusion supported by evidence from G-Tunnel. The ubiquitous-joint model predicts a slightly larger slip region for the rock surrounding G-Tunnel than for the repository drift, but no joint displacement is evident in the drifts of G-Tunnel. Limited amounts of vertical joint slip are predicted in the sidewalls of the drift both at and after waste emplacement.

Svalstad and Brandshaug (1983) report the effects of cooling a vertical emplacement drift after 39 yr of waste emplacement. The thermal portion of the analysis was performed using SPECTROM-41, and the mechanical portion used the elastic finite element code SPECTROM-11. An APD of 100 kW/acre was used to estimate the heat load in a 745-m drift. Blast cooling the rock for a year resulted in no change in the safety factor about the drift. Before and after cooling, the minimum safety factor was 2.0, and joint activation was limited to 2.0 m into the sidewall of the rectangular drift.

The results of the studies just reported indicate that the emplacement drifts will be stable and will provide a usable and safe environment for the retrievability period of approximately 84 yr. An additional positive factor in the long-term usability of the drifts is the requirement for drift support and periodic inspection and maintenance. The studies previously presented are based on thermal and mechanical properties considered to be representative of the rock mass (one exception to this is the analysis presented by Johnstone et al. (1984) that used limiting properties). The geometries and other model requirements reflected the anticipated design and environments at the time of the analyses. Because of the continual improvement in knowledge about the material properties and the design, an enlarged set of data was used in the analysis. However, the differences in the data used did not appreciably affect the results. This conclusion is based on the sensitivity studies presented below and the consistent prediction of drift stability by each of the studies.

Both general and specific sensitivity studies have been performed. Johnstone et al. (1984) documents drift conditions in not only the Topopah Spring but also in the underlying Bullfrog, Tram, and Calico Hills formations. Analyses were performed for times up to 100 yr after vertical waste emplacement for unventilated drift conditions. Thermomechanical properties for all the units differed. Johnstone et al. (1984) note that rock strength and modulus varied by a factor of three over the four units, but all units appear acceptable with regard to stability of the underground openings. Specific parameter sensitivities were investigated in Ehgartner (1987). The input parameters to the HEFF code were varied both individually and jointly to determine the effect on the horizontal emplacement drift at 50 yr. The results indicated that changes in rock strength and modulus affected the safety factors of the drift rock more than the other parameters that were varied, but in no case was the safety factor for the rock less than 1.0 over the probable range of input variables.

Ehgartner (1987) showed drift temperatures to be relatively insensitive to the thermal input variables. St. John (1987c) varied the shape of horizontal and vertical emplacement drifts over various in situ stress fields ranging from uniaxial to hydrostatic. The more rounded excavations had slightly lower stress concentrations. The elastic analyses used the boundary-element code HEFF and the elastic finite-element code, BMINES. BMINES enabled rock bolts to be included in the analyses. A damage region was modeled around the drift to simulate the impact of blasting during excavation, and rock bolts were inserted in the crown region. The calculated stresses in the rock bolts were approximately half the allowable strength of the rock bolts. The rock bolts had an insignificant impact on reducing drift closure or deformation, as compared to the unsupported drift analyses.

Johnson (1981) varied the APD for the vertical emplacement scheme to determine the effects on the drifts. The ADINAT and ADINA model incorporating ubiquitous jointing was used for analyses to 100 yr after waste emplacement. The two APDs of 75 and 100 kW/acre changed the maximum crown stress in the vertical emplacement drift by only 2 MPa. Drift temperatures were more affected by the APD change. The lower APD of 75 kW/acre resulted in a temperature of 98°C at the drift floor, whereas the 100 kW/acre APD increased the drift temperature to 107°C at 50 yr after waste emplacement. Johnstone et al. (1984) derived the maximum allowable APD for the Topopah Spring and the underlying Bullfrog, Tram, and Calico Hills units based on constraints for the vertical emplacement drift at 100 yr after waste emplacement. The APD determined for all the units including the Topopah Spring unit varied from 53 to 57 kW/acre.

In the previously mentioned sensitivity studies drift depth, shape, waste standoff, APD, and the thermomechanical properties were varied, and in each instance, it was concluded that drifts would remain stable. However, the stress ratio effects have not yet been examined.

Results of rock mass classification of the Topopah Spring tuff aid in estimating the ease or difficulty of constructing the drifts. Langkopf and Gnirk (1986) document the results of tunnel indexing or rock mass classification methods applied to the waste emplacement horizon of Yucca Mountain. Both the South African Council for Scientific and Industrial Research Classification System (CSIR) and Norwegian Geotechnical Institute Classification System (NGI) methods were applied. The CSIR gives an average standup time of 3 to 4 mo for an unsupported span of 6.1 m. The estimated standup times are based on a 6.1-m room or drift width, since this is typical in most mines. Drift widths for the vertical waste emplacement design vary from a minimum of 4.88 m (emplacement drift) to a maximum of 7.62 m for the mains. The horizontal waste emplacement design varies drift widths from a minimum of 6.40 m (access drift) to a maximum width of 7.62 m for the mains.

The NGI classification system estimates the maximum unsupported roof space from 2.3 to 9.9 m, the average being 6.0 m. The NGI system further qualifies the required support as ranging from grouted rockbolts on a 1-m spacing with chain-link mesh and shotcrete to a no-support requirement. The classification systems are based on the results of many diversified case studies, but a specific case to which anticipated repository excavation conditions can be related is found in G-Tunnel. The NGI and CSIR classifications systems both rank the welded Topopah Spring tuff and the nearby Grouse Canyon tuff almost exactly the same. This is because of the similarities in not only the geologic media but also in the in situ stress states. An underground facility (G-Tunnel complex) contains miles of drifts in a tuff unit known as Tunnel Bed 5 of the Grouse Canyon tuff; approximately 130 m of drifts in the Grouse Canyon tuff are in a welded tuff similar to the Topopah Spring unit. Drifts in this facility up to 9.2 m wide have been stable for periods up to 25 yr with a minimal amount of support.

The observations in G-Tunnel provide additional insight into the constructability and initial support requirements of the repository drifts. Even though faults and associated shear zones are expected to exist at Yucca Mountain, the preferred repository area is expected to be minable with standard equipment (Dravo Engineers, Inc., 1984). Rock with similar mechanical properties has been excavated at the G-Tunnel complex in Rainier Mesa using comparable methods of excavation and ground control.

The environmental assessment (DOE, 1986c) has documented tunneling experience in the welded Grouse Canyon Member at G-Tunnel. A nearly vertical fault with at least 1 m of vertical displacement was encountered during tunneling activities in the welded Grouse Canyon Member in G-Tunnel. No comments were noted by the mining inspector in his daily log; the lack of comments indicates that tunneling conditions had not varied appreciably. The fault zone was not noted until the tunnel had advanced about 6 m (18 ft) beyond the fault. The fault brought welded and nonwelded tuff together along a nearly vertical contact; no water influx was noted. The inspection record shows that the area of the tunnel with the fault was initially mined on November 19, 1981. Preliminary 2.5-m (8-ft) rock bolts were installed in the faulted area on November 20, 1981, and then on February 16, 1982, roughly 3 months later, 5-m (16-ft) resin-anchored hardening rock bolts were installed on a 1.3 by 1.3 m (4 by 4 foot) pattern across the back in the area adjacent to the fault. There was no record that the faulted area produced ground-support problems, and no special bolting was installed in the area of the fault. Crossing the nearly vertical fault with at least 1 m (3 feet) of vertical displacement did not result in the need for any special ground support in excess of the standard methods used in the drift where no faulting occurred. The observations at G-Tunnel and the results of rock mass classification apply to both emplacement drifts and access drifts. Panel access drifts are used between the repository mains and the emplacement drifts. The numerical analyses for the panel access drifts are discussed in the following paragraphs.

Panel access drifts

Results comparing panel access drift stability for various locations and standoff distances from the emplaced waste are documented by St. John and Mitchell (1987). The elastic two-dimensional calculations used the HEFF code for analyses of the horizontal emplacement scheme to 50 yr after waste emplacement at 57 kW/acre. Drifts were analyzed at locations in the central part and outer edges of the repository. The locations of the panel access drifts are shown in Figure 8-12. The hypothetical repository was configured of four panels, thus two of these are illustrated in the symmetric view presented in the figure. Interpanel locations also were considered. The thermally induced stresses (y stress) that correspond to Figure 8-12 are plotted in Figure 8-13. The induced stresses shown in Figure 8-13 are superimposed with the gravity induced stresses (x stress) to yield the total stress (z stress) to which the drifts are subjected. Analyses of the drifts indicated the results presented in Table 8-7 at 50 yr. A near hydrostatic in situ stress field was assumed. Although differences in results exist for the drifts at the various locations, no stability problems were identified at any of the potential locations.

Table 8-7. Predicted stress, factor of safety, and temperatures of panel access drifts at different locations at 50 yr after emplacement

| Parameter | Distance of drift from repository centerline (m) | | | | |
|---|---|---|---|---|---|
| | 115 | 606 | 1098 | 1148 | 1198 |
| Crown stress (MPa) | 36.0 | 48.6 | 34.0 | 24.1 | 19.1 |
| Safety factor at crown | 2.09 | 1.55 | 2.22 | 3.12 | 3.94 |
| Drift temperature (°C) | 56.7 | 71.3 | 55.8 | 28.5 | 23.6 |

The results of analyses on the intersection of the emplacement drift with a panel access drift are documented in St. John (1987b). The three-dimensional elastic calculations used STRES3D to generate the thermally induced stress field for the horizontal emplacement scheme and ADINA to elastically analyze the intersection. Stresses in the crown of the intersection reached approximately 23 MPa after 50 yr of waste emplacement. In this elastic analysis, tensile stresses approaching 9 MPa were predicted in the rib at the intersection. The tensile stresses dissipate 3 m into the rib. Note that the tensile stresses predicted in the elastic model will likely be reduced in the field because of the presence of existing horizontal fractures.

Waste emplacement boreholes

The stability of waste emplacement boreholes must be evaluated to understand the loading that may be imposed on a waste package (or borehole liner) and to evaluate the environment anticipated for retrieval operations. The thermal and mechanical calculations and observations made in G-Tunnel testing related to small-scale heated borehole stability are discussed in a subsequent section on verification and validation results. The emphasis of that discussion is on model validation (i.e., the model represents the intended physical system or process). The emphasis here is to provide a synopsis of the calculations performed on the waste emplacement boreholes using configurations similar to those shown in Figure 8-12. In addition, the evaluations of potential loads on the emplacement borehole liner for the horizontal emplacement option are described briefly. The analysis results to date predict that the boreholes will be stable but that some uncertainty exists regarding whether there will be small (bounded by a few centimeters) regions where localized fracturing of the rock might occur.

Results of analyses on the horizontal waste emplacement borehole (Arulmoli and St. John, 1987) are discussed for (1) the elastic model, and (2) inelastic mechanical models. The thermal modeling used fixed thermal properties for the host rock. The calculations are based on conceptual design information and the expected rock and site characterisitics. The two-dimensional finite-element calculations used boundary conditions that modeled an infinite series of boreholes of infinite length, and the thermal loading was imposed instantaneously. This approximation is considered appropriate since the focus is on very near-field effects and borehole loading rates would likely be a minor perturbation in the stresses imposed. The results reflect expected conditions in the central portion of the repository and are considered conservative near the outer regions of the repository.

The elastic horizontal borehole calculations were performed for times extending to 100 yr after waste emplacement using the DOT code with temperature constant properties and the VISCOT code with current thermomechanical properties and geometries. A maximum borehole wall temperature of 160°C occurred approximately 25 yr after the waste emplacement. Maximum borehole wall stresses ranged from 20 MPa at the sidewall to 50 MPa at the crown. Because of problem symmetry, the stresses are equivalent at the sidewalls and at the top (crown) and bottom of the borehole.

The inelastic horizontal borehole calculations used the JAC compliant-joint model, incorporating both single- and orthogonal-joint sets. The single-joint set was vertical with a strike parallel to the borehole axis. The orthogonal-joint set had both vertical and horizontal joints striking parallel to the borehole. The stresses predicted within a few centimeters of the borehole crown by the single-joint-set model were higher at the crown than those predicted by the elastic model. However, the sidewall stresses were lower for the joint model when compared to the elastic model results. The redistribution of stress is a result of joint slip in the sidewalls of the borehole and joint closure in the crown of the borehole. The joint closure is a result of increased horizontal stresses induced by the heat from the waste. The maximum borehole crown stress for the single vertical joint set was 96 MPa. This is nearly twice the magnitude of the elastic prediction of borehole crown stress.

An explanation of the difference in model predictions follows. The elastic analysis approximates the effects of joints through the use of a reduced elastic modulus meant to account for the deformation behavior of a jointed rock mass. The analyses using a compliant-joint model, on the other hand, use both the intact modulus for the rock matrix and a deformation modulus for the joints. Mechanically, as the vertical-joint set along the crown of the borehole closed, in the compliant-joint model the apparent modulus of the rock mass approached the modulus value of the intact rock. The intact modulus used in the compliant-joint analysis was twice the rock mass value used in the elastic analysis. The thermally induced stresses are proportional to the modulus of the rock; higher crown stresses were predicted by the compliant-joint analyses. When the horizontal-joint set is included with the vertical-joint set, the horizontal joints along the crown of the slip, resulting in a stress redistribution, lowering the crown stress by approximately 20 MPa. The orthogonal-joint case is considered to be more representative of emplacement conditions; therefore, the higher stresses predicted by the JAC model using a single vertical joint set may be higher than would be expected to be observed underground.

In the analyses, the stress gradient is abrupt near the borehole crown. The result of this is a rapid decrease in the stress magnitude from the borehole boundary into the rock mass for all the calculations. At a distance several centimeters from the borehole boundary, the crown stresses predicted by the elastic model and those predicted by the compliant joint models are essentially the same. Thus, the higher stresses predicted by the joint models are considered a potential "skin effect." However, the localized high stresses predicted by the joint models exceed the rock mass strength. Little consequence of this small overstressed region in the crown of the borehole is expected because a liner that can withstand the loads potentially imposed by fallen pieces of rock is planned for use in all horizontal emplacement holes. Indeed, preliminary liner loading analyses indicate that such loading will not compromise the structural integrity of the horizontal borehole liner. Borehole liner loading analyses are documented in Appendix B.

Shafts and ramps

St. John (1987a) contains analyses of a 6-m vertical repository access shaft at two different locations and an inclined repository access ramp. Elastic analyses of the 6-m shaft located it centrally in the repository within a central 200-m shaft pillar and alternatively at 100 m from the edge of the repository. The ramp was inclined at 10 degrees from the surface and intersected the repository at the edge of the 200-m shaft pillar. The analyses were time dependent, considering the thermally induced load up to 100 yr after waste emplacement. STRES3D generated a three-dimensional stress field of the repository superimposing both the in situ and thermally induced stresses. The stress field then was imposed on the circular shaft using LINED to calculate stresses for both the 0.5-m-thick concrete shaft liner and the rock mass surrounding it. The stress field also was used as input to the HEFF code to calculate stresses about the ramp. The alternative shaft locations at the center and edge of the repository showed slight differences, but in no instance was the rock mass surrounding it fractured because of the in situ or thermally induced loading. The concrete shaft liner was predicted to have approximately 3 MPa of tensile stress along its axis. The analysis assumed placement of the shaft in an elastic continuum, unreinforced concrete, and no expansion joints along the shaft. The transfer of the induced tensile stress from the rock mass to the liner will likely be moderate because of the presence of naturally occurring and excavation-induced joints in the rock mass surrounding the shaft liner. As shaft liner designs become more detailed, additional analyses are expected.

The ramp analyses contained in St. John (1987d) indicated no rock failure for the various cross sections analyzed along the length of the ramp from the surface to mid-repository. The minimum safety factor was 2.5, which corresponded to a maximum boundary stress of 31 MPa at 100 yr after waste emplacement.

Hustrulid (1984b) and Hill (1985) analyzed the structural stability of the exploratory shaft and facility, respectively. The analyses were time independent; therefore, the thermal effects of waste emplacement were not considered. The analyses showed safety factors greater than or equal to 3.0 for the underground facility. Both elastic three-dimensional and two-dimensional ubiquitous-jointing models were used in the ADINA code. Results were very similar between the two models. The shaft analyses implied no fracture potential for the rock at strengths corresponding to those of the Topopah Spring.

Hustrulid (1984a) considered rock units below the Topopah Spring--the Calico Hills, Bullfrog, and Tram units. Because the strength of the rock units underlying the Topopah Spring is generally lower, some rock failure was predicted but it was limited in extent. Concrete liner thickness of 0.41 and 0.30 m were recommended for the Calico Hills and Tram formations. The Bullfrog formation did not require a liner. Both elastic and plastic analyses were conducted, but no code was used. The analytic solutions are developed and applied in the text of the report.

These analyses indicate stability of both the ramps and shafts of the repository. Additional analyses 'are planned to evaluate seismic effects.

<u>Verification and validation results</u>

<u>Finite-element methods</u>. The finite-element method is planned to be the predominant method for license application design analyses. The status of work pertaining to qualification of models and codes in the context of verification (including benchmarking) and validation is that (1) a method of approach has been developed (SCP Section 8.3.2.1.4, repository modeling) and (2) initial work in this area has been completed.

Part of code qualification includes the verification of the equation solver, which is the heart of a code. Two types of problems are used in verification. Problems with known analytical solutions are used to test the code's numerical solution methods. These numerical solution methods give an indication of the accuracy of the code and also may point out areas where the code may be in error. The second type of problems are hypothetical repository-type problems. These are used to determine whether the code can simulate interactions typical to the repository design. Frequently, verification of the equation solver is accomplished by comparing the computer-calculated response for a simple boundary value problem with closed-form analytic solutions. What follows is a compilation of the types of problems presented in the user's manuals for a selection of the computer codes being considered for use in design and performance assessment calculations. This compilation demonstrates the ability of the codes being considered to handle a wide field of analyses, including problems similar to those to be encountered in repository design and performance assessment.

ABAQUS is a general purpose finite-element computer program for linear and nonlinear structural analyses (Hibbitt et al., 1982). A theoretical development of the appropriate governing equations and a description of the numerical algorithms are presented along with a user's guide that includes several sample problems and the solutions. The sample problems, which include comparisons with closed-form analytic solutions, are briefly summarized:

1. Analysis of a uniformly loaded, elastic-plastic plate is performed to serve two functions: to verify the coding of the rate-independent plasticity theory and to assess the accuracy of the time integration of this form of plasticity theory, especially in the form of nonproportional stressing.

2. Elastic analysis of the barrel-vault-roof problem is performed and is considered to be one of the standard shell-element convergence tests.

3. Elastic analysis of the pinched, open-ended circular-cylinder problem is performed and is considered to be one of the standard test cases used to evaluate the performance of shell-element formulations.

4. Elastic analysis of the cantilever beam to evaluate the accuracy of one of the beam elements in a single, large displacement case.

5. Analysis of the pressurization of a cylinder and a sphere are performed, with elastic and elastic-plastic material behavior. The structures are assumed to be quite thin, so that membrane analysis may be used to verify solutions obtained with the program. Further, the strains are quite large so that for the elastic-plastic cases, rigid-plastic analysis provides an accurate comparative result. The main purpose of the examples is to verify the capabilities of the axisymmetric shell elements at finite strains (Hibbitt et al., 1982).

SANCHO is a finite-element computer program designed to compute the quasi-static, large deformation, inelastic response of planar or axisymmetric solids (Stone et al., 1985). Finite-strain constitutive theories for plasticity, volumetric plasticity, and metallic creep behavior are included. A constant bulk strain, bilinear displacement isoparametric finite element is used for the spatial discretization. The solution strategy used to generate the sequence of equilibrium solutions is a self-adaptive, dynamic-relaxation scheme based on explicit central difference pseudo-time integration and artificial damping. A masterslave algorithm for sliding interfaces also is implemented. A theoretical development of the appropriate governing equations and a description of the numerical algorithms are presented along with a user's guide, which includes several sample problems and their solutions. The sample problems, which include comparisons with closed-form analytic solutions, are briefly summarized here:

1. The free thermal expansion of an infinite cylinder was included to demonstrate the input for a thermal stress problem and to demonstrate the ability of SANCHO to solve problems involving thermal loads.

2. The problem of an infinite cylinder loaded in the plastic range by an internal pressure serves as a good check of the elastic-plastic material model (Stone et al., 1985).

3. The stress relaxation of a single element is used to demonstrate the accuracy of the elastic creep model.

The last example problem is much more complex than the preceding examples and, therefore, relies on comparison with other finite-element programs for solution verification. The problem is a complex geotechnical analysis of an underground drift in a multilayered geologic medium, principally rock salt. It is characterized by creep and contains clay seams characterized with sliding interfaces and a friction coefficient of zero. Elastic anhydrite and polyhalite layers also are interspersed. The problem was specified as part of the Waste Isolation Pilot Plant (WIPP) Project code comparison activity called Benchmark II (Morgan et al., 1981). The problem involves determining the response of an infinitely long array of parallel drifts (Stone et al., 1985).

JAC is a finite-element computer program for solving large deformation, temperature-dependent quasi-static mechanics problems in two dimensions with the nonlinear conjugate gradient technique. Either plane strain or axisymmetric geometry assumptions may be used with material descriptions that include temperature-dependent elastic-plastic, temperature-dependent secondary creep and isothermal soil models. A four-node Lagrangian uniform-strain element is used with orthogonal hourglass viscosity control of the zero energy modes (Biffle, 1984). A theoretical development of the appropriate governing equations and a description of the numerical algorithms are presented along with a user's guide, which includes several sample problems and the solutions. The sample problems, which include comparisons with closed-form analytic solutions, are briefly summarized here:

1. The large deformation of an elastic cantilever beam is included since an analytical solution by Holden (1972) is available.

2. The plane strain crushing of a relatively thin tube in the diametrical direction by rigid platen represents a difficult elastic-plastic, large deformation and sliding surface problem for the finite-element technique.

3. The problem of the plane-strain extrusion of a plate (Biffle, 1984) is included to demonstrate a case where large amounts of sliding take place, along with elastic-plastic loading and unloading.

4. A laminated beam problem is used to demonstrate the behavior of multiple sets of slide lines. The problem is a simulation of the reaction of layers of material above a mine opening, as described by Sutherland et al. (1979).

5. A suddenly applied pressure is applid to the inside of a thick cylinder and the creep response is calculated (Biffle, 1984).

COYOTE is a finite-element program designed for the solution of two-dimensional, linear and nonlinear, steady- and transient-heat-conduction problems (Gartling, 1982). Available boundary conditions include constant temperature at a node, constant or time-dependent temperature along a side, adiabatic surface, forced convection, natural convection, and thermal radiation. Material properties (densities, specific heats, and conductivity tensors) may be dependent on temperature. A theoretical development of the appropriate governing equations and a description of the numerical algorithms are presented along with a user's guide, which includes several sample problems and their solutions. The sample problems, which include comparisons with closed-form analytic solutions, are briefly summarized here:

1. The problem of heat conduction in a steel bar (square cross section), with a circular hole that is subjected to prescribed temperature-boundary conditions, was performed.

2. To demonstrate the use of user subroutines for volumetric heating and generalized convection-radiation boundary conditions, a one-dimensional problem was considered. A cylindrical region of heat-generating material is encased by a thin layer of low-conductivity material and a thicker layer of material having a relatively high thermal conductivity. The outer surface of the cylinder loses heat to the surrounding environment by natural convection.

3. The finned tube radiator problem was chosen to illustrate the use of time-dependent boundary conditions.

4. Sensitivity analyses have been conducted using COYOTE and are reported by Branstetter (1983), Duffey (1980), and Gartling et al. (1981).

5. Duffey (1980) also reports the comparison of COYOTE's output with experimental results of a salt-block test. Good agreement was found for both the steady-state and transient conditions.

The SPECTROM codes solve for stresses around a repository using the finite-element method. Each of the codes can perform elastic and thermoelastic analyses with loads due to a nodal temperature distribution, boundary stresses, and boundary displacement. A theoretical development of the appropriate governing equations and a description of the numerical algorithms are presented along with a user's guide that includes several sample problems and their solutions. The sample problems, which include comparison with closed-form analytic solutions, are briefly summarized here:

1. Analysis of a thin-walled cylinder subjected to a cooling of the interior and to an internal stress.

2. Analysis of an internally pressurized cylinder with Tresca yield criterion, compared with an analytic solution.

3. Analysis of a biaxially loaded plate with a central hole with Drucker-Prager yield criterion.

4. Analysis of a circular hole in a Mohr-Coulomb medium.

Another part of verification involves testing of components of specific material models and is often found in the detailed write-up of the material model. A general three-dimensional material model for regularly jointed media is presented by Thomas (1982). The model is composed of two parts: a continuum approximation based on average discontinuous displacements across jointing planes within a representative elementary volume, and a material constitutive description based on the linear behavior of the base material and nonlinear normal and shear behavior between jointing plane. The sample problems are briefly summarized here:

1. The dilatation response only was analyzed for a rock mass with a prescribed joint set (Thomas, 1982).

2. The shear response without coupled displacements was analyzed for a rock mass with a prescribed joint set (Thomas, 1982).

3. The shear response with coupled displacements was analyzed for a rock mass with a prescribed joint set (Thomas, 1982). The compliant-joint model was further verified through a comparison with a closed-form analytic solution and a similar compliant-joint model developed by RE/SPEC (Labreche and Petney, 1987). In the simulation, a rock joint specimen consisting of intact rock matrix and one set of joints spaced 5 m apart and inclined zero degrees from the horizontal. The excellent comparison of results is shown in Figure 8-14.

The compliant-joint model has been recently updated and modified to include a second set of joints (Chen, 1987). The sample problems, which include comparisons with closed-form analytic solutions, are briefly summarized:

1. The dilatation response only was analyzed for a rock mass with a prescribed joint set (Chen, 1987).

2. The shear response without coupled displacements was analyzed for a rock mass with a prescribed joint set (Chen, 1987).

3. The shear response with coupled displacements was analyzed for a rock mass with a prescribed joint set in an arbitrary orientation (Chen, 1987).

The results of these analyses were used to verify both the code (the equation solver) and the material model (numerical representation of the physics).

Another step in code qualification is the demonstration of the adequacy of the code and models through applications to problems in physical situations in rock. Examples follow of code-model applications to physical situations in real rock.

PROBLEM 1: 20 MPa CONFINING PRESSURE

| | $G_s = 10^{10}$ MPa/m | | | $G_s = 10^7$ MPa/m | | |
|---|---|---|---|---|---|---|
| $\Theta$ | JAC | SPECTROM-31 | ANALYTIC | JAC | SPECTROM-31 | ANALYTIC |
| 0° | 0.166 | 0.166 | 0.166 | 0.166 | NOT CALCULATED | 0.166 |
| 30° | 0.150 | 0.150 | 0.150 | 0.495 | 0.495 | 0.495 |
| 60° | 0.122 | 0.122 | 0.122 | 0.467 | 0.466 | 0.467 |
| 90° | 0.114 | 0.114 | 0.114 | 0.114 | NOT CALCULATED | 0.114 |

PROBLEM 2: LOW CONFINING PRESSURE

| | $G_s = 10^{10}$ MPa/m | | | |
|---|---|---|---|---|
| | $\sigma_{cp}$ = 0 MPa | | $\sigma_{cp}$ = 1 MPa | |
| $\theta$ | JAC | ANALYTIC | SPECTROM-31 | ANALYTIC |
| 0° | 0.548 | 0.548 | 0.428 | 0.429 |

Figure 8-14. Compressive axial strain (%) at axial stress of 100 MPa (comparison of results of compliant-joint model (JAC), closed-form analytic solution, and a second compliant-joint (SPECTROM-31)) (Bauer et al., 1985b).

The ground support for the underground openings at the G-Tunnel underground facility are considered minimal (rock bolts and wire mesh) by rock mass classification ratings (Langkopf and Gnirk, 1986). The underground openings in welded and nonwelded tuff at G-Tunnel were the subject of finite-element analyses using the ubiquitous-joint model (Johnson and Bauer, 1987) and the compliant-joint model (Thomas, 1987). The models represent different approaches to modeling rock mass deformation. The details of accommodation of stresses and strains within the analyses performed by Johnson and Bauer (1987) and Thomas (1987) are different. Yet both models predicted stable openings at G-Tunnel, consistent with each other and with the observed physical situation at G-Tunnel. These calculation exercises provide a measure of credibility to the models-codes applied, which further justifies the concept that deformation of a rock mass may be represented by the combined deformation of the matrix plus fractures.

In a validation-type study, the mechanical response of thermally fractured granite was measured and calculated (Bauer et al., 1985b; Labreche, 1985). Analysis of the experimental results provides insight into the physical deformation of highly fractured rock, whereas the match between calculations and measurements (Figure 8-15) allows us to gauge the appropriateness of the numerical model and input parameters. In general, the calculated stress-strain behavior is in qualitative agreement with that measured. This agreement between measured and calculated response indicates a reasonable degree of validity in our modeling exercise for both the physical characterization and the numerical idealization.

Comparisons of measured and calculated thermal responses in welded and nonwelded tuff have been completed by Zimmerman (1983) and Blanford and Osnes (1987), respectively. As part of the experiment, observations were made of the borehole before and after the thermal cycling. No structural degradation was observed in the borehole. The comparison (Figure 8-16) of measured and calculated temperatures is rather good. This agreement between measured and calculated response indicates a reasonable degree of validity in the modeling exercise for both the physical characterization and the numerical idealization.

The models and codes proposed for use in thermal analyses (methods designed to model temperature-dependent heat conduction) have been subjected to numerous code qualification activities (NRC, 1984). Thus, the status of these codes is such that they are considered nearly ready for Level 1 analyses, pending a detailed review. The results of thermal analyses are used as input for thermomechanical analyses, therefore, differences between results from thermal codes must be well understood.

Comparisons of measured and calculated thermomechanical response are in a preliminary ongoing phase. Initial results (Zimmerman et al., 1986a) of such a comparison are encouraging and further analyses currently are being pursued.

Calculations in support of site evaluation, repository design, and performance assessment require accurate estimates of the in situ stresses and the variability of the in situ stress state within Yucca Mountain. A

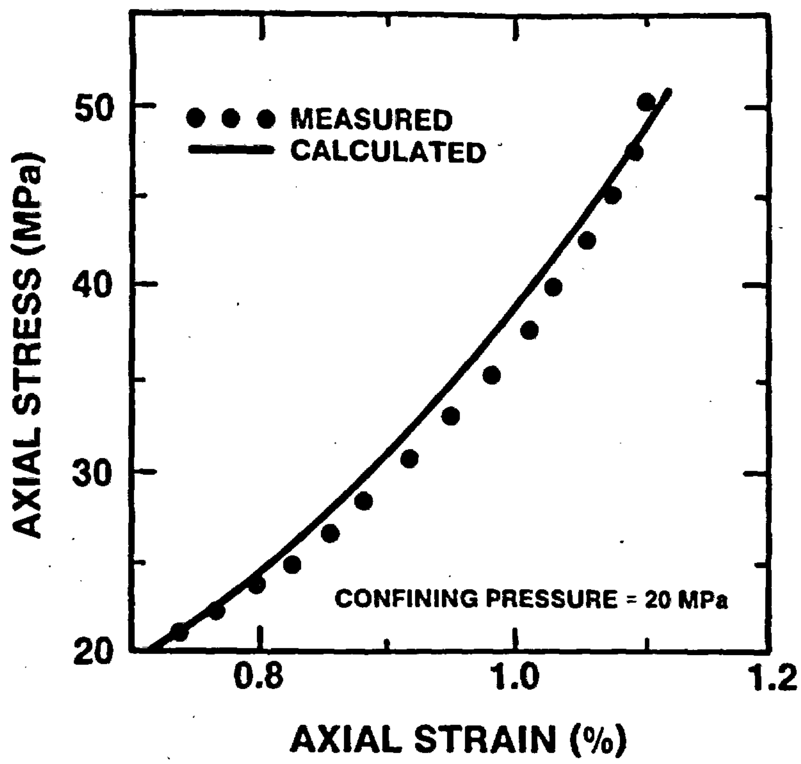


Figure 8-15. Measured versus calculated response for thermally cracked granite. Modified from Bauer (1985b).

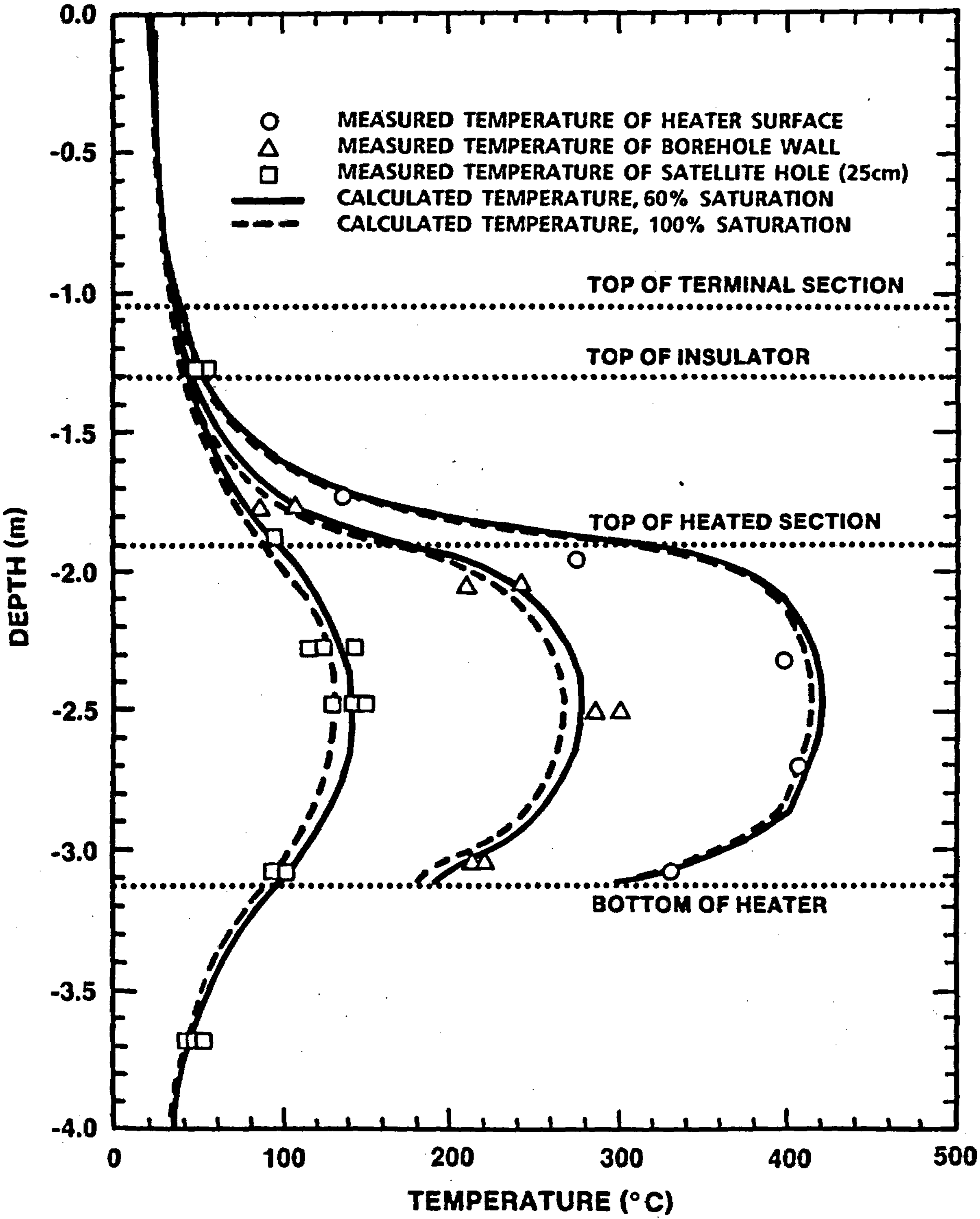


Figure 8-16. Comparison of measured and calculated temperature profiles for borehole in tuff subjected to thermal cycling. Modified from Blanford and Osnes (1987).

modeling approach was developed to assist in understanding the in situ stress state at Yucca Mountain (Bauer et al., 1985a). The validation of this modeling approach is portrayed in the comparison of measured and calculated results. An analysis of the regional geologic studies that pertain to the stress state at the NTS, stress measurements in Yucca Mountain, and stress measurements in nearby Rainier Mesa was performed in conjunction with finite-element calculations to estimate the in situ stresses at Yucca Mountain (Bauer et al., 1985a).

Gravitational stress was the only loading mechanism modeled. Other assumptions used in the calculations were plane-strain conditions and linear-elastic material responses. The mechanical effects of pore pressure were not included except as pore water modifies the effective mass that induces gravitational loads. The validity of the approximations for estimating the in situ stress field were demonstrated through comparing the calculated stresses with carefully measured stresses at Rainier Mesa. Because of this favorable comparison, the same assumptions then were used for calculations that were compared with measured stresses at Yucca Mountain. The results indicate that topographic effects may result in spatial variations in the horizontal stress field at elevations of the proposed repository horizon. Also, by considering the vertical variation in mechanical properties (mechanical stratigraphy), deviations from a smooth increase in horizontal stress with depth are predicted. The combination of tectonic setting, measured values of in situ stress, and finite-element approximations of the stress state at Yucca Mountain provide a basis for estimating the lateral earth-stress coefficient that should be used in design and performance assessment calculations (Bauer et al., 1985a).

Boundary-element method. Boundary-element methods used here (e.g., Brady, 1980) are analysis methods for plane-strain thermoelastic analyses that may be applied to many problems posed by the emplacement of heat sources in a conductive stressed medium. The effects of excavation and heat may be included in the analysis. Rock strength and fracture slip may be used to interpret results. These methods allow for efficient parametric studies to be undertaken in which design tradeoffs and potential effects of parameter sensitivities to design can be evaluated through the predictions of deformations and stress at specific locations as a function of time. The usefulness of boundary-element methods will be qualified through comparison with closed-form analytic solutions, finite-element codes, and underground exploration because their applicability generally is limited to the preliminary phases of design.

Boundary-element methods are a relatively new geotechnical tool for thermal, mechanical, and thermomechanical analyses; yet the methods have been accepted for fairly wide use in underground stability analyses (Hoek and Brown, 1980).

The program HEFF is the FORTRAN code of an indirect formulation of the boundary-element method for plane-strain thermoelastic analysis. A theoretical development of the appropriate governing equations and a description of the numerical algorithms are presented in (Brady, 1980) along with a user's guide that includes several sample problems and their solutions. The sample problems, which includes comparisons with closed-form analytic solutions, are briefly summarized here:

1. Analysis of a circular hole in an elastic continuum, subject to plane strain, was performed and provides a convenient test of the segments of the code concerned only with solution of elastostatic problems.

2. Analysis was performed concerning the two-dimensional thermal stresses in an infinite medium subjected to an exponentially decaying line heat source perpendicular to the plane of analysis (Brady, 1980).

Tunnel index methods. Tunnel index methods (Barton et al., 1974, Bieniawski, 1974) are empirical methods of classifying the rock mass through which ground support recommendations may be obtained. The tunnel indexing methods will be qualified through further studies of case histories specific to the repository in tuff, demonstrations in the exploratory-shaft facility, and checking against the implications of predictions made using boundary-element and finite-element analyses. The methods were each developed through an extensive study of case histories of underground openings in many types of rock, including tuff. The methods, Norwegian Geotechnical Institute Classification System (NGI) and the South African Council for Scientific and Industrial Research Classification System (CSIR) (Bieniawski, 1974), have been used to classify tuff rock masses at Yucca Mountain and G-Tunnel (Langkopf and Gnirk, 1986). These classifications have been used to recommend ground support for the repository openings (Dravo Engineers Inc., 1984). The methods were developed for a wide variety of rocks and currently do not incorporate the effects of heat in the considerations for their ground support recommendations.

### 4.4.7-2 Ventilation analyses

Results of the ventilation calculations completed to this time are discussed below. Both vertical and horizontal emplacement orientation have been analyzed. This report provides the basis for these discussions. Details are provided in Appendix C.

#### Mine ventilation calculations for normal conditions

The approach to the design of an underground ventilation system starts with the determination of the required air quantities based on applicable regulations. For the repository, the selected regulation for compliance consists of the Mine Safety and Health Administration (MSHA) regulations (30 CFR Part 57) and the California Administrative Code. The ventilation criteria obtained from these documents are (1) from MSHA, the quantity of air required for the dilution of diesel exhausts is 125 cfm per brake horsepower of diesel equipment at a working location, and (2) from the California Administrative Code (Title 8, Division of Industrial Safety, Subchapter 17, Article 31) the minimum air velocity for work areas based on area cross section is 60 ft/min (18 m/min) and the minimum air supplied per worker is 200 cfm.

The typical emplacement drift for vertical emplacement is 16 ft (5 m) wide and 21.5 ft (6.5 m) high, the maximum crew size in the drift during emplacement is 6 people, and the diesel-electric waste transporter is rated at 300 horsepower. Applying the requirements stated in the previous paragraph to the vertical emplacement system results in the following air quality requirements:

| | |
|---|---|
| Air required to dilute diesel exhaust | 37,500 cfm |
| Air required for 60 ft/min (18 m/min) velocity | 20,640 cfm |
| Air required for crew (200 cfm per crew member) | 1,200 cfm |

The controlling requirement is the 37,500 cfm requirement for the dilution of exhausts. The design of the ventilation system, as indicated in the approach section, is based on supplying 45,000 cfm to each active emplacement drift. The excess will provide the flexibility to compensate for changes in design requirements and philosophy and to provide for errors resulting from the estimates made for parameters, such as the roughness of mined surfaces and leakage.

The design accomplishes the goal of preferential leakage from the development (mining) side to the waste emplacement side of the repository by maintaining the pressures in the waste emplacement side lower than the development side. The pressure differential is accomplished by designing the waste emplacement ventilation system as a pull system with the suction fans located at the exhaust point and designing the development side ventilation system as a push system with the fans located at the air-intake point. The results of a point-by-point pressure calculation illustrate that this preferred pressure differential is maintained throughout the repository. These results are given in Section 3.4.

Table 8-8 presents the results of the normal mine ventilation calculations for horizontal and vertical emplacement under the two different scenarios. The results present the required fan airflow quantities and pressure heads to meet or exceed the criteria and boundary conditions of the problem, as described in the preceding approach and data sections. Because the mining and emplacement systems are separate, the fan quantities are given for each of these ventilation subsystems.

Table 8-8. Maximum ventilation airflow requirements for two ventilation scenarios

| | Maximum development side airflow scenario | | Maximum emplacement side airflow scenario | |
|---|---|---|---|---|
| Emplacement mode: | Vertical | Horizontal | Vertical | Horizontal |
| Development side airflow (cfm) | 411,800 | 281,300 | 209,400 | 117,200 |
| Emplacement side airflow (cfm) | 481,300 | 446,400 | 837,200 | 517,200 |

The quantities in Table 8-8 will be handled by the men-and-materials shaft as the intake and the tuff ramp as the exhaust for the mining ventilation system. The waste emplacement system uses the exploratory shaft and waste ramp as the intake and the waste ventilation exhaust shaft for exhaust. A more complete description of the ventilation system is provided in Section 3.4. The quantities required are presented in Table 8-8 to illustrate that the total air required is well within the capabilities of available mine ventilation equipment and is typical of the quantities required by conventional mines.

Drift cooling calculations

The required cooling times and loads calculated for the vertical and horizontal waste emplacement orientations are given in Table 8-9. Each orientation considers the alternatives of cooling the intake air or using ambient air. The results give the time required to achieve the conditions specified for the two different levels of activity (i.e., inspection and light maintenance, and heavy maintenance or retrieval). The calculations start with the conditions expected 50 yr after waste was emplaced.

Table 8-9 shows that, for the vertical emplacement orientation, cooled inlet air will be required in all instances for the expedient cooling of the drifts in preparation for reentry. The table shows that ambient air can be used to cool the horizontal emplacement drifts for reentry to perform inspection, but for reentry to perform major maintenance or retrieval, cooled air also may be required if a cool-down time of 70 d is not acceptable.

Table 8-9. Cooling requirements for vertical and horizontal emplacement using ambient and conditioned air

| | Inspection purposes (ACP[a]>300 $w/m^2$, $T_{dry}$ <45°C) | | | | Maintenance/partial retrieval (ACP>500 $w/m^2$, $T_{dry}$ <40°C) | | | |
|---|---|---|---|---|---|---|---|---|
| Emplacement method | Ambient inlet temperature | | Cooled inlet temperature | | Ambient inlet temperature | | Cooled inlet temperature | |
| | Time to cool (days) | Cooling load (kW) | Time to cool (days) | Cooling load (kW) | Time to cool (days) | Cooling load (kW) | Time to cool (days) | Cooling load (kW) |
| Vertical | 168 | 0 | 21 | 708 | >560 | 0 | 37 | 708 |
| Horizontal | 14 | 0 | 5 | 490 | 70 | 0 | 11 | 490 |

[a]ACP = Areal cooling power.

4.4.7-3 Hydrologic analyses

The flood hazard for a 14-km (9-mi) reach of Fortymile Wash and its principal southwestern tributaries--Busted Butte, Drill Hole, and Yucca washes--were evaluated (Squires and Young, 1984). Data from 12 peak-flow gaging stations adjacent to the Nevada Test Site were used to develop regression relations that would permit an estimation of the magnitude of the 100- and 500-yr flood peaks.

Among seven cross sections on Fortymile Wash, the estimated maximum depths of the 100-yr, 500-yr, and regional maximum floods are 2,3, and 9 m (8, 11, and 29 ft), respectively. At these depths, flood water would remain within the deeply incised channel of the wash. Near flow velocities would be as great as 3, 4, and 9 m/s (9, 14, and 28 ft/s) for the three respective flood magnitudes.

The study shows that Busted Butte and Drill Hole washes (9 and 11 cross sections, respectively) would have water depths of up to at least 1 m (4 ft) and mean flow velocities of up to at least 2 m/s (8 ft/s) during a 100-yr flood. A 500-yr flood would exceed stream-channel capacities at several places, with depths of 10 ft and mean flow velocities at 3 m/s (11 ft/s). The regional maximum flood would inundate sizable areas in the central parts of the two watersheds.

At Yucca Wash (5 cross sections), the 100-yr, 500-yr, and regional maximum floods would remain within the stream channel. Maximum flood depths would be about 1.5, 3, and 7 m (5, 9, and 23 ft) and mean velocities about 3, 4, and 7 m/s (9, 12, and 22 ft/s), respectively, for the three floods.

The results of this study were considered in the siting of the surface facilities and in the conceptual design of the flood protection features. No explicit design calculations were performed to support the conceptual design of flood protection features. Where needed, the features (dikes, channels, etc.) were identified in the conceptual design. The final design of these features will be developed during the license application design phase and will be based on the site-specific probable maximum flood (PMF) analysis.

This flood hazard calculation is preliminary partly because the surface facility locations are conceptual and partly because some regional, rather than site specific, data had to be used in the supporting calculations. Regional data provides the most accurate flooding potential data that can be obtained in advance of acquisition of site-specific data through site characterization. The report documents preliminary calculations of discharge volumes as a function of time for four locations under thunderstorm and general storm conditions.

4.4.7-4 Tectonic and seismic analyses

Evaluation of ground motion at the Yucca Mountain site must address two types of events: (1) natural seismicity (earthquakes) and (2) underground nuclear explosions (UNEs), which are conducted periodically at the Nevada Test Site (NTS). The seismic design assumption for this report is that 0.40g is the vibratory ground motion input. This value is based on information contained in current documents (USGS, 1984; DOE, 1986c; and URS/Blume, 1986) and seismologic and engineering judgment. This value may be revised as a result of ongoing studies, particularly the characterization of faults in the immediate vicinity of the site, for use in future design analysis. The assumption does not account for any potential surface rupture on the faults in the site vicinity. A value of 0.40g for vibratory ground motion envelops the maximum ground acceleration expected from ground motion induced by a maximum yield UNE (700 kilotons) at the NTS, which is equal to 0.32g based on a mean value plus 3 standard deviations, (Section 6.3.3.4, DOE, 1986c).

Two reports have been completed using probabilistic methods to estimate ground motion. In the first report (URS/Blume, 1986), seismogenic zones were delineated from regionalization of the southern Great Basin on the basis of historic seismicity, late Quaternary strain rates, and style of late Cenozoic deformation in order to predict the ground motion hazard at the site.

Further, an occurrence model for UNEs also was established in this study from historical data of NTS testing that occurred before the Threshold Test Ban Treaty. Any future testing was assumed to occur no closer than the Buckboard Mesa area, which is approximately 15 mi from the repository site and is closer than any of the locations on the NTS where testing actually occurs. A maximum yield of 700 kilotons was used for a UNE at Buckboard Mesa, based on the potential damage that a detonation that size would cause to the area surrounding the point of detonation. The current testing limit of 150 kilotons, as limited by the Threshold Test Ban Treaty, produces negligible ground motion at the repository site. The ground motions calculated in URS/Blume (1986) are (1) an acceleration value of 0.4g with a return period of 2,000 yr as a result of natural seismicity and (2) an acceleration value of 0.15g based on a mean plus 2 standard deviations for UNEs.

The second study, which is in the process of completion, assumes faults in the vicinity of the site are active. Fault-specific, random-earthquake-occurrence models have been developed to predict the hazard caused by ground motion and fault displacements. The earthquake/ occurrence was determined from published fault length and slip rate information. The faults considered in the model include the Bow Ridge, Paintbrush, Ghost Dance, Midway Valley, and Severe Wash faults.

Preliminary evaluations indicate that several local faults range in length to 20 km or more. If the waste-handling facility were to be located in Midway Valley, the controlling earthquake source would appear to be the north-south-trending Paintbrush Canyon fault. This fault may be capable of producing a M = 6.5 earthquake, with an average return interval of several tens of thousands of years. Preliminary ground motion studies indicate that the most probable value for peak acceleration in close proximity to a M = 6.5 earthquake is about 0.5g. The probability of having a M = 6.5 earthquake or any significant surface offsets on the faults considered during the preclosure period is extremely small. Technology exists for designing surface facilities for the design accelerations much larger than those described above. Typical examples include Diablo Canyon Nuclear Power Plant and San Onofre Nuclear Power Plant. Published literature also shows that structures can be designed to resist moderate surface displacement before any catastrophic failure would occur (Reed et al., 1979). Plans for characterizing potential ground motion for design purposes are discussed in SCP Section 8.3.1.17.

At the level of the underground facility, it is provisionally assumed that the peak accelerations are half those at the surface. This is based on a conservative estimate of attenuation of ground motion with depth available from UNE test data and other published information (URS/Blume, 1986; Carpenter and Chung, 1985) on earthquakes. Further investigation and data gathering during site characterization and the development of a satisfactory model for the surface and downhole data may result in revised estimates of peak accelerations. Carpenter and Chung (1985) indicate that up to surface shaking levels of 0.5g, no tunnel collapses as a result of shaking alone have been observed. Tunnels in poor soil and rock are more susceptible to damage than are tunnels deep in rock. Damages to all classes of deep tunnels consisted primarily of minor rockfalls and formation of new cracks except where active faults intersected tunnel bores. In these instances, localized severe damage was experienced. Hence, it can be seen that technology exists for designing of underground facilities for the levels of accelerations described previously.

8.3.7.3 Future work

The planned future work is identified in SCP Section 8.3.2.5.7. This work consists of (1) performing tradeoff and sensitivity studies to establish the design approach, the design configurations, and to select basic equipment types; (2) completing reference calculations; and (3) performing verification and validation of analysis codes.

For the underground facility, there are three specific things that need to be determined and assessed: (1) the potential for radon gas, (2) the impact of seismic events on the underground design, and (3) the radiation shielding characteristics of the formation.

The tunnel indexing methods will be qualified through further studies of case histories specific to the repository in tuff, demonstrations in the exploratory shaft facility (ESF), and checking against the implications of predictions made using boundary-element and finite-element analyses. The potential for studies of case histories may be limited because of the availability of underground openings in tuff. Demonstrations in the ESF will include evaluations of various ground support recommendations within the range of types of ground encountered. The boundary-element and finite-element techniques will be used to help qualify the tunnel indexing methods in at least two ways. In the first, the results of numerical analyses of openings without ground support for ambient temperature conditions will be compared with ground support recommendations using the tunnel indexing techniques to provide a second level of confidence to the initial ground support recommendations. Boundary-element and finite-element techniques (without ground support) will be applied next to determine the potential effects of heat on the opening stability. The results of these analyses will be studied to determine the potential for problems in the initial ground support design as a result of the heat. In this manner, analysis of these results will qualify the initial ground support recommendations.

Future work pertaining to method, model, and code qualification includes the following activities: (1) a review of existing methods, models, and codes; (2) verification; (3) benchmarking and parametric studies; and (4) validation. While it may appear that this work is to be completed sequentially, in reality, each progressive activity could lead to looping back through earlier ones. The following descriptions of activities apply to both boundary-element and finite-element models and codes.

At least three classes of material models (linear elastic and elastic-plastic, compliant joint, discrete discontinuities) are recommended for mechanical-structural calculations. A linear and nonlinear, steady- and transient-heat-conduction code is recommended for thermal calculations. A review of existing material models and codes will be performed to assess their applicability to repository performance, repository design, and site evaluation calculations. Selected material models and codes will be modified as necessary to satisfy requirements for analysis of repository performance and design.

Computer codes developed for engineering analysis will be verified to ensure that they correctly perform the operations specified in the numerical model. Verification will be accomplished by testing the model's numerical computations against closed-form analytic solutions. Part of the verification procedure for finite-element codes will be solutions comparisons with previously fully documented boundary-element codes.

Benchmarking is the comparison of the results on one item of software with the results of another item of software designed to solve a comparable problem to show that they produce similar results. Material models and codes will be benchmarked by cross-checking the numerical solutions to a series of well-defined thermal, mechanical, and thermomechanical boundary value problems. At least one benchmarking analysis will be run for each model for each problem scale to be encountered in repository design. Material properties, in situ conditions, boundary conditions, and loading conditions for these problems will be representative of those expected of the repository. The material models will be further evaluated through parametric studies in which input parameters are systematically varied to determine the relative significance of a parameter and to ensure that the variations impart the correct sense of change in material behavior.

It is currently planned to have models and codes qualified for Level I analyses by the end of final benchmarking activities. At that time only initial validation analyses will have been completed.

Validation is ensuring that the physical model, as embodied in software, is a correct representation of the intended physical system or process. Validation will be accomplished by comparing the results of numerical computations with the results of field-, bench- and laboratory-scale experiments. Certain G-Tunnel, exploratory shaft, and laboratory experiments were developed for this purpose. The purpose of these physical models is to test the physics embodied in the material models. Analog material tests may be appropriate for this purpose. Validation analysis also may be conducted by comparing calculated results to experimental results available in the open literature. In general the validation process will be conducted using the following series of steps:

1. Experimental design analysis is performed to develop the experiment concept in a design that will address the phenomena of interest.

2. Site-specific data and material properties are collected for model calculations.

3. A pretest analysis is performed.

4. The experiment is conducted.

5. The pretest analysis is reevaluated in light of the actual experimental procedure.

6. A posttest comparison of experiment and analysis is conducted by a peer review panel.

Field experiments in the ESF are in the process of being designed specifically for validation of models used for thermal, mechanical, and thermomechanical analyses. The design of these experiments will include pretest analyses to optimize the experiment and analysis for the validation activity. For example, experimental location, orientation, loading conditions, and data collection arrays will be chosen such that analysis of the experiment (i.e., validation) will be facilitated.

## 8.3.8 ISSUE 4.5 REPOSITORY SYSTEM COST EFFECTIVENESS

### 8.3.8.1 Introduction

The question asked by Issue 4.5 is

> Are the costs of the waste package and repository adequately established for the resolution of the performance issues?

This section is concerned with the cost estimating activities related to establishing the cost bases necessary to perform the comparative analysis required by the performance issue under Key Issue 4. That performance issue addresses the higher level finding for the system guideline on ease and cost of construction operation, closure, and decommissioning of the mined geologic disposal system required by 10 CFR Part 960. The higher level finding is concerned, in part with a comparative evaluation of the total system life cycle costs (TSLCC) for each of the repository siting options.

The work completed to date by the NNWSI Project has focused on the site specific aspects of the TSLCC. Specifically, cost estimates have been prepared for the construction, operation, and decommissioning phases for facilities and for waste packages. This information, which is tabulated in Table 8-10, is summed to produce the total repository life cycle cost (RLCC) estimate. The RLCC estimates are only a portion of the TSLCC; the resolution of this issue requires the consideration of nonsite specific costs such as those associated with a monitored retrievable storage (MRS) facility, as well as transportation costs.

Table 8-10. Repository Life Cycle Cost (RLCC) 1986 Constant[a] Estimate Analysis[b]

| Cost Account Description | Construction Phase Cost[c] | Construction Phase Percent of Phase | Construction Phase Percent of RLCC | Operations Phase Cost[c] | Operations Phase Percent of Phase | Operations Phase Percent of RLCC | Decommissioning Phase Cost[c] | Decommissioning Phase Percent of Phase | Decommissioning Phase Percent of RLCC | TOTAL RLCC | PERCENT of RLCC |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Management and integration | 346 | 24.4 | 5.2 | 49 | 1.0 | 0.7 | 20 | 5.3 | 0.3 | 415 | 6.3 |
| • Architect/Engineer | 217 | | | 0 | | | 14 | | | | |
| • Construction Management | 74 | | | 0 | | | 2 | | | | |
| • Other | 55 | | | 49 | | | 4 | | | | |
| Surface facilities | 785 | 55.4 | 11.9 | 2,546 | 52.9 | 38.6 | 116 | 31.3 | 1.8 | 3,447 | 52.3 |
| • Site | 167 | 11.8 | 2.5 | 114 | 2.4 | 1.7 | 38 | 10.2 | 0.6 | | |
| • Waste-handling facilities | 488 | 34.4 | 7.4 | 1,242 | 25.8 | 18.8 | 34 | 9.1 | 0.5 | | |
| • Balance of plant | 130 | 9.2 | 2.0 | 1,190 | 24.8 | 18.0 | 45 | 12.0 | 0.7 | | |
| Subsurface facilities | 286 | 20.2 | 4.3 | 1,610 | 33.5 | 24.4 | 235 | 63.4 | 3.6 | 2,131 | 32.3 |
| • Shafts and ramps | 62 | 4.4 | 0.9 | 28 | 0.6 | 0.4 | 3 | .8 | 0.0 | | |
| • Excavation and emplacement | 136 | 9.6 | 2.1 | 838 | 17.5 | 12.7 | 101 | 27.1 | 1.5 | | |
| • Service systems | 88 | 6.2 | 1.3 | 744 | 15.5 | 11.3 | 132 | 35.5 | 2.0 | | |
| Waste packages | 0 | NA[d] | 0.0 | 603 | 12.5 | 9.1 | 0 | 0.0 | 0.0 | 603 | 9.1 |
| • Spent fuel | 0 | | | 351 | 7.3 | 5.3 | 0 | 0.0 | | | |
| • Defense High Level Waste | 0 | | | 128 | 2.7 | 1.9 | 0 | 0.0 | | | |
| • Other | 0 | | | 125 | 2.6 | 1.9 | 0 | 0.0 | | | |
| Repository Life Cycle Cost | $1,417 | | 21.5 | $4,809 | | 72.9 | $371 | | 5.6 | $6,597 | 100.0 |

[a]Unescalated for the life of the repository
[b]Source: Gruer et al. (1987)
[c]All costs in millions of dollars
[d]NA = Not Applicable

The discussion of the proposed strategy for resolution of this issue is presented in SCP Section 8.2.3.1.1. Readers not familiar with the resolution strategy for this issue should review this section before continuing.

Issue 4.5 has been subdivided into three information needs. The text that follows briefly identifies each information need and discusses site specific work that has been completed to date for each of the information needs.

Information Need 4.5.1 Estimate the costs of the reference and alternative waste packages

This information need consists of preparing and compiling the costs associated with the fabrication of the reference waste package, as well as alternative designs. The waste package includes the container and the materials within the container. Under the current NNWSI Project design, the cost of the waste package is essentially the cost of the container. Waste container costs constitute a significant portion, about 9%, of the RLCC and are allocated entirely to the operations phase. They constitute over 12% of the operating phase costs (Table 8-10). There are several waste container design variables that affect these costs: size, material type, shell thickness, capacity, fabrication method, internal separator configuration, and quality assurance (QA). Cost analysis for alternative designs contributes to the TSLCC analysis and provides input for the selection of the final container design.

Information Need 4.5.2 Estimate the costs of the reference and alternative repository designs

This information need consists of preparing and compiling the costs associated with the construction, operation, and closure of the reference repository design, as well as alternative designs. Repository design costs allocated to the construction phase include the costs for the final design, construction, and inspection of surface and subsurface facilities, and for management and integration of these activities. The original construction and capital equipment cost estimate for the reference and alternative repository designs constitute approximately 21% of the RLCC or about $1.4 billion (Table 8-10). Repository life cycle costs for the construction phase are sensitive to the size and complexity of the physical plant required to support surface and subsurface operations.

Information Need 4.5.3 Estimate the life cycle costs of the reference and alternative total system designs

This information need consists of preparing and compiling the costs of the reference and alternative total system designs. The composite cost estimates for the reference and alternative total system designs cover all chronological phases and are referred to as the TSLCC. The TSLCC includes the costs of the waste package (Information Need 4.5.1) and the costs of the repository (Information Need 4.5.2). It also includes, however, costs for activities such as transportation and development of an MRS, which is relatively nonsite dependent. The NNWSI Project has prepared composite cost estimates for the reference and alternative waste package design, as well as the reference and alternative repository designs. These cost estimates cover only the site-specific portion of the TSLCC for three phases: construction, operation and decommissioning.

### 8.3.8.2 Work completed

Information Need 4.5.1 Estimate the cost of the reference and alternative waste packages

Several preliminary waste container cost estimates have been performed for the two-stage repository study (SNL, 1986). The first preliminary cost estimate was based on a generic waste package. This design was revised to be more site-specific and the cost estimate was recalculated.

Approach

Cost estimates for the boiling water reactor (BWR) fuel rod and pressurized water reactor (PWR) fuel rod emplacement containers were obtained by averaging several manufacturers' quotes. These quotes were obtained from manufacturers experienced in the fabrication of similar chemically resistant low-carbon stainless steel vessels. The technology for fabricating such stainless steel vessels is well established and is very similar to the fabrication process expected to be used for the emplacement containers.

Cost estimates for the alternative emplacement containers were determined by extrapolating the costs of the reference case containers. The similar physical parameters of the reference and alternative containers studied thus far have permitted plausible results. Shipping, handling, and quality assurance and quality control costs were also included.

Data

Data were obtained from manufacturer quotations for 2,000 units.

Results

Estimated emplacement container costs are identified specifically and included as data in RLCC reports, and in the cost estimate (Gruer et al., 1987) for this SCP-CDR.

Information Need 4.5.2 Estimate the cost of the reference and alternative repository designs

Cost estimates are only approximations of value at a given time and are very sensitive to the degree of completeness of the design definition and available historical data. In the initial design stages, such as at SCP conceptual design, design details are not defined, and large contingency factors were used to compensate for design uncertainty. As the design evolves through the conceptual phase, design options studies, development of the advanced conceptual design, and the later detailed design definition stages, the design information available upon which to base estimates becomes correspondingly more detailed, confidence increases, and contingency factors decrease.

Several traditional cost-estimating methods have been used to produce the direct (bare) labor and material costs because the amount of design detail available is not the same for each cost account considered (see Table 8-10). The design detail available for the particular category of cost account was the primary determining factor for the method used.

The subsurface cost-estimating methods were those traditionally used in the mining industry and included unit costs and itemized material take-off. A detailed explanation of the method is described in the cost estimate (Gruer et al., 1987) for this report.

Cost markup factors were applied to the bare costs using conventional computer-oriented methods that use off-the-shelf personal computer spreadsheet and data base management software. Guidance for the format, methods, and cost account definitions was provided by the DOE/Weston cost guidelines (DOE, 1986f).

Data

Data sources include the architect-engineering (A/E) data bases, commercial cost-estimating references, and vendor's quotes. Data types include direct labor units and/or lot costs, equipment costs, and indirect labor and material costs.

Indirect labor and material factors were determined by the A/Es from their historical data bases. Other cost factors, such as engineering and contingency, were determined by professional judgment.

Results

Work completed includes nine capital costs estimates. Four cost estimates were produced for the two-stage repository report (SNL, 1986), which compared a single construction stage to a repository constructed in two stages, plus a vertical (reference) emplacement design and a horizontal emplacement design (for each construction stage). These same two emplacement configurations were reestimated for this report. Construction costs are summarized in Table 8-10, which also shows the relative costs between the major cost accounts.

The results of the capital cost estimate are used for several purposes. During the conceptual design phase, the results are the basis for most of the input to the RLCC. This estimate is used as a factorable base from which other major project costs are derived, such as operations and maintenance, decommissioning, project management, equipment design and inspection, quality assurance, and contingency. These capital cost estimates are also used in the preparation of the project data sheets for project planning, funding, and management.

Information Need 4.5.3 Estimate the life-cycle costs of the reference and alternative total system designs

Approach

Total System Life Cycle Costs (TSLCC) estimates have been prepared to support the preliminary finding about the preclosure system guideline on ease and costs of construction (DOE, 1986e), as well as the annual assessment of waste fund fee adequacy (DOE, 1987b). The costs estimates prepared by the NNWSI Project under Information Needs 4.5.1 and 4.5.2 can be used to estimate the RLCC, which in turn is used to estimate the TSLCC. Different analytical approaches have been used to estimate the RLCC for each life-cycle phase, and several different approaches have been used within each phase. The costs for the construction phase are discussed under Information Need 4.5.2. The costs for waste packages, which are allocated to the operations phase, are discussed under Information Need 4.5.1. The operations phase, which lasts for 50 yr and accrues about 73% of the RLCC, is composed of two subphases: emplacement operations and caretaker operations. Preliminary estimates of the surface and subsurface facilities operations and maintenance cost were performed by the respective A/Es, based on preliminary information they had previously developed.

Emplacement phase operating labor, materials, and supply costs were estimated by using several methods. The labor force cost was estimated from a functional breakdown of site operations such as waste-handling equipment operation, hot cell operation, process maintenance, fire protection, training, health and safety, and quality assurance. Material and supply costs were factored as a percentage of the construction costs. Cost markup factors were determined by DOE guidance, historical data, and engineering judgment. The caretaker operations phase costs were estimated by the same method.

The final phase contains three distinct activities: closure, decommissioning, and site marking. All three costs were determined by examining plans for each activity and ascertaining sequences, material requirements, and costs, as well as labor requirements and associated costs.

Off-the-shelf personal computer spreadsheet and data base management software were used for the costs study (SNL, 1987). The cost matrix format, the cost account definitions, and the current RLCC methods were provided in the DOE/Weston cost guidelines (DOE, 1986f).

Data

The primary data sources included the A/E data bases, commercial cost-estimating references and vendor's quotes. Data types include direct labor units and/or lot costs, direct material units and/or lot costs, equipment costs, and indirect labor and material costs.

Results

The work completed for this information need includes nine RLCC estimates for various designs for a repository in tuff. An RLCC estimate was made for each of the four designs in the two-stage repository report, which are (1) a single-stage repository based on emplacement of single containers in short vertical boreholes, (2) a two-stage repository based on emplacement of single containers in short vertical boreholes, (3) a single-stage repository based on emplacement of multiple containers in long horizontal boreholes, and (4) a two-stage repository based on emplacement of multiple containers in long horizontal boreholes. The costs for current designs for a two-stage repository based on a single container in a short vertical borehole and multiple containers in a horizontal borehole were estimated for this report. Table 8-10, and additional information may be found in Stinebaugh and Robb (1987).

The RLCC information is used primarily for project management purposes, including project funding, funding schedule, socioeconomic impact studies, and electric utility fee adequacy analysis.

8.3.8.3 Future work

Analysis Needs

Estimation of waste package costs is an ongoing activity that will support waste package design decisions during the advanced conceptual design (ACD), the license application design (LAD), and the final procurement and construction design (FPCD).

Identified future analysis needs include physical parameter sensitivity studies; reappraising quality assurance factors, especially with regards to NQA-1 criteria; and shipping and handling costs. Other specific future cost analysis needs have not yet been identified. Special NNWSI intraproject and DOE interproject studies will likely be identified as the design detail develops.

Cost needs include (1) new requests for quotation when the design, scope, or assumptions change; (2) regular reassessment of the appropriate cost factors, such as quality assurance and quality control, contingency, and engineering; and (3) the use of a consolidated data base management system to facilitate integration of new emplacement container costs in the RLCC.

Repository construction and TSLCC estimates will be updated at each design phase; the TSLCC for the ACD will form the basis for resolution of Issue 4.5 through a comparative evaluation of costs among siting options. Alternative cost-analysis needs depend on the number of design considerations and the amount of design detail available. When more design detail is available, more detailed cost estimates with greater accuracy and smaller contingency are possible. Changes in economic conditions and labor policies that might impact the repository construction and operating costs will be considered in the analysis.

General cost-estimating analysis needs include analysis for staffing, quality assurance, operating and maintenance materials and supplies, decommissioning, site marking, and capital equipment.

Development needs

Internal to the cost-estimating process, there are no technical or process development needs. The repository life cycle cost data base will expand during the various design phases and become very site specific and detailed. Because of the large scope of this particular project, the only practical cost-estimating method requires the use of a computer.

Site information needs

There are no technical site characterization information needs related directly to the estimation of costs for resolution of this issue.

## 8.4 INTERFACE WITH OTHER DESIGN ISSUES

There are several design issues that are not fully resolved by the repository design activity but that require input from repository design for their resolution. They include

- Issue 1.10, Waste Package Characteristics; (Postclosure)

- Issue 2.6, Waste Package Characteristics; (Preclosure)

- Issue 4.3, Waste Package Production Technologies; and

- all design-related issues that may be developed under Key Issue 3, the key issue pertaining to environment, socioeconomics, and transportation.

Section 8.4.1 discusses the interfaces between repository design and the waste package design and identifies where those interfaces occur. No specifically defined issues will be identified for Key Issue 3 until after the scoping hearings for the environmental impact statement for the Yucca Mountain repository. However, based upon past experience and an examination of existing regulations, certain types of design and operating data will probably be required. Section 8.4.2 discusses anticipated data needs. A discussion of the waste package issues; 1.10, 2.6, and 4.3 can be found in Section 8.3.4 of the SCP.

### 8.4.1 INTERFACES WITH THE WASTE PACKAGE

The interfaces between the repository and the waste package can be divided into the following categories:

- the reference waste package design, including size, weight, and radiation and thermal characteristics of the waste;
- fabrication technology and requirements;
- acceptable handling environment; and
- emplaced environment.

Each category contains a large number of details that must be developed, agreed upon, and documented. Principal components of the documentation are the Interface Control Drawings (ICD), which are a part of the SDR. Once the details of the interface have been established and shown on an ICD, they are placed under change control procedures and distributed to all appropriate users to ensure consistency of design products. Because design is iterative in nature, the interface definitions are subject to change as the design matures. As more details are developed for the facilities or as changes are proposed for the waste package, the effects will be evaluated and the ICDs changed appropriately.

The resolution of Issue 1.10, Waste Package Characteristics (Postclosure), will require input from all four categories of interface information. The physical characteristics and the radiation and thermal outputs of the waste package interact with the overall design of the underground facility (including the APD and the waste spacing and emplacement configuration) to establish the postclosure environment of the waste package. The available fabrication technology and how well it can be carried out (i.e., closure welding, filling with inert gases, etc.), as well as how the container is likely to be handled (bumped, scraped, scratched, dropped, dented, etc.), may affect how well the package will perform in the postclosure environment. Conversely, the design of the waste-packaging, handling, and emplacement features will consider criteria established by postclosure performance assessment of the waste package. Therefore, information about all aspects of the waste-handling processes and the design of the underground portion of the waste operations area are required to resolve Issue 1.10.

A similar discussion is applicable to Issue 2.6, Waste Package Characteristics (Preclosure). The areas of concern shift from long-term effects (e.g., containment and isolation), to short-term effects (e.g., operation and radiation safety), but knowledge of the entire waste-handling system will be required to resolve the issue.

Resolution of Issue 4.3, Waste package production technologies involves only two of the four categories, the reference waste container design and fabrication technology. The proper specification of the fabrication technology requires knowledge of whether and how that technology can be implemented at the repository. Similarily, the fabrication technology has a major impact on the design of the waste-handling facilities on the surface and the preclosure radiation safety performance objective.

### 8.4.2 INTERFACE WITH FUTURE ENVIRONMENTAL, SOCIOECONOMIC, AND TRANSPORTATION ISSUES

The design and operating data expected to be needed for addressing environmental, socioeconomic, and transportation issues are identified in the following sections. The discussion cannot be complete because the issues have not been defined; however, experience indicates that these items will probably be required to some degree.

#### 8.4.2.1 General information

Detailed descriptions will be required of the location and layout of the repository facilities and of the operations conducted in each portion of the repository. These descriptions will be used in identifying the affected habitat and human populations, and the location and timing of potential emissions from the repository.

Information contained in these descriptions will include

- location of all surface facilities and accesses to the underground facility;
- design descriptions of facilities, with particular emphasis on potential environmental releases;

- sensitivity of facilities to surface flooding;
- operational activities during repository construction, operation, and closure, resulting in potential controlled or uncontrolled environmental releases;
- water supply requirements and anticipated sources;
- emergency response plan covering accidents involving nuclear, toxic, and nontoxic materials.

#### 8.4.2.2 Environmental releases

The potential environmental impact and public health hazards of both radioactive and nonradioactive releases from the repository will require a detailed description of all potential emission sources, normal and accidental conditions resulting in the release, and composition and rate of the release. Design features for mitigating these releases will need to be described, including containment systems, treatment systems, and monitoring systems.

The potential releases may include gaseous material, airborne particulates, erosion by surface waters, and liquid discharges to surface water or ground water. The potentially released materials may be radioactive, nonradioactive hazardous, or nonhazardous.

#### 8.4.2.3 Waste management

The repository will generate waste materials, partially contaminated with both radioactive and nonradioactive hazardous materials. A complete description of the airborne, liquid, and solid waste treatment systems will be needed to assess potential impacts of the end products of these systems. Assessment of potential releases will address these treatment systems. A description of these wastes will be needed, including volume, radioactive and hazardous characteristics, waste form, and anticipated disposal method. Tuff excavated during construction of the underground facility will be stored on the surface during repository operations. A description will be required of the quantity and characteristics of the excavated tuff and of the design of the tuff pile. A description of potential airborne or waterborne releases from the tuff pile, during pre- and postclosure periods will be needed.

#### 8.4.2.4 Resource requirements

Assessment of the socioeconomic impacts during the construction, operation, closure, decommissioning, and postclosure phases of the repository requires a detailed, time-phased characterization of the labor force involved in conducting repository operations.

Socioeconomic impact assessments will need detailed information about all materials and natural resources to be used by the repository, as well as information about the places from which the materials and natural resources will be purchased or obtained.

Detailed designs of repository and the life-cycle costs for repository operations are needed for assessment of socioeconomic impacts.

#### 8.4.2.5 Transportation

A detailed plot plan showing the location and design specifications for primary and secondary highway and rail access routes is needed to evaluate the socioeconomic impacts of construction, maintenance, use of access routes, and the improvement of existing access routes. Design information for access roads will include (1) specifications for existing roads to be used during repository operations; (2) designs and specifications for access roads to be constructed or improved; (3) design and specifications for bridges or other structures to be constructed along accesses; (4) clear identification of any components of the National Park System, National Wildlife Refuge System, National Wild and Scenic Rivers System, National Wilderness Preservation System, National Forest land, state or regional protected resources, wildlife or historical areas, native American resources, and any other sites of unique cultural interest; (5) identification of rights-of-way; and (6) terrain modifications associated with construction or improvement of rail or highway accesses.

Evaluation of the potential radiological consequences of the transportation of radioactive material to and from the repository requires a complete and detailed description of the components of the transportation system and of the radioactive material that will be transported.

The determination of transportation system load that results from the transportation of radioactive waste will require detailed long- and short-term schedules. Assessment of health and safety risks associated with transportation will require the identification of nuclear and non-nuclear accident scenarios.

## 8.5 FUTURE ISSUE RESOLUTION WORK

The future work toward resolution of design and preclosure performance issues that are associated with site characterization are discussed in Chapter 8 of the SCP. Future work on the complete set of design and preclosure performance issues, those that require site characterization data and those that do not, will be discussed in the Repository Design Plan. The current plan is to publish the design plan prior to the start of Advanced Conceptual Design.

Plans for the resolution of the issues that derive from Key Issue 3 cannot be formulated until the issues have been identified during the scoping hearings for the environmental impact statement. Before that time, the designers will collect the information they expect to need.

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# 9.0 QUALITY ASSURANCE PROGRAM

## 9.1 General

The quality assurance (QA) program for the Nevada Nuclear Waste Storage Investigations (NNWSI) Project is described in NVO-196-17, "Nevada Nuclear Waste Storage Investigations Quality Assurance Plan" (DOE, 1986). This program is applicable to the Waste Management Project Office (WMPO) and to all project participants and their subcontractors. The QA program is designed to address the requirements of 10 CFR 60 (Subpart G) (NRC, 1986). To do so, the NNWSI QA program fulfills the requirements outlined in two other documents: ANSI/ASME NQA-1, "Quality Assurance Program Requirements for Nuclear Facilities" (ANSI/ASME, 1983) and "NRC Review Plan: Quality Assurance Programs for Site Characterization of High-Level Nuclear Waste Repositories" (NRC, 1984).

As specified in the documents cited above, a graded approach has been established for applying the QA program to repository-related activities. In this approach, items and activities are classified by QA level, based primarily on their importance with regard to public health and safety and waste isolation, as well as concerns for reliability, maintainability, worker safety, etc. A description of the three QA levels and their attendant programmatic requirements is provided below.

Quality assurance Level I is assigned to those radiological health and safety-related items and activities that are important to either safety or waste isolation. These items and activities are associated with the ability of a geologic nuclear waste repository to function in a manner that prevents or mitigates the consequences of a process or event that could cause undue risk to the radiological health and safety of the public. Items important to safety are those engineered structures, systems, and components essential to the prevention or mitigation of an accident that could result in a radiation dose of 0.5 rem or greater, either to the whole body or to any organ either at or beyond the nearest boundary of the unrestricted area at any time until the completion of permanent closure of the repository. Items and activities important to waste isolation are those barriers and related activities that must meet the criteria addressing long-term performance of the engineered and natural barriers to inhibit the release of radionuclides from the site to the accessible environment after permanent closure.

Quality assurance Level II is assigned to those activities and items related to the systems, structures, and components that require a level of quality assurance sufficient to provide for reliability, maintainability, public and repository worker nonradiological health and safety, repository worker radiological health and safety, and other operational factors that would have an impact on the environment and on Department of Energy (DOE) and WMPO concerns.

Quality assurance Level III is assigned to those activities and items not classified as QA Levels I or II. The site characterization plan conceptual design effort has been governed by the requirements of QA Level III and stipulated adherence to customary engineering and laboratory practices.

The NNWSI Project has delegated to Sandia National Laboratories (SNL) the responsibility for the conceptual design of the prospective repository. SNL, in turn, has retained architect/engineer (A/E) contractors to develop the detailed conceptual design for both the surface and subsurface facilities. The requirements of the NNWSI QA Plan appropriate to QA Level III activities have been imposed on the A/Es.

Project-specific quality assurance program plans (QAPPs) have been developed by each NNWSI Project participant and by each design contractor for application to the conceptual design of the prospective repository. These QAPPs have been structured to conform to criteria given in the NNWSI QA Plan (DOE, 1986). All criteria presented in the NNWSI QA Plan are addressed in the QAPPs, and for those criteria that are not applicable to conceptual design, a justification for their exclusion is provided. The QAPPs and implementing procedures have been applied to the collection of data, design activities, and reports for the development of this document. In addition, the QAPPs, as applied to the conceptual design of the surface and subsurface facilities, conform in format and content to the requirements of 10 CFR 60 (Subpart G) for subsequent design efforts. This consistency will permit an orderly transition from the existing QAPP to future QA programs applicable to the more detailed designs intended to support licensing.

In addition to the QAPPs, the A/Es have developed procedures to prescribe how their work will satisfy the criteria and requirements for QA Levels I and II. These procedures also specify which organizations and individuals are responsible for quality-related activities. Although the conceptual design is designated as a QA Level III activity, aspects of several of these procedures have been applied to design activities, thereby exceeding the minimum requirements of QA Level III.

## 9.2 Design Criteria and Guidelines

The design criteria and guidelines that govern development of the conceptual design (Chapter 2) are controlled through procedures that ensure the use of up-to-date information. These procedures permit tracking the effect of the changes in criteria or guidelines on each design component. Thus, engineering design can proceed on the basis of existing guidelines and can be updated as those guidelines are modified throughout the conceptual design phase.

## 9.3 Design Control

The sections of the QAPPs that relate to conceptual design emphasize design control. Design information, such as drawings, calculations, and data, is controlled in accordance with the approved procedures mentioned above. The procedures include review of the design calculations and drawings. The review considers technical content, correctness, compliance with QA requirements, and appropriateness of the document. Once the review has been completed, the documents are revised as necessary. Revised drafts of engineering documents go through the same review and approval procedure as that followed for the original document.

## 9.4 Design Review

Design documents are reviewed at two levels--by the subcontracting A/Es and by NNWSI Project personnel. The A/Es' project teams conduct reviews as design elements are developed. A subsequent review of the work is conducted by a board of the A/Es' senior engineers who are not involved in the daily effort.

A separate review of design information is performed by appropriate individuals in the NNWSI Project. This final review is a formal part of all SNL report production for the NNWSI Project.

## 9.5 Records

The records of design documents on which this report is based are currently maintained by the A/Es and will be provided to the NNWSI Project for eventual retention in SNL's Department 6310 Project Records Center.

## REFERENCES FOR CHAPTER 9


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## GLOSSARY

Abnormal--See first definition under "off-normal."

Access drift--A drift that connects the mains and the perimeter drifts, delineating the waste emplacement panels and providing access to the waste emplacement drifts. In the vertical waste emplacement configuration, there is also a midpanel access drift that supplies additional ventilation to the more numerous drifts.

Accessible environment--The atmosphere, land surfaces, surface waters, oceans, and all of the lithosphere that is beyond the controlled area.

Actual retrieval period--The time required to retrieve all of the emplaced waste from the underground facility. For design purposes, this period is 34 yr.

Acute dose--A one-time radiation dose received during a relatively short period of time. Typically, the significance of an acute dose is related only to the magnitude of the exposure. See "dose."

Advanced conceptual design (ACD)--The design that presents the selected design alternatives and refines and fixes the design criteria and concepts to be made final in later design efforts. This design forms the basis for the demonstration of project feasibility and estimation of life-cycle costs. Preliminary drawings are prepared and a construction schedule is developed as required by DOE Order 6410.1.

Agreement state--A state that has developed a program to regulate nuclear materials in a manner no less complete or stringent than federal regulations promulgated by the Nuclear Regulatory Commission. Agreement states assume primary responsibility for matters otherwise regulated by the Commissioner.

Alluvium--Clay, silt, sand, gravel, or other rock materials transported by flowing water and deposited in fairly recent geologic time as sorted or semisorted sediments in riverbeds, estuaries, flood plains, lakes, shores, and fans at the base of mountain slopes.

Alpha radiation--Ionizing radiation composed of alpha particles emitted in the radioactive decay of certain nuclides. Alpha particles consist of two protons and two neutrons bound together; an alpha particle is identical to the nucleus of a helium atom. It is the least penetrating of the three common types of radiation--alpha, beta, and gamma.

Analytical approach--An approach to solving a problem that uses explicit mathematical relationships to predict results.

Analytical model--A representation of a process or system that uses explicit mathematical relationships.

Anfo--An explosive agent consisting of a mixture of ammonia nitrate and fuel oil.

Anisotropy--The condition of exhibiting properties whose values vary when measured along different spatial axes.

Annual dose--The amount of radiation received by an individual in one year.

Anticipated processes and events--Those natural processes and events that are reasonably likely to occur during the period the intended performance objective must be achieved.

Aquifer--A rock formation, group of formations, or a part of a formation that contains sufficient saturated permeable material to yield economically significant quantities of water to wells and springs.

Aquitard--A confining bed that retards but does not prevent the flow of water to or from an adjacent aquifer; a leaky confining bed. An aquitard does not readily yield water to wells or springs but may serve as a storage unit for ground water.

Areal power density (APD)--The concentration 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 at the time the waste is emplaced is a design input parameter used in far-field thermal and thermomechanical response calculations.

As low as reasonably achievable (ALARA)--As low as reasonably achievable, taking into account the state of technology and the economics of improvements in relation to benefits to the public health and safety, other societal and socioeconomic considerations, and the utilization of atomic energy in the public interest.

Ash-flow tuff--A tuff deposited by a hot density current, ash-flow tuff can be either welded or unwelded and often fills in channels, making the thickness of the resulting deposit a function of the underlying topography.

Atmospheric confining pressure--The amount of pressure equal to the pressure of the air at sea level (approximately 14.7 $lb/in.^2$).

Attenuation--(1) A reduction in the amplitude or energy of a signal such as might be produced by passage through a filter. (2) A reduction in the amplitude of seismic waves, as produced by divergence, reflection and scattering, and absorption.

Backfill--(1) The fill placed in the excavated areas of the underground facility, shafts, or ramps. Backfill materials may be either excavated tuff or other earthen materials. (2) The material or process used to refill an excavation.

Barrier--Any material or structure that prevents or substantially delays the movement of water or radionuclides. (See "natural barrier" and "engineered barrier system.")

Basalt--A dark to medium-dark fine-grained igneous rock usually formed from lava flows and composed chiefly of calcic plagioclase and clinopyroxene in a glassy or fine-grained ground mass.

Basin and Range Province--Physiographic province in the southwest United States characterized by a series of tilted fault blocks forming longitudinal, asymmetric ridges or mountains and broad, intervening basins.

Bedrock--Solid rock that underlies all soil, sand, clay, gravel, and loose material on the earth's surface.

Benchmark--Comparison of the results of one computer code with the results of another code designed to solve a comparable problem to show that they produce similar results. The particular problem for which this comparison is made is called a "benchmark problem."

Bentonite--A clay containing the mineral montmorillonite, and variable amounts of magnesium and iron, that formed over time by the alteration of volcanic ash. Bentonite can adsorb large quantities of water and expand to several times its normal volume.

Block--A three-dimensional geological area that is bounded by joints, fractures, and faults.

Block faulting--A type of vertical faulting in which the crust is divided into structural or fault blocks of different elevations and orientations.

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

Borehole--A hole made with a drill, auger, or other tools for exploring strata in search of minerals, supplying water for blasting, emplacing waste, proving the position of old workings or faults, or releasing accumulations of gas or water. Boreholes include core holes, dry-well-monitoring holes, waste emplacement boreholes, and test holes for geophysical or ground-water characterization.

Borehole cover--A cylindrical metallic cap placed on the end of a vertical or horizontal borehole after the waste containers and shielding plug have been emplaced to limit access, to identify borehole contents, and to prevent the accumulation of debris (vertical borehole). The borehole cover does not serve a shielding or containment function.

Borehole liner--See "emplacement borehole liner."

Boundary-element method--A method for modeling the behavior of continuous physical systems in which modeling segments are only defined along the boundary of the modeled region.

Breccia--Rock consisting of sharp, angular fragments cemented together or embedded in a fine-grained matrix.

Bridge plug--A downhole tool, composed primarily of slips, plug mandrell, and rubber sealing elements, which is run in and set in dense, nonfractured rock in a borehole to permanently isolate a zone. Multiple bridge plugs may be set in a borehole to isolate numerous zones.

Buffer zone--The portion of the site that surrounds the repository facility and is an essentially undisturbed geologic and surficial environment.

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

Burnup--A measure of nuclear reactor fuel consumption, expressed either as the percentage of fuel atoms that have undergone fission or as the amounts of energy produced per unit weight of fuel.

Byproduct material--Any radioactive material (except special nuclear material) yielded in or made radioactive by exposure to the radiation incident to the process of producing or utilizing special nuclear material.

Cage--The platform of a mine hoist used to carry men or materials.

Caldera--A volcanic collapse structure, generally on the order of tens of kilometers in diameter, formed during the eruption of volumetrically large (tens to hundreds of cubic kilometers of dense rock equivalent) ash-flow and ash-fall tuff deposits.

Caliche--Gravel, sand, or desert debris cemented by porous calcium carbonate; also, the calcium carbonate cement.

Cambrian--The oldest of the periods of the Paleozoic Era, which lasted from 570 to 500 million years ago.

Candidate site--An area within a geohydrologic setting that is recommended for site characterization by the Secretary of Energy under Section 112 of the Nuclear Waste Policy Act of 1982, approved for characterization by the President under Section 112, or undergoing site characterization under Section 113.

Canister--As used in this document, a canister is the initial metal receptacle in which solid radioactive waste is placed for transport to the repository. The canister is not intended to meet the 300- to 1,000-yr containment requirement of 10 CFR 60 113(a)(1)(ii)(A).

Capillary barrier--An interface between two geologic media that impedes unsaturated flow because the media have different properties. Flow from a medium with small pores or interstices into a medium with larger pores is inhibited if the receiving medium is unsaturated. The capillary barrier can be overcome if the potential difference across the interface exceeds the difference in matric potential of the two media in their respective states of saturation.

Capillary effects--See "capillary forces."

Capillary forces (pressure)--A difference in pressure across the interface between two immiscible fluid phases jointly occupying the interstices of a rock. The difference is caused by the tension of the interfacial surface, and its value depends on the curvature of that surface.

Carbide-insert cutter--A type of drilling bit that has removable edges made of tungsten carbide.

Caretaker period--The period that begins with the emplacement of the last waste package and continues through Nuclear Regulatory Commission review and concurrence with the performance confirmation program.

Carrier--The truck trailer or railcar used by a shipper to transport waste from the point of generation to the repository.

Cartridge filter--An in-line filter with a replaceable cartridge used to filter particles out of wash and decontamination solutions.

Cask--A receptacle that holds one or more fuel assemblies, canisters, or disposal containers and provides shielding for highly radioactive materials during transportation. (See "transporter cask," "shipping cask," and "transfer cask.")

Cask decontamination station--A location in the cask preparation area of the waste-handling buildings equipped to decontaminate the exterior surfaces of casks.

Cask mechanism--The mechanism on the cask used to push the container and its dolly into or pull it from the emplacement borehole.

Cask pusher plate/hook--Part of the emplacement mechanism in the transporter cask, which is attached to the roller chains on the extension plate. The device pushes a waste container on a dolly into a horizontal borehole or removes a dolly bearing a waste container from a borehole.

Cask-receiving and shipping bay--The area of the waste-handling buildings where full casks are offloaded from, or empty casks are returned to, the railcar or truck carriers.

Cask transfer cart--A rail-mounted, motorized vehicle located in the cask transfer tunnels of the waste-handling buildings. The cask transfer cart moves the cask from the cask preparation area to the cask-unloading hot cell.

Cask transfer tunnel--The tunnel that connects the cask-receiving and shipping bay to the area underneath the cask-unloading hot cell.

Chronic dose--A radiation dose received over a relatively long time period, as measured in months or years, that results from continuous or regular intermittent exposure to a source of radiation. Typically, the significance of a chronic dose is related to both the magnitude and duration of the exposure. (See "dose.")

Cladding--The metallic outer sheath of a fuel element, generally made of stainless steel or a zirconium alloy.

Closure--Final backfilling of the remaining open operational areas of the underground facility and boreholes after the termination of waste emplacement, culminating in the sealing of the shafts.

Coefficient of friction--A proportionality constant relating the value of the perpendicular force between contacting surfaces to the tangential force that develops to oppose sliding motion.

Coefficient of uniformity--An expression of variety in the size of grains that constitute a granular material.

Cohesion--Shear strength of a rock not related to interparticle friction.

Collar--The top or uppermost portion of a shaft. A concrete ring or slab around a shaft used to prevent water inflow and to support the headframe.

Colluvial--A term applied to loose and incoherent rock material usually deposited at the foot of a slope or cliff chiefly by gravity.

Commercial high-level waste--High-level radioactive waste generated in private industrial and other nongovernment facilities.

Commingling--The interspersing of spent fuel and defense high-level waste containers in different boreholes in the same panel or even in the same borehole in the event multiple-container boreholes are used.

Common facilities--Facilities used by more than one operations division of the repository. Examples are the parking lot and warehouse.

Compliant-joint model--A conceptual and numerical model for a jointed medium whereby the deformation of the joints is treated separately from and additionally to the deformation of the intact material between joints. The stress-strain behavior of the joints and the matrix are idealized from observations of rock-mass behavior. In general, this approach does not allow for coupling of normal and shear joint responses. The total response of a representative volume of jointed material is posed as a constitutive stress/strain relationship for an equivalent homogeneous material.

Compressive strength--The maximum compressive stress that can be applied to a material, under given conditions, before failure occurs.

Conceptual design--This design phase focuses on the surface and underground system, structure, emplacement, and component designs that require site characterization data and provides the information to ensure that the data-gathering plans related to the design are adequately included in the Site Characterization Plan. Data accuracy requirements are established, and site-specific licensing issues related to site characterization are identified.

Conceptual flow diagram--A diagram that shows the steps involved in a process of any type.

Confinement--As pertains to radioactivity, the retention of radioactive material within some specified bounds. Confinement differs from containment in that there is no absolute physical barrier in the former.

Confining pressure--An equal, all-sided pressure, such as lithostatic pressure, produced by overlying rocks in the crust of the earth.

Conservative--Describes an approach leading to the selection of assumptions and parameters that tend to overestimate the severity of potentially adverse processes or events.

Consolidation--The operation performed on spent fuel assemblies during which the upper and lower fuel assembly tie plates are removed, the assembly spacer grids and any other assembly structural members are removed, and the fuel rods are collected and formed into a closely packed bundle for insertion into a canister or container. The nonfuel structural members of the fuel assemblies are reduced in volume and placed in canisters or containers for shipment and disposal.

Constitutive model--A mathematical model of a material or a process that expresses its essential quality or nature. A constitutive model is expressed by constitutive equations that mathematically express the relationship between the quantities of interest (e.g., constitutive equations establishing a linear elastic relationship between stress and strain).

Constitutive relationship--An equation or set of equations that mathematically expresses the theoretical relationships between the physical properties of a material and its response to stimulus.

Construction authorization--Permit issued by the Nuclear Regulatory Commission to construct a facility that handles radioactive materials.

Contact-handled waste--Low-level radioactive waste that can be handled manually without exceeding established radiation exposure guidelines.

Contact maintenance area--An area for maintaining equipment that does not require remote handling. The area is located under the waste-packaging hot cell adjacent to the remote maintenance cell.

Container (disposal container or waste container)--The metal barrier portion of the waste package that is placed around the waste form.

Container-cutting machine--A machine that will either radially or axially cut through the waste container wall. The machine is used in performance confirmation testing or in repairing faultly containers.

Container transfer cart--The cart that runs in the container transfer tunnel.

Container transfer machine (CTM)--Equipment used to move waste containers between the waste transfer carts, which move between the hot cells and the surface storage vault.

Container transfer tunnel--Tunnel that connects the waste-packaging hot cell(s) to the surface storage vault.

Containment--The confinement of radioactive waste within a designated boundary.

Containment period--The first several hundred years following permanent closure of a geologic repository, when radiation and thermal levels are high, the uncertainties in assessing repository performance are large, and special emphasis is placed upon the ability to contain the wastes by waste packages within an engineered barrier system.

Continuum mechanics--The study of distributions of energy, matter, and other physical quantities under circumstances where their discrete nature is important and they may be regarded as continuous functions of position.

Controlled area--(1) A surface location, to be identified by passive institutional controls, that encompasses no more than 100 $km^2$ and extends horizontally no more than 5 km in any direction from the outer boundary of the original location of the radioactive wastes in a disposal system and (2) the subsurface underlying such a surface location.

Controlled blasting--One of several blasting techniques used to improve contour conditions around an opening by reducing overbreak and minimizing propagation of cracks.

Conventional mining--Drill-and-blast mining.

Core drill--A mechanism designed to rotate and cause an annular rock-cutting bit to penetrate rock formations, produce cylindrical cores of the formations penetrated, and lift these cores to the surface, where they are collected and examined.

Core hole--A hole that has been drilled by a core drill to obtain core samples.

Coulomb criterion--A criterion used to evaluate the shear fracture of a brittle material that states that the total shearing resistance is the sum of the cohesive shear strength (independent of direction) and the product of the effective normal stress and the coefficient of internal friction (a constant independent of normal stress).

Credible off-normal conditions--The state or conditions expected to have a reasonable potential for occurring infrequently during the life of a repository. The term is generally used to identify those conditions that need to be considered for use in developing contingency plans for related operations.

Criteria (design)--Quantitative limits placed on a design that ensure compliance with functional criteria.

Criteria (functional)--Quantitative (and qualitative) limits placed on a design for acceptability within the framework of performance criteria of the waste management system. Originally called "acceptance criteria."

Criteria (performance)--Qualitative limits placed on the geologic repository system for acceptability within the framework of waste management policy.

Criticality--The condition in which a nuclear chain reaction is self-supporting. Criticality occurs when the number of neutrons present in one generation cycle equals the number generated by the previous cycle.

Curie--A unit of radioactivity defined as the amount of a radioactive material that has an activity of $3.7 \times 10^{10}$ disintegrations per second.

Dacitic--Characteristic of a fine-grained extrusive rock with the same general composition as andesite but having a less calcic feldspar (dacite).

Damaged zone--See "modified permeability zone."

Decay--(1) The process whereby radioactive materials undergo a change from one nuclide, element, or state to another, releasing radiation in the process. This action ultimately results in a decrease in the number of radioactive nuclei present in the sample. (2) The spontaneous transformation of one nuclide into a different nuclide or into a different isotope of the same nuclide.

Decommissioning--The permanent removal from service of surface facilities and components necessary for preclosure activities only, after repository closure, in accordance with regulatory requirements and environmental policies.

Decontamination--The removal of unwanted material (especially radioactive material) from the surface of or from within another material.

Decontamination building--A building located just inside the waste operations area in which vehicles, casks, or any other contaminated equipment is decontaminated.

Decontamination facility--A subsurface shower room for workers.

Decontamination room--Generally, in this document, a room located adjacent to the remote maintenance cell in which remotely operated equipment is decontaminated.

Defense high-level waste (DHLW)--High-level radioactive waste generated by activities related to the national defense program, including the manufacture of nuclear weapons, the operation of naval reactors, and research and development at weapons laboratories.

Design activity--A component of a design information need under a design issue. The fourth level in the hierarchy of levels of work planned to be performed under a design issue.

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

Development area--The underground area being prepared for emplacement of waste packages. Development includes excavation of the emplacement drifts and boreholes, installation of rock support in the drifts, and outfitting the emplacement boreholes with liners and covers. As development of a panel is completed, bulkheads are installed to seal the panel from the development area and the panel is added to the ventilation circuit for the waste emplacement area.

Development prototype--Protypical hardware intended to provide information needed for further development of an equipment system.

Devonian--The fourth of seven periods (345 to 395 million years ago) of the Paleozoic Era, which precedes the Mississippian and follows the Silurian.

Discharge point (or area)--The point (or area) at which water released from an aquifer appears on the surface.

Disposal--The emplacement in a repository of high-level radioactive waste, spent nuclear fuel, or other highly radioactive material with no foreseeable intent of recovery, whether or not such emplacement permits the recovery of such waste.

Disposal container--See "container."

Disposal system--See "mined geologic disposal system."

Disturbed zone--That portion of the controlled area the physical or chemical properties of which have changed as a result of underground facility construction or as a result of heat generated by the emplaced radioactive wastes such that the resultant change of properties may have a significant effect on the performance of the geologic repository.

Diurnal--Having daily cycles.

Dolly--A device that cradles the waste container within the horizontal emplacement borehole. The dolly is emplaced in the borehole along with the container it carries.

Dose--The quantity of radiation absorbed, per unit of mass, by the body or by any portion of the body.

Dose commitment--The integrated dose that results from an intake of radioactive material when the dose is evaluated from the beginning of the intake to a later time; also used for the long-term integrated dose to which people are considered committed because radioactive material has been released to the environment.

Dose equivalent--An estimate of the amount of biological damage done by the deposition in tissue of a given unit of absorbed radiation dose. The dose equivalent is obtained by multiplying the absorbed radiation dose by a qualifying factor. The unit of dose equivalent is the rem.

Dose limit--The limit established by the Environmental Protection Agency or the Nuclear Regulatory Commission for the exposure of people to radiation.

Dosimetry--The measurement or quantification of radiation exposure of humans or animals.

Drift--Horizontal, or nearly horizontal, mined passageway. (See "main," "access drift," "emplacement drift," and "perimeter drift.")

Drill-and-blast mining--A method of mining in which holes are drilled into the rock and then loaded with explosives. The blast from the explosives breaks the rock so that the rock can be removed. The underground opening is expanded by repeated drilling and blasting.

Drill jumbo--Mobile mining equipment that has one or more drilling machines on it for use in drill-and-blast operations during drift construction.

Drucker-Prager yield criterion--This criterion is used to evaluate the yield response of a material subjected to a three-dimensional stress field. It states that the material will yield in a ductile fashion if the combination of stresses, as computed by an equation defining the criterion, exceeds the experimentally determined limiting values of the criterion for that material.

Dry-bulb temperature--Temperature that is indicated by a conventional dry thermometer and is not dependent on atmospheric humidity.

Dummy containers--Containers that do not contain waste but are used to provide standoff between the emplacement drift and the containers that do contain waste.

Effective porosity--The amount of interconnected pore space available for transmission of fluids, which is expressed as the ratio of the volume of the interconnected pores and openings to the volume of the rock.

Elastic perfectly plastic--A type of material behavior in which the material deforms elastically up to its yield stress and is able to sustain no stress greater than this so that it flows indefinitely at this stress unless restricted by some outside factor.

Elastic-plastic media--Materials in which instantaneous elastic strain at a constant stress is followed by continuously developed permanent strain so long as the stress is maintained.

Electromechanical manipulator--Electromagnetically activated or controlled manipulator used for remote handling.

Electropolishing--Smoothing and enhancing the appearance of a metal surface by making it an anode in a suitable electrolyte.

Empirical approach--An approach to solving a problem that relies on previous practical experience under similar conditions to predict results. This approach is often used to supplement the analytic approach when the physical processes involved are complex.

Emplacement--The act of placing waste containers in prepared positions. For the proposed repository at Yucca Mountain, two methods of waste emplacement are currently being considered: emplacement of a single waste container in a shallow vertical borehole in the floor of the emplacement drift or emplacement of multiple waste containers in long horizontal boreholes in the wall of the drift.

Emplacement area exhaust building--A surface facility associated with the emplacement area exhaust shaft, which contains HEPA filters and primary ventilation fans.

Emplacement borehole--A borehole used specifically for emplacement of waste.

Emplacement borehole liner--A sleeve placed in a vertical or horizontal borehole to prevent sloughed rock from interfering with the emplacement or removal of waste packages. The liner does not serve a shielding or containment function. The liner runs the complete length of horizontal boreholes, but, in vertical boreholes, extends only from the mouth of the borehole to just below the shoulder of the emplaced waste container.

Emplacement drift--A drift in which waste emplacement boreholes are located.

Emplacement envelope--The components that surround the emplaced waste container(s). The emplacement envelope includes boreholes, liner(s), borehole shield plug, and borehole cover.

Emplacement horizon--The specific geologic stratum, or portion thereof, in which waste will be emplaced below the earth's surface. A portion of the Topopah Spring Member of the Paintbrush Tuff is currently the target emplacement horizon at Yucca Mountain.

End fittings (of spent fuel assemblies)--Part of the mechanical support structure of fuel assemblies.

End shear--Describes the effect in which the edge of the ventilation bulkheads separates from the surface of the perimeter of the drift.

Engineered barrier system--(1) The waste packages and the underground facility (10 CFR 60). (2) The man-made components of a disposal system designed to prevent the release of radionuclides from the underground facility or into the geohydrologic setting. The term includes the radioactive waste form, radioactive waste containers, materials placed over and around the containers, any other components of the waste package, and barriers used to seal penetrations in and into the underground facility.

Environmental assessment (EA)--The document required by Section 112(b)(1)(E) of the Nuclear Waste Policy Act of 1982. The section also defines what is to be included in an environmental assessment.

Environmental impact statement (EIS)--The document required by Section 114 of the Nuclear Waste Policy Act of 1982.

Eolian--Pertaining to the wind, especially said of sediment deposition by the wind, of structures such as wind-formed ripple marks, or of erosion accomplished by the wind.

Equipment transfer tunnel--A tunnel for transferring maintenance equipment between hot cell areas and adjacent service areas.

Equivalent energy density concept--A procedure for determining the equivalent areal power density for wastes that differ in age and burnup from the average values used in determining the design-basis areal power density. The equivalent areal power density is the thermal power density of a given waste material that results in deposition of the same energy in the host rock over a fixed period of time (usually 2000 yr) as would be deposited by waste having the average characteristics.

Escarpment--A long, more or less continuous cliff or relatively steep slope that was produced by erosion or faulting and faces in one general direction, breaking the continuity of the land by separating two levels or gently sloping surfaces.

Exploratory borehole--A drilled hole, generally of small diameter (2 in. to 12 in.), used to provide information on site characteristics (usually hydrologic and geologic).

Exploratory shaft--A vertical shaft of sufficient depth to allow in situ characterization of the emplacement horizon. The shaft is large enough to allow people and test equipment to be transported from the surface to the underground excavations.

Exploratory Shaft 1 (ES-1)--The principal entry (12 ft in diameter) into the exploratory shaft facility. It contains a men-and-materials hoist, ventilation supply and exhaust ducts, and the utilities systems.

Exploratory Shaft 2 (ES-2)--A 6-ft-diameter shaft that provides the air supply for and an emergency egress from the underground facility.

Exploratory Shaft Facility (ESF)--The exploratory shafts, any associated surface structures, and underground openings constructed for the purpose of site characterization.

Extension plate--That part of the cask emplacement mechanism of the waste transporter that extends the waste container on a dolly into a horizontal borehole. The components of the cask mechanism are the extension plate, the ballscrew drive, roller drive chains, and pusher/plate hook.

Extraction ratio--The ratio of the excavated area of all drifts to the total area. (In the case of horizontal emplacement, the area of the emplacement boreholes is not included in the ratio.)

Facility cask--See "transporter cask."

Far field--That portion of the host rock surrounding the underground facility within which the thermal effects of the emplaced waste can be analyzed by considering only the areal power density without consideration of the specific geometric characteristics of the underground facility.

Fault--A fracture or zone of fractures along which there has been displacement of the sides relative to one another parallel to the fracture.

Fault block--A portion of the earth's crust formed by faulting and translated or rotated as a structural unit.

Fault system--A system consisting of two or more faults presumed to be of common origin.

Fault tree--A logic diagram depicting the component failure modes (faults) that combine to produce a failure of the system in a given scenario.

Favorable condition--A condition that, though not necessary to qualify a site, is presumed, if present, to enhance confidence that the qualifying condition of a particular guideline can be met.

Feeder/breaker--A mechanical device that reduces mined material to a predetermined size and places it on a conveyor belt.

Final procurement and construction design (FPCD)--The design that will develop the final (working) drawings and specifications for procurement and construction. The completion of this design phase will match the completion of the Title II design effort for the entire repository. This design phase will emphasize the completion of the design of ancillary support items, final design refinement for the items necessary to demonstrate compliance with the design criteria and performance objectives of 10 CFR 60, the development of construction bid packages for all systems, and the development of final procurement and construction schedules.

Final safety analysis report (FSAR)--A detailed safety document that discusses and resolves safety questions pertaining to a nuclear project. The document is considered final after public hearings have been completed and the Nuclear Regulatory Commission issues the document.

Fines--Clay- and silt-sized particles with a maximum particle size less than 8 mm.

Finite-element method--A numerical method used to study the domain of a material in which the domain is subdivided into finite elements so that the response in each element is homogeneous. The elements are connected, and the response is transferred at modal contracts.

Fissile material--One of several radionuclides, which, under proper conditions, undergoes slow, neutron-induced fission, producing sufficient neutrons to sustain a chain reaction.

Fission--The division of atomic nuclei into nuclides of lower mass, accompanied by the release of gamma rays, neutrons, and significant thermal energy.

Fission product--A nuclide produced by the fission of a heavier element.

Fixed-air-sampler monitor--A station in the waste-handling areas that samples breathing air.

Flood plain--That portion of a river valley that is built of sediments deposited during the present regimen of the stream and is covered with water when the river overflows its banks at flood stages.

Friction angle--The maximum slope at which a heap of any loose or fragmented solid material stands without sliding or comes to rest when poured or dumped in a pile or on a slope.

Friction bolt--A method of artificial ground support that relies on friction between the bolt and rock surfaces.

Fuel--As used in this document, fissionable material usable as the source of power when placed in a critical arrangement in a nuclear reactor.

Fuel assembly--A single mechanical unit consisting of a number of fuel rods held together by a mechanical support structure designed to maintain proper spacing of the fuel rods and facilitate their handling.

Fuel assembly hardware--The non-fuel-bearing mechanical support structure and component of a fuel assembly that is excess waste left after consolidation.

Fuel element--See "fuel assembly."

Fuel reprocessing--The chemical process by which uranium and plutonium (and sometimes other useful radionuclides such as cesium, strontium, neptunium) may be recovered from irradiated reactor fuel. The residual waste, containing highly radioactive fission products and heavy nuclides produced by neutron capture, is usually calcined and fixed in an inert matrix such as borosilicate glass (as in the case of defense high-level waste).

Fuel rod--A long, slender, cylindrical tube (usually made of stainless steel or Zircaloy) containing nuclear fuel in the form of uranium oxide fuel pellets. Also called "fuel pin."

Fuel transfer cart--The cart that runs in the fuel transfer tunnel.

Fuel transfer tunnel--A tunnel 25 ft below grade that connects the cask-unloading hot cell and the consolidation hot cell.

Geologic containment--The system of rocks, hydrologic conditions, and tectonic stability that inhibits or prevents the spread of radioactive waste from the repository.

Geologic disposal--Placement of radioactive waste in carefully selected deep, stable geologic formations (see "disposal").

Geologic repository--A system that is intended to be used, or may be used, for the disposal of radioactive wastes in excavated geologic media. A geologic repository includes (1) the geologic repository operations area and (2) the portion of the geologic setting that provides isolation of the radioactive waste and is located within the controlled area.

Geologic repository operations area--A facility for radioactive waste that is part of a geologic repository, including both surface and subsurface areas and facilities, in which waste-handling activities are conducted.

Great Basin--A subdivision of the Basin and Range Province located in southern Nevada in a broad desert region.

Ground water--All subsurface water as distinct from surface water.

Ground-water flux--The rate of ground-water flow through porous or fractured media per unit cross-sectional area measured perpendicular to the direction of flow.

Half-life--(1) The time it takes for one-half of the radioactive atoms initially present in a sample to decay. Each radionuclide has a characteristic but constant half-life.

Halon--Liquid or gaseous chemicals used in fire-extinguishing systems in which hydrogen atoms in one or more hydrocarbons have been replaced by atoms from the halogen series (fluorine, chlorine, bromine, or iodine). The resulting compounds are not only inflammable but act as flame extinguishers.

Headframe--The steel or timber frame at the top of a shaft that supports the sheave or pulley for the hoisting cables and serves various other purposes.

Health physics (laboratory)--Refers to the branch of science concerned with the biological effects of radiation exposure. A health physics laboratory is a facility for studying, measuring, and assessing radiation exposure and its biological effects.

High-efficiency filter bank--Extremely-high-efficiency particulate air filters capable of removing particulates greater than 0.3 micron in diameter.

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 radioactive waste--The highly radioactive material resulting from the reprocessing of spent nuclear fuel, including liquid waste produced directly in reprocessing and any solid material derived from such liquid waste that contains fission products in sufficient concentrations; and other highly radioactive material that the Nuclear Regulatory Commission, consistent with existing law, determines by rule to require permanent isolation.

Higher-level finding--Finding that must be made for each qualifying and disqualifying condition of the Department of Energy's siting guidelines (10 CFR 960) at or before the repository site selection decision point. Higher-level findings are Level 2 or Level 4 findings, which are defined in 10 CFR 960, Appendix III.

Holocene--An epoch of the Quaternary Period from the end of the Pleistocene to the present.

Host rock--The geologic medium in which radioactive waste is emplaced. (At Yucca Mountain, it is likely that the host rock will be the welded tuff of the Topopah Spring Member of the Paintbrush Tuff.)

Hot cell--A facility that allows remote viewing and manipulation of radioactive substances.

Hydraulic conductivity--The volume of water that will move through a medium in a unit of time under a unit hydraulic gradient through a unit area measured perpendicular to the direction of flow.

Hydraulic gradient--A change in the static pressure of ground water, expressed in terms of the height of water above a datum, per unit of distance in a given direction.

Hydraulic head--The height above sea level to which a column of water can be supported by the static pressure at that point. The total hydraulic head is the sum of elevation head and pressure head.

Hypalon--Brand name for an impermeable synthetic fabric manufactured by du Pont.

Imbricate normal fault--A set of normal fault planes that are closely spaced and in echelon.

Infiltration--Water flow into the soil at ground surface.

Inflow--Water movement into a reference location.

Information needs--(1) The lowest level of the Issues Hierarchy for performance and design issues. Information needs comprise requirements for additional data or analyses about particular natural conditions or design elements. (2) Additional information needed to satisfy information requirements (i.e., information requirements less available relevant information) so as to demonstrate compliance with regulations, etc.

Inner lid--This lid seals the inner cask cavity and contains the inner cask atmosphere-sampling ports.

In situ tests--Tests conducted with subject material in its original place (i.e., at the repository site and depth).

Institutional controls--Administrative controls, records, physical constraints, and combinations thereof that would limit intentional or inadvertent human access to the waste emplaced in a repository.

Intact spent fuel--A fuel assembly that is packaged for disposal without disassembly or consolidation.

Intensity (earthquake)--A measure of the effects of an earthquake on people, structures, and the earth's surface at a particular location; quantified by a numerical value on the modified Mercalli scale.

Interaction matrix--A logical depiction or list of events that could cause significant radiological releases to the environment and that reveals the interaction of the releases with the environment.

Interstitial--Referring to the space between rock materials or soil particles.

Ion exchange--A chemical reaction in which mobile ions from a solid are exhanged for ions of like charge in a solution.

Ionizing radiation--Any radiation (e.g., alpha, beta, and gamma radiation) displacing electrons from atoms or molecules, thereby producing ions.

Isokinetic sampler--A collector of airborne particulate matter that is designed so that the airstream entering it has a velocity equal to that of the air passing around and outside the collector.

Isolation--The inhibiting of the transport of radioactive material so that the amounts and concentrations of radioactivity entering the accessible environment will be kept within prescribed limits.

Isotropic--A condition in which the value of a material property does not vary with direction.

Issue--A question relating to the performance of the mined geologic disposal system that must be resolved to demonstrate compliance with applicable federal regulations (including 10 CFR 60, 10 CFR 960, 40 CFR 191, and 10 CFR 20). An issue is the second level in the Issues Hierarchy for design and performance issues.

Issues Hierarchy--A ranking of issues in three levels of detail--key issues, issues, and information needs--to make apparent the logic of site investigations and design activities and thereby ensure that no significant issues are overlooked and that no extraneous information is collected.

Items important to safety--Those engineered structures, systems, and components essential to the prevention or mitigation of an accident that could result in a radiation dose to the whole body, or any organ, of 0.5 rem or greater at or beyond the nearest boundary of the unrestricted area at any time until the completion of permanent closure.

Items important to waste isolation--Barriers structures, systems, and components that are relied on to achieve the postclosure performance objectives stated in 10 CFR 60, Subpart E.

Joint--A surface of a fracture or parting in a rock, without displacement.

Joint coefficient of friction--A proportionality constant relating the value of the perpendicular force between contacting surfaces to the tangential force that develops to oppose sliding motion.

Joint cohesion--The shear strength of a fracture not related to interparticle friction.

Joint set--A group of more or less parallel joints.

Key--To establish a mechanical bond in a construction joint to stabilize the rock mass.

Key issue--The four issues that compose the highest level of the Issues Hierarchy: (1) Postclosure Performance; (2) Preclosure Radiological Safety; (3) Health, Safety, Environment, Socioeconomic, Transportation; and (4) Preclosure Performance.

Keyway--An excavation, which extends beyond the original underground opening, that serves to provide additional structural support or reduces fluid flow once the keyway has been filled with sealing material.

Lag storage--The amount of storage time that occurs between the receipt and packaging of waste and emplacement of the waste.

Latite--A porphyritic extrusive rock composed of nearly equal amounts of plagioclase and potassium feldspar, little or no quartz, and a finely crystalline groundmass.

Leaching--The dissolution of soluble constituents of a solid material (e.g., the waste emplaced in a repository) by the natural action of percolating water or chemicals.

License application (LA)--An application for a license from the Nuclear Regulatory Commission to construct a repository.

License application design (LAD)--The design that presents the resolution of design and licensing issues identified and assessed in earlier design phases and develops the design of the items necessary to demonstrate compliance with the design requirements and performance objectives of 10 CFR 60. Design requirements resulting from safety and reliability analyses will be integrated in this design to support the safety analysis report and license application.

Lid--See "outer lid" and "inner lid."

Light water reactor--A nuclear reactor that uses ordinary water as a moderator instead of heavy water (a compound of hydrogen and oxygen containing a higher proportion of the hydrogen isotope deuterium).

Linear expansion--The change in linear dimension of a solid resulting from a change in temperature. The coefficient of linear expansion is the change in a solid's unit linear dimension per 1° change in temperature.

Liner--See "emplacement borehole liner."

Lithology--The study of rocks. Also the description of a rock on the basis of such characteristics as structure, color, mineral composition, grain size, and arrangement of its component parts.

Lithophysae--Bubblelike structures in rocks, generally hollow, composed of concentric shells of finely crystalline alkali feldspar, quartz, and other materials.

Load/haul/dump (LHD) unit--Mobile underground mining equipment that loads, transports, and dumps mined material.

Low-level waste (radioactive)--Radioactive material that is neither high-level waste, spent nuclear fuel, transuranic waste, or by-product material as defined in Section 11e(2) of the Atomic Energy Act of 1954.

Main (n)--One of the three main drifts that run from the base of the two ramps and men-and-materials shaft through the underground facility to provide access to the waste emplacement panels. (See "tuff main," "service main," and "waste main.")

Man-rem--A unit used in health physics to compare the effects of different amounts of radiation on groups of people. It is obtained by multiplying the average dose equivalent to the whole body or a given organ or tissue (measured in rems) by the number of persons in the selected population.

Master/slave manipulator--A mechanical, electromechanical, or hydromechanical device that reproduces the hand or arm motions of an operator, enabling the operator to perform manual motions remotely.

Material model--See "constitutive model."

Mathematical model--See "model, mathematical."

Matrix--Relatively fine material in which coarser fragments or crystals are embedded; also called "ground mass."

Maximally exposed individual--See "maximum individual."

Maximum individual--A hypothetical member of the public whose habits and location tend to maximize the radiological dose received from a given operation.

Maximum individual dose--The highest radiation dose delivered to the whole body, or to an organ, that a person can receive from a release of radioactivity. The hypothetical person who receives this dose, the maximally exposed individual, is one whose location, activities, and habits maximize the dose.

Mechanical--A term applied to the material properties that govern the physical response of a material to applied physical stress or to the analysis of that response (e.g., mechanical properties; mechanical analysis).

Mechanical mining system--A method of removing rock that does not rely on conventional drilling and blasting techniques.

Mechanized mining methods--The use of any tracked or wheeled equipment in mining operations.

Midpanel drift--A drift in the vertical emplacement configuration that runs parallel to the panel access drifts, dividing the panel into two 700-ft segments.

Migration--The movement of oil, gas, or water (including that containing radionuclides) through porous and permeable rock. Parallel (longitudinal) migration is movement across the bedding planes.

Mined geologic disposal system (MGDS)--A system requiring licensing by the Nuclear Regulatory Commission that is used for the disposal of high-level radioactive waste in excavated geologic media. The term is synonymous with "geologic repository."

Mississippian--The fifth of the seven periods (320 to 345 million years ago) in which the Paleozoic is divided in the United States.

Mitigation--(1) Avoiding an impact altogether by not taking a certain action or parts of an action. (2) Minimizing impacts by limiting the degree or magnitude of the action and its implementation. (3) Rectifying the impact by repairing, rehabilitating, or restoring the affected environment. (4) Reducing or eliminating the impact over time by preservation and maintenance operations during the life of the action. (5) Compensating for the impact by replacing or providing substitute resources or environments.

Mockup--A realistic model that demonstrates the functions, movements, or capabilities of a structure, system, or component.

Model, geologic--A quantitative or graphical description of the geology of an area.

Model, hydrologic--A mathematical representation of a hydrologic system (as embodied in a computer code).

Model, mathematical--An equation, or set of equations, that represents a real system and the ways that phenomena occur within that system.

Model, tectonic--A nonnumerical descriptive theory or concept that incorporates geological and geophysical factors to help understand the evolution of stress and strain in the earth's crust.

Modified forklift--A commercially available vehicle adapted for repository use with a shielded cab and extending boom to transport emplacement equipment to the borehole.

Modified permeability zone--The zone immediately surrounding an underground excavation in which the permeability of the rock mass has been altered as the result of stress redistribution and blast damage effects.

Modulus of deformation--Experimentally determined coefficient of proportionality relating applied stress to observed strain.

Modulus of subgrade reaction--Coefficient of proportionality (Cp) in the empirical expression:

$$P_s = (Cp)(S),$$

where $P_s$ is the soil pressure and S is equivalent to the settlement resulting from external pressure.

Mohr-Colomb criterion--A criterion of failure for solid material undergoing loading, relating peak stress conditions to confining pressure. May be used for intact material or used to represent the minimum "residual" strength reached by a material subjected to deformation beyond the peak.

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

Near field--That portion of the rock surrounding emplaced waste in which analysis of the thermal and thermomechanical effects of the waste must consider the specific geometric characteristics of the underground facility, including borehole size and orientation; standoff distance; drift shape, dimensions, and spacing; or overall layout of the facility.

Normal conditions--The state or conditions expected to be present most of the time. The term is generally used to indicate conditions of temperature, opening stability, equipment, etc., expected about 90% of the time.

Normal fault--A fault in which the hanging wall appears to have moved downward relative to the footwall. The angle of the fault is usually 45 to 90° measured from the horizontal.

Northern area--An area north of and adjacent to the primary target area for the underground facility whose use for expansion would enhance the flexibility of construction.

Nuclear Waste Policy Act (NWPA) of 1982--A federal law enacted to provide for the development of repositories for the disposal of commercially generated high-level radioactive waste, spent nuclear fuel, and defense high-level waste.

Numerical method--An approximation technique using numerical solutions for mathematical equations.

Numerical model--A representation of a process or system using numerical methods.

Off-normal--(1) Describes events or conditions that do not occur on a routine basis or that are not expected during normal operations. In future reports, the term "abnormal" will be used to describe these events or conditions. (2) Describes materials that are not handled routinely, such as experimental spent fuel.

Opening--Any excavation that is part of the subsurface facilities, including shafts, ramps, drifts, and boreholes.

Operations phase--The period of time from the receipt of the first waste at the site of the repository to closure and decommissioning.

Outer lid--The secondary containment seal for the cask (the inner lid is the primary seal). The outer lid contains a port for sampling the atmosphere in the cavity between the inner and outer lids.

Out-transfer bay--The area at the end of the container transfer tunnel at which disposal containers are positioned to allow loading onto the waste transporter for transfer underground. The waste transporter enters the waste-handling building through an airlock at the out-transfer bay to load disposal containers.

Overbreak--A condition where more rock is broken by blasting than was originally designed.

Overcoring (retrieval)--As used in this document, a process for removing waste from its emplacement location by extracting a cylinder of rock that surrounds and contains the waste.

Overpack--Any receptacle, wrapper, box, or other structure that becomes an integral part of a radioactive waste package and is used to enclose a waste container for purposes of providing additional protection or for meeting the requirements of an acceptance or isolation criterion for a specific site. An overpack is often used to encase a damaged or contaminated waste package for which repair or decontamination is impractical.

Packaged waste--The disposal container and its contents, including the waste form and any liner or stabilizing material inside the container.

Packaging--The container, any overpacks, and their contents, excluding radioactive materials and their encapsulating matrix but including absorbent material, spacing structures, thermal insulation, radiation shielding, devices for absorbing mechanical shock, external fittings or handling devices, neutron absorbers or moderators, and other supplementary equipment that surrounds the radioactive material.

Packer--A removable device used in drilled boreholes to isolate one part of a borehole from another to carry out studies of particular formations or parts thereof.

Paleozoic--The era of geologic time between the Precambrian and Mesozoic eras that consists of the Cambrian, Ordovician, Silurian, Devonian, Carboniferous (Mississippian and Pennsylvanian), and Permian periods (about 570 million to 225 million years ago).

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

Perched ground water--Unconfined ground water in a zone of saturation separated from an underlying saturated zone by an unsaturated zone. Perched ground water is supported by a perching bed whose permeability is so low that water percolating downward through it is not able to bring water in the underlying unsaturated zone above atmospheric pressure.

Percolate--The passage of a liquid through a porous substance; e.g., the movement of water, under hydrostatic pressure developed naturally underground, through the interstices and pores of the rock or soil; i.e., the slow seepage of water through soils or porous deposits.

Performance allocation--A part of the process for developing strategies for the resolution of issues used to guide the site characterization program.

Performance assessment--Any analysis that predicts the behavior of a system or system component under a given set of constant and/or transient conditions. Performance assessments will include estimates of the effects of uncertainties in data and modeling.

Performance confirmation--A program of tests, experiments, and analyses required by the Nuclear Regulatory Commission and conducted to evaluate the accuracy and adequacy of the information used to determine with reasonable assurance that the performance objectives for the period after permanent closure can be met.

Performance criterion--A criterion establishing qualitative operational, safety, or environmental limits.

Performance objective--The predetermined standard or specification used to evaluate the acceptability of each system, structure, or component during a performance assessment. Different performance objectives may be suitable for the preclosure and postclosure periods.

Perimeter drift--The drift that encircles the emplacement area, advancing in a clockwise direction as the emplacement area is developed. It functions as the exhaust airway for the emplacement area.

Period of retrievability--See "retrievability period."

Permanent closure--See "closure."

Pillar--A solid mass of rock left standing to support a mine roof.

Pintle--Handling fixture on the waste container; a knob welded to one end of the waste container that can be grappled by the handling mechanism in the surface facility or during emplacement or retrieval operations.

Plane strain--A state of strain in which all displacements that arise from deformation are parallel to one plane and the strain normal to that plane is zero.

Playa--The lowest, central portion of an arid basin, which is dry and totally barren most of the time but is occasionally flooded. Clay and silt are the principal sediments present, often resulting from lakes formed in Pleistocene time.

Plug (shaft or borehole)--A sealing component used for structural support.

Point-anchor bolt--An artificial method of ground support that relies on firmly imbedding the bolt end in the rock surface.

Poisson's ratio--The ratio of the lateral strain to the longitudinal strain in a body that has been stressed longitudinally within its elastic limit.

Population dose--The sum of the radiation doses received by the individual members of a population exposed to a particular source or event. It is expressed in units of man-rem.

Porosity--The ratio of the total volume of interstices in rock or soil to its total volume expressed as a percentage or as a fraction.

Port plug--A movable radiation shield that closes and provides radiation shielding for ports in the cask-unloading hot cell.

Portal--The surface entrance to a ramp.

Postclosure--Of or pertaining to the period of time, conditions, or events that occur after the closure of the geologic repository.

Potential Q-Scenario--Used to designate an accident scenario in which the probability and dose consequence are sufficiently close to the Q-Scenario criteria that a change in assumptions or data used could cause the criteria to be exceeded.

Precambrian--The geologic time that elapsed before the beginning of the Paleozoic era (the Paleozoic began about 570 million years ago).

Preclosure--Of or pertaining to the period of time, activities, operations, and conditions before and during the closure of the geologic repository.

Prefilter--A filter used to remove large particulates from an air stream before the stream enters the HEPA filter.

Preliminary radiological safety analysis (PRSA)--A preliminary radiological safety analysis of the conceptual design of the Yucca Mountain mined geologic disposal system (MGDS) under accident conditions. This analysis was performed to provide a numerical basis from which to develop the Q-List for the Yucca Mountain MGDS. The PRSA is documented in Appendix F of this report.

Preliminary Repository Concepts Report (PRCR)--A preliminary document showing the general arrangement of underground workings, general location of surface facilities and shafts, and general features of waste-handling facilities, and providing a general discussion of the method of waste emplacement and a feasibility assessment of waste emplacement and retrieval equipment.

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

Primary area--The surface location, as delineated on a map, of the principal area that may be suitable for waste emplacement. When projected downward along the location of faults and other geologic features, the boundaries of the primary area encompass the principal region within the target emplacement horizon that is considered potentially suitable for waste emplacement. See "emplacement horizon."

Principal stress--A stress that is perpendicular to one of three mutually perpendicular planes that intersect at a point in a body on which the shearing stress is zero; a stress that is normal to a principal plane of stress. The three principal stresses are identified as least or minimum, intermediate, and greatest or maximum.

Probabilistic risk assessment (PRA)--An approach to analyzing the response of an engineered facility or system to accidents or abnormal conditions that assigns frequencies of occurrence to the end results and assesses the consequences of those end results. The risk of an end result is then computed as the product of the frequency of occurrence and the consequence. The total risk of a system is the sum of all the individual end result risks.

Probable maximum flood (PMF)--The flood, measured as discharge, volume, and hydrograph shape, that is the most severe reasonably possible based on comprehensive hydrometeorological application of probable maximum precipitation and other hydrologic factors favorable for maximum flood runoff, such as sequential storms and snow melt.

Proof-of-concept demonstration--A test conducted using developed hardware to prove the viability of a design concept.

Q-List--A list of geologic repository structures, systems, and components that have been determined to be important to safety, waste isolation, or both, and are thereby subject to the highest quality assurance level (QA Level 1) of the formal QA plan.

Q-Scenario--An accident scenario that exceeds a probability of occurrence of $10^{-5}$/yr and causes an offsite dose of 0.5 rem or greater.

QA Level I--Those radiological-health- and safety-related items and activities that are important to either safety or waste isolation and that are associated with the ability of a geologic repository to function in a manner that prevents or mitigates the consequences of a process or event that could cause undue risk to the radiological health and safety of the public. Items and activities important to safety are those engineered structures, systems, and components essential to the prevention or mitigation of an accident that could result in a radiation dose either to the whole body, or to any organ, of 0.5 rem or greater either at or beyond the nearest boundary of the unrestricted area at any time until the completion of the permanent closure of the respository. Activities important to waste isolation are those activities that must meet the criteria that address postclosure performance of the engineered and natural barriers to prevent the release of radionuclides. The criteria for items or activities important to safety and waste isolation are found in 10 CFR 60 and 40 CFR 191.

QA Level II--Those activities and items related to the systems, structures, and components that require a level of quality assurance sufficient to provide for reliability, maintainability, public and repository worker nonradiological health and safety, repository worker radiological health and safety, and other operational factors that would have an impact on the environment and on Department of Energy and Waste Management Project Office concerns.

QA Level III--Those activities and items not classified as QA Levels I or II.

Quality assurance (QA)--All the planned and systematic actions necessary to provide adequate confidence that a structure, system, or component is constructed to plans and specifications and will perform satisfactorily.

Quality control--Quality assurance actions that provide a means of controlling and measuring the characteristics of an item, process, or facility to established requirements.

Quaternary--The second period of the Cenozoic era, following the Tertiary, and the corresponding system of rocks.

Radial stacker--A movable conveyor that operates in a semicircle.

Radiation monitoring--A term covering application of a field of knowledge, including the determination of dose rates and surveys of personnel and equipment for contamination control, air sampling, exposure control, etc.

Raise boring--A mining method by which a vertical circular opening is excavated from the bottom up using a special drill bit.

Raise drill--A type of drill designed specifically for mining raises.

Reasonably available technology--Technology that exists and has been demonstrated or for which the results of any requisite development, demonstration, or confirmatory testing efforts before application will be available within the required time periods.

Recharge--The process by which water is added to the zone of saturation, either directly into a geologic formation or indirectly by way of another formation or through unconsolidated sediments.

Recovery--A general term for removal of packages emplaced without features designed to facilitate retrieval or after retrieval operations are no longer feasible. Recovery implies higher costs and risks than retrieval.

Regulatory guide--One of a seriès of official Nuclear Regulatory Commission guides that prescribes standards and recommendations for nuclear facilities.

Release limit--A regulatory limit on the concentration or amount of radioactive material released to the environment; usually expressed as a radiation dose.

Remote maintenance cell--A hot cell for the maintenance of processing equipment. This maintenance is performed remotely.

Repository--See "geologic repository."

Repository site--The place, both at and below the surface, where the repository and ancillary facilities are constructed. This area includes the disturbed zone and the surrounding buffer zone and has a surface area of several square kilometers.

Respirator canisters--Disposable cartridges that attach to a respirator and filter potentially hazardous airborne materials from air being breathed by an individual. The respirators are for use by individuals and generally are not a self-contained apparatus.

Restricted area--Any area to which access is controlled by the Department of Energy for purposes of protecting individuals from exposure to radiation and radioactive materials before repository closure but not including any areas used as residential quarters, although a separate room or rooms in a residential building may be set apart as a restricted area.

Retardation--The act or process that reduces the rate of movement of a chemical substance in a water stream relative to the average velocity of the water. The movement of the chemical substance in the water can be retarded by sorption and desorption reactions, by precipitation and dissolution reactions, and by diffusion into the pore water of the rock matrix.

Retrievability--The capability that is provided by the repository system, by means of design approaches, construction methods, and operating procedures, to allow waste retrieval to be performed.

Retrievability period--The time during which emplaced waste is capable of being retrieved. For design purposes, this period begins with emplacement of the first waste and ends 50 yr thereafter at the end of the caretaker period.

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

Retrieval cart--A cart used in the alternate retrieval concept for the horizontal configuration to position a waste package at the drift end of the borehole.

Retrieval cart bridge--Component of the retrieval cart system used to move the retrieval cart from inside the retrieval cart cask to the inside of the emplacement borehole.

Retrieval cart transporter--Cart used to transport the retrieval cart system throughout the repository.

Retrieval cart system--System used in the alternate waste removal concept for pulling waste containers from their disposal positions in horizontal emplacement boreholes to the retrieval position near the borehole entrance.

Rhyolitic--Characteristic of a group of extrusive igneous rocks, generally porphyritic and exhibiting flow texture with crystals of quartz and alkali feldspar in a glassy to cryptocrystalline groundmass (rhyolite).

Riprap--A foundation or revetment in water or on soft ground made of irregularly placed stones or pieces of boulders used chiefly for river and harbor work, roadway filling, and on embankments.

Rolling disk cutter--A type of drill bit that utilizes a rotating disk. The edge of the disk is pressed against the rock as the disk is rotated.

Room-and-pillar mining--A system of mining in which the ground support is provided by having the cross-sectional shape and size of pillars and the spacing between pillars as uniform as possible.

Safety analysis report (SAR)--A document that analyzes the facility and its safety-related systems for use in establishing whether or not the facility can be operated with reasonable assurance of no undue risk to the health and safety of the public and with adequate provisions for the protection of property and the environment.

Salt--The common mineral, sodium chloride (NaCl), and any impurities in it.

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

Screening--The process of evaluating an area, according to specified criteria or guidelines, to identify places that best fulfill the criteria.

Seal--An engineered component that reduces water flow.

Seismic--Pertaining to, characteristic of, or produced by earthquakes or earth vibrations.

Seismicity--The occurrence of earthquakes or the spatial distribution of earthquake activity; also the phenomenon of earth movement.

Service main--That drift running parallel to the waste and tuff mains southwest through the longitudinal axis of the underground facility dedicated to equipment and personnel access.

Settlement plug--A plug of cast concrete or similar material placed in a shaft and anchored to the surrounding bedrock to provide physical support to overlying backfill in the shaft.

Shaft station--A horizontally excavated opening of a shaft at a desired depth.

Shear--(1) A stress rate that produces a strain, causing contiguous parts of a body to slide relative to each other in a parallel direction. (2) Surfaces and zones of failure by shear or surfaces along which differential movement has taken place.

Shield door--A large, movable radiation shield that closes and provides shielding for large entry points in hot cells.

Shield plug--A cylinder of concrete, steel, or other dense material used to plug emplacement boreholes after waste package emplacement. Its main function is to attenuate radiation by providing shielding from the radioactive waste.

Shield valve--A small movable radiation shield that closes and provides shielding for ports in hot cells.

Shielding--A material interposed between a source of radiation and personnel to protect against radiation exposure; commonly used shielding materials are concrete, water, and lead.

Shielding closure--A radiation shielding device attached to the emplacement borehole that provides shielded access to the borehole during waste package emplacement.

Shielding collar--A component of the shielding closure that provides radiation shielding by extending from the closure to the transporter cask during emplacement or 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--Cement-based compounds sprayed on mine surfaces to prevent erosion by air and moisture and on rock surfaces to stabilize against minor rock falls. Also used to prevent dehydration and decrepitation.

Shredder--A device that reduces large items (e.g., fuel assembly hardware) to smaller pieces and thereby decreases the overall volume occupied by the items.

Side-frame construction--A type of conveyor belt construction where the carrying idlers, rope support stands, return idlers, and wire rope side frames are on a single, relatively light structure.

Silurian--The third of seven periods (395 to 430 million years ago, before the Devonian and after the Ordovician) of the Paleozoic Era.

Site--A potentially acceptable site or a candidate site, as appropriate, until such time as the controlled area has been established, at which time the site and the controlled area are the same.

Siting--The collection of exploration, testing, evaluation, and decision-making activities associated with the process of site screening, nomination, recommendation, and approval for characterization or repository development.

Smooth blasting--Involves detonating a main blast after which lightly loaded charges in closely spaced perimeter holes are detonated, breaking a relatively thin slab of rock to the newly created free face.

Special nuclear material--(1) Plutonium, uranium 233, uranium enriched in the isotope 233 or in the isotope 235, and any other material that the Nuclear Regulatory Commission pursuant to the provisions of Section 51 of the Nuclear Waste Policy Act, determines to be special nuclear material but that does not include source material; or (2) any material artificially enriched by any of the foregoing but that does not include source material.

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

Spent fuel hardware--The structural materials that hold spent fuel rods in place in the assemblies. The hardware does not include the fuel rods.

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

Station plug--A plug of cast concrete or similar material placed at the intersection of a shaft with a drift that serves to seal the drift from communication with the shaft.

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

Strike (geologic)--The angle between the north and the horizontal line contained in any planar feature (e.g., a bedding or fault plane, as it intersects the horizontal).

Structural steel set--A type of ground support used for fairly heavy roof loads. It is made up of steel crossbars, wide-flange or H-sections, with guesset reinforcing over the posts.

Subsurface facilities--In this document, the underground facility and the shafts, ramps, boreholes, and shops.

Supercompacter--A high-pressure crushing system used to reduce the volume of radioactively contaminated filters.

Support facilities--All permanent facilities associated with site characterization activities and repository construction, operation, and closure activities, including surface structures, utility lines, roads, railroads, and similar facilities but excluding the underground facility. "Permanent" indicates a design life greater than 5 yr.

Support plate--A metal plate that distributes the weight of a waste package in the bottom of a vertical borehole.

Surface faulting--Differential ground displacement at or near the surface caused directly by fault movement.

Surface storage vault--The portion of the waste-handling buildings in which waste is stored after preparation for emplacement or shipment offsite.

Surge storage--Storage provided to accommodate a temporary excess of materials that results either from equipment outages or erratic deliveries from utilities.

System requirements (SR)--The federal, state, local, Department of Energy, and Office of Civilian Radioactive Waste Management programmatic requirements that must be met by the prospective mined geologic disposal system (MGDS) at Yucca Mountain during all phases of development and after permanent closure.

Tectonic--Of or pertaining to the forces involved in tectonics or the resulting structures or features.

Tertiary--The earlier of the two geologic periods that make up the Cenozoic Era, extending from 65 to 1.8 million years ago.

Thermal--A term applied to material properties that govern the flow of heat and the resultant temperature of the material; also, a term for the analysis of the response of a material to temperature changes (e.g., thermal properties; thermal analysis).

Thermal capacitance--The quantity of heat passing normally through a unit area per unit time divided by the product of specific heat, density, and temperature gradient.

Thermal/mechanical (units of rock)--A term applied exclusively to the delineation of stratigraphic units, based on a combined consideration of their bulk thermal, mechanical, and thermomechanical properties.

Thermoluminescence--The property, possessed by many substances, of emitting light when heated. Thermoluminescence results from release of energy stored as electron displacements in the crystal lattice.

Thermomechanical--An adjective applied to the material properties that govern the physical response of a material to applied thermal stress or to the analysis of that response (e.g., coefficient of thermal expansion; thermomechanical analysis).

Throughput--The rate at which waste is received and processed in the repository.

Tram (v.)--A mining term to transport or move mined material from one location to another. Tram is normally used in conjunction with work performed by a load/haul/dump unit.

Transfer cart--The vehicle used to transfer waste from the unloading bay to the cask-unloading hot cell.

Transfer cask--A shielded enclosure for movement of highly radioactive material.

Transfer/storage cart--A rail-mounted, motorized cart equipped with interchangeable underhung racks that allow the storage and transfer of either containers or spent fuel assemblies.

Translational wind speed--A measure of the horizontal displacement of air with respect to time.

Transmissivity--The volumetric rate at which water of the prevailing kinematic viscosity is transmitted through a unit width of an aquifer under a unit hydraulic gradient. Mathematically, it is the product of permeability and the thickness of the zone of the aquifer being measured.

Transporter--See "waste transporter."

Transporter cask--A cask mounted on the waste transporter that provides shielding while the waste container is being transported from the waste-handling buildings to the emplacement borehole.

Tresca yield criterion--This criterion states that, when a material is subjected to increasing stress, it will yield in a ductile fashion when the maximum shear stress attains a value equal to one-half the yield strength of the material.

Trim hole--A single hole in which explosives are loaded when a small amount of rock needs to be removed from the edges of an opening.

Tuff--A compacted pyroclastic deposit of volcanic ash and dust that contains rock and mineral fragments incorporated during eruption or transport.

Tuff main--A drift running southwest through the longitudinal axis of the repository that provides access from the surface to the underground facility for the removal of tuff and exhaust of air during development.

Tunnel-boring machine (TBM)--A mechanical device or machine used to drill a circular horizontal, or nearly horizontal opening in rock.

Ubiquitous joint model--A continuum model for jointed media that considers selected shear aspects of jointed rock masses.

Ultrasonic bath--A tank that generates ultrasonic waves in a liquid to clean items placed in the tank.

Unanticipated processes and events--Those processes and events affecting the geologic setting that are judged not to be reasonably likely to occur during the period the intended performance objective must be achieved but which are nevertheless sufficiently credible to warrant consideration.

Unconfined aquifer--An aquifer containing ground water that has a water table or upper surface at atmospheric pressure.

Underground facility--The underground structure, including mined openings and backfill materials, but excluding shafts, boreholes, and their seals.

Underground layout--The drawing that shows all underground accesses and drifts used for personnel, material and waste movement, and for supply and exhaust of ventilation air.

Underreamer--A machine that enlarges a drill hole below the casing.

Unrestricted area--Any area to which access is not controlled by the licensee for purposes of protection of individuals from exposure to radiation and radioactive materials, and any area used for residential quarters.

Unsaturated zone--The zone between the land surface and the water table. Generally, water in this zone is under less than atmospheric pressure, and some of the voids may contain air or other gases at atmospheric pressure. Beneath flooded areas or in bodies of perched water, the water pressure locally may be greater than that of the atmosphere.

Usable area--The surface location, as delineated on a map, of that portion of the primary area within which the underground facility can be located. Delineation of the usable area within the primary area will consider overburden thickness; the characteristics of the target emplacement horizon, including mechanical and thermal properties of the tuff, thickness and dip; and mining feasibility. (See "primary area.")

Validation (of computer a code)--The documented confirmation of the adequacy (i.e., suitability for its intended purpose) of the computer code under review including a demonstration that what the software does is appropriate to the problem. Validation includes assurance that any physical model, as embodied in software, is a correct representation of the intended physical system or process.

Verification of computer codes--The documented confirmation that the computer code performs exactly the mathematical and logical operations described in the user's manual and other documents.

Vitric--Said of igneous material that is characteristically glassy, i.e., contains more than 75% glass.

Vitrophyre--Any porphyritic igneous rock having a glassy groundmass.

Volcanism--The processes by which magma and its associated gases rise into the crust and are extruded onto the earth's surface and into the atmosphere.

Waste--As used in this document, high-level radioactive waste or spent fuel.

Waste container--See "container."

Waste emplacement borehole--See "emplacement borehole."

Waste emplacement envelope--See "emplacement envelope."

Waste form--The radioactive waste materials and any encapsulating or stabilizing matrix.

Waste main--A drift running parallel to the tuff and service mains southwest through the longitudinal axis of the underground facility and dedicated to transporting waste.

Waste operations area--Area in which waste-handling operations occur, including both the surface and subsurface portions.

Waste package--The waste form and any containers, shielding, packing, and other absorbent materials immediately surrounding an individual waste container.

Waste-receiving and inspection area--Location in which waste shipments delivered by truck and railcar are inspected before they are transferred to the waste operations area.

Waste transfer tunnel--An area enclosed by reinforced-concrete shielding walls (25 ft below grade) that connects an area below the cask-unloading hot cell with the surface storage vault. Transfer/storage carts located in this tunnel are used to remove waste that has been packaged in the cask-unloading hot cell directly to the surface storage vault.

Waste transporter--The vehicle used to move radioactive waste from the waste-handling building to the waste emplacement borehole in the underground facility.

Waste treatment building--The building in which radioactive waste generated at the site is processed and placed in containers for disposal offsite.

Waste type--As used in this document, waste type refers to spent fuel [such as fuel rod assemblies from BWR or PWR systems and high-level waste (commercial and defense)].

Water table--The surface of a body of ground water at which the water pressure is atmospheric.

Wet-bulb temperature--Temperature at which water evaporating into air can bring the air to saturation adiabatically at that temperature; a measure of the evaporating capacity of air.

X-ray diffraction--A qualitative analytical technique that detects and interprets the diffraction of a beam of x-rays, usually by the three-dimensional periodic array of atoms in a crystal that has periodic repeat distances (lattice dimensions) of the same order of magnitude as the wavelength of the x-rays. This technique is most widely used for qualitative identification of crystalline substances.

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 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.

Young's modulus--A linear relationship of stress and strain in an elastic material under tension or compression loading.

Zeolites--A group of hydrous aluminosilicate minerals containing sodium, calcium, barium, strontium, and potassium, and characterized by the ease with which they exchange these ions.

Zone, seismic--A generally large area within which absolute seismic design requirements for engineered structures are uniform. A determination seismic-zone map is included as part of the Uniform Building Code, but this zoning does not apply to any facilities housing any part of the nuclear fuel cycle.

## LIST OF ACRONYMS

| | |
|---|---|
| ACD | Advanced conceptual design |
| ACP | Air-cooling power |
| A/E | Architect/engineer |
| ALARA | As low as reasonably achievable |
| ANSI | American National Standards Institute |
| APD | Areal power density |
| BNI | Bechtel National, Inc. |
| BWR | Boiling-water reactor |
| CFR | Code of Federal Regulations |
| DBA | Design-basis accident |
| CHLW | Commercial high-level waste |
| CSIR | Council for Scientific and Industrial Research (South Africa) |
| CTM | Container transfer machine |
| DAS | Data acquisition system |
| DBA | Design-basis accident |
| DBE | Design-basis earthquake |
| DHLW | Defense high-level waste |
| DOE | Department of Energy |
| DOL | Department of Labor |
| EA | Environmental assessment |
| EPA | Environmental Protection Agency |
| ESF | Exploratory shaft facility |
| ES-1 | The main shaft (12 ft in diameter) in the ESF |
| ES-2 | The second shaft (6 ft in diameter) in the ESF |
| FPCD | Final procurement and construction design |
| GR | Generic Requirements (document) |
| HEPA | High-efficency particulate air |
| HVAC | Heating, ventilating, and air conditioning |
| ICD | Interface control drawing |
| IGIS | Interactive Graphics Information System |
| IRS | Issues resolution strategy |
| LA | License application |
| LAD | License application design |
| LANL | Los Alamos National Laboratory |

## LIST OF ACRONYMS AND ABBREVIATIONS
(continued)

| | |
|---|---|
| LHD | Load/haul/dump unit |
| MGDS | Mined geologic disposal system |
| MRS | Monitored retrievable storage |
| MSHA | Mine Safety and Health Administration |
| MTU | Metric tons of uranium |
| NGI | Norwegian Geotechnical Institute |
| NNWSI | Nevada Nuclear Waste Storage Investigations (Project) |
| NQ-Scenario | Non-Q-Scenario |
| NRC | Nuclear Regulatory Commission |
| NRDA | Nevada Research and Development Area |
| NRS | Nevada Revised Statutes |
| NTS | Nevada Test Site |
| NWPA | Nuclear Waste Policy Act of 1982 |
| OCRWM | Office of Civilian Radioactive Waste Management (an office of the DOE) |
| OGR | Office of Geologic Repositories (an agency of the DOE) |
| PBQ&D | Parsons Brinckerhoff Quade & Douglas, Inc. |
| PMF | Probable maximum flood |
| PMP | Probable maximum precipitation |
| PRA | Probabilistic risk assessment |
| PRSA | Preliminary radiological safety analysis |
| PQ-Scenario | Potential-Q-Scenario |
| PWR | Pressurized-water reactor |
| QA | Quality assurance |
| QAPP | Quality Assurance Program Plan |
| RDR | Repository Design Requirements (document) |
| RIB | Reference Information Base |
| RLCC | Repository life-cycle cost |
| RT | Tons of refrigeration |
| SCP | Site Characterization Plan |
| SCP-CD | Site Characterization Plan Conceptual Design |
| SCP-CDR | Site Characterization Plan Conceptual Design Report |
| SDR | Subsystems Design Requirements (document) |
| SNL | Sandia National Laboratories |

## LIST OF ACRONYMS AND ABBREVIATIONS
(concluded)

| | |
|---|---|
| SR | System Requirements (document) |
| TBM | Tunnel-boring machine |
| TSLCC | Total system life-cycle costs |
| UNE | Underground nuclear explosion |
| UPS | Uninterruptible power supply |
| USBR | U.S. Bureau of Reclamation |
| WHB-1 | Waste-Handling Building 1 |
| WHB-2 | Waste-Handling Building 2 |
| WMPO | Waste Management Project Office (an office of the DOE) |
| WVHLW | West Valley high-level waste |

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