CONF-890736--74

WBS: 1.2.4.7.1

SAND89-0590C

THE YUCCA MOUNTAIN PROJECT REPOSITORY SEALING PROGRAM*

Received by OSTI

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SAND--89-0590C

DE90 003923

ABSTRACT

Yucca Mountain is being characterized for the development of a high-level nuclear waste repository. The repository is planned to be located in the unsaturated zone in fractured, welded tuff. Sealing of the repository is one element of the Yucca Mountain Project. This paper presents a description of the current sealing design options, design requirements, and the design constraints. Design options for the shafts include anchor-to-bedrock seals, shaft fill, and settlement plugs; in the underground facility, they include drift seals, drainage channels, sumps, and bulkheads. Design requirements are those quantitative requirements imposed on the sealing design options to achieve a desired level of performance. For example, a design requirement could be a restriction on the hydraulic conductivity of a design option. Constraints are restrictions placed on the repository design by the sealing design. An example of a constraint could be establishing the drainage pattern to direct flow from emplacement drifts to nonemplacement drifts. As (1) additional hydrogeologic data are obtained through site characterization, (2) approaches to allocating performance to various subsystems within the Yucca Mountain Project are refined, and (3) the exploratory shafts and the associated testing results are developed, the design requirements and constraints may be modified and used in developing the License Application Design.

INTRODUCTION

The Yucca Mountain site lies in a semiarid region of southern Nevada. Average annual precipitation is 150 mm (Montazer and Wilson, 1984). Underlying Yucca Mountain is a volcanic sequence as much as 3000 m thick (DOE, 1988; Carr and Yount, 1988). The repository, as planned, would be excavated in the Topopah Spring Member, which is located in the upper portion of this thick volcanic sequence. The Topopah Spring Member is predominantly a densely welded, highly fractured tuff having a low matrix hydraulic conductivity and a high bulk hydraulic conductivity. The proposed repository lies in the unsaturated zone 200-400 m above the ground-water table. Based on available saturation data of the Topopah Spring unit, water flow through this unit probably occurs principally in the rock matrix and not in the fractures. However, fracture flow could occur locally in zones of higher saturation. Therefore, because the proposed repository would be located in the unsaturated zone, the approach to sealing is different than it would be in a saturated environment. Specifically, the sealing approach used in the Yucca Mountain Project (YMP) is to divert water, if encountered from discrete, water-producing zones in significant amounts, from the waste emplacement areas and drain this water in nonemplacement areas through the highly fractured Topopah Spring Member. Water encountered in nonemplacement areas would be prevented from entering waste emplacement areas by diverting and draining this water into the nonemplacement areas. An additional consideration in the approach used for the YMP sealing program is to ensure that the shafts, ramps, and exploratory boreholes do not become preferential pathways for the release of radionuclides by water or gaseous transport.

The options for sealing designs (or sealing components), their design requirements, and the design constraints contained in this paper reflect an approach that is suitable for the unsaturated condition at Yucca Mountain.

SEALING COMPONENTS

Sealing is part of the permanent closure of the underground facility, shafts, ramps, and boreholes. It includes emplacing backfill, seals, or plugs in shafts, ramps, drifts, and boreholes and isolating discrete, water-producing zones from the waste packages. The sealing components discussed below are based mostly on the concepts first presented by Fernandez and Freshley (1984). The concepts were modified during the development of the Site Characterization Plan Conceptual Design Report (SNL, 1987). Because of the distinction made in 10 CFR 60 between the shaft and borehole seals and sealing in the underground facility (NRC, 1986), the sealing components can be organized according to their locations. Figure 1 identifies specific sealing components according to their location, i.e., shafts and ramps, the

*This work was supported by the U.S. Department of Energy (US DOE) under contract no. DE-AC04-76DP00789. The data or analyses for this document were gathered under Quality Assurance Level II.

SHAFTS AND RAMPS

- ANCHOR-TO-BEDROCK PLUG/SEAL
- GENERAL FILL
- STATION PLUGS
- UNSATURATED TOPOPAH SPRING MEMBER AT BASE OF SHAFTS AND RAMPS

UNDERGROUND FACILITY

- SINGLE DAM OR BULKHEAD
  - A. EMPLACEMENT DRIFT
  - B. PERIMETER AND MAIN DRIFTS
- DOUBLE BULKHEAD
  - A. EMPLACEMENT DRIFT (NO BULKHEAD SETTLEMENT)
  - B. EMPLACEMENT DRIFT (BULKHEAD SETTLEMENT)
- BACKFILLED SUMP
- BACKFILLED CHANNEL
- PLUG IN HORIZONTAL EMPLACEMENT BORE-HOLE
- DRIFT BACKFILL

EXPLORATORY BOREHOLES

- EXPLORATORY BOREHOLE SEAL
  - A. UPPER BOREHOLE SEAL
  - B. LOWER BOREHOLE SEAL (INCL. CALICO HILLS)

Figure 1. Sealing Component Categorized by Location

underground facility, and the exploratory boreholes. A brief description of each location follows.

The underground facility is composed of a series of access and emplacement drifts which are >200 m beneath the ground surface. More than 160 km (100 miles) of drifts will be developed to support the repository operations and testing in the exploratory shaft facility (ESF). The extent of the underground openings is about 2.4 x 3.2 km. Access to the facility, as defined in the conceptual design, is provided by four shafts and two ramps. Exploratory boreholes are located within and outside the perimeter of the underground facility.

Specific sealing components proposed for inclusion into the shafts and ramps, the underground facility, and exploratory boreholes are described in the next three sections.

SHAFT AND RAMP SEALING

There are three primary sealing components proposed for sealing the shafts: the anchor-to-bedrock plug/seal, the general fill, and the station plug. A fourth sealing component, the Topopah Spring Member, although a physical feature of the site, is included here because water drainage through this sealing component at the base of the shaft is part of the sealing strategy. As shown on Figure 2, liner removal at the base of the shaft is proposed to expedite water drainage.

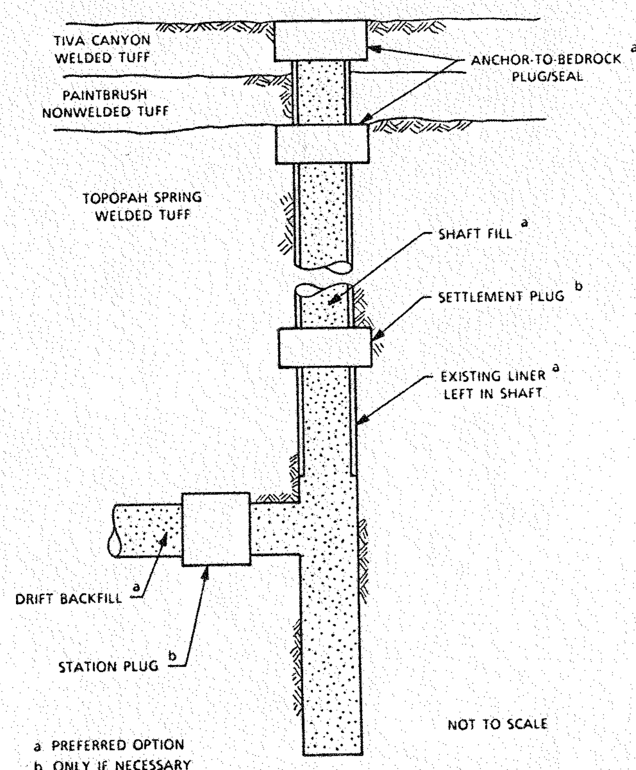

Figure 2. Conceptual Design for Sealing a Shaft in the Unsaturated Zone at Yucca Mountain

Although not indicated in Figures 1 and 2, a barrier could be placed over the entry point. This barrier would include restoration of the ground surface by placing a layered sequence of earthen materials over the shaft entry.

The concepts for sealing a ramp are similar to those for sealing a shaft. The primary difference in the ramp sealing concept is the installation of "dams" in the ramp to encourage downward flow of water through the highly fractured tuff rather than lateral flow along the floor of the ramp. A single repository station seal placed at the base of the ramp could accomplish the same function as the numerous dams periodically placed in the ramps. The necessity for and frequency of dams depends on the potential water inflow into the ramps.

UNDERGROUND FACILITY SEALING

The following options are proposed for sealing components in the underground facility: single dams or bulkheads, double bulkheads, backfilled sumps, backfilled channels, plugs in horizontal emplacement boreholes, and drift backfill. An integral part of these sealing components is the drainage capacity of the Topopah Spring welded unit upgradient from the sealing component. The identification of these sealing components does not suggest that all these components will be required in the underground facility. Rather, these options can be used in the underground facility to accommodate a broad range of water inflows, if necessary.

Sumps and drains are the simplest means for controlling water that enters the drift. Both can be used to increase the drainage capacity of the floor and to provide storage capacity. Holes could be drilled in the bottom of the sump and filled with gravel to increase the drainage capacity. When the flows 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 larger amount of water. Dams or bulkheads could 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.

An alternative method of handling larger inflows into the drifts would be construction of channels to transport water to nonemplacement drifts. Benefits of directing water flow to these nonemplacement drifts include (1) removal of water from the waste emplacement area and (2) identification of drainage areas before waste emplacement so that remedial measures can be taken to insure an adequate drainage capacity of the fractured rock. Figure 3 illustrates the backfilled sump, the single dam, and channel concepts. Figure 4 illustrates the potential seal locations in the larger perimeter drifts and tuff and service mains.

Use of the various concepts described above depends on the water inflow conditions encountered at the repository horizon. Current site information indicates that the flow is expected to be negligible. If, however, larger-than-expected inflows are encountered, the range of design concepts presented above provides the flexibility to accommodate these larger inflows. The concepts presented above are for selected locations in the repository. They represent a small portion of the total volume for the repository.

The current basis for the repository sealing program is that the majority of the repository

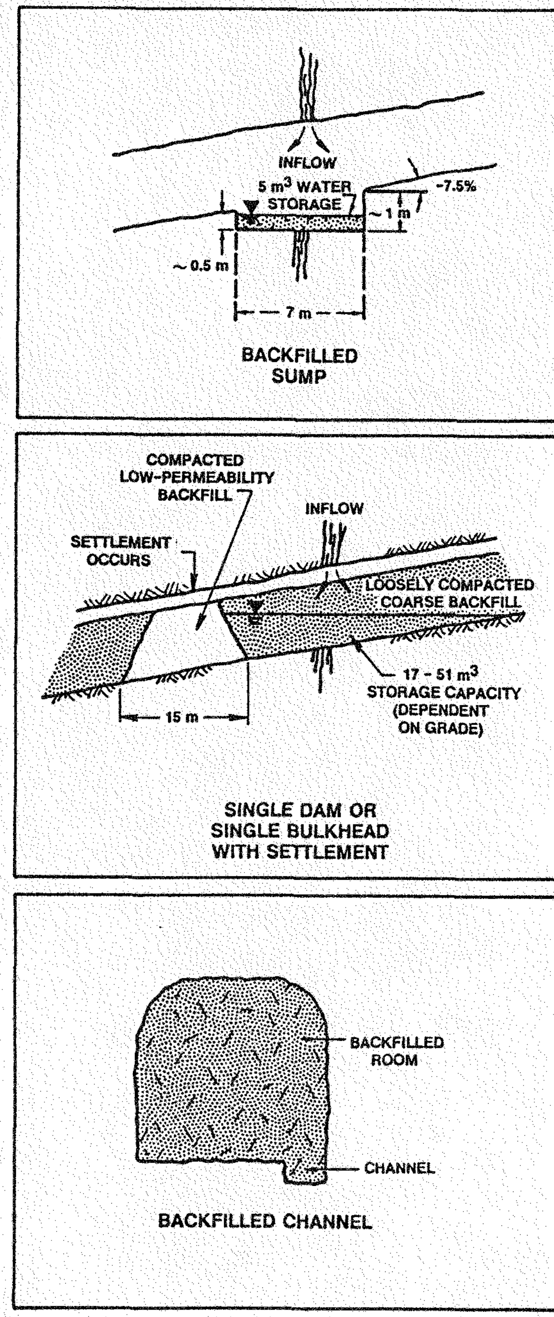

Figure 3. Sealing Concepts in the Repository

will be backfilled. The selection of suitable backfilling methods and emplacement methods will be based on the intended function of the backfill as well as practical considerations. Currently, the most desirable material would be crushed tuff with or without fines or clays added.

EXPLORATORY BOREHOLES

The principal intent of borehole sealing is to prevent the boreholes from becoming a preferential pathway for radionuclide release into the accessible environment. Deep exploratory boreholes that penetrate the water table could act as preferential pathways. To reduce this potential, a lower borehole seal over the length of at least the Calico Hills unit between the repository and

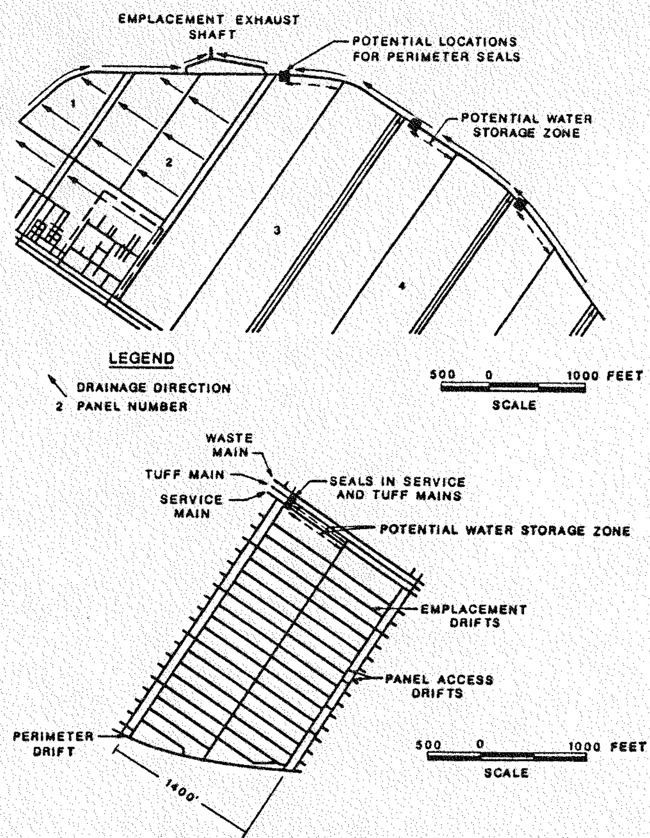

Figure 4. Proposed Locations for Single Dams and Bulkheads in the Underground Facility

the water table could be emplaced. For simplicity in design and emplacement, this plug could be extended to the surface. Such a design would serve as an upper borehole seal and reduce water entry to or gaseous release from the borehole.

DESIGN REQUIREMENTS

Design requirements for sealing originate from several primary regulations contained in 10 CFR 60 (NRC, 1986). The quantitative criteria in Section 60.113 are used to develop the hydrologic design requirements for the underground facility and the shafts and ramps. The qualitative design criteria for seals in shafts and boreholes are given in 10 CFR 60.134 and are used to develop the airborne design requirements for shafts and ramp seals and hydrologic design requirements for borehole seals.

The process of arriving at the design requirements for sealing components is referred to as the performance allocation process. Because this process is detailed and beyond the scope of the paper, it is not presented here. Comprehensive discussions of the performance allocation process and development of the design requirements are presented elsewhere (Fernandez et al., 1987 and Fernandez et al., 1989). As (1) additional hydrogeologic data are obtained through site characterization, (2) the performance allocation process is refined, and (3) the exploratory shafts and the associated testing results are developed, the design requirements may be modified.

The hydrologic design requirements typically fall into two categories: (a) a requirement that specifies a maximum allowable, equivalent hydraulic conductivity for a specific sealing component and (b) a requirement that specifies a maximum water storage volume and drainage capacity. The purpose in achieving the requirement in Category "a" is to restrict the water flow past the sealing component to a specific value that can achieve the criteria in 10 CFR 60.113. The purpose in achieving the requirement in Category "b" is to control the water flow and drainage in the shafts, ramps, and the underground facility.

The hydrologic design requirements for sealing components in the shafts, ramps, and boreholes are tabulated in Table I. Hydraulic requirements for components in the underground facility are tabulated in Table II. Design requirements are identified for all of the sealing components in Figure 1 with the exception of the drift backfill. Currently, no requirement has been identified for this component. Because the hydraulic conductivity of the Topopah Spring Member at the base of shafts and ramps is a site property, it is inappropriate to define a requirement for this geologic unit.

Table I. Hydrologic Design Requirements for Sealing Components in Shafts, Ramps, and Boreholes

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Anchor-to-Bedrock Plug[(1)]

- Construct an anchor-to-bedrock plug having an effective hydraulic conductivity [including interface zone and modified permeability zone (MPZ)] $\leq 10^{-5}$ cm/s to 10^{-4} cm/s.

General Fill[(1)]

- Emplace ramp fill having a saturated hydraulic conductivity $\leq 10^{-2}$ cm/s[(2)].

Station and Shaft Plug[(1)]

- Construct a station or shaft plug having an effective hydraulic conductivity (including interface zone and MPZ) $\leq 10^{-6}$ to 10^{-5} cm/s.

Lower Borehole Seal[(3)]

- Construct a borehole seal having a hydraulic conductivity of $\leq 10^{-3}$ to 10^{2} cm/s depending on bulk rock hydraulic conductivity of the Calico Hills unit.

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(1) Sealing components in shafts and ramps.

(2) Selection of general fill conductivity is based primarily on airflow analyses.

(3) An upper borehole seal will also be emplaced. However, no specific design requirements are currently identified.

Table II. Hydrologic Design Requirements for Sealing Components in the Underground Facility

Single Dam or Bulkhead

a. Emplacement Drifts

- Provide a minimum storage volume of 17 m^3.
- Design a drainage capacity of >470 m^3/yr through the drift floor upgradient from dam.
- Construct a dam with an effective hydraulic conductivity of $\leq 10^{-5}$ to 10^{-4} cm/s and <10% settlement.

b. Perimeter Drifts or Mains

- Provide a minimum storage volume of

  350 m^3 (perimeter drift)
  620 m^3 (tuff and service mains).
- Ensure a drainage capacity of >2,000 m^3/yr through the drift floor upgradient from the dam.
- Construct a dam with an effective hydraulic conductivity of $\leq 10^{-4}$ cm/s and <10% settlement.

Double Bulkheads

a. Emplacement Drifts (no bulkhead settlement)

- Provide a minimum storage volume of 300 m^3.
- Design a drainage capacity of the drift floor to be >470 m^3/yr.
- Construct bulkheads with an effective hydraulic conductivity of $\leq 10^{-8}$ to 10^{-7} cm/s and no settlement.
- No storage above upper dam.

b. Emplacement Drift (bulkhead settlement)

- Provide a minimum storage volume of 210 m^3.
- Design a drainage capacity of the drift floor between bulkheads to be >470 m^3/yr.
- Construct bulkheads or dams with an effective hydraulic conductivity of $\leq 10^{-5}$ to 10^{-4} cm/s.
- No storage above upper dam.

Backfill Sump

- Provide a minimum storage volume of 5 m^3 and a drainage capacity of >100 m^3/yr.

Backfill Channel

a. Emplacement Drifts

- Area in cross section >0.25 m^2.

  Hydraulic conductivity of backfill is high, 0.1 to 100 cm/s.

b. Access Drifts

- Area in cross section >2 m^2.

  Hydraulic conductivity of backfill is high, 0.1 to 100 cm/s.

Plug in Horizontal Emplacement Borehole

- Emplace a borehole plug having an effective hydraulic conductivity (including interface zone and MPZ) of $\leq 10^{-7}$ to 10^{-6} cm/s.

The second category of design requirements relates to the design of the underground facility or the site conditions that would be encountered. For example, to determine sump capacity it is assumed that the maximum depth of the water in a typical 6.5 meter drift is limited to 0.5 m, the drift grade is 7.5%, and the sump is backfilled. With these assumptions, the storage volume would be 5 m^3 and the drainage capacity would be 100 m^3/yr if the saturated, hydraulic conductivity of the rock mass is assumed to be 10^{-5} cm/s. Another example is the requirement for channels. Channels are intended to direct water away from emplacement areas. With this goal in mind, and because the exact hydrologic conditions at the repository depth are not known, multiple design requirements are proposed which could handle a broad range of hydrologic conditions.

As indicated by Footnote 2 in Table I, the requirement for shaft and ramp fill was determined primarily through airflow analyses. Both convective and barometric airflow analyses were performed. The purpose in doing these analyses was to determine the air conductivity of a shaft and ramp fill at which the shafts and ramps would not be considered preferential pathways. From the analyses reported by Fernandez et al. (1987 and 1989), it was concluded that if the air conductivity of the shaft and ramp fill was 3 x 10^{-4} m/min (equivalent to a hydraulic conductivity of 10^{-2} cm/s), the shafts and ramps would not be preferential pathways. The analysis assumed no other seals were emplaced in the shafts and ramps. Further, obtaining a shaft fill that has a hydraulic conductivity of 10^{-2} cm/s is achievable. For example, for cohesionless materials (i.e., with no clay), values may range from as high as 100 cm/s for a clean, coarse gravel or rock fill to 10^{-5} cm/s for a fine silt. Specific values within this range can be engineered by crushing and screening the tuff. Lower values of hydraulic conductivity can be obtained by adding clay or crushed tuff. For example, a value of about 10^{-10} cm/s can be obtained from a mixture of crushed tuff with 30% Na-bentonite (Fernandez et al., 1987, Appendix D).

Finally, the development of a design requirement for a borehole seal was based on the 10 CFR 60 requirement that "boreholes be designed so that following closure they do not become pathways that compromise the geologic repository's ability to meet the performance objective." In the YMP repository sealing program, the position adopted was that this 10 CFR 60 requirement is achieved if the potential for vertical flow through boreholes is only 1% of the potential for vertical water flow through the host rock mass. Because the requirement is tied to the bulk rock hydraulic conductivity of the Calico Hills unit beneath the repository and the range of this unit can vary from 10^{-8} to 10^{-4} cm/s, the requirement for the borehole seal within the Calico Hills unit also varies from 10^{-3} to 10^{2} cm/s. Emplacement of a borehole seal having these conductivities is considered to be easily achievable. Further, emplacement of a similar quality seal in the upper portion of the borehole could also reduce the water inflow into the borehole as well as the airflow out.

CONSTRAINTS

Because of the uncertainties in the site characteristics and the performance of the sealing components, it is necessary to maintain flexibility in the design of the sealing component. This flexibility is maintained by proposing multiple design options that incorporate the uncertainties in the site properties including the hydrology. An additional way to maintain flexibility is to impose logical constraints on the repository design so that the repository design can compliment the sealing design and concepts.

The most immediate area in which to impose design constraints is the ESF. Because the ESF is planned to be incorporated into the repository, it is necessary to impose several seal-related constraints regarding the design and operation of the ESF and the repository. Constraints that apply to the ESF as well as the repository involve restricting flow into and from the repository, draining water into the bulk rock, and preventing complicating conditions associated with seal evaluations and emplacement.

Constraints currently in place to restrict the flow into and from the repository include the following: placing portals of shafts and ramps outside of the flood plain, restricting the number of shafts and ramps, restricting the distance between the bottom of the shafts and the water table, and controlling and monitoring water usage in developing the shafts, ramps, and the underground facility. As indicated earlier, one of the fundamental concepts in the sealing program is to divert water away from waste emplacement areas and drain the waters in nonemplacement areas. Several logical constraints include

- ensuring that the shaft liner can be removed, especially at the base of the shafts, to promote contact of water with the formation, and thereby enhancing drainage;
- ensuring that the compacted tuff on the drift floors in selected areas can be removed and the floor reconditioned to enhance drainage;
- providing a water storage capacity of 150 m^3 at the base of shafts and 10,000 m^3 at the low point of the repository before any water enters the waste emplacement drifts (both areas are backfilled);
- establishing a drainage pattern for emplacement drifts to nonemplacement drifts;
- establishing drift grades so that drifts in the ESF dedicated test area drain to Exploratory Shaft No. 1 (ES-1) and the

drifts associated with the development support shops drain towards the men-and-material (MM) shaft; and

- establishing grades of access drifts so that no drainage occurs into the ES-1 and MM shaft areas.

Finally, so as not to complicate the emplacement and evaluation of seal components, the following constraints are imposed.

- Drifts in the underground facility should be at least 15 m from the exploratory boreholes.

- No grouting of the rock mass should take place were seals are currently proposed.

- Controlled blasting techniques should be used while excavating rock in potential seal locations so that fracturing of the rock can be reduced.

The constraints identified above are conservative and allow flexibility in the design of sealing components. It is anticipated that as more information is obtained on the site, the repository design is modified, and the performance allocation process is refined, the design requirements and constraints will also be modified.

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