8. SUBSURFACE DESIGN DESCRIPTION

8.1 REPOSITORY HOST HORIZON DESCRIPTION

The repository host horizon for the proposed repository at Yucca Mountain has been identified as the welded, lithophysae-poor, ash-flow tuffs in the Topopah Spring Tuff of the Paintbrush Group (DOE 1988a). This section addresses the background for selecting this unit as the host horizon and describes the results of computer modeling used to define the spatial limits of the volume available for repository siting. The available siting volume was used as input to the engineering design for positioning the repository.

8.1.1 Previous Work

Initial siting activities for the potential high-level nuclear waste repository for the Nevada Nuclear Waste Storage Investigations Project (a predecessor name for the current Yucca Mountain Site Characterization Project) focused on characterizing geologic units below the water table at Yucca Mountain. By mid-FY 1981, the welded, devitrified portions of the Bullfrog and Tram Members of the Crater Flat Tuff were identified as potential host geologic units. Late in FY 1981, however, attention was redirected to identifying potential repository units in the unsaturated zone above the water table. Based on this work, the welded, devitrified Topopah Spring Tuff of the Paintbrush Group containing generally less than 10 percent lithophysal cavities, and the nonwelded, highly zeolitized Calico Hills Formation, were identified as potential repository units within the unsaturated zone. In FY 1982, Johnstone et al. (SNL 1984b) conducted an evaluation of all four potential repository units (Bullfrog, Tram, Topopah Spring, and Calico Hills) and came to the conclusion that the Topopah Spring Tuff unit should be selected as the primary target horizon, followed by, in descending order, the Calico Hills Formation, Bullfrog Member, and Tram Member.

A subsequent study by Mansure and Ortiz (SNL 1984a) identified the potentially useable areas for repository siting in the vicinity of Yucca Mountain. These areas were numbered one through six (Figure 8.1.1-1) and were identified based on the limiting criteria that located the potential repository facility within the Topopah Spring Tuff horizon containing less than 15 to 20 percent lithophysal cavities, under at least 200 m of overburden, and above the water table. Area 1, known as the Primary Area, was identified as the most promising site, within which a potential repository block of 750 hectares (1850 acres) was identified. The siting of the repository block in the Primary Area utilized a three-dimensional computer model developed by Nimick and Williams (SNL 1984c) that was based on a geology modeling framework.

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A recent investigation concerning the repository block limits was presented in the Civilian Radioactive Waste Management System (CRWMS) Management and Operations Contractor (M&O) design analysis entitled *Definition of Repository Block Limits* (CRWMS M&O 1994b). This analysis presented maps and cross sections that illustrate the limiting criteria used in siting the potential repository block. The limiting criteria in this analysis included topography, overburden, faults, stratigraphy, lithophysal cavities, zeolitic tuffs, rock properties, rock quality designation, constructability, maintenance, rock thermal properties, thermal goals, and groundwater.

This M&O design analysis was later enhanced by more detailed, three-dimensional computer modeling, which was presented in the M&O technical report entitled *Definition of Potential Repository Block* (CRWMS M&O 1995n). The volume of rock available for placement of the repository was identified by computer modeling, using the Lynx Geoscience Modeling software system (LYNX). The volume was defined by overburden, fault, host geologic horizon, and groundwater criteria.

8.1.2 Requirements and Assumptions

The principal requirements and assumptions applicable to repository siting fall within the areas of overburden thickness, fault avoidance and standoff, repository host horizon, and the groundwater table.

8.1.2.1 Overburden

Based on the following postclosure guidelines, as specified in the general guidelines for erosion presented in 10 CFR 960, *General Guidelines for the Recommendation of Sites for Nuclear Waste Repositories*, a minimum emplacement overburden of 200 m is assumed for the repository areas.

> The site shall be disqualified if site conditions do not allow all portions of the underground facility to be situated at least 200 m below the directly overlying ground surface.

This parameter is a long-term waste isolation consideration intended to prevent erosion from exposing the underground facility and the emplaced waste packages.

8.1.2.2 Faults

Fault locations on the surface are identified in the *Controlled Design Assumptions Document* (CDA Document) (CRWMS M&O 1995a), but subsurface locations are not addressed.

> TDS 001 (Technical Data Assumptions – Surface):
>
> > The Surface Facilities fault displacements, fault locations, and fault attitudes shall be as described in Section 1.23 of the *Reference Information Base* (YMP 1995a).

For the subsurface extension of the surface-mapped faults, the projections presented by the U.S. Geological Survey in their LYNX computer model YMP.R1.1 was assumed.

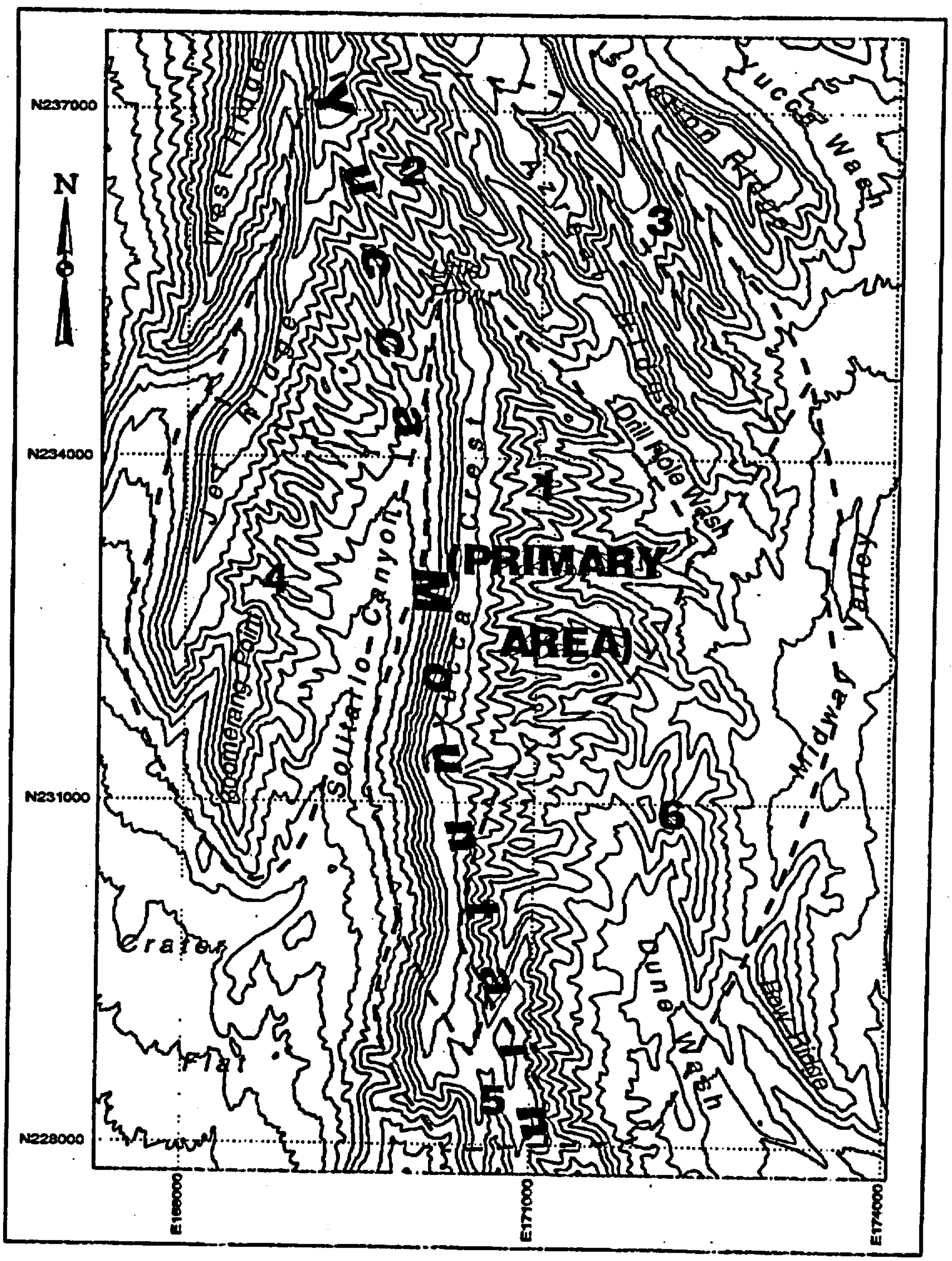

Figure 8.1.1-1. Primary Area and Adjoining Potential Repository Areas

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General assumptions for standoff from faults is addressed in the CDA Document (CRWMS M&O 1995a).

Key 023 (Key Assumption):

To the extent practical, repository openings will be located to avoid Type I faults. For unavoidable Type I faults that intersect emplacement drifts, allow a 15-m standoff from the edge of the fault zone to the nearest waste package.

Avoidance is assumed to be adequate by using a 60-m offset from the main trace of a fault at the repository level. Exception: 120-m offset should be used on the west side of the Ghost Dance Fault because the Exploratory Studies Facility (ESF) Topopah Spring Main drift will be excavated before the Ghost Dance Fault characteristics are fully investigated.

8.1.2.3 Repository Host Horizon

The repository host horizon is identified in the CDA Document (CRWMS M&O 1995a).

Key 022 (Key Assumption):

For the reference thermal loading of 80 to 100 metric tons of uranium (MTU) per acre, the repository horizon will be located mainly in the TSw2 geologic unit within the primary area.

Underground development standoff from the lower boundary of the TSw2 unit is not specifically identified in the CDA Document (CRWMS M&O 1995a) as a distance, but is specified as an upper temperature limit for the TSw3 basal vitrophyre unit.

EBDRD 3.7.G.3 (Requirements Assumptions (EBDRD):

To limit the thermal and thermomechanical response of the host rock and surrounding strata and groundwater system, the Engineered Barrier System (EBS) configuration and loading shall limit the TSw3 (basal vitrophyre) maximum temperature to less than 115°C.

Currently, a standoff of 30 m from the TSw2/TSw3 contact has been conservatively selected (CRWMS M&O 1995ai).

8.1.2.4 Groundwater

Favorable groundwater conditions for disposal in the unsaturated zone are specified in the general guidelines for geohydrology presented in 10 CFR 960.

A water table sufficiently below the underground facility such that the fully saturated voids continuous with the water table do not encounter the host rock.

8.1.3 Computer Geology and Engineering Models

In order to define the volume of rock available for repository siting, a geology and engineering computer model was developed for the Primary Area (CRWMS M&O 1995n). This model was developed within LYNX, Version 3.06, which is a three-dimensional, volume-based, geology and engineering computer modeling system. The M&O system is operating on a Silicon Graphics Unix-based workstation. The LYNX Version 3.06 software has been qualified for Quality Affecting Work and is in the Las Vegas baseline of qualified software with the Computer Software Configuration Item (CSCI) number B00000000-01717-1200-30018. The model developed for defining the potential repository block is referred to as YMP.MO2. It contains a model of the limiting geologic features and models of the current engineering design for the ESF and repository. The geology model is based on the limiting criteria for repository siting, including overburden, faults, host geologic horizon, and groundwater.

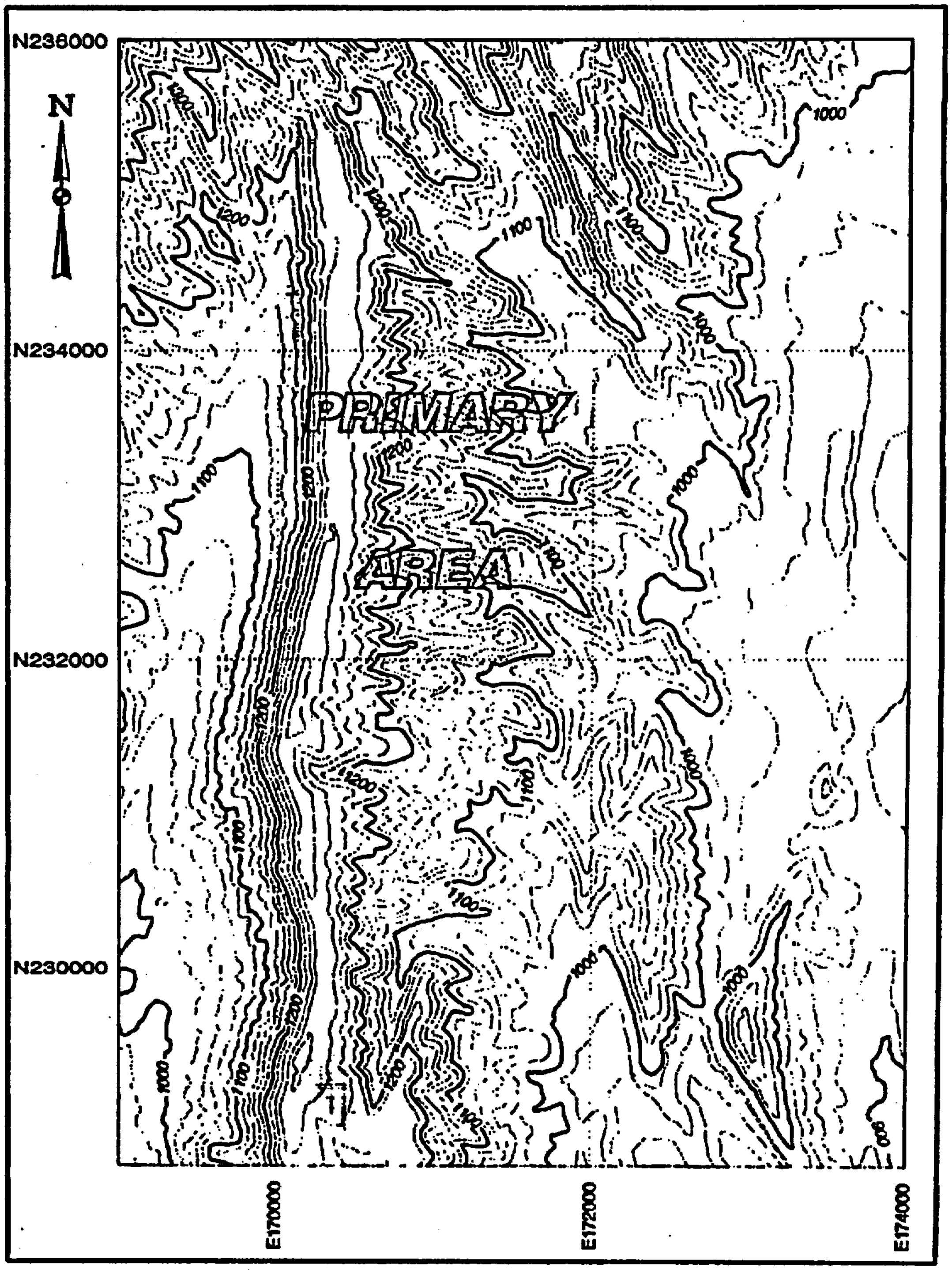
8.1.3.1 Overburden

To define this limiting overburden criteria in the LYNX geology model, the topography of the ground surface was first defined as a metric contour map (Figure 6.2.3-1). Since no metric contour maps exist for the area, the metric digital map data were developed by a computer generating metric contours through interpolation of the existing 1:12,000 scale digital topographic data with 20-foot contour intervals. A duplicate surface 200 m below the ground surface was then developed by subtracting 200 m from the topographic contour values (Figure 8.1.3-1). The Primary Area of Mansure and Ortiz (SNL 1984a) is shown for reference. To meet the overburden criteria, the potential repository block must be entirely below this minus-200-m surface.

8.1.3.2 Faults

The faults mapped on the surface in the area are illustrated on the Scott and Bonk geology map (USGS 1984b) and are shown in Figure 6.5.3-1. The main faults that surround the Primary Area include the Solitario Canyon fault, Drill Hole Wash fault, western limit of the Imbricate fault system, and the Abandoned Wash fault. Identified faults located within the Primary Area include the Ghost Dance fault, Sundance fault, two fault splays from the Solitario Canyon fault, and an unnamed fault along the northern edge of the area to the west of the Ghost Dance fault. In addition, a swarm of small faults is located to the west of the Abandoned Wash fault.

The main faults, including Solitario Canyon, Drill Hole Wash, Imbricate system, and Abandoned Wash, in part, defined the limits of the Primary Area (SNL 1984a). The outline was also affected by the fault swarm in the southeast and the lower stratigraphic limit of the host horizon in the southwest. In the ESF Topopah Spring North Ramp, some small faults were found in the tunnel and were identified as the Drill Hole Wash fault, but it was not manifested as the major structure that was anticipated. In the ESF Topopah Spring Main Drift, the Sundance fault was recognized as a small fault near the location projected from the surface. Refer to subsection 6.5.3 for more information on these faults.



Contour Interval
= 20 meters

Figure 8.1.3-1. Contour Map on the Minus-200-m Surface

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In the M&O LYNX YMP.MO2 geology model, only the major faults were included. For the most part, the fault definitions were taken from the U. S. Geological Survey (USGS) LYNX model YMP.R1.1 (USGS 1994d). These faults included the Solitario Canyon fault, Drill Hole Wash fault, western limit of the Imbricate fault system, Ghost Dance fault, and Abandoned Wash fault. The location of the faults at depth is based on USGS projections of fault dips measured on the surface. Fault definitions added to the geology model in M&O LYNX project YMP.MO2 include the two fault splays from the Solitario Canyon fault. The Sundance fault and the unnamed fault along the northern edge of the area to the west of the Ghost Dance fault were not included in the YMP.MO2 model because of their apparent minor displacement.

8.1.3.3 Repository Host Horizon

The thermal/mechanical stratigraphic units were originally defined by Ortiz et al. (SNL 1985a) to directly address engineering properties of the rock. They grouped together rock units predicted to have similar thermal and mechanical properties based on correlation with their grain density and porosity. Using this basis, they identified sixteen thermal/mechanical stratigraphic units from the surface down to, and including, the Tram Member of the Crater Flat Tuff. Their groupings reflected to a large extent the general degree of welding and, in the case of the Topopah Spring rocks, the volume of lithophysal cavities. The proposed repository host rock was identified as the TSw2 thermal/mechanical unit because of its favorable thermal and mechanical properties. The TSw2 unit was defined as consisting of moderately to densely welded, devitrified ashflows of the Topopah Spring Tuff that contains less than approximately 10 percent lithophysal cavities by volume. The overlying TSw1, in contrast, contains greater than approximately 10 percent lithophysal cavities by volume.

Rautman (SNL 1985b) recognized a potential problem with the Topopah Spring T/M units. He found that the USGS core descriptions of lithophysae, which Ortiz et al. (SNL 1985a) used as a basis in their study, included not only the central cavity, but also the vapor-phase alteration rinds surrounding the cavity. When the core was reevaluated to estimate only the cavity portion of the lithophysae, it was found that there were significant differences between the previous depths selected and the new depths, based on lithophysal cavity content.

In a 1991 committee evaluation (SAIC 1991) of the actual core from the boreholes used by Ortiz et al. (SNL 1985a), it was determined that their interpretation of logs from two boreholes (USW G-1 and UE25 a-1) were not stratigraphically consistent with the contacts chosen in other boreholes. Based on an evaluation of the core from five boreholes, revised depths were selected for the TSw1/TSw2 contact. These revised depths corresponded very closely to the base of the upper lithophysal zone, which is a consistently recognizable, field mappable contact, and agrees with a majority of the depths selected by Ortiz et al. (SNL 1985a). This letter, in effect, redefined the TSw1/TSw2 contact to be equivalent to the bottom of the upper lithophysal zone, rather than basing the contact on lithophysal cavity content. This lithostratigraphic contact was identified in the ESF TS main drift and was named as nominally equivalent to the TSw1/TSw2 contact (USGS 1995b).

In the M&O investigation for defining the potential repository block (CRWMS M&O 1995n), it was found that the lower 5 to 40 m of the overlying TSw1 unit may be similar in thermal and mechanical characteristics to the lithophysal part of the TSw2 unit and therefore may also be suitable for repository development. This lower part of the TSw1 unit is equivalent to the lower part of the upper lithophysal zone (Table 6.4.3-1), which is very dissimilar in characteristics to the overlying upper part of the upper lithophysal zone. This subdivision appears to reflect a significant change in lithophysal cavity content, as estimated from cores, and is easily recognized in geophysical down-hole density logs. Based on these observations, a nominal upper boundary for the repository host horizon was selected at this stratigraphic location. The repository host horizon used in the M&O investigation (CRWMS M&O 1995n) therefore included the TSw2 and the lower portion of the TSw1 thermal/mechanical units. Investigation of this upper contact is continuing with the evaluation of thermal and mechanical properties such as thermal expansion, thermal conductivity, Young's Modulus, Poisson's Ratio, tensile strength, axial stress, and wave velocities. Preliminary indications from this investigation still support the initial conclusion that the lower part of the upper lithophysal zone is very similar in thermal and mechanical characteristics to the lithophysal part of the TSw2 unit. Selection of this upper contact as the top of the potential repository horizon does not affect the current repository design because the repository design elevation was referenced to TSw1/TSw2 contact at the bottom of the upper lithophysal lithostratigraphic unit. What this additional strata provides is more flexibility in the repository design. The contoured top surface of the repository host horizon is shown in Figure 8.1.3-2. In the computer model, a 5 m standoff below this top surface was taken as the upper limit for the potential repository placement. This was based on the fact that directly above this surface is the upper portion of the upper lithophysal lithostratigraphic horizon, which contains a significantly greater amount of lithophysal cavities.

The lower limit of the repository host horizon is defined by the top of the basal vitrophyre (TSw3 thermal/mechanical unit). The structural contour map for this surface is illustrated in Figure 8.1.3-3. The glassy, brittle nature of the vitrophyre may affect the stability of underground development within the TSw3 unit (CRWMS M&O 1994b). The thermal characteristics of the vitrophyre and the proximity to the underlying, nonwelded, CHn (Calico Hills nonwelded unit) may necessitate a standoff of waste emplacement from the TSw3 unit. The required standoff, however, will depend upon the designed thermal load of the repository and the thickness of the TSw3 unit. A conservative standoff of 30 m from the TSw3 vitrophyre unit was assumed for the lower stratigraphic limit for the repository host horizon.

8.1.3.4 Groundwater

An interpretation of the groundwater surface is presented in Figure 6.6.5-1. This illustration was developed mostly from 1988 average groundwater level data (USGS 1994c). A more detailed description of the map is presented in subsection 6.6.5. Within the Primary Area, the groundwater table is below the lower defined limit for the repository host horizon, therefore, groundwater is not a limiting criteria.

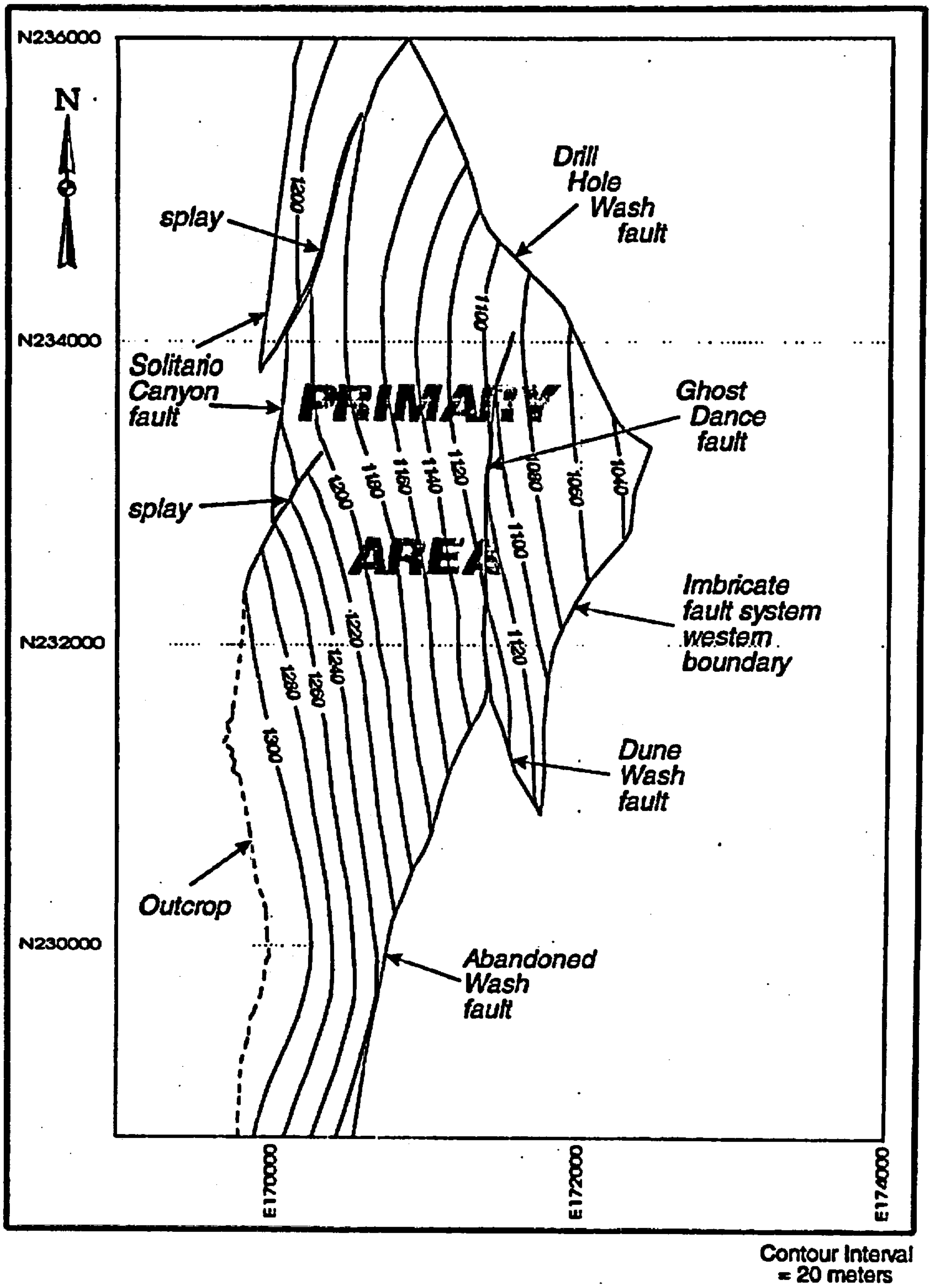

Figure 8.1.3-2. Structural Contour Map for the Top of Repository Host Horizon

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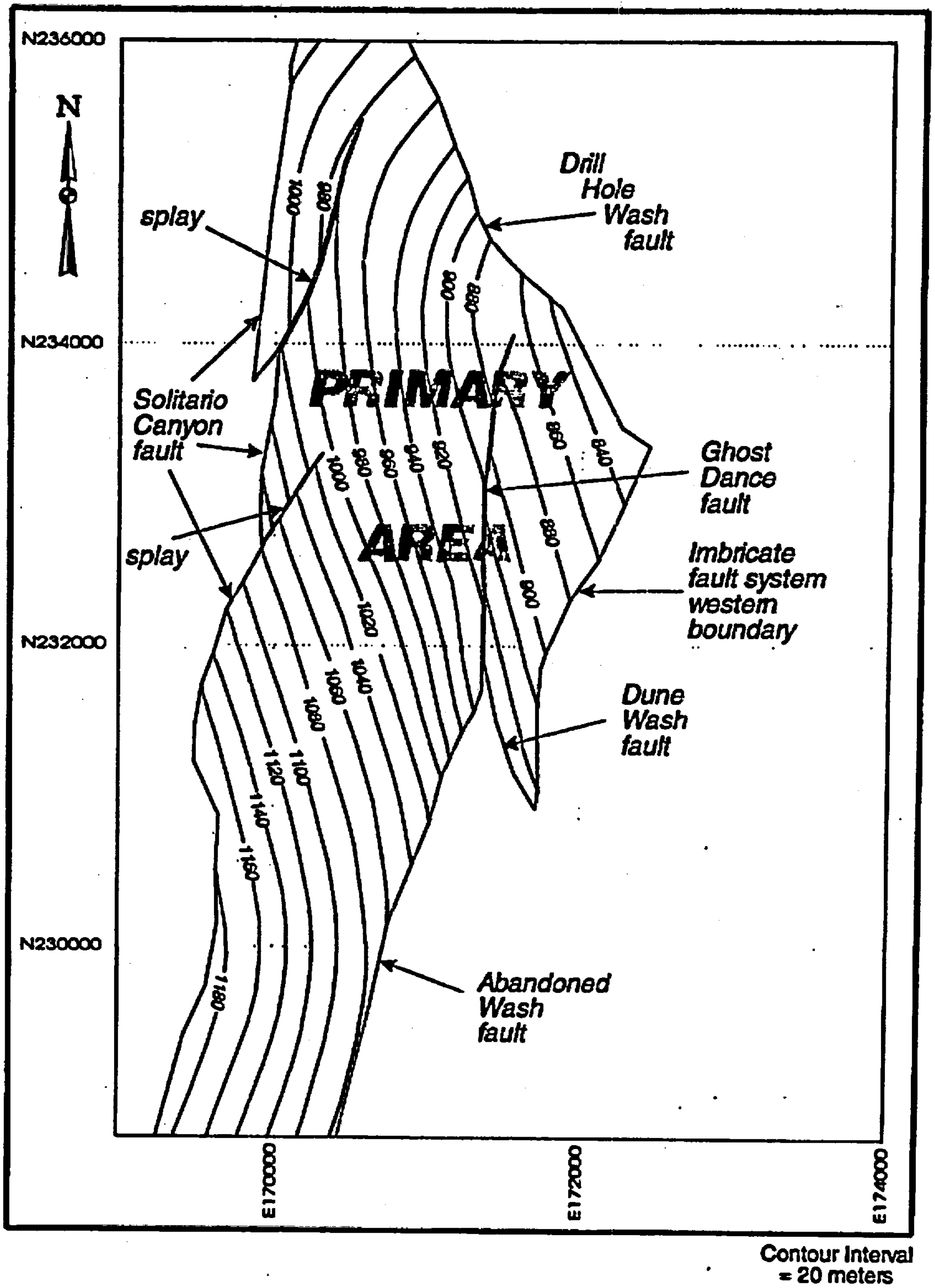

Figure 8.1.3-3. Structural Contour Map for the Bottom of Repository Host Horizon

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8.1.4 Potential Repository Areas

The potential repository areas are defined by a number of criteria discussed in the previous sections, including:

- 200 m overburden surface
- 5 m standoff below top of repository host horizon
- 30 m standoff above bottom of repository host horizon
- top of groundwater table
- 60 m standoff from Type I faults (120 m from the west side of the Ghost Dance fault).

The upper limit of the available repository areas is defined by either the top of the repository host horizon minus a 5-m standoff or the 200-m overburden surface, whichever is at the lowest elevation. The lower limit is defined by either the bottom of the repository host horizon plus a 30-m standoff, or the top of the groundwater table, whichever is the highest. Since the groundwater table is significantly lower than the bottom of the repository host horizon in the Primary Area, it is not a limiting criteria. The lateral limits are defined by the location of the major faults minus a 60-m standoff, except for the Ghost Dance fault, which has a 120-m standoff on the west side. The resulting potential repository areas defined by these criteria are shown in Figure 8.1.4-1. The Primary Area, and ESF and repository layouts are also shown in the figure for reference.

As can be seen in Figure 8.1.4-1, most of the potential repository areas are utilized in the design. For the upper repository block, the eastern limit is controlled by the ESF Topopah Spring Main Drift and the Ghost Dance fault (Figure 6.5.3-1). On the north, it is limited by the Drill Hole Wash fault (Figure 6.5.3-1), but the discovery that this fault appears to be insignificant may provide for possible expansion to the north. On the west, the Solitario Canyon fault and a splay from this fault (Figure 6.5.3-1) controls the limit. The 30-m standoff from the bottom of the repository host horizon restricts the available area in the southwest. This, together with the swarm of small faults in the south (Figure 6.5.3-1), limit the southern extension of the repository. If the 30-m standoff from the bottom of the repository host horizon could be reduced, additional area to the south and southwest could be gained. For comparison purposes, Figure 8.1.4-1 includes the potential repository area based on a 5-m standoff from the bottom of the repository host horizon.

The lower repository block utilizes most of the available area, as is shown in Figure 8.1.4-1. On the west, it is limited by the standoff from the Ghost Dance fault (Figure 6.5.3-1) and on the east it is limited by the western limit of the Imbricate fault system (Figure 6.5.3-1). In the north, it is limited by the ESF Topopah Spring North Ramp. In the south, the area pinches to an unusable area.

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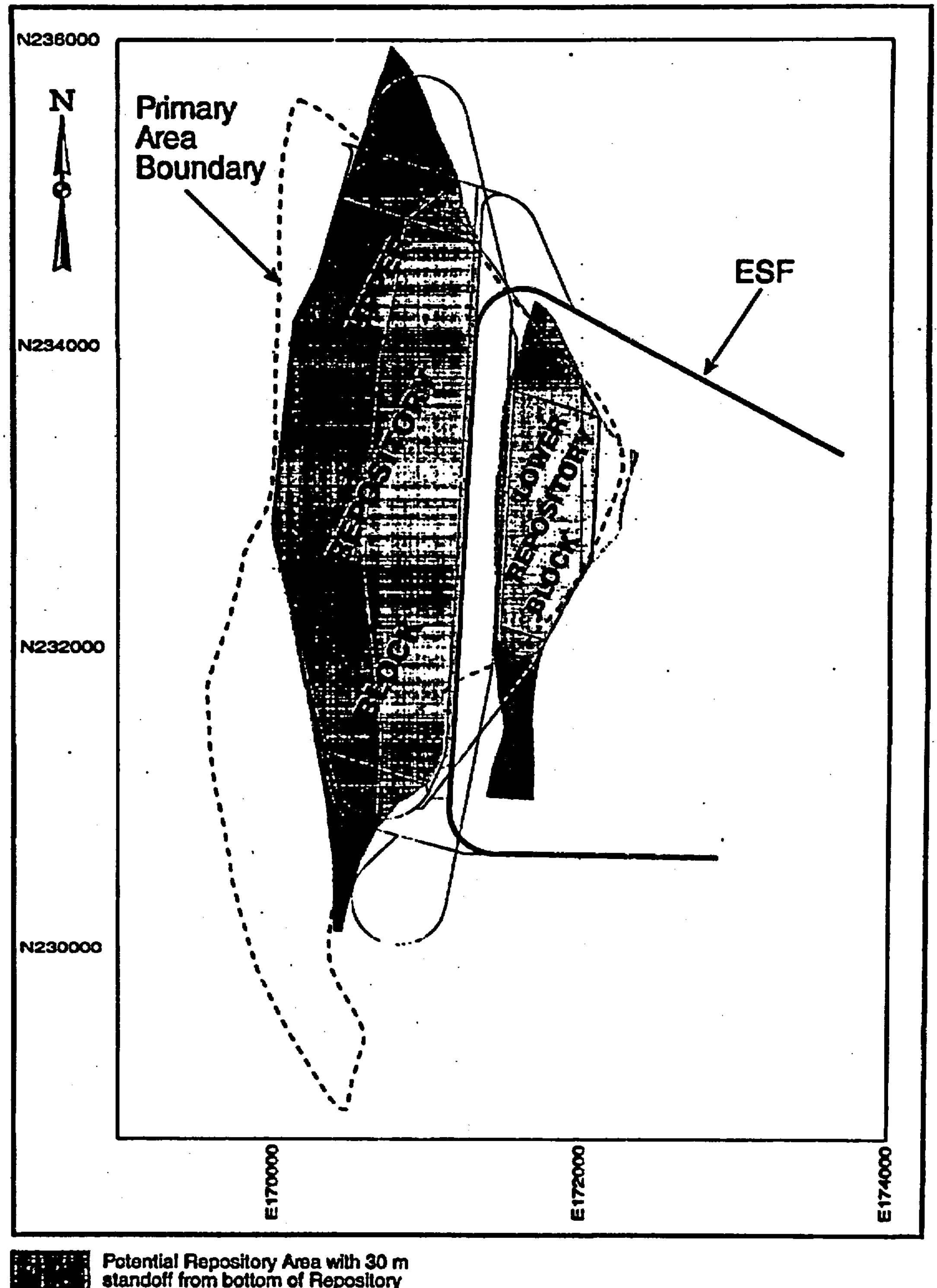

Figure 8.1.4-1. Potential Repository Areas Showing ESF and Repository Layout

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8.2 THERMAL CONSIDERATIONS

This section contains discussion of the thermal considerations inherent in the design, construction, operation, closure, and long term performance of a high-level nuclear waste repository. The currently projected waste package physical characteristics and emplacement schedule is provided, as well as discussion of the various methods of describing thermal loading.

Heat from emplaced nuclear waste increases rock and air temperatures in repository openings and in the surrounding rock mass and leads to the following considerations for design:

- Thermal loading selection – magnitude of the areal thermal load determines waste package emplacement density which in turn is a major factor in repository layout size and configuration.

- Operations planning – repository operations, such as ventilation, monitoring, maintenance, and retrieval, are affected by the temperature and moisture content of the air and rock.

- Materials behavior – the amount of humidity and the magnitude and rate of heating affect the corrosion of structural components (e.g., waste packages and ground support) placed in the openings.

- Opening behavior – opening and ground support deformation, especially for emplacement drifts, as well as large scale deformation of the surrounding rock mass, are affected by thermomechanical effects due to emplaced waste.

- Rock as a natural barrier – the long-term ability of the host rock mass to retard radionuclide migration is affected by mineralogical and hydrological changes due to heating.

Determination of the effects of heating and cooling on design components requires the development of criteria, the performance of design analyses, in situ testing and monitoring, and the development of appropriate methods of operation in a high temperature environment. These factors are discussed in the following or reference is given to relevant sections of the report.

8.2.1 Previous Work

Thermal considerations were addressed in Section 8.3 of the *Initial Summary Report for Repository/Waste Package Advanced Conceptual Design* (CRWMS M&O 1994a). Included in that discussion were *Site Characterization Plan, Yucca Mountain Site, Nevada Research and Development Area, Nevada* (SCP) (DOE 1988a) thermal goals, concepts for thermal loading, waste package standoff from accesses, thermomechanical effects on openings, and the use of thermohydrologic models.

A thermal loading study, *Thermal Loading Study for FY 1995*, (CRWMS M&O 1995ac) provided recommendations for the thermal testing of such parameters as rock mass gas and liquid permeability and thermal conductivity. In addition, the study evaluated various thermal management issues including ventilation analysis, optional areas for repository expansion, increasing thermal loads at repository edges to more evenly distribute heat, waste stream variability, and the effects of allowing spent fuel to age prior to emplacement.

8.2.2 Design Inputs

Significant design inputs for consideration of thermal aspects of repository design include project requirements and acceptability criteria for temperatures and temperature-induced effects. These inputs are listed below.

8.2.2.1 Requirements

The following requirements relating to thermal testing, thermal analysis, and thermal load are quoted directly from the *Repository Design Requirements Document* (RDRD) (YMP 1994a).

3.2.1.1 CONSTRUCTION MODE REQUIREMENTS

A. During the early or developmental stages of construction, a program for in situ testing of such features as borehole and shaft seals, backfill, and the thermal interaction effects of the waste packages, backfill, rock, and groundwater shall be conducted.

3.2.3.2.2 REPOSITORY SEGMENT – ENGINEERED BARRIER SEGMENT INTERFACE

A.3. Performance confirmation testing interfaces will incorporate the following requirements:

a) Thermomechanical Response. Waste emplacement methods and configurations shall permit in situ monitoring of the thermomechanical response of the emplacement areas until permanent closure to ensure that the performance of the natural and engineering features are within design limits.

A.11. b) The layout shall also ensure that the design limit temperatures [TBD] for waste forms are not exceeded.

3.2.6.1 NATURAL ENVIRONMENT

GROA [Geologic Repository Operations Area] SSCs [systems, structures, and components] important to safety shall be designed so that the effects of anticipated natural phenomena and environmental conditions will not interfere with necessary safety functions.

I. Thermal Analysis. The design of structures shall include the effects of stresses and movements resulting from variations in temperature, including the effect of emplaced waste packages. The rise and fall in the temperature must be determined for the localities in which the structures are to be built. Structures must be designed for movements resulting from the maximum seasonal temperature change. The design must provide for the lags between air temperatures and the interior temperatures of massive concrete members or structures. In cable-supported structures, changes in cable sag and tension must be considered.

3.7.5 REPOSITORY UNDERGROUND REQUIREMENTS

E. Underground Openings.

7. 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, and groundwater system.

P. Emplacement Area.

1. Emplacement drift spacing shall consider the heat load as indicated by thermal analysis related to the thermal characteristics of the waste over the life of the repository.

3.7.6 PERFORMANCE CONFIRMATION REQUIREMENTS

C. Rock Measurements. The Repository Segment shall be capable of measuring, as a minimum, rock deformations and displacement, changes in rock stress and strain, rate and location of water inflow into underground areas, changes in groundwater conditions, rock pore water pressures, including those along fractures and joints, and the thermal and thermomechanical response of the rock mass as a result of development and operations of the geologic repository.

D. Thermomechanical Response. The Repository Segment shall be capable of in situ monitoring of the thermomechanical response of the underground facility until permanent closure to ensure that the performance of the natural and engineering features are within design limits.

8.2.2.2 Assumptions

Current design assumptions, listed in the CDA Document (CRWMS M&O 1995a) that relate to thermal considerations for repository design are stated below. Only the wording of the basic assumption is given. Refer to the CDA Document (CRWMS M&O 1995a) for background and rationale. These assumptions are used for guidance in performing current conceptual design work and will be substantiated, modified, or dropped before becoming requirements for design.

Eight of the assumptions listed here describe the SCP (DOE 1988a) thermal goals which, although tentative, have become important criteria for repository design. These thermal goals are also given in Table 8.2-1 along with the affected design activities. Thermal goals were established in the SCP (DOE 1988a) to minimize the possible effects of temperature and temperature-induced displacement on the repository host rock. Limits were set initially for waste package emplacement in vertical boreholes. Since that time, in-drift emplacement to accommodate larger waste packages and the proposed application of high thermal loads have led to a revaluation of the goals, for which details and rationale can be found in an M&O report (CRWMS M&O 1993c) and in the *Initial Summary Report for Repository/Waste Package Advanced Conceptual Design* (CRWMS M&O 1994a).

Key Assumptions

Key 019: Surface, subsurface and waste package designs will be based on a reference thermal load of 80-100 MTU per acre. The reference thermal load for this MGDS ACD Report is 83 MTU/acre.

Requirements Assumptions (*Engineered Barrier Design Requirements Document* [EBDRD])

EBDRD 3.7.G.2

G. To limit the predicted thermal and thermomechanical response of the host rock and surrounding strata and groundwater system, the EBS configuration and loading shall:

2. Keep emplacement drift wall temperatures < 200°C.

EBDRD 3.7.G.3

G. To limit the thermal and thermomechanical response of the host rock and surrounding strata and groundwater system, the EBS configuration and loading shall:

3. Limit the TSw3 (basal vitrophyre) maximum temperature to less than 115°C.

EBDRD 3.7.G.4

G. To limit the thermal and thermomechanical response of the host rock and surrounding strata and groundwater system, the EBS configuration and loading shall:

4. Limit the maximum ground surface temperature change in the vicinity of the repository to 2°C.

Table 8.2-1. Thermal Goals For MGDS ACD

Thermal Goals for MGDS ACD			
CDA Assumption	SCP Issue	Thermal Goal	Affected Design Activity
DCSS 025	(1)* Limit chemical and physical effects detrimental to waste isolation	Temperature limit of CHn unit <115°C	Definition of repository layout (Section 8.1)
EBDRD 3.7.G.3	(2) Limit chemical and physical effects detrimental to waste isolation	Temperature limit at top of TSw3 <115°C	Definition of repository layout (Section 8.1)
DCSS 030	(3) Limit deleterious rock movement or preferred pathways	Displacement limit of top of TSw1 unit <1 m	Thermomechanical analysis for drift stability (Appendix B)
EBDRD 3.7.G.4	(4) Limit impact on surface environment	Temperature change limit at ground surface <2° C	Definition of repository layout (Section 8.1)
DCSS 030	(5) Limit impact on surface environment	Uplift limit of ground surface <0.5 cm/yr	Definition of repository layout (Section 8.1)
DCSS 023, EBDRD 3.7.G.2	(8) Prevent thermally-induced rock failure	Temperature limit of emplacement drift wall rock <200° C	Thermomechanical analysis for drift stability (Appendix B)
DCSS 023	(13) Provide an appropriate operational environment	Temperature limit of main access wall rock <50° C	Planning subsurface operations (Sect. 8.5 and 9.)
DCSS 031	(16) Limit chemical and physical effects detrimental to waste isolation	Temperature limit of PTn unit <115°C	Definition of repository layout (Section 8.1)

* Thermal goal number (see Table 8.3.1-1, CRWMS M&O, 1994a)
SCP = *Site Characterization Plan, Yucca Mountain Site, Nevada Research and Development Area, Nevada* (DOE 1988a)

Design Concept Subsurface Assumptions

DCSS 023: Maximum allowable preclosure rock surface temperature in:

Shafts:	35°C – unventilated
Ramps:	35°C – unventilated
Mains:	50°C
Emplacement Drifts:	200°C

DCSS 025: Maximum allowable temperature within CHn: 115°C

DCSS 030: Limit surface uplift to less than 0.5 cm/yr and relative motion of the top of TSw1 to less than 1 m with no intact rock failure and no continuous joint slip.

DCSS 031: Limit temperatures in PTn (Upper Paint Brush non-welded) to less than 115°C.

8.2.3 Thermal Loading Considerations

Thermal Loading Strategy

The final thermal loading value for the repository has not yet been determined. The strategy being executed by the program to reach closure on this issue involves the following actions and features.

- Establish "Thermal Goals" for the repository. These goals take the form of maximum allowable temperatures at various points in and around the repository emplacement areas. Section 8.2.3 contains a discussion of these goals. The goals are intended to either prevent deleterious temperature-induced changes in the rock (such as the 200°C emplacement drift wall rock goal), or to help maintain reasonable working conditions during preclosure (such as the 50°C main drift temperature goal.)

- Set reference thermal loading which meets these goals. An areal mass loading of 83 MTU/acre has been used for the ACD, and all thermal goals can be met with this loading.

- Maintain design and operations flexibility to adjust the thermal loading. The design contains a great deal of inherent flexibility. The use of railcar emplacement coupled with possible adjustment of emplacement drift spacing allows a wide range of thermal loading to be achieved. Potentially useable additional area outside the primary emplacement area has been identified for use if required.

- Acquire needed site information to validate or change the reference thermal load. Thermal testing is to be conducted in the ESF. This thermal testing will provide direct input to the thermal loading issue, and should increase confidence that our understanding of the thermally-induced effects is correct.

- Adjust as indicated. As noted above, the design has a great deal of flexibility for adjustment of the thermal load. If new site information indicates that adjustment of the thermal load is needed, it can be readily accommodated.

Thermal Loading Methods

Heat output between individual waste packages can vary widely depending on the type of spent fuel and characteristics such as age and burnup (see Waste Emplacement Considerations, Section 8.2.7). Depending on how waste packages are spatially arranged in the repository, large differences in heat output could result in large variations in rock temperature, displacement, and stress. Such variations could produce instability in the rock surrounding emplacement drifts. Uneven heating may also result in uneven cooling which may have undesirable effects on postclosure repository performance. Because of these concerns, three different methods have been considered for determining waste package spacing in an effort to produce a more uniform areal heating of the rock mass for both preclosure and postclosure.

The three different thermal loading schemes used to achieve uniform areal heating are areal power density, areal mass loading (AML), and equivalent energy density (EED). Characteristics of these approaches are discussed and illustrated in Section 8.2.8 , Emplacement Methodology. As explained in that section, the approach used for the MGDS ACD Report is that waste packages are emplaced by the AML approach, according to their MTU or metric tons of uranium content. For design, the thermal loading currently under consideration is the range from 80 to 100 MTU/acre. A value of 83 MTU/acre has been specified as a reference value for this design description (CRWMS M&O 1995a, Key 019).

Modifications of the use of a single thermal loading density have been considered to establish more uniform temperature conditions. One approach is expressed in thermal evaluations performed by Lawrence Livermore National Laboratory (*Evaluation of Thermo-Hydrological Performance in Support of the Thermal Loading Systems Study* [LLNL 1994]) for a higher thermal load repository that suggests that it may be desirable to vary the emplacement density so that higher thermal loads exist at the edges of the emplacement area (relative to the center) in order to mitigate effects associated with edge cooling. Another consideration is the intermingling of hot and cool waste (i.e., waste packages of different waste types, quantities, and thermal characteristics) in the emplacement drifts to achieve a more uniform temperature distribution. However, neither of these approaches is part of the current ACD design approach which is that waste packages will be emplaced essentially in the order received (Section 8.2.8).

8.2.4 Heating of Emplacement Drifts

Principal considerations regarding heat generated in emplacement drifts are the:

- Magnitude and distribution of temperature relative to the thermal goals stated in Section 8.2.2.2

- Effect of elevated temperature on material properties

- Effects of thermally-induced mechanical loads on rock mass and ground support stability.

Depending on mechanical loads and temperature, the thermal loading can be modified to reduce or increase temperature by changing drift and waste package spacings.

Mechanical loads resulting from temperature changes are discussed in Section 8.5, and supporting analyses are presented in Appendix B. Material behavior resulting from temperature changes is summarized in Section 8.5 and evaluated in Appendix C. Calculations of temperature magnitudes and distributions, which provide input to the analysis of mechanical loads and their effect on rock behavior and ground support components around the drift, are discussed in the following.

Figure 8.2.4-1 is a three-dimensional model of temperature distributions for center-in-drift (CID) emplacement (see Section 8.6 for discussion of waste package emplacement) for a thermal loading of 83 MTU/acre. Results indicate that rock temperatures remain well above the boiling point of water at the repository elevation (95°C) but below the limiting temperature of 200°C. Maximum drift rock surface temperatures of 155°C for CID and 153°C for off-center in-drift (OCID) are reached between 46 and 63 years after emplacement and decrease only a few degrees over the remainder of the 100 year-duration shown. As indicated by previous analysis (CRWMS M&O 1995ad), the gradual decrease in temperature continues throughout the preclosure lifetime of 150 years. The larger diameter of OCID results in slightly lower wall temperatures (see Table 8.2-2).

Results of the three-dimensional modeling for OCID emplacement show that wall temperatures nearest the waste package are about 6° higher than at the opposite wall (Table 8.2-2). The temperature of the wall at the waste package midpoint is about 10°C greater than at the midpoint between adjacent waste packages (not shown). Overall, however, temperatures are symmetrically distributed, in a manner similar to the distribution for the center in-drift emplacement mode.

Table 8.2-2. Maximum Rock Temperatures for In-Drift Emplacement (Three-Dimensional Model)

Emplacement Mode/Drift Size	Years After Emplacement	Floor (°C)	Right Sidewall (°C)	Left Sidewall (°C)	Crown (°C)
In-center/5.0-m	46 to 54	152	155	155	152
Off-center/5.5-m	52 to 63	147	153	147	147

8.2.5 Heating of Non-Emplacement Openings

Openings adjacent to emplacement areas, such as the East Main, Upper Block TBM (tunnel boring machine) Launch Main, and the Upper Block Exhaust Main, will experience moderate temperature increases (unventilated) to 44°C, 66°C, and 93°C at 100 years for 83 MTU/acre (see Section 8.7.6.2). Changes in thermally-induced mechanical rock loads will be less than those predicted for emplacement drifts and approximately proportional to the temperature change.

In order to limit temperature changes in the affected drifts, a thermal buffer, or "standoff distance" has been established and is defined as the distance that waste packages are set back from the nearest access. This is considered important in terms of establishing a working environment in these drifts and in controlling the influence that elevated temperatures might have on the stability of the drift. While few studies have been performed to determine appropriate standoffs as a function of thermal loading, the M&O *Initial Summary Report for Repository/Waste Package Advanced Conceptual Design* (CRWMS M&O 1994a) selected a value of 35 m as the distance from the centerline of the closest waste package to the nearest access drift wall. The cooling effect of ventilation air in the access drift is not considered in establishing standoff. See Section 8.7.6.2 for a discussion of standoff.

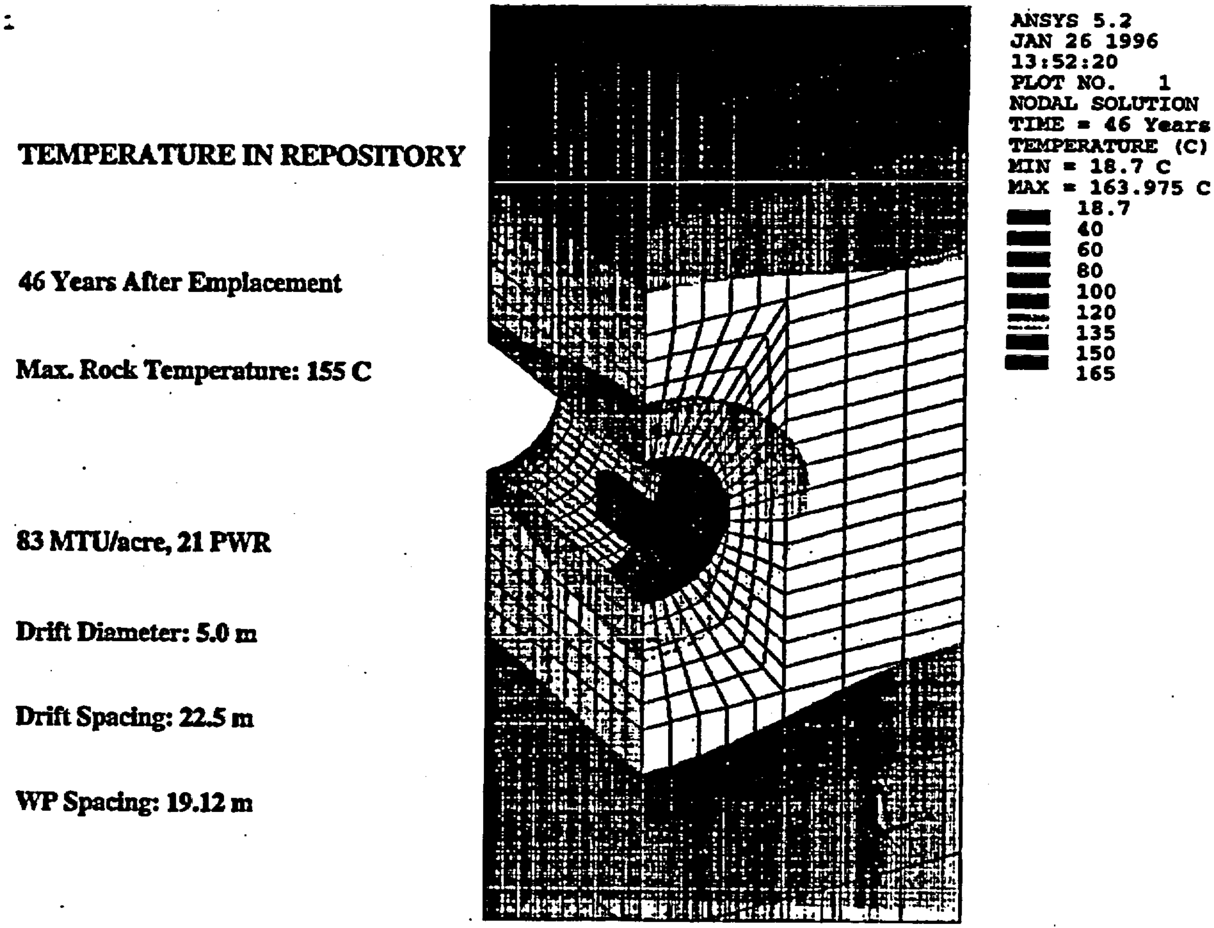

Figure 8.2.4-1. Three-Dimensional Model of Temperature Distributions for Center-In-Drift Emplacement for a Thermal Loading of 83 MTU/acre

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8.2.6 Rock Mass Hydrothermal Effects

Broad (Repository-scale) and local (drift-scale) models, as discussed in the *Initial Summary Report for Repository/Waste Package Advanced Conceptual Design* (CRWMS M&O 1994a), have been used to simulate heat and fluid flow and to provide predictions for the planning of thermal tests. The principal application of this work is the evaluation of potential movement of radionuclides, which is of concern for the assessment of repository performance during postclosure but is not addressed in this volume.

8.2.7 Waste Emplacement Considerations

8.2.7.1 The Waste Package Inventory

This section contains discussion of the projected schedule and characteristics of waste package receipt and emplacement. Waste packages of several different sizes and weights will be emplaced over a 24-year period. A total of 70,000 MTUs or equivalent is scheduled to be handled at the surface facility and emplaced underground.

8.2.7.1.1 Waste Stream

The waste package emplacement schedule for the repository is shown in Table 8.2.7-1 (and also in Table 4-4). This waste stream is based on an "Oldest Fuel First" or OFF waste acceptance strategy. It is assumed that waste will be emplaced in the repository at the same rate as it is received, and that there will be no significant surface lag storage capability. The waste emplacement schedule also assumes the receipt and disposal of canistered spent fuel at the repository.

It is important to note that the waste stream described here is based on an Oldest Fuel First (OFF) waste acceptance strategy. OFF implies that, as each utility ships spent nuclear fuel (SNF) to DOE, the oldest (i.e., longest elapsed time since removal from the reactor) SNF available at that time is shipped. The values shown in Tables 8.2.7-2 and 8.2.7-3 are annual averages for each waste package type based on OFF acceptance. This is in contrast to the "design basis" SNF characteristics discussed in Volume III. Waste package design is performed for fuel characteristics that are more severe than the average values on which the tables in this section are based.

8.2.7.1.2 Waste Package Types and Sizes

Each of the eight package types is summarized below:

21 Pressurized Water Reactor (PWR) Spent Fuel Assembly (SFA) Canister Waste Package ("P-LG" in Table 8.2.7-1)

Table 8.2.7-1. Number of Packages Received for Disposal Each Year
(OFF Waste Acceptance)

YEAR	B-LWT	P-LWT	B-LG	P-LG	B-SM	P-SM	B-IN-P	DHLW	TOTAL PACKAGES
2010	1	1	24	12	11	5			54
2011		5	20	21	43	26	2		117
2012	1	12	28	61	80	22	1		205
2013		10	63	116	88	31	2		310
2014		14	120	163	87	34	4		422
2015	1	10	88	179	111	43	3	199	634
2016		13	100	190	76	36	3	202	620
2017		10	106	189	87	34	2	200	628
2018		8	98	212	62	28	4	200	612
2019		10	101	196	54	37	1	199	598
2020		5	98	206	46	46	2	200	603
2021		7	102	193	72	29	2	200	605
2022		10	105	211	39	40	2	200	607
2023		5	113	187	59	37	3	202	606
2024		6	116	204	62	18	1	200	607
2025		5	86	210	61	38	0	200	600
2026		9	111	201	40	29	8	199	597
2027		2	119	202	63	28		200	614
2028		9	100	206	47	40		200	602
2029		6	98	205	74	33		200	616
2030		7	123	191	56	41		47	465
2031		4	139	185	49	33		109	519
2032		10	115	182	84	34		102	527
2033		4	69	119	54	23			269
TOTALS	3	182	2242	4041	1505	765	40	3259	12037

"B-LWT": BWR SF SHIPPED VIA LEGAL WEIGHT TRUCK - BARE SFA WP
"P-LWT": PWR SF SHIPPED VIA LEGAL WEIGHT TRUCK - BARE SFA WP
"B-LG": BWR SF SHIPPED IN LARGE (40 ASSEMBLY) BWR SFA CANISTER
"P-LG": PWR SF SHIPPED IN LARGE (21 ASSEMBLY) PWR SFA CANISTER
"B-SM": BWR SF SHIPPED IN SMALL (24 ASSEMBLY) BWR SFA CANISTER
"P-SM": PWR SF SHIPPED IN SMALL (12 ASSEMBLY) PWR SFA CANISTER
"B-IN-P": LARGE BWR FUEL PLACED IN SMALL PWR BARE SFA WP

Table 8.2.7-2. Average MTU/Package Received for Disposal Each Year (OFF Waste Acceptance)

YEAR	B-LWT	P-LWT	B-LG	P-LG	B-SM	P-SM	B-IN-P	DHLW	TOTAL MTU/YEAR
2010	0.06	8.25	7.45	8.05	2.08	3.94			326
2011		6.66	6.94	8.26	3.94	4.97	1.63		647
2012	0.59	6.48	7.4	8.46	4.04	4.4	1.64		1223
2013		8.85	7.3	8.7	3.88	4.31	1.6		2036
2014		8.96	7.41	8.88	4.35	4.83	1.57		3011
2015	0.38	8.93	7.25	8.87	4.21	4.79	1.52	2.15	3421
2016		9.09	7.28	8.81	4.31	4.61	1.64	2.15	3453
2017		8.95	7.11	8.91	4.22	4.67	1.65	2.15	3486
2018		9.2	7.07	8.74	4.37	4.58	1.56	2.15	3455
2019		8.8	6.98	8.96	4.37	4.81	1.59	2.15	3393
2020		8.88	7.08	8.95	4.51	4.47	1.59	2.15	3428
2021		8.94	7.06	8.86	4.28	4.93	1.59	2.15	3377
2022		8.94	7.08	8.87	4.27	4.97	1.59	2.15	3503
2023		8.78	6.99	8.85	4.21	4.95	1.58	2.15	3359
2024		8.71	7.09	8.83	4.27	4.94	1.61	2.15	3461
2025		8.84	6.92	8.92	4.2	4.94		2.15	3386
2026		8.87	7.06	8.87	4.16	4.99	1.53	2.15	3398
2027		8.23	6.86	8.92	4.18	4.64		2.15	3458
2028		8.65	7.03	8.8	4.19	4.68		2.15	3408
2029		8.02	6.95	8.72	4.05	4.64		2.15	3400
2030		8.34	6.89	8.85	4.2	4.17		2.15	3103
2031		7.97	6.88	8.71	4.2	4.56		2.15	3190
2032		7.99	7.17	8.62	4.16	4.41		2.15	3192
2033		6.97	7.01	8.87	4.12	4.26			1885
	1.03	8.61	7.07	8.83	4.18	4.67	1.57	2.15	70000

Table 8.2.7-3. Initial Heat Output (kW/Pkg) Received for Disposal Each Year
(OFF Waste Acceptance)

YEAR	B-LWT	P-LWT	B-LG	P-LG	B-SM	P-SM	B-IN-P	* DHLW	TOTAL HEAT OUPUT
2010	0.03	4.84	0.97	3.1	0.67	1.84			82
2011		3.82	3.68	6.11	2.17	2.5	0.43		381
2012	0.19	2.96	3.9	8.63	1.89	2.32	0.65		674
2013		5.77	4.3	8.44	1.96	2.37	0.67		1555
2014		6.53	4.25	8.12	2.67	2.83	0.72		2260
2015	0.23	6.88	4.71	9.16	3.29	3.24	0.81	1.5	2929
2016		7.38	6.2	9.16	3.48	3.32	0.75	1.5	3049
2017		7.88	7.18	9.22	3.61	3.84	0.82	1.5	3329
2018		8.35	8.21	9.37	3.3	4.47	0.83	1.5	3491
2019		8.61	7.89	9	2.96	5.34	0.86	1.5	3314
2020		8.67	8.2	8.92	1.91	4.58	0.82	1.5	3285
2021		9.5	7.69	8.43	3.31	5.63	0.86	1.5	3181
2022		11.4	7.76	9.16	2.67	6.04	0.89	1.5	3469
2023		10.6	8.23	9.22	3.61	6.45	0.92	1.5	3422
2024		12.4	7.5	9.56	3.45	7	0.93	1.5	3535
2025		12.1	8.47	9.52	3.77	5.92	0.7	1.5	3543
2026		12	7.8	9.23	4.31	6.74		1.5	3495
2027		7.37	8.81	9.46	4.19	6.86		1.5	3730
2028		12.5	6.74	9.42	4.21	6.71		1.5	3493
2029		10.8	7.55	9.89	3.73	7.26		1.5	3648
2030		9.73	6.94	9.57	4.51	6.42		1.5	3336
2031		12	6.38	9.27	4.59	6.18		1.5	3242
2032		7.73	4.8	9.73	3.87	6.4		1.5	3096
2033		13.2	6.35	10.3	3.46	7.97			2067
TOTAL KW	0.5	1564	15284	37216	4948	3902	25	4889	67825
AVE/PKG	0.15	8.69	6.82	9.21	3.29	6.10	0.82	1.60	5.63

* DHLW HEAT OUTPUT ESTIMATED

The 21 PWR SFA canister waste package is the largest and heaviest waste package, and has the highest heat output at the time of emplacement. It also represents the single largest segment of the waste package inventory, making up 33.6 percent of the total number of waste packages and occupying slightly over 50 percent of the emplacement area in the repository. For these reasons, the 21 PWR SFA canister waste package has been used as the "design" waste package. Its size and weight have been used as the design parameters for transportation and emplacement equipment design, its size is used in developing the emplacement drift geometry, and its heat output is used in modeling the effects of heat on the emplacement drift environment.

The 21 PWR SFA canister waste package has the following physical characteristics:

Overall Length	=	5682 mm (see Volume III, Appendix B)
Overall Diameter	=	1802 mm (see Volume III, Appendix B)
Loaded Weight	=	65,900 kilograms (see Volume III, Appendix B)
Average Waste Content	=	8.83 MTU (CRWMS M&O 1995ae)
Average heat output at emplacement	=	9.21 kilowatts (CRWMS M&O 1995af)

40 Boiling Water Reactor (BWR) SFA Canister Waste Package ("B-LG" in Table 8.2.7-1)

The 40 BWR SFA canister waste package is the same physical size as the 21 SFA canister waste package. It is slightly lighter, and contains an average of 7.07 MTU/waste package. The 40 BWR SFA canister waste package inventory makes up about 18.6 percent of the waste package inventory, and will occupy approximately 22.5 percent of the emplacement area.

The 40 BWR SFA canister waste package has the following physical characteristics:

Overall Length	=	5682 mm (see Volume III, Appendix B)
Overall Diameter	=	1802 mm (see Volume III, Appendix B)
Loaded Weight	=	65,463 kilograms (see Volume III, Appendix B)
Average waste content	=	7.07 MTU (CRWMS M&O 1995ae))
Average heat output at emplacement	=	6.82 kilowatts (CRWMS M&O 1995af)

12 PWR SFA Canister Waste Package ("P-SM" in Table 8.2.7-1)

The small PWR SFA canister waste packages are virtually the same length as the larger packages, but are smaller in diameter and considerably lighter. This package type makes up 6.4 percent of the total package count, and occupies 5.1 percent of the repository's emplacement area.

The 12 PWR SFA canister waste package has the following physical characteristics:

Overall Length	=	5647 mm (see Volume III, Appendix B)
Overall Diameter	=	1531 mm (see Volume III, Appendix B)
Loaded Weight	=	47,752 kilograms (see Volume III, Appendix B)
Average waste content	=	4.67 MTU (CRWMS M&O 1995ae)
Average heat output at emplacement	=	5.10 kilowatts (CRWMS M&O 1995af)

24 BWR SFA Canister Waste Package ("B-SM" in Table 8.2.7-1)

The 24 BWR SFA canister waste package has the same physical dimensions as the 12 PWR SFA canister waste package, but is slightly lighter. It represents 12.5 percent of the waste package inventory and occupies approximately 8.9 percent of the emplacement area.

The 24 BWR SFA canister waste package has the following physical characteristics:

Overall Length	=	5647 mm (see Volume III, Appendix B)
Overall Diameter	=	1531 mm (see Volume III, Appendix B)
Loaded Weight	=	47,089 kilograms (see Volume III, Appendix B)
Average waste content	=	4.18 MTU (CRWMS M&O 1995ae)
Average heat output at emplacement	=	3.29 kilowatts (CRWMS M&O 1995af)

21 PWR Bare SFA Waste Package ("P-LWT" on Table 8.2.7-1)

A small portion of the spent fuel inventory will come to the repository without first being placed in a canister. This fuel will be placed in a disposal container in the surface Waste Handling Building (WHB). These PWR bare SFA waste packages will be shorter, smaller in diameter, and considerably lighter than the SFA canister waste packages. The 21 PWR bare SFA waste package will make up about 1.5 percent of the package count, and occupy approximately 2.2 percent of the emplacement area.

The 21 PWR bare SFA waste package has the following physical characteristics:

Overall Length	=	5335 mm (see Volume III, Appendix B)
Overall Diameter	=	1629 mm (see Volume III, Appendix B)
Loaded Weight	=	47,797 kilograms (see Volume III, Appendix B)

Average waste content	=	8.51 MTU (CRWMS M&O 1995ae)
Average heat output at emplacement	=	8.59 kilowatts (CRWMS M&O 1995af)

24 BWR Bare SFA Waste Package ("B-LWT" on Table 8.2.7-1)

A very small quantity of BWR bare SFA will arrive at the repository. The current waste stream information indicates that a total of three packages of this type may be expected.

The 24 BWR bare SFA waste package has the following physical characteristics:

Overall Length	=	5335 mm (see Volume III, Appendix B)
Overall Diameter	=	1265 mm (see Volume III, Appendix B)
Loaded Weight	=	30,394 kilograms (see Volume III, Appendix B)
Average waste content	=	1.03 MTU (CRWMS M&O 1995ae)
Average heat output at emplacement	=	0.15 kilowatts (CRWMS M&O 1995af)

12 PWR Bare SFA Waste Package ("B-in-P" in Table 8.2.7-1)

Fuel from one BWR power station is considerably larger than most BWR fuel. This fuel is assumed to be placed in a PWR Bare SFA waste package for disposal. Approximately 40 packages of this type are expected.

The 12 PWR bare SFA waste package has the following physical characteristics:

Overall Length	=	5335 mm (see Volume III, Appendix B)
Overall Diameter	=	1298 mm (see Volume III, Appendix B)
Loaded Weight	=	32,236 kilograms (see Volume III, Appendix B)
Average waste content	=	1.57 MTU (CRWMS M&O 1995ae)
Average heat output at emplacement	=	0.62 kilowatts (CRWMS M&O 1995af)

Defense High-Level Waste (DHLW in Table 8.2.7-1)

DHLW will come to the repository in a glass matrix contained in "pour canisters." The DHLW is expected to be packaged for disposal with four pour canisters in each waste package. The DHLW waste packages are much shorter than the spent fuel packages, and considerably lighter. The DHLW packages will make up 27.1 percent of the total number of waste packages, and occupy 10.6 percent of the emplacement area.

The DHLW Waste Package has the following physical characteristics:

Overall Length	=	3680 mm (see Volume III, Appendix B)
Overall Diameter	=	1709 mm (see Volume III, Appendix B)
Loaded Weight	=	22,222 kilograms (see Volume III, Appendix B)
Average waste content	=	2.15 MTU
Average heat output at emplacement	=	1.5 kW*

* DHLW heat output estimated

Tables 8.2.7-2 and 8.2.7-3 show the average waste content and initial heat output of each waste package type over each year of the 24 year emplacement schedule. Table 8.2.7-4 shows the length of emplacement drift (at a 22.5 m drift spacing) required during each year of the emplacement operations.

8.2.8 Emplacement Methodology

8.2.8.1 Introduction

The discussion below is intended to point out the differences in thermal results which would be experienced using three different methods for determining waste package spacing. Two of the methods are well known, while a third, though not new, has not been as widely discussed as the other two.

8.2.8.2 Background

High-level nuclear waste produces heat as it decays. At the utilities, this heat output is controlled because the fuel is stored underwater in spent fuel storage pools. In addition to radioactive shielding, underwater storage is necessary to prevent the fuel from overheating, which could result in radioactive releases. After an initial decay period, dry storage becomes feasible and the spent fuel is removed from the pools and put into a dry storage container for disposal. When containers of spent fuel are put in a geologic repository for disposal, they will heat up the surrounding rock. The resulting elevated rock and air temperatures will affect the subsurface environment in a number of ways, including:

- Changes in the stability of the underground opening in which the waste is emplaced
- Changes in the moisture content of the rock and air
- Changes in the accessibility of the waste packages for inspection or retrieval
- Changes in the ability of the host rock to impede the migration of radionuclides
- Changes in corrosion mechanisms and rates, both internal and external to the waste package

Table 8.2.7-4. Length of Emplacement Drift Required for Each Package Type Each Year

LENGTH OF EMPLACEMENT DRIFT REQUIRED FOR EACH PACKAGE TYPE EACH YEAR (METERS)
DRIFT SPACING = 22.5 METERS / THERMAL LOAD = 83 MTU/ACRE

YEAR	B-LWT	P-LWT	B-LG	P-LG	B-SM	P-SM	B-IN-P	DHLW	TOTAL METERS/YEAR	CUM. USAGE
2010	7	18	387	209	81	43	0	0	746	746
2011	0	72	301	376	387	280	15	0	1,411	2,156
2012	7	169	449	1,118	700	210	7	0	2,661	4,817
2013	0	192	897	2,167	740	290	15	0	4,419	9,236
2014	0	272	1,927	3,137	820	356	29	0	6,541	15,777
2015	7	194	1,383	3,441	1,013	446	22	1,031	7,536	23,313
2016	0	256	1,678	3,627	710	360	22	1,046	7,699	30,912
2017	0	194	1,633	3,649	796	344	15	1,036	7,667	38,578
2018	0	159	1,501	4,015	587	278	29	1,036	7,607	46,185
2019	0	191	1,528	3,806	611	386	7	1,031	7,459	53,644
2020	0	96	1,504	3,995	450	446	15	1,036	7,541	61,185
2021	0	136	1,561	3,706	668	310	15	1,036	7,430	68,615
2022	0	194	1,611	4,056	361	431	15	1,036	7,703	76,318
2023	0	95	1,712	3,586	538	397	22	1,046	7,397	83,714
2024	0	113	1,782	3,903	574	193	7	1,036	7,609	91,323
2025	0	96	1,290	4,059	555	407	0	1,036	7,443	98,766
2026	0	173	1,698	3,863	361	314	59	1,031	7,498	106,264
2027	0	36	1,769	3,905	671	282	0	1,036	7,597	113,862
2028	0	169	1,623	3,928	427	406	0	1,036	7,489	121,350
2029	0	104	1,476	3,874	649	332	0	1,036	7,471	128,822
2030	0	127	1,836	3,663	510	370	0	243	6,750	135,571
2031	0	69	2,072	3,492	446	326	0	565	6,970	142,541
2032	0	173	1,787	3,400	757	325	0	528	6,970	149,511
2033	0	60	1,048	2,287	482	212	0	0	4,090	153,602
TOTALS	22	3,356	34,352	77,282	13,673	7,740	294	16,882		
AVE/PKG	7.35	18.44	15.32	19.12	9.08	10.12	7.35	5.18		12.78

NOTE: ADDITIONAL DRIFTING REQUIRED FOR THERMAL BUFFERS AND ACCESS TO CENTRAL EXHAUST DRIFT NOT INCLUDED IN THIS TABLE

2.167 METERS OF DRIFT PER MTU

The density at which the waste packages are emplaced, along with the characteristics of the spent fuel, determine the "areal loading." For a fixed amount of waste, the areal loading, in turn, determines the area of the repository, or if the repository area is fixed, the total amount of waste which can be emplaced.

Areal loading is simply the density (amount per area) at which the waste is emplaced in the repository. It can be computed in at least three different ways. The examples below use 100 MTU/acre, 100 kW/acre, and 122 GJ/m² for comparison purposes only. Table 8.2.8-1 contains a summary of waste package spacings resulting from each of the three emplacement approaches.

8.2.8.3 Areal Power Density

Areal power density (true "thermal" loading) considers only the initial heat output of the packages at the time of emplacement. This is most often expressed in the units kW/acre. For example, if a waste package has an initial heat output of 9.6 kW, and it is emplaced in such a pattern that the package occupies an area of 0.096 acre (waste package spacing x drift spacing), then the resulting area power density is 100 kW/acre.

The problem with this concept is that the area power density is 100 kW/Acre only on the day the waste is first emplaced. After that, as the spent fuel continues to decay, the current area power densities continues to decrease. Compounding the problem is the fact that spent fuel has a wide range of characteristics, which make the rate of change of the heat output vary widely from package to package. An area that was emplaced at a uniform 100 kW/acre on day one will have spots warmer or cooler than the average in just a few years. See Figure 8.2.8-1 for an illustration of this effect.

Table 8.2.8-1. Summary of Waste Package Spacings

Areal Loading Concept	Waste Package Spacings Age of Fuel (Years out of Reactor)			
	10 Years	20 Years	30 Years	40 Years
Area Power Density 100 KW/ACRE	22.3 m	17.3 m	14.4 m	12.2 m
$EED_{(1000)}$ 122 GJ/m²	17.9 m	16.7 m	15.7 m	14.0 m
AML 100 MTU/ACRE	16.0 m	16.0 m	16.0 m	16.0 m

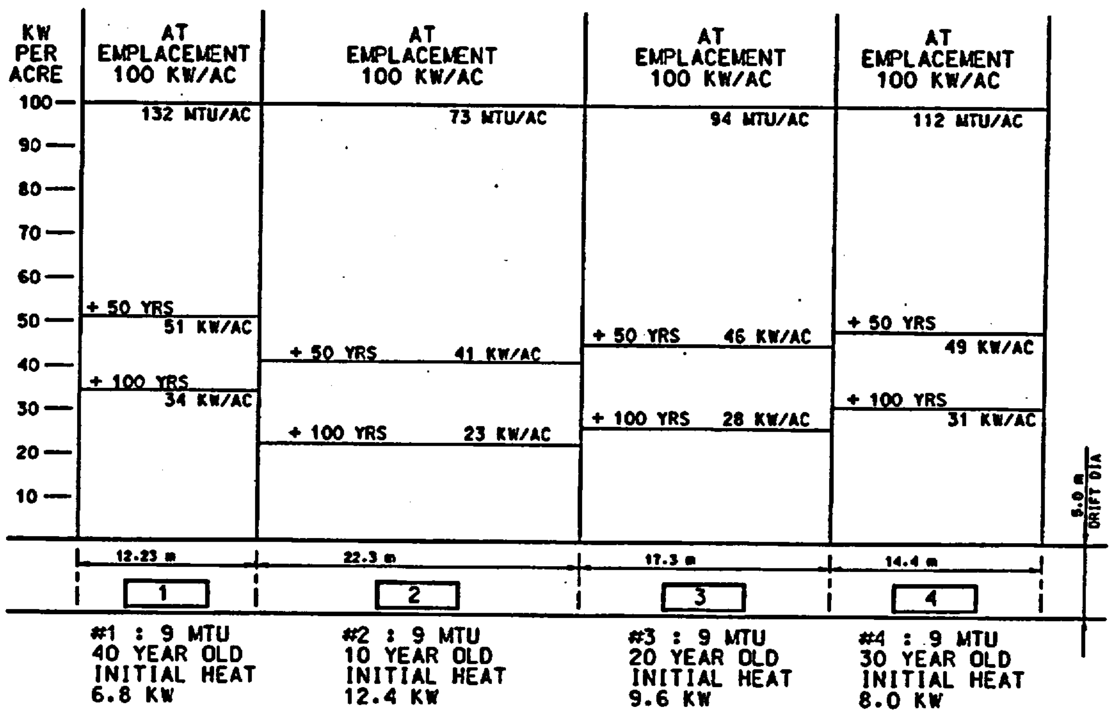

Figure 8.2.8-1. Emplacement at a Uniform 100 kW/acre (All 40 Gwd/MTU Burnup Fuel)

8.2.8.4 Areal Mass Loading

A second method is to emplace by AML. In this method, the packages are allocated space according to the number of MTU they contain. Since the amount of heavy metal in a package does not change with time, the AML never changes. If waste is initially emplaced at 100 MTU/acre, it will always be at 100 MTU/acre. The problem with this method is that it ignores the heat output of the packages. Waste packages containing the same MTU can differ significantly in thermal output. Thus, strict emplacement by AML will lead to initial hot spots and cold spots, but the areal thermal output will become more uniform over time. See Figure 8.2.8-2 for an illustration of the effects of AML.

8.2.8.5 Equivalent Energy Potential Loading

A potential compromise method is to emplace by the "equivalent energy potential" of the packages calculated over a length of time. The equivalent energy potential of a package is the area under the decay curve for the time span chosen. Emplacing by this method could result in a compromise between the area power densities and AML methods called "Equivalent Energy Density." An important factor is the length of time chosen to determine the energy potential. If the time period chosen is short, say 10 years, the package spacings will resemble those of the area power densities method. If the time period chosen is long, say 10,000 years, the spacings will resemble those of the AML method. Usable units for this concept are Gigajoules/square meter (GJ/m^2), and an $EED_{(1000)}$ (1,000 year energy potential) value approximately similar to the above two examples would be about 122 GJ/m^2. See Figure 8.2.8-3 for an illustration of the EED concept.

8.2.8.6 ACD Emplacement Concept

For the purposes of the MGDS ACD Report, the Areal Mass Loading concept is used. Waste packages are assigned emplacement space according to their MTU content, except as noted below. An AML of 83 MTU/acre was used to develop the waste package spacings and the overall required emplacement area of the repository. Table 8.2.7-4 shows the average length of emplacement drift allotted to each waste package type.

No segregation of waste package types is required in the subsurface repository. Packages will be emplaced in the active emplacement drift in the order received. This will result in a somewhat "random" pattern similar to that shown in Figure 8.2.8-4. The spacing between adjacent packages will be a function of their MTU content. The only exception to this will be those spent fuel packages which contain less than approximately 3.3 MTU, and DHLW packages. The spacing for these package types is driven not by MTU content but by the physical space required in the drift for emplacement. Each package is assumed to require a minimum space of its length plus 1.5 m. The 1.5 m minimum allowance between adjacent packages is to provide physical separation for handling, emplacement, and retrieval (if required).

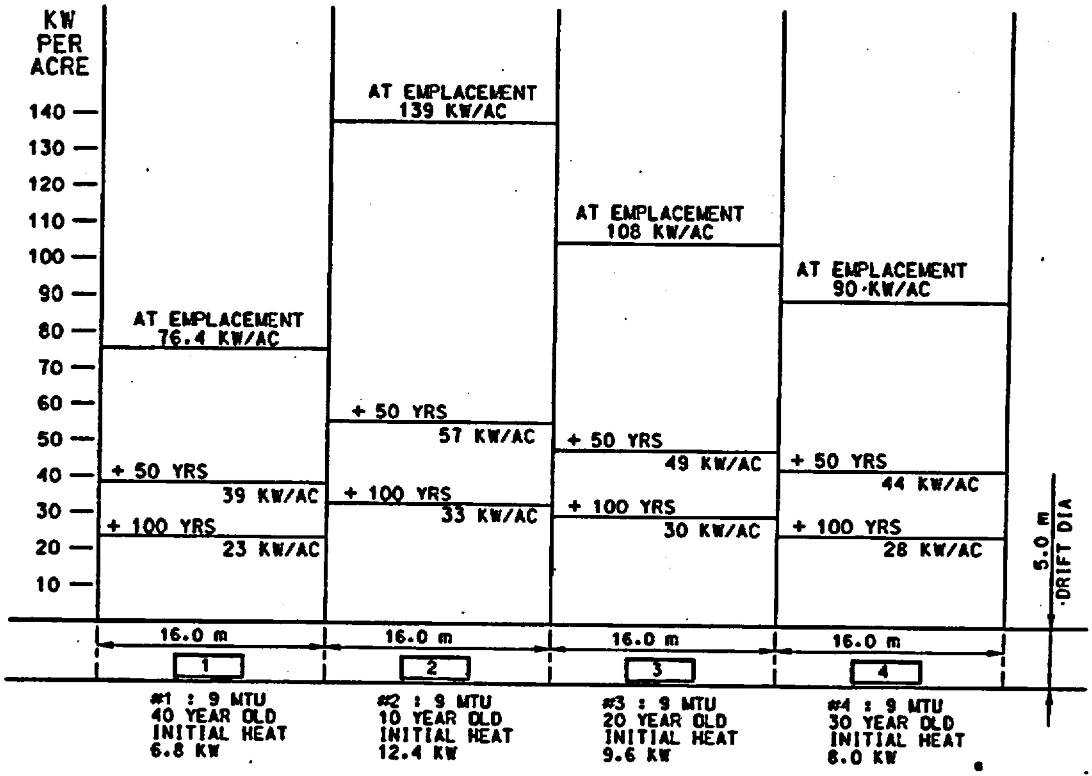

Figure 8.2.8-2. Emplacement at a Uniform 100 MTU/acre
(All 40 Gwd/MTU Burnup Fuel)

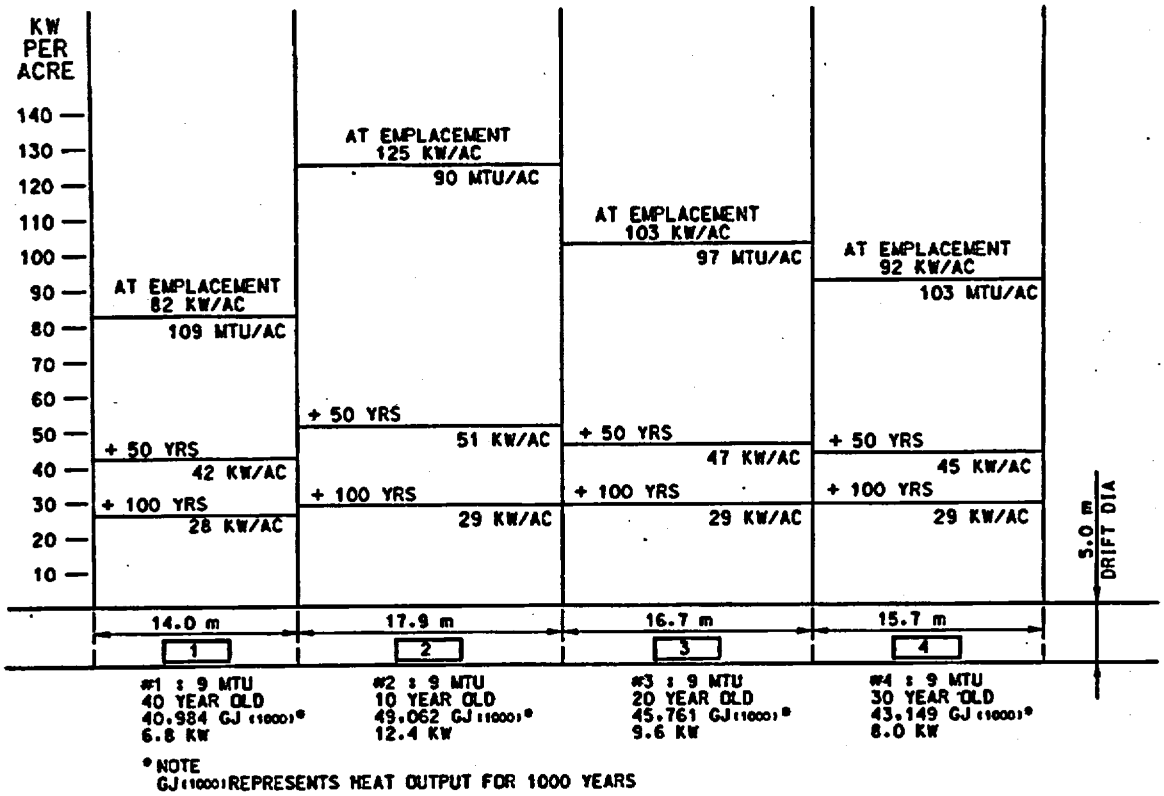

Figure 8.2.8-3. Emplacement at a Uniform 122 GJ/m²
(Based on Energy Potential (1000))

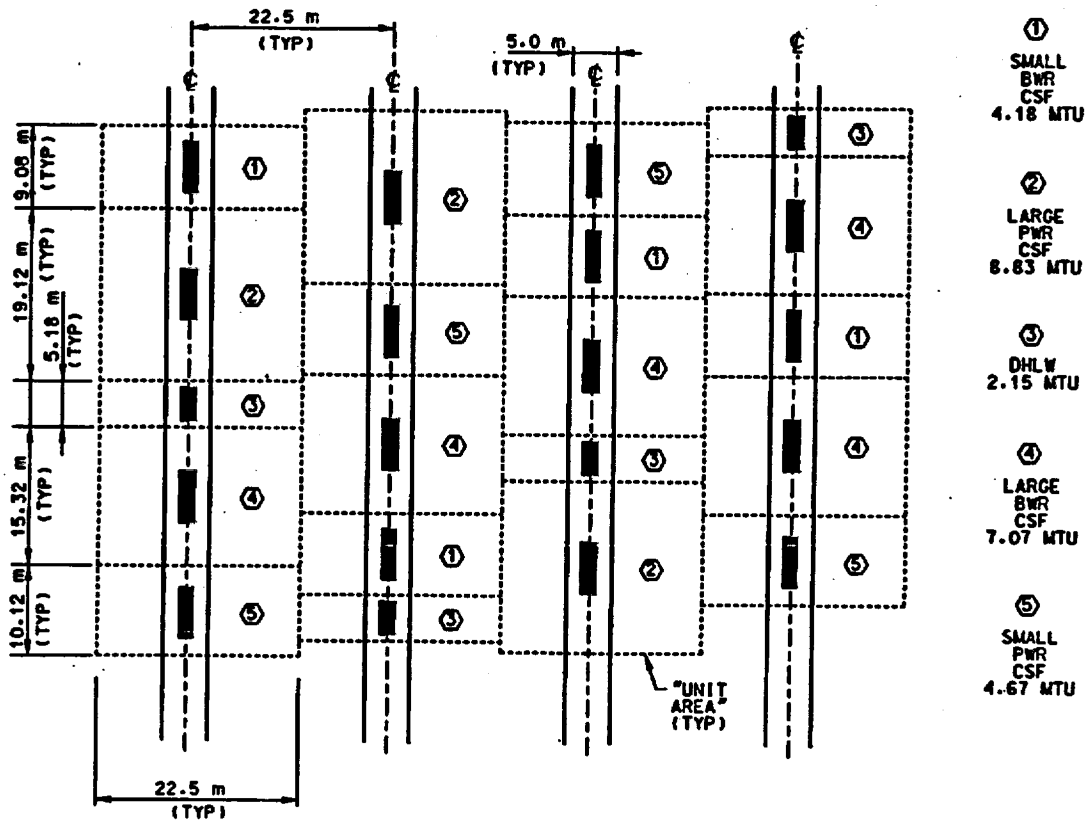

Figure 8.2.8-4. Example of 83 MTU/acre "Emplaced as Received"

8.2.8.7 Emplacement Mode

Emplacement mode refers to the positioning of the waste package relative to the underground opening. Several previous evaluations of this subject have been performed. The most recent, *Emplacement Mode Evaluation Report,* (CRWMS M&O, 1995ag) resulted in the selection of CID (Figure 8.2.8-5) and OCID (Figure 8.2.8-6) over other modes, which included emplacement in short-excavated-alcoves and in short-cross-drifts. The evaluation did not produce a clear preferred option between CID and OCID.

The CID mode has been shown in most design products over the past year and a half. The CID mode requires a nominal 5 m diameter drift. The primary disadvantage of the CID mode is limited access to the drift after emplacement. This is most disadvantageous when considering backfilling of emplacement drifts, and when developing a plan for performance confirmation monitoring.

The current assumption regarding emplacement drift backfill is that it will not be required. However, some long term site performance models suggest that some types of backfill may have significant beneficial effect on the system's performance. The CID mode, when used in a long parallel emplacement drift concept, is not conducive to emplacement of backfill.

Limited drift accessibility after emplacement is also a concern when examining options for drift monitoring after emplacement. A program of performance confirmation is required , and though no requirements have yet been developed, it is likely that options which allow access beside the emplaced waste packages will be considered preferable to those which do not.

Both emplacement modes are discussed in this report. However, it was not considered necessary to duplicate figures to show both options. The OCID option is generally shown in figures, except when a clear difference between the two modes is being demonstrated by showing both.

Volume III of this document, which covers the waste package design, shows CID in the thermal modeling done to assess peak internal temperatures. Due to the slightly larger drift size associated with OCID (5.5 m diameter as opposed to 5.0 for CID) the peak wall rock temperature for identical thermal loads and package power output is slightly lower for OCID than for CID. See Table 8.2-2. This indicates that thermal modeling done based on CID will be slightly conservative when the results are applied to OCID.

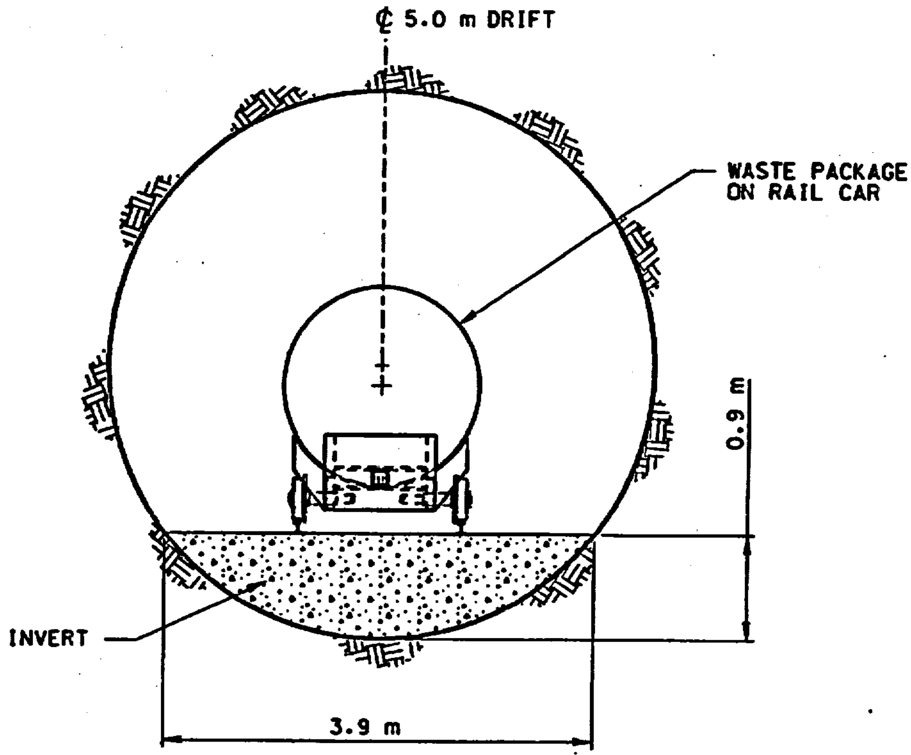

Figure 8.2.8-5. Center In-Drift Emplacement Mode

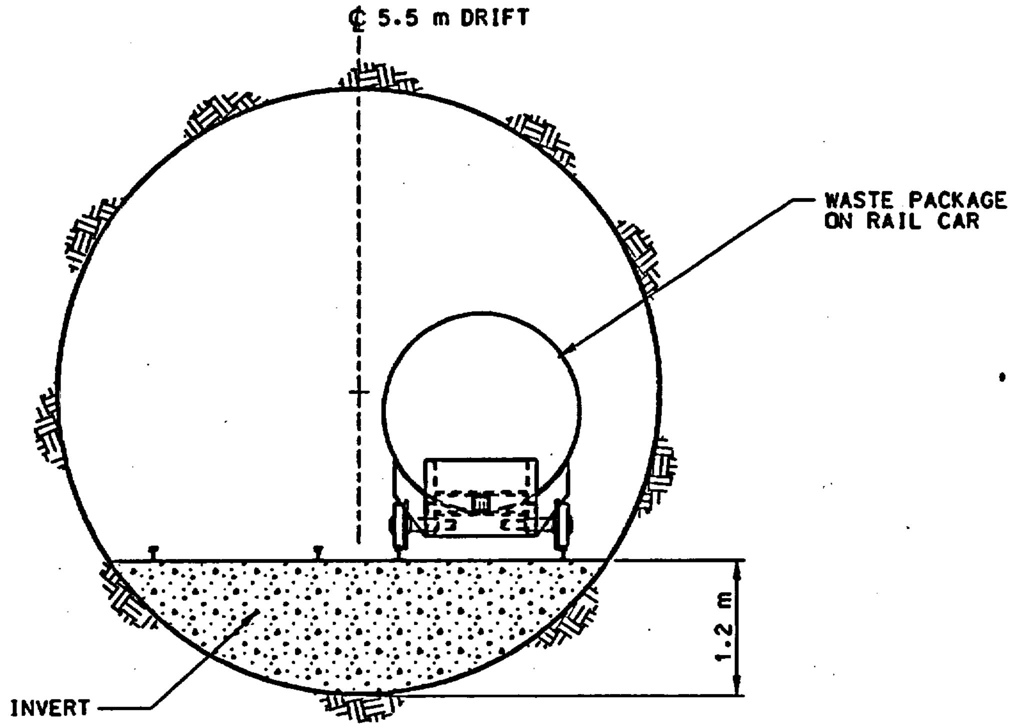

Figure 8.2.8-6. Off-Center In-Drift Emplacement Mode

8.3 SUBSURFACE LAYOUT

The repository subsurface layout will accommodate the emplacement of 70,000 MTU of waste (CRWMS M&O 1995a, Key 003 and Key 005) at an areal density of 83 MTU per acre (CRWMS M&O 1995a, Key 019) with an estimated excess capacity of approximately 10 percent. The final capacity will depend on ground conditions encountered as waste package emplacement will be avoided in areas of poor ground. The subsurface layout is designed so that construction and emplacement operations can be carried out safely and maintains the option of retrievability. The repository subsurface layout is configured for mechanical excavation for the majority of the openings (CRWMS M&O 1995a, Key 027, Key 028, and DCSS 005). Access ramps and main drifts will be excavated by TBMs similar to that used for driving the 7.62 m ESF tunnel. The emplacement drifts will be excavated by either a 5.0 or 5.5 m diameter TBM and secondary openings by another, as yet undetermined, form of mechanical excavator. The shaft will be excavated by both mechanical methods and drill-and-blast (CRWMS M&O 1995a, DCSS 014). Throughout this document the term "drill-and-blast" means the use of controlled drill-and-blast practices which may include pre-split or cushion blasting, or the use of multiple delays with light explosive loads on each delay. These methods are intended to minimize blasting-induced damage to the rock surrounding repository openings. See Section 8.4.4 for discussion on mechanical excavation methods.

Key factors governing the subsurface design include transportation of large, heavy waste packages from the surface to the emplacement area; protection of personnel from radiation; thermal impacts (from heat generated by the waste) on opening and ground stability; thermal impacts on the working environment for machinery and personnel; ventilation considerations to adequately control separate emplacement and excavation systems; access for monitoring waste packages in the emplacement drifts; ground support installation and maintenance (including the emplacement drifts); equipment operation and maintenance; and waste retrieval, backfill, and closure considerations.

The repository subsurface layout will incorporate the majority of the ESF tunnels developed as part of the site characterization activities. ESF development, when complete, will comprise the North Ramp, the North Ramp Extension, the Topopah Spring Main Drift (Upper Block East Main), the South Ramp, and various test alcoves. The North Ramp Extension is currently designed as part of the ESF; however, there are indications that the North Ramp Extension will not be excavated with the ESF drifts. Therefore, this MGDS ACD Report considers that the North Ramp Extension is constructed as part of the repository and provides access to the west side of the upper emplacement area. The TBM-excavated ESF access ramps and the Topopah Spring Main Drift will serve similar functions in the repository as in the ESF. Test alcoves will have no operational functions for repository construction and operation. ESF openings will be upgraded as necessary to meet repository requirements for ground support, access, and utilities.

Excavation of the repository will utilize existing ESF utilities and systems whenever possible. These include water, compressed air, waste water, electrical power, ventilation system, and conveyor. The supporting facilities for the repository will be located on the surface. The facilities will include, but are not limited to, warehouses, equipment maintenance shops, change houses, and offices. During the pre-emplacement construction phase, the facilities will be located at the North Portal. However, all large TBM (7.62 and 9.0 m diameter) servicing and breakdown maintenance will be performed in situ underground. The rest of the equipment used during construction and parts of the TBM that can be removed will be taken to the surface facilities for maintenance. During the emplacement phase, facilities for the simultaneous development and emplacement operations will be separated. The development facilities will be located at the South Portal and the emplacement facilities will be located at the North Portal. The emplacement drift TBMs will be serviced in situ and breakdown maintenance will be performed underground in the TBM Launch Main disassembly chamber. All other equipment used for development and parts of the TBM than can be removed will be taken to the surface facilities for maintenance. All emplacement equipment will be taken to the surface facilities for maintenance.

To satisfy the requirement of separate ventilation systems during simultaneous emplacement and development operations (YMP 1994a, 3.7.5.B.3), isolation air locks will segregate the emplacement side from the development side. The ventilation system is designed to keep development side air pressure higher than that on the emplacement side so as to prevent movement of airborne radioactive particles and gases to the development side (YMP 1994a, 3.7.5.B.4); see Section 8.7 for discussion on the ventilation system. Limited and controlled access between the two sides will be possible either in the case of an emergency that threatens personnel safety, such as a fire, or for special construction and operational purposes. Rail access between the two sides will not be possible because of different track gauges on either side.

The layout description presented in this section is based largely on previous work performed by the M&O; see Section 8.3.1 for details of supporting studies. Since completion of these studies, the layout concept has undergone a number of refinements. These included development of design detail necessary to demonstrate conceptual level constructability and operability and to support the cost estimate and construction schedule. In addition, some modifications have been proposed to improve emplacement drift access for performance confirmation and potential retrieval activities and to support the placement of backfill in emplacement drifts, if required.

8.3.1 Previous Work

This section of the report presents a background summary of the Yucca Mountain Project (YMP) repository layout development prior to the start of advanced conceptual design (ACD) through the present. The interface of the repository layout with the ESF is also included.

Early in the YMP, a study by Mansure and Ortiz (SNL 1984a) identified the potentially useable areas for repository siting in the vicinity of Yucca Mountain. This study is described in Section 8.1.1 and the resulting areas of potential interest are shown in Figure 8.1.1-1. A substantial portion of Area 1, known as the Primary Area, was studied in more detail and a potential repository block of 749 hectares was identified.

The siting of the repository block in the Primary Area later resulted in a conceptual layout and design of a potential high-level nuclear waste repository at Yucca Mountain. This design was prepared in support of site characterization planning and was presented in the *Site Characterization Plan Conceptual Design Report* (SCP-CDR) (SNL 1987). The reference repository layout presented in the SCP-CDR (SNL 1987), shown in Figure 8.3.1-1, was based upon the emplacement of 70,000

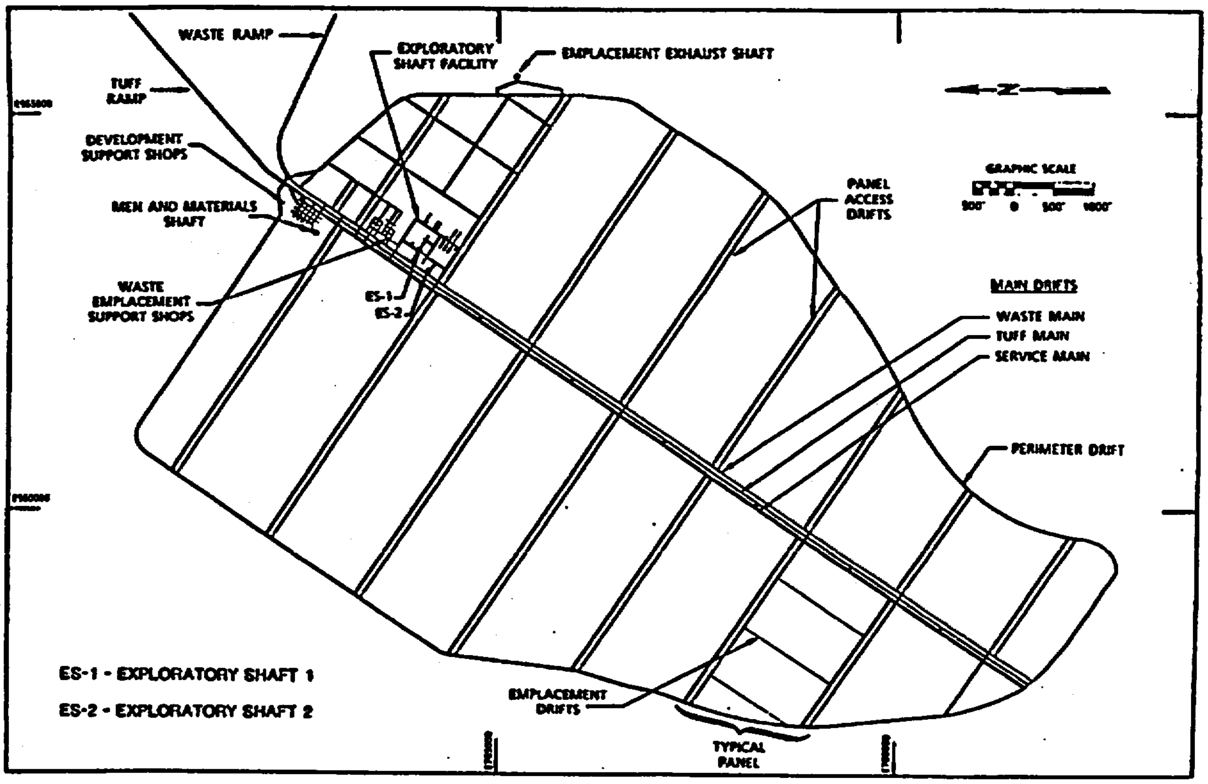

Figure 8.3.1-1. SCP-CDR Vertical Borehole Repository Layout (SNL 1987)

metric tons of uranium (MTU) equivalent in thin-walled, single purpose canister-based waste packages inserted into short vertical boreholes. An alternative layout using the same waste packages and a long, horizontal borehole emplacement mode was also presented. A planned panel areal power density thermal load of 57 kW/acre was the result of those layouts.

The SCP-CDR (SNL 1987) layouts used TBMs to develop primary ramps and accesses, and they extensively used drill-and-blast excavation techniques to develop the emplacement areas. Comments and concerns expressed by the Nuclear Regulatory Commission (NRC 1989a) and the Nuclear Waste Technical Review Board (NWTRB 1990), regarding the use of drill-and-blast techniques, resulted in a shift in YMP program direction.

The change in program direction resulted in a later report, the *Exploratory Studies Facility Alternatives Study: Final Report* (ESFAS) (SNL 1991), which evaluated 34 different, integrated ESF/repository configurations. The study concluded that the alternative identified as "Option 30" facilitated the use of a TBM as a primary excavation tool and was most preferred, based on a multi-attribute decision analysis that considered waste-isolation, operability, programmatic viability, and other features of the various designs. Option 30 was later modified to move the dedicated main test level (MTL) area from the southeast to the northeast corner of the repository footprint and to include an optional shaft for site characterization purposes. The resulting layout was called "Modified Option 30."

The Modified Option 30 layout, shown in Figure 8.3.1-2, became the starting point for Title I ESF design via a document (YMP 1991) which summarized the ESFAS findings to develop a reference ESF design concept. This document also stressed the need to pursue development of other ESF/Repository layouts that incorporate all of the favorable waste-isolation design features identified in the ESFAS.

In October 1992 the design of the multi-purpose canister (MPC) concept was initiated. In 1994, the MPC concept, along with disposal overpack designs, was adopted by the Office of Civilian Radioactive Waste Management, changing the waste package design from the smaller one in the *Site Characterization Plan, Yucca Mountain Site, Nevada Research and Development Area, Nevada* (DOE 1988a) to this new larger waste package concept. The MPC concept, coupled with the aforementioned NRC and NWTRB comments, made many repository design concepts developed prior to that time somewhat obsolete. In that year, an enhanced ESF layout was developed by the M&O and accepted by the YMP Change Control Board. The document which advanced the enhanced ESF layout was entitled *Description and Rationale for Enhancement to the Baseline ESF Configuration* (CRWMS M&O 1993d) and proposed changes that were consistent with recommendations made as a result of the ESFAS and findings summary, as well as the change in program direction to use the MPC.

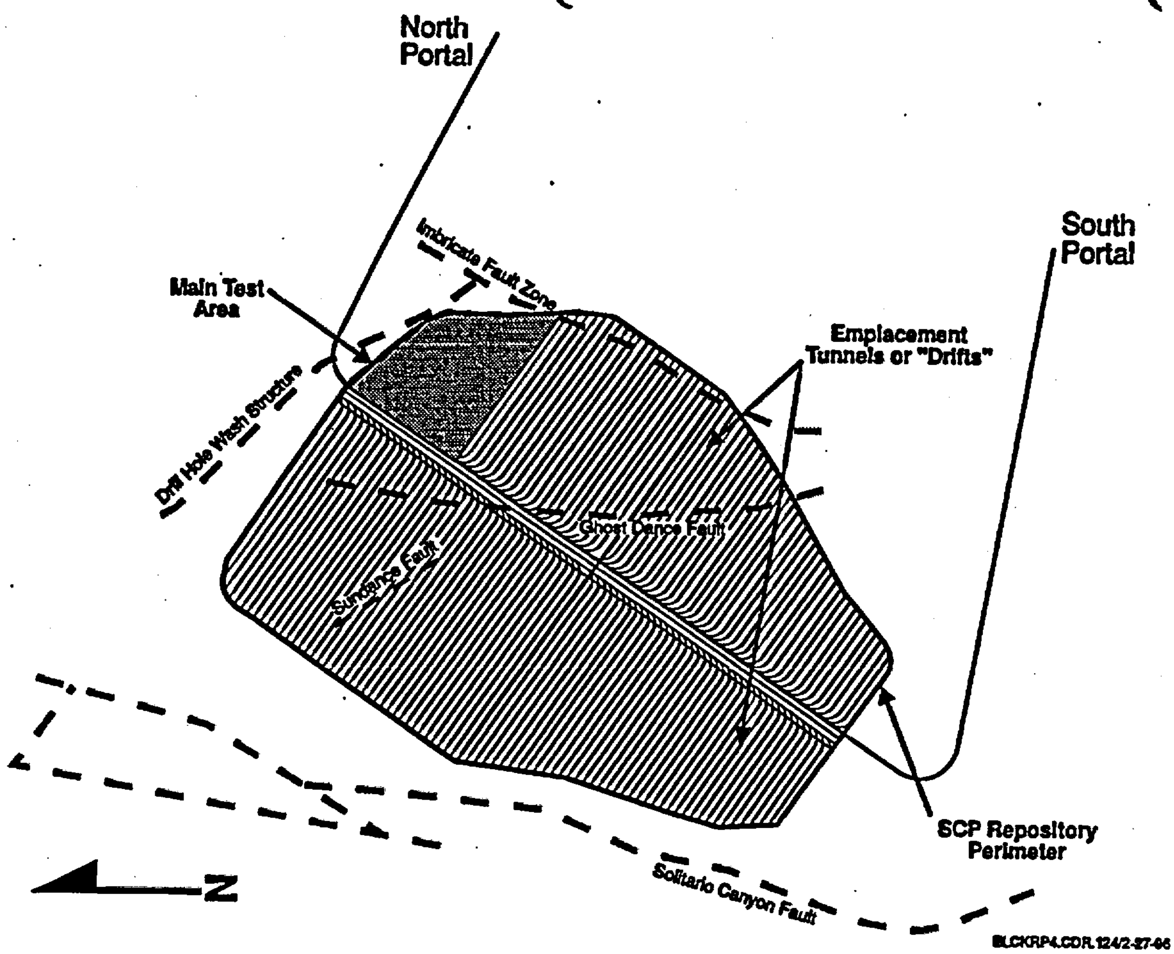

Figure 8.3.1-2. Modified Option 30 Repository Layout (CRWMS M&O 1994a)

In concert with the enhanced ESF configuration, the Repository Subsurface Design Group within the M&O completed a conceptual design report entitled *Repository Subsurface Layout Options and ESF Interface* (CRWMS M&O 1993e). That report described various operational elements and features of a conceptual repository layout that were compatible with both emplacement of MPC-based waste packages and the enhanced ESF configuration. In that report, the concept of in-drift emplacement was expanded to address the high heat output and handling challenges associated with a large waste package. The report also presented a variety of alternative layout concepts which were examined to address evolving hydrothermal models and questions regarding numerous TBM launches that would be needed in a repository.

In early FY 1994, a set of six ESF/potential repository interface drawings was developed and submitted to the DOE (CRWMS M&O 1994l) that promoted results from FY 1993 repository ACD. These drawings were baselined and provided a repository configuration for ongoing ESF Title II design. Figure 8.3.1-3 shows the baseline repository layout.

In FY 1994, the *Initial Summary Report for Repository/Waste Package Advanced Conceptual Design* (CRWMS M&O 1994a) was completed and presented a reference or interim repository layout concept, shown in Figure 8.3.1-4, that was considered to be a refinement to the baselined ESF/repository interface configuration. The primary reasons for this refinement were the incorporation of more up-to-date geologic information to define the limits of the TSw2 thermal-mechanical (T/M) unit and the location of major faults, as well as more in-depth considerations of emplacement operations and equipment concepts.

The interim repository layout developed in FY 1994 was geared toward accommodating the emplacement of spent fuel and high-level waste at a primary high thermal load (80 to 100 MTU/acre) and an alternative low thermal load (25 to 35 MTU/acre) (DOE 1994a). In addition, that layout was based on an assumption that the repository horizon will be limited stratigraphically to the TSw2 thermal-mechanical unit and laterally to the Primary Area (DOE 1994a) identified by Mansure and Ortiz (SNL 1984a).

The low thermal load range was simulated in FY 1994 layout concept development work as a source of input for FY 1994 system studies. Generic repository layouts (CRWMS M&O 1994m) were prepared for a wide range of thermal loadings to be considered in the system studies. The "expanded" repository layouts used portions of the six potentially usable areas shown in Figure 8.1.1-1. That report presented layouts of 24 MTU/acre which used a majority of the "expansion areas," used the basic layout concept developed for the enhanced ESF configuration in FY 1993, and used the concept of in-drift emplacement in long parallel drifts. Areas considered for these are shown in Figure 8.3.1-5.

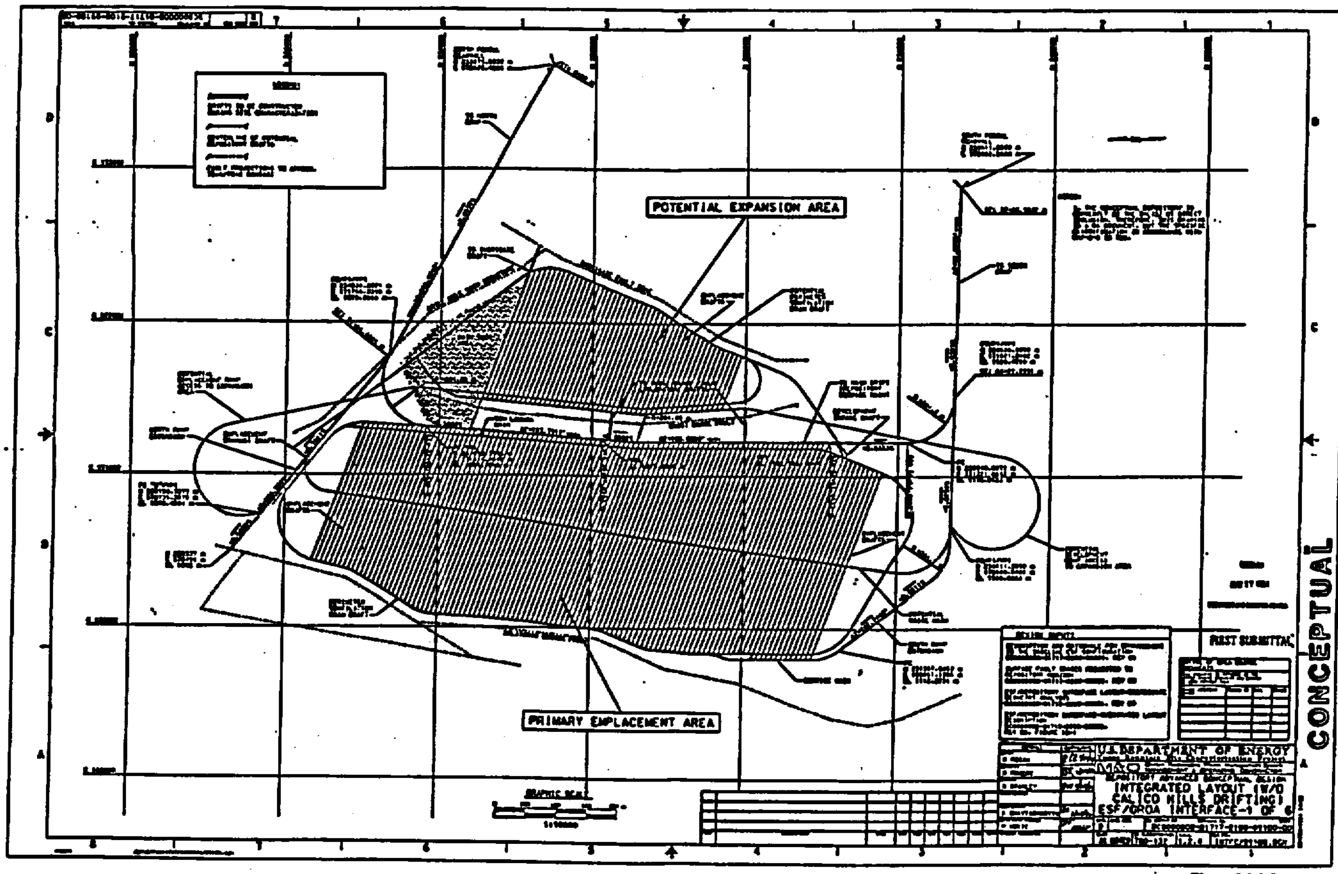

Figure 8.3.1-3
Baseline Repository Layout

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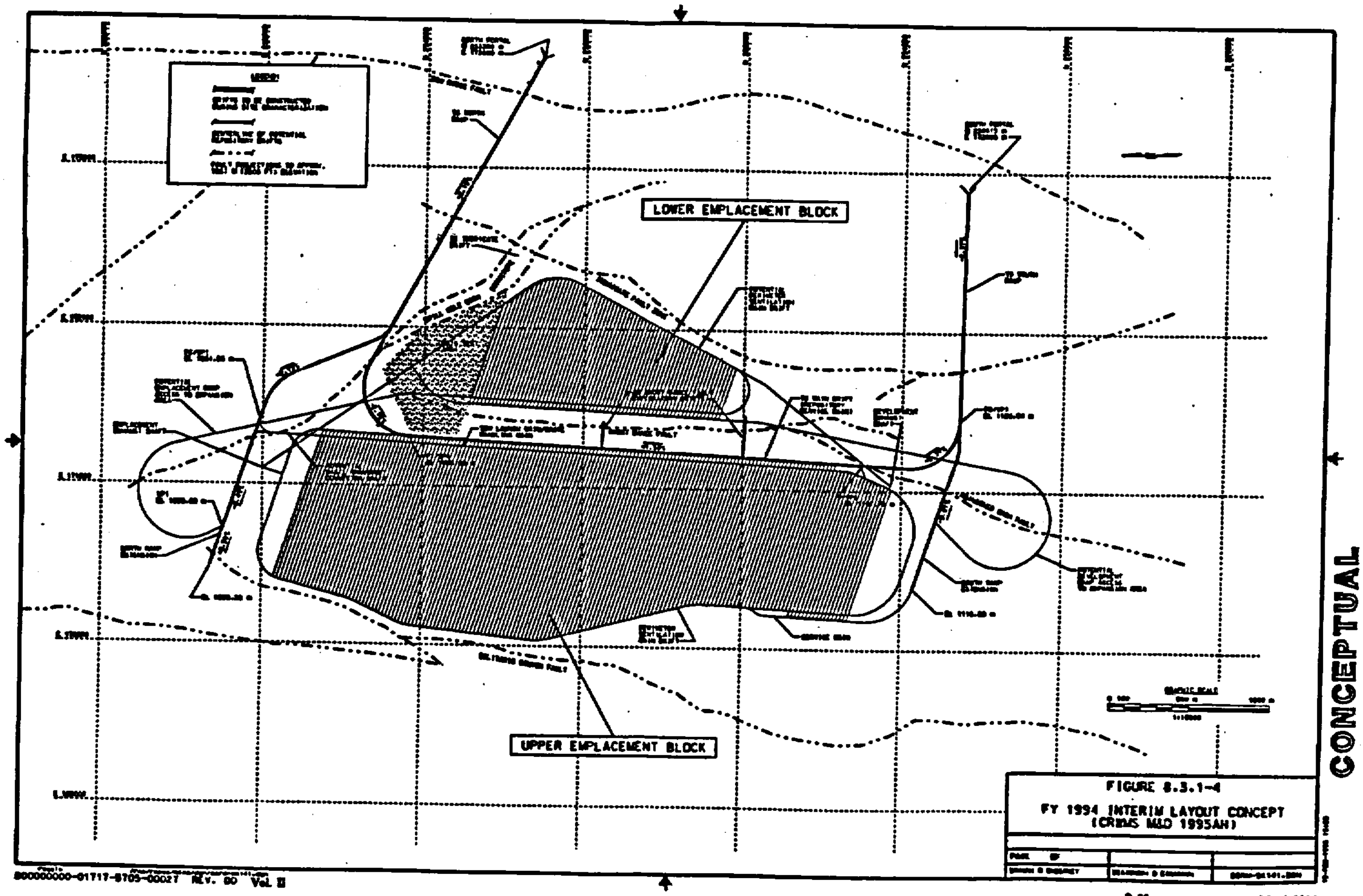

FIGURE 8.3.1-4
FY 1994 INTERIM LAYOUT CONCEPT
(CRWMS M&O 1995AH)

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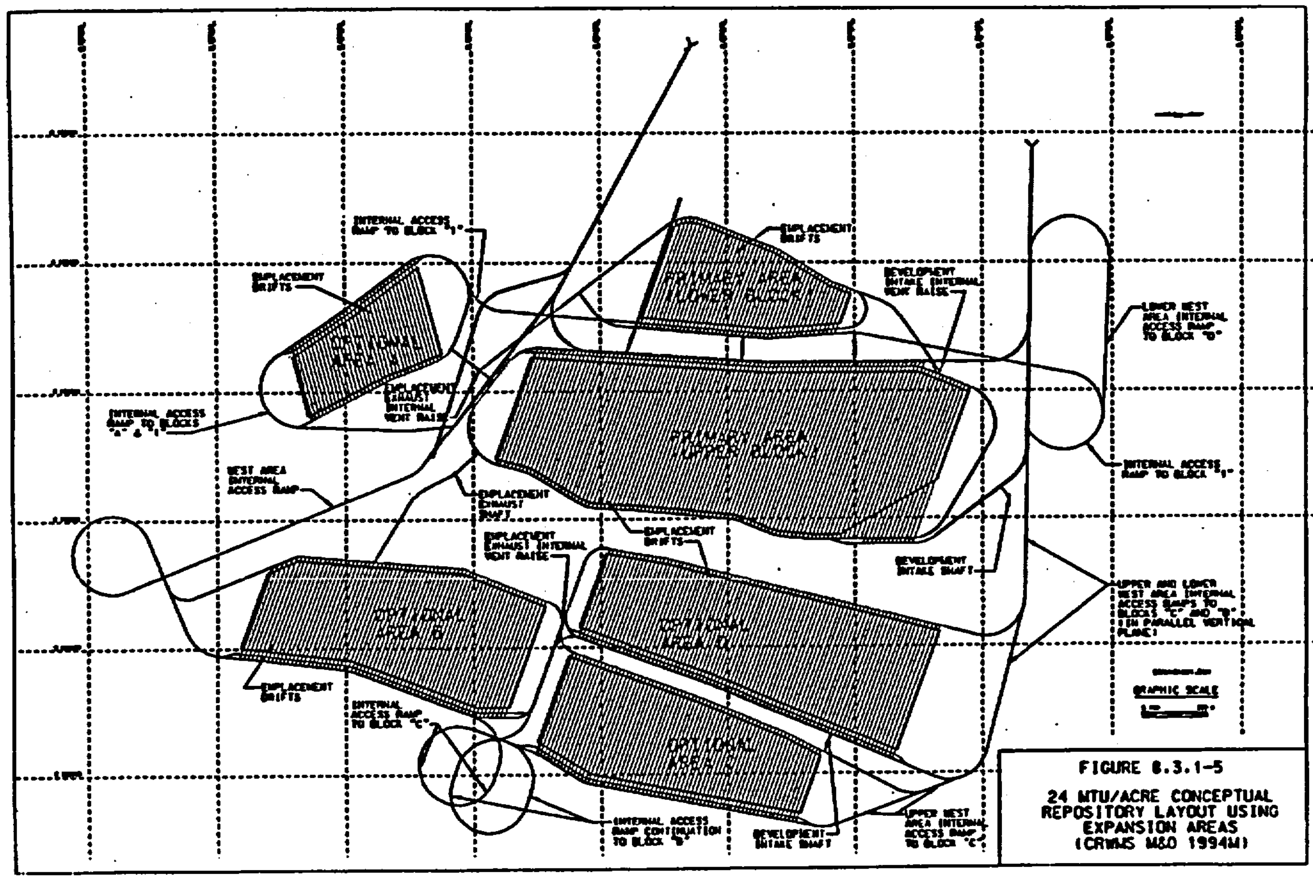
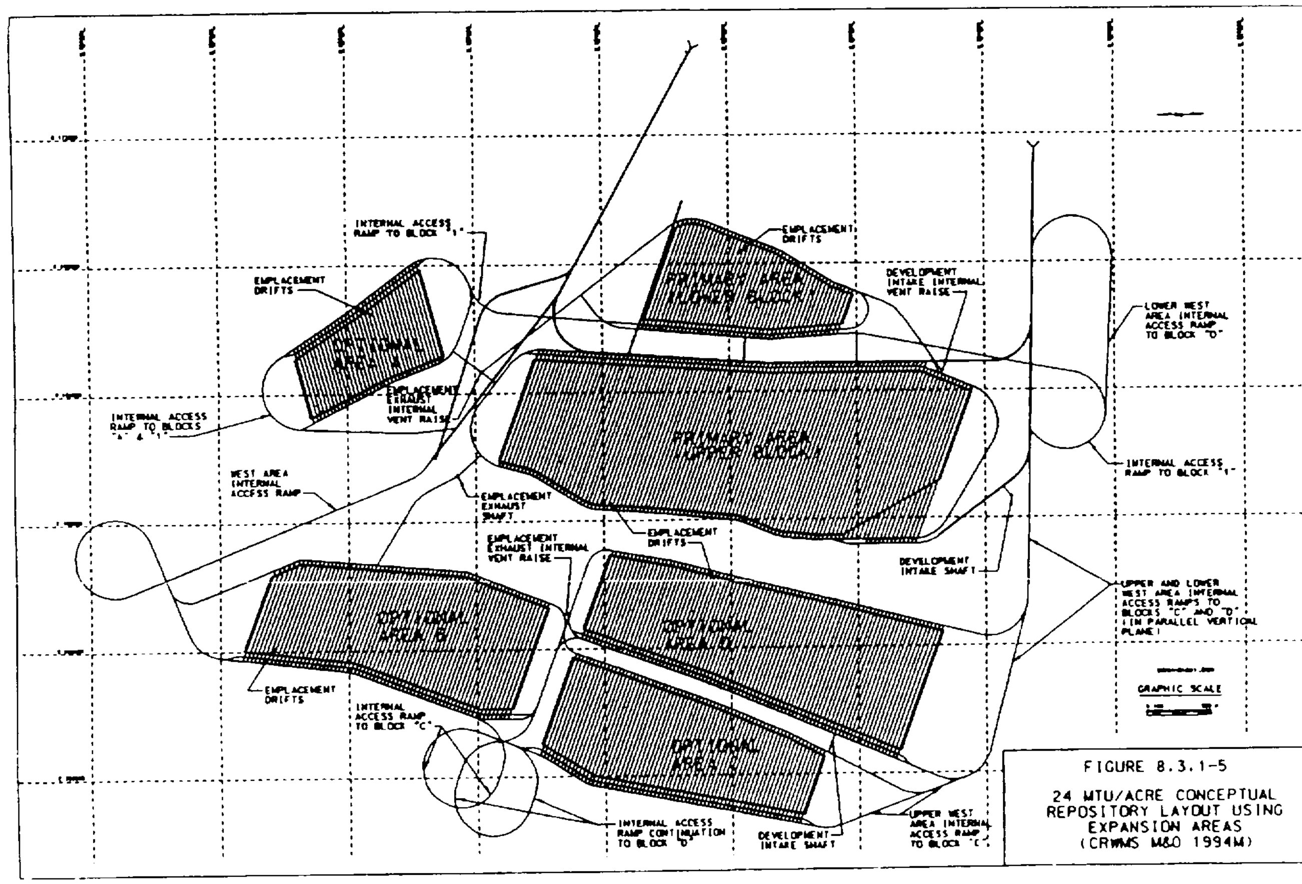


Figure 8.3.1-5. 24 MTU/Acre Conceptual Repository Layout Using Expansion Areas (CRWMS M&O 1994m)



CONCEPTUAL

Figure 8.3.1-5. 24 MTU/Acre Conceptual Repository Layout Using Expansion Areas (CRWMS M&O 1994m)

In FY 1995, the FY 1994 interim layout concept shown in Figure 8.3.1-4 was analyzed in an ACD report along with three other layout concepts (CRWMS M&O 1995ah). In that report, the interim layout was termed "option I" and the other three concepts were termed "options II, III, and IV", respectively.

Layout option II, shown in Figure 8.3.1-6, was an alternative design originally presented in the *Initial Summary Report for Repository/Waste Package Advanced Conceptual Design* (CRWMS M&O 1994a). Specifics of the layout were discussed in that report. In general, the option was developed to allow relatively continuous TBM excavation using only the amount of secondary excavation necessary to provide access to the inner "rings" of emplacement drifts and for waste package handling equipment operating compatibility. The relatively continuous TBM operation (compared to layout option I, for example) was achieved at the expense of creating a somewhat complex emplacement drift arrangement. Using a nine drift panel, as shown in Figure 8.3.1-6, the number of TBM launches that were necessary was a function of the emplacement drift spacing and the radius-of-curvature used in the end sections of the emplacement drifts. The drift spacing and resulting curvature needed were a direct function of the repository thermal loading.

Layout option III, shown in Figure 8.3.1-7, was a new concept developed in FY 1995 to provide a significant reduction in the number of TBM launches and moves using a continuous drifting pattern. The basic concept was first presented to M&O repository and ESF design personnel in a meeting held in Las Vegas on September 12, 1994, by Harrison Western Corporation from Wheat Ridge, Colorado. Specifics of the concept presented in that meeting by Harrison Western Corporation included details of a TBM system which was represented as proprietary information. A center-point of the option III concept, for a majority of the thermal loading range currently being considered, was the need to use a TBM capable of excavating drifts with short radius curves. Figure 8.3.1-7 is based on a high thermal loading and includes an emplacement drift spacing of 22.5 m and 22.5 m radius curves. The use of more traditional machines would require an emplacement drift spacing greater than 100 m, which was not compatible with the full range of thermal loadings being considered. A TBM capable of excavating short-radius curves was commercially available using a machine design concept developed by International Tunnel Equipment Limited (ITEL). The capabilities of the ITEL machine were utilized in the layout of option III.

Layout option IV, shown in Figure 8.3.1-8, was a concept broached during the development of the baseline repository layout (CRWMS M&O 1993e, CRWMS M&O 1994a). It was similar to the option I layout except that it did not include TBM launch mains in either of the upper or lower emplacement blocks. The basic premise of the concept is that the same conventional and well-proven TBM technology used in option I could be used in option IV.

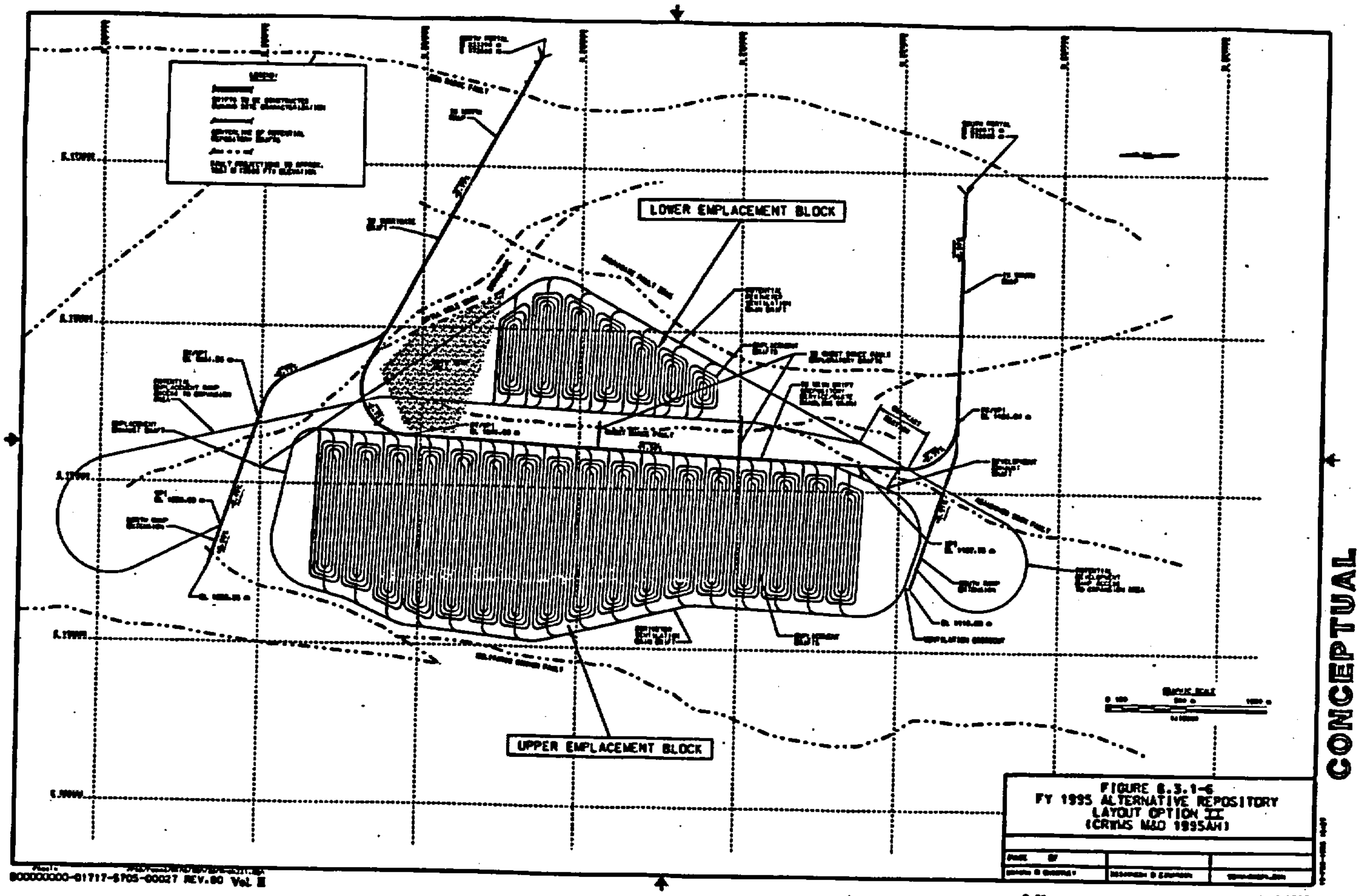


FIGURE 8.3.1-6
FY 1995 ALTERNATIVE REPOSITORY LAYOUT OPTION II
(CRWMS M&O 1995AH)

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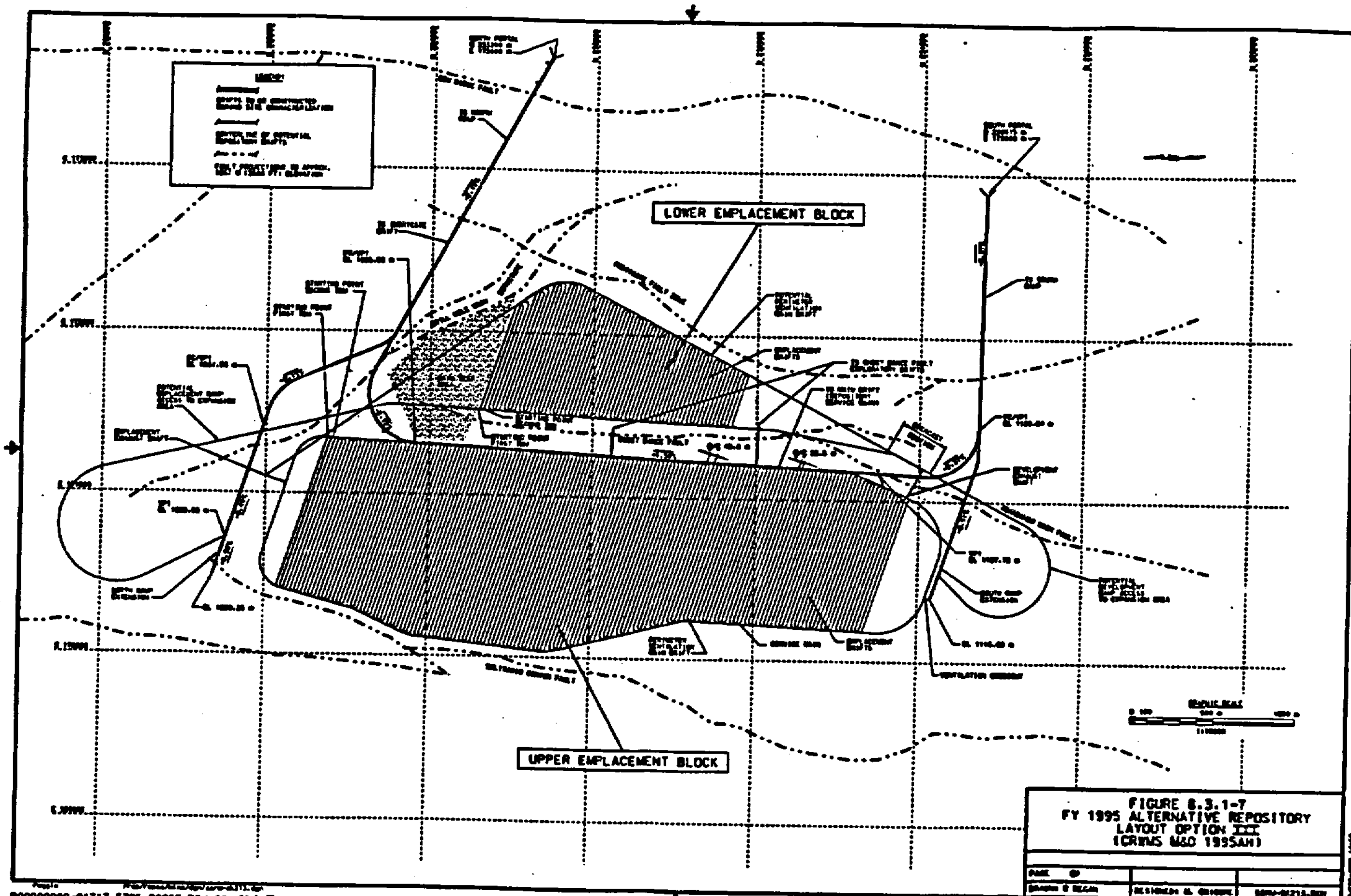

FIGURE 8.3.1-7
FY 1995 ALTERNATIVE REPOSITORY
LAYOUT OPTION III
(CRWMS M&O 1995AH)

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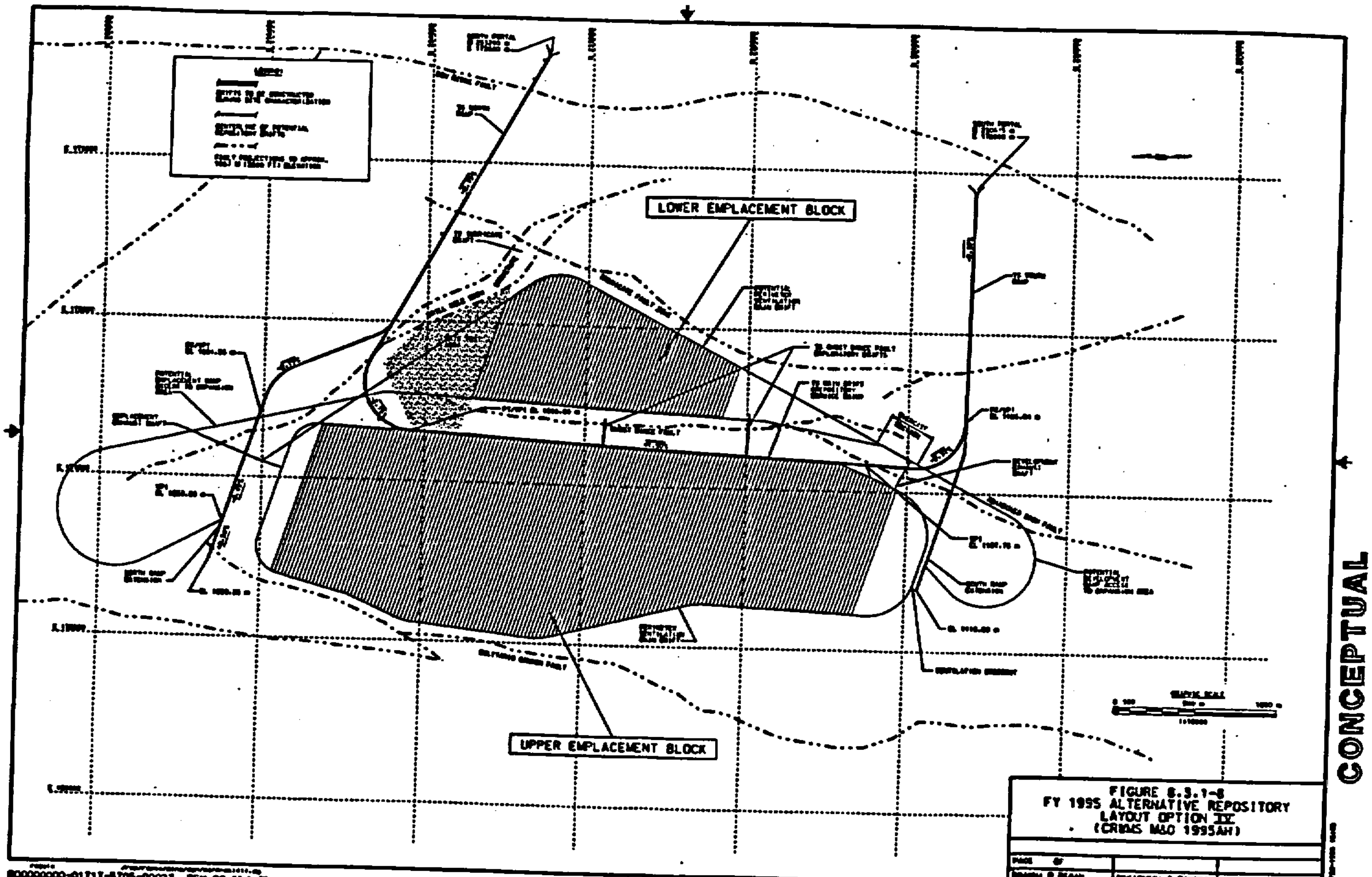

FIGURE 8.3.1-8
FY 1995 ALTERNATIVE REPOSITORY
LAYOUT OPTION IV
(CRWMS M&O 1995AH)

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Some of the more significant conclusions drawn in the FY 1995 layout options analysis report (CRWMS M&O 1995ah) are summarized here. Layout options II and III required the use of TBM excavation technology (i.e., short-radius curves) that has not been field-tested under geologic conditions similar to Yucca Mountain. In addition, the flexibility to adjust emplacement drift spacing and emplace waste packages to virtually any conceivable pattern or position (within certain constraints) was concluded to be an essential part of the repository licensing strategy to achieve the wide range of thermal loadings currently being articulated in the *Civilian Radioactive Waste Management Program Plan* (DOE 1994b). Drift layout options which could readily adjust drift spacing with minimal disruption to the layout geometry or excavation equipment were considered advantageous. It was concluded that layout options I and IV allowed the use of proven excavation technology and flexibility in drift spacing with minimal disruption, and a recommendation was made that layout options I and IV should be carried forward for a more comprehensive comparative layout evaluation.

The FY 1995 layout analysis report (CRWMS M&O 1995ah) was a result of a recommendation made in FY 1993 ACD. The recommendation was to perform a study to further investigate potential alternative repository layout concepts. It was further recommended that the alternatives be evaluated with a ranking established, and a preferred option with one alternative configuration be selected. The recommendation emphasized that during development of the alternatives, vital systems and subsystems of each must be worked out in sufficient detail to provide confidence in the final selection process (CRWMS M&O 1993e).

The FY 1995 layout analysis report (CRWMS M&O 1995ah) fulfilled the above recommendation to further investigate potential alternative repository layout concepts. This report narrowed the range of layout alternatives to two final ones, keeping the FY 1993 recommendation in mind. Because two of the four layout alternatives were clear choices, no effort was made in that report to rank the alternatives. Option I and Option IV were the two layouts selected as the final two alternatives.

The two selected layouts were detailed further in the *Recommended Layout Concepts Report* (CRWMS M&O 1995ai) in late FY 1995. The two layouts were termed "option X" and "option Y" which corresponded to option I and option IV, respectively. The report discussed the advantages and disadvantages of both layouts and selected a final scenario to be used as the ACD layout. Option X was the layout selected. Some slight modifications were made to the option X layout in early FY 1996 which lead to the current layout used for this MGDS ACD Report, see Figure 8.3.3-1 in Section 8.3.3.

8.3.2 Design Inputs

This section lists design assumptions and the design requirements governing the repository layout configuration. Design inputs in this report that are used to generate concepts during ACD work, are considered preliminary, and in some cases unqualified.

8.3.2.1 Requirements

All text in this section is excerpted directly from the RDRD (YMP 1994a), which is the reference source for repository requirements. Upper level requirements from within the program and outside the program (such as 10 CFR 60 requirements) are included in the RDRD (YMP 1994a). The specific RDRD (YMP 1994a) requirements quoted below are considered applicable to aspects of the repository subsurface layout. Other RDRD (YMP 1994a) requirements, which may apply in a more general way, are not included here.

3.1.5.I The EBS, described in 10 CFR 60, overlaps with the GROA in that the underground facility is included in both. For the purposes of defining the MGDS, the underground facility including emplacement drifts is part of the Repository Segment. The waste packages and any backfill placed in emplacement drifts are part of the Engineered Barrier Segment.

3.2.1 PERFORMANCE CHARACTERISTICS

Performance characteristics are the system's capabilities specified in terms of states, phases, or modes of operation in which the system can exist.

A. Mission Requirement. The design of the Repository Segment shall provide for the disposal of SNF and civilian and defense HLW such that the public health and safety and the environment are protected.

B. Modes. The Repository Segment will operate in seven of the eight modes depicted in the MGDS-RD (DOE 1995b). The only mode not applicable to the repository is Site Characterization which is the topic of the SD&TRD [Site Design and Test Requirements Document] (YMP 1995g).

The Repository Segment can operate in more than one mode at a time. For example, the construction mode will begin after NRC issuance of the repository construction license. According to the current concept, only a portion of the emplacement locations will have been finished when the repository begins emplacement operations (again, after NRC approval). The Repository Segment will continue to expand the underground facility in parallel with waste emplacement operations. This is a unique program aspect in that construction becomes part of the operation of the system.

The requirements cited in the following Sections [3.2.1.1 through 3.2.1.7] are descriptive of the modes but may not be unique to the modes with which they are identified. For example, a performance confirmation program is required in all of the modes.

3.2.1.1 CONSTRUCTION MODE REQUIREMENTS

As stated above, the construction mode will begin after NRC issuance of the repository construction license. According to the current concept, only a portion of the emplacement locations will have been finished when the repository begins emplacement operations (again, after NRC approval). The Repository Segment will continue to expand the underground facility in parallel with waste emplacement operations.

D. Because subsurface construction will continue after emplacement operations begin, radiological protection is required. The GROA shall be designed so that until permanent closure has been completed, radiation exposures, radiation levels, and releases of radioactive materials to unrestricted areas will at all times be maintained within the limits specified in 10 CFR 20 and applicable environmental standards for radioactivity established by the EPA, as listed in Section 3.2.2 [of the RDRD].

3.2.1.2 EMPLACEMENT MODE REQUIREMENTS

The emplacement mode is defined to include all activities related to waste handling from receipt at the MGDS to permanent emplacement.

A. Assuming the MRS facility is located more than 50 miles from the repository, no quantity of SNF and solidified HLW resulting from the reprocessing of such a quantity of spent fuel containing in excess of 70,000 metric tons of heavy metal shall be emplaced in the repository until such time as a second repository is in operation. (See Section 3.2.3.1.1.A [of the RDRD])

B. The repository shall be capable of receiving waste according to the schedule shown in Table 3-3 in Section 3.2.3 of this volume.

(See Table 3-4 in Section 3.2.3.)

C. The GROA shall be designed so than until permanent closure has been completed, radiation exposures, radiation levels, and releases of radioactive materials to unrestricted areas will at all times be maintained within the limits specified in 10 CFR 20 and applicable environmental standards for radioactivity established by the EPA, as listed in Section 3.2.2 [of the RDRD].

3.2.1.3 CARETAKER MODE REQUIREMENTS

When the repository has reached its legislated or physical capacity for waste disposal, it will be in the caretaker mode. The option to retrieve any and all emplaced waste will be preserved from the time of emplacement for up to 50 years. Performance confirmation will continue during this mode.

The GROA shall be designed so that until permanent closure has been completed, radiation exposures, radiation levels, and releases of radioactive materials to unrestricted areas will at all times be maintained within the limits specified in 10 CFR 20 and applicable environmental standards for radioactivity established by the EPA as listed in Section 3.2.2 [of the RDRD].

3.2.1.4 RETRIEVAL MODE REQUIREMENTS

The retrieval mode includes functions related to removing waste packages from the underground facility.

A. The repository shall be designed and constructed to permit the retrieval of any SNF and HLW emplaced in the repository, during an appropriate period of operation of the facility, as specified by the Secretary of Energy.

   This schedule applies to the first repository only. The CRWMS WA system element will begin accepting title to waste in 1998 and the disposal function will continue until all waste is disposed of (conceptually, in a second repository).

B. The GROA shall be designed to preserve the option of waste retrieval throughout the period during which wastes are being emplaced and, thereafter until the completion of a performance confirmation program and NRC review of the information obtained from such a program. To satisfy this objective, the geologic repository shall be designed so that any or all of the emplaced waste could be retrieved on a reasonable schedule starting at any time up to 50 years after waste emplacement operations are initiated, unless a different time period is approved or specified by the NRC. 10 CFR 60.111(b)(3) gives guidance for developing the schedule.

C. The GROA shall be designed so that until permanent closure has been completed, radiation exposures, radiation levels, and releases of radioactive materials to unrestricted areas will at all times be maintained within the limits specified in 10 CFR 20 and applicable environmental standards for radioactivity established by the EPA, as listed in Section 3.2.2 [of the RDRD].

3.2.1.7 OFF-NORMAL MODE REQUIREMENTS

The off-normal mode involves accident, natural disaster, and other unexpected scenarios and can occur during any of the other modes.

A. The GROA design shall 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 SSCs important to safety.

3.2.2.1.A The GROA shall, to the extent practicable, be designed and constructed to use procedures and engineering controls based upon sound radiation protection principles to achieve occupational doses and doses to members of the public that are as low as is reasonably achievable (ALARA). ALARA principles shall be based on the applicable sections of NRC Regulatory Guides 8.8 and 8.10.

3.2.2.3.A Concentrations of radioactive material in air shall to the extent practicable be controlled through the use of process or other engineering controls (e.g., containment or ventilation).

3.2.3.2.2.A.11.a The repository layout shall be designed so that a combination of characteristics will assist in keeping liquid water from contacting the waste packages for the first 300 to 1000 [TBV] years after closure.

3.2.3.2.2.A.11. b The layout shall also ensure that the design limit temperatures [TBD] for waste forms are not exceeded.

3.2.4.3.3 UNDERGROUND ACCESS CONTROLS

A system shall be provided to control access to the underground as required by 30 CFR 57.11058 and 29 CFR 1926.800(c).

3.2.4.5.1.C Concrete. Concrete radiation shielding design shall comply with ANSI/ANS 6.4 and ACI 349 and shall consider the material specifications of ANSI/ANS 6.4.2 where it provides a critical confinement or structural function. For other shields, ACI 318 is appropriate and provides adequate strength for design earthquake (DE) loads.

3.2.5.2.2 PHYSICAL CLEARANCE

A. Corridors. The size and arrangement of interior corridors and drifts shall accommodate the movement of equipment including initial equipment installation, facility operations, and possible future removal or replacement of equipment. Movement of waste packages into and out of the emplacement drifts requires specific attention.

B. Maintenance Accessibility. Facility design shall provide access for routine maintenance, repair, or replacement of equipment subject to failure. Accessibility includes proper lighting and utility hookups and acceptable levels of radiological exposure.

3.2.5.4.A The Repository Segment shall be designed for a maintainable service life of at least 100 years [TBR] or the period of time authorized by the license granted by the NRC in accordance with the provisions of 10 CFR 60.3.

3.2.6.2.2.D To the extent practicable, the Repository Segment facilities shall be designed to incorporate the use of noncombustible and heat resistant materials.

3.7.5.B Underground Facility Ventilation. The underground facility ventilation system shall be designed to:

3. separate the ventilation of excavation and waste emplacement areas;

4. ensure that ventilation leakage between the emplacement system and the development system will always be from the development system to the emplacement system;

6. supply air to and exhaust adequate quantities of air [TBD] to and from underground working areas such that operator safety, health and productivity requirements are maintained;

3.7.5.E Underground Openings.

1. Openings in the underground facility shall be designed so that operations can be carried out safely and the retrievability option maintained.

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

3. 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.

4. The location of underground openings shall be placed such that the effects of a maximum possible flood will not intrude on the operations of the subsurface facilities.

5. The openings shall be maintainable until closure.

6. The underground excavation shall allow for flexibility in closure, such as the location of seals, so that a seismic event is unlikely to compromise the ability of the facility to isolate wastes.

7. 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, and groundwater system.

3.7.5.F Underground Facilities and Systems.

1. Underground facilities and systems shall be in accordance with the applicable health and safety requirements of 30 CFR 57.

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.

7. Space for storage of emergency equipment shall be provided.

3.5.7.G.2 The design of the underground facility shall incorporate excavation methods that will limit the potential for creating a preferential pathway for groundwater to contact the waste packages or radionuclide migration to the accessible environment.

3.5.7.H Flexibility. The underground facility shall be designed to allow adjustments to accommodate specific site conditions identified through in-situ monitoring, testing, or excavations.

3.5.7.N Ramps and Shafts.

1. The waste ramp shall permit flow of intake ventilation air for the emplacement area, which, when combined with the airflow in the shafts, is adequate for emplacement operations [TBV].

2. The tuff ramp shall permit flow of ventilation airflow capacity adequate to meet the return air requirements of the development area during the construction and operation periods [TBV].

5. If shafts are used, the shaft size shall be determined by the size of the conveyances needed to move materials, personnel, and equipment underground; the volume of ventilation flow needed; and the space required for utility lines. [TBD]

6. The shafts shall be designed to prevent objects or missiles from accidentally falling or being dropped down the shaft.

7. The structures in the shafts and ramps shall be designed to withstand the expected static (e.g., earth pressures within the shaft fill, water column pressures, and in situ stresses) and dynamic loading conditions so that performance is not impaired.

3.5.7.O Drifts.

1. Drift sizes shall take into account requirements for hauling equipment and shall allow for clearances, ground support, and ventilation.

2. The service main shall be adequate to handle the transport of development personnel, supplies, utility lines, and machinery to the men-and-materials shaft

[TBV], to the service facilities for the development area, and to the development area.

3. The service main shall permit flow of adequate ventilation airflow to supply the volumes of air needed in the development area.

3.5.7.P Emplacement Area.

1. Emplacement drift spacing shall consider the heat load as indicated by thermal analysis related to the thermal characteristics of the waste over the life of the repository.

2. The design of the access and emplacement drifts must take into account requirements for the transporter, haulage equipment, and other support equipment and shall include allowances for clearances, ground support, and ventilation.

3. In a drift emplacement concept the design of the emplacement area shall ensure that the emplacement drifts can accommodate the potential disposal of partial or fully shielded waste packages and the accommodations required for performance confirmation instrumentation. [TBD]

3.7.7.C The repository shall provide a reasonable assurance that the public and the environment will be adequately protected from the hazards posed by radioactive wastes emplaced therein.

8.3.2.2 Assumptions

All text in this section is excerpted directly from the *Controlled Design Assumptions Document* (CDA Document) (CRWMS M&O 1995a). The CDA Document (CRWMS M&O 1995a) assumptions quoted below contain only the items that have been used in the evaluations of the subsurface layout.

Key 003 The waste package emplacement scenario at the MGDS for the reference thermal load is as indicated in the attached table. The table is compatible with the tables in Key Assumptions 001 and 002 for higher thermal loads.

Total commercial spend nuclear fuel – 63000 MTU in about 9000 MPCs and about 200 uncanistered fuel waste packages.

The following table is consistent with MGDS-RD Table 3-3.

(See Table 4-4 in Section 4.1).

Key 005	Total high-level waste (HLW): 70000 MTU equivalent in about 13000 commercial and defense high-level waste canisters containing an immobilized waste form (e.g., vitrified glass). Potential sources include waste resulting from SNF reprocessing at the Savannah River Site, Hanford Reservation, Idaho National Engineering Laboratory, and the West Valley Site.
Key 010	Integrated rail transport will be used for subsurface transport of waste packages.
Key 011	Waste packages will be emplaced in-drift in a horizontal mode.
Key 016	The repository will be designed for a retrievability period of up to 100 years after initiation of emplacement.
Key 019	Surface, subsurface, and waste package designs will be based on a reference thermal load of 80-100 MTU per acre. The reference thermal load for the revised [MGDS ACD Report] is 83 MTU/acre.
Key 022	For the reference thermal loading of 80-100 MTU per acre, the repository horizon will be located mainly in the TSw2 geologic unit within the primary area.
Key 023	To the extent practical, repository openings will be located to avoid Type 1 faults. For unavoidable Type 1 faults that intersect emplacement drifts, allow a 15 m stand off from the edge of the fault zone to the nearest waste package. Avoidance is assumed to be adequate by using a 60 m offset from the main trace of a fault at the repository level. Exception: 120-m stand off should be used on the west side of the Ghost Dance Fault because the ESF Topopah Spring Main drift will be excavated before the Ghost Dance Fault characteristics are fully investigated.
Key 027	The primary method of tunnel excavation will be mechanical.
Key 028	Where it is impractical to use mechanical methods, drill-and-blast may be used to a limited degree primarily in non-emplacement areas of the repository.
Key 030	Rail will be used for transporting underground supplies and personnel to the extent practical.
Key 047	The proposed repository waste handling and administrative surface facilities will be located adjacent to the north portal.
EBDRD 3.2.3.3.A.13	Lining and grouting materials will be used during the construction of the ESF and repository. They will be evaluated for chemical reactions that may adversely impact waste isolation.

EBDRD 3.2.5.4 EBS structures, systems, and components shall be designed for a maintainable preclosure service life of at least 150 years following first emplacement of waste or the period of time authorized by the license granted by the NRC in accordance with the provisions of 10 CFR 60.3.

EBDRD 3.7.1.J.1 The waste package shall meet the following criteria:

1. External dimensions shall not exceed: Outer Diameter: 1850 mm; Outer Length: 5850 mm

RDRD 3.7.5.N.5 If shafts are used, the shaft size shall be determined by the size of the conveyances needed to move materials, personnel, and equipment underground; the volume of ventilation flow needed; and the space required for utility lines.

DCSS 001 Repository layout – preferred orientation:

- Orientation of emplacement drifts will be at least 30° from dominant joint orientation. Using the latest information on joint orientations, the emplacement drift orientation will generally fall between N70W and S75W.
- Orientation of maintainable access drifts, mains, ramps, etc. will be as needed to complement emplacement drift orientation, generally forming intersections of 70-90° where practicable.

DCSS 005 Drift excavation methods:

- Primary: TBM
- Secondary: other mechanical methods, and drill-and-blast where mechanical methods are impractical.

DCSS 006 Maximum excavation extraction ratio for emplacement drifts: 30 percent.

DCSS 009 Maximum grade in ramps: ≤3 percent to accommodate rail transport.

Maximum grade in mains: minimize, but ≤2 percent in mains used for emplacement drift access.

Maximum grade in emplacement drifts: minimize within 0.25 to 0.75 percent range for drainage.

DCSS 010 Repository material handling equipment: 1) Supplies: rail transport; 2) Excavated rock: conveyor belt, or conveyor belt variation preferred when practical.

DCSS 014 Shaft excavation method: Mechanical where practical.

DCSS 027 Organic materials (e.g., epoxy resin, timber) are limited for use as rock support and other postclosure permanent materials in all openings. Organic admixtures used in cementitious materials should be minimized to the extent practical.

Concrete and steel are allowable preclosure construction material in all openings.

DCSS 028 Emplacement drifts will be designed to be stable through the caretaker period, with the goal to minimize or eliminate planned maintenance to sustain the ability to retrieve, sample, or relocate waste packages. Shafts, ramps, and all other drifts will be designed to be stable, but may rely on periodic planned maintenance.

8.3.3 Layout Configuration

The repository horizon lies entirely within the TSw2 unit (CRWMS M&O 1995a, Key 022) and is divided into two emplacement areas: the upper block, located to the west of the Ghost Dance Fault; and the lower block which is located on the east side of the fault but at a lower elevation. Figure 8.3.3-1 illustrates the repository subsurface general layout. Figures 8.3.3-2, 8.3.3-3, 8.3.3-4, and 8.3.3-5 show cross sections through the upper and lower emplacement blocks near the north end of the Primary Area, along the North Ramp and North Ramp Extension, along the Upper Block East Main, and along the South Ramp, respectively. These cross sections show generally flat lying emplacement drifts and shallow gradients for the North and South Ramps and the East Main (CRWMS M&O 1995a, DCSS 009). Figure 8.3.3-6 shows tunnel sizes and excavation methods. A summary of the total repository development by type of excavation is shown in Table 8.3.3-1.

TBM excavated ramps driven from the surface provide access to the repository horizon and service mains (main drift or tunnel) and support both construction/development and emplacement operations. Waste packages will be stored in the emplacement drifts driven between the service mains. A central ventilation drift, the Upper Block Exhaust Main, divides the upper block into two parts, cutting the length of the emplacement drifts approximately in half. The intent of the division is to facilitate access for emplacement, monitoring, retrieval, and drift maintenance. In effect, the Exhaust Main reduces the maximum length of the upper block drifts from approximately 1,200 m to 600 m.

In the upper block, waste packages will enter the emplacement drifts from both the East and West Mains with emplacement starting near the Exhaust Main and working back towards the service mains. In the lower block, waste packages will enter the emplacement drift from the Main with emplacement starting at the far end near the Exhaust Main and working back towards the Main.

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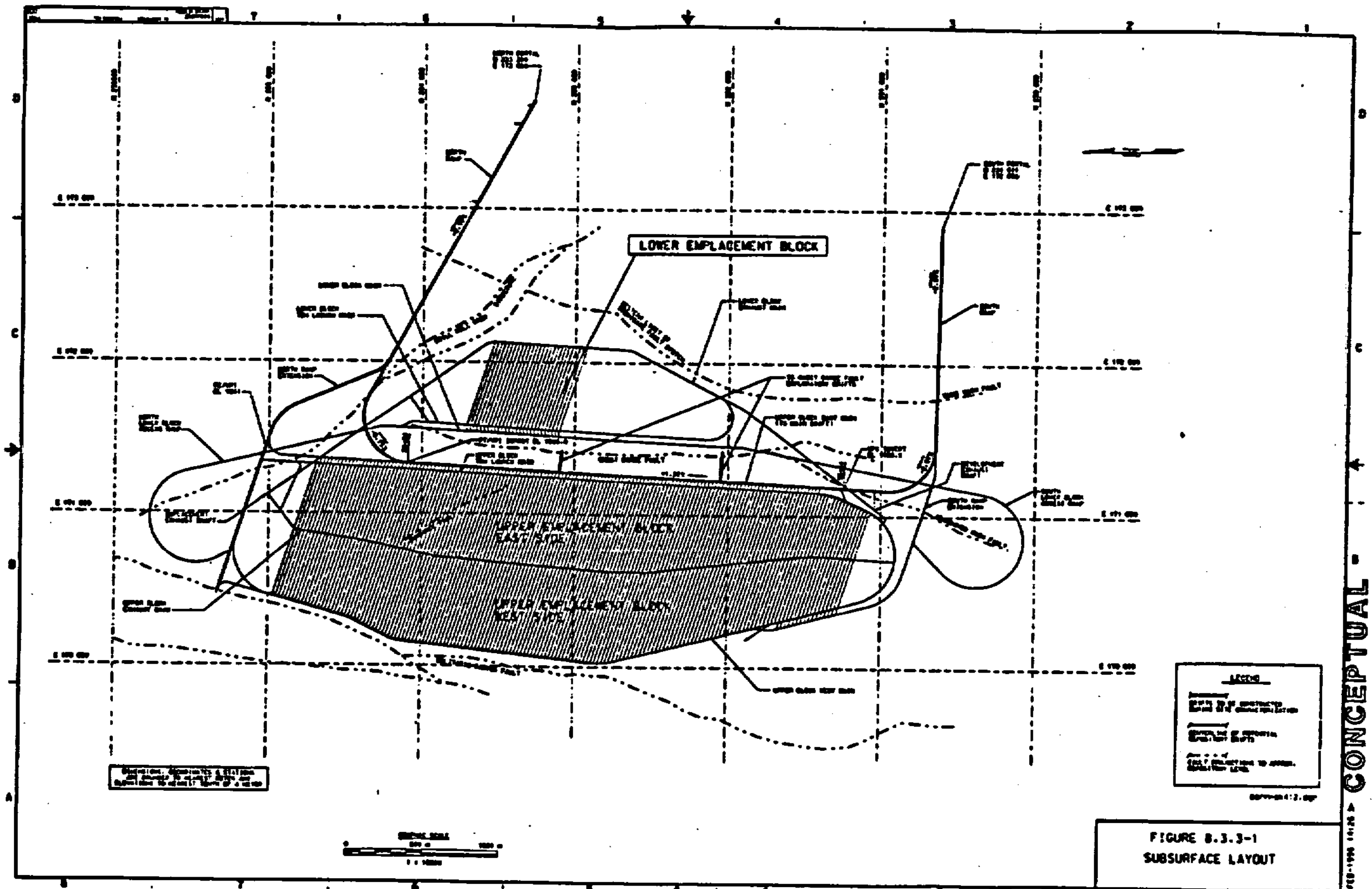

FIGURE 8.3.3-1
SUBSURFACE LAYOUT

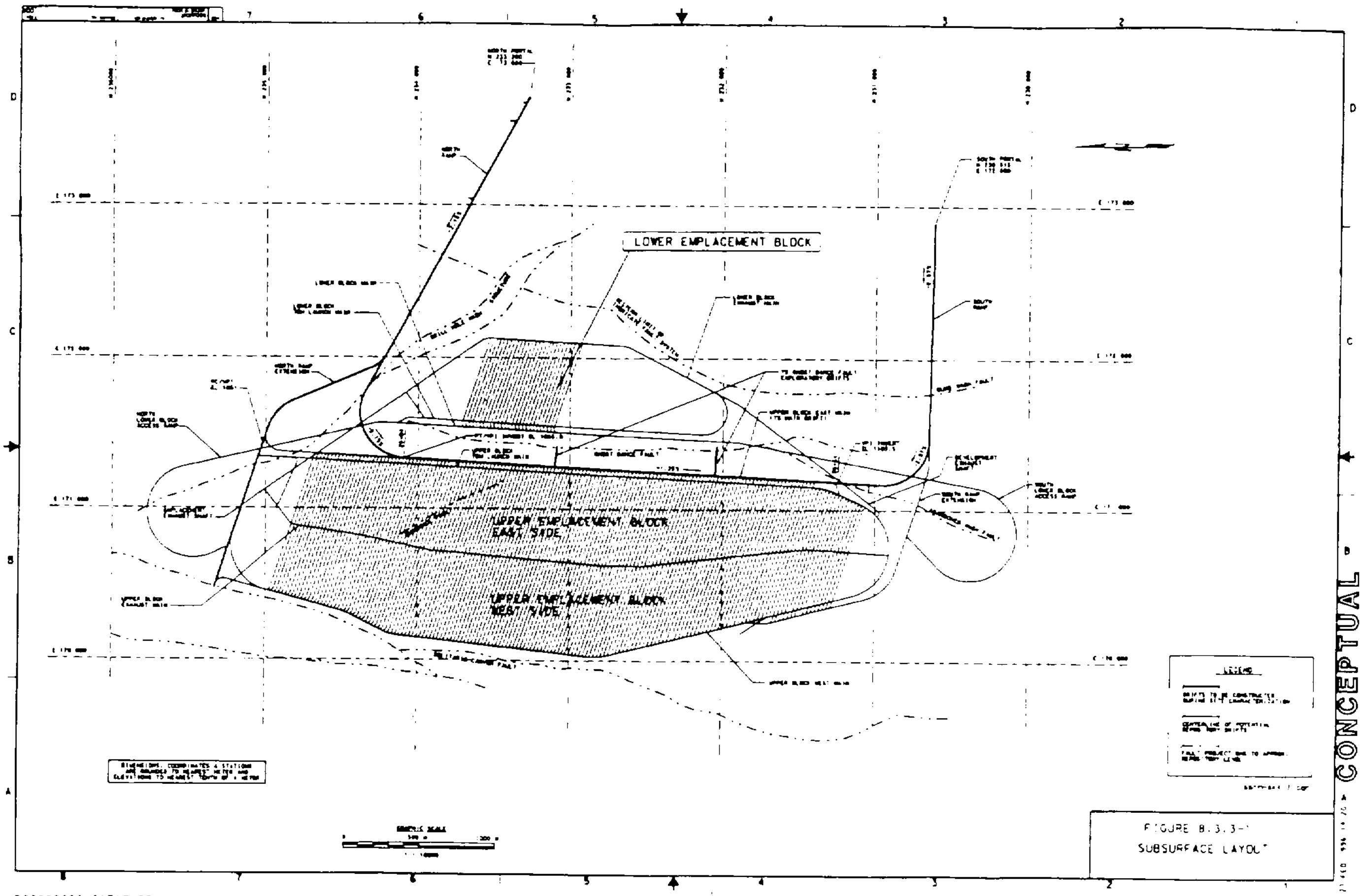

FIGURE 8.3.3-1
SUBSURFACE LAYOUT

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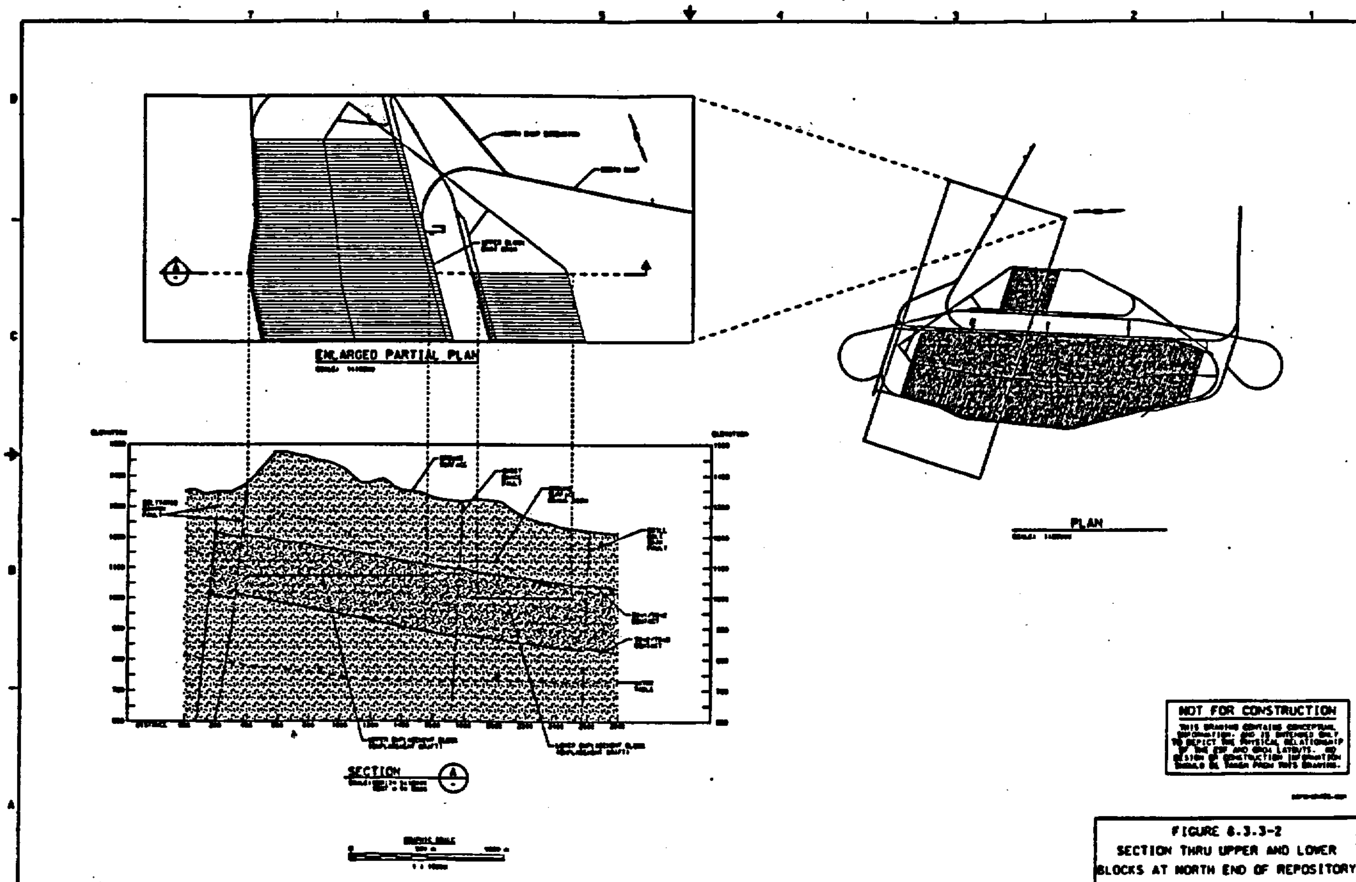
ENLARGED PARTIAL PLAN
SECTION
PLAN
NOT FOR CONSTRUCTION
FIGURE 8.3.3-2
SECTION THRU UPPER AND LOWER
BLOCKS AT NORTH END OF REPOSITORY

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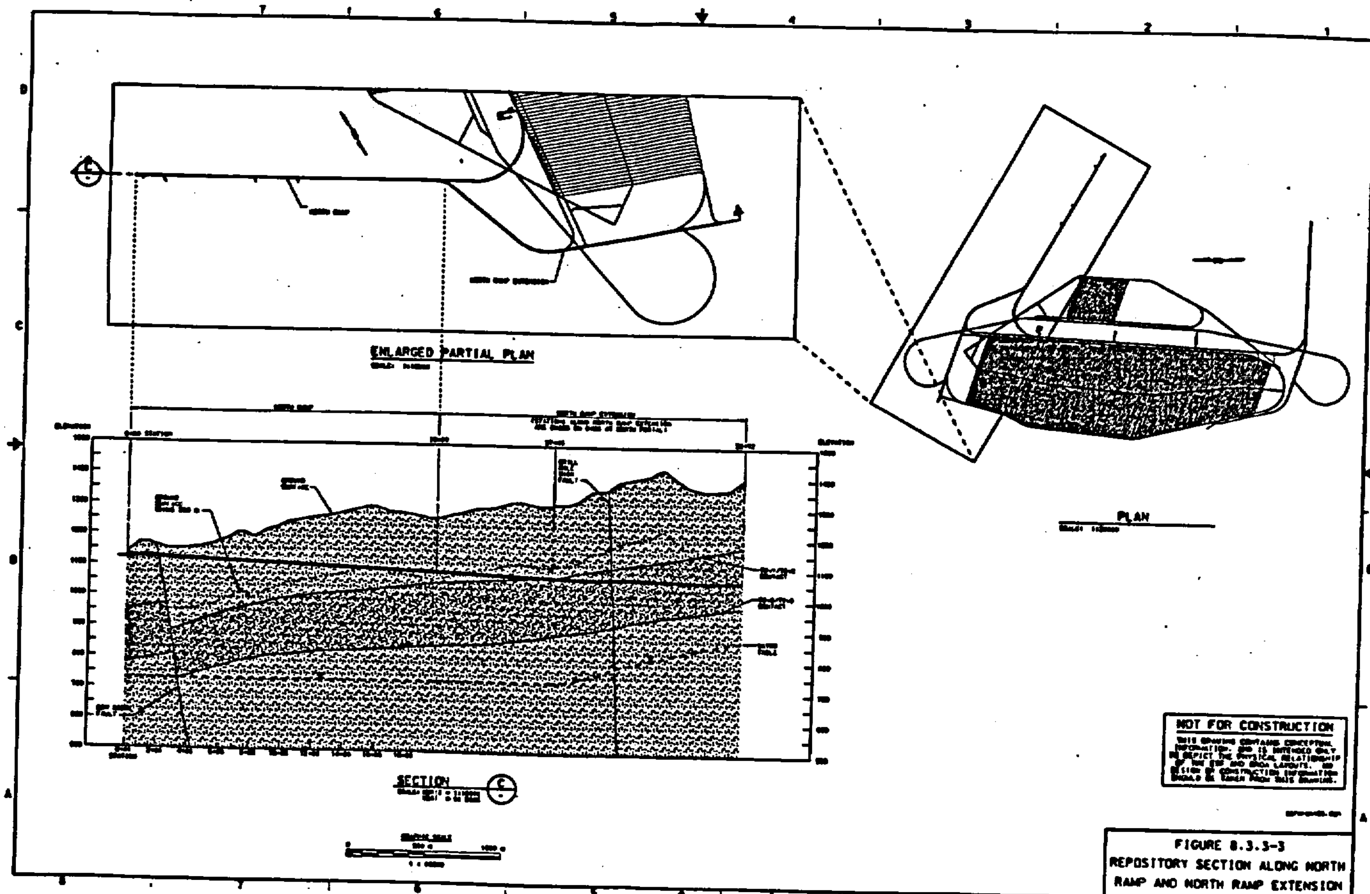

FIGURE 8.3.3-3
REPOSITORY SECTION ALONG NORTH RAMP AND NORTH RAMP EXTENSION

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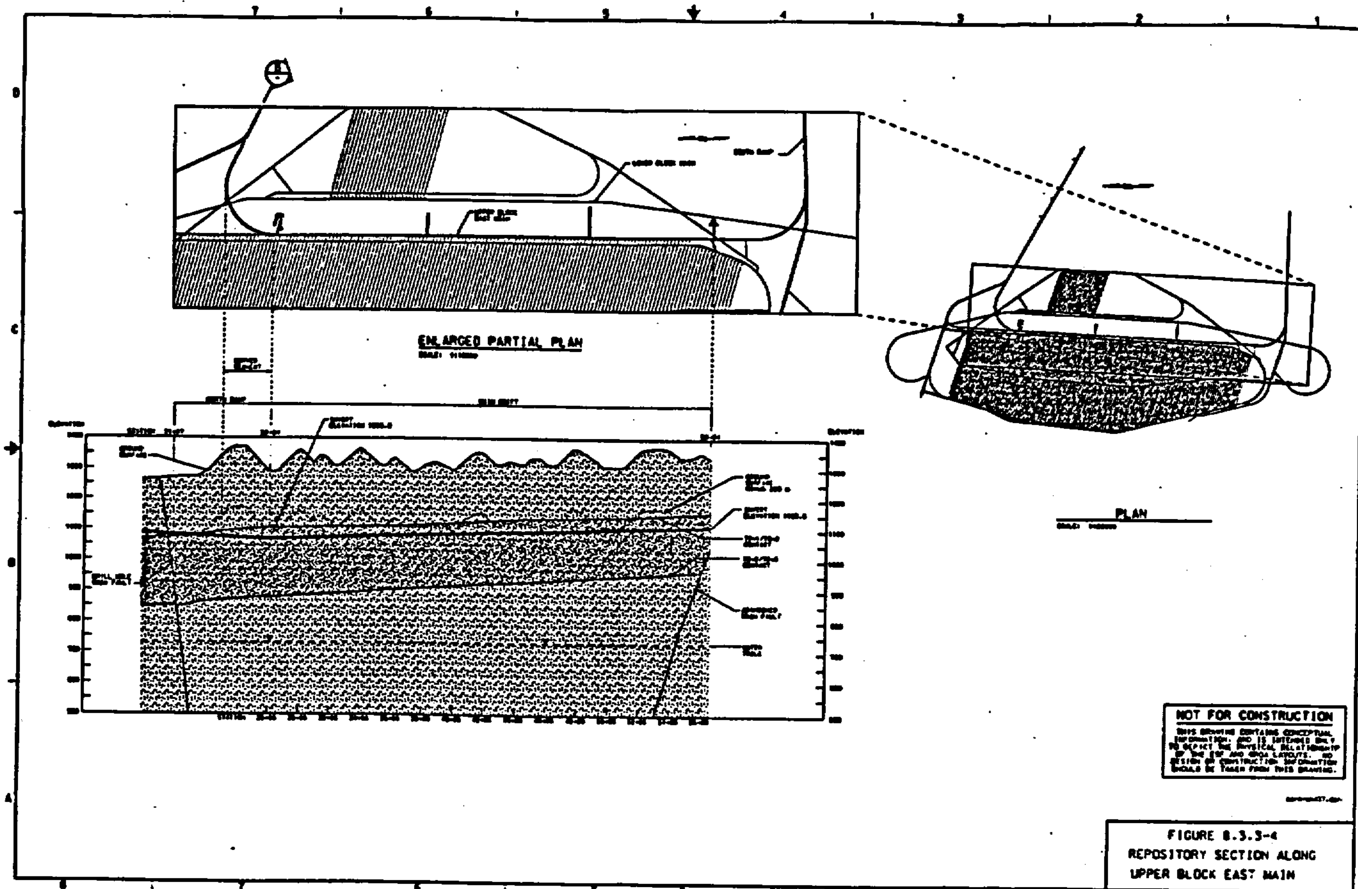

FIGURE 8.3.3-4
REPOSITORY SECTION ALONG
UPPER BLOCK EAST MAIN

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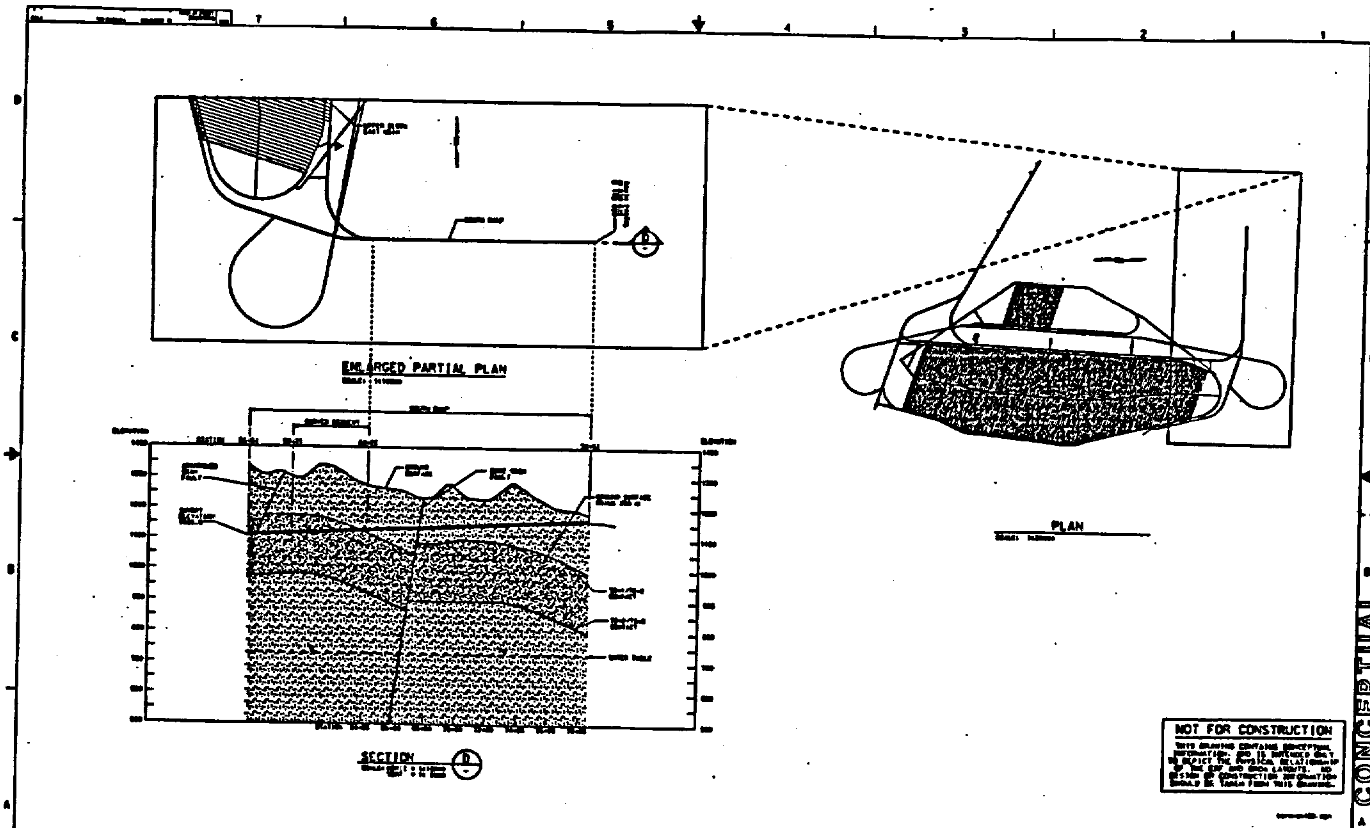

FIGURE 8.3.3-5
REPOSITORY SECTION ALONG
SOUTH RAMP

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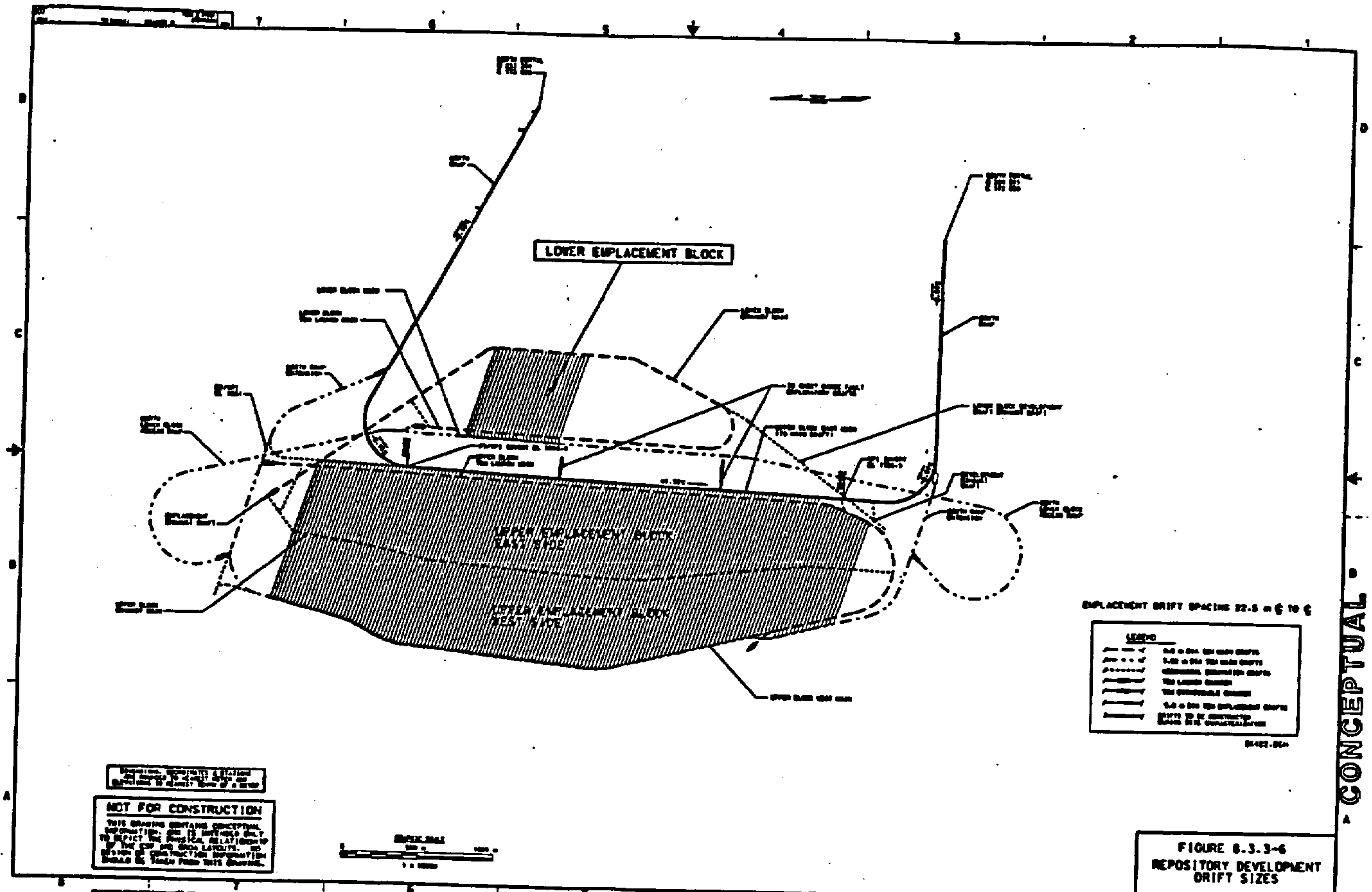

FIGURE 8.3.3-6
REPOSITORY DEVELOPMENT DRIFT SIZES

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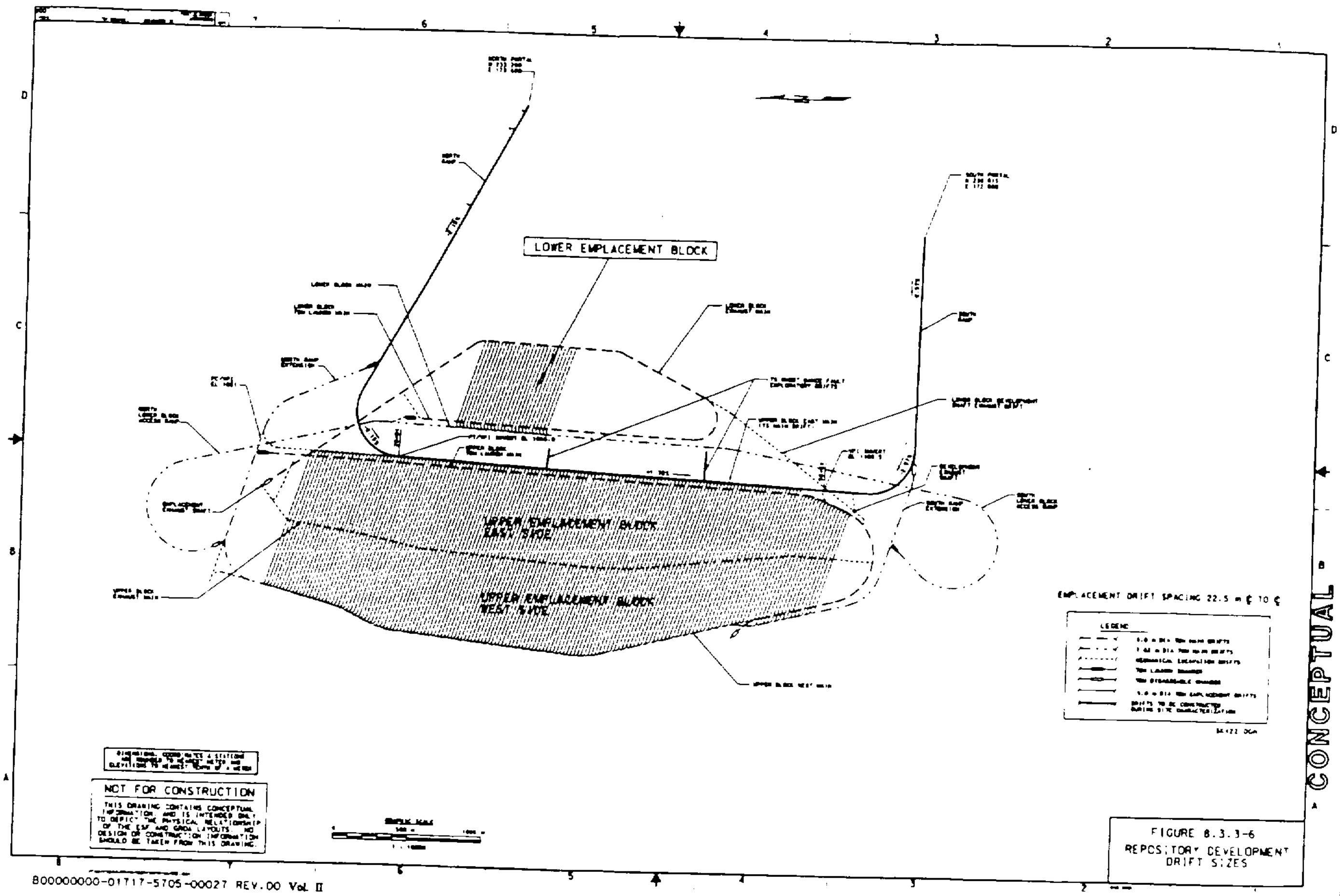

FIGURE 8.3.3-6
REPOSITORY DEVELOPMENT DRIFT SIZES

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Table 8.3.3-1. Summary of Repository Development

Excavation Type	Length (m)	Volume (cu. m)
9 m TBM (Launch Mains)	11,400	723,500
7.62 m TBM (Service Mains)	13,900	635,100
5.0 m TBM (Emplacement Drifts)	179,000	3,515,700
Non-TBM Excavation -- Mechanical Excavator (Exhaust Main & Miscellaneous Access Drifts)	22,900	955,900
Shafts	700	24,800
Total	227,900	5,855,000

For all 7.62 m and 9.0 m diameter repository TBM tunnels, the construction utilities, muck conveyor, roadway, rail (CRWMS M&O 1995a, Key 030), and ventilation systems will be similar to those used for ESF construction. In all openings excavated for the repository, ground support will be installed to final repository standards at the time of excavation. Ground support in ESF openings incorporated into the repository will be upgraded to repository standards where deterioration is present. Tables 8.3.3-2 and 8.3.3-3 summarize, for both the construction/ development and emplacement phases, opening configuration and sizes, functions, ground support, roadway and rail configurations, and excavation methods of all repository openings. The construction roadway in the ramps and service mains will be upgraded to repository standards prior to emplacement activities, first by grouting to stabilize and strengthen the concrete invert segments, and then by overlaying a reinforced cast-in-place concrete cap (CRWMS M&O 1995a, EBDRD 3.2.3.3.A.13 and DCSS 027). The concrete cap will be 300 mm thick in the ramps and 600 mm thick in the service mains. The extra concrete in the service mains will provide height for the waste package transporter to unload the waste packages into the emplacement drift, since the emplacement drifts are at a slightly higher elevation. The roadway must be upgraded because the construction roadway allows for excavation equipment clearances and will endure great use, especially in the Upper Block West Main and TBM Launch Main where the emplacement drift TBM travels from recovery to launch locations. The construction roadway also has a different track arrangement than the emplacement roadway: it has a narrower gauge and lighter-weight rail. The percentages shown in parentheses in the ground support column represent an estimate of the percentage of drift length that may require that particular type of support. The percentages used were chosen for cost estimating purposes. Ground control is discussed further in Section 8.5. Figures 8.3.3-7, 8.3.3-8, and 8.3.3-9 show examples of tunnel cross sections.

Table 8.3.3-2. Repository Openings Configuration and Equipment – Construction and Development Phases

Opening	Ground Support	Roadway	Utilities/Conveyor	Remarks
ESF 7.62 m TBM tunnel - North Ramp - TS Main Drift - South Ramp	ESF: <u>Starter tunnel</u> Temporary support consists of Splitset bolts. Permanent support of cement grouted bolts and dowels, WWF, and Fibercrete. <u>TBM Tunnel</u> Mainly 3.0 m Swellex & a few 3.0 m Williams rock bolts, 75 mm WWF & steel channel, W8x31 steel sets and lagging. FOR REPOSITORY CONSTRUCTION: Maintain as necessary.	ESF: Pre-cast concrete invert segments 633 mm deep, 915 mm gauge, double track on steel ties with 44.64 kg/m rail. REPOSITORY: Use existing ESF roadway & track.	Use existing utilities consisting of: - 150 mm Water - 200 mm Compressed air - 150 mm Waste water - 12.47 kV Power - 1675 mm Vent duct - 915 mm Conveyor	North Ramp will provide initial access for repository construction. Use existing utilities and conveyor to support these activities. Switch over to South Ramp for these functions when the North Ramp is modified for emplacement functions. Reverse South Ramp conveyor to carry muck to South Portal. South Ramp will then support construction functions throughout repository emplacement phase, and the service functions for the caretaker phase.

Table 8.3.3-2. Repository Openings Configuration and Equipment – Construction and Development Phases (Continued)

Opening	Ground Support	Roadway	Utilities/Conveyor	Remarks
7.62 m TBM North & South Ramp Extensions Upper Block (UB) West Main Lower Block (LB) Access Ramps LB Main	Category A: Rockbolts, 1.5 x 1.5 m pattern & 75 mm WWF (19%) Category B: Rockbolts, 1.0 x 1.0 m pattern & 75 mm WWF (54%) Category C: Rockbolts, 1.0 x 1.0 m pattern & 75 mm WWF, 100-150 mm Fibercrete (13%) Category D: Steel sets at 1.22 m spacing & lagging (14%)	Pre-cast concrete invert segments 633 mm deep, 915 mm gauge, double track on steel ties with 44.64 kg/m rail Note: Pre-cast invert segments and rail for TBM tunneling will be similar to those used for ESF.	- 150 mm Water - 200 mm Compressed air - 150 mm Waste water - 12.47 kV Power - 1675 mm Vent duct - 915 mm Conveyor	
9 m TBM UB & LB TBM Launch Mains LB Exhaust Main	Category A: Rockbolts, 1.5 x 1.5 m pattern & 75 mm WWF (19%) Category B: Rockbolts, 1.0 x 1.0 m pattern & 75 mm WWF (54%) Category C: Rockbolts, 1.0 x 1.0 m pattern & 75 mm WWF, 100-150 mm Fibercrete (13%) Category D: Steel sets at 1.22 m spacing & lagging (14%)	Pre-cast concrete invert segments 633 mm deep, 915 mm gauge, double track on steel ties with 44.64 kg/m rail Note: Pre-cast invert segments and rail for TBM tunneling will be similar to those used for ESF.	- 150 mm Water - 200 mm Compressed air - 150 mm Waste water - 12.47 kV Power - 1675 mm Vent duct - 915 mm Conveyor	

Table 8.3.3-2. Repository Openings Configuration and Equipment – Construction and Development Phases (Continued)

Opening	Ground Support	Roadway	Utilities/Conveyor	Remarks
5.0 m or 5.5 m TBM (Depending on emplacement mode selected)				
Emplacement Drifts	Temporary support for all categories consists of Splitset rockbolts and WWF. Final support consists of: Category A: Grouted rockbolts, 1.5 x 1.5 m pattern. (19%) Category B: Grouted rockbolts, 1.5 x 1.5 m pattern with spot bolting. 25-75 mm Fibercrete. (54%) Category C: Grouted rockbolts, 1.0 x 1.0 m pattern, 75-150 mm Fibercrete. (27%) In intersection of the emplacement drift & Exhaust Main, Fibercrete only to facilitate excavation of the main.	Access ramp through crosscut fitted with 915 mm gauge, single track on steel ties with 44.64 kg/m rail required for constructing the Emplacement Drifts. Upset end steel ties directly on tunnel invert, 915 mm gauge, single track on steel ties with 44.64 kg/m rail.	- 100 mm Water - 150 mm Compressed air - 100 mm Waste water - 12.47 kV Power - 915 mm Vent duct - Muck removal by railcars to a conveyor transfer point.	"Analysis of Ground Stability and Support," see Appendix B, is based on 2.5 m cement grouted steel dowels in emplacement drifts. Further analyses needed to optimize bolt type and length.

Table 8.3.3-2. Repository Openings Configuration and Equipment – Construction and Development Phases (Continued)

Opening	Ground Support	Roadway	Utilities/Conveyor	Remarks
Mechanical Excavator				
UB Exhaust Main, LB Development Shaft Exhaust Drift, Misc. Access & Ventilation Drifts (6.75 m x 6.75 m)	Category A: 1.5 x 1.5 m pattern rockbolts, 100 - 150 mm Fibercrete. (46%) Category B: 1.0 x 1.0 m pattern rockbolts, 100-150 mm Fibercrete (54%).	Cast-In-Place (CIP) 300 mm concrete floor.	- 100 mm Water - 150 mm Compressed air - 100 mm Waste water - 12.47 KV Power - 915 mm Vent Duct - LHD muck removal to conveyor transfer point. In Exhaust Main, LHD transfers to railcars in a previously finished Emplacement Drift.	Drive exhaust main in short sections as the emplacement drifts are completed.
UB East Main Extension & Misc. Drifts (6 m x 6 m)	As above.	CIP 300 mm concrete floor, 915 mm gauge, single track on steel ties with 44.64 kg/m rail.	As above except muck removal by railcar.	
UB East Main & LB Main Crosscuts (5.5 m x 5.5 m)	As above.	CIP 300 mm concrete floor.	As above.	

Table 8.3.3-2. Repository Openings Configuration and Equipment – Construction and Development Phases (Continued)

Opening	Ground Support	Roadway	Utilities/Conveyor	Remarks
Mechanical Excavator				
UB West side Turnouts (7.6 m x 7.0 m)	Category A: 1.5 x 1.5 m pattern rockbolts, 100 - 150 mm Fibercrete. (46%) Category B: 1.0 x 1.0 m pattern rockbolts, 100-150 mm Fibercrete (54%).	CIP 300 mm concrete floor.	- 100 mm Water - 150 mm Compressed air - 100 mm Waste water - 12.47 kV Power - 915 mm Vent duct - LHD muck removal to a conveyor transfer point.	Use "Air Pallets" to carry emplacement drift TBM from breakout to transporter. Move TBM by rail to UB TBM Launch Main. Back out trailing gear through completed emplacement drift to next drift.
Access Drift (5 m x 5 m)	As above.	CIP 300 mm concrete floor.	As above.	
TBM Launch and Disassemble Chambers	As above.	Steel/concrete launch cradle, 300 mm concrete floor, 915 mm gauge, double track on steel ties with 44.64 kg/m rail. Overhead monorails installed for TBM assembly/disassembly.	As per corresponding main.	9 m TBM chambers 10.5 m x 12 m x 42 m, plus 20 m access drift. 7.62 m TBM chambers 9 m x 11 m x 42 m, plus 20 m access drift.

Table 8.3.3-2. Repository Openings Configuration and Equipment – Construction and Development Phases (Continued)

Opening	Ground Support	Roadway	Utilities/Conveyor	Remarks
Ventilation Shafts Emplacement & Development Exhaust Shafts (6.1 m finished diameter)	Splitset bolts, 1.5 m x 1.5 m pattern, and 75 mm WWF for temporary support, concrete lining from surface to UB and shotcrete lining from LB to UB for permanent support.		- 100 mm Water - 150 mm Compressed air - 100 mm Waste water - 12.47 kV Power - 915 mm Vent duct	From surface to horizon, raise borer and down reamer shaft excavation. Sinking bucket and deck needed for shaft excavation. From LB to UB, drill-and-blast using raise climber or similar technique.

Table 8.3.3-3. Repository Openings Configuration and Equipment – Emplacement Phase

Opening	Ground Support	Roadway	Utilities	Remarks
ESF 7.62 m TBM tunnel - North Ramp - UB East Main - South Ramp	Maintain as necessary	In the North Ramp, grout existing pre-cast concrete inverts and overlay with 300 mm reinforced CIP concrete cap. (Note: In the UB East Main, CIP concrete cap 600 mm thick to accommodate emplacement drift elevations.) Replace ESF track with 1.44 m gauge, double track with 57.05 kg/m rail. In the South Ramp, use ESF roadway and track during construction. By Caretaker period upgrade as per North Ramp. (Note: See Section 9.1 for details of Caretaker period)	Remove conveyor and ventilation duct, and replace construction utilities with repository grade systems, consisting of: - Water - Compressed air - Mine water - Electric power - Monitoring - Control Details of these systems not yet determined.	Maintenance may include removal of channel sections and WWF, scaling to firm ground, installation of grouted steel dowels, and/or application of Fibercrete.

Table 8.3.3-3. Repository Openings Configuration and Equipment – Emplacement Phase (Continued)

Opening	Ground Support	Roadway	Utilities	Remarks
7.62 m TBM North & South Ramp Extensions UB West Main LB Access Ramps LB Main	Maintain as necessary.	In the North Ramp Extension and LB Access Ramps overlay existing pre-cast concrete invert with 300 mm CIP reinforced concrete cap. In the UB West Main and LB Main CIP concrete cap 600 mm thick. Replace construction track with 1.44 m gauge, double track with 57.05 kg/m rail.	Remove conveyor and ventilation duct, and replace construction utilities with repository grade systems, consisting of: - Water - Compressed air - Mine water - Electric power - Monitoring - Control Details of these systems not yet determined.	Maintenance may include removal of channel sections and WWF, scaling to firm ground, installation of grouted steel dowels, and/or application of Fibercrete.

Table 8.3.3-3. Repository Openings Configuration and Equipment – Emplacement Phase (Continued)

Opening	Ground Support	Roadway	Utilities	Remarks
9 m TBM				
UB & LB TBM Launch Mains	Maintain as necessary.	Overlay existing pre-cast concrete invert with 600 mm reinforced CIP concrete cap. Replace construction track with 1.44 m gauge, single track with 57.05 kg/m rail.	Remove conveyor and ventilation duct, and replace construction utilities with repository grade systems, consisting of : - Water - Compressed air - Mine water - Electric power - Monitoring - Control Details of these systems not yet determined.	Maintenance may include removal of channel sections and WWF, scaling to firm ground, installation of grouted steel dowels, and/or application of Fibercrete.
LB Exhaust Main		Replace construction track with 1.44 m gauge, single track with 57.05 kg/m rail.	As above.	
5.0 m or 5.5 m TBM (Depending on emplacement mode selected.)				
Emplacement Drifts	Ground support design for emplacement drifts based on "No Planned" maintenance.	Remove construction track. Place graded and compacted tuffaceous fill to depth of 700 mm. Install 1.44 m gauge, double track on steel ties with 44.64 kg/m rail.	Remove all construction utilities.	

Table 8.3.3-3. Repository Openings Configuration and Equipment – Emplacement Phase (Continued)

Opening	Ground Support	Roadway	Utilities	Remarks
Mechanical Excavator				
UB Exhaust Main, LB Development Shaft Exhaust Drift, Misc. Access & Ventilation Drifts (6.75 m x 6.75 m)	Maintain as necessary.	Install 1.44 m gauge, single track on steel ties with 57.05 kg/m rail.	Remove construction utilities.	Maintenance to include installation of additional rockbolts or application of additional Fibercrete.
UB East Main Extension & Misc. Drifts (6 m x 6 m)		Remove construction track, and install appropriate repository grade track.	Remove construction utilities. In UB Main Extension install repository systems as per UB East Main.	
UB East Main & LB Main Crosscuts (5.5 m x 5.5 m)		Remove construction track and ramp, and replace with 1.44 m gauge, single track with 57.05 kg/m rail.	Remove construction utilities.	

Table 8.3.3-3. Repository Openings Configuration and Equipment – Emplacement Phase (Continued)

Opening	Ground Support	Roadway	Utilities	Remarks
Mechanical Excavator				
UB West Main Turnouts (7.6 m x 7.0 m)	Maintain as necessary.	Install 1.44 m gauge, single track on steel ties with 57.05 kg/m rail.	Remove construction utilities.	Maintenance to include installation of additional rockbolts or application of additional Fibercrete.
Access Drift (5 m x 5 m)		As above.	Remove construction utilities.	
TBM Launch and Disassemble Chambers		Remove construction track and install appropriate repository grade track.	Remove construction utilities and install appropriate repository systems.	
Ventilation Shafts				
Emplacement & Development Exhaust Shafts (6.1 m finished diameter)	Maintain as necessary.		Remove construction systems.	Install headframe structure, hoist, and conveyance for inspection and maintenance.

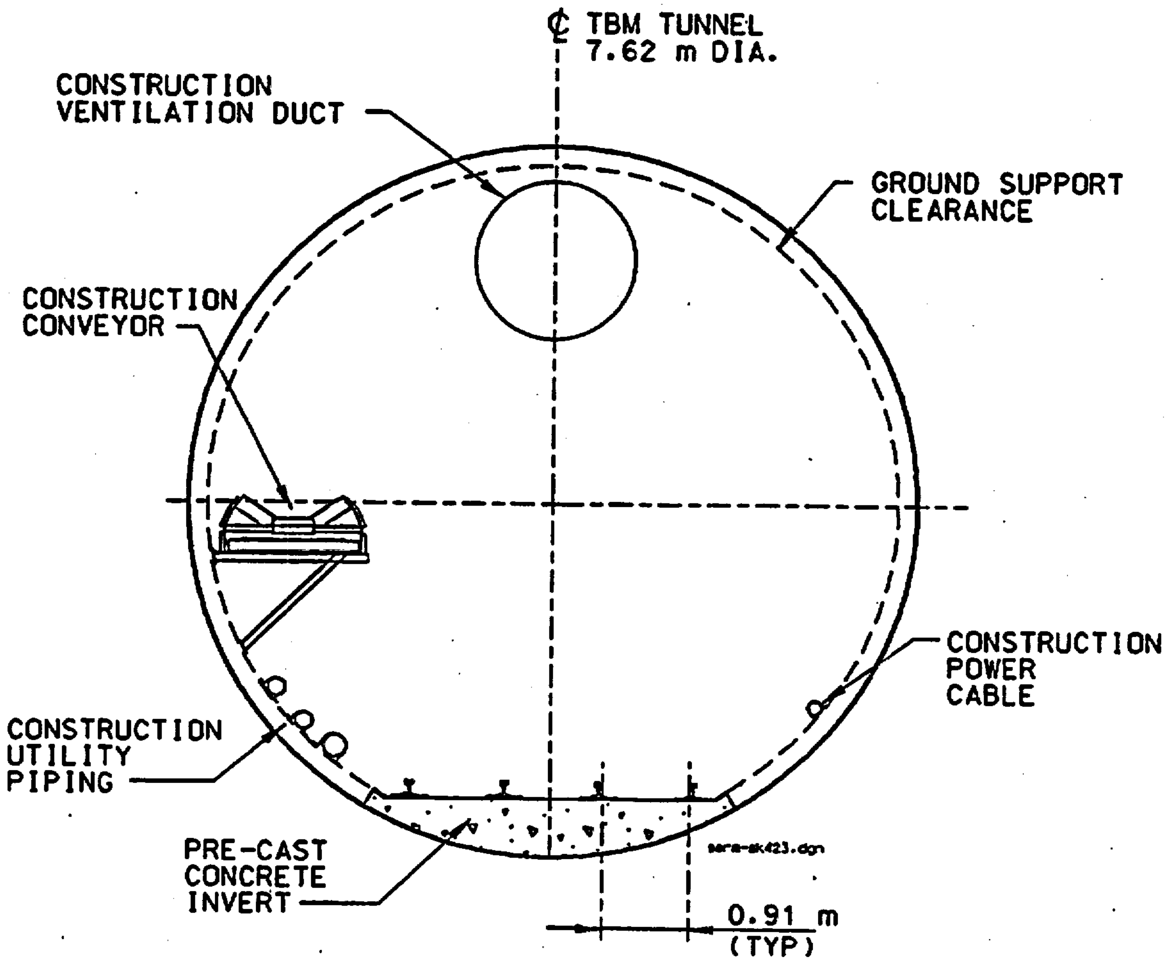


Figure 8.3.3-7. Cross Section of 7.62 m Diameter TBM Tunnel - Construction Phase

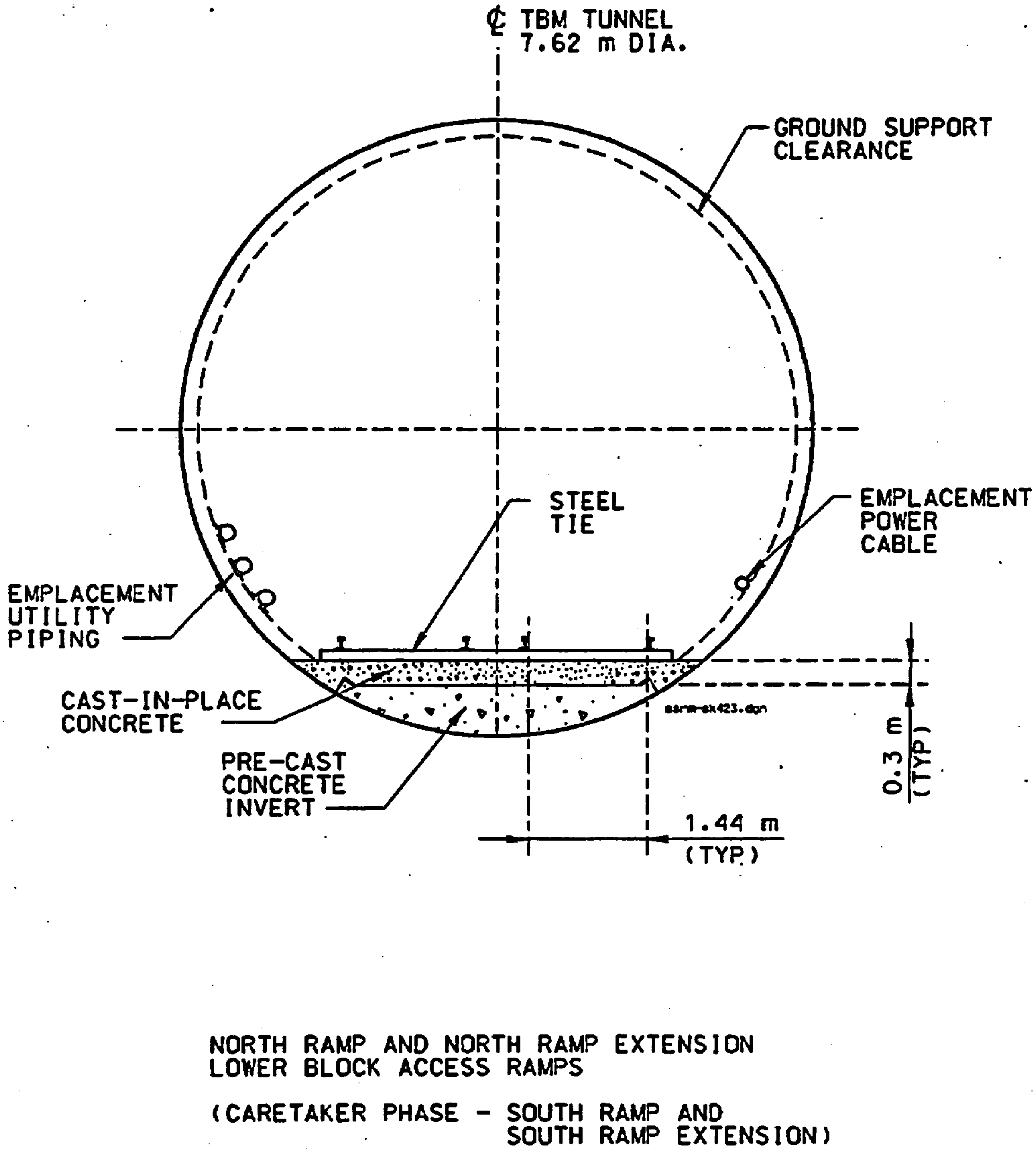
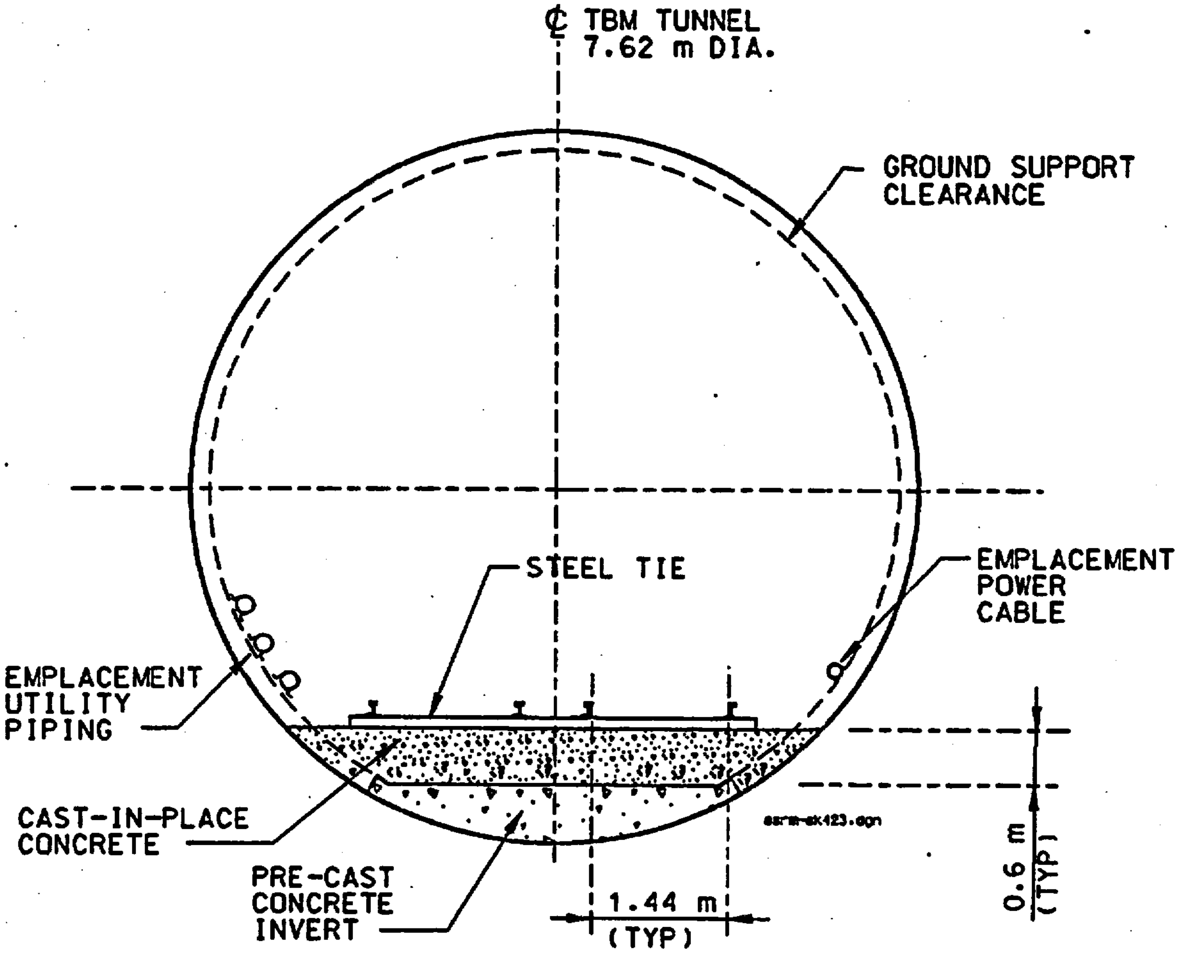


Figure 8.3.3-8. 7.62 m Diameter TBM Tunnel Cross Section of Ramps - Emplacement Phase



UPPER BLOCK WEST MAIN
UPPER BLOCK EAST MAIN
LOWER BLOCK MAIN

Figure 8.3.3-9. 7.62 m Diameter TBM Tunnel Cross Section of Mains- Emplacement Phase

8.3.3.1 Access Ramps

Access ramps will be 7.62 m diameter and excavated by TBM. Repository access includes the North Ramp, North Ramp Extension, South Ramp, South Ramp Extension, and the Lower Block North and South Access Ramps. The North Ramp and South Ramp will be constructed as part of the ESF and incorporated into the repository. The South Ramp Extension and both Lower Block Access Ramps will be excavated as part of repository development. The North Ramp Extension is currently designed to be part of the ESF; however, there are indications that this drift will not be excavated with the ESF drifts. Therefore, for this MGDS ACD Report, the North Ramp Extension is considered to be constructed as part of the repository.

The North Ramp will initially support repository construction. It will then serve as the access for waste package transportation from the surface to the repository horizon (CRWMS M&O 1995a, Key 047) and as the primary air intake for the emplacement side. Since the ventilation systems between emplacement and excavation are to be separated (YMP 1994a, 3.7.5.B.3), the South Ramp will serve as the access for development and as the primary air intake for the development side. During the caretaker period, the South Ramp will serve as a second access for the repository.

Details of the repository operations support systems have not yet been determined, although they will likely include water, compressed air, and waste water lines; fire suppression system; electric power distribution system; lighting; and monitoring and control systems.. The North Ramp, Upper Block East Main, and South Ramp ground support will be upgraded to repository standards where deterioration is present to minimize tunnel maintenance during the emplacement and caretaker periods.

8.3.3.2 Service Mains

The service mains will be 7.62 m diameter and excavated by a TBM. They will consist of the North Ramp Extension, the Upper Block East Main (ESF Topopah Spring Main Drift), the Upper Block West Main, and the Lower Block Main. The Upper Block East Main will be driven as part of ESF construction and the two other service mains as part of repository construction. Over their life, the service mains will have both construction/development and emplacement functions. During the simultaneous repository emplacement and development phases, one section of the mains will be equipped for emplacement and the other for development. For example, as development advances from north to south along the upper block, the north end of the Upper Block East Main will have repository roadway and track designed for the heavy waste package transporters and will be equipped with repository utilities, operating systems, and control systems. The south end of the main will utilize the construction track and roadway, muck conveyor, ventilation duct, and utilities installed as the tunnel is excavated. Isolation air locks will separate the two sections of the main. As construction advances south in steps along the block, the construction systems will be removed and the repository operating systems installed.

Crosscuts are excavated from the Upper Block East Main and the Lower Block Main through to the Upper and Lower Block TBM Launch Mains, respectively. The crosscuts are excavated after the mains are complete and ahead of the emplacement drifts. They provide access for the waste package transporter and carry control and monitoring systems for the emplacement drifts.

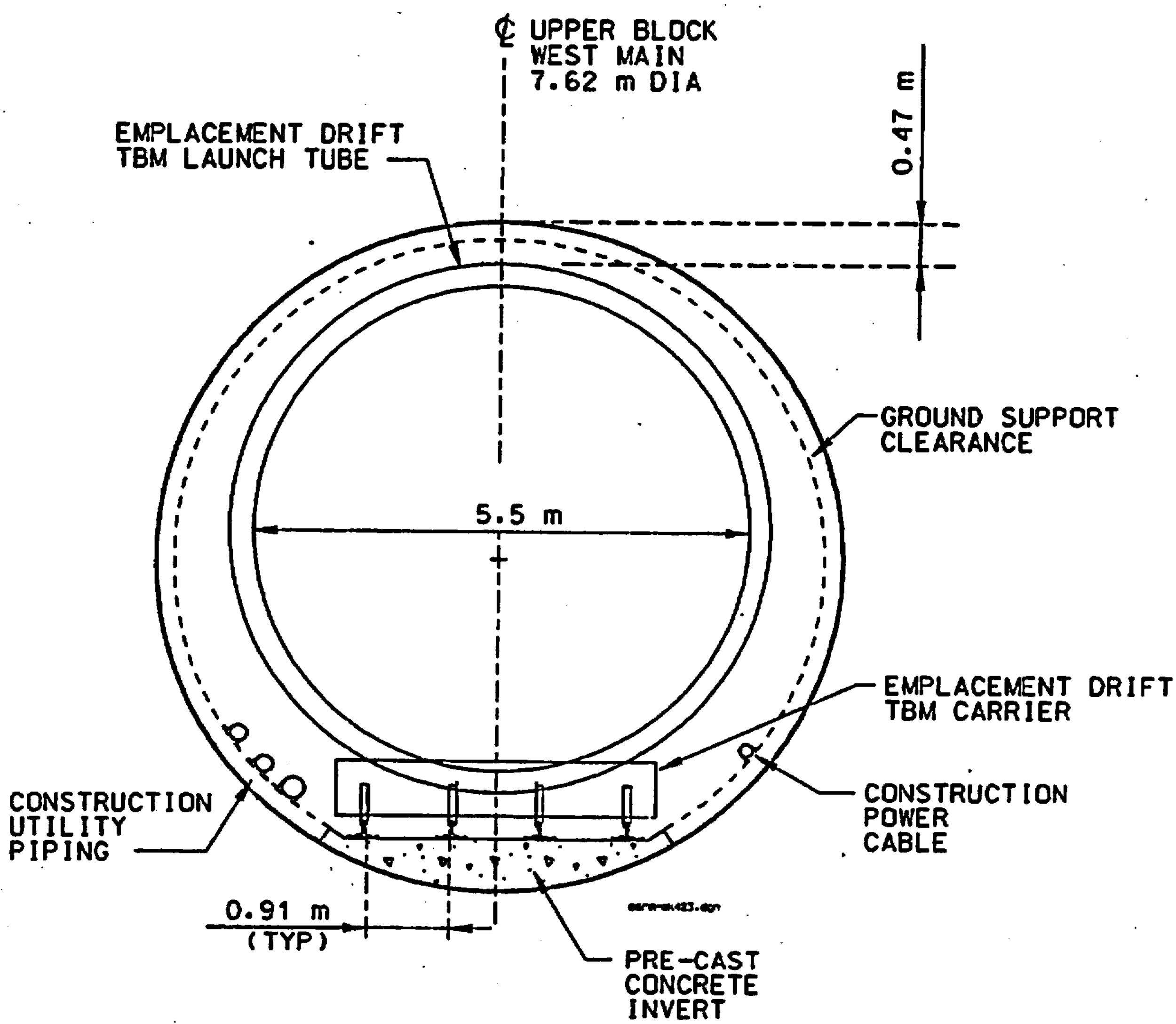
During construction, the Upper Block West Main will have a somewhat different function than that described for the East Main. On completion of TBM excavation, the conveyor and ventilation duct will be removed to provide clearance for the TBM carrier that will relocate the emplacement drift TBM; see Figure 8.3.3-10. The TBM carrier will travel along the 7.62 m diameter West Main, into the 9.0 m diameter TBM launch main, and to the launch position for the next emplacement drift. See Section 8.4.3 for a description of the emplacement drift construction, including the TBM carrier concept.

Turnouts excavated from the West Main will facilitate recovery of the emplacement drift TBM and provide access for the waste package transporter into the emplacement drifts on the west side of the upper block. Figure 8.3.3-11 shows a typical turnout configuration and waste package transporter. The turnouts will be excavated ahead of the emplacement drifts as the emplacement drift TBM needs space to break out into. The turnouts turn to the north at the West Main, as they are shorter than if turned to the South. This will maximize the effective length of the emplacement drifts and reduces the distance for moving the emplacement TBM to the service main track after it breaks out from the emplacement drift. The turnouts will also allow the emplacement drift TBM carrier clearance to turn into a 7.62 m drift. Direct breakout of the TBM into the West Main would necessitate a larger 9.0 m diameter opening because of equipment clearances, as is the case with the Upper Block and Lower Block TBM Launch Mains and the Lower Block Exhaust Main.

8.3.3.3 TBM Launch and Recovery Mains

The TBM launch mains will be excavated by a 9.0 m diameter TBM. The launch mains include the Upper Block TBM Launch Main and the Lower Block TBM Launch Main. The recovery main in the lower block is a continuation of the TBM Launch Main. This recovery main will double as the Lower Block Exhaust Main after it is excavated. The 9.0 m diameter tunnel provides necessary clearance to turn the emplacement drift TBM within the launch tube into position when starting excavation of the emplacement drift and for recovering it when excavation is completed. See Section 8.4.3 for discussion on launching the TBM for emplacement drift excavation.

Upon completion, the conveyor and ventilation duct will be removed from the launch mains to provide clearance for the emplacement drift TBM carrier. During emplacement, the TBM Launch Mains will provide an alternative pathway for air flow and will remain open to facilitate inspection of the emplacement drifts; otherwise, this drift has no major function during the emplacement phase.



NOTE: 5.5 m TBM SHOWN BECAUSE IT IS MORE LIMITING THAN 5.0 m TBM

Figure 8.3.3-10. Emplacement Drift TBM Carrier in 7.62 m Upper Block West Main

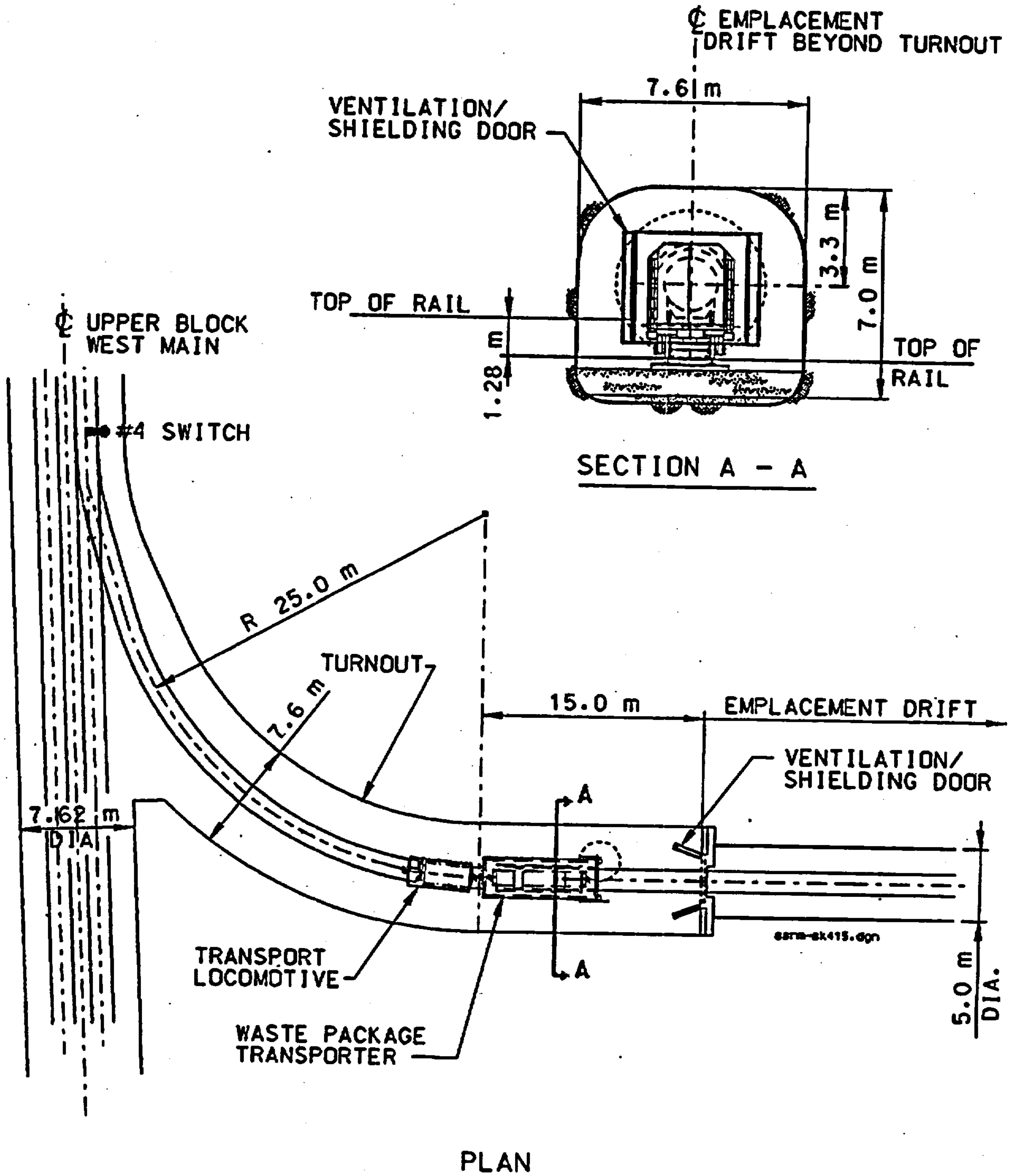


Figure 8.3.3-11. West Main Turnout

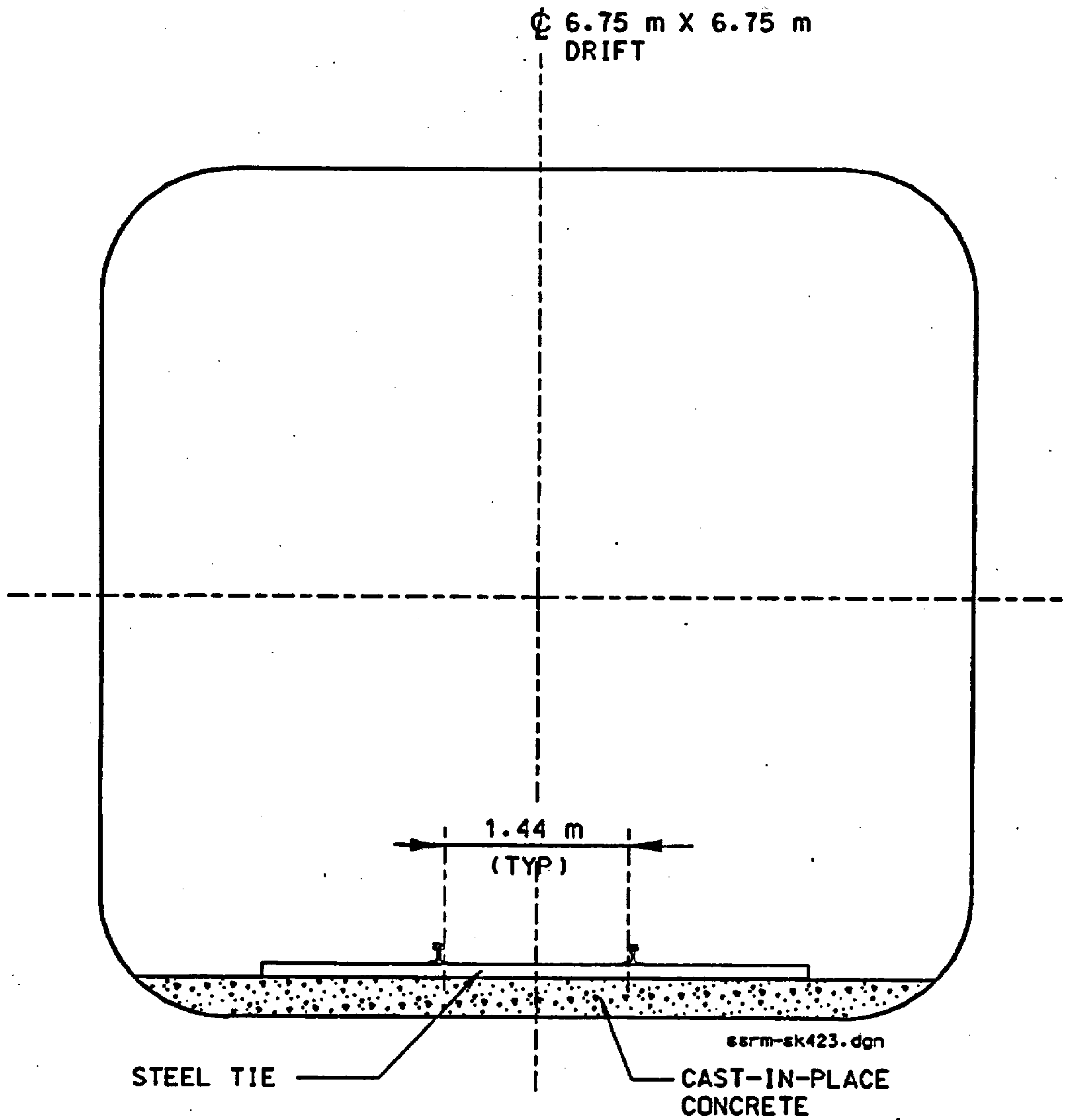
8.3.3.4 Non-TBM Openings

Slightly less than 10 percent of the repository openings will be excavated by mechanical excavators other than a TBM. These openings are either too short to justify setting up a TBM or they will be required to launch and recover a TBM. The non-TBM openings include the 7.62 m and 9 m TBM assembly and disassembly chambers, east side crosscuts, west side turnouts, the Upper Block Exhaust Main, ventilation connection drifts, and miscellaneous access connectors. The Upper Block Exhaust Main is the longest non-TBM opening and will be driven in sections as the emplacement drifts are completed. Figure 8.3.3-12 shows a 6.75 m x 6.75 m drift cross section (i.e., the Upper Block Exhaust Main) during the emplacement phase. All non-TBM openings will be equipped with a single track for monitoring and access throughout the life of the repository. Crosscuts and turnouts will be equipped with a double track for waste emplacement operations if a 5.5 m diameter emplacement drift is used. Other non-TBM openings will be similar to the 6.75 m x 6.75 m openings but of different dimensions. The opening cross sections will depend on function. Figure 8.6.3-2 in Section 8.6.3 illustrates the layout with emphasis on crosscuts and turnouts.

Figure 8.6.3-3 in the same section shows the detail of a typical crosscut using a 5.5 m diameter emplacement drift, which is a more complex arrangement because of the double track. Figure 8.3.3-11 in Section 8.3.3.2 shows the detail of a typical turnout for the emplacement drifts. This figure uses a 5.0 m diameter emplacement drift; however, the turnout configuration would not change much if a 5.5 m diameter emplacement drift was used because the turnouts are sized for the recovery of the emplacement drift TBM.

The 7.62 m assembly chambers, Figure 8.3.3-13, will be 9 m wide x 11 high x 42 m long. The 9.0 m assembly chambers, Figure 8.3.3-14, will be 10.5 m wide x 12 m high x 42 m long. There will be a 20 m access drift connecting each chamber to its host main drift. All assembly chambers will have the same setup inside the chamber for erecting TBMs. This includes a 300 mm concrete floor placed in the area around the launch cradle and a 633 mm concrete floor in the rest of the assembly chamber to bring the floor up to the same level as the pre-cast concrete invert in the main drift. A rail spur inside the chamber will connect with the main drift. The TBM head will be erected in place on the pedestal. Three monorails with overhead cranes mounted on the roof will carry TBM parts from railcars to the TBM for assembly. Utilities will be mounted on the drift walls. Once the TBM is complete, steel formwork will be placed between the grippers and the drift wall and concrete will be placed to form the launch cradle. The trailing gear is assembled on the surface, transported down the main drift, and connected to the TBM once the launch cradle is complete. When the TBM starts excavating, pre-cast concrete inverts will be added behind the head allowing the trailing gear to follow the TBM.

The disassembly chambers are similar to the assembly chambers, except they do not contain a launch cradle, and will be approximately the same size as the assembly chambers. Most of the disassembly chambers will be excavated ahead of time so as to not interfere with the TBM advance and will be excavated at the end of a TBM drift. When the TBM excavation is complete, the TBM will move forward into the chamber for disassembly. The trailing gear for the TBM will be disconnected and taken away before disassembly of the TBM head.



UPPER BLOCK EXHAUST MAIN
LOWER BLOCK DEVELOPMENT SHAFT EXHAUST DRIFT
MISCELLANEOUS ACCESS AND VENTILATION DRIFTS

Figure 8.3.3-12. Cross Section of 6.75 m x 6.75 m Drift - Emplacement Phase

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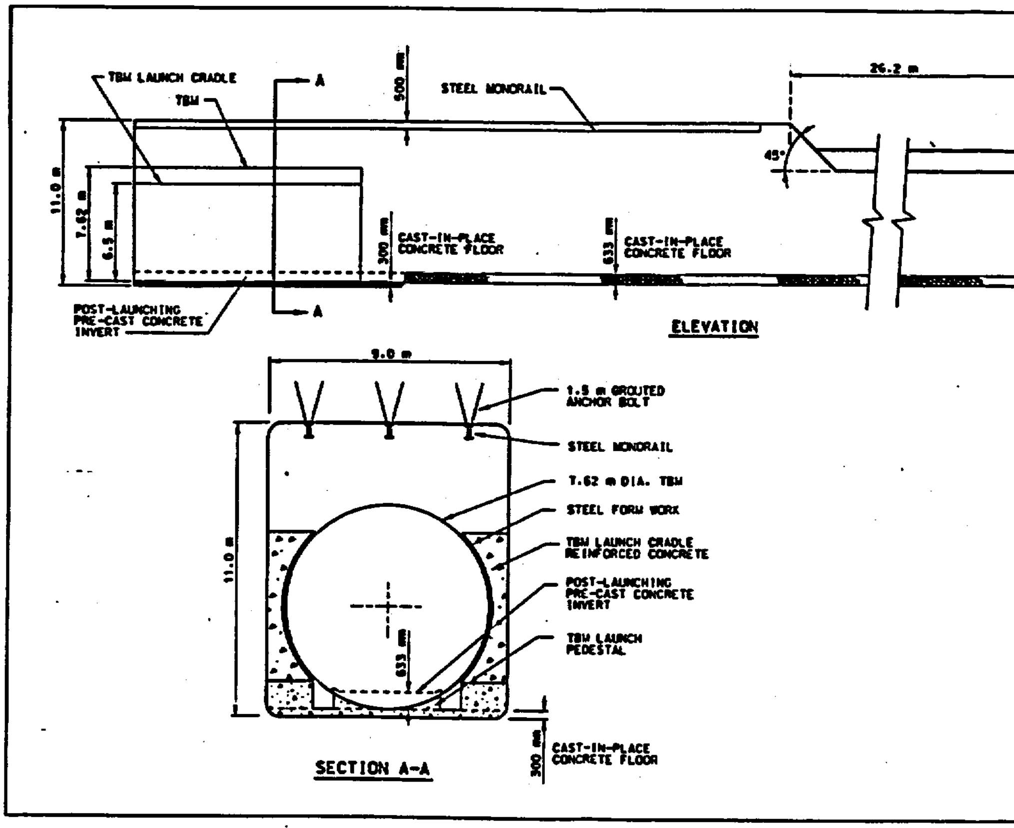

FIGURE 8.3.3-13

7.62 m TBM ASSEMBLY CHAMBER

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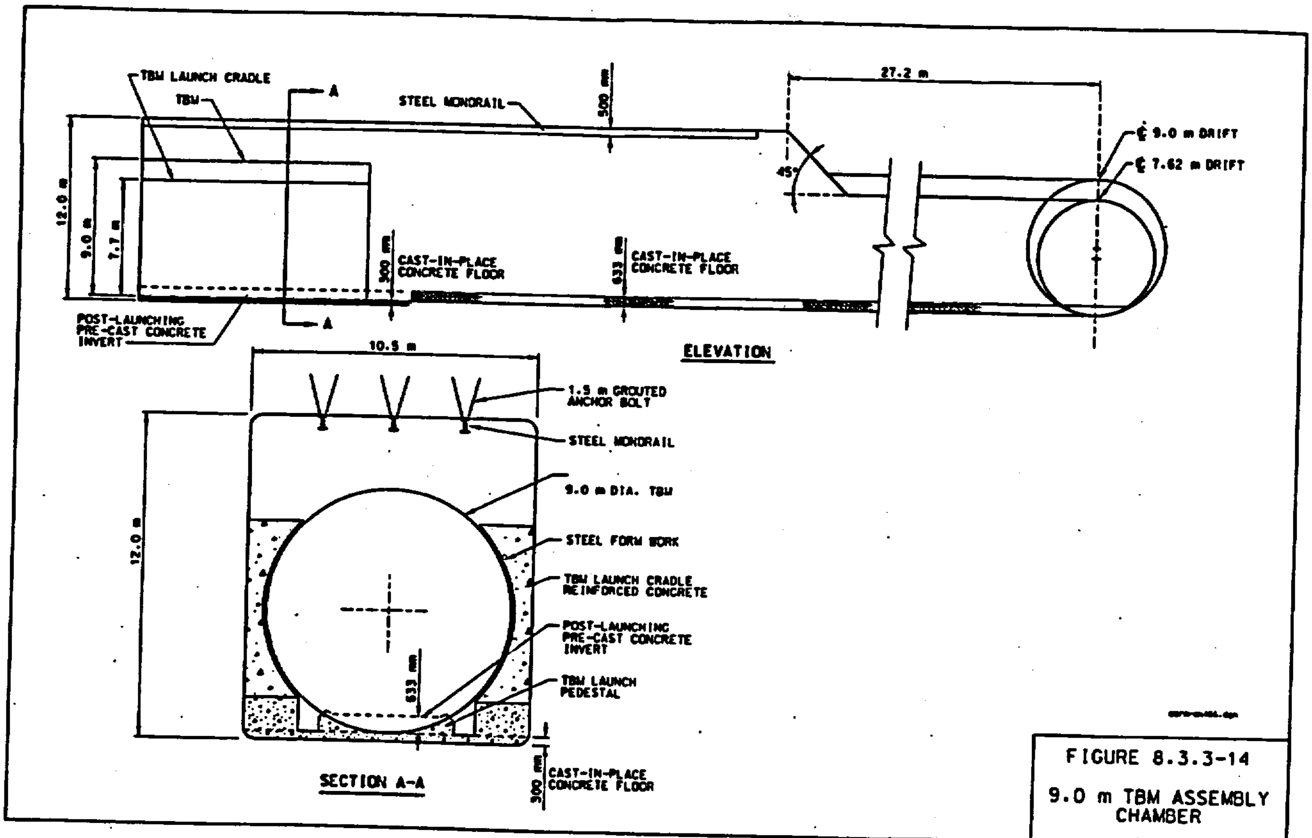

FIGURE 8.3.3-14

9.0 m TBM ASSEMBLY CHAMBER

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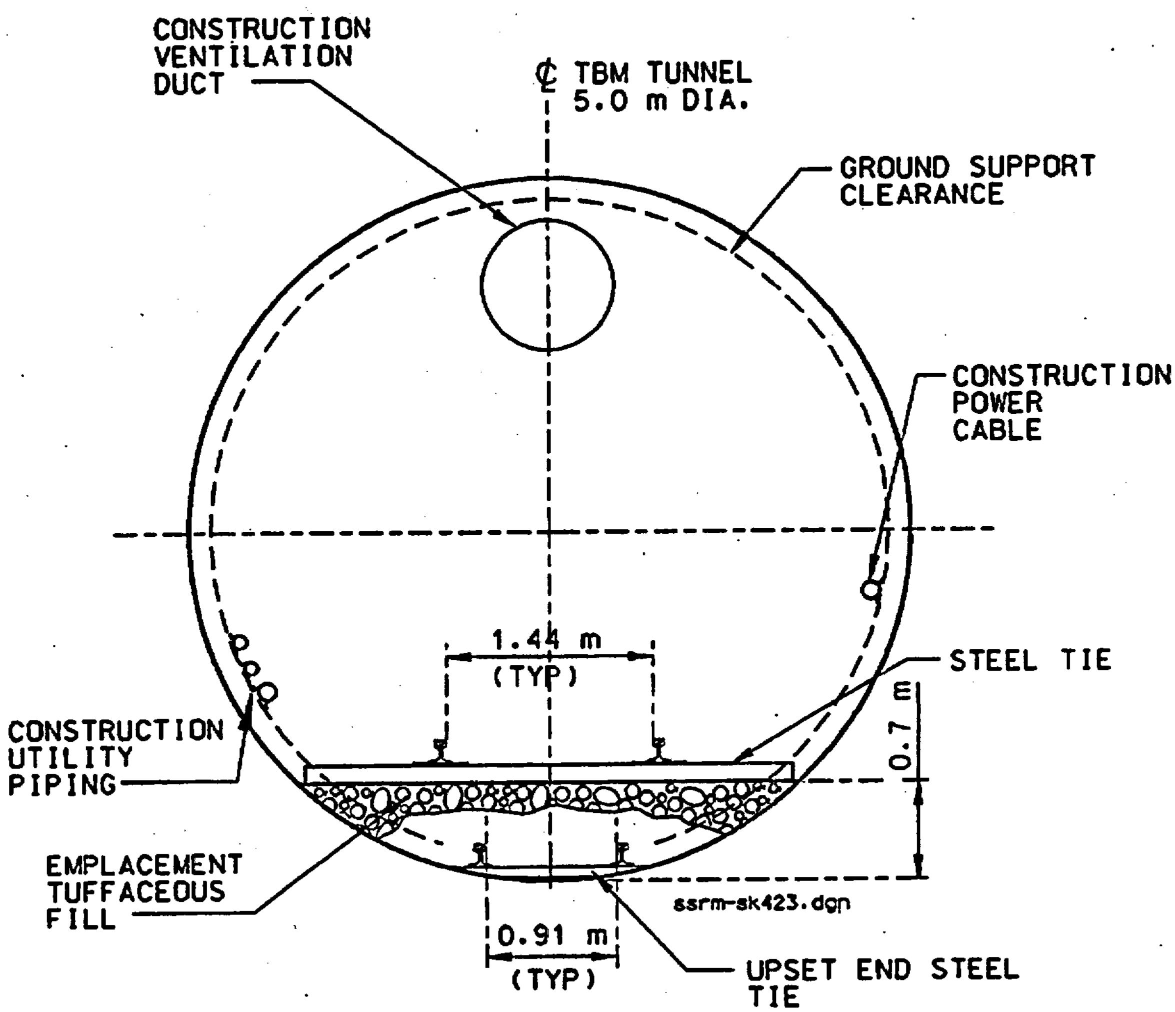
There is one instance when the disassembly chamber will not be at the end of the drift: the Lower Block Exhaust Main. The disassembly chamber will be constructed behind the TBM as the TBM reaches the Emplacement Exhaust Shaft. The drift will be over-excavated to the correct chamber size, then the TBM will be backed up into the chamber for disassembly.

8.3.3.5 Emplacement Drifts

The 5.0 m or 5.5 m diameter emplacement drifts will be excavated by a TBM. Drift spacing will be 22.5 m center line to center line in either case. Figure 8.3.3-15 shows the drift cross section during construction and emplacement phases. The 5.0 m diameter emplacement drift would have a single track installed in the center of the drift (CRWMS M&O 1995a, Key 011). The 5.5 m diameter will allow installation of the double track needed for the off-center in-drift waste emplacement mode. The waste packages are set on railcars which are pushed by a remote control locomotive to their assigned positions in the drift. The railcars remain with the waste packages in the drift. Normal retrieval simply involves pulling the railcars and waste packages back out of the drift in the opposite order of emplacement.

A 35 m "standoff" from the edge of the adjacent main to the center line of the nearest emplaced waste package has been established to limit thermal effects on the main. This standoff also reduces radiation entering the main. Radiation shields ("shadow shields"), constructed of reinforced concrete, will be placed in front of the first and behind the last waste package in the emplacement drifts. The radiation shields will further reduce the radiation leaving the emplacement drift by blocking the direct radiation component; although, reflected (albedo) radiation will bypass the shields. Total radiation at the ends of the drift will be reduced by approximately 90 percent. Figure 8.3.3-16 illustrates the radiation shield at the West Main end of the emplacement drifts. The radiation shields at the West Main are shown closer to the entrance of the emplacement drift because the turnouts provide most of the space needed to encompass the 35 m standoff distance. The radiation shields placed at the Upper and Lower Block TBM Launch Mains and at Lower Block Exhaust Main are positioned much farther from the entrance of the emplacement drift. This is because the 35 m standoff is the limiting factor, not the direct radiation component. These shields will be rail mounted to facilitate their placement and removal, if necessary. Figure 8.3.3-17 shows the radiation shields at the Upper Block Exhaust Main. These shields will be placed directly on the emplacement drift invert fill. See Section 10 for further discussion of radiation issues.

The heavy steel and concrete radiation doors, shown in the *Initial Summary Report for Repository/Waste Package Advanced Conceptual Design* (CRWMS M&O 1994a), have been eliminated in favor of lighter, although still substantial, nominal 25 mm thick plate, steel radiation/ventilation doors. These doors will provide additional radiation protection and control air flow in the emplacement drifts. The doors will be opened and closed remotely from the service mains by electric actuators. During emplacement and in the event of drift maintenance or retrieval, the ventilation doors will be opened; otherwise, they will be kept closed.



UPSET END STEEL TIE USED FOR CONSTRUCTION. TUFFACEOUS FILL INVERT AND 1.44 m GAUGE TRACK FOR EMPLACEMENT.

NOTE : UPSET END STEEL TIE, CONSTRUCTION RAIL, UTILITIES, AND VENTILATION DUCT REMOVED FOR EMPLACEMENT.

Figure 8.3.3-15. Cross Section of 5.0 m Diameter Emplacement Drifts

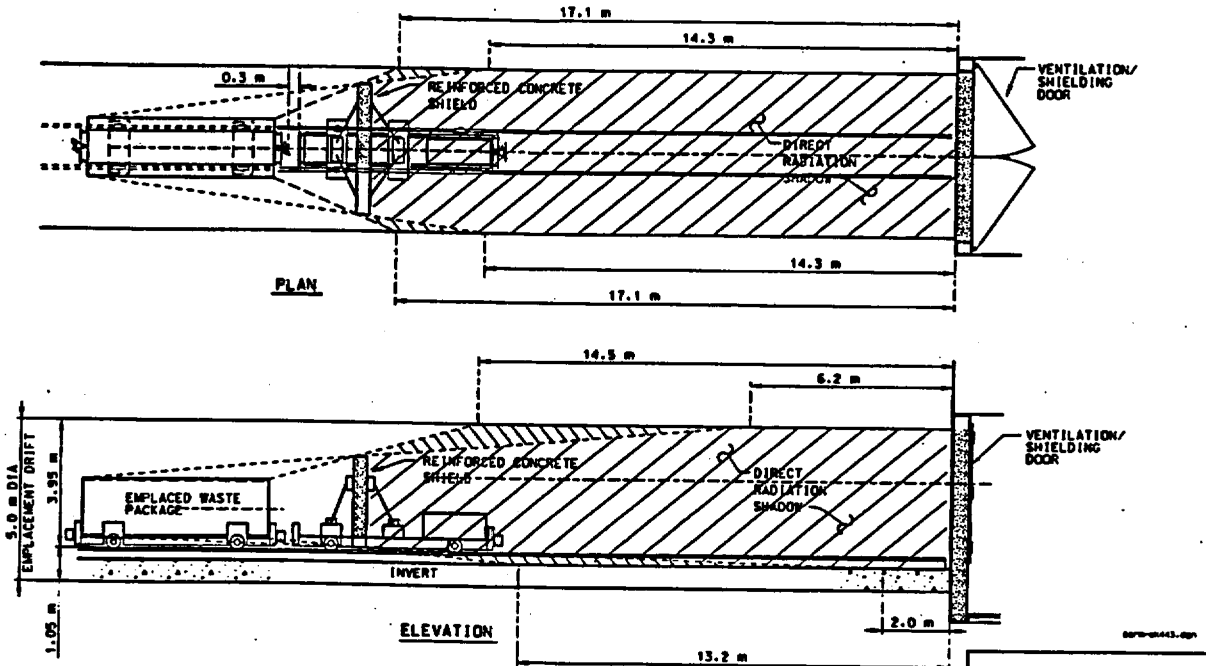


FIGURE 8.3.3-16
EMPLACEMENT DRIFT RADIATION SHIELD AT WEST MAIN

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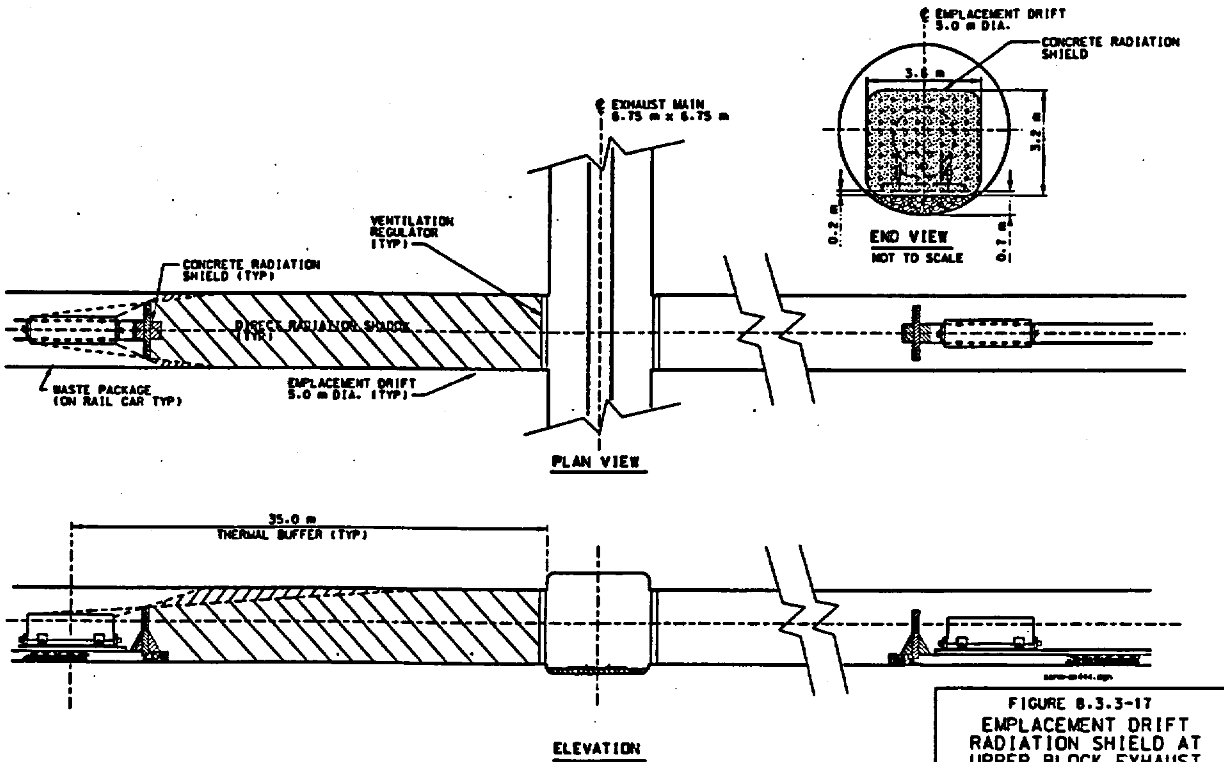

FIGURE 8.3.3-17
EMPLACEMENT DRIFT RADIATION SHIELD AT UPPER BLOCK EXHAUST MAIN

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8.3.3.6 Shafts

Two 6.1 m finished diameter shafts will be excavated for repository ventilation (CRWMS M&O 1995a, RDRD 3.7.5.N.5). One shaft will be located at the north end of the repository block and will serve as the emplacement exhaust pathway. The other shaft will be located at the south end of the block and will serve as the construction exhaust pathway. See Section 8.7 for a more complete description of the ventilation system. Figure 8.3.3-18 shows the two ventilation shafts.

The shafts will be excavated by mechanical methods where practical (CRWMS M&O 1995a, DCSS 014) and drill-and-blast where mechanical methods are impractical. The shafts will be excavated in two phases. First, the shafts will be excavated by mechanical methods from the surface to the upper block level. To accomplish this, access to each shaft at the upper block level must be complete. A raise bored pilot shaft, smaller than the final diameter, will then be excavated in each shaft from the upper block level to the surface. Once complete, the pilot shafts will be down reamed, at the final diameter size, to the upper block level. Muck will fall through the pilot shaft to the upper block level. The muck will be loaded by load-haul-dumps and carried to the nearest conveyor transfer point.

As excavation continues down each shaft, temporary ground support of Splitset rockbolts and welded wire fabric will be installed followed by a permanent concrete lining (CRWMS M&O 1995a, EBDRD 3.2.3.3.A.13 and DCSS 027). Sumps, 5 m deep, will be excavated by drilling-and-blasting below the upper block level of each shaft. Muck from the sumps will be removed by clamshell or similar method to a conveyor transfer hopper located near the shafts. The walls of the sumps will be concrete lined and the bottom left unlined. A bulkhead will be installed above the sumps even with the floor of the upper block stations to alleviate any hazards when the lower portion is excavated at a later date.

Second, the continued deepening of the shafts will not be initiated until the lower block main drift excavation is complete. Each shaft will use a raise climber or similar system to excavate the lower portion of the shaft from the lower block level to the upper block level. Blasted rock will fall to the lower block level where LHDs will load it and carry it to the nearest conveyor transfer point. Temporary ground support of Splitset rockbolts and welded wire fabric will be installed as the excavation advances upward. Once excavation of the entire lower portion of each shaft is complete, a layer of Fibercrete will be added for permanent support. The bulkheads at the upper block level will be removed when emplacement operations in the lower block begin.

On the emplacement side, the exhaust air fans will be located on the surface and "pull" air up the shaft; fresh air will enter through the North Ramp. The emplacement side will, therefore, be under slight negative pressure relative to atmosphere. Should monitors detect radiation, the exhaust air will be automatically diverted through high efficiency particulate air (HEPA) filters located on the surface, adjacent to the fans. This air will be a mixture of hot air, approximately 155°C, from leakage through the closed emplacement drifts, and cooler air from open drifts where waste packages are being emplaced. Therefore, the average air temperature exhausting through the shaft will be somewhat higher than the subsurface ambient temperature of 26°C.

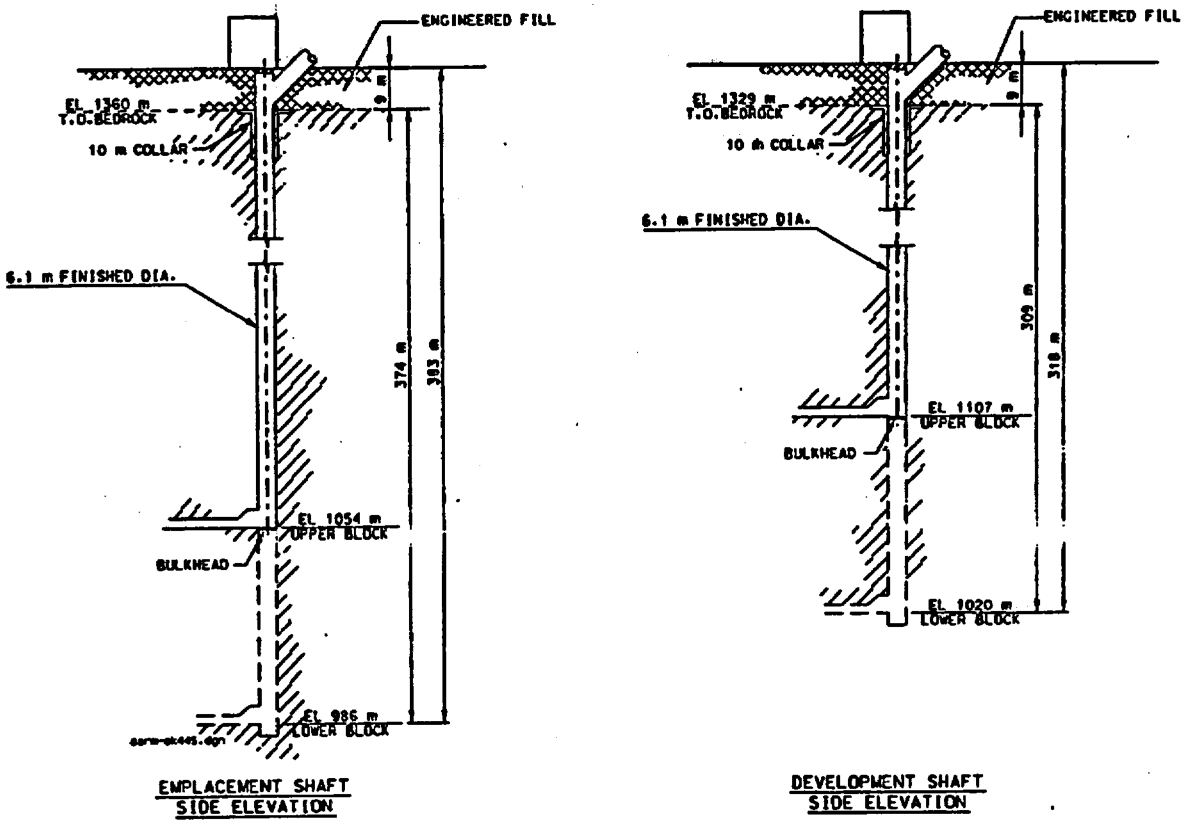

Figure 8.3.3-18. Repository Exhaust Ventilation Shafts During Upper Block Development

Construction side air will be forced by fans at the South Portal through the South Ramp to the repository level and will exhaust up the shaft. The construction side will, therefore, be under slight positive pressure relative to both atmosphere and the emplacement side, thus ensuring air leakage from the development to the emplacement side and not the other way around. Air in the construction side shaft will be at ambient repository temperature although dust laden from the excavation process.

The two shafts will also be used for emergency egress only as a last resort, and personnel will not normally be allowed in the shafts. The emplacement shaft will contain permanent monitoring equipment for radiological contamination; the development shaft will have the monitoring equipment installed once it is turned over to emplacement operations. Both shafts will require periodic monitoring to inspect the condition of the shaft lining and will be equipped accordingly. The concrete lining will require very little maintenance during the repository construction and emplacement phases.

8.3.4 Drainage Control

The low point for the upper block lies along the North Ramp Extension at the north end of the repository block. The low point for the lower block is the emplacement exhaust shaft. Water entering the repository will have a tendency to drain to these points. Water could be generated on the emplacement side by drilling operations for tunnel maintenance, from fire suppression incidents, or from a broken or open water line.

The emplacement drifts will be excavated at slight gradients so that any water entering the drifts will flow back to the service mains. The upper block drifts will slope up from the East and West Mains towards the Exhaust Main. Figure 8.3.4-1 illustrates a cross section of the 25th emplacement drift and shows the 0.5 percent gradient that slopes upwards to the Exhaust Main (CRWMS M&O 1995a, DCSS 009). The lower block emplacement drifts will slope up from the Main to a peak and then back down to the Exhaust Main.

A greater potential will exist for accumulations of water on the construction side. Since the entire repository layout slopes down towards the north end of the block, water will tend to flow from the development side to the emplacement side. Sumps and pumps will be installed on the development side of the isolation air locks to collect any water accumulation and pump it to the surface. However, ESF experience suggests that very little water flow occurs from excavation operations and that the dry ventilation air will quickly remove any accumulations of water.

8.3.5 Design Considerations

8.3.5.1 Layout Flexibility

Two types of flexibility are required of the subsurface layout. These include the flexibility to:

- accommodate a range of areal mass loads ("thermal load")
- allow adjustments to account for site specific conditions found during development (YMP 1994a, 3.5.7.H)

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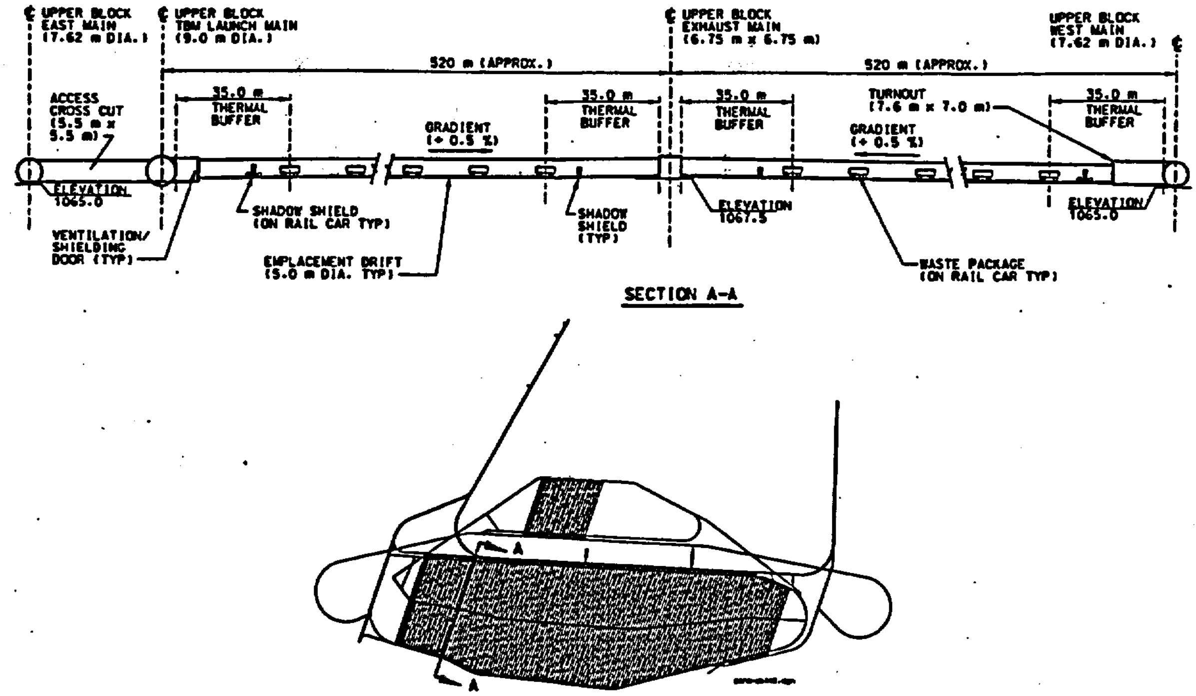

FIGURE 8.3.4-1
SECTION THROUGH
EMPLACEMENT DRIFT
#25 - UPPER BLOCK

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Because a final decision on AML (see Section 8.2 for detailed discussion of AML) has not yet been made, the repository subsurface design must incorporate flexibility to accommodate a range of AMLs. A layout (e.g., emplacement drift spacing) which allows a high AML can also be used for a low AML case (albeit with some wasted drift space). However, the converse is not true. That is, a layout developed specifically for a low AML will not easily accommodate a later change to a high AML.

A high AML requires drifts of reasonably close spacings to achieve the needed waste package density. If emplacement drifts are driven at 22.5 m center-to-center, for example, an AML of 100 MTU/acre is possible. If however, drifts are driven on 45 m or 90 m spacings to allow only a low AML, the individual waste packages cannot later be emplaced closely enough to achieve a high AML. For this reason, flexibility to change the AML comes at the expense of developing closely spaced emplacement drifts regardless of the AML being pursued. Section 12 details a strategy by which the program could maintain a high degree of AML flexibility well into the emplacement period without ultimately developing a great deal of unnecessary drifting.

As indicated above, the subsurface layout must also have sufficient flexibility, as required in 10 CFR 60.133(b), to "... allow adjustments where necessary to accommodate specific site conditions ..." This feature is provided in the reference layout as follows. During the course of emplacement drift excavation, ground conditions may be encountered which are considered unacceptable for waste emplacement. In this eventuality, two options are available to the repository constructor/operator. The drift being excavated can be completed and only those areas of the drift considered suitable for emplacement used; or the drift could be abandoned with the TBM being removed and relocated to the next emplacement drift to be excavated. The call would be made by the repository constructor/operator at the time it occurs, taking into account all known conditions.

Either of these events (completion with partial use or abandonment) would result in a loss of emplacement area. The layout accommodates this by having additional area in the lower block that can be excavated if more emplacement drifts are needed. The completed layout as shown in Figure 8.3.3-1 contains space for approximately 40 emplacement drifts that could be excavated over what is theoretically needed to emplace 70,000 metric tons at 83 MTU/acre. This amounts to approximately 10 percent additional space to account for lost emplacement area. Figure 8.3.5-1 shows the area which would be utilized at 83 MTU/acre with no loss of emplacement area. The lower block area without cross hatching represents the additional space available for emplacement if needed.

Another factor in maintaining flexibility is the orientation of the emplacement drifts. The emplacement drifts have been orientated to provide the most inherently stable arrangement; the orientation is such that the emplacement drifts are not parallel with any of the major joint sets (CRWMS M&O 1995a, DCSS 001). However, they could be reoriented, if necessary, should site characterization data dictate. Although the layout will handle this change, this action would cause part of the emplacement area to be lost if it occurs after excavation begins. Preferably, changes to the drift orientation should be made before emplacement drift excavation starts.

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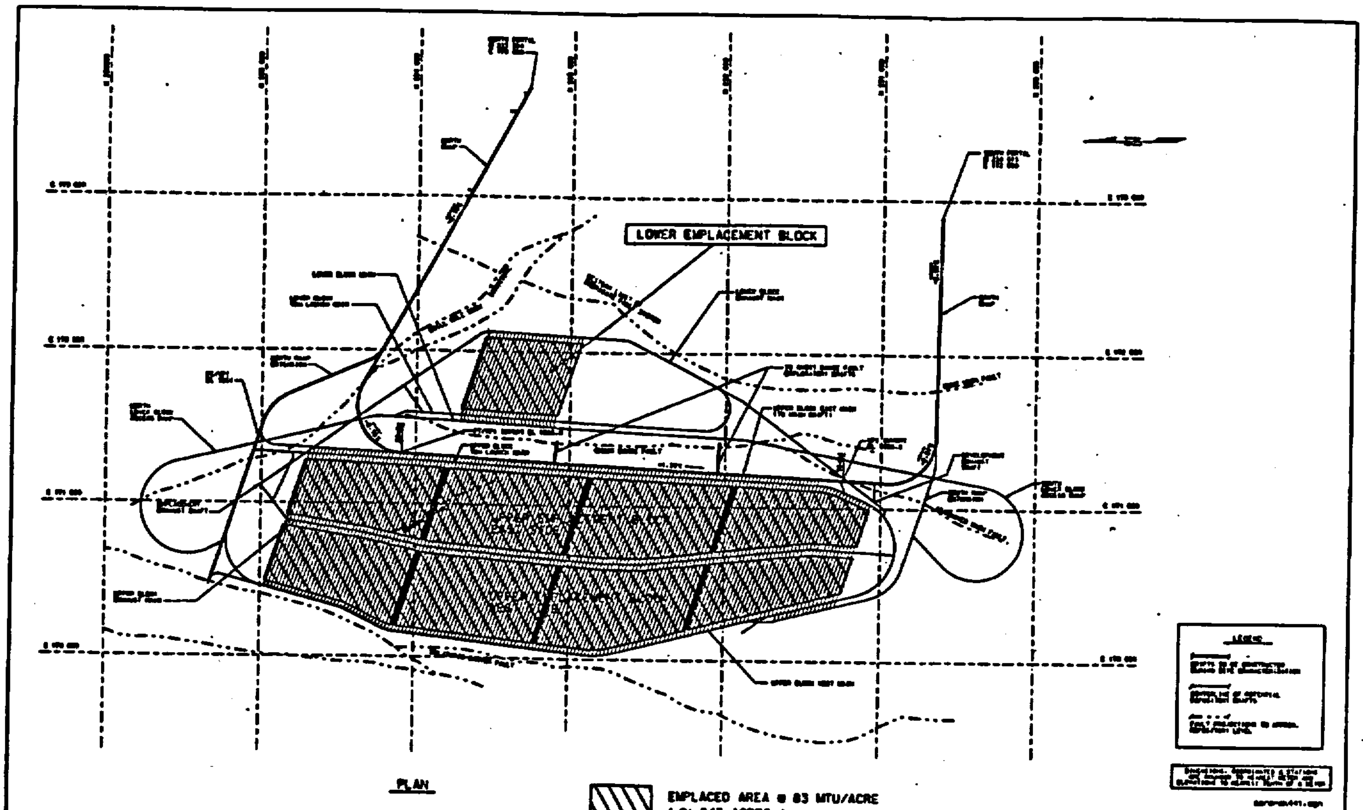

FIGURE 8.3.5-1
EMPLACEMENT AREA USED
@ 83 MTU/ACRE

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Not only will the layout accommodate changes in the orientation of emplacement drifts, but it will also accommodate a change to the diameter of the emplacement drifts. Experience gained during development and operation of the upper block or changes in scientific data could result in the need to modify the opening size of the emplacement drifts, even while still developing the upper block. Changes could be attributed to thermal considerations; construction techniques; or modifications to the ground support design, invert configuration, or rail configuration. The drift size could be increased or decreased depending on the need. It may also be possible that the lower block mains or emplacement drifts may undergo changes in tunnel sizes for the same reasons.

8.3.5.2 Layout Issues

The design of the repository layout is complex. There are several factors which influence the layout design, including: geology, spatial arrangement of the layout, thermal goals, thermal loading, excavation method, primary transportation method, emplacement mode, waste package design, and a change in the capacity of the repository. Future analyses will be needed to address these factors in terms of functionality, safety, constructability, and cost effectiveness. Further discussion of selected issues can be found in Section 12.2.

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8.4 SUBSURFACE CONSTRUCTION AND DEVELOPMENT

Repository subsurface construction is scheduled to begin three years after initiating the detailed design work. Detailed design will cover preparation of drawings and specifications for procurement and construction, and will include bidding documents and layouts for the initial construction effort. Contractors will be selected for the different phases of work and strategies for repository operations will be finalized.

Initial construction will cover all subsurface work that must be completed prior to emplacement of waste, and it includes the main TBM development and a finished block of emplacement drifts. The subsurface design will be based on the license application design, though some detailed design will continue throughout the subsurface development period.

8.4.1 Previous Work

The *Initial Summary Report for Repository/Waste Package Advanced Conceptual Design* (CRWMS M&O 1994a) provided a description of subsurface construction operations in Section 8.7 of that report. The discussion centered around the repository layout as it was presented at that time and consolidated information on the overall construction approach and interface of the development and emplacement modes of operation. It was in this report that the "in-drift" concept of emplacement was first described, since the concept of emplacing large waste packages had moved to the forefront with the advent of the MPC concept. This concept identified and broadly defined the emplacement side of the subsurface repository as a radiologically controlled area that would be separated from normal underground development operations by a system of controlled barriers that restrict the movement of personnel, equipment, and ventilation. A key philosophy of how and why a radiological boundary would be crossed was described, along with the implications of ventilation control, movement of supplies, equipment and personnel, and the physical movement of barriers between the two areas during development and emplacement activities.

Components of design were categorized under logical headings that described physical structures that were either connected or had a functional interface such as shafts and ramps, ventilation, excavation or utilities. These areas have been identified as configuration items and tend to organize design work into logical packages and deliverables. In the future these areas of interest will be investigated in specific reports.

The *Repository Shafts and Ramps Design Concepts Report for FY 1994* (CRWMS M&O 1994n) provided background information and preliminary shaft and ramp design concepts with key considerations in several major areas. Four different repository shaft configurations in conjunction with various South Ramp functions were described for the development side. Variations in configuration considered location of personnel and material transport systems, ventilation direction (intake or exhaust), excavated tuff handling, and routing of utilities.

Estimates of repository ventilation quantities, for both the development and emplacement sides, were summarized, and the configuration of the surface facilities that must be incorporated into shaft and ramp design was also presented.

Shaft sizes, hoisting alternatives, collar arrangements, and preliminary shaft surface facility arrangement concepts were developed for the four shaft configurations on the development side. Generic site plans were then developed for those shafts. The basic size and configuration of an emplacement side exhaust shaft was discussed. Preliminary ramp and ramp surface facility configuration concepts were also developed for selected ramp configurations on the development side.

Shaft construction alternatives were summarized, and methods that had been considered on an initial basis as potentially most suitable for mechanical excavation of shafts were presented. Mechanical methods considered most applicable used a pilot bore and ream approach.

Temporary shaft support and permanent support and lining considerations were summarized and options identified, by engineering judgement, for the various shaft sizes listed in the report. Emphasis on lining efficiency from a ventilation cost standpoint, and compatibility with the construction method, were also noted.

Conclusions were oriented toward the need to establish whether a shaft or a ramp is preferable for use as a corridor for personnel and materials to the repository. In conjunction with this, the location of the muck handling system, with its inherent health and safety risks, must be factored into shaft and ramp configuration selection.

In connection with subsurface development of access drifts, emplacement areas, and support areas, the *Excavation Systems Parameters* report (CRWMS M&O 1995aj) was produced in June 1995. This report addressed the equipment required for excavation and construction of the underground repository. A key design assumption was that the repository will be constructed by mechanical excavation equipment as opposed to drilling and blasting. This report reviewed the physical properties of the Topopah Spring welded tuff thermomechanical unit. These properties provided a basis for the preliminary evaluation and development of technical characteristics for excavation equipment. Both primary and secondary excavation equipment were considered in this report. Primary excavation was considered to be by TBM and constitutes the bulk of the excavation for the repository. Secondary excavation consisted of all other excavation and included short drifts, crosscuts, and ventilation/radiation door cutouts.

The TBMs that could be used for primary excavation were described as open beam, single shield, double shield, grip shield, and short-turning radius. The operating characteristics of the open beam TBM allow the installation of a wide variety of ground support systems, but a high length-to-diameter ratio makes this machine difficult to move as one piece in constricted underground tunnels. The grip-shield TBM has grippers used for advancing and positioning the machine as part of the machine's shielding. This type of TBM is currently being used in the ESF development. The grip-shield machine can use a wide variety of ground support systems and thus advance in difficult ground conditions. The short-turning radius TBM, as its name implies, has a turning radius of about 12 m versus 200-300 m for other TBMs. This type of machine has only been used once for construction of a tunnel; therefore, the *Repository Layout Options Analyses Report* concluded that it would be risky to advocate this machine for the project (CRWMS M&O 1995ah).

The Repository Layout Options report addressed the four options being considered for the conceptual design of the repository at that time. Two of those options have sharp curves that require the short-turning radius TBM be used for their construction. Since this machine is not being considered for the project, the layout options with the sharp curves are not being considered further. One difference between options I and IV of that report is that in option I a 9.0 m diameter tunnel serves as the TBM launching drift and in option IV a 7.62 m diameter tunnel that has been excavated to a 7.62 m wide by approximately 8.1 m high horseshoe shape drift serves as the TBM launching area. Option I also has crosscuts that connect to the service main to facilitate TBM launching and muck haulage.

The report considered the large number of individual emplacement drifts that will be constructed. Construction of these emplacement drifts will require an equally large number of TBM launchings and retrievals. The launching system chosen should be simple and efficient to use. The concept of using a cylindrical "launching tube" to transport and launch the TBM can fulfill these goals. The necessity of moving the TBM many times in constricted underground openings suggests that a low length-to-diameter ratio be specified.

The grip-shield TBM, with its short-coupled design, offers significant advantages to the repository because of its low length-to-diameter ratio and its flexibility to advance in varying ground conditions. An open-beam TBM, if the machine's length can be reduced to nearly that of a grip-shield machine without compromising performance, also warrants further consideration. This is especially true because of its ability to accommodate a wide variety of ground support systems. It is recommended that the grip-shield type machine be used as a reference in future repository conceptual design work until better information on conditions in the Topopah Spring welded tuff unit are available from the ESF.

A number of machines and methods to perform secondary excavation were considered. All machines considered for secondary excavation will not be reiterated but the most promising equipment will be mentioned. A roadheader with a disc cutterhead is an emerging technological development for excavating the Topopah Spring welded tuff rock. A prototype of this machine could be tested in the ESF if available. The penetrating cone fracture machine uses a high pressure charge of propellent to fracture the rock. The ability to break the rock in tension may prove to be very cost effective when compared to other secondary excavation techniques.

The Wirth Continuous Mining Machine was considered worthy of further investigation because of its ability to perform both primary and secondary excavation roles and its potential to excavate non-circular drift profiles, that could reduce man-made material use in the emplacement drifts. Investigations should include detailed construction cost comparisons, including detailed logistical analysis.

8.4.2 Design Inputs

This section lists design inputs as contained in the *Repository Design Requirements Document* (YMP 1994a) and the *Controlled Design Assumptions Document* (CRWMS M&O 1995a). Design inputs from these documents are considered as unqualified, preliminary data that are used to generate concepts during Advanced Conceptual Design work.

8.4.2.1 Requirements

The following requirements are from the RDRD (YMP 1994a):

3.2.1.B: The Repository Segment will continue to expand the underground facility in parallel with waste emplacement operations. This is a unique program aspect in that construction becomes part of the operation of the system.

3.2.1.1.D: Because subsurface construction will continue after emplacement operations begin, radiological protection is required.

3.2.1.4.A: The repository shall be designed and constructed to permit the retrieval of any SNF [spent nuclear fuel] and HLW [high-level waste] emplaced in the repository, during an appropriate period of operation of the facility, as specified by the Secretary of Energy.

3.2.2.3.C: The GROA shall be capable of implementing and maintaining air sampling sufficient to identify potential hazards, to permit proper protective equipment selection, and to estimate exposure.

3.2.2.4.C: Visual and audible alarm systems shall be provided to alert workers if radiation levels exceed established design levels. Visibility and audibility of alarms shall be in accordance with NRC [U.S. Nuclear Regulatory Commission] Regulatory Guide 8.5.

3.2.3.2.2.A.5: All fluids used in the construction and operation of the underground facility shall be strictly controlled to avoid introduction of products that could accelerate waste package corrosion or transport radionuclides.

3.2.5.2.2.A: The size and arrangement of interior corridors and drifts shall accommodate the movement of equipment including initial equipment installation, facility operations, and possible future removal or replacement of equipment.

3.2.5.2.2.B: Facility design shall provide access for routine maintenance, repair, or replacement of equipment subject to failure.

3.2.6.2.5: Underground openings shall be designed and constructed to provide suitable ground control in compliance with 30 CFR 57, Subpart B.

3.3.8.1.E: Materials used for stabilization, compaction, dust control, site preparation, surface paving, construction, and utility systems shall be evaluated to ensure that they do not adversely impact waste isolation.

3.7.5.B.3: The underground facility ventilation system shall be designed to separate the ventilation of excavation and waste emplacement areas.

3.7.5.B.4: The underground facility ventilation system shall be designed to ensure that ventilation leakage between the emplacement system and the development system will always be from the development system to the emplacement system.

3.7.5.B.6: The underground facility ventilation system shall be designed to supply air to and exhaust adequate quantities of air [TBD] to and from underground working areas such that operator safety, health and productivity requirements are maintained.

3.7.5.C.1: The underground facility shall be ventilated to comply with the requirements of 30 CFR 31.9(a) for diesel locomotives, if used.

3.7.5.C.2: The underground facility shall be ventilated to comply with the requirements of 30 CFR 32.9(a) for other diesel-powered equipment, if used, in a non-gassy environment.

3.7.5.C.3: The underground facility shall be ventilated to comply with the requirements of 30 CFR 36.45 for other diesel-powered equipment, if used, in a gassy environment.

3.7.5.F.7: Space for storage of emergency equipment shall be provided.

3.7.5.G.1: Provisions shall be made to control dust due to drilling in rock, by the use of dust collectors, or by water or water with a wetting agent (water is the least preferred means), or by ventilation, or by any other approved method or device that is at least as effective in controlling dust.

3.7.6.B: During the early developmental stages of construction, a program of in situ testing of such features as borehole and access seals, backfill, and the thermal interaction effects of the waste packages, backfill, rock, and groundwater shall be conducted.

8.4.2.2 Controlled Design Assumption Document

The following assumptions are from the *Controlled Design Assumption Document* (CRWMS M&O 1995a):

Key 010	Integrated rail transport will be used for subsurface transport of waste packages.
Key 013	No human entry is planned in emplacement drifts while waste packages are present. The waste emplacement/retrieval equipment may use robotics and/or remote control features to perform operations and monitoring within the emplacement drifts. Under off-normal conditions, human entry will be considered if protection to the workers can be provided.
Key 027	The primary method of tunnel excavation will be mechanical.

Key 028	Where it is impractical to use mechanical methods, drill-and-blast may be used to a limited degree primarily in non-emplacement areas of the repository.
Key 030	Rail will be used for transporting underground supplies and personnel to the extent practical.
Key 047	The proposed repository surface facilities will be located adjacent to the north portal.
DCSS 005	Drift excavation methods: • Primary: TBM • Secondary: other mechanical methods, and drill-and-blast where mechanical methods are impractical.
DCSS 010	Repository material handling equipment: 1) Supplies: rail transport; 2) Excavated rock: conveyor belt, or conveyor belt variation preferred when practical.
DCSS 027	Organic materials (e.g., epoxy resin, timber) are limited for use as rock support and other postclosure permanent materials in all openings. Organic admixtures used in cementitious materials should be minimized to the extent practical. Concrete and steel are allowable preclosure construction material in all openings.
DCSS 028	Emplacement drifts will be designed to be stable through the caretaker period, with the goal to minimize or eliminate planned maintenance to sustain the ability to retrieve, sample, or relocate waste packages. Shafts, ramps, and all other drifts will be designed to be stable, but may rely on periodic planned maintenance.

8.4.3 Construction and Development Approach

Construction of the repository will commence three years after initiation of the final design. During the pre-emplacement construction period (scheduled to last six years), only construction will be in effect. After emplacement of waste begins, both development and emplacement activities will occur concurrently underground for 22 years. (YMP 1994a, 3.2.1.B.)

Prior to emplacement of waste, underground work is referred to as *construction*. Once emplacement starts subsurface construction is referred to as *development*. Emplacement and development activities will be separated, and generally dedicated emplacement and development crews will perform the respective work. With the exception of emergency or special, prearranged situations, the respective work crews will have no contact underground, and substantial isolation airlocks will separate the emplacement and development activities. Development activities will be conducted by underground workers and other individuals trained in subsurface excavation. Their separation from the emplacement activities will isolate them from the radiation hazards present on the emplacement side of the repository (YMP 1994a, 3.2.1.1.D.). Emplacement activities will be conducted by workers experienced in nuclear safety, remote handling and the special hazards associated with radioactive materials.

The ESF North Ramp will function as the main access for the initial repository construction that will consist of the North Ramp Extension, West Main, South Ramp Extension, and Upper Block TBM Launch Main. See Section 8.3 for the layout and orientation of these tunnels. Initial construction will use the existing ESF utilities (compressed air, water and waste water), conveyor, roadway (precast concrete invert segments), rail, ventilation ducts and fans, lighting, electric power distribution system, and construction control and monitoring systems. The construction systems installed in the new 7.62 m and 9.0 m TBM tunnels will be similar to those installed in the ESF tunnel. Section 8.3 contains construction system details. These systems will be used to support all construction and development activities in the subsurface.

The 7.62 m and 9.0 m TBM tunnels will start with the excavation of assembly and launch chambers and finish with the disassembly chambers. The TBMs will be assembled and disassembled underground and transported to and from the surface in components.

While the large TBM tunnels are under construction, crews can separate and reverse the conveyor in the East Main and South Ramp so that muck will exit the South Portal. Upon completion of the main TBM tunnels, all construction and development support will be shifted to the South Ramp. Using the North Ramp for initial construction will ensure minimal delays to the overall construction schedule. As construction support shifts to the South Portal, the North Portal will shift to waste emplacement operations (CRWMS M&O 1995a, Key 047). Construction of auxiliary support facilities such as shops, offices, and storage areas will also be completed.

Upon completion of the initial construction work the North Ramp construction systems will be removed and the ramp will be upgraded to repository standards. For repository operations the roadway will be improved and wider gauge track with heavier rail will be installed for waste emplacement (CRWMS M&O 1995a, Key 010). Roadway improvements will include injection of grout to stabilize the invert segments and placing of a 300 mm thick reinforced concrete cap. Section 8.3 details the emplacement phase repository configuration and equipment systems. The upper block East Main and West Main will be upgraded to repository standards as development proceeds from north to south across the block. The lower block upgrades will be treated in a similar manner.

The upper and lower repository blocks are divided into increments of 13 emplacement drifts. The final increment of the upper block has 14 drifts and the final increment of the lower block has 15 drifts. Figure 8.4.3-1 shows the proposed sequence of emplacement drift development. The increments will allow completion of the repository in phases and the subsequent delivery to emplacement operations of drifts that are ready to receive waste packages. Increments will have a number of drifts under various stages of development as shown in Figure 8.4.3-2 and final completion of drifts in a particular increment may occur simultaneously with development in another increment before the isolation airlocks are relocated. Though the current concept involves

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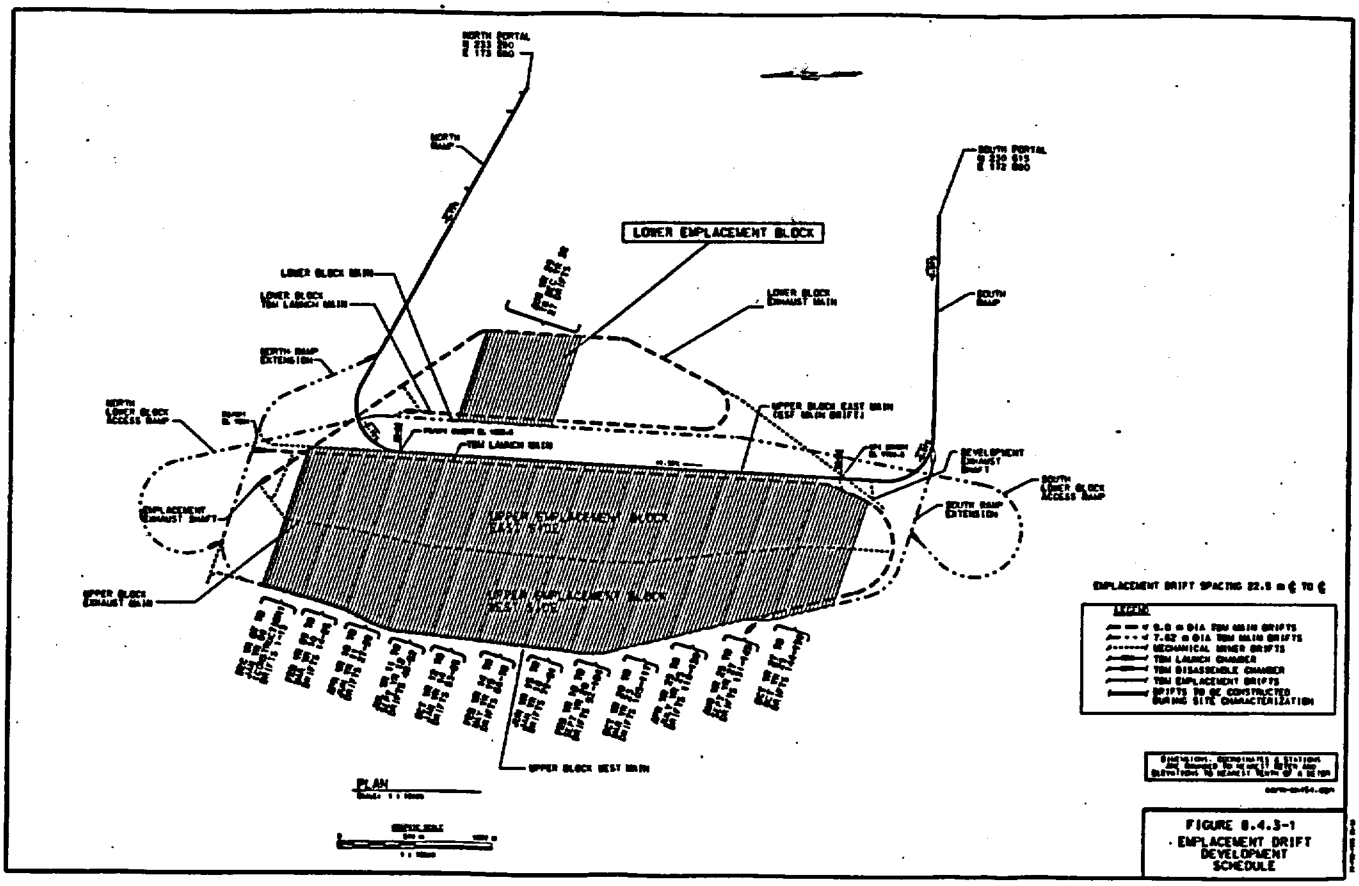

FIGURE 8.4.3-1
EMPLACEMENT DRIFT DEVELOPMENT SCHEDULE

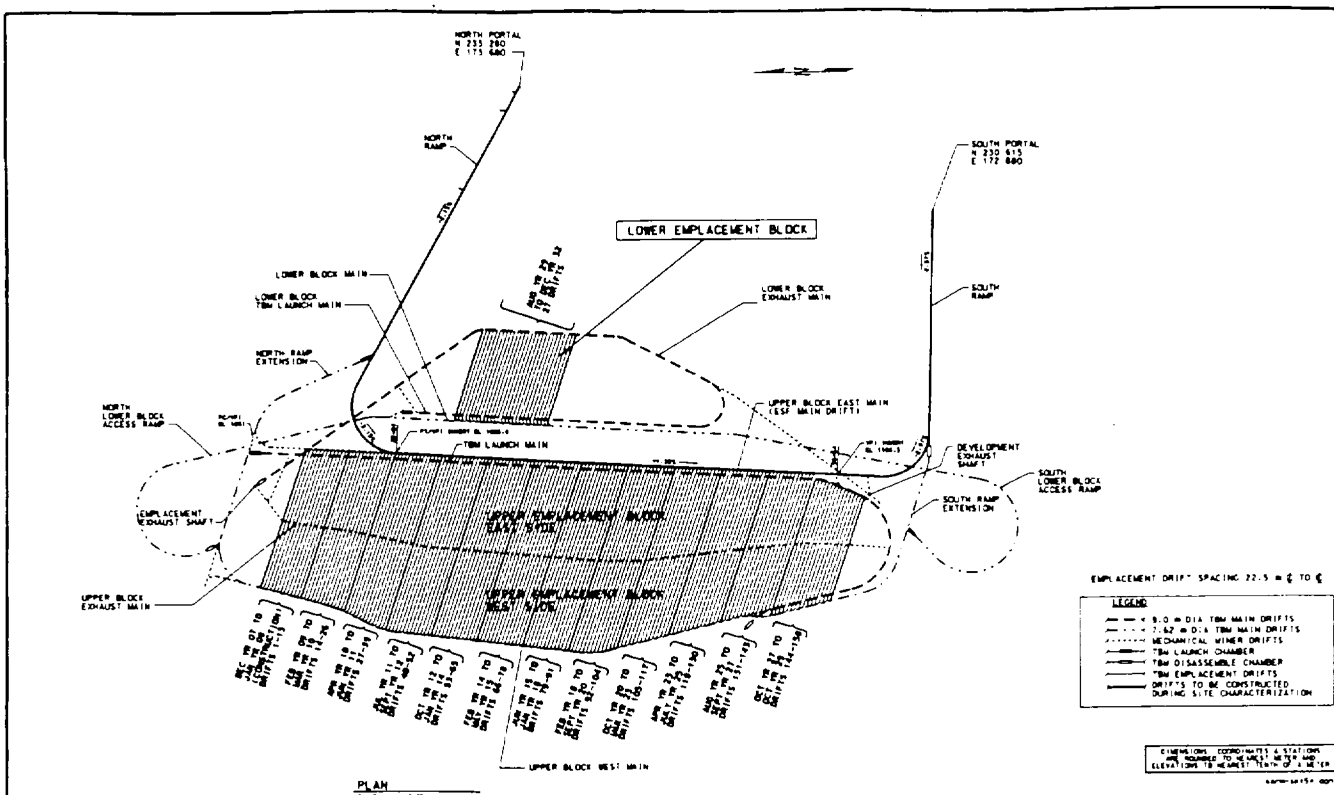

FIGURE 8.4.3-1
EMPLACEMENT DRIFT DEVELOPMENT SCHEDULE

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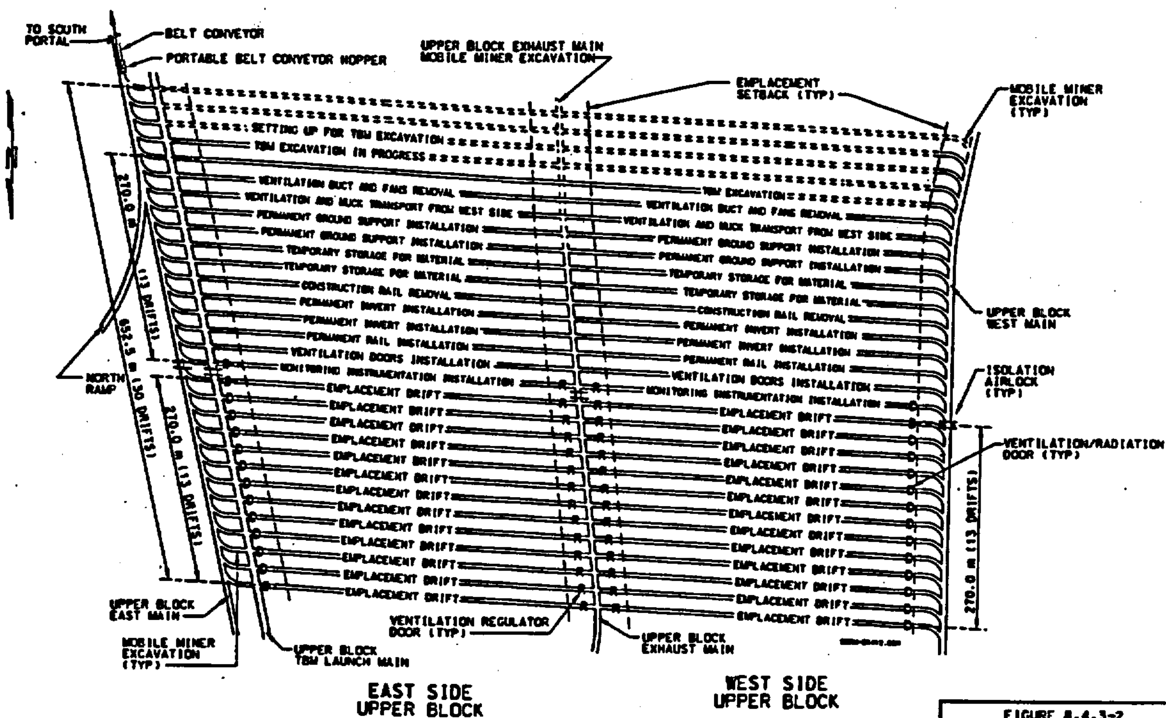

FIGURE 8.4.3-2
EMPLACEMENT DRIFT DEVELOPMENT SEQUENCE

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relocating the isolation airlocks when 13 drifts are ready to receive waste packages, the actual number of completed drifts could vary.

8.4.3.1 Separation of Development and Emplacement Operations

Separation of emplacement and development is a key driver in the repository layout design and construction approach. A number of factors were considered including Nuclear Regulatory Commission regulations requiring separation of the ventilation air in the emplacement and construction sides (YMP 1994a, 3.7.5.B.3); unfamiliarity of construction crews working around high-level waste; and required security levels. More stringent radiological health, safety and work rules will apply on the emplacement side than on the construction side. Emplacement crews will be more specialized and will require special training. The separation of activities also permits the retrieval of any spent nuclear fuel or high-level waste emplaced without adversely affecting the entire operation (YMP 1994a, 3.2.1.4.A.).

In the upper block East Main, West Main, TBM Launch Main, and Exhaust Main the isolation airlocks separating the emplacement and development sides will consist of a double bulkhead with ventilation doors to allow travel between the two sides. The doors will form an air lock. The air lock will be necessary because of the pressure difference between the two sides. Relative to the atmosphere the emplacement side will be at negative pressure and the construction side will be at positive pressure (YMP 1994a, 3.7.5.B.4.). Administrative controls will be in effect to control pedestrian traffic between the emplacement and construction sides. Rail traffic will not be possible because of different track gauges on the two sides, but rubber tired vehicle traffic may be maintained as an option. The doors installed across the emplacement drifts will be designed to make human entry very difficult without following specific safety and operational procedures (CRWMS M&O 1995a, Key 013).

The potential radiation hazard that exists on the emplacement side of the bulkhead will be conveyed to development side workers by the use of appropriate warning signs, alarms and monitors on the development side of the isolation airlock (YMP 1994a, 3.2.2.4.C.). Monitoring devices will be placed on the development side of the bulkhead to measure radiation levels on both sides of the isolation airlock.

8.4.3.2 Construction and Development Schedule

Repository construction will commence with excavation by TBM of the access mains, as described above, and excavation by mechanical excavator of secondary openings. The mechanical excavators will start excavation of the emplacement drift crosscuts and turnouts, followed by TBM excavation of the emplacement drifts.

Figure 8.4.3-3 represents the subsurface construction and development schedule, starting with preconstruction activities in year 1 and finishing with completion of mining the final block of emplacement drifts in year 32. Figure 8.4.3-1 indicates the approximate time frame for completion of emplacement drift increments. Volume IV of this MGDS ACD report contains the specific parameters that were used to arrive at the schedule.

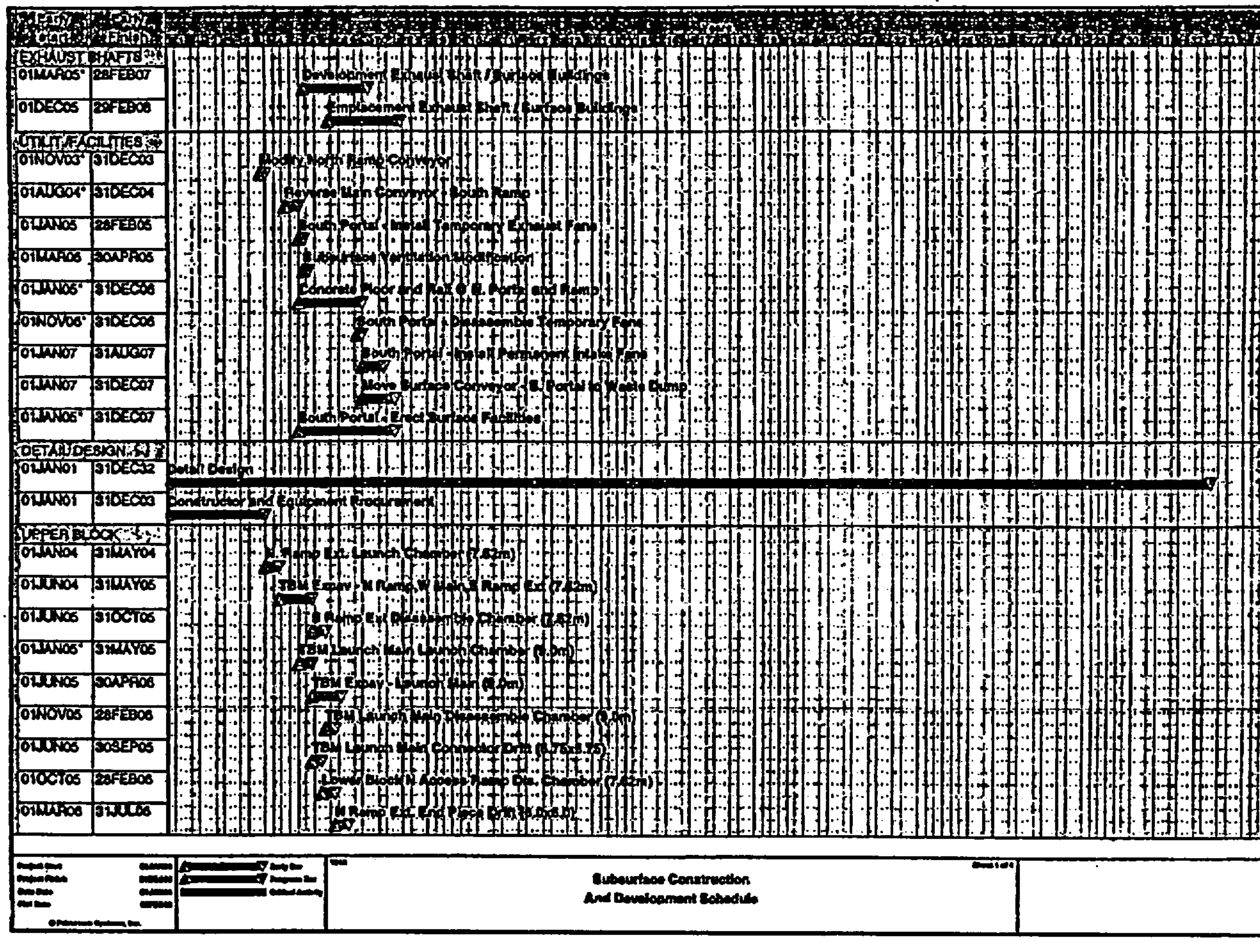

Figure 8.4.3-3. Subsurface Construction and Development Schedule

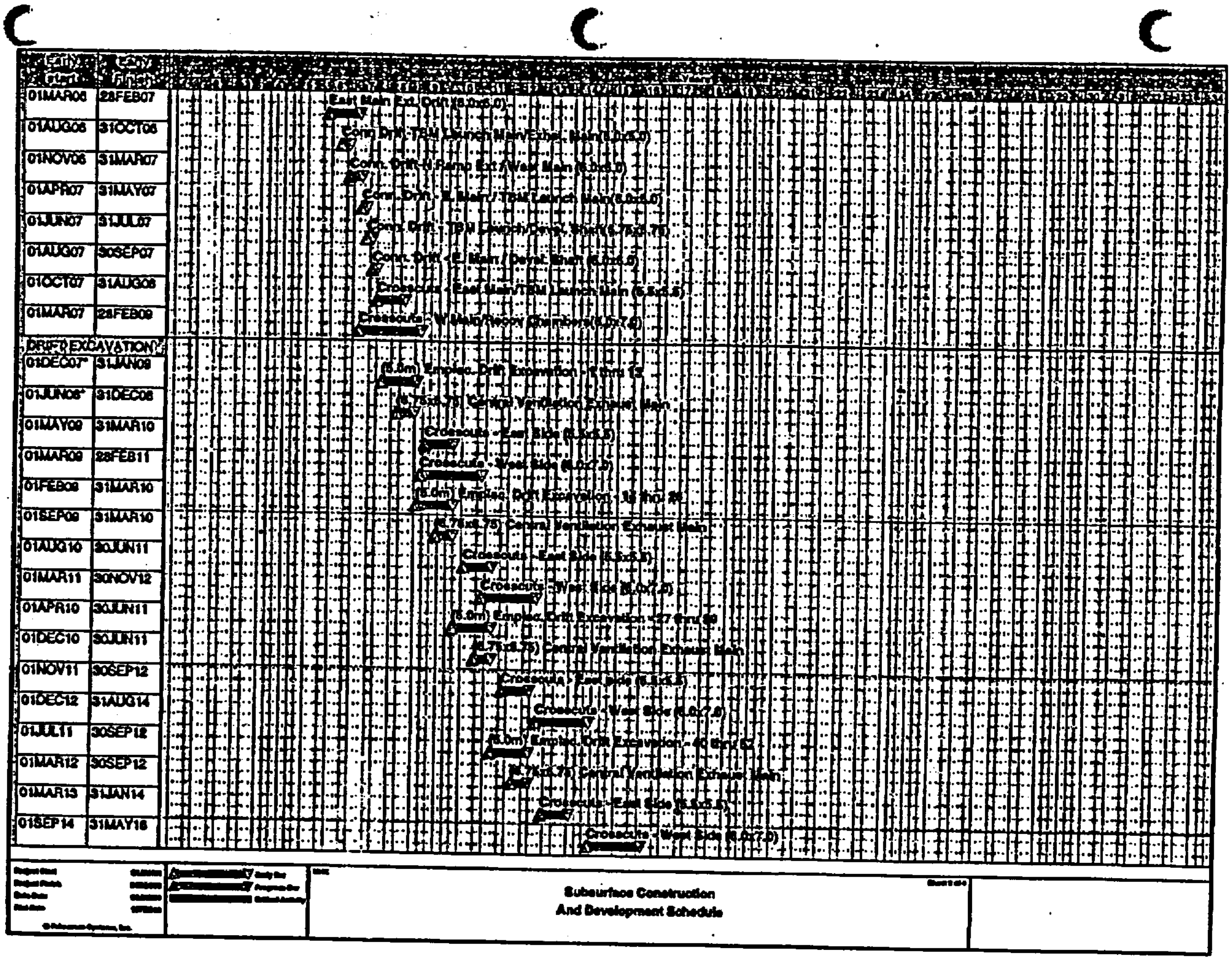

Figure 8.4.3-3. Subsurface Construction and Development Schedule (continued)

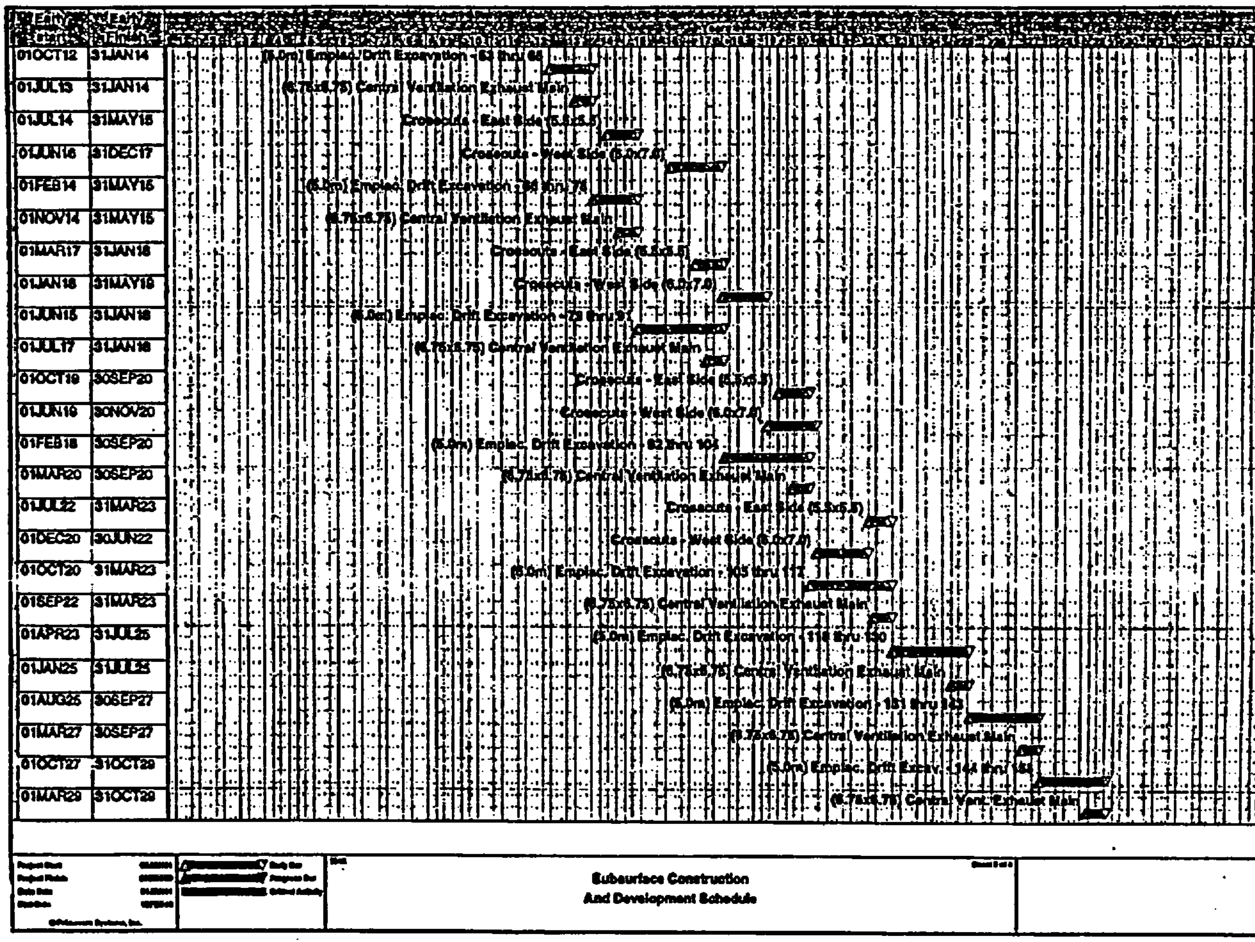

Figure 8.4.3-3. Subsurface Construction and Development Schedule (continued)

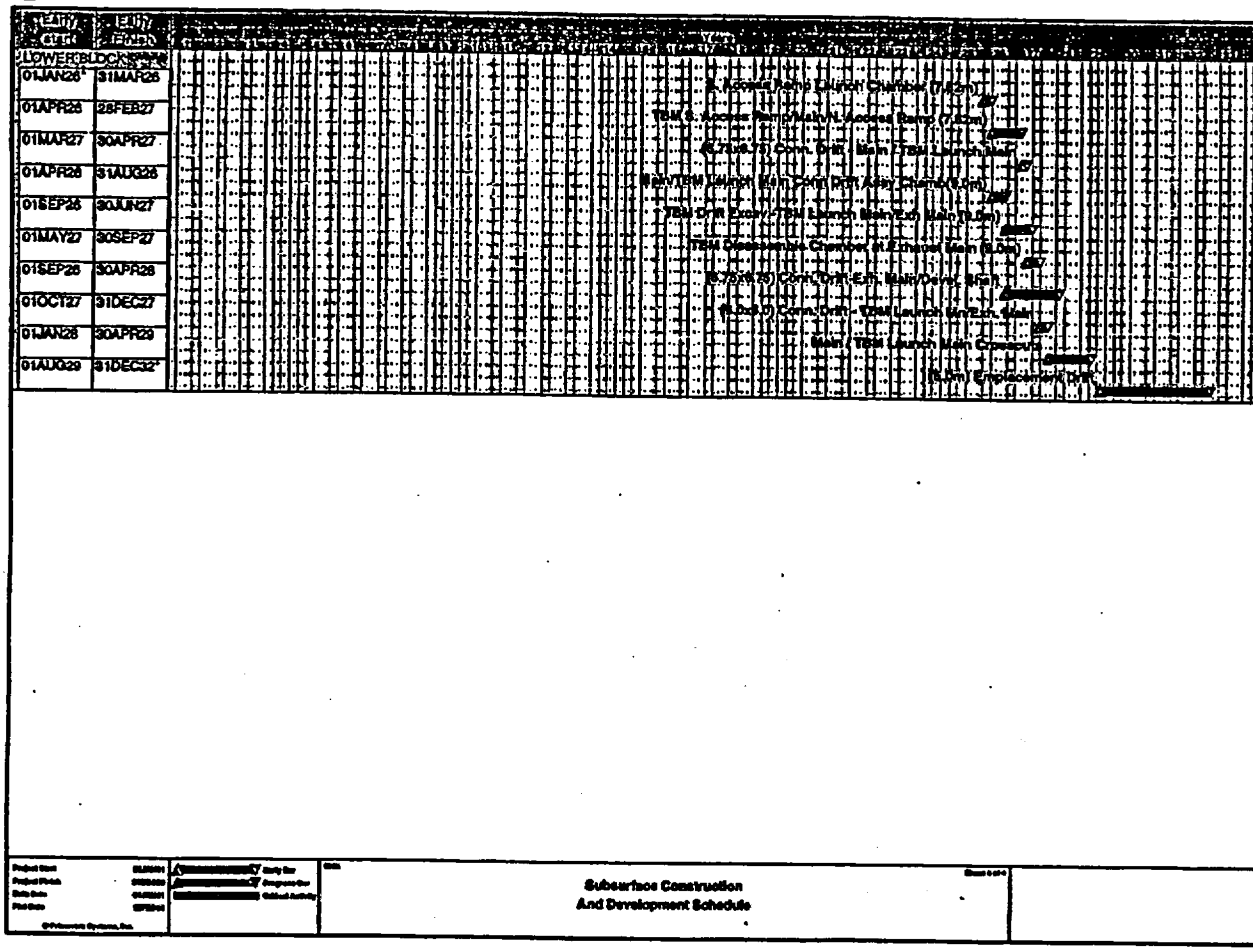

Figure 8.4.3-3. Subsurface Construction and Development Schedule (continued)

During the first years of construction, adequate time is available to complete testing requirements as currently envisioned (YMP 1994a, 3.7.6.B.). However, if further testing or study is required before construction commences, construction may be delayed. A delay in construction could adversely affect the waste receipt schedule if the delay is prolonged enough.

8.4.3.3 Construction Responsibilities

For the purposes of this study and the cost estimate, it is assumed that shaft construction and initial TBM construction will be performed by independent contractors. Initial construction is the 7.62 m West Main, the ramp extensions, and the 9.0 m Launch Main. While the 7.62 m ESF TBM may be available for this work, contractors would, in general, be responsible for providing their own construction equipment, including the 9.0 m TBM, conveyor, rail haulage equipment, shaft sinking headframe, hoists and sinking equipment.

Under the direction and control of the repository operating contractor, repository construction crews will perform all other work. The repository operating contractor would excavate the secondary openings and the emplacement drifts, and would construct the isolation airlocks.

The repository contractor would also upgrade tunnels to repository standards, install emplacement systems, and perform repository maintenance as needed. The rationale for this approach is based on the relatively small amount of 7.62 m and 9.0 m TBM development required and the specialized nature of shaft construction. See Section 8.3 for details on the relatively small amount of specialized construction, 7.62 m TBM, 9.0 m TBM, and shafts, needed when compared to emplacement drift and long-term repository construction. The schedule for completion of these items is of relatively short duration and independent contractors are best suited for this work. On the other hand, the majority of subsurface construction will be completed over a period of 25 to 30 years. This is normally too long a period for an independent contractor to be involved. Much of the repository work will require specialized skills and permanent, highly trained crews can be developed and should provide a more cost effective approach for completing the work.

8.4.3.4 Construction Systems and Equipment

The systems and equipment required for subsurface construction and development will be similar to those used for ESF construction. Many of the controls in place in the ESF regarding fluids and materials can be used with the construction systems required in this design (YMP 1994a, 3.2.3.2.2.A.5.) Adverse impacts to waste isolation are not anticipated with any of the proposed construction systems or equipment, but specific criteria will be developed in future analyses to ensure waste isolation requirements are met (YMP 1994a, 3.3.8.1.E.). Specialized mechanical equipment will be required for excavating the non-TBM openings. The mechanical excavators, described in Section 8.4.4.2, are specialized, but can be repaired, replaced and maintained (YMP 1994a, 3.2.5.2.2.B.).

The TBM for excavating the emplacement drifts will be specified for this purpose. The design presented in this report requires that the TBM be launched from a mobile launch tube and after breakthrough, be recovered in the same launch tube. Construction and Tunneling Services, the designers and fabricators of the 7.62 m ESF TBM, have provided a concept of a launch and recovery tube. Figure 8.4.3-4 shows the concept with the TBM being launched directly from the rail carrier in the TBM Launch Main. The TBM would be positioned at the emplacement drift starter cutout, reaction blocks would be lined up, and TBM excavation could start with minimal secondary excavation required. Pivoting of the TBM head and positioning of the machine will be detailed in the final design.

Alternatively, the TBM could be positioned utilizing "air pallets" as shown in Figure 8.4.3-5. The air pallet concept was developed for moving heavy industrial loads, in some cases 900 metric tons or more, over a flat surface, such as a concrete floor. The air pallet concept provides more maneuverability than rail, but represents an unproven technology for underground use.

The recovery area for the emplacement TBM is designed to ensure compatibility with the launching system and can use rail or air pallets. The TBM will be recovered into the launching tube to facilitate a quick turn around time for excavating the next emplacement drift.

The air pallet concept for recovering the arrangement is shown in Figure 8.4.3-6. The launch and recovery assembly would be equipped with heavy jacks for positioning, and attached to rail bogie assemblies for transportation. A system could also be developed to recover the TBM directly onto a rail carrier.

The TBM will be transported via rail between the recovery chamber and the launching chamber. Due to the weight involved, the assembly will be designed to run on four rails. The TBM head may be faced the wrong direction for direct launching after recovery; therefore, a turntable may be required on the south end of the block to turn the TBM around. Figure 8.4.3-7 shows a possible configuration for the TBM carrier assembly from recovery to launch areas. The final design will detail specific criteria to ensure the system is efficient and relatively fast in transporting the TBM from recovery to launching. The four rail layout, similar to the layout in the ESF, can also be used to transport the TBM to the surface via the South Portal for periodic maintenance.

8.4.3.5 Health and Safety

Construction crews will follow Occupational Safety and Health Administration (OSHA) regulations and other applicable industrial codes and standards on the construction side. Underground ventilation (see Section 8.7) is a key to providing a safe working environment (YMP 1994a, 3.7.5.B.6.). Where diesel equipment is used and specified in the final design, special attention to ventilation will be required (YMP 1994a, 3.7.5.C.1.; 3.7.5.C.2.; 3.7.5.C.3.) As previously stated there will be no regular passage from the construction to the emplacement side. Procedures and controls will govern entry from either side. The location of emergency equipment underground will be determined during the final design phase (YMP 1994a, 3.7.5.F.7.).

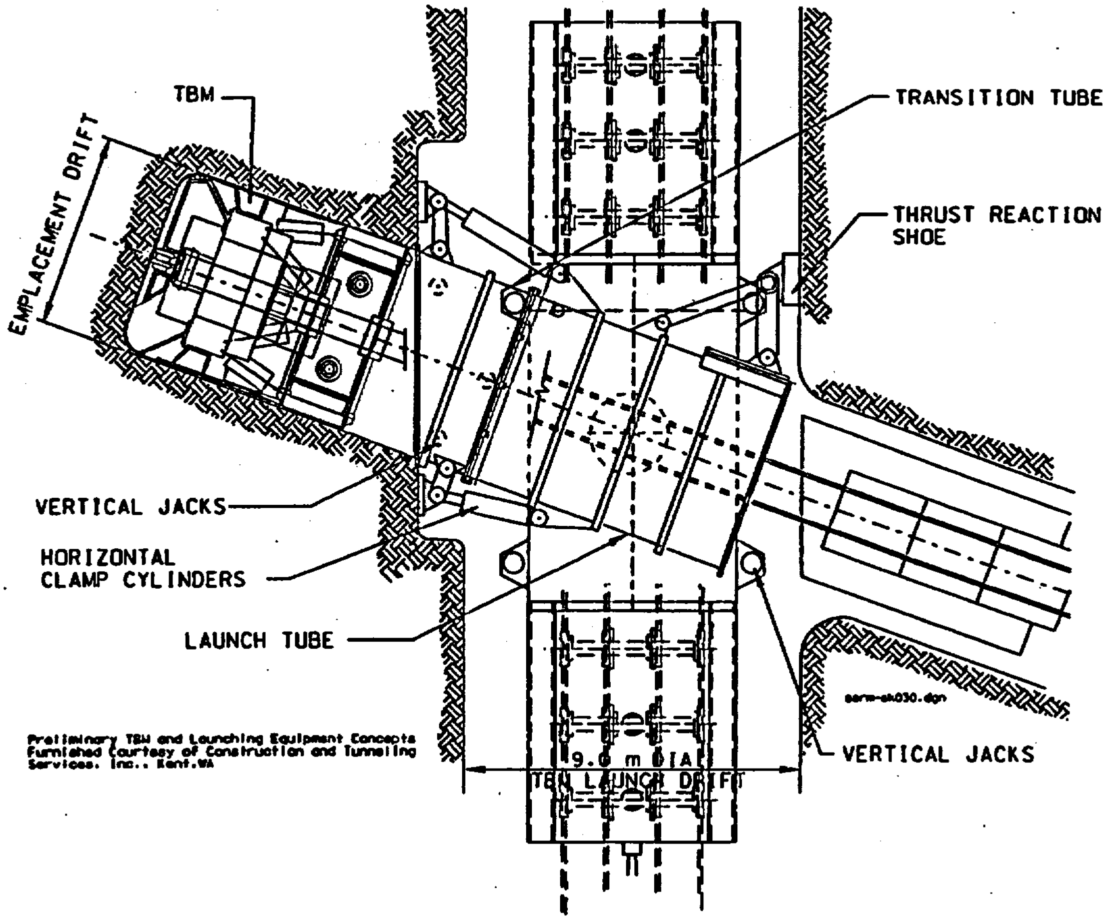

Figure 8.4.3-4. TBM Launch – Rail Concept – Plan View

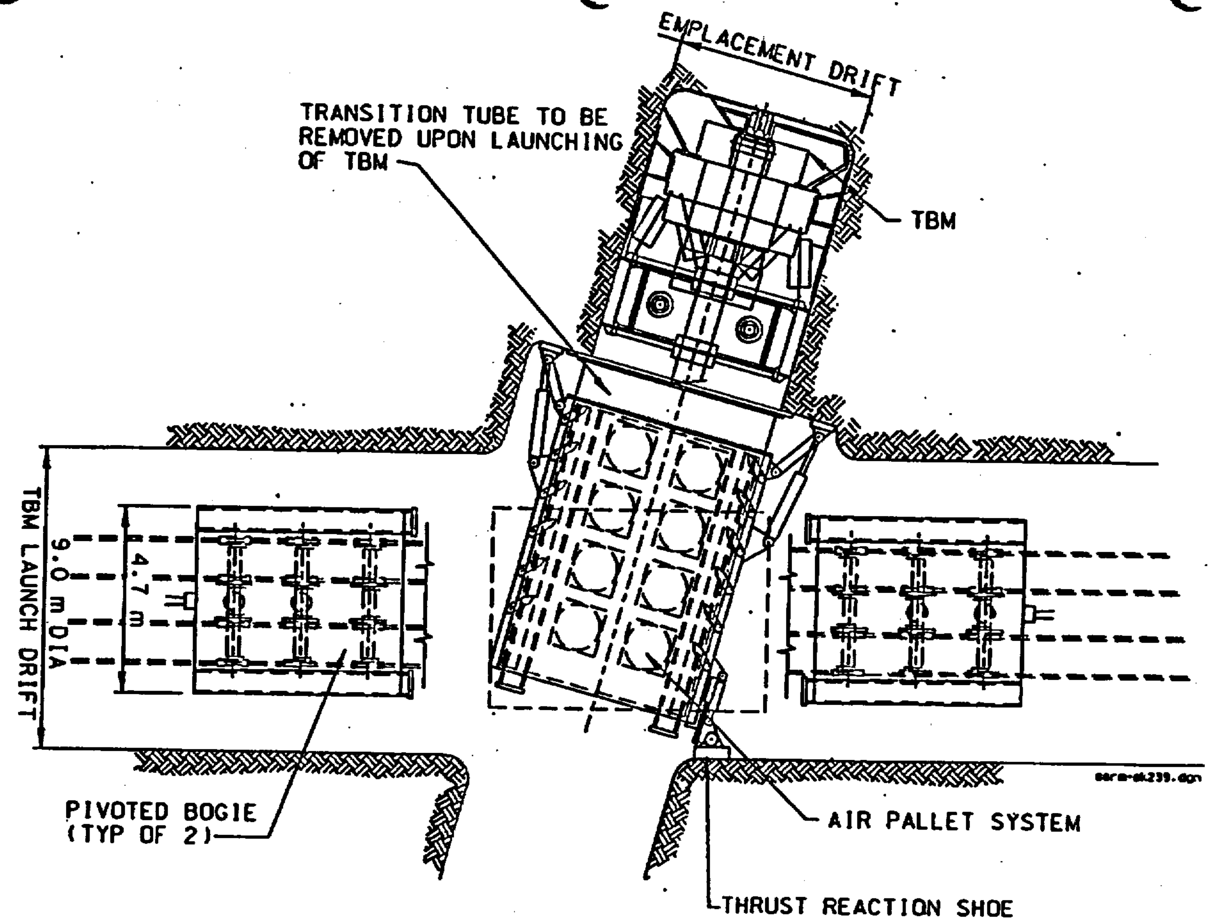

Figure 8.4.3-5. TBM Launch – Air Pallet Concept – Plan View

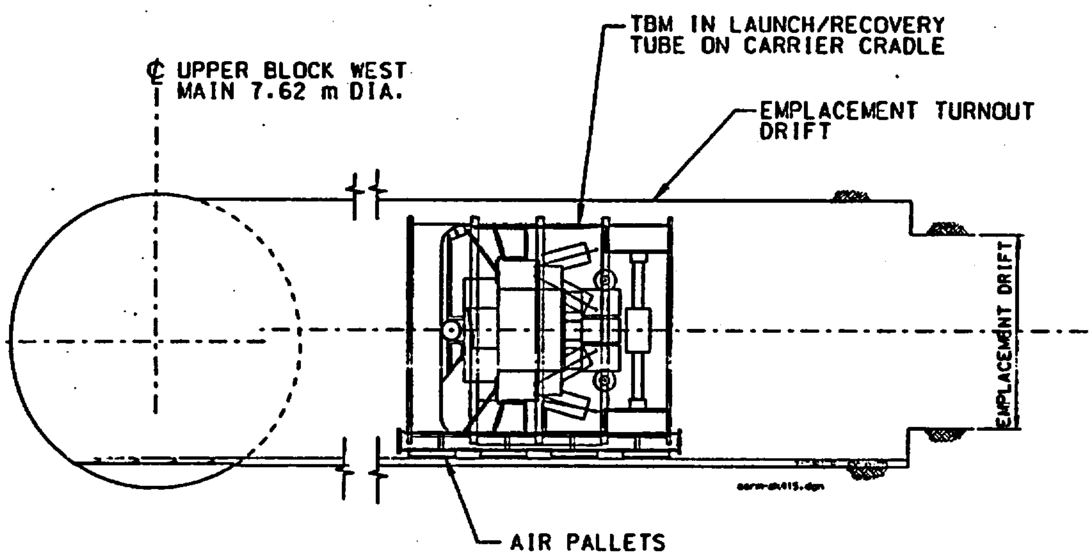

Figure 8.4.3-6. TBM Recovery, Emplacement Drift

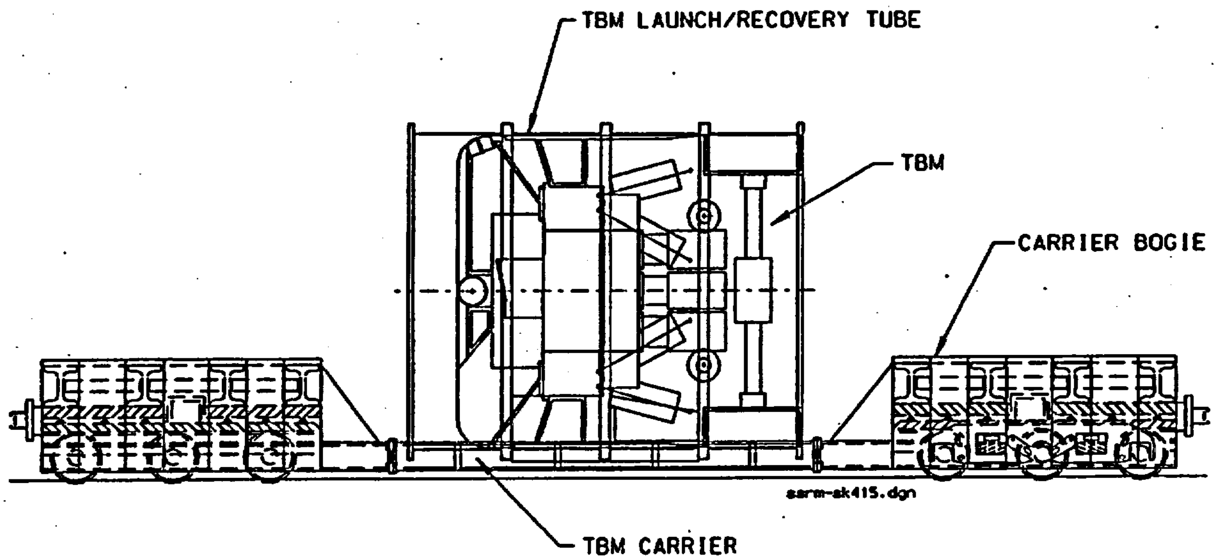

Figure 8.4.3-7. Emplacement Drift TBM Carrier

8.4.3.6 Quality Assurance

Construction work performed by the contractor and the repository crews will be in accordance with an approved quality assurance program. Construction controls, such as apply in the ESF, for limiting organic contamination and controlling line and grade will be applied (CRWMS M&O 1995a, DCSS 027). Construction items and activities will be evaluated in the future to determine the level of quality assurance required for specific elements.

8.4.4 Excavation

TBMs will be the primary means of excavation for the repository subsurface, and other mechanical excavators will be the secondary means (CRWMS M&O 1995a, Key 027 and DCSS 005). Though most excavation will be accomplished with mechanical miners, some drill-and-blast excavation is probably inevitable (CRWMS M&O 1995a, Key 028). Drill-and-blast operations will be subject to approved controls to ensure that regulatory and design requirements are met. Though TBM excavation is fairly inflexible, the size and arrangement of the drifts will meet operational requirements (YMP 1994a, 3.2.5.2.2.A.).

8.4.4.1 Primary Excavation

The design indicates that primary TBM excavation of access and emplacement drifts will total over 200,000 m.

The TBM excavates an inherently stable circular opening, but ground support such as rockbolts, welded wire fabric, and steel sets will be required for tunnel safety and long term stability (CRWMS M&O 1995a, DCSS 028). The final design ground support will meet Mine Safety and Health Administration (MSHA) ground control requirements (YMP 1994a, 3.2.6.2.5.). The circular tunnel profile generally requires a roadway, such as fill, cast-in-place concrete, or pre-cast concrete segments, placed in the invert to form a travelway for equipment.

The main advantage of TBMs is the high rate of tunneling advance they can accomplish when compared to drill-and-blast or when compared to other mechanical excavators such as roadheaders. Their main disadvantages are high capital costs, long procurement lead time, the long time needed for assembly and start-up and less flexibility than drill-and-blast once excavation has started.

The ESF TBM, after a slow start, has achieved impressive rates of advance. The predicted repository advance rates are based on the ESF average rate of advance, and include time for start up problems, servicing, and breakdowns. ESF TBM experience will provide valuable data for specifying and procuring the repository TBMs. Dust control, always an important industrial hygiene consideration underground, can be achieved using TBMs (YMP 1994a, 3.7.5.G.1).

8.4.4.2 Secondary Excavation

The current estimate indicates that approximately 23,000 m of tunnel, which is about 9 percent of the total, will be excavated utilizing secondary excavation techniques. Secondary excavation will be done by mechanical excavators, and two machines offer reasonable assurance that a mobile, mechanical excavator can be procured in the final design phase for secondary excavation.

The first machine under consideration is the Robbins Mobile Miner. The Mobile Miner has successfully excavated tunnels in mining and civil projects with rock strengths similar to those in the repository. The cost estimate for the ACD study includes rates for secondary excavation based on the Mobile Miner experience in hard rock and, therefore, provides some basis for the secondary excavation design and cost estimate used.

A second possible machine is based on a concept developed by the Colorado School of Mines in which a roadheader is equipped with mini-disc cutters.

The mechanical excavator concepts are relatively unproven and cannot match the productivity of the TBM. However, the amount of secondary excavation needed in the repository permits consideration of these machines. The secondary excavation could be accomplished utilizing drill and blast techniques if the final design indicates that using mechanical excavators is not the best solution.

8.4.4.3 Muck Removal

The primary method for muck removal from the 7.62 m and 9.0 m TBM headings to the surface will be by conveyor. Load-Haul Dumps (LHD), underground front-end loaders, will be used for mucking behind the mechanical miners in the crosscuts, the turnouts, and in the shaft stubouts. LHD muck could be loaded directly onto a conveyor or into railcars. Rail haulage will be used for men and materials and for muck removal from the emplacement drifts and the longer mechanical excavator openings (CRWMS M&O 1995a, Key 030).

During initial repository construction, Phase I, muck will be removed from the underground via the North Portal. See Figure 8.4.3-8 for muck removal details during Phase I. Once the West Main and the TBM Launch Main are completed, muck will be handled through the South Portal. Phase II muck handling is shown on Figure 8.4.3-9 and will remain in effect for all underground excavation at the repository. Conveyor handling of muck will be the primary handling method, but rail haulage of muck will remain an option during all phases of construction (CRWMS M&O 1995a, DCSS 010).

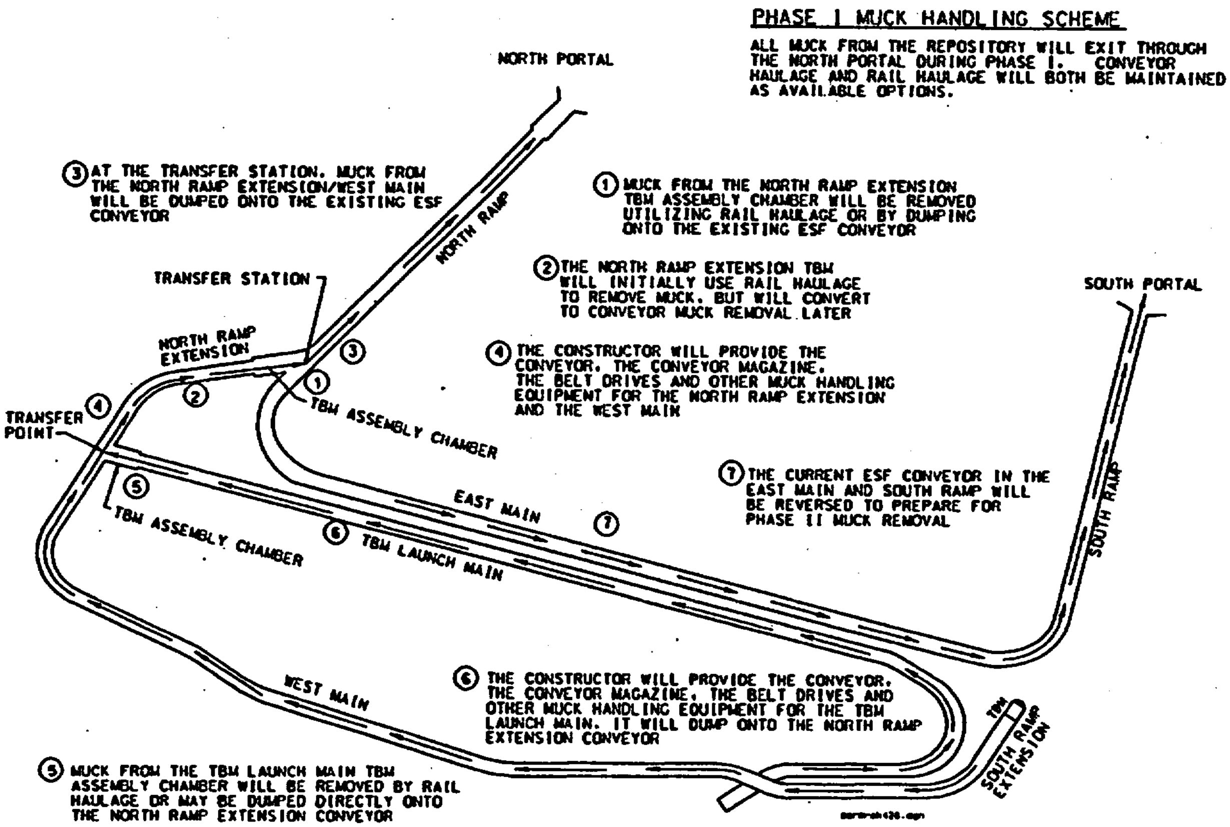

Figure 8.4.3-8. Phase I Muck Handling Scheme

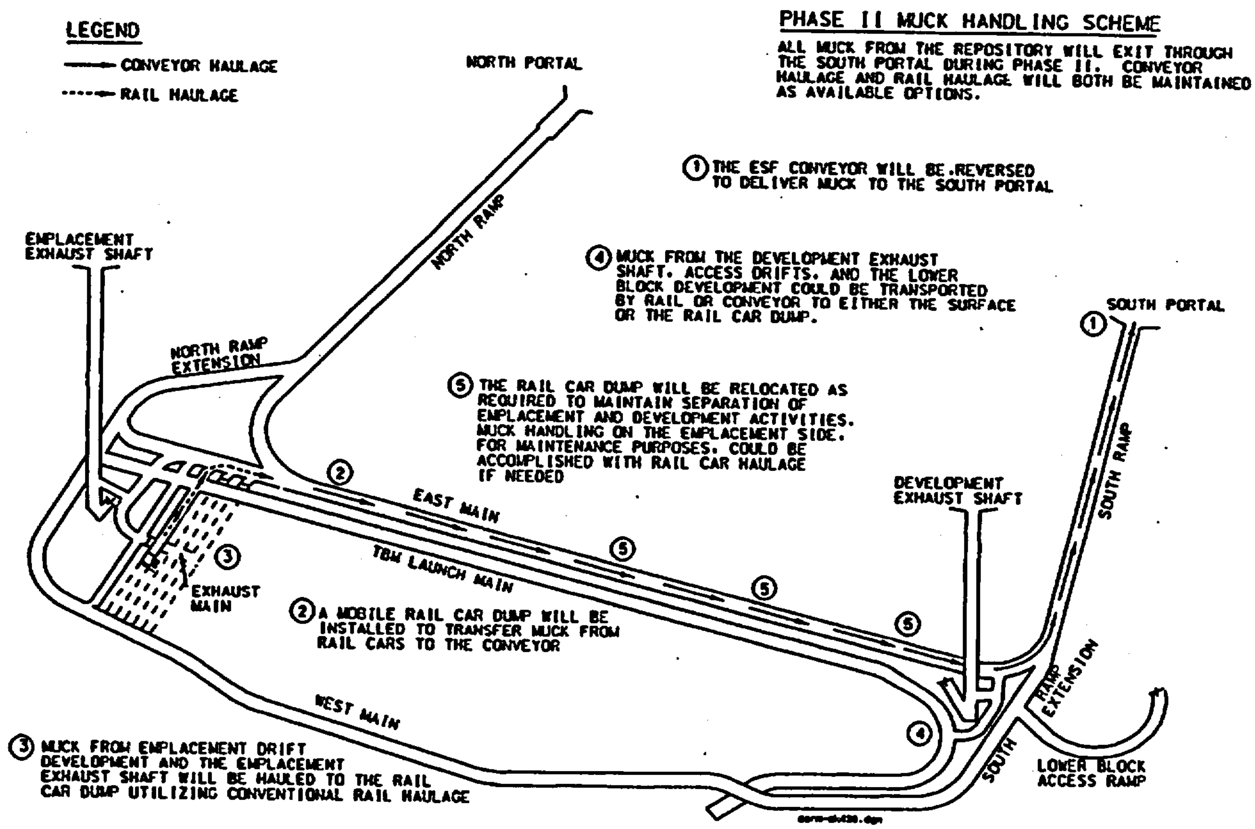

Figure 8.4.3-9. Phase II Muck Handling Scheme

8.4.4.4 Shaft Construction

The emplacement side and development side ventilation shafts will be excavated to provide separate ventilation systems underground (RDRD 3.7.5.B.3 [YMP 1994a]). Air sampling at each shaft will provide information on radiological conditions underground for the ventilated subsurface (RDRD 3.2.2.3.C [YMP 1994a]).

The shafts from surface to the upper block will be excavated by mechanical methods. There will be three main stages in the excavation sequence.

First, a pilot hole, approximately 200 mm in diameter, will be drilled from the surface to break into a previously excavated drift at the upper block horizon.

Second, a 1.5 to 2.0 m diameter raiseborer reamer head will be attached underground and a borehole backreamed to surface. Cuttings from the raiseborer backreaming operation will fall to the upper block elevation and will be moved by LHDs from the borehole bottom to rail cars or a conveyor transfer point.
The third step will involve setting up the down reamer head at the surface over the borehole. The down reamer will excavate the shaft to its full diameter as it progresses downward, and the cuttings, which fall to the upper block through the borehole, will be removed by LHDs in the same manner as the raiseborer cuttings.

Robbins has developed a down reaming system that operates much like a vertical TBM except that the cuttings must fall down a previously excavated borehole. This machine has grippers to hold it in place and to maintain alignment, and an electric powered reamer head. A sinking deck lowered from the surface provides a working platform for installing temporary ground support, such as rock bolts and wire mesh, and concrete lining. A small sinking hoist and conveyance service the sinking deck. As the machine descends a concrete liner will be poured as the final permanent support. The cost estimate assumed that the liner would be 300 mm thick. Design analyses will be required in the future to determine the characteristics and requirements for the permanent shaft liners.

Mechanical methods cannot be considered for the lower portions of the shafts during the pre-emplacement construction period as there will be no access for attaching a raiseborer reamer head and removing muck until the lower block drifts have been excavated. Lower block excavation will not occur until well into the emplacement period. Ramping down from the upper block elevation to the lower block elevation as part of pre-emplacement construction would add costs and delay completion of the shafts. Mechanical methods for re-deepening the emplacement shaft at the time of developing the lower block also appears impracticable. This is because of a requirement to separate the emplacement and development ventilation systems, and working from the upper level with a down reamer or raiseborer system would contravene this requirement.

Shaft sumps 5 m in depth will be excavated by drill-and-blast below the upper block level. Muck from the sumps will be removed by clamshell, overshot mucker, or other method and handled by LHDs the same as the shaft muck. The sump walls will be concrete lined and the bottom left unlined. A bulkhead will be installed above the sump at the floor level of the upper block station to provide separation of activities when the lower portion is excavated at a later date.

The lower block drifts will be excavated underneath the shafts some twenty years or more in the future. The remaining sections of the shafts, approximately 54 m, between the lower block exhaust main and the bottom of the existing shaft sumps will be excavated using a raise climber or similar technology. A raise climber is a mechanical elevator, that climbs a cogged rail attached to the sides of the opening and transports men and materials on a workdeck to the working face. At the face, the overhead round will be drilled and blasted conventionally. The raise climber will also be used to install temporary ground support and utilities. The cogged rail is extended as the raise advances. The method takes advantage of gravity to move muck from the face. Broken muck will be removed from the lower level by LHD. The final lining for the lower block, probably a layer of steel fiber reinforced shotcrete (fibercrete) will be installed from the raise climber workdeck working downward from the top of the raise prior to removal of the bulkhead at the upper block. Once the lower block is ready for delivery to emplacement operations, the bulkhead will be removed and ventilation established to the surface.

There are a number of other ways to excavate shafts. They include conventional sinking by drill-and-blast, slabbing to a borehole, backreaming the full diameter, or blind drilling the full opening. Future analyses will examine ground conditions, waste isolation concerns and many other factors to determine the final criteria for the shaft construction.

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8.5 GROUND CONTROL

This section on repository ground control summarizes the results of previous work and presents requirements and assumptions that provide the basis for developing ground control methods. Factors that control ground subsidence are discussed, and the potential for subsidence is evaluated. The effects of temperature, radiation, and other environmental parameters are presented in regard to the longevity of materials used in the fabrication of ground reinforcement and support methods. The approach to ground support for emplacement drifts is presented, based on requirements, materials considerations, and results of numerical modeling. Ground support for other repository openings is also presented. The definition and functions of repository ground control are briefly stated in the following introductory comments.

Ground control is the process of maintaining subsurface repository openings in a safe and stable condition in order that the functions of the openings are preserved for their intended lifetimes. Ground control activities and procedures are carried out during repository construction, development, and operations phases and principally involve the following:

- Application of ground reinforcement and excavation methods
- Monitoring of ground behavior
- Inspection, maintenance, and rehabilitation of openings.

Subsurface openings are constructed to serve a variety of functions such as access (shafts and ramps), ventilation, emplacement, maintenance, and personnel and materials handling (CRWMS M&O 1995a, Section 5.4.3.1). Mechanical excavation is preferred (CRWMS M&O 1995a, Key 027); the TBM method is considered the best. Where use of a TBM is not feasible, other mechanical methods may be used (CRWMS M&O 1995a, DCSS 005). If neither of these methods is feasible, drill-and-blast excavation will be used (CRWMS M&O 1995a, Key 028). Comparable mechanical methods are also available for shaft excavation.

A principal requirement of the MGDS is the ability to retrieve waste at any time following the initiation of emplacement and prior to closure, if required (CRWMS M&O 1995a, Key 016). Retrievability is a major requirement for ground support for subsurface openings because it dictates the length of time that repository openings must remain functional and, thus, the lifetime of the ground support system itself (CRWMS M&O 1995a, DCSS 028). Another requirement, that of performance confirmation, which will rely on in situ monitoring and testing, requires preclosure access to emplacement drifts.

8.5.1 Previous Work

The report *Repository Ground Control Evaluation* (CRWMS M&O 1995b) provides the most recent review and analysis of ground control and forms a basis for what appears in this section, in Appendix B, Analysis of Ground Stability and Support, and in Appendix C, Materials Evaluation. Although reflecting the earlier report, Appendices B and C contain significant changes, which include results of the application of a reference thermal load of 83 metric tons of uranium/acre, the addition of seismic loading, and further evaluation of materials. Other documents, including

Sandia National Laboratories reports and various CRWMS M&O documents, are considered to provide background information applicable to the subject of repository ground control, and are discussed in the following.

8.5.1.1 Drift Analyses for the ESF

Results of geologic and geotechnical investigations for the 7.62 m diameter ESF North Ramp, based primarily on eleven North Ramp Geologic boreholes, were compiled and evaluated in a two-volume report (SNL 1995a). Rock mass classification according to the Q-system (Barton, Lien, and Lunde 1974) was done for all rock units encountered by the North Ramp, and ground support recommendations were made. The indicated range of support methods for the Topopah Spring welded unit is given in Table 8.5-1. The report states that, although support categories include cast concrete arches, conditions requiring such support are not expected. Also, steel ring beams are expected to provide sufficient support for the range of conditions anticipated.

A ground support analysis (CRWMS M&O 1995b) was performed for ESF drifts, using data given by Sandia National Laboratories (SNL 1995a), considering specific excavation methods, and incorporation of results of numerical stress analysis. All or portions of the ESF access ramps and a main drift at the repository horizon, may become part of the potential repository at Yucca Mountain. Drifts were modeled for a jointed rock mass, with and without ground support components, for a range of in situ and seismic loading conditions. Thermal loads were not considered. Five rock mass quality categories (SNL 1991) were used to represent the expected range of ground conditions and to provide a basis for developing ground support design classes.

Two-dimensional modeling was performed to simulate rock mass response at stations along the ESF Main Loop. The stations examined include one each in the TCw, PTn, and TSw1 thermal/mechanical units, and three in the TSw2, in which the proposed repository block is located. Following excavation, these stations will become locations for monitoring rock mass displacement and drift closure, thereby providing information for verification of existing ground support design and for improvement of subsequent ground support design.

Recommended ground support is shown in Table 8.5-2. Additional support may be installed during construction for personnel safety. Candidate ground support components considered in the study included rock bolts, welded wire fabric, shotcrete, and steel sets. Shotcrete, in combination with rock bolts, was to provide immediate support to control potential raveling or block loosening, especially in weak rock such as the PTn unit and fault zones. Because shotcrete was not considered compatible with the TBM operation and geologic mapping required that the rock surface remain visible, steel ring beams (steel sets) and steel lagging were selected to provide immediate support.

In addition to these support components, friction-type rock bolts were recommended in situations where mechanically-anchored bolts were not practical. The welded wire fabric would be either a 75-by-75 mm or a 150-by-150 mm mesh size. It was also stated that a "specially designed interlocking steel mesh" may be used in lieu of welded wire fabric. The support classes listed here, in general, correspond to increasingly poor ground conditions from Class I to V and also reflect two different approaches to ground support; one based on rock bolts and one based on steel sets.

Table 8.5-1. Range of Ground Support Indicated by Rock Support Categories for the TSw2 Thermomechanical Unit based on North Access Ramp Geologic Boreholes (after SNL 1995a, Table 7-12)

Thermo-Mechanical Unit	Ground Support Category	Range of Q for Ground Support Category		Proportion of Data Intervals in Support Category	Cumulative Frequency of Occurrence at Max. Q	Range in Ground Support Measures
TSw2	31	0.1-0.4	v. poor	14%	14%	Tensioned, grouted rock bolts on a 1 m pattern plus 50-125 mm thick, mesh reinforced shotcrete; to 300-500 mm thick, steel reinforced cast concrete arch plus tensioned, grouted rock bolts on a 1 m pattern.
	27	0.4-1.0	v. poor	13%	27%	Tensioned, grouted rock bolts on a 1 m pattern plus 75-100 mm thick, mesh reinforced shotcrete; to 200-400 mm thick, steel reinforced cast concrete arch plus tensioned, grouted rock bolts on a 1 m pattern.
	22	1.0-4.0	poor	46%	73%	Untensioned, grouted rock bolts on a 1 m pattern plus chainlink mesh; to untensioned, grouted rock bolts on a 1 m pattern plus 25-50 mm thick mesh reinforced shotcrete.
	18	4.0-5.5	Fair	8%	81%	Tensioned, grouted rock bolts on a 1-1.5 m pattern plus chainlink mesh; to untensioned, grouted rock bolts on a 1-1.5 m pattern plus 20-30 mm mesh reinforced shotcrete.
	17	5.5-10.0	fair	11%	92%	Untensioned, grouted spot bolting; to 20-30 mm shotcrete.
	13	10-26	good	8%	100%	Untensioned, grouted spot bolting; to untensioned, grouted rock bolts on a 1.5-2.0 m pattern plus 20-30 mm shotcrete.

Table 8.5-2. Ground Support Recommendations for the ESF Main Loop (after CRWMS M&O 1995al)

Ground Support Class	*Support Category	Range of NGI Q Value and Classification		ESF Ground Support Recommendations
I	13	> 10.0	good	Rock bolts nominal 1.5 x 1.5 m spacing w/WWF. Spot bolt as necessary. (Pins and channel may be used to secure mesh as needed). **Alternative: Light (W6x20) steel sets spaced 1.22 -1.8 m w/WWF.
II	17	6.0 -10.0	fair	Rock bolts nominal 1.0 x 1.0 m spacing w/WWF. Spot bolt as necessary. (Pins and channel may be used to secure mesh as needed). **Alternative: Light (W6x20) steel sets spaced 1.22 m w/WWF.
	18	4.0 -6.0	fair	Rock bolts nominal 1.0 x 1.0 m spacing w/WWF. Spot bolt as necessary. (Pins and channel may be used to secure mesh as needed). **Alternative: Light (W6x20) steel sets spaced 1.22 m w/WWF.
III	22	1.0 - 4.0	poor	Rock bolts nominal 1.0 x 1.0 m spacing w/WWF (Spot bolt as necessary) plus 100 -150 mm Shotcrete. **Alternative: Light (W6x20) steel sets spaced 1.22 m w/WWF and partial lagging as needed.
	27	0.4 -1.0	very poor	Rock bolts nominal 1.0 x 1.0 m spacing w/WWF (Spot bolt as necessary) plus 100 -150 mm Shotcrete. **Alternative: Light (W6x20) steel sets spaced 1.22 m w/WWF and partial lagging as needed.
IV	31	0.1 - 0.4	very poor	Medium (W8x31) steel sets spaced 0.61 - 1.22 m w/WWF and crown lagging as necessary.
V	34	0.01 - 0.1	extr. poor	Medium (W8x31) steel sets spaced 0.61 m w/ full lagging.

WWF – Welded wire fabric
* Based on Barton, Lien, and Lunde 1977.
** Alternative ground support for PTn unit is medium (W8x31) steel sets for all ground support classes.

Results of the numerical modeling of the unsupported ESF Main Loop indicated stable openings following excavation, except for poorer rock conditions in the PTn unit where yield is shown. In modeling supported openings, axial forces, shear forces, and moments were determined for rock bolts, shotcrete, and steel sets at stations along the ESF drift that were representative of the principal rock units. Results indicated no failure in these components. ESF ground support will be evaluated against repository requirements and will be supplemented as necessary.

8.5.1.2 Drift Analyses for the Repository

Thermomechanical analyses (CRWMS M&O 1995ak) and a more general ground control evaluation (CRWMS M&O 1995ad) predicted temperature, stress, displacement, and zones of potential rock yield for a 5-m diameter drift with in-center emplacement for the preclosure repository period. Thermal loads of 25 to 100 metric tons of uranium/acre were modeled for both unsupported and supported openings, and support materials were evaluated for durability.

Drift closures, joint displacements, and potential yield zones were found to be small. Strength to stress ratios in the pillar between emplacement drifts for in situ and high thermal load cases were sufficiently high to preclude the development of ground surface subsidence. This finding substantiated the *Site Characterization Plan* determination that backfilling of openings is not necessary for structural support before closure.

It was determined that the function of ground support for emplacement drifts should be to provide light to moderate confinement to the rock mass in order that rock loosening and fallouts be prevented. For this application, the most appropriate ground support design measures were found to be those that accommodate long-term rock mass deformation due to the thermally-induced stresses. That is, rather than design to resist a thermal stress change, ground support components should be fabricated for ductility and structural flexibility.

It was generally concluded that carbon steel at 200°C may experience modest decreases in strength and deformability, and that at temperatures below 300°C, Portland cement-based concrete with "standard" aggregate should be adequate for all concrete used for ground support. Radiation effects are believed to be insignificant and not expected to lead to degradation of either concrete or steel material properties.

8.5.1.3 Shaft Analysis

A methodology for the design of a shaft liner for potential repository shafts was developed for Yucca Mountain (SNL 1990). The primary purpose of a liner is to structurally support the rock strata and prevent rockfall hazards to personnel. Secondary purposes are to:

- Provide a stable anchorage for installing and anchoring shaft equipment,
- Create a low-friction surface to increase the efficiency of ventilation, and
- Protect the shaft wall against weathering. Principal loads on the liner are considered to result from rock relaxation (i.e., ground pressure), seismic events, and thermally-induced stresses.

The study considered several traditional methods of support. No support or rock-bolts-only support was not considered appropriate because of the need to control rockfall, while rock bolts, shotcrete, and mesh could not provide adequate attachment for shaft equipment. A cast-in-place concrete liner was deemed the most attractive concept for both ground support and the other shaft functions. Although qualified site-specific data would be needed for a complete analysis, example problems suggested that a 305-mm-thick unreinforced concrete liner (34.5 MPa, 28-day strength) would have sufficient compressive strength to sustain all load combinations studied for the preclosure life of the repository.

8.5.2 Design Inputs

8.5.2.1 Requirements

All text in this subsection is excerpted directly from the RDRD (YMP 1994a), which is the reference source for repository requirements. Upper level requirements from within the program (i.e., CRWMS upper level requirements) and outside the program (such as 10 CFR 60 requirements) are included in this requirements document. The specific requirements quoted below are considered applicable to aspects of repository ground control. Other requirements of the RDRD (YMP 1994a), which may apply in a more general way, are not included here.

3.2.5.2.8 DESIGN FOR MAINTAINABILITY

A. The Repository Segment shall be designed and constructed so that facilities are easily and economically maintained. Maintainability considerations include:

1. Use of easily maintained features and durable materials.

2. Ease of replacement of installed equipment (i.e., without structure modification).

3. Accessibility of installed equipment and building systems for performance of maintenance.

4. Life cycle costs in selection of features, systems, and finishes.

5. Provisions of maintenance instructions and as-built drawings, especially the location of underground and otherwise concealed utility lines, process chemical and coolant piping.

3.2.5.4 SERVICE LIFE

A. The Repository Segment shall be designed for a maintainable service life of at least 100 years [TBR] or the period of time authorized by the license granted by the NRC [U.S. Nuclear Regulatory Commission] in accordance with the provisions of 10 CFR 60.3.

3.2.6.1 NATURAL ENVIRONMENT

GROA SSCs important to safety shall be designed so that the effects of anticipated natural phenomena and environmental conditions will not interfere with necessary safety functions.

A. Natural Conditions. Natural phenomena and environmental conditions at the GROA considered in the design shall include events and conditions such as earthquakes, tornados, wind, lightning, floods, precipitation, humidity, temperature, sand and dust, and fungus, bacteria, and algae.

B. Combinations. The design bases shall reflect appropriate consideration of the most severe conditions reported for the site and surrounding area and appropriate combinations of the normal and accidental conditions and the effects of natural phenomena, with appropriate margins to take into account the limitations of the data and the period of time in which the data have accumulated.

I. Thermal Analysis. The design of structures shall include the effects of stresses and movements resulting from variations in temperature, including the effect of emplaced waste packages. The rise and fall in the temperature must be determined for the localities in which the structures are to be built. Structures must be designed for movements resulting from the maximum seasonal temperature change. The design must provide for the lags between air temperatures and the interior temperatures of massive concrete members or structures. In cable-supported structures, changes in cable sag and tension must be considered.

3.2.6.2.5 UNDERGROUND OPENINGS

Underground openings shall be designed and constructed to provide suitable ground control in compliance with 30 CFR 57, Subpart B.

3.3.6 SAFETY

This section addresses the occupational safety requirements for the Repository Segment. The safety of workers and members of the public is paramount at the repository and is addressed throughout this document.

3.3.6.1 GENERAL REQUIREMENTS

B. All Repository Segment work places shall be designed to comply with occupational safety and health standards promulgated under 29 CFR 1910, 29 CFR 1926, and 30 CFR 57.

3.3.6.2 SYSTEM SAFETY PRECEDENCE

The order of precedence for satisfying system safety requirements and resolving identified hazards shall be as follows:

E. This Section (3.3.6) imposes requirements from 29 CFR 1910, 29 CFR 1926 and 30 CFR 57.

1. 30 CFR 57 shall apply only to underground facilities and equipment and to those mining-related surface facilities and equipment specifically addressed in 30 CFR 57.

2. 29 CFR 1910 and 29 CFR 1926 shall apply to all other surface facilities and equipment. 29 CFR 1910 and 29 CFR 1926 shall also be applied to underground facilities and equipment not addressed by 30 CFR 57 and where safety hazard analysis following the precedence in Section 3.3.6.2.A-D deems it necessary.

3.7.5 REPOSITORY UNDERGROUND REQUIREMENTS

D. Retrieval of Waste. The underground facility shall be designed to permit retrieval of waste in accordance with the performance objectives of 10 CFR 60.111. (Section 3.2.1.4.B of the RDRD).

E. Underground Openings.

1. Openings in the underground facility shall be designed so that operations can be carried out safely and the retrievability option maintained.

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

5. The openings shall be maintainable until closure.

7. 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, and groundwater system.

H. Flexibility. The underground facility shall be designed to allow adjustments to accommodate specific site conditions identified through in-situ monitoring, testing, or excavations.

N. Ramps and Shafts.

7. The structures in the shafts and ramps shall be designed to withstand the expected static (e.g., earth pressures within the shaft fill, water column pressures, and in situ stresses) and dynamic loading conditions so that performance is not impaired.

O. Drifts.

1. Drift sizes shall take into account requirements for hauling equipment and shall allow for clearances, ground support, and ventilation.

P. Emplacement Area.

2. The design of the access and emplacement drifts must take into account requirements for the transporter, haulage equipment, and other support equipment and shall include allowances for clearances, ground support, and ventilation.

8.5.2.2 Assumptions

Current design assumptions, listed in the CDA Document (CRWMS M&O 1995a) that relate to repository ground control are stated below. Only the wording of the basic assumption is given. Refer to the CDA Document (CRWMS M&O 1995a) for background and rationale. These assumptions are used for guidance in performing current conceptual design work and will be substantiated, modified, or dropped before becoming requirements for design.

Key Assumptions

Key 011 Waste packages will be emplaced in-drift in a horizontal mode.

Key 013 No human entry is planned in emplacement drifts while waste packages are present. The waste emplacement/retrieval equipment may use robotics and/or remote control features to preform operations and monitoring within the emplacement drifts. Under off-normal conditions, human entry will be considered if protection to the workers can be provided.

Key 016 The repository will be designed for a retrievability period of up to 100 years after initiation of emplacement.

Key 019 Surface, subsurface and waste package designs will be based on a reference thermal load of 80 to 100 MTU [metric tons of uranium]/acre. The reference thermal load for the *MGDS Advanced Conceptual Design Report* is 83 MTU/acre.

Key 022 For the reference thermal loading of 80 to 100 MTU per acre, the repository horizon will be located mainly in the TSw2 geologic unit within the primary area.

Key 023 To the extent practical, repository openings will be located to avoid Type I faults. For unavoidable Type I faults that intersect emplacement drifts, allow 15-m stand-off from the edge of the fault zone to the nearest waste package.

Avoidance is assumed to be adequate by using a 60-m stand-off from the main trace of a fault at the repository level. (Exception: 120-m stand-off should be used on the west side of the Ghost Dance Fault because the ESF Topopah Spring Main drift will be excavated before the Ghost Dance Fault characteristics are fully investigated.)

Key 027 The primary method of tunnel excavation will be mechanical.

Key 028 Where it is impractical to use mechanical methods, drill-and-blast may be used to a limited degree primarily in non-emplacement areas of the repository.

Requirements Assumptions *(Engineered Barrier Design Requirements Document)*

EBDRD 3.2.3.3.A.13

Lining and grouting materials will be used during the construction of the ESF and repository. They will be evaluated for chemical reactions that may adversely impact waste isolation.

EBDRD 3.2.5.4

EBS structures, systems, and components shall be designed for a maintainable preclosure service life of at least 150 years following first emplacement of waste or the period of time authorized by the license granted by the NRC in accordance with the provisions of 10 CFR 60.3.

Note: The rationale for this assumption states that "The 150-year period is rounded up from the 144-year period, which is based on a 100-year retrieval period plus 10 years retrieval preparation plus 24 years to perform retrieval plus 10 years to close the repository."

EBDRD 3.7.G.2

G. To limit the predicted thermal and thermomechanical response of the host rock and surrounding strata and groundwater system, the EBS configuration and loading shall:

2. Keep emplacement drift wall temperatures < 200°C.

EBDRD 3.7.G.6

G. To limit the thermal and thermomechanical response of the host rock and surrounding strata and groundwater system, the EBS configuration and loading shall:

6. Limit the access drift wall rock maximum temperature to 50°C during preclosure.

Design Concept Subsurface Assumptions

DCSS 001: Repository layout – orientation:

- Orientation of emplacement drifts will be at least 30 degrees from dominant joint orientations. Using the latest information on joint orientations, the emplacement drift orientation will generally fall between N70W and S75W.
- Orientation of maintainable access drifts, mains, ramps, etc. will be as needed to complement emplacement drift orientation, generally forming intersections of 70-90 degrees where practicable.

DCSS 005: Drift excavation methods:

- Primary: Tunnel boring machine
- Secondary: other mechanical methods, and drill-and-blast where mechanical methods are impractical.

DCSS 006: Maximum excavation extraction ratio for emplacement drifts: 30 percent.

DCSS 014: Shaft excavation method: Mechanical where practical.

DCSS 023: Maximum allowable preclosure rock surface temperature in:

Shafts:	35°C – unventilated
Ramps:	35°C – unventilated
Mains:	50°C
Emplacement Drifts:	200°C

DCSS 027: Organic materials (e.g., epoxy resin, timber) are limited for use as rock support and other postclosure permanent materials in all openings. Organic admixtures used in cementitious materials should be minimized to the extent practical.

Concrete and steel are allowable preclosure construction material in all openings.

DCSS 028: Emplacement drifts will be designed to be stable through the caretaker period, with the goal to minimize or eliminate planned maintenance to sustain the ability to retrieve, sample, or relocate waste packages. Shafts, ramps, and all other drifts will be designed to be stable, but may rely on periodic planned maintenance.

DCSS 030: Limit surface uplift to less than 0.5 cm/yr and relative motion of the top of TSw1 to less than 1 m with no intact rock failure and no continuous joint slip.

8.5.3 Subsidence Considerations

The SCP (DOE 1988a), Section 8.3.2.2.5, states that ground movements in the vicinity of repository openings must not result in significant postclosure surface subsidence or in the creation of preferred pathways for water migration. Furthermore, the SCP (DOE 1988a) indicates that a strategy for controlling subsidence is needed, which is based on the results of drift and pillar stability analyses. Such analyses, using continuum and jointed rock thermomechanical models, are presented in Appendix B and provide a basis for evaluating the potential for subsidence.

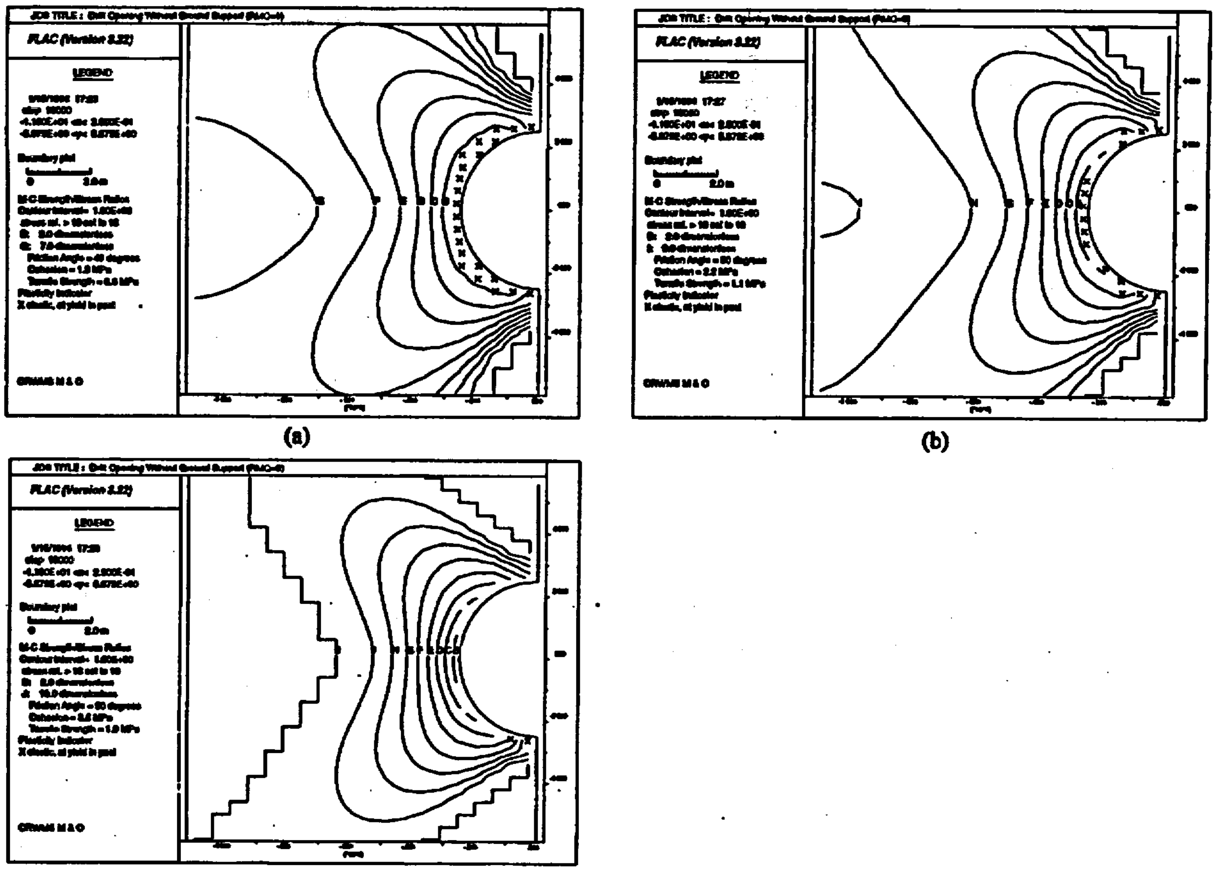
Jaeger and Cook (1976, p 501) state that the problems of ground control depend primarily on the extent to which the rock around an opening becomes fractured, and they further estimate that a series of openings should have a minimum center-to-center spacing of 3 diameters to minimize excavation-induced fracturing. A center-to-center spacing of 3 diameters results in an extraction ratio (excavated area in plan view divided by the total area considered) of one third. The SCP (DOE 1988a), Table 8.3.2.2-3, gives an extraction ratio of 30 percent as a design goal to limit the potential for subsidence in emplacement areas and this value is also assumed as a maximum limit for current repository design (CDA Document, DCSS 006, Section 8.5.2.2).

Stress distributions calculated for drift stability allow the distribution of strength-to-stress ratios to be estimated for the pillar between 5-m-diameter emplacement drifts at a center-to-center spacing of 22.5 m. This case gives an extraction ratio of about 22 percent. For the case of initial opening excavation (in situ stress only), the zone of potential rock yield extends to a depth of less than 1 m from the perimeter of the opening (Figure 8.5.3-1) for the lowest rock mass quality category (RMQ=1) (see B.2.2 for explanation of RMQ categories). This depth of excavation-induced damage is less than 10 percent of the pillar width and should not significantly influence behavior of the pillar, which in this case remains mostly in the elastic state. This finding is further substantiated by evidence from room and pillar mining; for example, Peng (1992, Chapter 8) states that for low extraction ratios (less than 50 percent), a pillar can support the overburden without collapse, and therefore, without surface subsidence.

For a thermal loading of 83 metric tons of uranium/acre, the maximum depth of potential yield in the pillar is about 0.5 m. In addition, more than three-quarters of the pillar thickness has a strength-to-stress ratio greater than 6.0 during preclosure (Figure 8.5.3-2). For both in situ and thermal loads, the extent and location of possible yield zones and strength-to-stress ratios is such that overall elastic deformation of the pillar is maintained. This level of rock mass deformation would not be expected to result in surface subsidence and substantiates the SCP (DOE 1988a) determination that backfilling of openings is not necessary for structural support before closure (DOE 1988a, Section 6.2.7.1). In addition, thermomechanical modeling indicates that the ground surface will in fact rise during preclosure at a rate of about 2.7 mm/year, resulting in a heat-induced heave of about 400 mm at 150 years which is within the limits stated in CDA Document, DCSS 030.

Pillar stability during preclosure and experience with mine subsidence at low extraction ratios, as discussed above, indicate little potential for long-term subsidence and no need for structural backfill. However, postclosure requirements for emplacement drift backfill in relation to repository performance goals have not yet been fully evaluated, thus emplacement drift backfill at closure is not precluded. See Section 8.8 for discussion of emplacement drift backfill and Section 9.4 for discussion of repository backfill at closure.

Creep deformation of TSw2 at elevated temperatures was observed in the laboratory creep experiments conducted by Sandia National Laboratories (SNL 1995c). However, these tests are considered to be preliminary, and their results do not allow any definitive conclusion to be drawn about the effect of creep deformation of tuff at elevated temperature on stability of emplacement drift openings as well as performance of ground support. Therefore, this issue is not addressed in this report.



(a)

(b)

(c)

Figure 8.5.3-1. Factors of Safety Contours and Plasticity Indicators around Opening without Ground Support: (a) RMQ=1; (b) RMQ=3; (c) RMQ=5

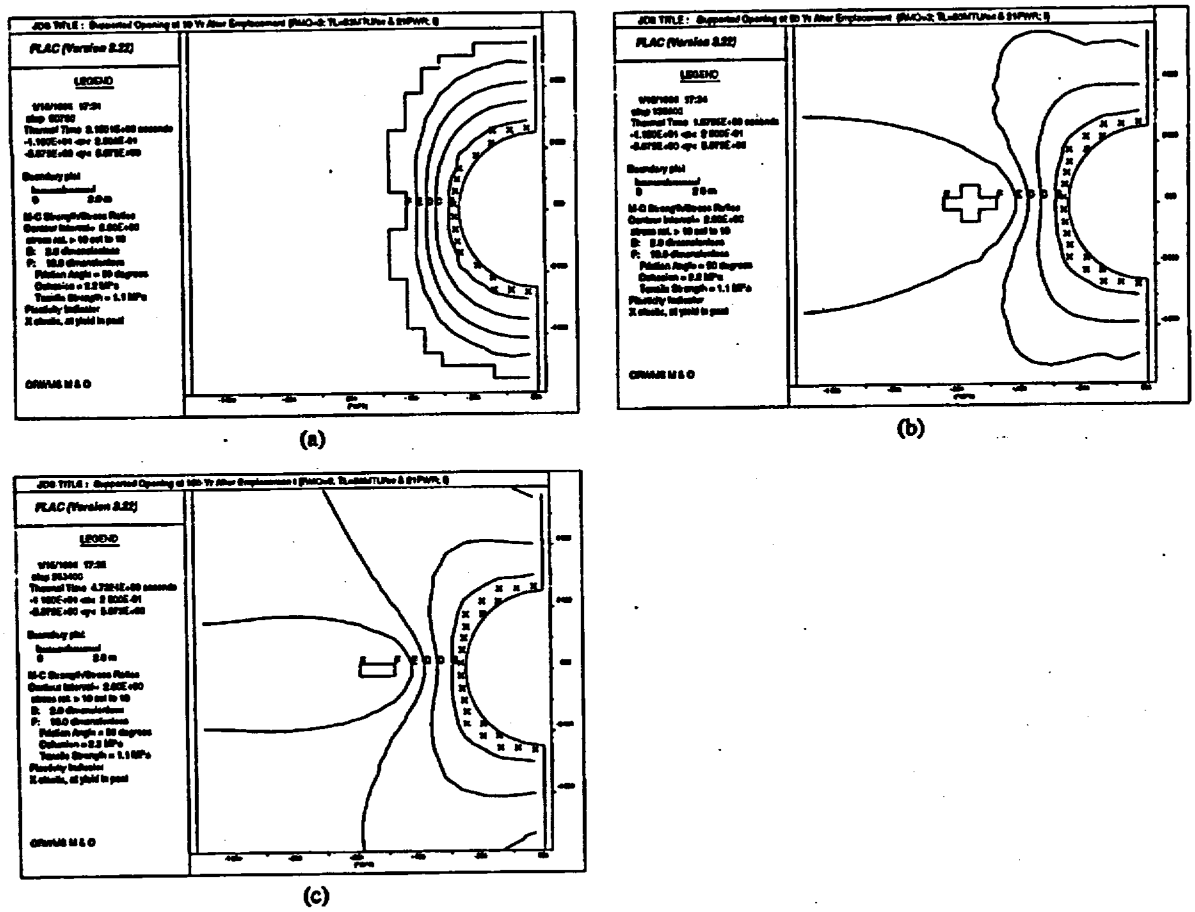


Figure 8.5.3-2. Factors of Safety Contours and Plasticity Indicators around Opening with Ground Support Type I for RMQ=3 and 83 MTU/acre: (a) 10 Years after Emplacement; (b) 50 Years after Emplacement; (c)150 Years after Emplacement

8.5.4 Materials for Ground Support

For support and reinforcement of repository openings, concrete and steel are considered to be allowable construction materials (CDA Document, DCSS 027). The use of organic materials, such as epoxy resin grout and timber blocking, is limited, as are admixtures used in cementitious materials. The longevity of these materials is addressed in Appendix C and discussed below.

Materials used for ground support in emplacement drifts, including drift invert fill, are required to perform under thermally-induced loads, nominally 83 metric tons of uranium/acre. Performance of some materials may be required for periods up to 150 years during the Preclosure Phase. The postclosure behavior of materials in the subsurface openings is also of concern in regard to the potential for degradation of waste packages and radionuclide transport, both of which will depend on the ultimate geochemical environment. Postclosure aspects of material performance have not been specifically considered in this volume, although measures taken to prolong the preclosure lifetime of materials will certainly increase their postclosure survival.

8.5.4.1 Steel

Steel for ground support may exist in the following forms:

- Rock bolts (including face plates)
- Welded wire fabric and chainlink mesh
- Structural steel sets (also referred to as steel ribs, ring beams, and arch supports)
- Bar, welded wire fabric, or fiber reinforcement in concrete and shotcrete
- Straps, channels, and lagging.

The performance of steel subjected to high temperature, radiation, and to potential corrosive conditions is expected to be as follows (Appendix C):

- Carbon steel at about 200°C may experience modest decreases in strength and deformability of about 10 and 15 percent, respectively, in comparison to these same parameters at about 20°C.

- Carbon steel has a thermal expansion that is consistently higher than that of concrete containing a tuff aggregate. That is, the expansion of steel at about 20°C is about 7×10^{-6}/°C higher than the tuff concrete and at about 200°C is about 5×10^{-6}/°C higher. Further testing is recommended to verify these results.

- Radiation effects are believed to be insignificant and not expected to lead to degradation of steel material properties.

- Sulfur-reducing bacteria may penetrate concrete and come into contact with steel. The presence of oxygen, excessively high temperatures, and inadequate sources of sulfate and carbon create an environment hostile to sulfur-reducing bacteria. In the absence of the specialized environment required for sulfur-reducing bacteria metabolism, corrosion of steel by sulfur-reducing bacteria is expected to be limited.

- Zinc galvanization of such steel components as rock bolts and welded wire fabric offers significant protection from electrochemical corrosion. Steel can also be protected from corrosion due to moisture and temperature changes by embedment in shotcrete or grout.

8.5.4.2 Cementitious Materials

Cementitious materials for ground support may exist in the following forms:

- Shotcrete and fibercrete (full circle structural lining, 100 to 150 mm thick; or partial lining to secure fractured rock, less than 100 mm)

- Grout (typically to encapsulate and secure rock bolts, but also to consolidate and strengthen the rock mass)

- Concrete lining (pre-cast segments, cast-in-place, with or without reinforcement such as steel bars, welded wire fabric, or fibers).

In addition to ground support applications, concrete may be used for all or part of an invert fill and for a waste package pedestal.

The performance of cementitious materials subjected to high temperature, radiation, and to potential corrosive conditions is expected to be as follows (Appendix C):

- At temperatures below 300°C, Portland cement retains sufficient strength (unconfined compressive strength) that substitution of a more thermally resistant material appears unnecessary. Consequently, Portland cement-based concrete with "standard" aggregate should be adequate for all concrete used for ground support.

- In regard to blast cooling of emplacement drifts, cooling (from about 200°C to 50°C in a matter of weeks) is expected to result in a maximum strength loss of about 25 percent. This indicates that, even though the results are conservative for repository conditions, repeated cycles of cooling and heating are to be avoided.

- Gamma radiation is believed to be sufficiently below the threshold above which measurable degradation of concrete is observed. Also, gamma heating may result within concrete structures. However, this is expected to be a minor contributor compared to heat transfer between waste packages and exposed concrete surfaces.

- Bacterial degradation of concrete is not considered an important factor overall because such degradation can occur only for a relatively short time immediately after waste emplacement due to suppression of bacterial activity by combined radiation and heating.

An additional finding, based on evaluation of fiber-reinforced concrete (Appendix C), is that fibercrete (shotcrete reinforced with steel fibers) is expected to maintain a level of flexural strength beyond the onset of cracking failure. This residual ductility coupled with the desirability of embedding steel components in cementitious material for corrosion protection and the expectation of good temperature response, as stated above, suggests that fibercrete can perform satisfactorily for the anticipated repository conditions.

8.5.5 Ground Support for Emplacement Development

The primary functions of the emplacement drifts are to provide space for waste packages and to allow for waste retrieval during the lifetime of the repository. Characteristics of emplacement drifts are as follows:

- Shape and size – Circular Tunnel boring machine excavation, 5-m diameter for CID and 5.5 m for OCID.

- Lifetime – Lifetime of 150 years (from initial construction to repository closure).

- Temperature – Ambient temperature about 25°C. Forty-six to 54 years after waste emplacement, at a thermal load of 83 metric tons of uranium/acre, the maximum wall rock temperature is about 155°C. After about 150 years, the average wall temperature drops only about 2°C. For OCID emplacement, the maximum sidewall temperature nearest the waste package is 153°C, 52 to 63 years after waste emplacement (Section 8.2.4). The design rock temperature limit is 200°C.

- Temperature change due to blast-cooling from 150°C to 50°C in 2 to 6 weeks.

- Radiation – Maximum dose rate of 28.9 rem/hr at the waste package wall (CRWMS M&O 1995bf, Table 7-42)

- Inspection/Maintenance – Periodic inspection possible, but severely limited access for maintenance.

Requirements for worker health and safety and for retrievability, as stated above and in the requirements listed in Section 8.5.2.1, dictate that repository openings be usable during a 150-year lifetime. The temperature and radiation conditions of these drifts indicate that, although periodic inspection is possible, maintenance will be severely limited. In this regard, emplacement openings are planned to be as inherently stable as possible, the goal being to minimize the need for engineered support and thus enhance the maintenance and retrieval operations.

Factors that contribute to the inherent stability of emplacement drifts are as follows: First, emplacement drifts are planned to be as small as practical, based on equipment and waste package operational requirements, thus limiting the maximum size of rock blocks that could potentially fall. Second, emplacement drifts have been spaced about four drift diameters apart (center-to-center) to minimize pillar stress and the potential for rock failure and to eliminate the possibility of surface subsidence. Third, emplacement openings have been oriented to avoid having the long axes of drifts parallel to major joint sets (Appendix B.2.3) so that the size and frequency of potential block falls are limited. Fourth, excavation by TBM minimizes rock mass disturbances that could create and loosen rock blocks. In addition, the circular shape results in a theoretically smooth "flow" of stress around the opening. That is, upon excavation this shape tends to produce a compression arch of interlocked blocks that transmit the predominately vertical overburden stress around the drift. As horizontal stress increases in response to waste package heating, compressive stress around the drift becomes initially more uniform before stresses peak at the crown and floor.

As a further aid in understanding emplacement drift stability, potential rock mass behavior modes have been examined by numerical modeling (Appendix B). Load cases examined included in situ overburden (with and without seismic loads) and thermomechanical loads (with and without seismic loads). For in situ conditions following excavation, overburden stress and relatively low lateral stress produce joint movement and the potential for loosening of blocks at the crown. Inward rock mass movement of the drift is small (e.g., closure between crown and floor is from 3 to 10 mm) and between walls is from 1 to 2 mm (Figures 7a and b, Appendix B).

Predictions of stress and displacement around a drift heated by waste packages indicate small values for closure, about 13 mm maximum horizontal closure, but show tangential stresses on the order of 17 to 56 MPa that can exceed the rock mass strength close to the opening (Table B-9, Appendix B). Although the stress increase due to heating may induce rock cracking and spalling at the drift crown and floor, this effect is expected to be relatively shallow. In general, heating is expected to increase the confining stress in rock surrounding the openings, thereby enhancing stability by reducing the potential for block movement.

An exception to the confining stress state may occur during periods of rapid cooling (see Section 8.7.6.3) for maintenance or for retrieval that will temporarily lower temperature close to the opening surface, producing steep thermal gradients. In addition, as the temperature of the surface rock decreases due to rapid cooling, thermal contraction of the rock takes place. These changes in temperature and displacement may cause individual blocks of rock adjacent to the opening to become unstable as indicated in *Stability of Disposal Rooms During Waste Retrieval* (NRC 1989b). Thermomechanical analysis of ventilation cooling, *Thermomechanical Calculations for FY93 Thermal Loading System Study* (CRWMS M&O 1994u), also showed a potential for rockfall due to a predicted decrease in stress in the rock mass immediately surrounding the drift.

Emplacement drifts can be expected to exhibit general stability, that is, large drift-scale ground movement and yield are not expected. However, ground support will be needed to control the potential loosening and fall of blocks in certain portions of the drifts, especially from the upper half of the opening. Critical periods for such behavior apparently occur prior to waste package heating when in situ stress is low and possibly during periods of cooling. It does not appear critical to drift stability to control rockfall due to surface spalling, although cracking at the crown may increase the potential for key block formation.

The function of ground support for emplacement drifts is to provide light to moderate confinement to the rock mass so that loosening and falls of rock blocks in limited areas are prevented. Rather than design to resist mechanical strain resulting from a thermal stress change or from seismic load, ground support components will be fabricated for durability, ductility, and structural flexibility. Because grouted rock bolts and fibercrete constitute a structurally flexible support system that is resistant to corrosion, these components are expected to be applicable for the majority of emplacement drift ground conditions. Steel components, such as steel sets, lattice girders, and welded wire fabric, may be used for initial and final support, but it is expected that all steel components will be incorporated in a final application of fibercrete for longevity. Further testing, including in situ tests, and analysis are necessary to determine the proper approach for all ground conditions anticipated.

Numerical structural analysis (Appendix B) indicates that over the expected range of repository temperature change, candidate ground support components (rock bolts, shotcrete, and steel sets) experience high stress. In certain cases the induced stress exceeds yield limits. For example, full circle shotcrete and steel sets exhibit compressive yield (Figures B-12a and B-14a, Appendix B), and tensile yield is exhibited for certain rock bolt cases (Figure 8.5.5-1). Modification of these components may be necessary to accommodate thermal loading. These points are summarized as follows:

Rock bolts – Rock bolts are assumed to be fully encapsulated with cementitious grout. Bolts become overstressed (strength/load ratio < 1.0) for the poorer (lower modulus) rock that exhibits relatively larger deformations (Figures B-10a and b, Appendix B). Apparent stress concentration in bolts installed at the drift springline could be alleviated by debonding the bolts near the face. Compressible materials could also be incorporated at the bolt head or face plate, although a period of cooling (for example, a cool-down for inspection) may result in a temporary unloading of the bolt if the compressible component does not behave elastically.

Steel sets – Steel sets are analyzed as full-circle ring beams, in full contact with the drift surface. In this configuration the steel sets, in about 15 to 30 years after emplacement, reach a strength/load ratio of less than 1.0 for all rock quality cases examined (Figure B-14a and b, Appendix B). Steel sets, in general, are considered as possible installation as ground support for the poorer rock conditions (highly fractured rock) and thus initial rock deformation may alleviate the subsequent accumulation of high member stresses. In any case, provision should be made for structural flexibility in order that high axial (hoop) stress does not exceed limiting values. Compressible materials or structures at connections could be used to accommodate

the buildup of thermally-induced load, but possible unloading during a cool-down episode should be taken into account.

Shotcrete – Shotcrete, specifically steel-fiber reinforced shotcrete or fibercrete, is considered a possible component for emplacement drift support. However, stress analysis of a full circle or ring of shotcrete shows that, like steel sets, high axial stress may result in compressive failure. Also, tensile failure is expected in the area of the springline.

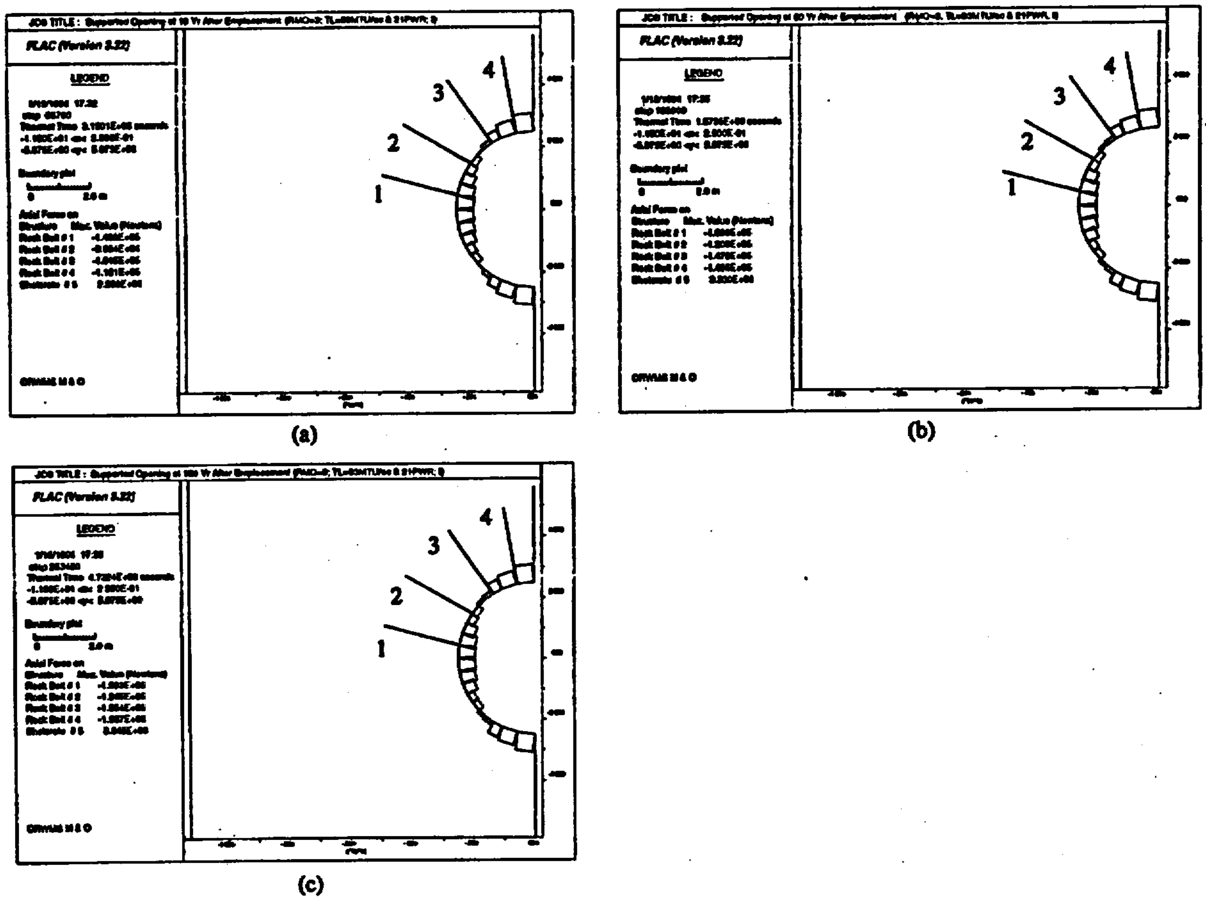


Figure 8.5.5-1. Axial Forces in Rock Bolts and Shotcrete for Ground Support Type I, RMQ=3 and 83 MTU/acre: (a) 10 Years after Emplacement; (b) 50 Years after Emplacement; (c)150 Years after Emplacement

These analyses indicate that shotcrete performs more successfully for the poorest rock, due to the lower rock stiffness associated with that category. To alleviate overstressing, full circle installation of shotcrete should be avoided. Rather, shotcrete installed in the upper half of a drift may react more flexibly with reduced stress. For increased ductility and tensile strength, fibercrete may prove most useful.

Based on the ground support recommendations reported in Sections 8.5.1.1 and 8.5.1.2, the points discussed above, and other considerations as reported in Appendices B and C, Table 8.5-3 presents an estimation of final ground support requirements for emplacement drifts. Grouted rock bolts and fibercrete are listed as final ground support components. In practice, initial support during excavation may also rely on such components as steel split sets and welded wire fabric that are more compatible with TBM excavation but that would subsequently become part of the final fibercrete/grouted bolt support system. The final ground support can be installed as a second stage, remote from the TBM operation; however, it is expected that both grouted rock bolts and fibercrete can be installed initially as needed, during the TBM advance. In addition, steel sets or lattice girders may be used in limited areas of poor ground with allowance made for maintaining clearance requirements in the drift to allow encapsulation of the steel components in fibercrete. These recommendations have been incorporated in the detailed listing of ground support in Section 8.3 that has considered the additional questions of opening function and constructibility.

Further analyses related to mechanical stability and longevity of materials must be completed to provide final recommendations for ground support. Such analyses would include in situ thermal testing and the incorporation of other ESF performance confirmation data. The recommendation of fully grouted rock bolts for repository design reflects a conservative approach due to uncertainties regarding long-term corrosion resistance and thermal loading efforts.

8.5.6 Ground Support for Mains and Ramps

Characteristics of mains and ramps are as follows:

- Primary functions – access, service, waste transport, and ventilation
- Shape and size – circular TBM excavation, 7.6 to 9 m diameter
- Lifetime – lifetime up to 150 years (from initial construction to end of closure)
- Temperature – rock temperatures from ambient (25°C typically) to a calculated maximum of:
  - 100°C for drift at center of emplaced area (Central Exhaust Main)
  - 80°C for drift at 35 m standoff from edge of emplaced area (Tunnel Boring Machine Launch Main)
  - 50°C for 75 m standoff from edge of emplaced area (Service/Perimeter Main)
  - 35°C for ramps and other drifts not adjacent to emplaced area.

Table 8.5-3. Ground Support for Emplacement Drifts

Rock Mass Quality Category (RMQ)	NGI Classification (Q-Value Range)	NGI Support Category	Approximate Frequency of Occurrence of Support Categories	ESF Ground Support Class	Initial Ground Support	Final Ground Support
5	Fair to Good (5.5 - 26)	13, 17	20%	I and II	Split sets, welded wire fabric.	Rock bolts, grouted, 1.5 m pattern. Spot bolt as needed.
3 and 4	Poor and Fair (1.0 - 5.5)	18, 22	60%	II and III	Split sets, welded wire fabric, final support as needed.	Rock bolts, grouted, 1.0-1.5 m pattern, 25-75 mm fibercrete to springline.
1 and 2	Very Poor (0.1 - 1.0)	27, 31	20%	III and IV	Split sets, welded wire fabric, final support as needed.	Rock bolts, grouted, 1.0 m pattern, 75-150 mm fibercrete.

Temperature changes due to blast-cooling to 50°C in 2 to 6 weeks.

- Inspection/Maintenance – Periodic inspection and maintenance.

Types of ground support for mains and ramps are expected to be similar to support used for the emplacement drifts, that is, rock bolts, welded wire fabric, shotcrete, and steel sets will be the primary components (see recommended support in Section 8.4). Except perhaps for those openings, such as the Exhaust Main and the TBM Launch Main, which will receive a significant thermally-induced mechanical load from the heated emplacement drifts, modifications to accommodate the stress/displacement change will not be necessary and better performance can be expected from the installation of full-circle shotcrete linings if needed. An advantage to ground control for non-emplacement drifts is that inspection and maintenance can be carried out without the severe restraints of radiation and heat exposure.

8.5.7 Ground Support for Shafts

Characteristics of shafts are as follows:

- Primary function – ventilation
- Shape and size – circular excavation by shaft boring machine, 6 m diameter
- Lifetime – lifetime up to 150 years (from initial construction to end of closure)
- Temperature – rock temperatures from ambient (25°C typically) to a maximum of 35°C
- Inspection/Maintenance – periodic inspection and maintenance.

Shafts are expected to be constructed with a final concrete liner basically for long-term structural support of the rock mass and to prevent rockfall hazards. The type of lining, benefits of increased ventilation performance, and other factors are discussed in Section 8.5.1.3. Initial support placed during shaft sinking, but in advance of lining operations, is likely to consist of rock bolts, welded wire fabric, and shotcrete.

8.5.8 Maintenance Considerations

8.5.8.1 Monitoring for Ground Control

Monitoring for ground control will include the measurement of rock and air temperatures, humidity, seismic events, rock mass displacements, drift closure, and loads on ground support components. Baseline or reference conditions, established during the ESF monitoring of construction activities and during thermomechanical testing, will be used to develop criteria for subsequent monitoring of repository openings. Monitoring will continue during repository construction, development, caretaker, and closure phases. Post-emplacement monitoring, at least in part, will take the form of global measurement of ventilation parameters (e.g., air temperature and humidity), rock mass temperature, and drift closure adjacent to emplacement areas. It may be necessary to develop remote methods of monitoring for these purposes. These data are also a component of the performance confirmation program that additionally monitors the waste packages and related systems.

8.5.8.2 Inspection, Maintenance, and Rehabilitation

Although it is a currently stated assumption that emplacement drifts are designed to be stable through the retrievability period and will not rely on planned maintenance (CDA Document, DCSS 028), some degree of post-emplacement drift maintenance may be necessary. In any case, a goal is to develop emplacement drifts having long-term stability and to minimize the number of times that emplacement drifts will be re-entered because of potential safety concerns, potentially damaging thermomechanical effects due to cooling of drifts, and the high cost of emplacement drift maintenance.

Inspection will be necessary to determine the need for drift repair. Since operating temperature limits for equipment of the sort needed to carry out such inspections are about 50°C, cooling of unventilated drifts would be required. Even infrequent, say 10-year-interval inspections, could result in undesirable thermomechanical cycles on structures, including the waste package. Alternatives are to continuously cool the emplacement drifts throughout the retrievability period, or to develop techniques for inspection of emplacement drifts at elevated temperatures. It is assumed that inspection would not disturb waste packages, although inspection in the confines of a CID emplacement mode is expected to be difficult.

Drift inspection concepts, related to the CID emplacement configuration, are evolving. Preliminary concepts are being explored for using small, 1-m wide, remotely operated vehicles that could be driven along either side of the emplaced waste packages and provide real-time video and radiation sensing. One of the principal advantages of emplacing waste packages in an off-center emplacement configuration, rather than CID, is the added accessibility off-center provides for rail-based inspection and monitoring equipment, which could be remotely controlled by human operators. These mobile remote systems would have complete access along the entire length of the emplacement drifts, even after waste packages are in place. These systems would have capabilities similar to those outlined in the Performance Confirmation Equipment Section (Section 9.3.4).

Necessary drift repair work for CID emplacement, as well as for OCID emplacement, is expected to require the complete removal of waste packages. In such a case, temporary storage, possibly equal to that of an emplacement drift, must be available. Temporary retrieval and relocation of waste packages would allow work crews to enter the empty drifts and perform inspection, maintenance and rehabilitation work. Retrieval concepts call for using the same, or similar, remotely operated equipment and systems as would be used for emplacement. Normal and off-normal retrieval operations and equipment concepts are presented in Section 9.2.3 of this report.

Openings exclusive of emplacement drifts (e.g., mains, ramps, and shafts) may rely on periodic, planned maintenance (CDA Document, DCSS 028), although these openings would be designed for long-term use with emphasis on low maintenance.

8.6 WASTE PACKAGE EMPLACEMENT

Subsurface functions for waste package emplacement begin with the transfer and receipt of each waste package originating from the surface WHB to the subsurface repository. This section covers the various phases that lead from waste package receipt to emplacement. Major issues addressed include waste package transport and the emplacement concept, emplacement equipment details, and related remote handling considerations.

The purpose of the WHB is to receive the radioactive waste materials from various nuclear facilities throughout the United States. The waste will arrive in the form of both sealed canisters and uncanistered spent fuel assemblies. The WHB places both canistered fuel and uncanistered spent fuel into disposal containers. Loaded and sealed disposal containers are termed waste packages. After completion of the packaging functions, tests, and evaluations, the loaded waste packages are ready and available for transportation and subsequent emplacement in the subsurface repository.

Functions in the WHB conclude with the transfer of each waste package from the surface facility to the subsurface facility. This includes the release of the waste package from within the WHB through an air lock system to a fully enclosed, annexed transfer facility where the waste package is transferred into a radiation shielded underground waste package transporter. Due to the radioactive environment near the waste packages, all handling functions of the waste package will be remotely controlled (CRWMS M&O 1995a, Key 012); this includes the loading/unloading of the waste package and the closure/opening of the waste package transporter doors.

Once the waste package has been placed inside the waste package transporter and its shielded doors are closed, the operating personnel are able to walk and work near the waste package transporter to perform any additional functions as necessary. After final inspection the waste package transporter is ready and available for shipment into the subsurface repository. There will be direct rail access from the WHB (CRWMS M&O 1995a, Key 010) to the entrance of the repository at the North Portal.

The waste package transporter will be pulled by a transport locomotive which functions as a dedicated prime-mover. Operator controls of the locomotive and waste package transporter will have dual features for manually and remotely controlled operations, depending on the requirements and the environment in a given area.

Since the handling functions of the waste package in the WHB and in the subsurface repository are very similar, similar equipment and systems will be utilized to meet the requirements in both areas.

8.6.1 Previous Work

This section of the report addresses a number of alternative emplacement related equipment, concepts, and technologies that were considered in the development of the waste package emplacement concepts for ACD.

A summary discussion of Waste Emplacement Concepts and Considerations was presented in the *Initial Summary Report for Repository/Waste Package Advanced Conceptual Design* (CRWMS M&O 1994a). That discussion addressed waste package emplacement for CID and off-center in-dirft-on-rail-car . The term CID refers to emplacement of a waste package on a single set of tracks or a pedestal, which is located along the drift center line. The term OCID refers to emplacement of a waste package to one side of the drift off the center line (off-center), providing additional clearance on one side and to enhance future access in the emplacement drift. The waste package emplacement on-rail-car requires an emplacement locomotive for placement of the waste package on an emplacement railcar in the emplacement drift(s). The on-pedestal concept requires a mobile gantry crane to transport and lift the waste package onto a permanent pedestal in the emplacement drift. Concepts of several gantries and waste package transporters are shown in the Initial Summary Report (CRWMS M&O 1994a).

- **Waste Package Transporter.** Several waste package transporter designs were examined in FY 1995 in the *Recommended Layout Concepts Report* (CRWMS M&O 1995ai). One design option involved a waste package transporter that had fixed (non-pivoting) travel wheels. This general concept was first presented in the *Initial Summary Report for Repository/Waste Package Advanced Conceptual Design* (CRWMS M&O 1994a). The fixed travel wheel design required that supplementary equipment be used for subsurface transport to negotiate track curves enroute to the emplacement drift. An option presented for that purpose in previous conceptual design studies was to place the waste package transporter atop a specially designed but relatively simple rail carrier equipped with pivoting wheel truck assemblies. A notable disadvantage of this concept is the overall height of the waste package transporter/carrier assembly and the potential for instability; for these reasons the fixed travel wheel concept is no longer being pursued.

  More detailed features and design considerations regarding the waste package transporter are presented in Section 8.6.4.1. The waste package transporter is equipped with pivoting travel wheel assemblies, thus eliminating the need for an additional rail carrier and enhancing stability during travel. This option allows the waste package transporter to directly approach the entrance to an emplacement drift without the need for supplementary handling and positioning equipment, such as a turntable.

- **Turntable.** The use of a turntable for rotation of the waste package transporter and the contained waste package is a concept that was developed early in ACD and was presented in several past design reports (CRWMS M&O 1993e and CRWMS M&O 1994a). In those reports, the turntable was placed in a 9 m diameter tunnel used first for TBM launching operations during repository development and then converted to a dedicated Waste Handling Main during emplacement operations. The turntable was designed to operate at a raised elevation above the existing rail system, thus requiring additional transfer equipment.

Drawbacks of the raised turntable concept were in the related transport equipment. The waste package transporter, if moved on the separate rail carrier, would have added additional height and weight to the assembly. This additional equipment height could have been cause for instability during the rail travel from the WHB to the repository emplacement area, and it would have required larger drift dimensions. In addition, the substantial weight for the rail carrier and the related mobile equipment would have required a rather large transport locomotive. These conditions would have led to excessive wheel loads onto the rail system and the supporting concrete inverts in the drifts.

Additional waste package transport concepts through the TBM Launch Main and utilizing the turntable have been developed during FY 1995 in the *Emplacement Equipment/ Concept Development Report* (CRWMS M&O 1995q). However, a further review of this waste package transport concept led to the conclusion to look for other, less complex waste package transport methods.

- **Gantry Crane.** The gantry crane is an option for waste package transport in the emplacement drifts that has been evaluated and could be used instead of the waste package on railcar concept.

  Gantries are commonly used in many heavy industrial, underground tunneling, and nuclear applications to lift and move large, heavy objects. They are often custom designed to fit a specific application. Gantry concepts for waste package emplacement were introduced into ACD in FY 1994 (CRWMS M&O 1994a). This gantry concept is similar to that described in Section 8.6.3.2, except that the waste packages do not require a permanent railcar to facilitate the emplacement and retrieval processes. Rather, a self-powered gantry is used to move the waste packages inside the emplacement drift and to lower them onto pedestals in predetermined emplacement positions. Two gantry concepts have been considered: jack screw design and rotating hinge design.

  With the jack screw gantry, lifting brackets engage the waste package on its outer circumference. With the rotating hinge design, two hinged arms engage the waste package on both ends. A preliminary evaluation regarding the structural integrity of the waste package confirmed this method of support with an ample safety margin (CRWMS M&O 1995an).

  A gantry would be propelled at a slow speed, probably in the range of 2 to 4 km/hr, by a system such as an electric motor which drives a gear box. The slow speed will allow a reasonably sized motor to be used and would reduce the potential for accidents during the transportation operation. Braking mechanisms would be provided and designed to stop the gantry without aid of the drive system components. Drive system components could also provide dynamic braking capability.

The gantry concept involves more complex remote handling movements inside the emplacement drift, but offers the ability to thermally manage the repository during emplacement by adjusting the position of the waste packages inside the drift during the preclosure years without removing any packages from the drift. The gantry concept could be designed to lift the waste package off the waste package transporter loading mechanisms discussed in Section 8.6.4.3, and to place the waste package onto pre-positioned pedestals in the emplacement drifts. This lifting of the waste package would occur near the emplacement drift entrance, just inside of a shielding door.

- **Air Bearing Technology.** Another relatively new method that has been investigated to handle and transport heavy loads is the application of air bearing technology.

  Air bearings and air pallets are commonly used in a variety of heavy industrial, manufacturing, and nuclear applications to move large and heavy loads in an efficient and highly maneuverable manner. An air pallet, equipped with several individual air bearings, can be furnished on a commercial basis. The air bearing/pallet concept uses compressed air to float heavy loads on a thin film of air. Relatively low-pressure compressed air is required and is dependent upon the weight to be carried and the size of the bearing/pallet. The volume of air needed to generate and maintain a sufficient air cushion is a function of the surface quality on which the bearing/pallet must operate. Several handling concepts for the waste package on air bearings were considered for the application of this technology in the repository. Two concepts used a skid-mounted waste package as discussed in the *Emplacement Equipment/Concept Development Report* (CRWMS M&O 1995q) and *Recommended Layout Concepts Report* (CRWMS M&O 1995ai).

  The first of several concepts included permanent air bearings of steel construction which were integral to the skid. The second concept used a removable air pallet equipped with air bearings. Both concepts used a small battery-powered, rail-mounted emplacement locomotive to push the skid-mounted waste package down the emplacement drift. Such a locomotive would be smaller than the locomotive discussed in Section 8.6.4.6 because the air cushion presented a relatively small frictional resistance to overcome, compared to the rolling resistance of a rail-mounted car. An air compressor, built integrally into the locomotive to supply air to the air bearing/pallet, was required.

  Both concepts were ultimately judged to be impractical. A major reason for this conclusion was that relatively large volumes of air would be needed to raise a typical waste package above its pedestal and to keep it suspended on an air film during the transport and emplacement functions, thus requiring a large energy source. Feasibility of using battery power as the energy source was questionable compared to concepts using steel wheels on rail which are more efficient for the relatively long travel distance of up to 600 m in the emplacement drifts.

  A third concept uses the air bearing technology only for the transfer functions of the waste package into and out of the waste package transporter. The compressed air supply to the waste package transporter would be provided through supply lines from subsurface utilities. The skid-mount would be attached to an air hose which would be stored inside the waste package transporter on an automated hose reel. The remotely controlled air supply would activate the air bearings and the air powered tractor drive units in the skid-mount. After the transfer of the waste package/skid-mount assembly onto the waste package transfer dock at the emplacement drift entrance, a gantry crane would move the waste package into the emplacement drift. The empty skid-mount would retract back inside the waste package transporter prior to returning to the WHB.

- **Waste Package Lifting Car.** Another emplacement equipment design concept that has been considered in FY 1995 was a waste package lifting car. This concept consists of a car similar in design to the emplacement railcar. The waste package would rest on a steel support structure which would be designed to allow the lifting car to pass under the support structure. The lifting car would be equipped with several low height air pillow jacks and the rails in the emplacement drift would be placed in a recessed pocket in the emplacement drift invert. Both of these features would allow the height of the support structure and the waste package to be minimized. However, the combined height of this concept would still be considerably greater than that for other pedestal schemes. The lifting car would be pushed by an emplacement locomotive of similar size to that described in Section 8.6.4.6.

  The lifting car would be equipped with a small air compressor or compressed, bottled air system which would supply the relatively low quantity of air needed to raise the air pillow jacks, and consequently the supporting structure, several centimeters off the floor during transport in the emplacement drift. This concept would have a built in fail-safe feature. In the event of an air pillow failure, the pedestal would automatically be lowered to the ground and the lifting car could then be pulled out from underneath the pedestal and taken out of the emplacement drift for repair or replacement.

- **Waste Package Emplacement by Automated Guided Vehicle System.** Key Assumption 010, as listed in the CDA (CRWMS M&O 1995a), states that "Integrated rail transport will be used for transport of waste packages." Based on this assumption, discussions in previous reports have focused primarily on rail-based equipment and emplacement concepts. However, one established manufacturer of Automated Guided Vehicle Systems provided preliminary information for the transport and handling of the waste package in the emplacement drifts by use of a non-rail Automated Guided Vehicle System, in place of the gantry crane concept. This system utilizes polyurethane tires for traveling instead of steel wheels on rails.

  An Automated Guided Vehicle System is a computer-controlled, wire guided vehicle used to transport and transfer heavy loads in a wide variety of industrial material handling and robotics applications. Such a battery-powered driverless vehicle can be programmed for path selection and positioning and is designed to follow a flexible guide-path. Typical methods for guidance and communication are by low frequency or laser signals. Further investigation regarding the technology and the merits of this concept should be continued.

8.6.2 Design Inputs

Project requirements, controlled design assumptions, and other design-based criteria and assumptions that have been considered in the preparation of this section of the report are included in this section.

8.6.2.1 Requirements

8.6.2.1.1 Regulatory Requirements

10 CFR 60, Disposal of High-Level Radioactive Wastes in Geologic Repositories

The requirements of 10 CFR 60 flow down to the project level RDRD (YMP 1994a).

8.6.2.1.2 Project Requirements

All text in this section is excerpted directly from the RDRD (YMP 1994a), the reference source for repository requirements. Upper level requirements from within the program (i.e., CRWMS upper level requirements) and outside the program (such as 10 CFR 60 requirements) are included in the RDRD (YMP 1994a). The specific RDRD (YMP 1994a) requirements quoted below are considered applicable to aspects of repository waste package emplacement. Other RDRD (YMP 1994a) requirements, which may apply in a more general way, are not included here.

3.2.4.5.1 SHIELDING DESIGN

A. Normally Occupied Areas. The shielding design basis shall limit the maximum exposure to an individual worker to one-fifth of the annual occupational external exposure limits. Within this design basis, personnel exposures must be maintained ALARA. Specifically, the shielding should be designed with the goal of limiting the total effective dose equivalent to less than one rem per year to workers, based on their predicted exposure time in the normally occupied area. The effective dose equivalent is the sum of all contributing external penetrating radiation (gamma and neutron). In addition, appropriate shielding must be installed, if necessary, to minimize non-penetrating external radiation exposures to the skin and lens of the eye of the worker. In most cases, the confinement barrier or process equipment provides this shielding.

B. Intermittently Occupied Areas. Shielding and other radiation protection measures shall be provided for areas requiring intermittent access, such as for preventive maintenance, component changes, adjustment of systems and equipment, and so forth, with the goal of limiting dose rates based on occupancy, time, and frequency of exposure to one rem per year.

C. **Concrete.** Concrete radiation shielding design shall comply with ANSI/ANS 6.4 and ACI 349 and shall consider the material specifications of ANSI/ANS 6.4.2 where it provides a critical confinement or structural function. For other shields, ACI 318 is appropriate and provides adequate strength for design earthquake loads.

D. **Penetrations.** Design of shield walls shall avoid straight-line penetrations to prevent radiation streaming.

3.2.5.1 RELIABILITY

The Repository Segment shall provide a fault-tolerant (or fail-safe) system that allows for the continued management, handling, transfer, storage, emplacement, retrieval, and isolation of SNF and HLW in a safe manner that optimally protects health, safety, and the environment under all operational conditions. Nothing in this section shall be construed to indicate that NRC-mandated redundancy of systems may be neglected.

3.2.5.1.2 RELIABILITY OF EQUIPMENT[1]

A failure modes and effects analysis shall be performed for all major equipment whose failure can result in personnel injury or illness. Based on this analysis, designs shall be developed to ensure reliability which minimizes safety hazards to the extent possible. Under such design conditions, failures shall not result in personal injury or occupational illness. If designs cannot be developed to these requirements, then the reliability of systems will be shown by analysis to be such as to minimize the probability of injury or illness to personnel. In demonstrating system reliability, MIL-STD-882B shall be considered in the design, where applicable. (These requirements differ from "items important to safety" and "items important to waste isolation," both of which have very specific meanings for meeting NRC requirements. Further, these criteria do not supplant radiological standards contained in NRC or EPA requirements; e.g., the radiological standards of 10 CFR 20).

3.2.5.2.2 PHYSICAL CLEARANCE

A. **Corridors.** The size and arrangement of interior corridors and drifts shall accommodate the movement of equipment including initial equipment installation, facility operations, and possible future removal or replacement of equipment. Movement of waste packages into and out of the emplacement drifts requires specific attention.

B. **Maintenance Accessibility.** Facility design shall provide access for routine maintenance, repair, or replacement of equipment subject to failure. Accessibility includes proper lighting and utility hookups and acceptable levels of radiological exposure.

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[1]This requirement is applicable only prior to permanent closure.

3.2.5.2.6 MAINTENANCE IN RADIOACTIVE ENVIRONMENTS

Equipment which normally operates in a radioactive environment or in the vicinity of radioactive components shall be designed to be moved to a non-radioactive environment for maintenance or repair, whenever possible. When that is not possible, the design shall allow for installation of temporary shielding, permit minimizing radiation exposure times, and provide sufficient space for ease of operation, maintenance, and repair.

3.2.5.2.7 IMPORTANT TO SAFETY EQUIPMENT

Equipment which could fail during an operation important to safety shall be designed to permit recovery of the operation without compromising the health and safety of the public or the repository employees.

3.2.5.2.8 DESIGN FOR MAINTAINABILITY

E. The time required to perform work in the vicinity of radioactive components shall be kept to an absolute minimum; for example, by providing sufficient space for ease of operation and designing equipment for ease of repair and replacement.

3.7.3.6 TRANSPORTATION

G. The railroad track design shall conform to the applicable requirements of the Manual for Railway Engineering, American Railway Engineering Association (AREA 1987/1988).

3.7.4.1 WASTE HANDLING REQUIREMENTS

4. The facilities and equipment used for waste-handling operations shall be designed so that waste-handling operations can be performed in reverse order to permit retrieval of emplaced waste packages.

5. Cranes and similar handling equipment shall be capable of meeting the requirements specified by DOE Order 6430.1A, Section 1460 and the CMAA 70 Standard.

6. All remotely operated cranes, manipulators, and other equipment used for handling highly radioactive solid wastes, shall be capable of being viewed and remotely monitored for contamination and radiation levels.

3.7.5 REPOSITORY UNDERGROUND REQUIREMENTS

D. Retrieval of Waste. The underground facility shall be designed to permit retrieval of waste in accordance with the performance objectives of 10 CFR 60.111. (Section 3.2.1.4.B of this document)

8.6.2.2 Controlled Design Assumption Document

The following assumptions from the CDA Document (CRWMS M&O 1995a) developed by earlier repository studies in many cases present reasonable design solutions.

8.6.2.2.1 Key Assumptions

Key 010: Integrated rail transport will be used for subsurface transport of waste packages.

Key 011: Waste packages will be emplaced in-drift in a horizontal mode.

Key 013: No human entry is planned in emplacement drifts while waste packages are present. The waste emplacement/retrieval equipment may use robotics and/or remote control features to perform operations and monitoring within the emplacement drifts. Under off-normal conditions, human entry will be considered if protection to the workers can be provided.

Key 030: Rail will be used for transporting underground supplies and personnel to the extent practical.

Key 031:

A. Waste package containment barriers will provide sufficient shielding for protection of waste package materials from radiation enhanced corrosion.

B. Individual waste packages will not provide any additional shielding for personnel protection.

C. Additional shielding for personnel protection will be provided on the subsurface transporter and in surface and subsurface facilities.

Key 047: The proposed repository waste handling and administrative surface facilities will be located adjacent to the north portal.

EBDRD 3.7.1.J.1 The waste package shall meet the following criteria:

1. External dimensions shall not exceed:
   Outer Diameter:1850 mm
   Outer Length:5850 mm

EBDRD 3.7.1.J.2:

The waste package shall meet the following criteria

1. Weight shall not exceed 69,000 kg (this excludes filler material).

2. The internal waste package/MPC filler material, if required, is estimated to add a maximum of 24,000 kg.

EBDRD 3.7.3:

The emplacement hardware requirements are for hardware used to support and protect the emplaced waste packages. Examples of emplacement hardware are a pedestal under the waste package for the in-drift emplacement concept and a carriage and rail system for the horizontal opening concept. Emplacement hardware does not include ground support hardware, which is part of the Repository Segment. Emplacement hardware requirements will be added during and after ACD.

RDRD 3.2.3.2.2.A:

The Repository Segment shall accommodate the emplacement concept selected during ACD.

DCS 003: The Surface Facilities that house radioactive materials, or in which work is performed on radioactive materials, will be designed to control occupational exposures to ALARA and less than 500 millirem per year.

DCSS 009:

1) Maximum grade in ramps: ≤ 3% to accommodate rail transport.

2) Maximum grade in mains: minimize, but ≤ 2% in mains used for emplacement drift access.

3) Maximum grade in emplacement drifts: minimize within 0.25 to 0.75% range for drainage.

8.6.3 Waste Package Emplacement Concept

This subsection provides a detailed description of waste package transport and emplacement in the subsurface repository.

8.6.3.1 Subsurface Handling and Transportation Description

Major activities of the waste package emplacement operation can be summarized in six broad and sequential functional steps, each with specific sub-functions, as shown in the following block flow diagram, Figure 8.6.3-1. The specific order, as well as the exact number of sub-functions, is general in nature. Details of these functions are discussed in the following sections of this report.

Waste package emplacement consists of waste package handling functions such as transport and transfer. Transportation and the final emplacement of the waste package will be on a continuous rail system (CRWMS M&O 1995a, Key 010) that starts at the WHB and connects to all emplacement drifts by means of rail and switches.

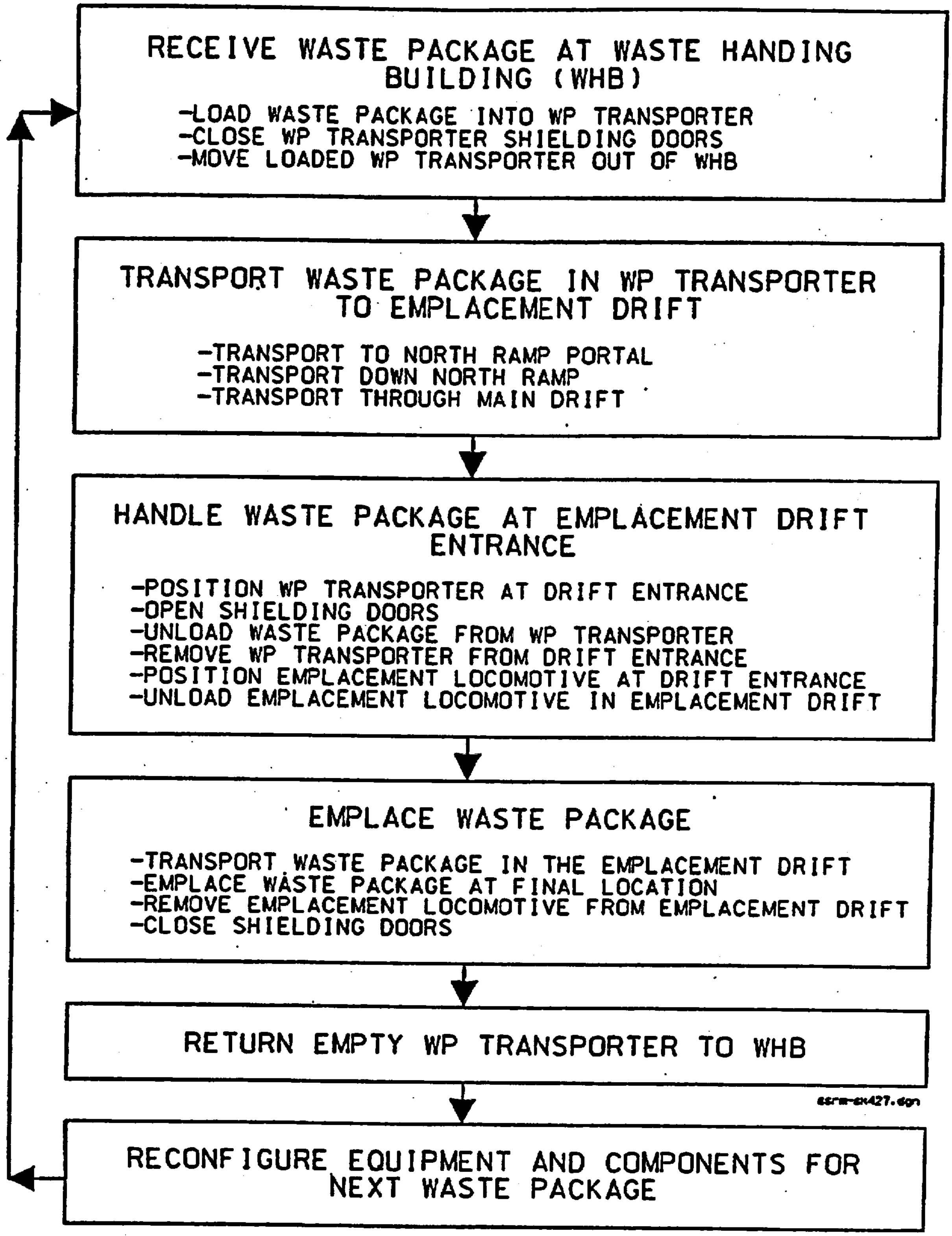

Figure 8.6.3-1. Sequence of Major Emplacement Functions

As presented in Section 8.3, the repository consists of two major areas for waste package emplacement: the upper and lower emplacement blocks. The upper block has been divided into two parts with relatively equal emplacement drift lengths, see Figure 8.6.3-2 for details. However, passage and transportation of the waste package to the east or the west sides of the upper block and the lower block requires routing of the waste package transporter through different access main drifts.

The east side of the upper block includes two types of drifts, the main access drifts and emplacement drifts. The main access drifts for the east side are identified as the Upper Block East Main and the Upper Block TBM Launch Main. The East Main is the continuation of the North Ramp that starts at the North Portal and ends with the South Ramp at the South Portal; the diameter of the East Main and the ramps is 7.62 m. The TBM Launch Main is oriented parallel to the East Main and the two are interconnected by crosscuts at each emplacement drift location. A crosscut is the curved drift connection between the East Main and the TBM Launch Main. The TBM Launch Main has a diameter of 9 m. For a typical layout of an emplacement drift entrance located in the upper block east side, see Figure 8.6.3-3.

The west side of the upper block consists of only a single main access drift, the Upper Block West Main which is the continuation of the North Ramp Extension that originates at the curve of the North Ramp and leads directly to the individual emplacement drifts. Curved drift connections (turnouts) provide for a continuation of the rail tracks between the West Main and the emplacement drifts. The West Main has a diameter of 7.62 m. For a typical layout of an emplacement drift entrance located in the upper block west side, see Figure 8.6.3-4.

Two waste package emplacement positions are addressed in this report. One, the CID, is based on a 5 m diameter emplacement drift with a single set of tracks for waste package emplacement. The second, OCID, involves a slightly larger diameter of 5.5 m. The waste package emplacement concept is virtually identical for both positions as they are both "waste package-on-rail-car" options. The only major difference of the OCID is that the 5.5 m drift dimension provides adequate space for two rail tracks placed in parallel. One track will serve for the transport and emplacement of the waste package on the railcar. The second track will serve for future functions that would require access into the emplacement drift for such purposes as performance confirmation of the waste packages, inspection of the emplacement drift, or related equipment in the drifts and other functions. The rail switch for selective access to the two tracks will be placed outside the emplacement drift entrance.

The determination of the final emplacement drift diameter will require further evaluation. Drift diameters from 4.3 m (CRWMS M&O 1994a) to 6.5 m (CRWMS M&O 1995ag) have been discussed in previous work. Such evaluations would address practicality and cost effectiveness of various drift configurations.

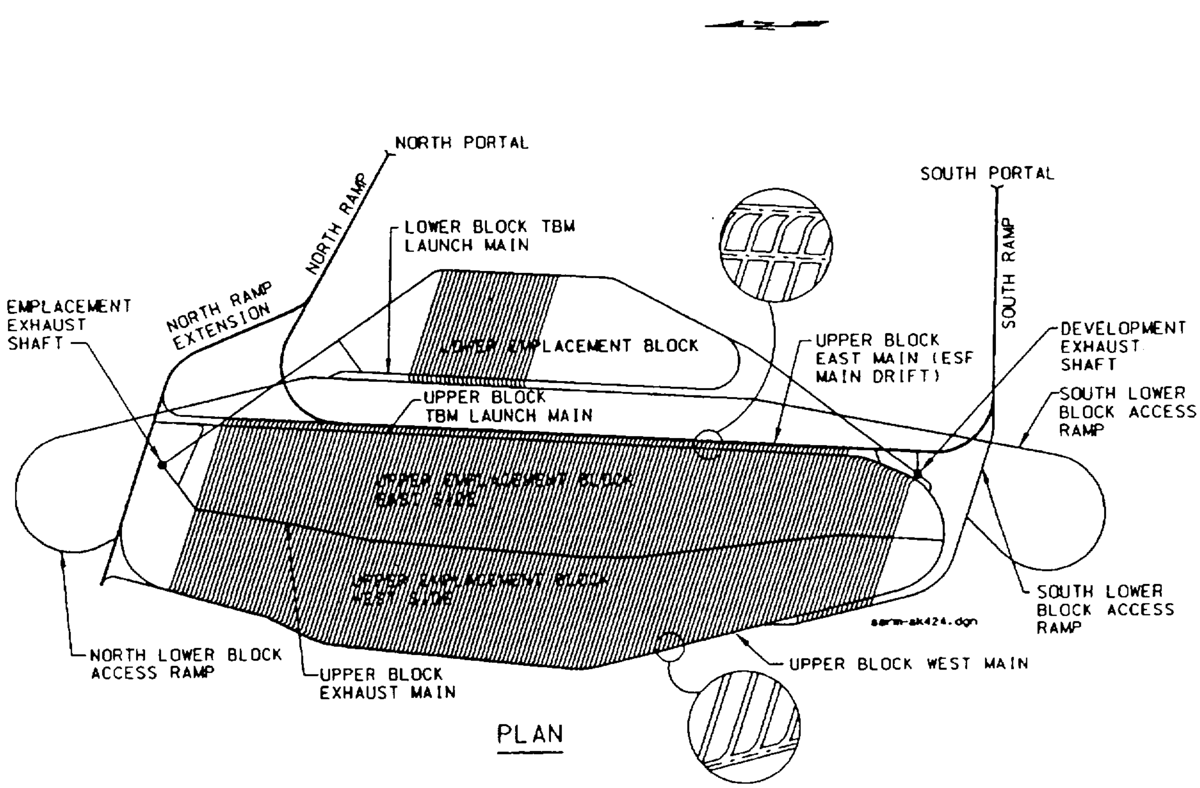

Figure 8.6.3-2. Emplacement Drift Layout

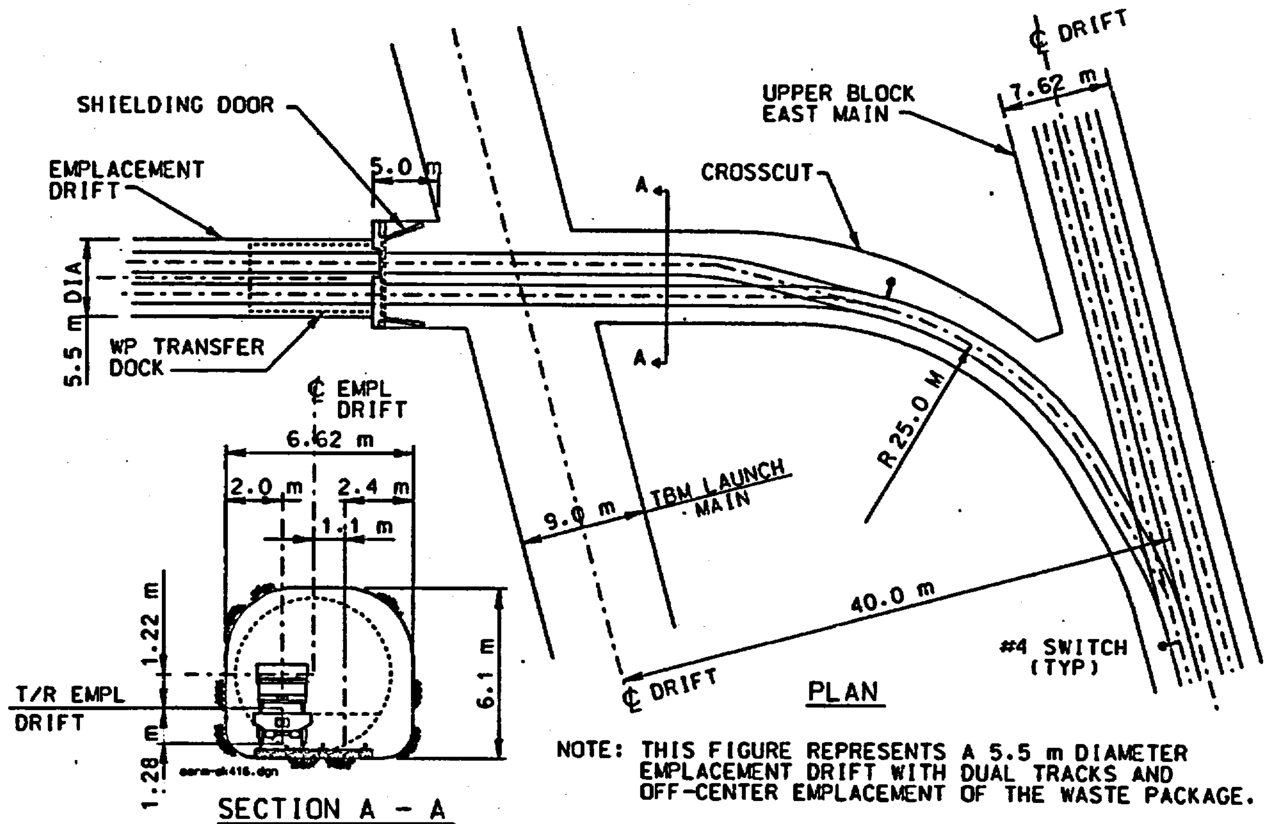

Figure 8.6.3-3. Typical Track and Switch Layout at Upper Block East Side for 5.5 m Diameter Emplacement Drift Entrance

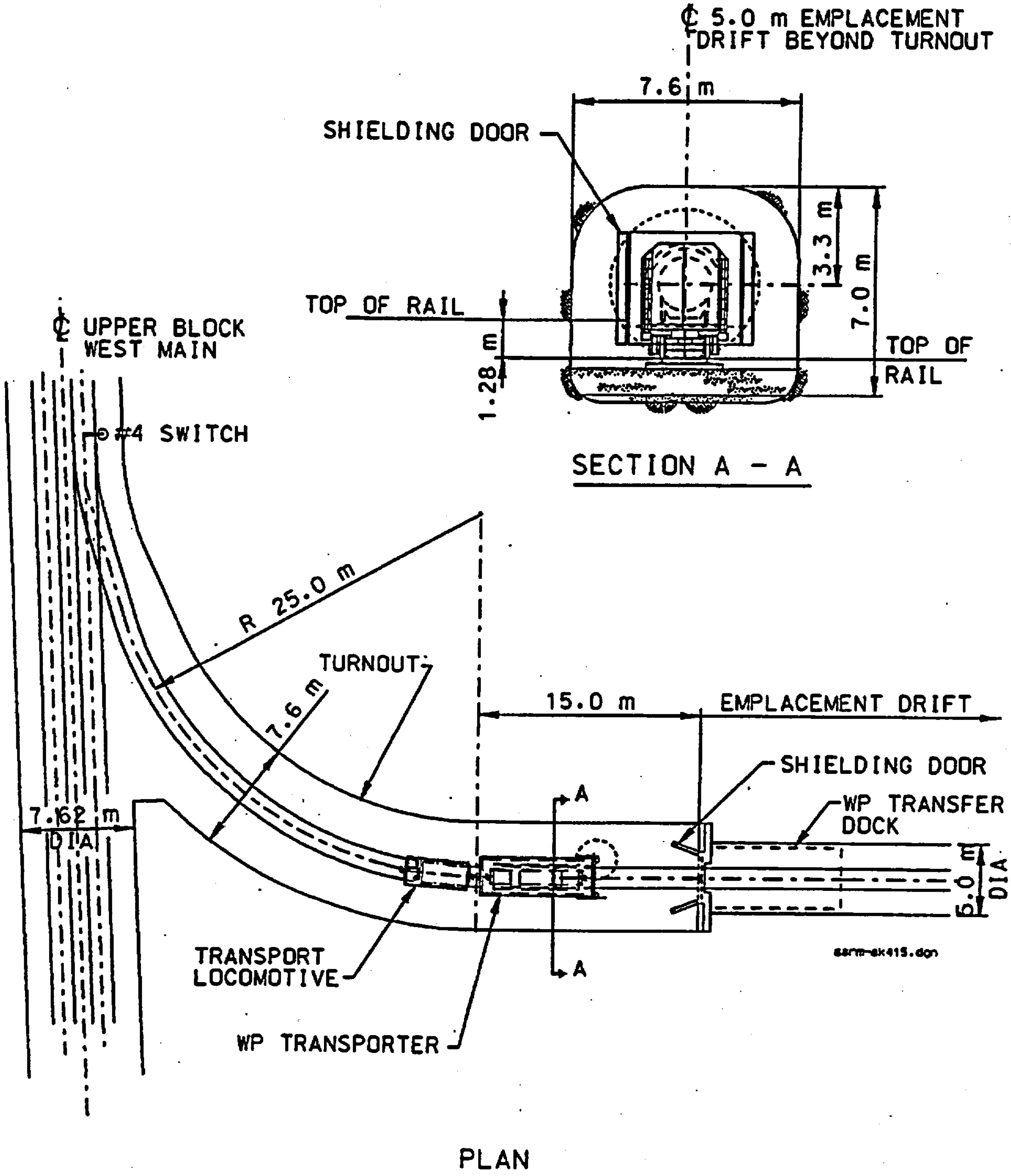

Figure 8.6.3-4. Typical Track and Switch Layout at Upper Block West Side Emplacement Drift Entrance

The pros and cons of both concepts have been discussed in the *Initial Summary Report for Repository/Waste Package Advanced Conceptual Design* (CRWMS M&O 1994a). Due to the fact that CID meets the basic requirements for waste package emplacement, later reports, such as the *Emplacement Equipment/Concept Development Report* (CRWMS M&O 1995q) and the *Recommended Layout Concepts Report* (CRWMS M&O 1995ai) focused only on CID emplacement methods.

However, most recent evaluations of the CID emplacement method led to the conclusion that this concept has many limitations in regards to accessibility in an emplacement drift loaded with waste packages. It would be difficult to reach individual waste packages in a loaded emplacement drift, and backfill (if required) of a loaded emplacement drift would be extremely difficult. For these reasons, serious consideration is being given to OCID emplacement. Both concepts are discussed throughout this report. Figures, however, are not duplicated unless required to illustrate specific points of interest between the two concepts. For additional details regarding CID and OCID see Section 8.2.8.7, Emplacement Mode.

8.6.3.1.1 Normal Conditions

Transport of Waste Package to Emplacement Drift Entrance

Transport of each waste package to the subsurface repository starts after completion of the waste package loading functions into the shielded waste package transporter and after the final acceptance for shipment. The transport locomotive will be located ahead of the waste package transporter as it travels into the repository via the North Ramp and the Upper Block East Main or the Upper Block West Main, depending on the waste package emplacement location selected.

To emplace in the east side of the upper block, the train, consisting of the transport locomotive and the waste package transporter, reaches the crosscut adjacent to an active emplacement drift, a rail switch is thrown, the locomotive reverses its travel direction, from pulling to pushing, then pushes the waste package transporter into the crosscut toward a shielding door located at the emplacement drift entrance.

To emplace in the west side of the upper block, the train travels toward the end of the North Ramp Extension where it passes a rail switch. Once the rail switch has been passed, the train comes to a complete stop. A rail switch is thrown and the locomotive reverses its travel direction, from pulling to pushing, into the Upper Block West Main until it reaches an active emplacement drift. A second rail switch is thrown and the locomotive pushes the waste package transporter into the turnout toward a shielding door located at the emplacement drift entrance.

Transport and emplacement of the waste package in the lower block will be similar to the description for the upper block, east side.

Transfer of Waste Package at Emplacement Drift Entrance

Prior to any commands that control the opening and closing functions of either the waste package transporter door and/or the drift entrance shielding door, all operating personnel will evacuate the drift entrance area. All functions that involve the opening and closing of the waste package transporter and drift shielding door and the unloading/loading of the waste package from within the waste package transporter will be remotely controlled (CRWMS M&O 1995a, Key 013). Functional details regarding shielding doors and the loading mechanism are discussed in Sections 8.6.4.3 and 8.6.4.8.

With this waste package transfer concept, the waste package transporter and the locomotive remain outside the drift entrance/shielding door. Transfer of the waste package will be through the shielding door, as opposed to transfer behind the shielding door. The transfer method through the shielding door requires a more complex interface between the waste package transporter and the shielding door. However, the benefit of this concept is that the mobile equipment is on the outside of the emplacement drift and it is therefore more accessible for unscheduled service or maintenance, if necessary.

Waste Package Emplacement in the Emplacement Drift

Once the waste package has been transferred from within the waste package transporter to a waste package transfer dock (see 8.6.3-5), located directly behind the drift entrance shielding door, the waste package is ready and available for final positioning in the emplacement drift. The ACD concept for waste package emplacement is on a railcar. Waste package emplacement on a railcar requires a dedicated, remotely controlled secondary locomotive, the "emplacement locomotive," for operations within the emplacement drift. After the unloading of the waste package into the emplacement drift, the emplacement locomotive is transferred into the emplacement drift, behind the waste package to be emplaced. The remotely controlled locomotive and the railcar with the waste package atop travels on a permanently installed rail system to a pre-determined emplacement location. Once the locomotive reaches its destination, it uncouples from the railcar, and a braking mechanism is activated to hold the waste package and railcar at that final position, prior to departure. After completion of the emplacement function, the locomotive returns to the drift entrance, where it exits the drift entrance past the shielding door, prior to the arrival of the next waste package.

A more detailed description and accompanying graphics of representative waste package emplacement operations are presented in Section 8.6.3.2 of this report.

8.6.3.1.2 Off-Normal Conditions

Off-normal waste package emplacement conditions include any deviation from the expected, or normal condition. A rigorous treatment of this issue will involve an analysis of Design Basis Events and Design Basis Accidents to determine the credibility of the various potential abnormal conditions. Such a treatment was beyond the scope of design activity to date. Design basis events and Design

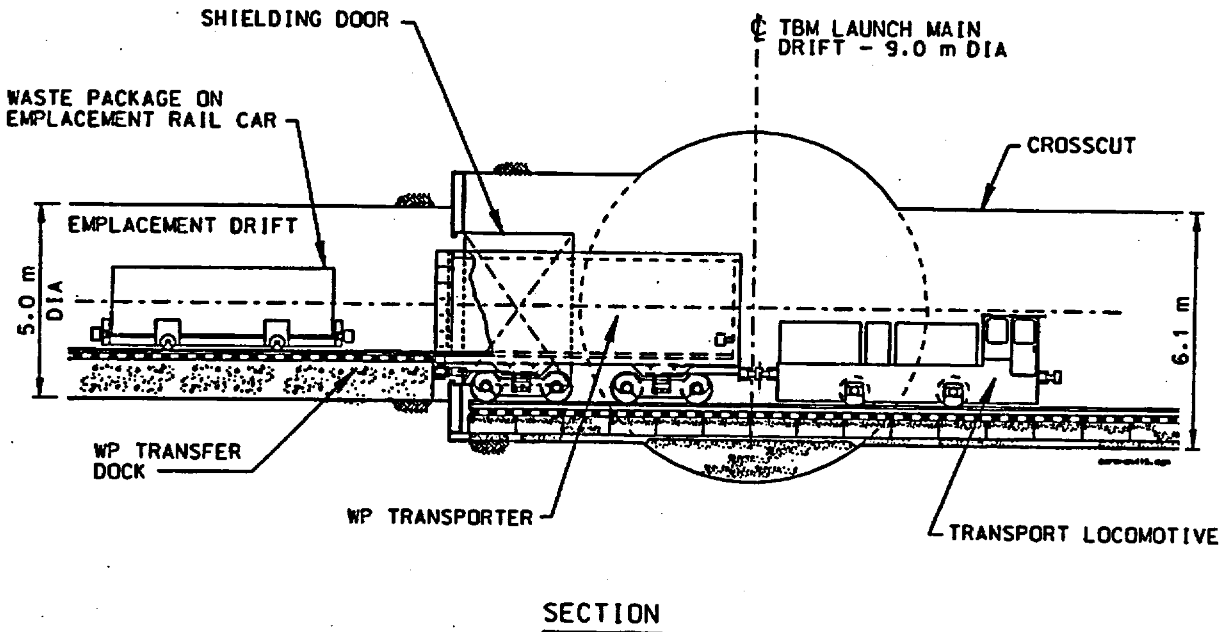

Figure 8.6.3-5. Waste Package Transporter and Transport Locomotive at Upper Block East Side Emplacement Drift Entrance

basis accident events are addressed as a separate issue in Section 10.1, Preliminary Design Basis Event Hazards Analysis, of this report. The approach used for design to date was to postulate, based on experience and engineering judgment, a number of potential off-normal mechanical conditions that could occur. The credibility of these scenarios has not been established, nor has the possibility of combinations of these events been considered.

The balance of this sub-section consists of descriptions of potential off-normal conditions, each followed by a brief discussion of the possible ramifications and conceptual mitigative measures. This discussion is limited to those events which could occur within the emplacement drifts. It is assumed that events (e.g., rockfalls, fires) which could occur in the ramps, shafts, and main drifts can be dealt with independently of the emplacement areas, and that subsequent waste package emplacement would not be compromised.

- Postulated condition:

  Rail system within an emplacement drift is damaged and needs repair.

  Corrective measures:

  If work was required on the rail system due to damage from a fall or subsequent waste package removal, it could be accommodated by placing a movable radiation shielding barrier by means of a remotely controlled forklift as close to the nearest waste package as possible to allow workers to make the necessary repairs without excessive radiation exposure. The shield would have to allow air flow around its edges to maintain drift ventilation. The same concept of movable shield barriers would be applicable to making ground control system repairs, or any other manned operations where access is needed in the emplacement drift.

- Postulated condition:

  Emplacement drift shielding door is inoperative.

  Corrective measures:

  If a shielding door becomes stuck while opening or closing, it could be manipulated with an auxiliary mechanism or equipment designed to alleviate this condition, or it could simply be nudged with a piece of mobile equipment to allow it to move freely. This condition is not anticipated to present a major problem.

- Postulated condition:

  Emplacement locomotive loses power and/or becomes inoperative.

Corrective measures:

In the event that the emplacement locomotive loses power while in the emplacement drift, another remotely controlled back-up locomotive of equal or larger size with increased tractive power could be dispatched to couple to the stranded locomotive and to tow and/or remove it from within the emplacement drift.

- Postulated condition:

  Waste package emplacement railcar derails, gets off-track.

  Corrective measures:

  Railcars can be put back on the track (re-railed), by placing re-railers on the rails and by pulling the de-railed railcar across the re-railer. Re-railers are essentially small ramps with ridges to direct the wheel flanges up, back across, and down onto the rails. The main differences between performing this task in a normal underground operation and in an emplacement drift is that the re-railers would have to be placed remotely, and the locomotive which pulls the railcar would be operated remotely. Placing the re-railer should not be a complex task and could be performed by a remotely controlled operated crane or similar robotics equipment. Pulling the railcar through the re-railer would require more tractive effort than pulling the railcar on normal tracks and may require tandem operation or a larger locomotive. The same corrective measures would apply to derailed locomotives and any other rolling stock.

8.6.3.2 Waste Package Emplacement Mode Description

This section provides a summary of major operational steps associated with the transport and emplacement of the waste package to the upper block, east side. Waste package transport and emplacement to the Lower Emplacement Block will be similar. For identification of major emplacement equipment at an emplacement drift entrance, see Figure 8.6.3-5. The following steps and graphic illustrations (see Figure 8.6.3-6) are based on waste package transport and waste package emplacement on a railcar, OCID.

8.6.3.2.1 Normal Conditions

This section provides a description of waste package transport through the East Main and crosscut, and emplacement from the TBM Launch Main. For orientation of a typical track and switch layout at the upper block, east side, just ahead of an emplacement drift entrance, see Figure 8.6.3-3.

A. The waste package transporter is coupled to a transport locomotive, and the pair move down the North Ramp, to the East Main, to just beyond the rail switch located at the entrance of each crosscut for access to the emplacement drift entrance.

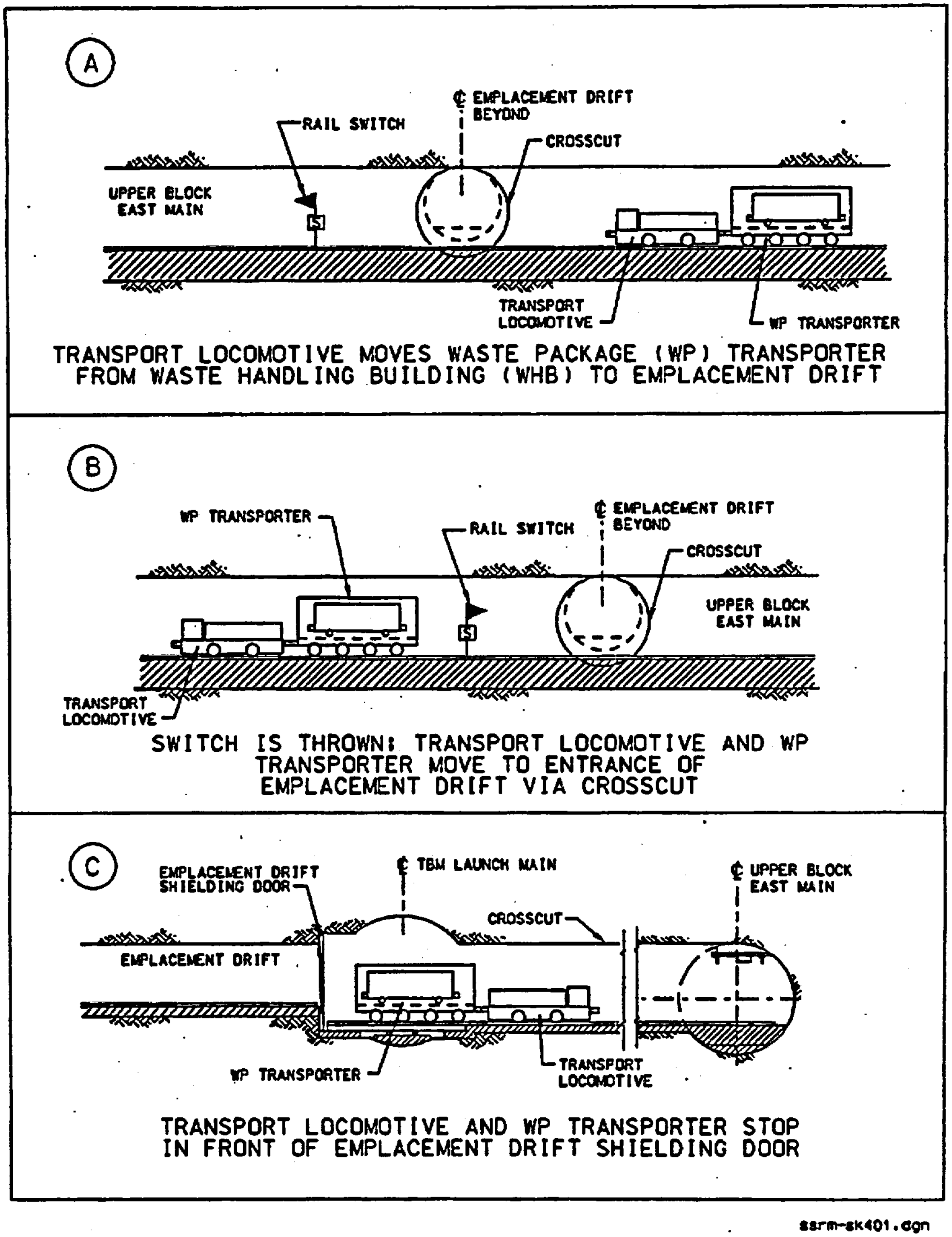

Figure 8.6.3-6. Waste Package Emplacement (Sheet 1 of 7)

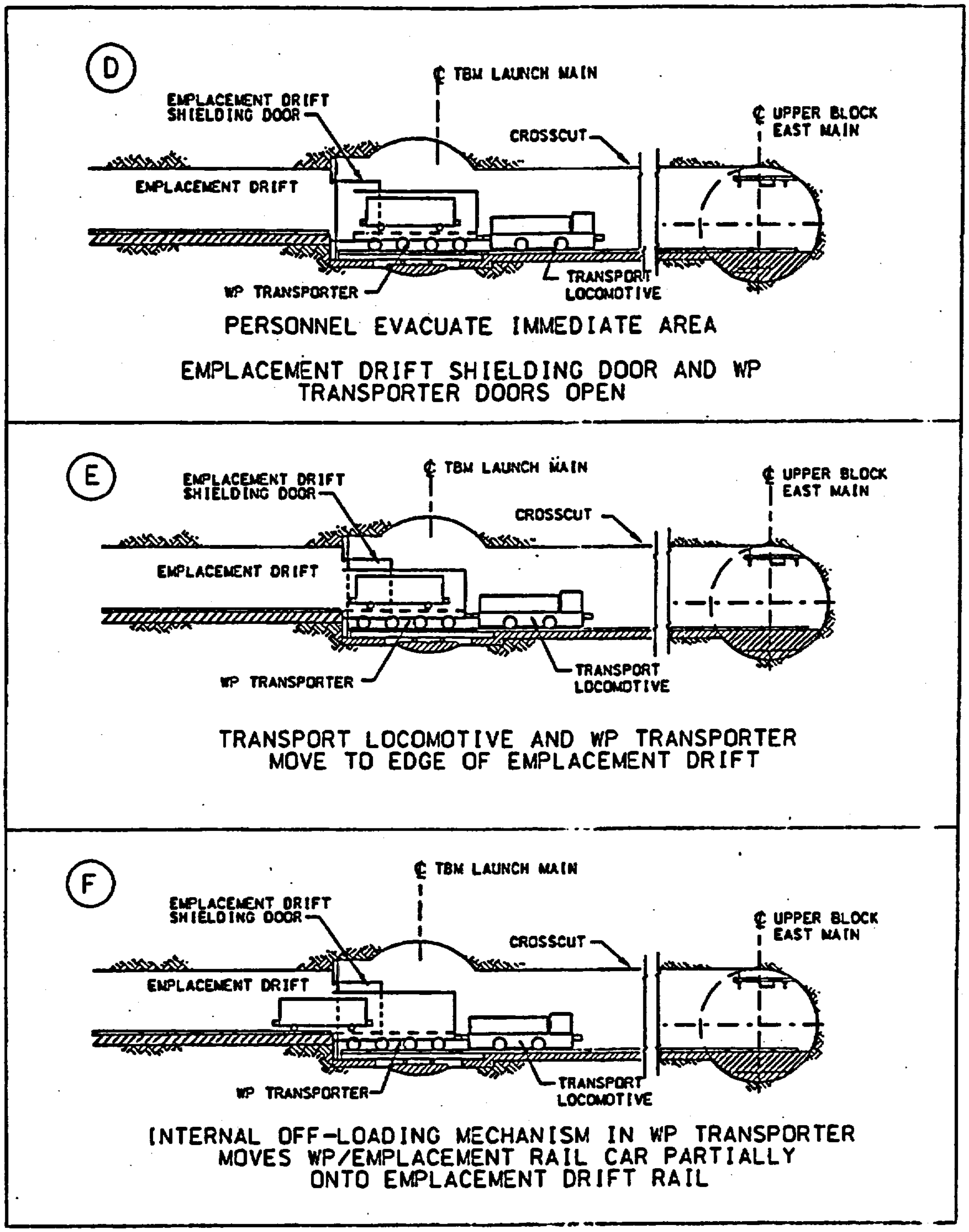

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Figure 8.6.3-6. Waste Package Emplacement (Sheet 2 of 7)

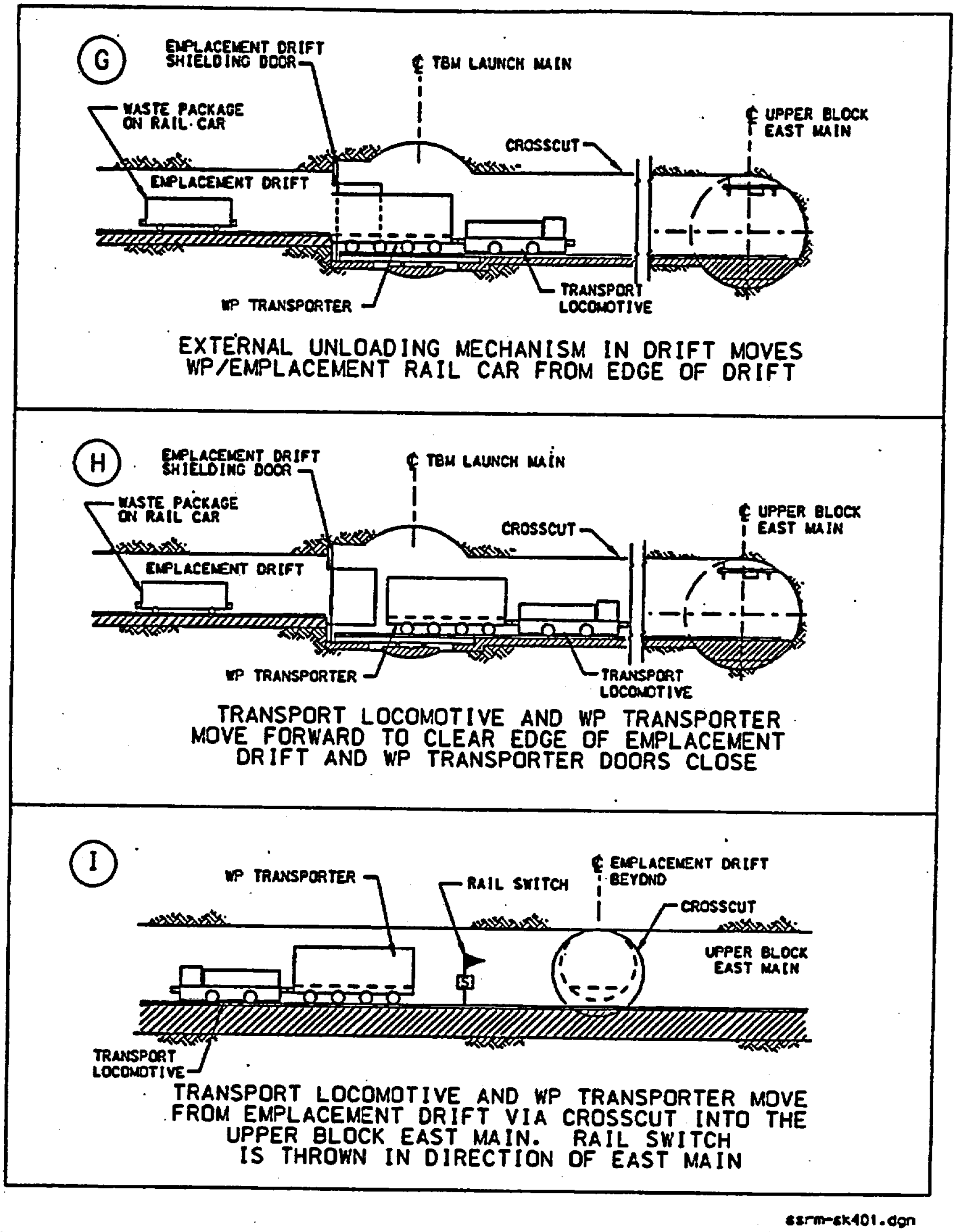

Figure 8.6.3-6. Waste Package Emplacement (Sheet 3 of 7)

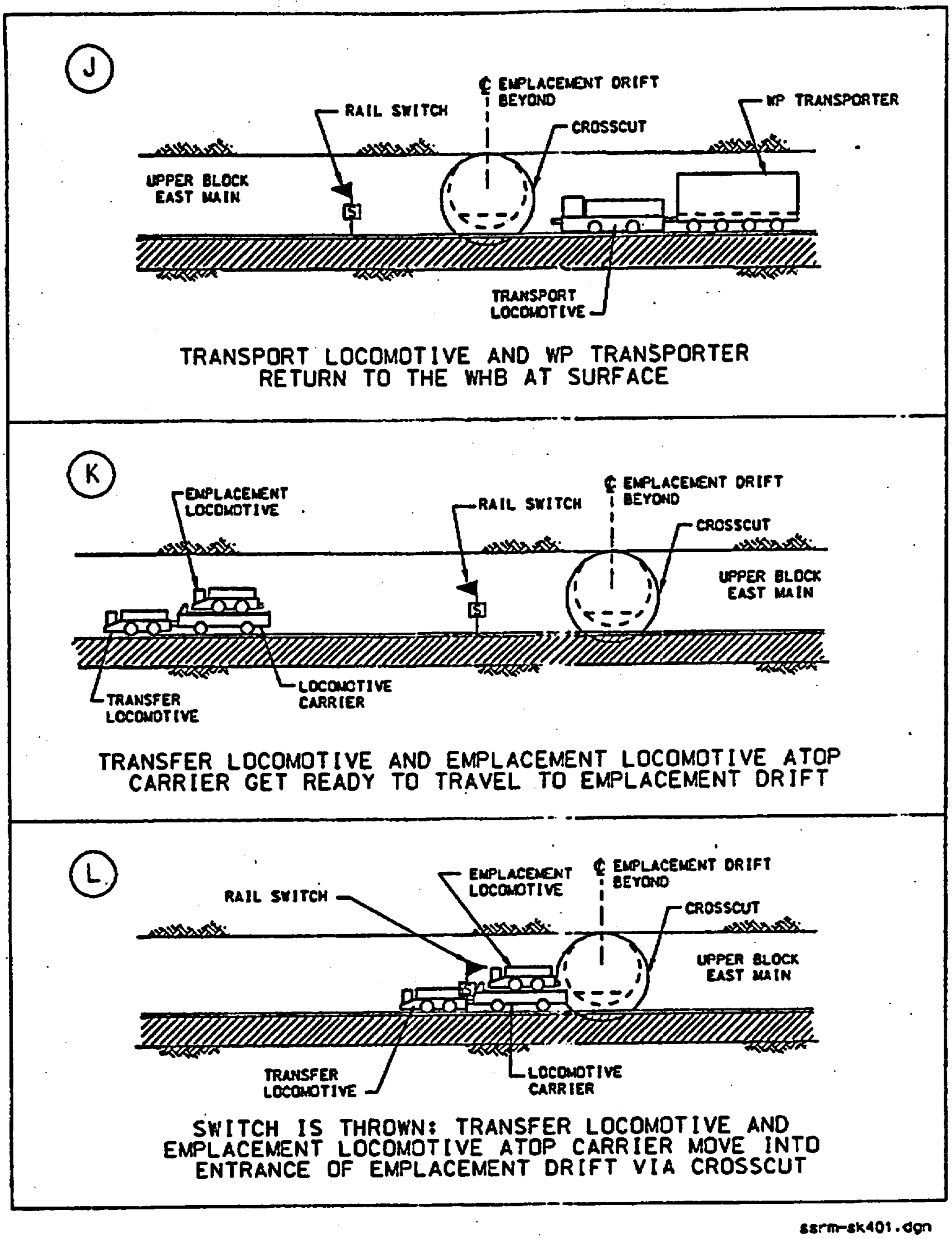

Figure 8.6.3-6. Waste Package Emplacement (Sheet 4 of 7)

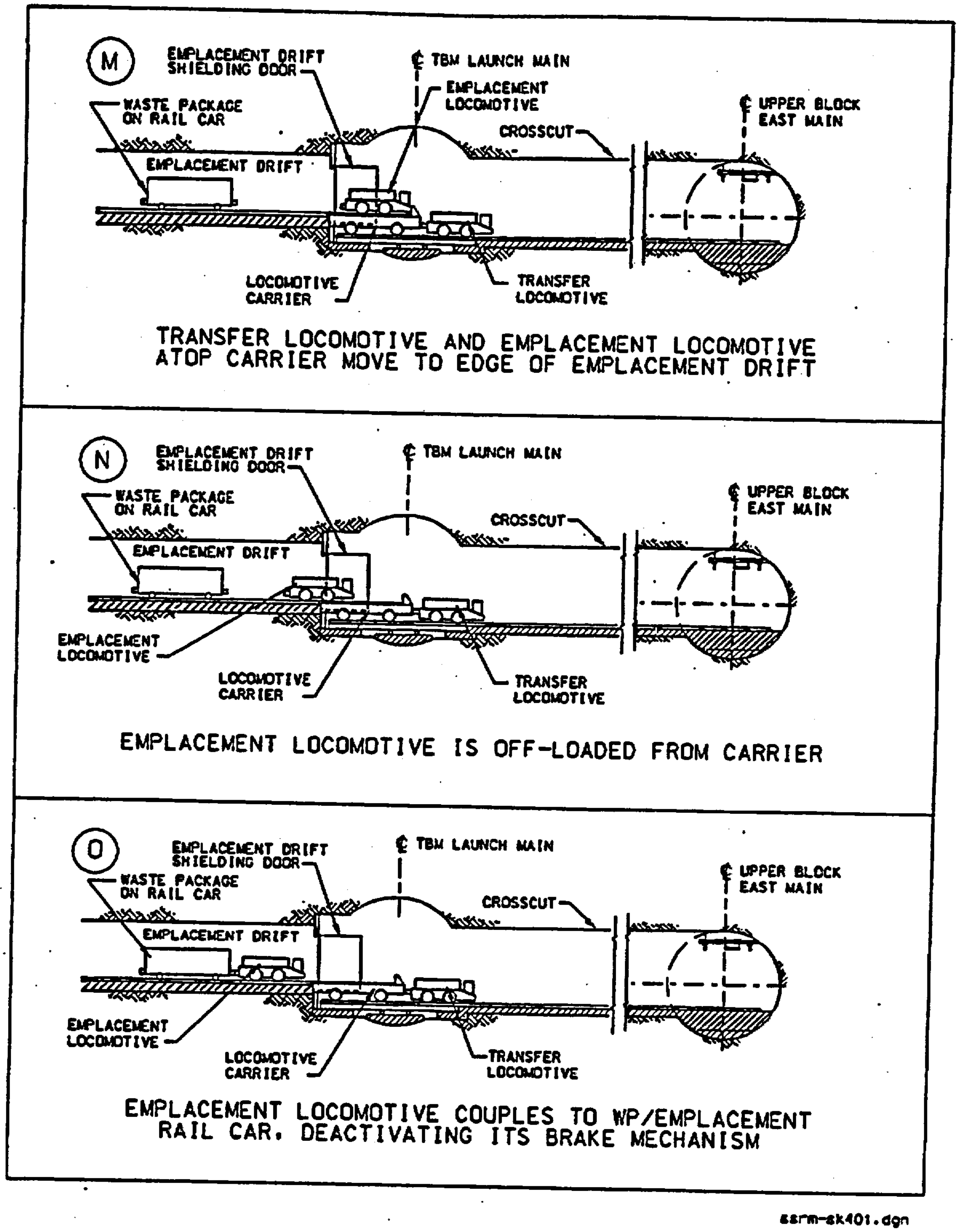

Figure 8.6.3-6. Waste Package Emplacement (Sheet 5 of 7)

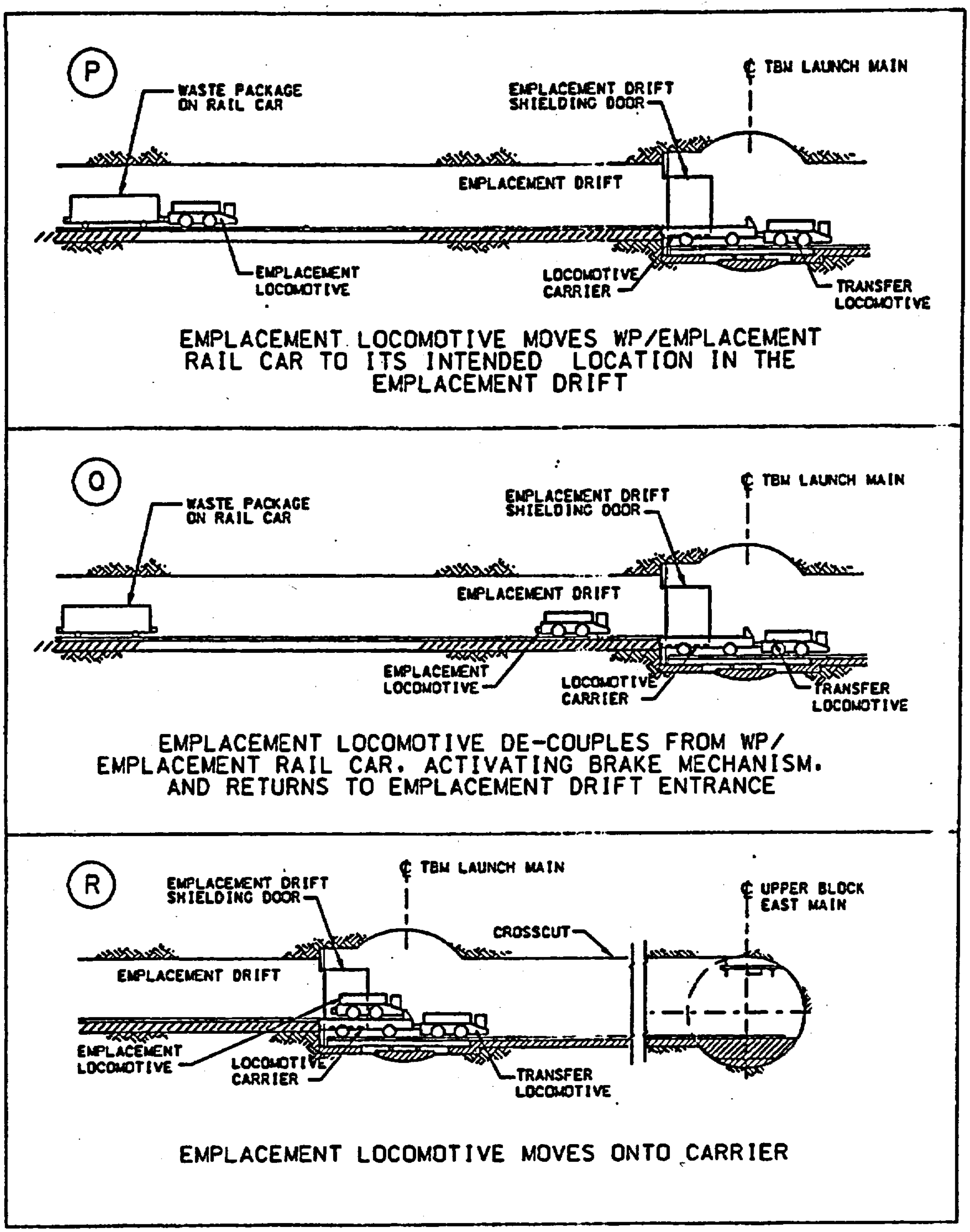

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Figure 8.6.3-6. Waste Package Emplacement (Sheet 6 of 7)

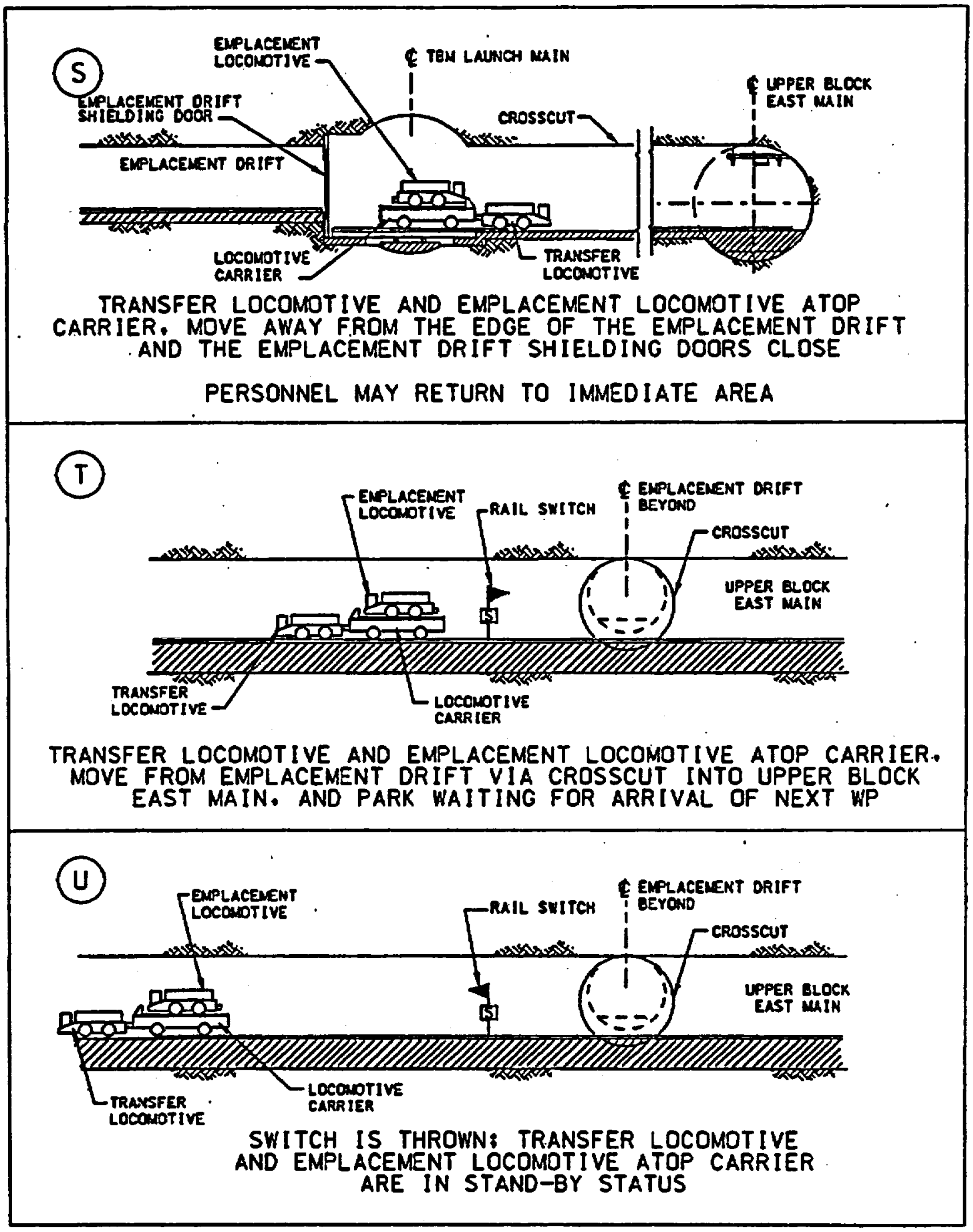

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Figure 8.6.3-6. Waste Package Emplacement (Sheet 7 of 7)

B. The rail switch positioned in the East Main is thrown in the direction of the pre-determined crosscut. A second rail switch in the crosscut directs the waste package transporter toward the dedicated track in the emplacement drift.

C. The transport locomotive backs the waste package transporter directly into the crosscut and stops several meters short of the closed shielding doors that leads to the emplacement drift entrance. This provides adequate room to allow for the swing envelope of the hinged shielding doors.

D. With the waste package transporter parked near the emplacement drift entrance, the doors of both the emplacement drift and the waste package transporter are sequentially activated to assume the full open position.

E. As the shielding doors assume full open position, the waste package transporter is pushed toward the drift by the transport locomotive until the rails in the emplacement drift are mated firmly with the rails inside of the waste package transporter. Brake mechanisms, on both the transport locomotive and the waste package transporter, would prevent movement during subsequent off-loading functions of the waste package from within the waste package transporter.

F. A loading mechanism built into the waste package transporter, provided to push the waste package on the emplacement railcar into the drift, is then activated.

G. A similar loading mechanism placed inside the drift entrance completes the off-loading function from within the waste package transporter. This second mechanism is capable of pushing the waste package partially into the drift entrance and to activate a brake mechanism on the emplacement railcar to hold it in position. The same mechanism is also used to pull waste packages into the waste package transporter, if necessary, for performance confirmation, retrieval, or any other purposes.

H. With the waste package "parked" inside the drift, the waste package transporter is partially withdrawn from the front of the emplacement drift by the transport locomotive to accommodate for door closure of the waste package transporter. The emplacement drift shielding doors remain open.

I. After closure of the cask doors, the waste package transporter is fully withdrawn out of the crosscut beyond the rail switch and into the East Main.

J. The rail switch would be thrown in the direction of the East Main and the transport locomotive and waste package transporter return to the WHB for loading of another waste package.

K. A remotely operated battery-powered locomotive, utilized to push the waste package to its emplacement position in the emplacement drift, is then readied for operation. This emplacement locomotive is normally parked in a stand-by position atop a locomotive carrier in the East Main beyond the operational emplacement drift. The locomotive carrier has a transfer locomotive coupled to it to provide traction power. This transfer locomotive has remote control features similar to the emplacement locomotive.

L. The rail switch is thrown toward the emplacement drift entrance, and the transfer locomotive, with emplacement locomotive atop the locomotive carrier moves to the emplacement drift entrance in the same manner as the waste package transporter and transport locomotive.

M. The emplacement locomotive/locomotive carrier moves backward until mated firmly with the rails in the emplacement drift and the rails atop the locomotive carrier. Brakes of the transfer locomotive secure the locomotive carrier and prevent movement as the emplacement locomotive atop the locomotive carrier is off-loaded into the emplacement drift.

N. The emplacement locomotive atop the locomotive carrier is then activated and moved forward into the emplacement drift.

O. The emplacement locomotive couples to the waste package emplacement railcar and deactivates its brake mechanism.

P. The emplacement locomotive pushes the waste package/emplacement railcar to its intended location in the emplacement drift.

Q. The emplacement locomotive activates the parking brake and de-couples from the waste package/emplacement railcar once the pair has reached the designated emplacement location in the drift and then returns to the emplacement drift entrance.

R. The emplacement locomotive moves back onto the locomotive carrier.

S. The locomotive carrier with the emplacement locomotive atop moves away from the edge of the emplacement drift and the shielding doors are then closed.

T. The transfer locomotive/locomotive carrier and the emplacement locomotive move through the crosscut and into the East Main to be parked, ready for the next waste package emplacement.

U. The rail switch is thrown towards the main drift, ready for the arrival of the next waste package.

8.6.3.2.2 Off-Normal Conditions

Waste package emplacement under off-normal conditions is not planned. All systems in the repository must be in normal operation mode for emplacement to proceed. Possible exceptions to this condition would have to be reviewed on an individual case by case basis. Exceptions may be granted for situations where emplacement equipment or related components break down after the start of the emplacement process, if it has been concluded that this decision is the preferred option and it is safe to proceed. Based on the foregoing, waste package emplacement mode description for off-normal conditions would be similar to the description under Section 8.6.3.2.1.

8.6.4 Waste Package Emplacement Equipment

8.6.4.1 Waste Package Transporter

A shielded waste package transporter has been proposed in previous ACD work to carry the waste packages from the WHB to the emplacement drift entrances. It has been proposed that the waste package transporter be designed to "stand-beside" standards (CRWMS M&O 1994a, p. 8-132). The actual shielding design and exposure limits have been given preliminary examination during ACD. The design involves an iterative process which takes into account the ALARA (as low as reasonably achievable) principle for dosage rate control (YMP 1994a, 3.2.4.5.1.A), waste package transporter weight, and transport feasibility. In-process and very preliminary estimates of the waste package transporter weight are approximately 225 metric tons (MT) inclusive of a maximum 69 MT waste package (CRWMS M&O 1995a, EBDRD 3.7.1.J.2) containing no filler material and approximately 10 MT for the emplacement railcar.

The current waste package transporter design, as presented in this section, is based on carbon steel gamma shielding for a total thickness of 165 mm. This shielding thickness, and the resulting waste package transporter weight, originate from an earlier shielding analysis (CRWMS M&O 1995ap) that identified three suitable gamma shielding materials: lead, depleted uranium, and carbon steel.

Structural and manufacturing considerations led to the decision to consider carbon steel shielding as an initial material of construction. Waste package transporter shielding and the resulting weight will be reviewed and revised during subsequent iterations of shielding materials evaluations.

A basic equipment outline and pertinent features of the waste package transporter are shown in Figure 8.6.4-1. This waste package transporter is equipped with pivoting travel wheel assemblies, thus eliminating the need for a rail carrier and thus enhancing stability during travel. This design option allows the waste package transporter to directly approach the entrance to an emplacement drift without the need for supplementary handling and positioning equipment. The waste package transporter, as presented, is shown with a basic double door of the side-swing type.

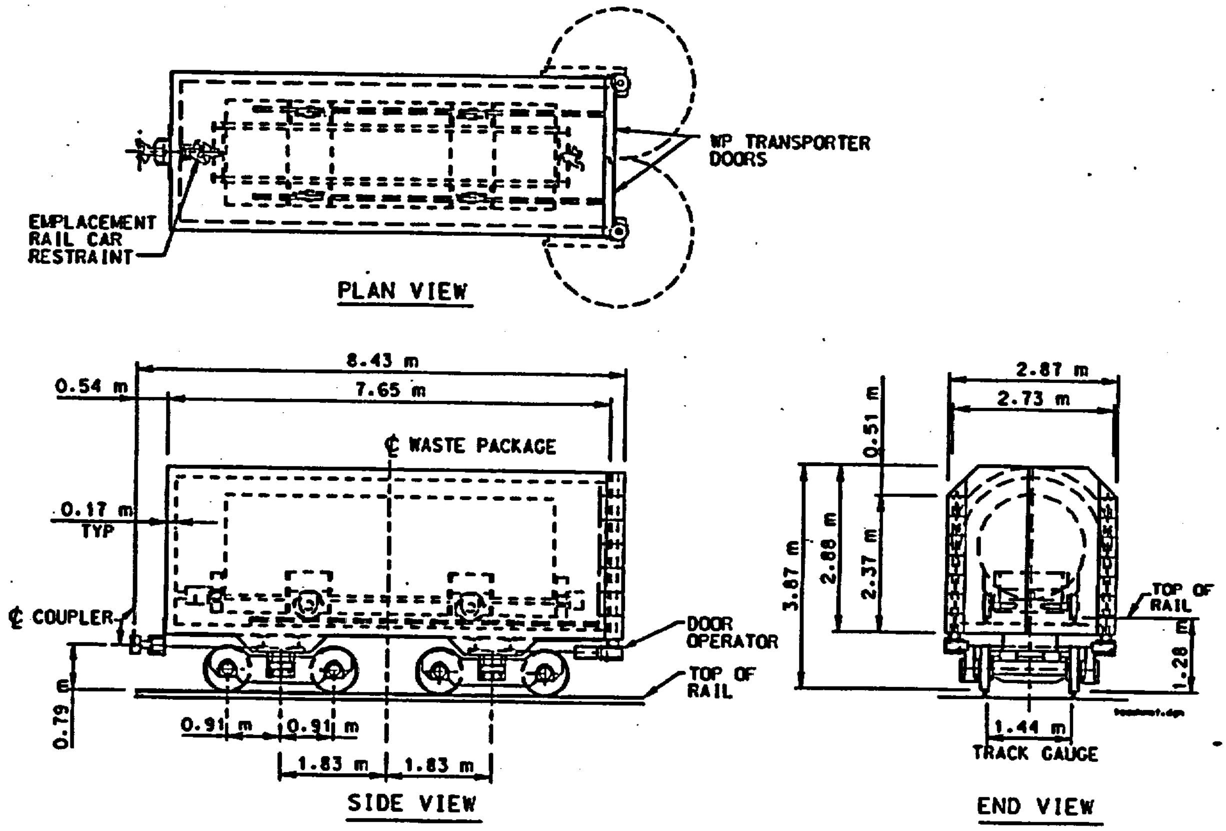


Figure 8.6.4-1. Waste Package Transporter

Other features of the waste package transporter include:

- Railcar brake system(s)
- Waste package restraint
- Automated unloading system for waste package
- Automated shielding doors
- Railcar coupler.

Each of these components will be designed as an independent, remotely controlled subsystem. Redundancy features will be provided where feasible.

8.6.4.2 Transport Locomotive

A prime-mover, the transport locomotive, is required to provide tractive power for the waste package transporter because the transporter has no built-in mechanisms for that purpose. The transport locomotive has been proposed in previous work (CRWMS M&O 1994a, p. 8-132) which allows integrated rail transport to be incorporated into the design of the repository (CRWMS M&O 1995a, Key 010). An electric-powered transport locomotive is coupled to the waste package transporter at the WHB and travels down the ramp to the repository horizon level and then down a main drift paralleling the emplacement area to the entrance to an emplacement drift. Current controlled design assumptions limit ramp grades to three percent and main drift grades in which waste packages are handled not to exceed two percent (CRWMS M&O 1995a, DCSS 009).

Preliminary studies indicate that a 32 MT locomotive is required to move a waste package transporter, including the waste package, weighing 225 MT (see Section 8.6.4.1), at 8 km/hr, up a 2 percent grade. This represents the worst normal upgrade case as the loaded waste package transporter is normally transported down the ramp. If a loaded waste package transporter is required to be brought up a ramp, estimates have indicated that an approximate 55 MT locomotive is required. Since this is an off-normal occurrence, and because a 55 MT locomotive is a very large piece of machinery, it is more practical to use two 32 MT locomotives operating in tandem. For outline dimensions of the transport locomotive, see Figure 8.6.4-2.

Operator controls of the locomotive include dual features for manually and remotely controlled locomotive functions such as speed control, brakes, and automated couplers. Additional features may include remotely controlled video cameras, sensing elements, and other safety related devices to control the travel and positioning of the locomotive and waste package transporter. For further details regarding Remotely Controlled Equipment, see Section 8.6.5.1.

Features of the proposed locomotive include a battery power supplement to the primary electric power system. The electric power system is by trolley wire or third rail. The battery supplement allows limited operation to maneuver the waste package transporter for short durations, either at the surface or underground. For additional locomotive details, see Preliminary Data Sheet No. 1 in Appendix E.

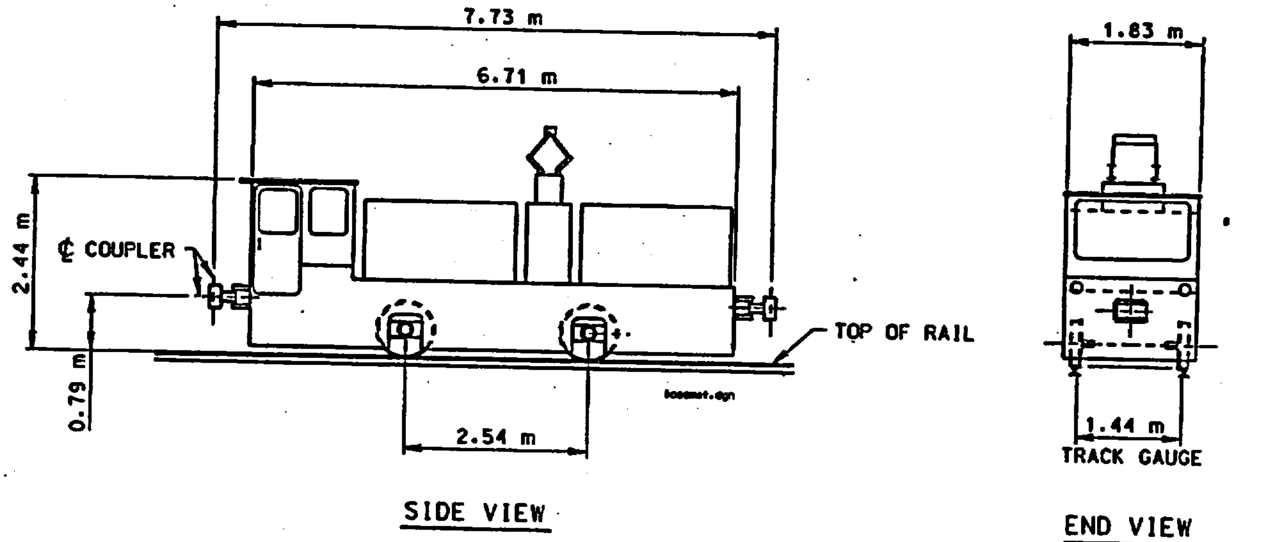


Figure 8.6.4-2. Transport Locomotive

8.6.4.3 On/Off-Loading of Waste Package

The purpose of the loading mechanisms is to remotely control loading or unloading functions of the waste package into and out of the waste package transporter . Such a system utilizes a motorized ball bearing screw assembly connected to gear reducers. The system is powered by an electric motor. Due to the limited stroke length, which is restricted by the inside dimensions of the waste package transporter and the practicable length of the ball-screw assembly, two similar loading mechanisms are required. One mechanism operates from inside the waste package transporter (see Figure 8.6.4-3). The second mechanism is installed inside the emplacement drift and outside the waste package transporter to complete the loading or unloading function behind the drift entrance shielding doors.

The loading mechanism inside the waste package transporter is permanently installed. The second system, for installation inside the drift just behind the drift shielding doors, is skid-mounted. The skid-mount feature allows for the removal and transfer of the system from one emplacement drift to another.

8.6.4.4 Transfer Locomotive

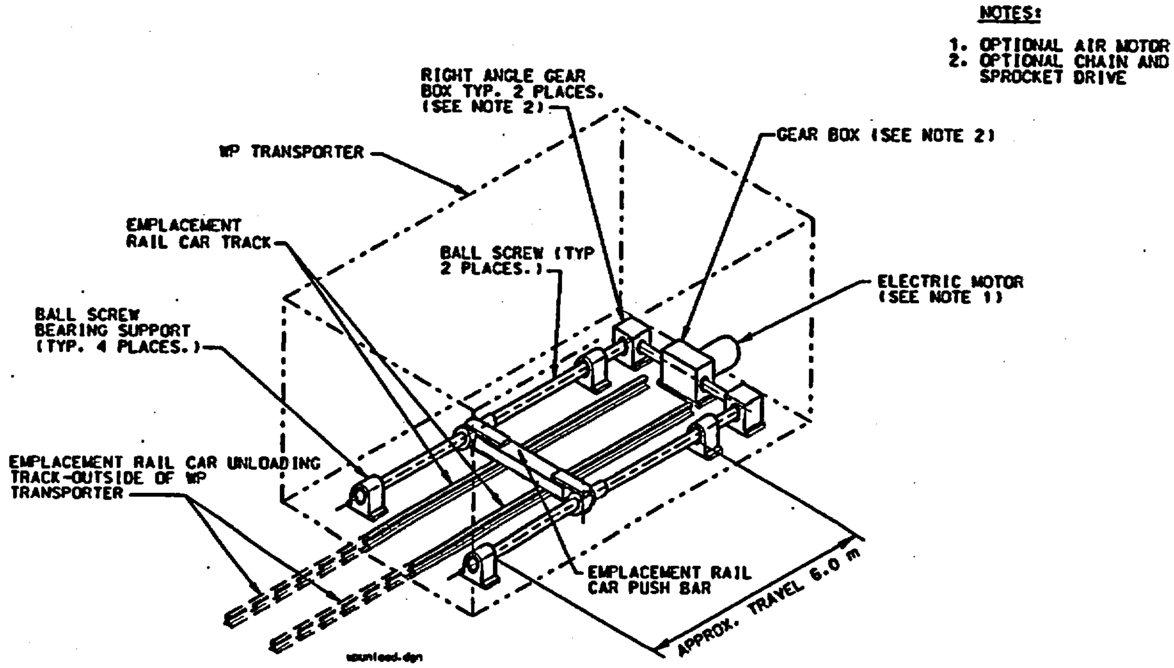
The transfer locomotive will move the emplacement locomotive atop a locomotive carrier to and from the emplacement drift entrance. This locomotive (see Figure 8.6.4-4) will have the same basic features and outline dimensions as the emplacement locomotive described in Section 8.6.4.6. The only significant difference is with the raised, standardized coupler mechanism connecting with the emplacement locomotive carrier. For additional details, see Preliminary Data Sheet No. 2 in Appendix E.

Operator controls of the locomotive include dual features for manually and remotely controlled locomotive functions such as speed control, brakes, and automated couplers. Additional features may include remotely controlled video cameras, sensing elements, and other safety related devices to control the travel and positioning of the transfer locomotive and emplacement locomotive carrier. For further details regarding Remotely Controlled Equipment, see Section 8.6.5.1.

The workshop located on the surface for maintenance and repair of underground equipment will be equipped with battery chargers. Additional battery chargers for the transfer and emplacement locomotives will be located underground in well ventilated areas.

8.6.4.5 Emplacement Locomotive Carrier

The locomotive carrier, moved by the transfer locomotive, will carry the emplacement locomotive to and from the emplacement drift entrance. The carrier will be constructed of structural steel and will be equipped with wheels and bearings sufficient for the slow speed operation in the repository. The rails on top of the carrier (see Figure 8.6.4-5) will have the same elevation as the rails within the waste package transporter to accommodate the change in elevation between main and emplacement drifts to provide for the transfer of the emplacement locomotive into the emplacement drift.



SCHEMATIC DIAGRAM

THE ABOVE SCHEMATIC SHOWS THE WP LOADING MECHANISM INSIDE THE TRANSPORTER. A SECOND, SIMILAR MECHANISM ON A PORTABLE SKID MOUNT (NOT SHOWN) WILL BE PLACED ON THE TRANSFER DOCK INSIDE THE EMPLACEMENT DRIFT.

Figure 8.6.4-3. Waste Package Loading Mechanism

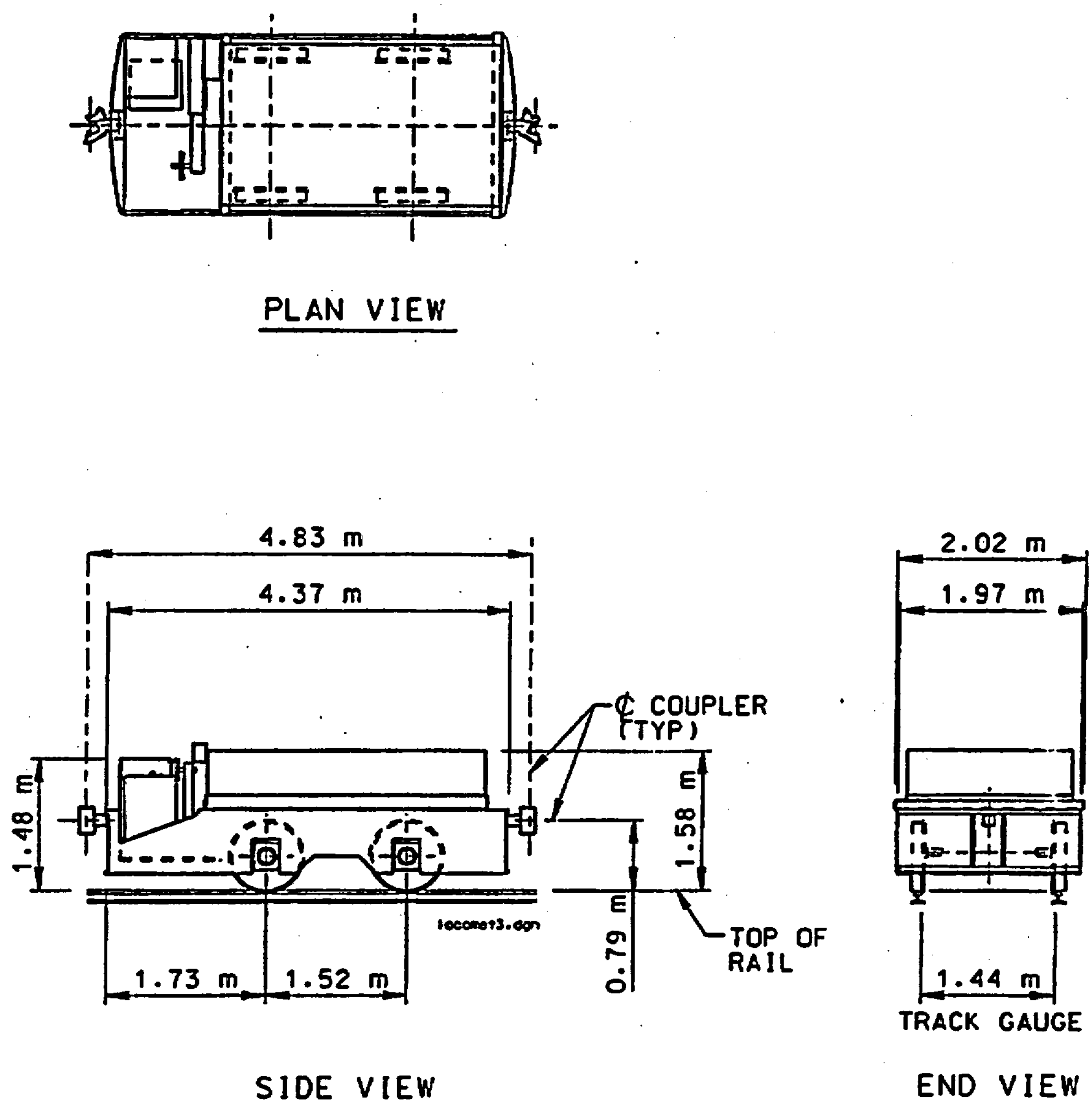


Figure 8.6.4-4. Transfer Locomotive

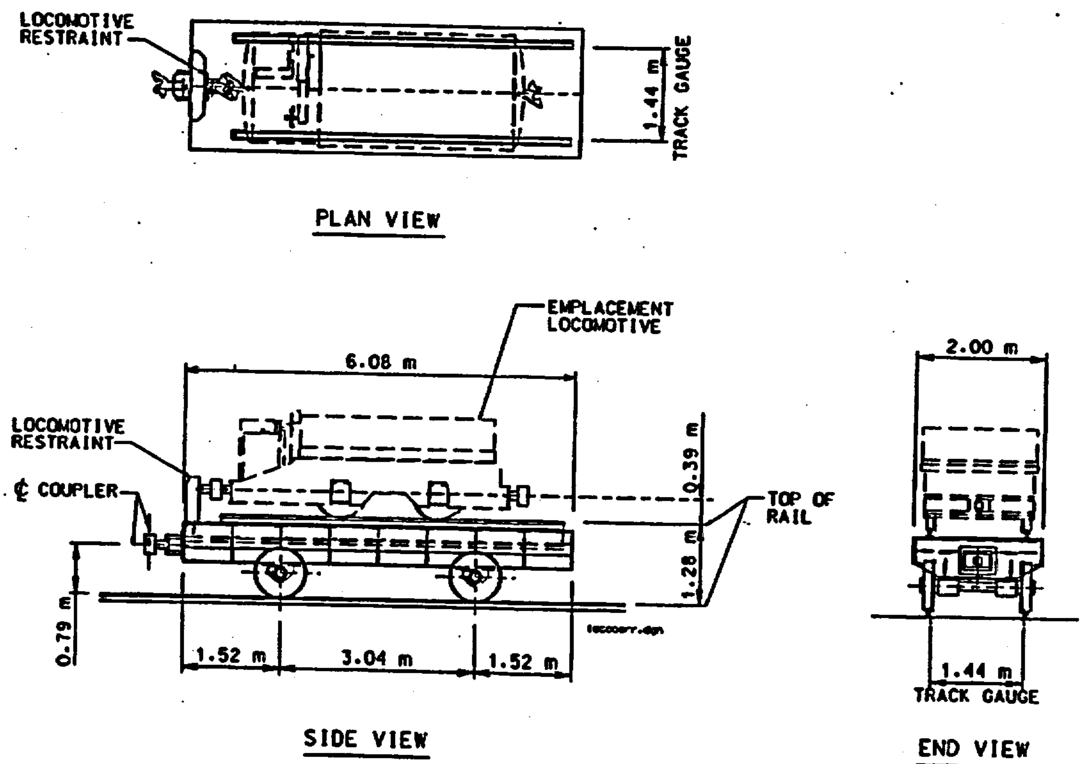


Figure 8.6.4-5. Emplacement Locomotive Carrier

8.6.4.6 Emplacement Locomotive

A remotely operated (CRWMS M&O 1995a, Key 013), battery-powered locomotive (Figure 8.6.4-6) was presented in earlier ACD work (CRWMS M&O 1994a, p. 8-138) to transport a waste package from the emplacement drift entrance to its final emplacement position.

Current controlled design assumptions state that emplacement drift grades will be minimized within the 0.25 to 0.75 percent range (CRWMS M&O 1995a, DCSS 009). The low gradient and the use of a slow emplacement speed will allow a relatively small and compact locomotive to be used. Order-of-magnitude estimates indicate that a 10 MT locomotive is required to move a 79 MT load (consisting of an emplacement railcar, as described in Section 8.6.4.7, plus a maximum 69 MT waste package with no filler material [CRWMS M&O 1995a, EBDRD 3.7.1.J.2]), at 5 km/hr up a maximum 0.75 percent grade. This represents the worst upgrade case in the emplacement drift. A 5 km/hr speed is considered to be a conservative upper bound and actual emplacement speeds may be lower. For additional details, see Preliminary Data Sheet No. 3 in Appendix E.

Operator controls of the locomotive include dual features for manually and remotely controlled locomotive functions such as speed control, brakes, and automated couplers. Additional features may include remotely controlled video cameras, sensing elements, and other safety related devices to control the travel and positioning of the emplacement locomotive and emplacement railcar. For further details regarding remotely controlled equipment, see Section 8.6.5.1.

The workshop located on the surface for maintenance and repair of underground equipment will be equipped with battery chargers. Additional battery chargers for the transfer and emplacement locomotives will be located underground in well ventilated areas.

After the emplacement of each individual waste package, the emplacement locomotive has to exit the emplacement drift prior to the arrival of an another waste package. The transfer of the locomotive to or from the emplacement drift requires a dedicated locomotive carrier (Section 8.6.4.5) and another locomotive, the transfer locomotive (Section 8.6.4.4), to move this locomotive carrier.

8.6.4.7 Emplacement Railcar

An emplacement railcar is a concept that was developed early in ACD (CRWMS M&O 1993e, pp. 5-44 to 5-47; CRWMS M&O 1994a, pp. 8-62 to 8-63) to efficiently move the large waste packages in the emplacement drifts. An example of the concept is shown in Figure 8.6.4-7. Each emplacement railcar remains permanently in the emplacement drift with its waste package.

The cars will be constructed of a relatively simple structural steel base and will be equipped with wheels and bearings sufficient for slow speed operation. These features will minimize the production cost associated with the approximately 12,000 units that will be needed. Because of long term waste isolation considerations, special attention will need to be paid to the wheel bearing design to minimize or eliminate the introduction of lubricants into the emplacement drift. Although not

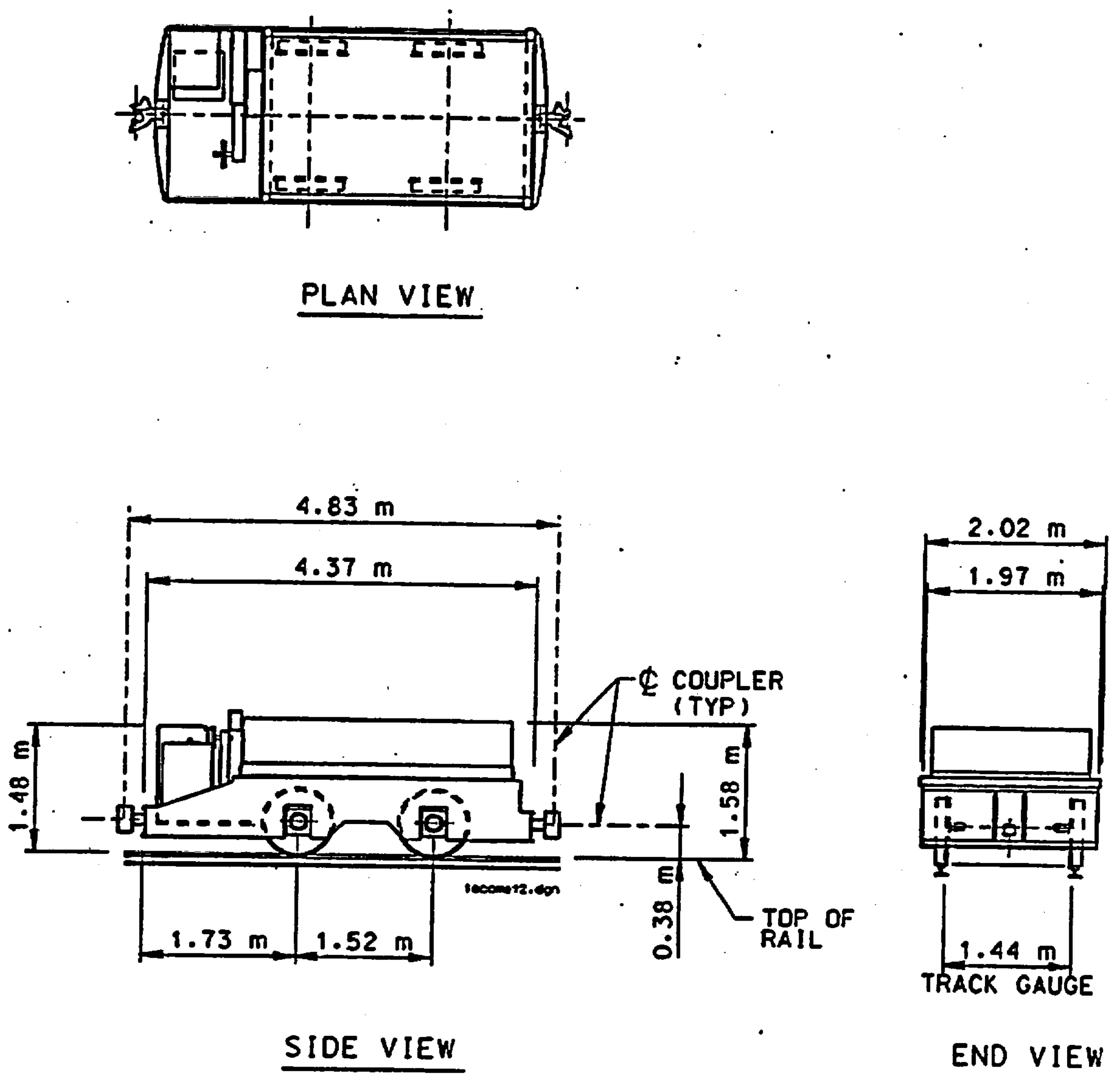


Figure 8.6.4-6. Emplacement Locomotive

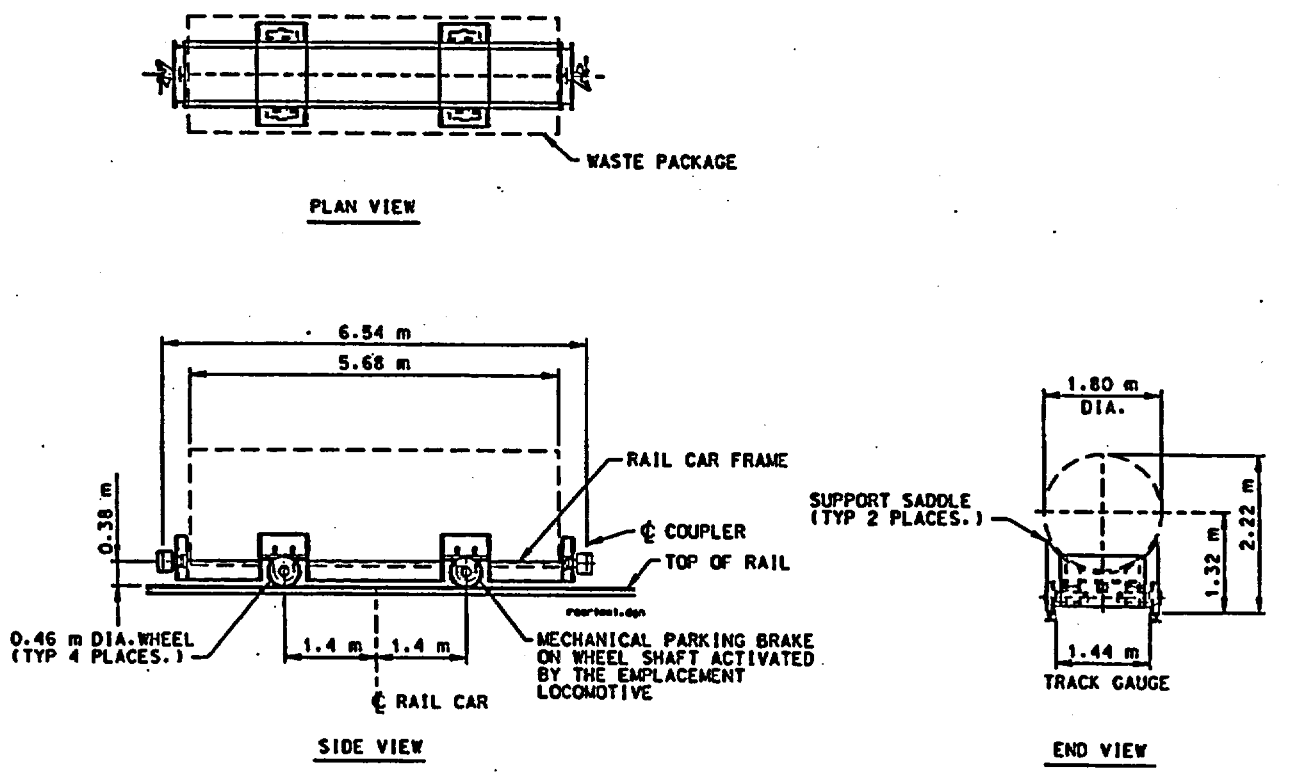


Figure 8.6.4-7. Emplacement Railcar

absolutely necessary, it also may be advantageous to pay particular attention to bearing materials to provide for the possibility of future serviceability for retrieval after having been exposed to the harsh environment associated with the emplacement drift. Each emplacement railcar will be equipped with mechanical parking brakes which will be activated/deactivated by the emplacement locomotive.

8.6.4.8 Shielding Doors

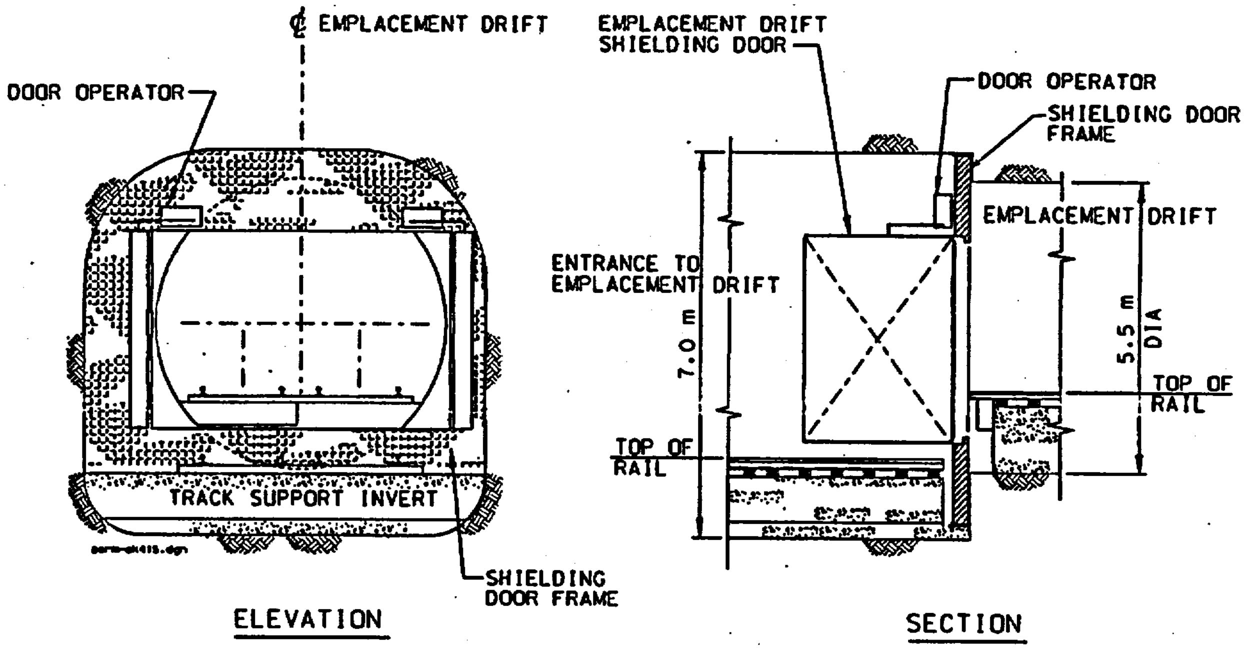
Due to the radiation emanating from the waste packages, each emplacement drift entrance will be provided with a set of shielding doors. An example of this concept is shown in Figure 8.6.4-8. The emplacement drift shielding doors will have multiple functions, including:

- restricting unauthorized entrance into an emplacement drift loaded with waste packages
- shielding operations personnel outside the emplacement drifts from radiation
- serving as a ventilation air control device.

Each door assembly will consist of an extremely rugged pre-manufactured structural steel frame with two hinged door sections of the side-swing type. The door frames will be supported in concrete walls which will be anchored to the emplacement drift walls. The basic material of construction for the doors will be carbon steel. The operating mechanism will be powered by electrically driven actuators. The functions to open and to close both door sections and the locking mechanism will be remotely controlled. For design specific considerations regarding shielding, see Section 10.2, Radiological Safety.

8.6.4.9 Rail Connections through Shielding Doors

The track for the transfer of the waste package from the waste package transporter into the emplacement drift consists of two basic parts. One part is installed in the mobile equipment, and the second part is in a fixed, permanent position in each emplacement drift. Both parts of the track need to be joined at the same elevation to provide for the smooth and uninterrupted transfer of the waste packages atop the emplacement railcars into the emplacement drifts. The first part of the track system is installed inside the waste package transporter to support the waste package during transport to the emplacement drift. The length of this rail section is limited by the length of the waste package transporter and the position of the transporter shielding doors.



NOTE: DOOR ARRANGEMENT SHOWN FOR 5.5 m DIA. EMPLACEMENT DRIFT AND DUAL TRACK, OFF-CENTER EMPLACEMENT. SINGLE TRACK, IN-CENTER EMPLACEMENT WILL REQUIRE A SMALLER DOOR.

Figure 8.6.4-8. Emplacement Drift Shielding Door Concept

The second part of the track system is placed inside each emplacement drift. This track begins at the waste package transfer dock which is located directly behind the shielding doors. The shielding doors limit access into the emplacement drift. Prior to backing-up the waste package transporter against the transfer dock, the shielding doors of both the waste package transporter and the emplacement drift need to be in the full open position. After these doors have assumed the full open position, the waste package transporter is then fully backed up against the transfer dock and the short rail section that extends just beyond the end of the transfer dock will serve to provide for the continuous, in-line rail connection. In this docking position, the extended rail section will rest and be supported on the end section or platform of the waste package transporter. For determination of rail sizes in the main and emplacement drifts, see Preliminary Rail Size Selection in Appendix E.

For reasons of uniformity and with considerations for equipment stability, a rail gage of 1.44 m was selected for emplacement operations. Based on the preliminary rail selection data, the weight of the rails are 57.05 kg/m for main drifts and 44.64 kg/m for emplacement drifts.

The track gage of 1.44 m is the equivalent to North American standard gage, and the nominal rail weights are consistent with the standards of the American Railway Engineering Association and the American Society of Civil Engineers.

8.6.5 Remote Handling Systems for Waste Package Emplacement

Work began in 1995 on developing an overall conceptual design and strategy for implementation of remote handling and robotic systems within the underground repository. A brief survey of relevant technologies was conducted and a preliminary evaluation of potential application areas for remote systems was performed (CRWMS M&O 1995ao).

The primary impetus for using remote handling and robotic systems for waste package emplacement comes from the severe thermal and radiological conditions that will be encountered during the emplacement process. Initial estimates indicate that waste package surface temperatures may reach 190°C. Radiation levels near the waste packages will well exceed those considered safe for human exposure. Current estimates indicate that a human, standing 1 m away from a waste package, would exceed annual occupational radiation dose allowance in a few minutes.

Motivation to use remote systems also comes from a need to comply with 10 CFR 60 and DOE regulatory criteria which call for the implementation of ALARA concepts seeking to minimize possible radiation exposure to humans. Accordingly, Key Assumption 013 listed in the CDA Document essentially states that the emplacement drifts will be off-limits to humans once waste package emplacement operations begin.

This section outlines preliminary remote systems concepts for the subsurface repository and focuses on the selected waste package emplacement concept presented in Sections 8.6.3 and 8.6.4.

8.6.5.1 Remotely Controlled Equipment

As indicated in Figure 8.6.5-1, a large portion of the emplacement operation will use remotely operated and remotely controlled equipment, including:

Remotely Operated Equipment	Description
• Transport Locomotive	A trolley locomotive primarily operated manually by a crew of 2 on-board operators. It will also be equipped with a secondary remote control system that will provide optional real-time monitoring, supervision, and control from a master control room located on the surface outside the subsurface repository. This locomotive will be equipped with articulated cameras, fore and aft.
• Transfer Locomotive	This battery operated locomotive will also be equipped with both a set of on-board manual controls and remotely operated controls. Critical segments of the emplacement process will require that this locomotive have the capability of being unmanned and totally remotely controlled. This locomotive will be equipped with articulated cameras, fore and aft.
• Emplacement Locomotive	In size and construction, this locomotive will be very similar to the transfer locomotive; however, it will be used almost exclusively in remote control mode. The on-board manual controls will only be used for incidental equipment transfers outside the emplacement drifts. This locomotive will be equipped with articulated cameras, fore and aft.
• Waste Package Transporter	Waste Package loading/unloading and latching mechanisms internal to the waste package transporter will be remotely operated as will the waste package transporter doors. In addition to feedback from mechanical and electronic sensors, there will be strategically located video cameras that will provide human operators with visual confirmation of operations.
• Emplacement Locomotive Carrier	Locomotive loading/unloading and latching mechanisms will be remotely controlled.
• Actuated Devices	Emplacement drift shielding doors, docking devices, rail switches, etc., will be operated by remote control.
• Instrumentation and Monitoring Equipment	Remotely operated pan/tilt camera systems, remote temperature and radiation monitoring systems, computer work stations, local area networks, and communication systems, etc., will be used for emplacement operations, performance confirmation activities and emplacement drift monitoring.

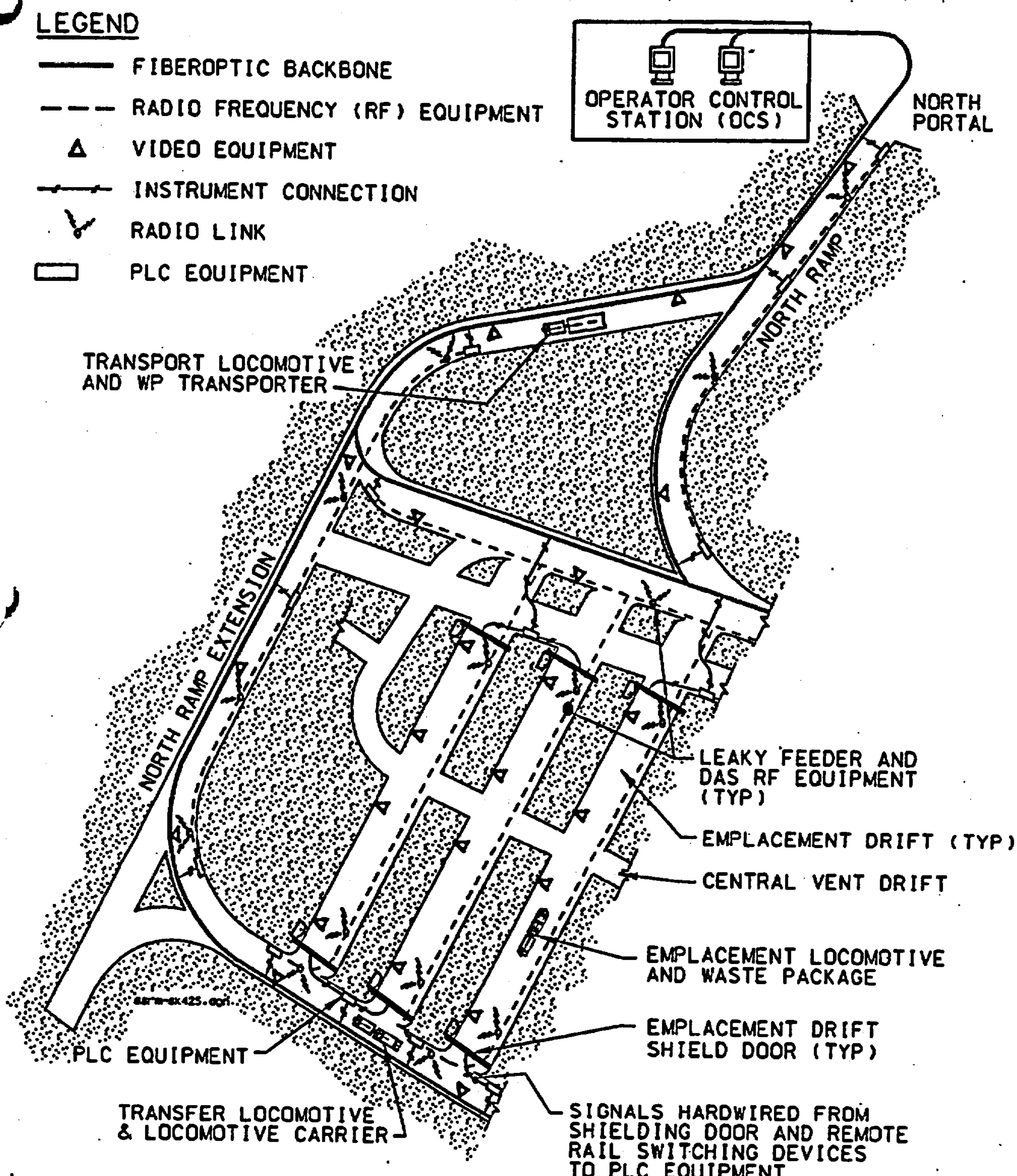


Figure 8.6.5-1. Remote Systems Used for Waste Package Emplacement

8.6.5.2 Remote Systems Design Issues

Project constraints call for the use of "reasonably available technology" in designing component systems for the repository. Initial evaluations indicate that the level of technology needed to implement remotely controlled systems will not need to be particularly sophisticated. Most of the hardware and software will consist of custom adaptations of commercially available technologies; however, developing and integrating these technologies into highly reliable, fail-safe systems will require a significant design effort. Benefit can be gained by reviewing relevant technologies in areas such as industrial automation, mining, railroad, nuclear and aerospace industries, and university robotics programs.

It is also noted here that the actual emplacement operations are not scheduled to occur for about 15 to 20 years. The preliminary conceptual control systems discussed below serve only as an initial step to show that remote operations can be achieved by relatively common and well understood technologies, even by today's standards. With the rapid advancement of computer and communication technologies, the actual control system implemented may be quite different.

Initial scoping efforts sought to use the minimum level of technology sophistication necessary to do the job. The control system presented below follows this guideline; however, this does not preclude future consideration and implementation of more advanced, autonomous, and robotic vehicles as these systems become more proven and widely accepted.

Significant design challenges for remote systems design arise from two key environmental conditions within the subsurface repository, namely elevated temperatures and high radiation. Estimates indicate that waste package surface temperatures may reach 190°C. Therefore, during waste package emplacement, the drifts will be actively ventilated to maintain air temperatures at less than 50°C. While this temperature is relatively high, it is still within the upper operating limit for many standard off-the-shelf components and technologies, such as those indicated within this section, for use during emplacement.

The current repository design concept calls for the active ventilation of each drift to cease once the drift has been filled with waste packages. The impact on equipment designs for post-emplacement operations (i.e., during the Performance Confirmation phase of the project) is still being evaluated. Allowing temperatures to rise in unventilated drifts, and remain high in order to avoid thermal cycling, would preclude use of many materials and components. Typically only metallic, ceramic, specialty composites, and heat tolerant materials would be expected to survive after the drift heats up. Conventional components such as cameras, controllers, electronic sensors, actuators, and many other devices would rapidly fail at these temperatures. It would require major design efforts to develop heat tolerant or actively self-cooled devices which might survive, even for a limited amount of time, in such a harsh thermal environment. Such designs augmentations, while theoretically possible, would result in relatively elaborate and expensive designs, and the economic feasibility of such systems will need serious consideration.

In addition, remotely operated systems will be required to withstand relatively high levels of radiation. It is expected that the basic technologies needed to operate in such an environment currently exist; however, the additional cost, time, and testing necessary to meet the exceptionally high quality and reliability standards associated with working in a nuclear radiation environment should be emphasized. The remote systems being evaluated will typically be equipped with moderately sensitive electronic and computer components requiring the design of specific radiation shielding or radiation tolerant devices. The impact of emplacement drift radiation levels on electronic subsystem is an important factor that will require thorough consideration during the design of radiation sensitive components. There are design techniques, such as component shielding and use of radiation hardened components, that can be used to minimize or eliminate the possible negative effects from radiation doses encountered by subsurface remotely operated systems.

8.6.5.3 Control System Architecture

By focusing on existing, well understood and relatively mature technologies, a fairly simple monitoring and control system can be devised that will enable remote control of the emplacement equipment identified above (see Figure 8.6.5-1). Critical emplacement operations can be remotely monitored, supervised, and controlled by human operators located at a central operator control station. This can be accomplished via a local area network and fiber optic backbone connected to a subsurface network of computer workstations, programmable logic controllers, and wireless, radio frequency (RF), communications links to mobile equipment. For details regarding schematic subsurface repository control systems see Figure 8.6.5-2.

8.6.5.3.1 Distributed Control Systems

Advancements in distributed control systems and process safety management techniques has resulted in readily available triple, and even quadruple, redundant control systems. These types of control systems are in use today in many mainstream industrial manufacturing and processing plants around the world. These systems provide real-time monitoring, control, safety system interlocking, component health checking, system warnings, data analysis, trending, reporting and archiving, and emergency shutdown procedures. Critical and/or vulnerable system components can be implemented using completely separate and independent redundant control system components which will help prevent and eliminate single-point component failures.

A Programmable Logic Controller is a type of computer-based system designed to process large amounts of discrete input and output. Discrete input and output are devices having either an "off" or "on" state such as push buttons, indicating lights, alarm horns, limit switches and motor contractors. These are the types of signals that will be necessary to operate the emplacement drift shielding doors and the rail switches. The programmable logic controller system is also capable of providing interlocks and sequencing since they are programmed in what is known throughout the industry as relay ladder logic. The programmable logic controllers will receive a supervisory command from the main computer system to either open or close the shielding door, and, provided all interlocks are satisfied, will then provide the appropriate outputs to the door actuator. The programmable logic controller(s) will also ensure that the track switches are in the correct position to allow for a waste package to travel to its place in the proper emplacement drift.

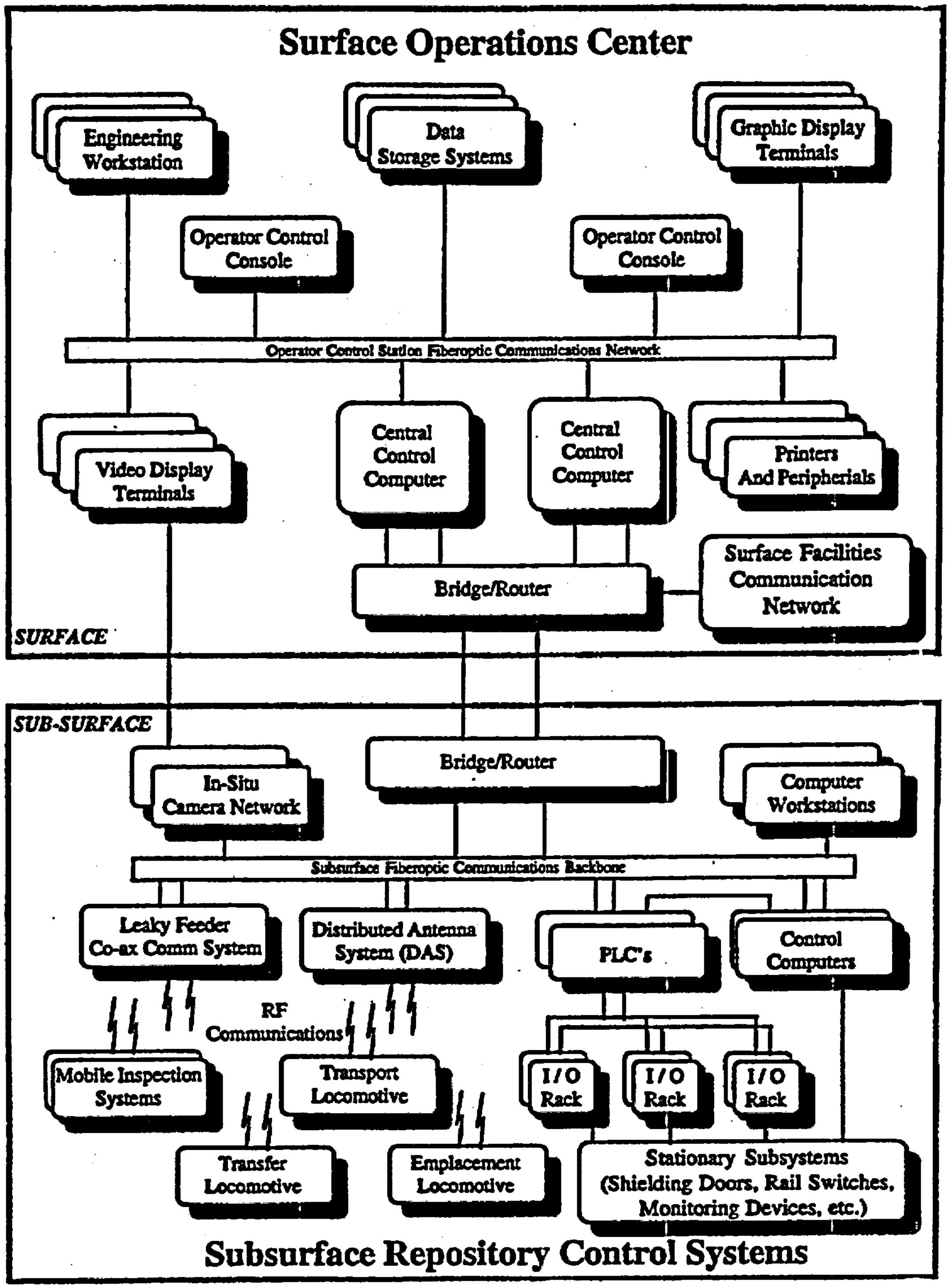


Figure 8.6.5-2. Remote Control System Block Diagram

8.6.5.3.2 Operator Interfaces and Control Stations

Subsurface emplacement operations and activities will be coordinated from an operations control center housed in a building on the surface. The operations control center will include a central control room for remotely controlled subsurface systems. It will be equipped with workstations, control consoles, video displays, and graphic terminals that can provide human operators with direct real-time control, along with visual and auditory feedback of the entire subsurface emplacement process.

There will be two basic modes of operation: manual remote mode (i.e., tele-operated) and a supervisory mode which will allow semi-autonomous control of a remote operation. In manual remote mode, all actions of a remote system are under the direct real-time control of a human operator located at the operator control station. In supervisory mode, on-board control systems coordinate and control the performance of simple, well structured tasks under supervision of a human operator located at the operator control station. These tasks, such as positioning the waste package at the desired location within the emplacement drift, can be performed with minimal human interaction; although the supervising operators will be able to take over direct manual remote control of the system at any time.

8.6.5.3.3 Subsurface Networks and Communications

A review of the communication technology presently used in mines was made and many applications similar to those anticipated for the repository were found. In comparing some of the characteristics of a mine to that of the repository, it is worth noting that, from a communication standpoint, the repository is a less demanding environment. A mine's physical layout is constantly changing due to production, whereas the repository's will be relatively static. Mine automation is being applied to load haul dumps which are trackless vehicles whereas the repository will deal with primarily track-based vehicles. Traffic control will also be easier to monitor in the repository due to the limited amount of remote activity being performed. The repository will also consist of long, relatively straight drifts allowing for radio communications to be accomplished with less equipment. The repository, however, is not without its areas of concern. The emplacement area will be relatively hot, have a significant radiation level, and will require wireless communications to cover over 200 linear kilometers of tunnel.

Communication is the most important element with regard to automation. Without communications, devices can be individually automated but the information can never be integrated or processed for optimized control. The wireless systems and the programmable logic controllers will interface to a redundant computer mainframe assembly via a fiber optic communications backbone that will run down each of the main drifts and access ramps. The fiber optic medium provides excellent immunity to electrical noise and can accommodate long distances with relatively low signal attenuation. Present day equipment can also transmit data at speeds of over 150 megabits per second (Mbps) which should be more than sufficient for the needs of the repository. Due to the adverse sensitivity optical fibers demonstrate in ionizing radiation environments, fiber optics will not be used in the emplacement drift areas. The use of fiber optic networks will be restricted to the human-rated main and perimeter drifts.

The combined overall length of repository tunnels and drifting will be approximately 250 km. To provide communication across this distance, which is roughly equivalent to the distance from Cleveland to Detroit, it is necessary to utilize a Metropolitan Area Network (MAN). A MAN is a high speed network which provides integrated services over a large geographic area and typically interconnects local area networks. Fiber optic cable will be installed in all main access drifts totaling approximately 50 km. Hubs and bridges will be installed as required to support communications with the programmable logic controllers and RF equipment. Two types of communication technologies currently under evaluation for the fiber optic backbone are ANSI's Fiber Distributed Data Interface and the IEEE Distributed Queue Dual Bus. Each emplacement drift will have a dual redundant wireless communication system, consisting of a Distributed Antenna System and a coaxial Leaky Feeder RF communication system, to remotely control the emplacement equipment.

The Distributed Antenna System consists of a shielded trunk cable run throughout the main drift areas with multiple copper coaxial antenna run along each emplacement drift and connected to the trunk cable via special taps. The taps convey RF energy from the trunk cable to drive the antenna. The bi-directional antenna transmits and receives RF energy within the emplacement drift. The Distributed Antenna System is well suited for communications in long, straight drifts that possess some waveguide properties. The Distributed Antenna System network will be used to support multiple channel Ultra High Frequency radio bands to transmit/receive simultaneous data and real-time video signals from the mobile equipment. Radio signals in the Ultra High Frequency bands propagate very effectively underground due to their short wavelength. This results in being able to cover relatively large distances (500 to 1000 m) with an individual antenna. Another advantage of the Ultra High Frequency band is that the physical dimensions of the antenna are small and very practical for use underground.

A Leaky Feeder Coaxial Cable System (coax) is a transmission line that has a loosely attached shield or slots cut in the shield of helical type cable. These cuts allow the RF energy to leak out gradually, or create small antennas and radiate some power at each slot. RF energy will broadcast outward from the coax, as well as into the coax, allowing one run of coax to operate as both a transmit and receive antenna. Since the power is radiated gradually along the length of the transmission line, the distance can extend several hundred meters before bi-directional amplifiers are required to be installed.

Other wireless communication technologies are being explored; such as the digital transmission of data, voice, and video signals using Super High Frequency radio, which is also known as microwave communication. Microwave energy is normally transmitted in air at frequencies ranging from 4 to 11 GHz. These systems all require line of sight between sets of sophisticated microwave receiver and transmitter stations. One inherent disadvantage of microwave telemetry is the high signal attenuation rates. To avoid these losses, parabolic reflectors are used to focus the energy between two stations.

All mobile equipment such as transport locomotives, waste package transporters, loading mechanisms, emplacement locomotives, and transfer locomotives will be designed to operate remotely by the addition of pneumatic, hydraulic, and electrically actuated brakes, throttles, valves, and solenoids. A receiver/transmitter for each RF system will be mounted on the mobile equipment, and each will be hardwired to a control system such as a programmable logic controller which will ultimately send the outputs to the above mentioned actuators to achieve the required control action. Each piece of mobile equipment will have two or more video cameras mounted that will be able to zoom, pan, and tilt via instructions received from the operator on the surface. The mobile equipment control system will monitor the signals from each RF medium and verify the integrity of those signals. Upon detecting an error in transmission, the other medium can be used to inform the operator and allow for safe immobilization of the equipment.

8.6.5.3.4 Video Systems

Providing the operators on the surface with as much information as possible about the underground activity is a definite objective of implementing remote handling technology. As stated previously, two video cameras will be located on each piece of the mobile equipment except on the emplacement railcar. These will have to be wireless and utilize the fiber optic backbone to ultimately display the information to the operator in the main control room. It is also planned to have a hardwired video network which will have cameras mounted to the walls of the main and access drifts. The cameras will be spaced at predetermined intervals so that movement of the waste packages can be tracked/monitored independently from the control system. These cameras will have the same zoom, pan, and tilt characteristics of those on the mobile equipment. A bank of display monitors will be located in the main control room along with the necessary selector switches to allow the operator to assume control of a particular camera to obtain the required information.

8.6.5.4 Remote Control System Summary

Remote handling of the waste packages can be accomplished by utilizing technology that is currently available. All activity that takes place within the emplacement drifts such as emplacement, caretaking, backfill, and retrieval must be performed remotely to satisfy the ALARA guidelines. Transporting the waste packages from the WHB to an emplacement drift can either be done remotely or by a manned locomotive since the waste package will be contained in the shielded waste package transporter.

Redundant wireless communication systems will be employed to control/monitor the mobile equipment as listed in Section 8.6.5.1. The wireless communication network will be designed to transmit and receive information from specific areas of the repository. In other words, the repository may be divided into quadrants so that the RF energy is only directed where it is required. The main drifts and all access drifts will always be able to transmit and receive data and information. The area around an emplacement drift in which an operation is taking place, will also be activated. However, emplacement drifts in which there is no activity will have their RF systems shut down. The computer system will be able to determine this and will direct the RF transmissions accordingly.

Redundancy will be a key attribute of the remote handling control system. All critical areas of control will incorporate some level of redundancy so failures of the control equipment will have minimal effects on the operation of emplacing waste packages.

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8.7 SUBSURFACE VENTILATION

Ventilation is a critical support function in the subsurface repository. In addition to providing the normally expected attributes (supply of fresh air and removal of exhaust air), the subsurface repository ventilation system must accommodate a number of unconventional design requirements, such as separating the ventilation of construction and waste emplacement operations and controlling the direction of air leakage between these two areas (YMP 1994a, RDRD 3.7.5.B.3 and 3.7.5.B.4). Subsurface ventilation may also be required to control the temperature of emplacement drifts for potential maintenance and/or waste retrieval (CRWMS M&O 1995a, Key 016 and 017). This section discusses the design methodologies and preliminary subsurface ventilation concepts developed as a part of the repository ACD efforts.

8.7.1 Previous Work

Work on repository subsurface ventilation during ACD has been documented in a series of repository ventilation evaluation reports (CRWMS M&O 1993f; CRWMS M&O 1995aq; CRWMS M&O 1995ar; and CRWMS M&O 1995as) and a number of repository design documents (CRWMS M&O 1993e, CRWMS M&O 1994a and CRWMS M&O 1995am). Evaluation of using ventilation as one of the potential thermal management methods was also conducted and preliminary results were included in an M&O document (CRWMS M&O 1995at).

The *Repository Underground Ventilation System Concepts* Report (CRWMS M&O 1993f) summarized the initial repository ventilation study performed during FY 1993 to evaluate ventilation systems for an ESF/repository design concept. Analysis was intended to identify repository ventilation requirements, to develop ventilation design methodology, and to evaluate required air volume flow rates and concepts of ventilating air distribution.

Development ventilation requirements were evaluated by considering the air flow requirements for underground personnel, dilution of diesel emission, air velocity, air cooling, and special mining operations and equipment. Results showed that the air flow quantity requirement for the development of the repository was anticipated to be within the common range of the ventilation requirement for conventional underground mines.

Emplacement air quantities were investigated based on the air flow requirements to control drift temperature during the emplacement activities, as well as other standard requirements for underground operations. Analysis of heat transfer between the waste packages and the surrounding air and rock was performed using the in-drift emplacement mode (to represent the worst case scenario) to control drift temperature during the emplacement operations. It was anticipated that the forced convection in the drift will predominate the overall heat transfer process and remove a significant portion of the heat generated by the waste packages during the emplacement operations, if adequate ventilation is provided. Effects of ventilation on the air temperature in the drift were demonstrated through typical numerical calculations using the overall energy balance relation. The calculated results showed that the temperature of the operating emplacement drift can be controlled within an acceptable level for the range of areal power densities evaluated.

Air flow requirements for retrieval of emplaced waste were also addressed. Heat transfer during the cooling period was analyzed using traditional methods for fluids. The numerical results for a typical blast cooling scenario indicate that it is possible to regain access within a few weeks to an emplacement drift sealed for an extended period of time, such as 50 years, by ventilating the drift with a fairly large air flow rate for the range of APD's evaluated.

General concepts of air flow distribution and repository ventilation interface with ESF design were discussed (CRWMS M&O 1993f). The preliminary evaluations indicated that the ESF/repository interface layouts (CRWMS M&O 1993e), under development at that time, allowed sufficient flexibility for efficient ventilation design of development and emplacement activities.

In the *Subsurface Ventilation Concepts Report for Repository ACD – FY 94* (CRWMS M&O 1995aq), air flow quantities and network arrangements for two conceptual repository subsurface layout concepts were evaluated. Computer simulations of ventilation network balance were performed using standard ventilation software. The results of modeling indicated that network balance and desired air flow distribution can be properly managed such that no primary working areas are obstructed by ventilation control devices. Effects of refrigerating intake air were evaluated and compared with ventilation using airflow at ambient temperature. The results indicated that ventilation intake air at ambient temperature has the capability of removing the desired amount of heat energy from the repository, if appropriate air flow rates are applied. For blast cooling, pre-cooling the intake air can significantly reduce required cooling time or airflow rate, but is inefficient as far as power consumption is concerned. Preliminary evaluation of escape routes in the study showed that the repository interim layout (CRWMS M&O 1994a) allows provision of adequate refuge facilities and/or escape routes in the repository, regardless of accident location.

The *Repository Subsurface Ventilation Scoping Evaluation Report* (CRWMS M&O 1995ar) analyzed rather detailed repository ventilation arrangements at various typical development and operational stages. Preliminary concepts for ventilation fans and airflow control devices, such as doors, regulators and barriers, were addressed. The evaluation of the effects of potential natural ventilation pressures within the repository showed that natural ventilation pressures could be an assistance to the main fans. The effect of adding water to the emplacement drift intake airstream to enhance latent heat removal was also evaluated.

The *Repository Heating and Cooling Scoping Analysis Report* (CRWMS M&O 1995as) discussed concepts of evaluation for emplacement drift temperatures as a function of repository thermal loading, waste stream, drift and package spacings, emplacement drift size, emplacement modes, and standoff distance. A technical approach to be used in conjunction with general analysis programs was developed to determine the effects of the coupled thermal conduction, convection and radiation in ventilated emplacement drifts. Three-dimensional finite element programs were used to evaluate several levels of continuous emplacement drift ventilation (0, 2 and 10 m^3/s per drift). The results indicated that, without ventilation, waste emplacement at an aeral mass load of 100 MTU/acre will result in maximum drift temperatures of 170 to 179°C; for the cases modeled with drift spacings of 20 to 25 m and waste package spacings of 14.2 to 17.7 m for 21 PWR packages and 7.5 to 9.4 m for 12 PWR packages. A low areal mass load of 20 MTU/acre was also evaluated over a wide range of drift and package spacings. For the seven cases modeled, the maximum drift wall temperatures were between 78 and 129°C. Of these seven cases, the calculated maximum drift wall temperatures in four cases were below 100°C.

Continuous emplacement drift ventilation of 2 and 10 m^3/s per drift was evaluated for the first year after emplacement. The results indicate that ventilation in the drift will reduce the drift wall temperature, and the net reduction of temperature depends on the air flow rate applied. The temperature difference between the drift wall and the air decreases along the drift length in the direction of flow. Ventilation air flow removes more heat from the beginning of the drift near the air intake than from farther down the drift. For the 10 m^3/s case, the calculated convective heat transfer into the air decreases from about 78 percent of the total heat at the drift entrance to 38 percent at the drift exhaust.

Additional results from the repository heating and cooling analysis efforts were included in Section 7.2 of the *Waste Emplacement Management Evaluation Report* (CRWMS M&O 1995at). Evaluations used the following data: 100 MTU/acre aeral mass load, center-in-drift emplacement, 1,200-m long and 5-m diameter emplacement drift, 21 PWR packages, and drift intake air and initial rock temperature of 26°C. Initial results included the air and drift wall temperatures and heat removal rates for ventilation rates of 2 and 10 m^3/s per drift. They showed that during ventilation, the air and rock temperatures increase along the drift and reach the maximum at the drift exit. The air temperature at the drift exit increases from 74°C in the first year to 123°C (peak) in the 20th year, and then decreases to 96°C in the 100th year for limited ventilation of 2 m^3/s per drift. If an aggressive airflow of 10 m^3/s is applied, the maximum air temperature of 62°C occurs at the 9th year of ventilation, and then steadily decreases to 50°C in the 100th year. Under aggressive continuous ventilation (10 m^3/s), the maximum drift wall temperature of 74°C occurs in 9 years. For limited ventilation (2 m^3/s), the maximum drift wall temperature of 136°C occurs in the 27th year of ventilation.

Compared with an unventilated scenario of the same waste emplacement conditions, in which the maximum drift wall temperature of 177°C is observed along in the entire drift length, ventilation can reduce the peak wall temperature by 103°C at the drift exit, for an airflow of 10 m^3/s per drift. For an airflow of 2 m^3/s, the reduction in the maximum wall temperature is 41°C at drift exhaust end. The calculations also demonstrate that an airflow of 2 m^3/s per drift can remove from the drift 51 percent of the heat generated by the waste, within a 100-year ventilation period. If the airflow is increased to 10 m^3/s, more heat (74 percent of the total) can be removed within the same ventilation period.

Ventilation for potential waste retrieval was further analyzed during the recent efforts on the evaluation of retrieval conditions (CRWMS M&O 1995am). The required times to cool emplacement drifts were evaluated for a range of air flow rates (20 - 200 m^3/s per drift) and thermal loads (25 - 100 MTU/acre). The results showed that, using air flow rates of 80 - 120 m^3/s, the temperature of a 1,200 m long emplacement drift can be reduced to 50°C or less in about 0.4 to 4.6 weeks, for the range of thermal loads evaluated.

8.7.2 Design Inputs

8.7.2.1 Requirements

All text in this section is excerpted directly from the RDRD (YMP 1994a), which is the reference source for repository requirements. Upper level requirements from within the program (i.e., CRWMS Upper Level requirements) and outside the program (such as 10 CFR 60 requirements) are included in the RDRD (YMP 1994a). The specific RDRD (YMP 1994a) requirements quoted below are considered applicable to aspects of repository subsurface ventilation. Other RDRD (YMP 1994a) requirements, which may apply in a more general way, are not included here.

3.7.5.B Underground Facility Ventilation. The underground facility ventilation system shall be designed to:

1. Control the transport of radioactive particulates and gases within and releases from the underground facility in accordance with the performance objective of 10 CFR 60.111(a) (Section 3.2.2 of this document);

2. Assure continued function during normal operations and under accident conditions;

3. Separate the ventilation of excavation and waste emplacement areas;

4. Ensure that ventilation leakage between the emplacement system and the development system will always be from the development system to the emplacement system;

5. Take into account geologic conditions encountered during in situ monitoring, testing, or development of subsurface facilities, which affect air contaminant levels, temperatures, or other conditions;

6. Supply air to and exhaust adequate quantities of air [TBD] to and from underground working areas such that operator safety, health and productivity requirements are maintained;

7. Contain safety features in accordance with 30 CFR 57, Subpart G and 30 CFR 57, Subpart T [*see Note below*]

[NOTE: 30 CFR 57, Subpart T is concerned with mines that are classified as "gassy" by definition. Since the ESF tunnel has been classified as "non-gassy" (CRWMS M&O 1993g), Subpart T is considered not applicable in this report. The "Subpart T" in the above text (3.7.5.B.7) is a direct quote from the current revision of the RDRD (YMP 1994a), which cannot be changed when cited in design documents.]

3.2.4.2.2 Heating, ventilating, and air conditioning (HVAC) equipment in facilities shall be sized to conform with the guidelines in NUREG 0700 Section 6.1.5. MIL-STD-1472D Section 5.8.1 and the applicable ASHRAE standard may be used for reference.

3.3.6.3.G Ventilation meeting the standards of 30 CFR 57, subpart D shall be provided as applicable in underground facilities.

8.7.2.2 Assumptions

All text in this section is excerpted directly from the *Controlled Design Assumptions Document* (CDA) (CRWMS M&O 1995a). The CDA Document (CRWMS M&O 1995a) assumptions quoted below contain only the items that have been used in the evaluations of the subsurface ventilation system.

Key 004 The average spent nuclear fuel characteristics upon receipt at the Repository and based on the Oldest Fuel First (OFF) acceptance strategy, no MRS, deferred dry storage, derated canisters, and four truck sites:

26.4 years old with 39.65 Gwd/MTU burnup and 3.68 wt. % enrichment (PWR).
26.1 years old with 31.19 Gwd/MTU burnup and 2.97 wt. % enrichment (BWR)

The following table provides the total repository emplacement decay heat by waste package type as a function of time. (see Section 4.1, Table 4-5)

Key 011 Waste packages will be emplaced in-drift in a horizontal mode.

Key 016 The repository will be designed for a retrievability period of up to 100 years after initiation of emplacement.

Key 017 Retrieval of emplaced waste may be performed for the following reasons:

- Failure in site, waste package, or some other system causing an unreasonable risk to public health and safety.

- The determination that recovery of valuable resources from the spent nuclear fuel is necessary.

Key 019 Surface, subsurface and waste package designs will be based on a reference thermal load of 80-100 MTU per acre. The reference thermal load for the revised MGDS ACD Report is 83 MTU/acre.

Key 022 For the reference thermal loading of 80-100 MTU per acre, the repository horizon will be located mainly in the TSw2 geologic unit within the primary area.

Key 027 The primary method of tunnel excavation will be mechanical.

EBDRD 3.7.1.J.1

The waste package shall meet the following criteria:

1. External dimensions shall not exceed:

Outer Diameter:	1850 mm
Outer Length:	5850

RDRD 3.7.5.B.6

Supply air to and exhaust adequate quantities of air to and from underground working areas such that operator safety, health, and productivity requirements are maintained.

DCSS 015

Properties of ventilation air:	Standard Density	1.2 kg/m^3
	Thermal Conductivity	0.02564 W/mK
	Heat Capacity	1.2082 kJ/m^{3}K
	(Adjustment for site conditions is required)	

DCSS 016

Maximum allowable air velocity in:	Ramps:	7.6 m/s
	Ventilation Shaft:	20.3 m/s
	Personnel Shaft:	11.7 m/s
	Emplacement Drifts during Construction:	3.0 m/s
	Exhaust Mains:	10.2 m/s
	Service Mains:	7.6 m/s
	Waste Handling Main:	7.6 m/s
	Ductwork:	30.5 m/s

DCSS 017

Minimum required air velocity in:

	(For Active Excavation)	(For Development Maintenance)
Ramps:	0.51 m/s	0.31 m/s
Shafts:	0.51 m/s	0.31 m/s
Emplacement Drifts:	0.51 m/s	0.31 m/s
Exhaust Mains:	0.51 m/s	0.31 m/s
Service Mains:	0.51 m/s	0.31 m/s
Waste Handling Main:	0.51 m/s	0.31 m/s
Ductwork:	12.7 m/s	10.2 m/s

DCSS 018

Minimum required air volume per:

Diesel kW:	0.0791 (m^3/s)kW
Underground Worker:	0.0944 (m^3/s)/person

DCSS 019

Maximum allowable air temperature in emplacement drifts during:

Construction:	27°C effective
Emplacement:	50°C dry-bulb, only in portion requiring access
Caretaker:	no limit, determined by rock temperature
Retrieval:	50°C dry-bulb, only in portion requiring access
Backfilling:	50°C dry-bulb

DCSS 020

Maximum allowable air temperature in access (ventilation intake) mains during:

Construction:	27°C effective
Operations:	27°C effective
Caretaker:	27°C effective
Retrieval:	27°C effective
Backfilling:	50°C dry-bulb

DCSS 021

Underground air quality in drifts occupied by personnel during:

Construction:	$O_2 \geq 19.5\%$, air cooling power ≥ 260 W/m^2, contaminants <TLV values
Operations:	$O_2 \geq 19.5\%$, air cooling power ≥ 260 W/m^2, contaminants <TLV values
Caretaker:	$O_2 \geq 19.5\%$, air cooling power ≥ 260 W/m^2, contaminants <TLV values
Retrieval:	$O_2 \geq 19.5\%$, air cooling power ≥ 260 W/m^2, contaminants <TLV values
Backfilling:	$O_2 \geq 19.5\%$, air cooling power ≥ 260 W/m^2, contaminants <TLV values

DCSS 022

"K" factors for ventilation air flow in:

Shafts:	
Ventilation Shaft	0.0030 kg/m^3
Man-and Material Shaft	0176 kg/m^3
Ramps:	
Waste Ramp	0.0056 kg/m^3
Tuff Ramp	0.0111 kg/m^3
Exhaust Mains:	0.0111 kg/m^3
Service Mains:	0.0130 kg/m^3
TBM Launch Mains:	0.0130 kg/m^3
Waste Main:	0.0111 kg/m^3
Emplacement Drifts:	
Without Waste Packages	0.0130 kg/m^3
With Waste Packages	0.0158 kg/m^3

DCSS 023

Maximum allowable preclosure rock surface temperature in:

Shafts:	35°C – unventilated
Ramps:	35°C – unventilated
Mains:	50°C
Emplacement Drifts:	200°C

Temporary increases in these temperatures are allowed during initial cooling of emplacement drifts for maintenance, performance confirmation, retrieval and backfillings.

DCSS 029

Maximum allowable air temperature in exhaust mains during:

Construction:	27°C effective
Operations:	50°C dry-bulb
Caretaker:	50°C dry-bulb
Retrieval:	≤ emplacement drift rock surface temperature
Backfilling:	50°C dry-bulb

TDSS 004

Rock index properties:

In Situ Density	TSw2: 2297 kg/m^3
Dry Density	TSw2: 2219 kg/m^3

TDSS 005

Thermal conductivity of in situ rock mass – TSw2: 2.1 W/mK

TDSS 006

Heat capacitance of in situ rock – TSw2:

2.0324×10^6 J/m³K @ 25°C	2.0065×10^6 J/m³K	@ 115°C
2.1280×10^6 J/m³K @ 50°C	2.1114×10^6 J/m³K	@ 155°C
2.2638×10^6 J/m³K @ 94°C	2.1912×10^6 J/m³K	@ 195°C
10.7683×10^6 J/m³K @ 95°C	2.2692×10^6 J/m³K	@ 235°C
10.4690×10^6 J/m³K @ 105°C	2.3410×10^6 J/m³K	@ 275°C
10.1984×10^6 J/m³K @ 114°C		

8.7.3 General Considerations of Subsurface Ventilation

The basic function of the repository subsurface ventilation system is to control air movement (quantity, quality, and direction of airflow) to meet the needs of repository activities including: construction, simultaneous development and waste emplacement, repository caretaker operations, and potential retrieval, backfilling and closure operations (YMP 1994a, 3.7.5.B.6 and 3.7.5.B.7; and CRWMS M&O 1995a, EBDRD 3.7.5.B.6).

The required air quantities vary with repository activities during different time periods. In general, total air quantity must be estimated by considering the following:

- Minimum and maximum air velocities in various underground areas
- Minimum air quantity for TBM operations
- Minimum air volume for underground personnel and special equipment
- Minimum air quantity for diesel equipment (if considered desirable)
- Minimum air flow rate to control temperature in active emplacement areas
- Minimum quantity for emplacement drift cooling (if necessary)
- Minimum quantity to support backfilling (if necessary)
- Potential air leakage and uncertainty allowance.

The concepts of underground air flow arrangement and ventilation network modeling must also be developed to:

- Separate the ventilation system of excavation and waste emplacement areas
- Prevent ventilation leakage from emplacement system to development system
- Limit the dispersion areas of potential dust/contaminants
- Allow sufficient flexibility for planning of emergency escape routes
- Ensure balanced air flow distribution using reasonable ventilation control measures.

General airflow distribution strategies for a ventilation system are governed by factors including safety, cost, flexibility, and development sequence. A primary concern is safety. The repository design requirement stipulated by the RDRD (YMP 1994a) dictates that the underground facility ventilation system shall separate the ventilation of excavation and waste emplacement areas (YMP 1994a, 3.7.5.B.3). Although specific definition of the separate system is not given in the RDRD (YMP 1994a), the main purpose of the requirement is to limit the potential for contamination movement within, and release from, the facility. To meet this requirement, proper arrangement of the primary air intake and exhaust for development and emplacement areas needs to be considered. The *Repository Underground Ventilation Systems Concepts* report (CRWMS M&O 1993f) analyzed several alternatives regarding separate ventilation. It indicated that planning two entirely independent ventilation systems is a favored scheme insofar as safety is concerned.

Figure 8.7.3-1 shows (diagrammatically) an arrangement of two separate ventilation systems during simultaneous development and waste emplacement. One system provides air for the development of the repository, while the other provides air for the waste emplacement operations. Each system has its own primary intake and exhaust openings to the surface for the supply of fresh air and exhaust of return air. Underground openings between the two ventilation systems are sealed with isolation air locks. Details of this ventilation system arrangement will be further discussed in subsequent ventilation sections.

8.7.4 Construction and Development Ventilation System

Construction and development ventilation systems will support construction (before start of waste emplacement) and continuous development after waste emplacement begins. During simultaneous development and emplacement operation, although heat released from waste packages will affect ventilation of the emplacement area, it will have little effect on the development system. This is because the air flows of the two ventilation systems are independent and thermal conduction is the only means for heat exchange between the two systems; when there is insufficient time for conductive heat to reach the advancing development areas, the rock temperatures in development airways will not be affected. Thus, ventilation considerations for construction and development will be governed by conventional underground ventilation requirements (YMP 1994a, 3.3.6.3.G, 3.7.5.B.7 and 3.2.4.2.2).

8.7.4.1 Air Flow Quantities for Construction/Development

During the underground construction of a repository, continuous ventilation is required not only for supporting human life but also for enhancing employee safety, comfort and health. Since the principal environmental conditions in underground areas are strongly dependent on the flow rates of ventilation air, analysis of air quantities that satisfy the requirements must be performed.

Minimum Air Quantity per Person

The Code of Federal Regulations (29 CFR 1926) requires that a minimum of 200 cubic feet ($5.6634\ m^3$) of fresh air per minute ($0.0944\ m^3/s$) shall be supplied for each employee underground. This requirement has been included in the CDA Document (CRWMS M&O 1995a, DCSS 018), and is used in this MGDS ACD Report.

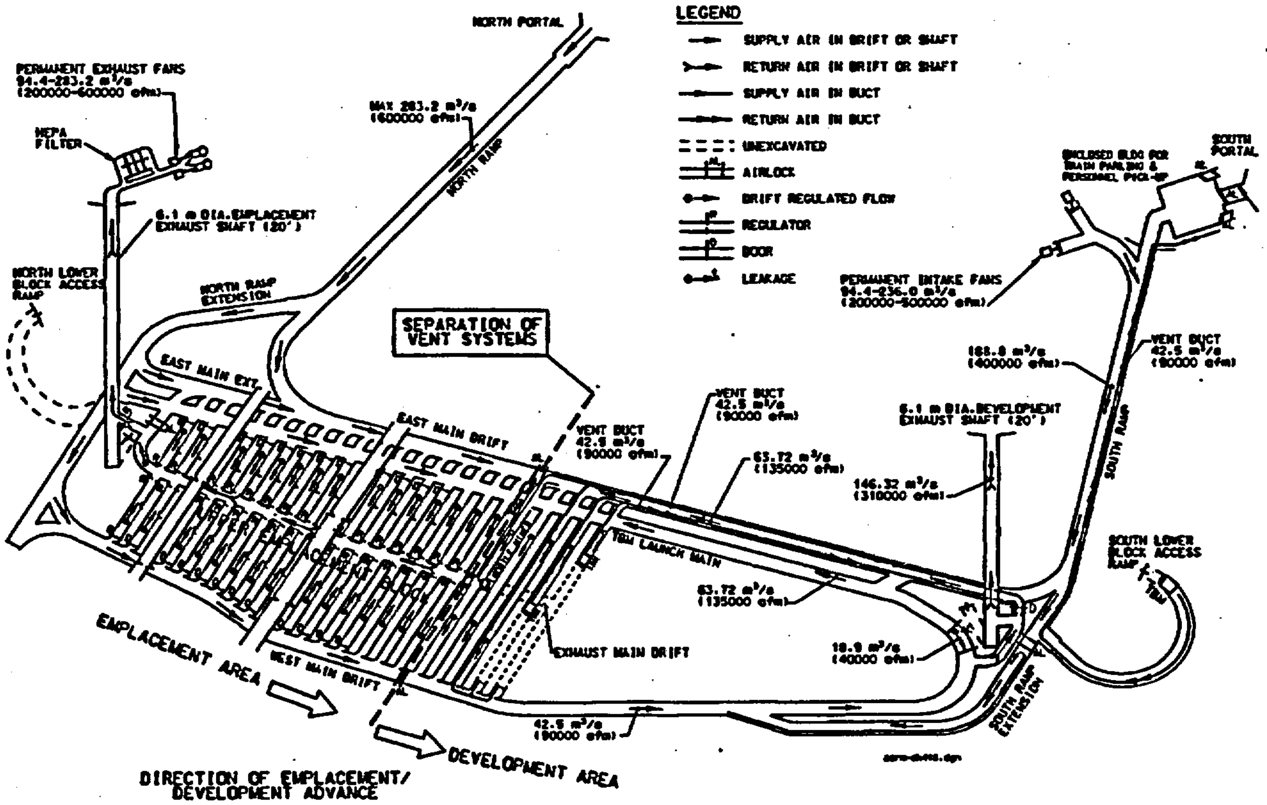

Figure 8.7.3-1. Separate Ventilation Systems for Development and Emplacement

Minimum Air Velocity in Drifts

Air velocity has very significant effects on dispersion and dilution of potential dust or contaminants in the underground work place. To achieve adequate air mixing and dilution, turbulent air flow is required. Evaluations on the critical air velocity for turbulent flow, underground field air velocity data, industrial ventilation standards, and special ventilation considerations for repository development have been performed (CRWMS M&O 1993f and CRWMS M&O 1995aq). Based on the results of these evaluations, 0.51 m/s is considered to be the minimum air flow velocity for active excavation faces and 0.31 m/s for post-excavation activities. Documentation of these minimum air velocity values can be found in the CDA Document (CRWMS M&O 1995a, DCSS 017).

Maximum Air Velocity in Drifts

Excessively high air velocities tend to raise settled dust and create other problems. Generally, the maximum allowable velocities of airflow in various underground areas are derived from dust abatement needs, fan operating costs, and comfort considerations. Maximum air velocity constraints are provided in the CDA Document (CRWMS M&O 1995a, DCSS 016). Table 8.7.4-1 lists the maximum allowable air velocity values.

Table 8.7.4-1. Maximum Velocity Constraints

Underground Area	Maximum Velocity m/s
Ramps	7.6
Ventilation Shaft	20.3
Personnel Shaft	11.7
Emplacement Drift (during construction)	3.0
Exhaust Mains	10.2
Service Mains	7.6
Waste Handling Main	7.6
Ductwork	30.5

Equipment Heat

The primary method of repository tunnel excavation will be mechanical (CRWMS M&O 1995a, Key 027). The electrically powered mechanical equipment (i.e., TBM) is the major heat source in the development area because all the electrical energy consumed is converted into either heat energy or useful work (useful work being defined in the thermodynamic sense). If the heat generated in the development area is greater than the capacity of ground or the ventilation to dissipate it, the temperature will rise. The heat energy entering the ventilation air must be considered in the air flow quantity evaluation.

Numerous methods of estimating the electrical energy dissipated as heat have been developed for underground air temperature calculations. In most literatures (e.g., Hartman, Mutmansky, and Wang 1982), it is assumed that the entire electrical energy input is converted to heat. The intention of this assumption was to provide conservative estimations of air quantity needed to maintain acceptable underground air temperature.

However, in some circumstances the air quantity estimated using this assumption could be much higher than the actual situation in the field. For example, the air quantities calculated using this assumption are about 170 m^3/s for a 5 m diameter TBM with 1,800 kW electrical power input and 208 m^3/s for a 7.62 m diameter TBM with 2,200 kW electrical power input, in order to limit the air temperature increase within 10°C (CRWMS M&O 1995ar). These estimated air quantities are much higher than the actual quantity of air being supplied to the 7.62 m diameter TBM currently excavating the ESF at Yucca Mountain. The actual field measurements at this TBM face at Station 15+00 m showed that for air flow quantities ranging from 19 to 30 m^3/s, the temperature of return air from the operating TBM face increased by less than 2°C and relative humidity increased by less than 1 percent.

Another ventilation study of a 4.6 m diameter TBM face at the San Manuel Mine in Arizona, (Calizaya, Mousset-Jones, and Casten 1995) presented the data of ventilation air from the field monitoring system. An intake air flow of 23.50 m^3/s was sent to the face by a ventilation duct, the quantity of return air from the duct outlet at the rear of the TBM was about 17.95 m^3/s. The field measurements on return air from the TBM operations that has a 2,000 kW electrical power input observed only about 2.5°C and 5.8°C increases in dry- and wet-bulb temperatures, respectively.

Based on the above discussed information, it is unlikely that large scale air temperature increases will be caused by the heat energy from the TBM operations. Furthermore, the local exhaust ventilation arrangement (as discussed in Section 8.7.4.2) will directly remove a significant portion of the TBM heat at the face. Therefore, only a very small fraction of the equipment heat will be transferred to the working areas in the drift. In this MGDS ACD Report, 10 percent of the total electrical power input of the TBM operations is considered as heat load on the air flow in the drift working areas.

Geothermal Gradient and Surface Temperature

It is stated in the RDRD (YMP 1994a) that the underground facility ventilation system shall be designed to take into account geologic conditions encountered during in situ monitoring, testing, or development of subsurface facilities, which affect air contaminant levels, temperatures, or other conditions (YMP 1994a, 3.7.5.B.5). The temperature of the virgin rock that will be excavated varies between approximately 19°C near the North Portal and 23°C at the potential repository horizon (YMP 1995a). Previous ventilation analyses (CRWMS M&O 1993e, CRWMS M&O 1994o, and CRWMS M&O 1995aq) have indicated that the wall rock will be a massive cooling media for the ventilation air passing through the excavated drifts in the development area. In these analyses a wide range of air velocities and air temperatures were evaluated and compared with the standard heat stress indices, such as a minimum power of 260 W/m^2 of human skin surface area (CRWMS M&O 1995a, DCSS 021) or a wet-bulb or effective temperature of 27°C (CRWMS M&O 1995a, DCSS

019, DCSS 020 and DCSS 029). It was determined that an acceptable temperature-humidity environment can be provided through the use of ambient air in normal quantities required for excavation. No mechanical refrigeration will be needed in the repository excavation areas.

An adequate data base of site-specific measurements at the proposed Yucca Mountain repository is not yet available. Most of the meteorological information being used by the project (YMP 1995a) has been taken from the 17-year climatological summary of regional data from the Yucca Flat weather station located approximately 40 km northeast of Yucca Mountain. Using this information, evaluations (CRWMS M&O 1994o) indicated that the daily maximum average temperatures were 31.7 to 35.6°C during the summer, and the daily minimum average temperatures were -6.7 to -3.9°C during the winter. The extreme temperatures of -25.5 and 42.2°C were recorded in the winter and summer, respectively.

The seasonal variations in surface air temperatures will have an impact on the temperatures of air flow in the repository drifts. This impact, however, is expected to be less significant in the inner underground areas than in the openings near the air intake. When the air flow travels in the drifts, the convective heat transfer into or from the wall rock will cause changes in the temperature of the air flow. Compared with the thermal energy that is needed to cause a significant temperature change in the rock mass, the change in enthalpy (heat content) of the intake air flow due to seasonal temperature variation is very small. In other words, the rock mass has such a high thermal capacitance that its temperature will not be significantly affected by the seasonal air temperature on the surface. When an air flow at a given temperature is traveling in a drift that has a different wall rock temperature, the convective heat transfer will always increase or decrease the air temperature, resulting in an air temperature that is closer to the temperature of the rock mass. If there is no other heat source/sink in the drift, the longer the distance of air travel, the smaller the difference will be between the air and the wall rock temperatures.

The massive cooling/heating capability of the rock mass was observed in the temperature data measured at the Nevada Test Site tunnels located about 40 kilometers away from the current ESF tunnel (CRWMS M&O 1994o). For the summer daily maximum average surface air temperatures of about 32 to 35°C, the average temperature measured in the working areas during summer was about 16°C. For the winter daily minimum average surface air temperatures of -7 to -4°C, the average temperature measured in the working areas during the winter was approximately 10 to 16°C.

Based on the above information and field data, it is envisioned that the seasonal surface temperature variation will not have an impact that is significant enough to justify the inclusion of surface temperature variations in the determination of air quantities in underground working areas.

Air Quantity for Special Mechanical Excavation

It is worth noting that the considerations of the minimum air velocity in the drifts were based on the principles of dilution ventilation. If special alternative excavation methods or equipment, such as roadheaders or Mobile Miners, were chosen to excavate small cutouts or specially shaped openings, ventilation for the applicable face areas may need additional considerations for dust control. Like a TBM, other types of excavation machines produce large amounts of dust during the excavation operations. The ventilating air at the working face is normally saturated with dust, and it must be removed continuously because dust may become too concentrated to allow the use of dilution ventilation for the face. The exhaust-duct system is especially effective in removing the dusty air from the working place if properly arranged. The efficiency of dust control at such locations is affected by numerous factors including generation rate and size distribution of the dust, use of water sprays, and arrangement and size of ventilation duct. Studies have shown that when exhaust ventilation with low air velocity is used at a dead-end heading, the air flow becomes almost completely non-directional and its range of influence is greatly reduced (approximately 10 percent of face velocity at one diameter away from opening of exhaust duct). Removal of dust by an exhaust duct is very effective if the velocity of the air in the extracting duct is approximately 20 m/s (CRWMS M&O 1993f). The determination of air quantity for such a heading will have to consider the duct velocity for dust capture, in addition to other ventilation considerations.

Air Quantity for Potential Use of Diesel Equipment

A determination of the suitability of diesel powered equipment is not available at the time of this MGDS ACD Report. If the option to use diesel equipment is considered desirable, the air flow quantity for diluting the combustion products from diesel equipment will be estimated on a minimum air flow rate of 0.0791 m^3/s for each kilowatt of diesel equipment operating in the underground areas (CRWMS M&O 1995a, DCSS 018).

Air Leakage and Uncertainty Allowance

A previous repository ventilation analysis (CRWMS M&O 1993f) evaluated the normal range of air leakage observed in general mining ventilation systems, the expected construction and maintenance conditions of repository ventilation ducts, and other ventilation uncertainties. An equivalent leakage factor of 20 percent was considered appropriate to conservatively account for actual air duct leakage and uncertainties, such as inaccuracy of air control devices and extra air that may be needed for local dust control. This estimated leakage factor was also used in subsequent repository ACD efforts (CRWMS M&O 1994a, CRWMS M&O 1995aq, and CRWMS M&O 1995ar). Consideration of this equivalent leakage factor (20 percent) will be included in the estimation of typical sizes of the ventilation fans in Section 8.7.9.

Estimated Air Quantity for Individual Working Areas

Based on the above-discussed air flow considerations for the construction/development areas, the required air flow quantities at each individual working place have been estimated and are summarized in Table 8.7.4-2. The values shown in the second column of the table are the minimum flow rates at which the air should be delivered to the working place in order to satisfy all the air flow requirements. The third column of the table lists the air flow quantities needed to maintain a minimum air velocity of 0.31 m/s in the excavated drifts where access is required or preparation work (for waste emplacement) is in process.

Table 8.7.4-2. Air Quantity for Individual Working Place During Development

Development Area (See Section 8.3 for Description of Drifts)	Required Air Quantity (m^3/s per workplace)	
	For Excavation Activities	For Post-Excavation Maintenance *
Emplacement Drift (5.5 m Diameter) (5.0 m Diameter)	18.78 16.90	7.37 6.09
Lower Block Exhaust Main, Upper and Lower Block TBM Launch Mains (9.0 m Diameter)	32.44	19.72
North and South Lower Block Access Ramps Lower Block Main, South Ramp Extension, West Main, North Ramp Extension (7.62 m Diameter)	23.26	14.14
Upper Block Exhaust Main Lower Block Development Shaft Exhaust Drift Miscellaneous Access and Ventilation Drifts (6.75 m x 6.75 m)	23.24	14.12
Upper Block West Side Turnouts (7.6 m x 7.0 m)	27.13	16.49
East Main/TBM Launch Main Crosscuts Lower Block Main Crosscuts (5.5 m x 5.5 m)	23.35	9.38
Development Shaft, Emplacement Shaft (6.7 m excavated diameter)	17.88	9.06
Access Drift (5.0 m x 5.0 m)	16.21	7.75
East Main Extension Miscellaneous Drifts (6.0 m x 6.0 m)	23.35	11.16

* Air flow quantities needed to maintain a minimum air velocity of 0.31 m/s in the excavated drifts where access is required or preparation work (for waste emplacement) is in process.

8.7.4.2 Ventilation System During Construction

Construction covers the excavation period prior to the start of waste emplacement. Due to potential scheduling constraints, it would not be desirable to construct the entire repository before waste emplacement begins. To facilitate simultaneous development and emplacement and maintain separate ventilation circuits, the initial excavation of the repository is needed to provide excavated underground area and sufficient major openings to the surface.

It is stated in 10 CFR 60.41 that a "*license to receive and possess source, special nuclear, or byproduct material at a geologic repository operations area may be issued by the Commission upon finding that: (a) Construction of the geologic repository operations area has been substantially completed in conformity with the application as amended, the provisions of the Atomic Energy Act, and the rules and regulations of the Commission. Construction may be deemed to be substantially complete for the purposes of this paragraph if the construction of (1) surface and interconnecting structures, systems, and components, and (2) any underground storage space required for initial operation are substantially complete*".

Based on this requirement, it is estimated that at least 26 emplacement drifts in the Upper Block need to be excavated initially (in addition to the excavated shafts and main drifts). The estimated number of drifts includes the needs of 13 emplacement drifts in each of the East and West sides of the upper block, before the repository is physically divided into two systems (development and emplacement sides).

This initial excavation can proceed in much the same manner as the development of a comparably sized mine, and can be supported by a single ventilation system. The ventilation considerations for this stage will be governed by regular underground ventilation requirements. Conceptual ventilation arrangements during the construction were evaluated for a number of typical scenarios.

Figure 8.7.4-1 shows a typical ventilation scheme that may be used to support the construction of the Upper Block West Main, Upper Block TBM Launch Main and both ventilation shafts. The intake air for this stage of development is brought through the North Ramp, then is split into the North Ramp Extension, and then is split again into the West Main and TBM Launch Main to the active TBM headings. Return air from the TBM operations is routed through a ventilation duct installed in each drift and discharged at the North Portal.

Ventilation for the mechanical excavation of both shafts, as shown in Figure 8.7.4-1, is supported by an auxiliary ventilation system operating in an exhaust mode. If drill-and-blast excavation methods were used for shaft development, a blowing ventilation system would be recommended to effectively sweep dust from the face while the ventilation duct can be positioned at an adequate distance from the face to avoid or minimize blast damage to the duct.

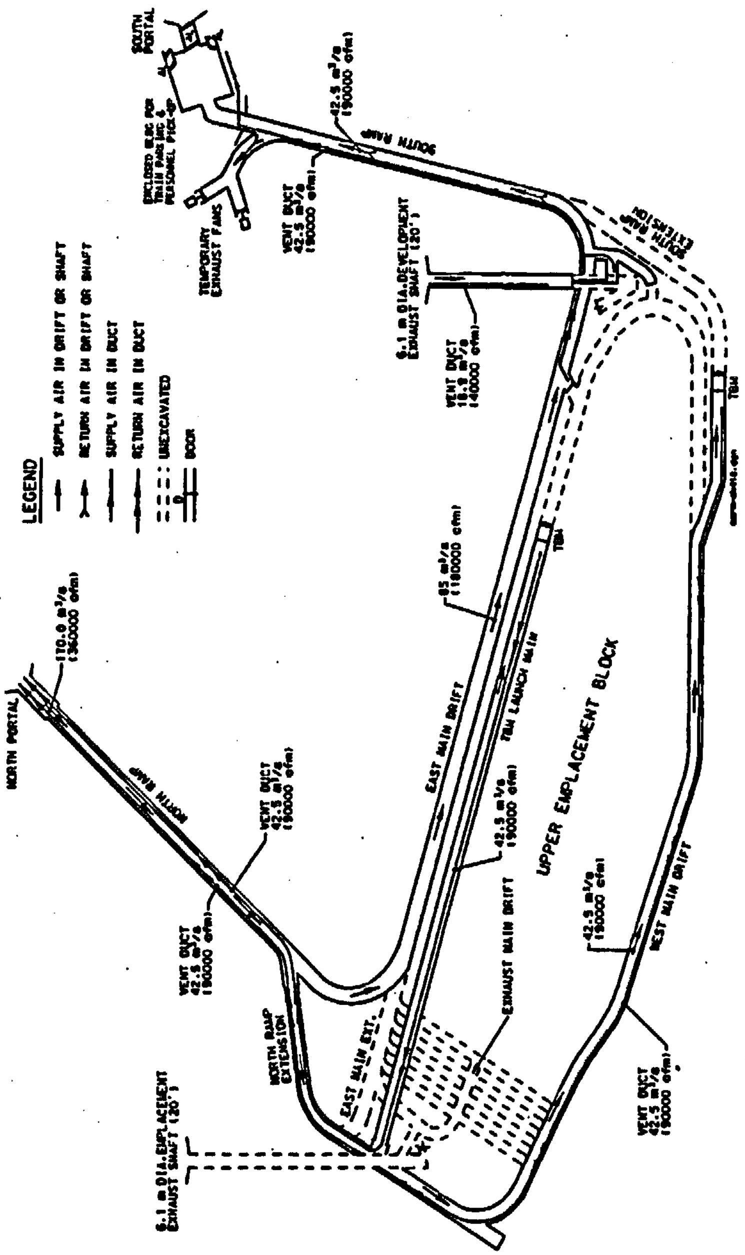

Figure 8.7.4-1. Airflow Paths During West Main, TBM Launch Main, and Shaft Construction

Figure 8.7.4-2 shows a ventlation arrangement near the completion of the major openings before the start of emplacement drift excavation. In this stage, the excavation of the East Main Extension that connects the North Ramp Extension and the East Main is supported by an air flow split from the North Ramp intake air stream. Return air from the East Main Extension excavation heading is directed into the ventilation duct extended to the North Portal. The maintenance ventilation air flow (for drift access and/or post-excavation activities) in the excavated West Main and the TBM Launch Main is supported by a temporary fan installed at the south side of the TBM Launch Main.

Figure 8.7.4-3 shows the general method that is envisioned for air flow distribution during the excavation of the first set of emplacement drifts in the upper block, prior to the start of simultaneous development and waste emplacement. In this stage of development, the shaft excavation has been completed, resulting in a total of four major openings to the surface. The intake air is brought through both South and North Ramps; return air is exhausted through both shafts. The active TBM excavation faces of emplacement drifts and crosscuts are supported by the air streams from the East Main and TBM Launch Main, which receive intake air from both South and North Ramps. Fresh air for active emplacement drifts and crosscut headings is drawn into the working ends of these drifts from the East and/or TBM Launch Mains by auxiliary fans and ventilation duct that extend to the mechanical cutting faces and that operate in an exhausting, or locally negative pressure, mode. Dusty air from the cutting zone is routed through the dust scrubbers and directly into the ventilation duct that extends to the Development Exhaust Shaft. Maintenance air flows for the North Ramp Extension and the excavated emplacement drifts are directed to the surface through the Emplacement Exhaust Shaft.

8.7.4.3 Ventilation System During Simultaneous Development/Emplacement

As indicated in Section 8.7.3, the subsurface ventilation system must be designed to separate the ventilation of excavation and waste emplacement areas. This section provides a conceptual ventilation plan utilizing two entirely independent ventilation systems for simultaneous development and emplacement.

After construction of the shafts and main drifts is complete, development of the emplacement drifts would begin, advancing from north to south, followed by emplacement.

Figures 8.7.4-4 and 8.7.4-5 show the typical arrangement of the two separate ventilation systems. One system will be used to provide air for the development of the repository while the other will be used to support the waste emplacement operations. Each system has its own primary intake and exhaust openings to the surface for the supply of fresh air and exhaust of return air. Underground openings between the two ventilation systems are sealed with isolation air locks. Once a set of emplacement drifts are developed and ready to be turned over to the emplacement system, a new set of isolation air locks is built. When these are ready and in place, the old isolation air locks are removed.

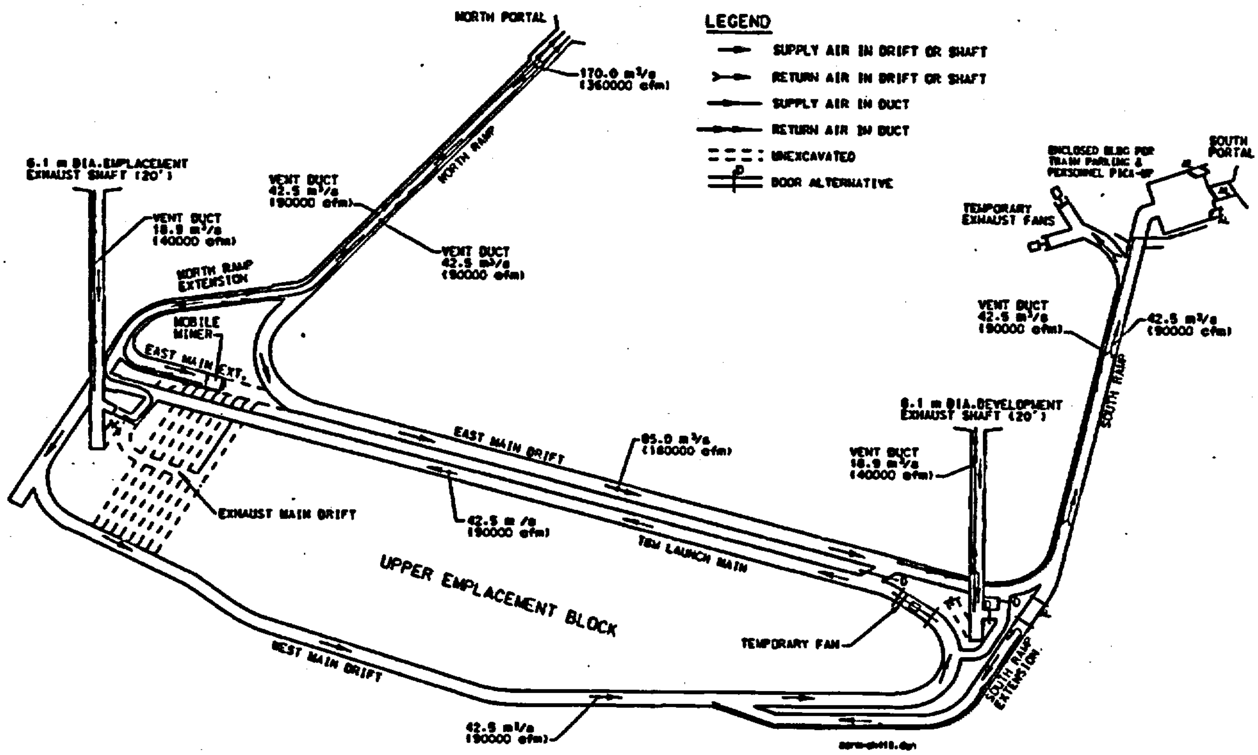

Figure 8.7.4-2. Airflow Paths Before Start of Emplacement Drift Construction

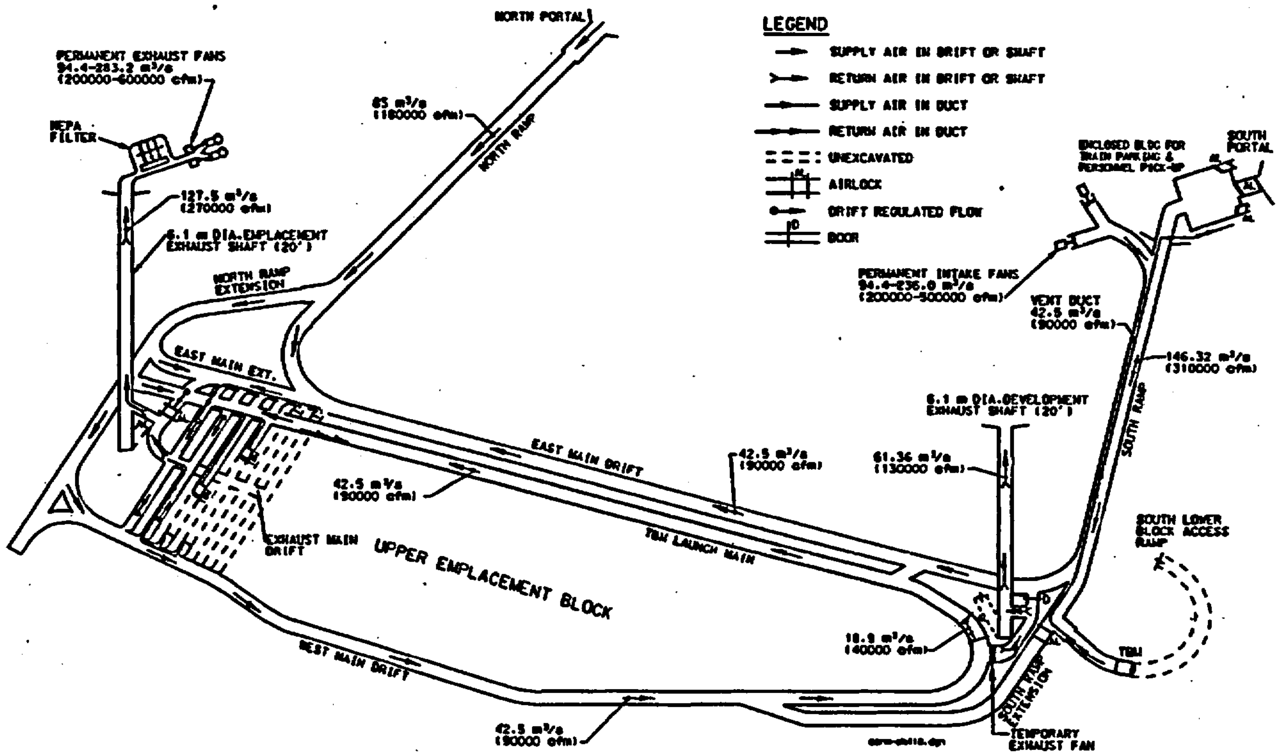

Figure 8.7.4-3. Airflow Paths During Early Emplacement Drift Construction

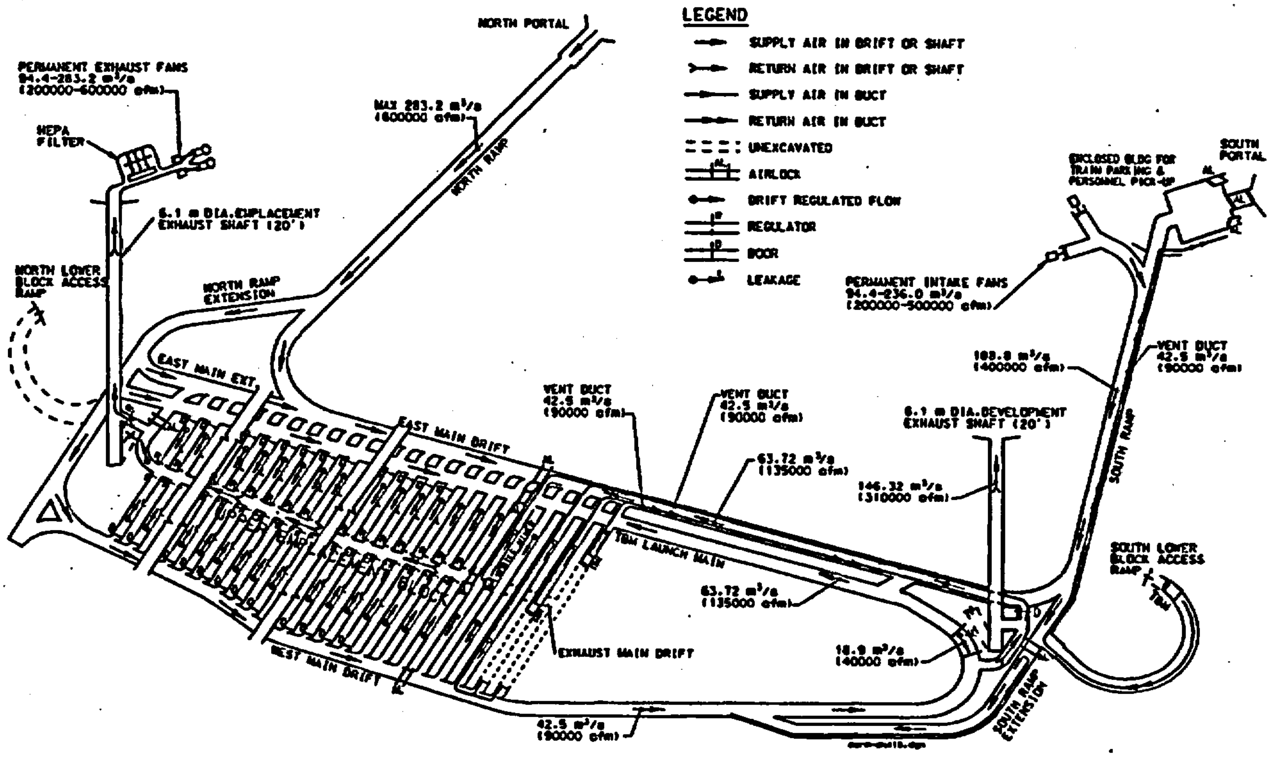

Figure 8.7.4-4. Airflow Paths During Simultaneous Development/Emplacement (Typical)

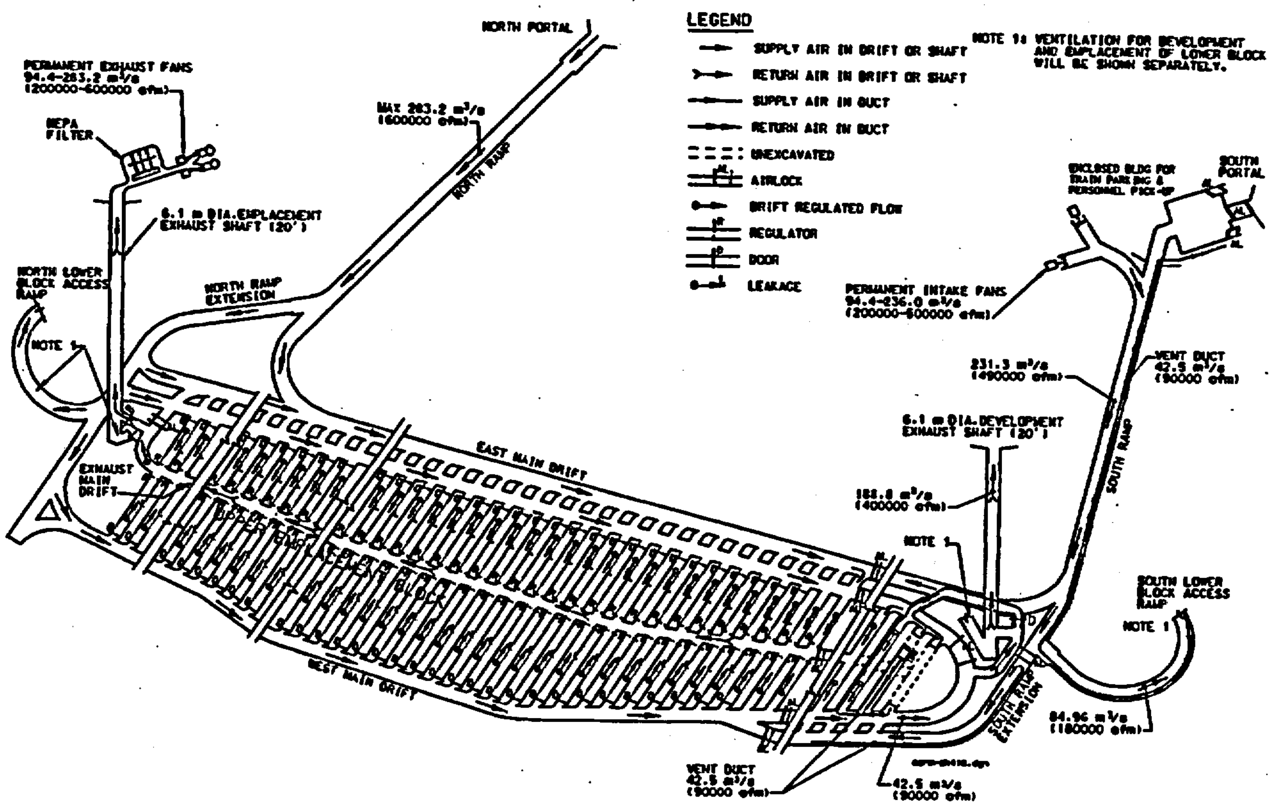

Figure 8.7.4-5. Airflow Paths During Simultaneous Development/Emplacement (For Development of Last 16 Emplacement Drifts)

The two completely independent ventilation systems basically have no operational impacts with each other except for leakage. Balancing the network, fan coordination, design and construction of ventilation control devices for independent systems requires less effort than for systems with common intake or exhaust airways. The pressure difference of the ventilating air between the two systems is created by using a primary forcing, or positive pressure, main fan(s) in the development intake (South Ramp) and using exhausting, or negative pressure, main fan(s) installed at the collar of the emplacement exhaust shaft. This arrangement is to assure that unavoidable air leakage always moves from the development to the emplacement area (YMP 1994a, 3.7.5.B.4), even if the ventilation pressure supplied by one of the systems is interrupted. If an accident occurs in one system, the other system will continue to function (YMP 1994a, 3.7.5.B.4). Also, personnel, during an emergency, have an extra choice to escape by entering the other system through the isolation air locks. It is recommended that fans, isolation air locks and doors be monitored to ensure that they operate within design limits, and pressure differences are maintained in the correct direction at all times.

In previous repository ventilation studies (CRWMS M&O 1993f, CRWMS M&O 1994a, and CRWMS M&O 1995aq), options of using the South Ramp as development exhaust or intake airway were evaluated. The feasibility of these two options was demonstrated by a few conceptual ventilation plans developed during these studies. A comparison of the advantages and disadvantages of both options was made, and it indicated that the South-Ramp-intake option has the following major advantages over the exhaust option:

A. The primary travel way to the surface is ventilated with fresh intake air;

B. The main return air can be exhausted through the shaft, thus the dispersion of potential dust/gases from the development operations can be limited in a short travel distance;

C. With fresh intake air in the South Ramp (the only foot access to surface in the development system), underground personnel will have a convenient and safe exit way during emergency;

D. It is less costly and easier to install and maintain the main ventilation fans and control devices at the South Portal than at the shaft collar, due to the remote surface location of the shaft collar;

E. With the South Ramp-intake option, the intake air has the longest travel distance before reaching the work areas, thus the impact of surface temperature variation on the face air temperature can be minimized; and

F. It is easier to remove occasional ice formation at the ramp portal than at the shaft collar.

The disadvantages of the South Ramp-intake option are the potential fire hazard of the conveyor, which will have to be minimized by adequate fire protection and conveyor monitoring systems, and the needs to have an airlock entrance at the South Portal. While having the muck conveyor in antitropal flow with the main intake airstream is likewise not desirable (a potential source of airborne dust), it was felt that sufficient mitigation (i.e., conveyor cover or alternatively, an enclosed pipe conveyor system) could be provided. If these dust control measures are found incapable of limiting the airborne dust within the acceptable range, the option of using the South Ramp as development exhaust (and Development Shaft as intake) will be considered. A conceptual ventilation layout of this alternative was developed and documented in a previous repository ventilation report (CRWMS M&O 1993f).

Figure 8.7.4-4 shows the general airflow schemes during simultaneous development and emplacement in the upper block, using the South Ramp-intake option. The intake air for the development side of operations will be brought through the South Ramp, and then split into two paths: (1) through the East and TBM Launch Mains, then entering the active TBM excavation faces of emplacement drifts; and (2) directly split into the other TBM development face for the South Lower Block Access Ramp. Fresh air for active emplacement drift headings being excavated by the TBM is drawn into the ends of these drifts from the East Main and/or TBM Launch Main by auxiliary fans and ventilation duct that extend to the TBM cutter head and that operate in an exhausting, or locally negative pressure, mode. Dusty air from the TBM cutting zone is routed through the TBM dust scrubbers and then directly into the ventilation duct that extends to the development exhaust shaft, thereby allowing personnel in both developing emplacement drifts and crosscut areas to work in fresh intake air.

Development of crosscuts for TBM launching will also be ventilated using auxiliary fans and duct that operate in an exhaust mode. Air supply for developing crosscuts is taken from the main intake air stream in the East Main where the flow contains no potential dusty air exhausted from the TBM operations; the return air from the crosscut faces exhausts through ventilation duct, which is connected to the Development Exhaust Shaft.

Figure 8.7.4-4 also illustrates a conceptual arrangement of the ventilation system for the upper block emplacement area. Ventilation intake air for the emplacement side of operations is supplied via the North Ramp, and then split into two flow paths:

- Through the East Main and TBM Launch Main, then entering the active and standby emplacement drifts on the east side

- Through the North Ramp Extension, into the West Main, and then entering the active and standby emplacement drifts on the west side.

Return air from the emplacement area is directed into the central Exhaust Main, and exhausted through the Emplacement Exhaust Shaft. If an accident were to result in the release of radionuclides, the return air would be routed through a bank of HEPA filters before being discharged into the atmosphere. The conceptual filtration (HEPA) system is discussed in Section 8.7.7.1.

Figure 8.7.4-5 shows a ventilation arrangement concept for the development of the last 16 emplacement drifts located at the south end of the upper emplacement block, where the excavation operation will be changed to launch TBMs from the west end of the emplacement drifts. The intake air for the development side of operations will be brought through the South Ramp, and then split into two paths:

- Through the East Main, into the East Main/TBM Launch Main Connector Drift, and into two or more excavated emplacement drifts (awaiting turnover to emplacement operations) that deliver the fresh air to the nearby TBM Launch Main and West Main

- Directly through the South Lower Block Access Ramp delivering air flow to the lower emplacement block development activities.

Fresh air for active emplacement drift headings being excavated by the TBMs is drawn into the ends of these drifts from the West Main by auxiliary fans and ventilation duct that extend to the TBM cutter head and that operate in a locally negative pressure mode. Dusty air from the TBM cutting zone is routed through the TBM dust scrubbers and then directly into the ventilation duct that extends to the Development Exhaust Shaft.

Figures 8.7.4-6 through 8.7.4-9 are the computer outputs illustrating the air flow quantity and pressure distributions of a typical ventilation scenario (shown in Figure 8.7.4-4) during simultaneous development and emplacement. The results were obtained from ventilation network simulations using the VNETPC software described previously in Section 3.1.3. The VNETPC is capable of modeling ventilation network balance and predicting air flow rates, airway resistances, frictional pressure drops, air power losses and electrical power costs for ventilation of each air path; air pressure at each network junction; fan operating points (air pressure and flow rates), and air regulators and/or boosters fans (if needed). Although the network balance in this model is based on simplified incompressible flow, the mass flow rates of air obtained from the network simulations will be the bases for in-depth ventilation analyses. With the established mass flow rates, the effects of air temperature change (caused by elevation difference, surface seasonal variation and underground heat sources) on the air flow volume can be further evaluated. The results of the evaluation can be used in finalizing the selection of ventilation equipment. The calculations used the friction factors for ventilation air flows in various drifts listed in the CDA Document (CRWMS M&O 1995a) (DCSS 022). Units on Figures 8.7.4-6 through 8.7.4-9 are English, therefore, English units are included, along with metric, in the discussions of these figures.

Figure 8.7.4-6 is an example of typical air flow quantity distribution during the simultaneous development and emplacement operations. The air pressure distribution for this typical scenario is shown in Figure 8.7.4-7. The development ventilation system delivers a total air flow quantity of about 210 m^3/s (445,200 ft^3/min) to the development area, at a pressure of approximately 1,296 Pa (5.215 in.w.g). The total air flow rate and pressure for the emplacement ventilation system are about 160 m^3/s (338,700 ft^3/min) and 617 Pa (2.480 in.w.g), respectively. In this scenario, the pressure differences between the development and emplacement areas (at the isolation air locks) range from 189 to 531 Pa (or 0.758 to 2.135 in.w.g), depending on the location of the isolation air locks.

Figures 8.7.4-8 and 8.7.4-9 show the maximum capacity of the ventilation systems during a stage of simultaneous development and emplacement operations. The maximum air flow quantity that can be delivered to the development area is about 238 m^3/s (520,500 ft^3/min), with a total pressure of 1,820 Pa (7.321 in.w.g). A total air quantity of up to 292 m^3/s (617,900 ft^3/min) can be supplied to the emplacement area, with a total pressure loss of 2,025 Pa (8.146 in.w.g) or less. The maximum differences of air pressure between the development and emplacement areas (at the isolation air locks) range from 507 to 959 Pa (or 2.041 to 3.856 in.w.g), depending on the location of the air locks.

Results in Figures 8.7.4-6 through 8.7.4-9 indicate that ventilation network balance and desired air flow distribution can be achieved using the above proposed concept (or other identical concepts) of ventilation system arrangement.

8.7.5 Emplacement Ventilation System

The ventilating air in the emplacement drifts is planned to flow in the direction opposite of the sequence of waste package placement. This arrangement assures that the emplacement operations are performed at a location upstream of the emplaced packages, and surrounded by fresh intake air. However, during the emplacement of waste packages, heat released from the waste packages will increase the temperature of the surrounding rock and air flowing in the emplacement drifts. The impact of heat load on the ventilating air flow, especially on the return air streams, needs to be evaluated in addition to the considerations of ventilation for conventional underground operations.

8.7.5.1 Emplacement Drift Temperatures During Emplacement Activities

Emplacement drift temperature during ventilation is a complex function of the air flow rate, time of cooling, drift configuration, rock properties, heat load, and emplacement mode. This transient state heat transfer process involves thermal conduction, convection and radiation. An understanding is needed of the heat transfer processes in order to quantify the heat flow rates due to different mechanisms coupled in the process and to determine the resulting temperatures. The rates of thermal convection, conduction, and radiation can be described by Newton's cooling law, Fourier's conduction law and the Stefan Boltzmann law, respectively. However, determination of these rates requires known temperatures of the waste package surface and airflow, and rock temperature gradient. These variables (temperatures) are all time-dependent and coupled throughout the process. Therefore, they have to be determined simultaneously. By using the energy conservation law these variables can be correlated, but analytical solutions are not possible because the number of equations available is less than the number of variables involved. A methodology for reaching approximate solutions was developed during the ACD efforts (CRWMS M&O 1995as and CRWMS M&O 1995at).

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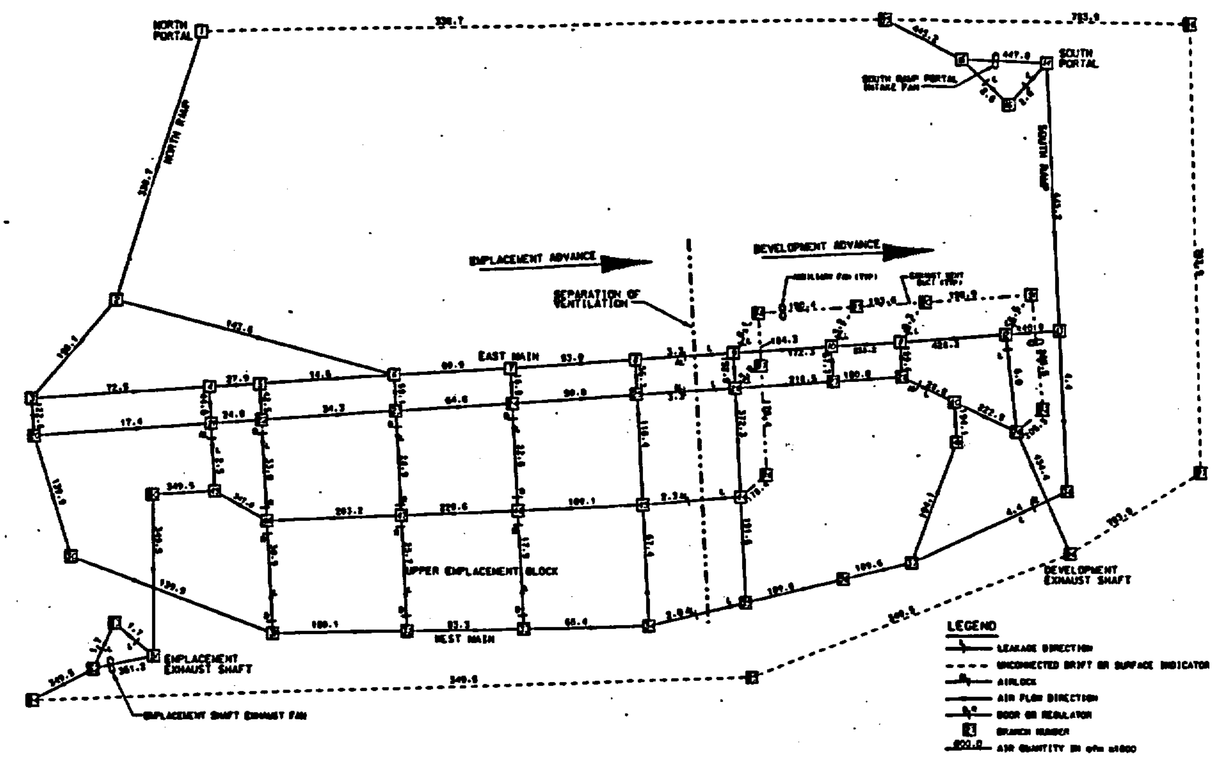

FIGURE 8.7.4-6 EXAMPLE OF TYPICAL AIR FLOW DISTRIBUTION DURING SIMULTANEOUS DEVELOPMENT AND EMPLACEMEMT
(SOFTWARE: VNETPC VERSION 3.1)NETWORK SCENARIO AS SHOWN IN FIG. 8.7.4-4)

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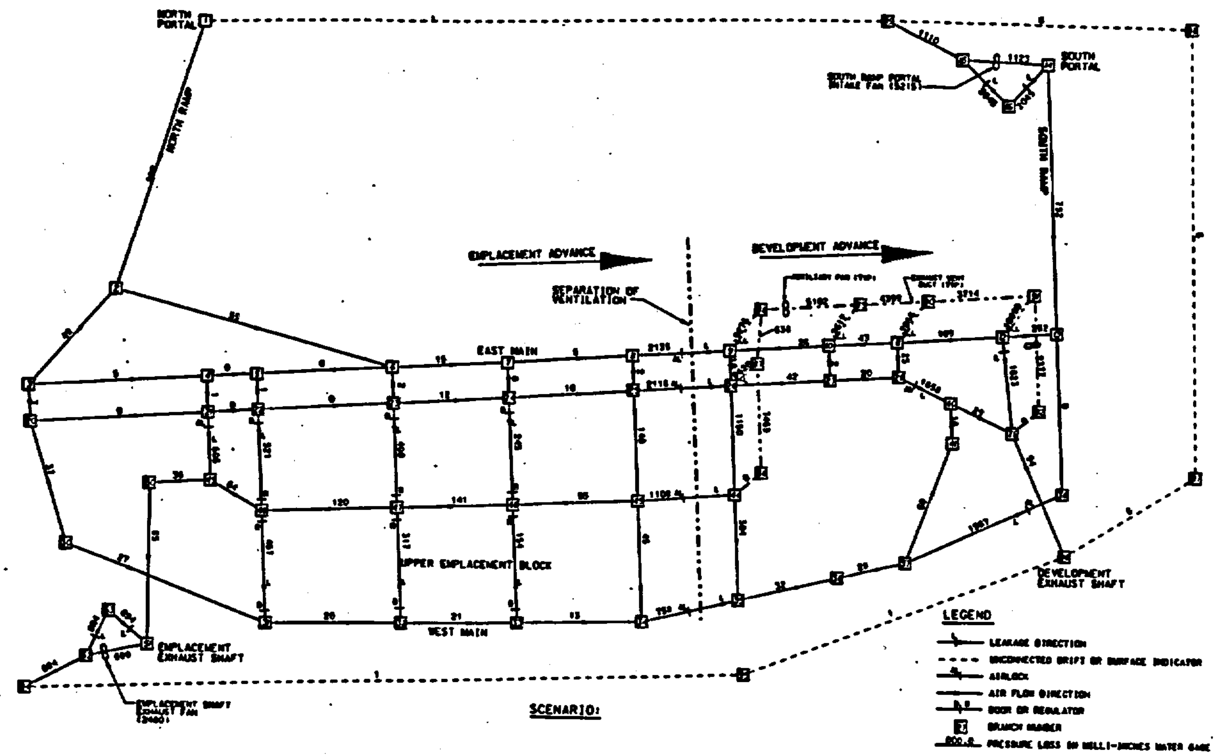

FIGURE 8.7.4-7 EXAMPLE OF TYPICAL AIR PRESSURE DISTRIBUTION DURING SIMULTANEOUS DEVELOPMENT AND EMPLACEMEMT
(SOFTWARE: VNETPC VERSION 3.1;NETWORK SCENARIO AS SHOWN IN FIG. 8.7.4-4)

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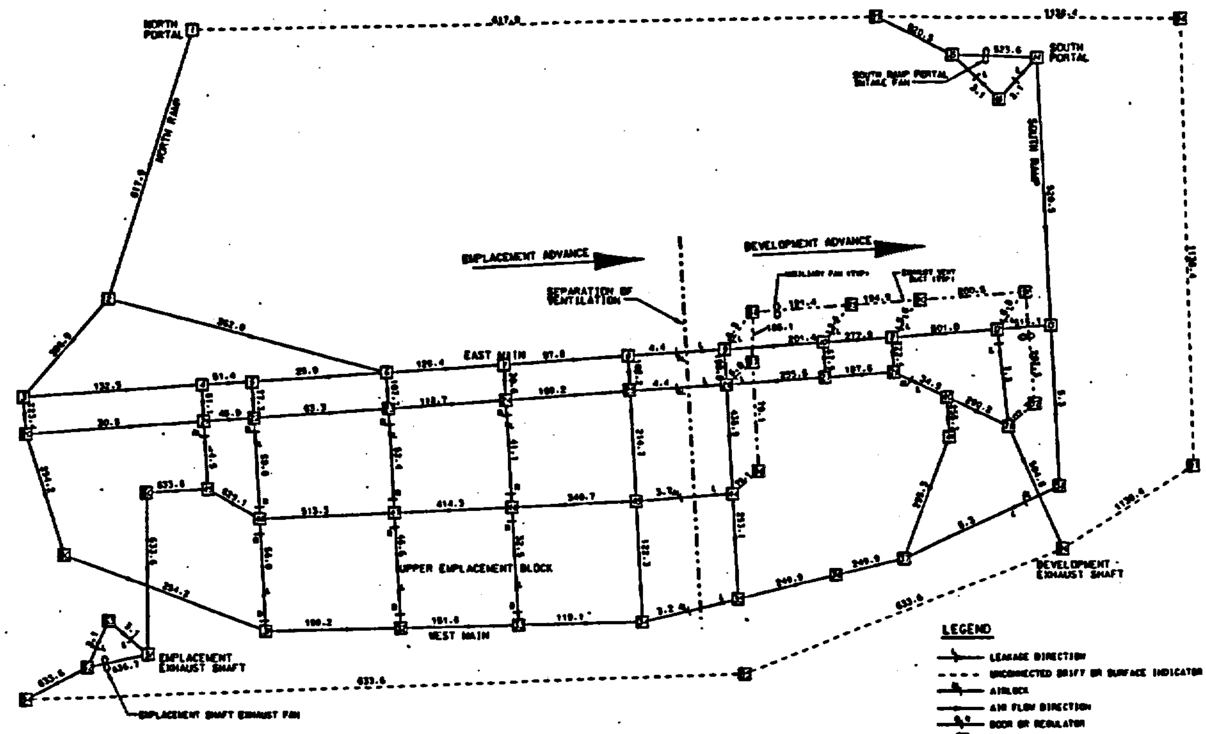

FIGURE 8.7.4-8 MAXIMUM AIR SUPPLY CAPABILITY OF VENTILATION SYSTEM DURING SIMULTANEOUS DEVELOPMENT AND EMPLACEMEMT
(SOFTWARE: VNETPC VERSION 3.1;NETWORK SCENARIO AS SHOWN IN FIG. 8.7.4-4)

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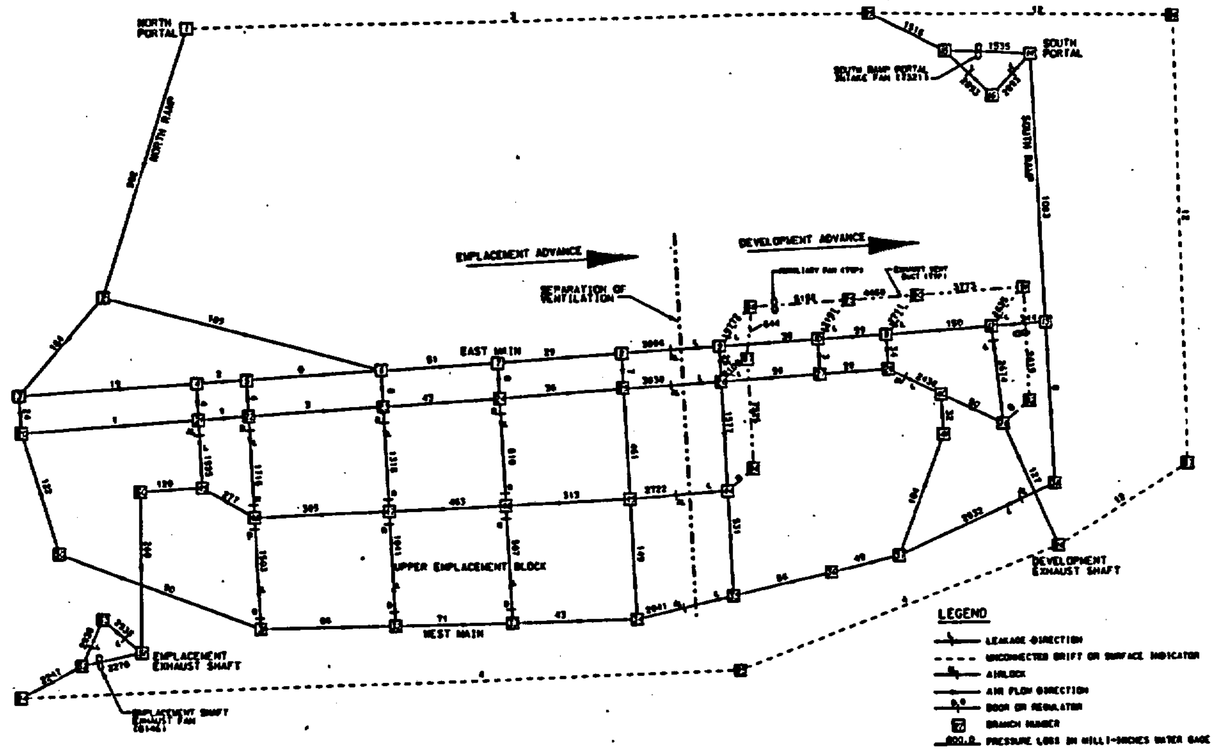

FIGURE 8.7.4-9 AIR PRESSURE DISTRIBUTION AT MAXIMUM AIR FLOW RATES DURING SIMULTANEOUS DEVELOPMENT AND EMPLACEMEMT
(SOFTWARE: VNETPC VERSION 3.1:NETWORK SCENARIO AS SHOWN IN FIG. 8.7.4-4)

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This method for performing the heat flow and temperature calculations treats a ventilated emplacement drift as a series of finite drift segments, and considers the entire ventilation time period as a number of short time-steps. With this approach, the temperature of air traveling in a drift segment within a short time span can be reasonably represented by a constant, which is required as a boundary condition by general thermal analysis software. Thermal analysis with the ANSYS computer code (described in Section 3.1.3) was performed for each drift-section sequentially from the beginning to the end of the drift. Outputs from a drift segment at a given time-step were used as inputs and initial conditions of the calculations for the next drift/time step. Detailed description of this approach has been documented in (CRWMS M&O 1995as). Due to the complex thermal processes involved, quantifying the ventilation effect requires substantial numerical computation. Evaluations performed to date considered only a limited number of scenarios of emplacement drift ventilation. Some preliminary results have been described in Section 8.7.1.

The range of the maximum air temperature in the emplacement drift during waste emplacement activities can be estimated using the energy conservation law and the calculation method described in previous ventilation work (CRWMS M&O 1993f). Figure 8.7.5-1 shows the maximum emplacement drift temperatures for various ventilation scenarios. The results are based on using a thermal loading of 83 MTU/acre (CRWMS M&O 1995a, Key 019), 630 m long drift emplaced with 21 PWR packages, and a package spacing of about 19 m. It demonstrates that when reasonably high air flow quantities (20 to 40 m^3/s per drift) are supplied to the emplacement drift, the maximum air temperatures in the drift would be in the range of about 33 to 40°C, even if 100 percent of the total waste heat is assumed to enter the air stream. In reality, only a portion of the waste heat can be transferred into the air flow; therefore, the drift air temperatures are expected to be lower than the above mentioned temperature range. An estimate of actual heat energy entering the air flow will be discussed in the next section, together with the evaluation of the emplacement drift air quantity during waste emplacement.

8.7.5.2 Air Flow Quantity for Emplacement Activities

Air quantity required for emplacement drift temperature control is dependent upon the amount of heat energy transferred into the air flow during the active waste emplacement period (about 1-2 months per drift). Unfortunately, most information on emplacement drift ventilation developed to date was concerned with the ventilation effects for long terms, such as a 100-year ventilation period. The short term ventilation effects were evaluated only for the first year of emplacement drift ventilation (CRWMS M&O 1995as). The evaluation was performed for a 100 MTU/acre thermal loading, a 1,200 m long drift, 21 PWR packages, a 22.5 m drift spacing, and a 16 m package spacing. Only two air flow rates (2 and 10 m^3/s per drift) were used to analyze the heat transfer process during the first year of ventilation. The results for the first 600 m of the drift showed that for an air flow of 2 m^3/s, about 24.4 percent of total heat generated by the waste in the drift can be removed by ventilation, and the maximum air and rock wall temperatures were about 67 and 76°C, respectively. If the air flow rate were increased to 10 m^3/s, the heat removal rate would increase to 64.7 percent, and the maximum air and rock wall temperatures would be reduced to approximately 45 and 57°C, respectively.

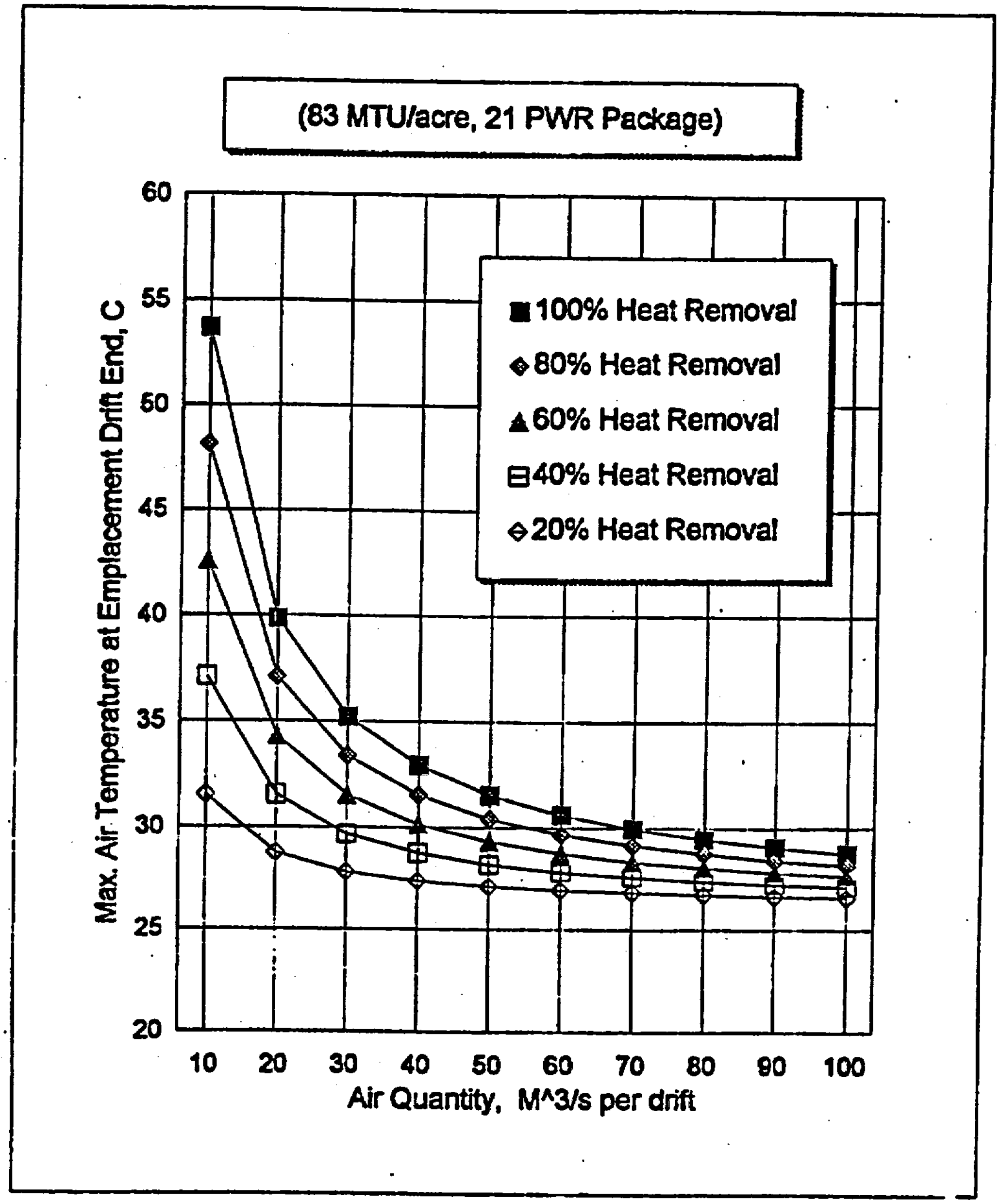

Figure 8.7.5-1 Emplacement Drift Air Temperature During Emplacement Activities

In Section 8.7.4.1 (Table 8.7.4-2), it is calculated that the minimum air flow rates to maintain the minimum air velocity of 0.51 m/s in the 5.5 m diameter drift during active excavation is 18.78 m^3/s. It is considered that during emplacement activities, this air flow rate will be needed to support equipment operations. From the above discussed results of heat removal by ventilation (at 2 and 10 m^3/s per drift), it is estimated that when the emplacement drift is ventilated at a significantly higher flow rate (18.78 m^3/s), about 80 percent of the total heat generated by the waste packages in the drift will be entering the ventilation air through convective heat transfer. Under this circumstance, the maximum air temperature in the drift (at the drift exit) is expected to be 37.8°C. For the worst case scenario (in terms of air temperature increase) in which 100 percent of the total heat is transferred into the ventilation air, the maximum air temperature will be less than 41°C, which is below the maximum allowable air temperature (50°C) in emplacement drifts during emplacement (CRWMS M&O 1995a, DCSS 019). Therefore, the minimum required air quantity for an active emplacement drift is considered to be 18.78 m^3/s.

In order to emplace the waste packages in a timely manner, emplacement may have to proceed in two drifts at a given time to allow for delays in the operation. Maintenance ventilation for this "standby drift" needs to considered. Since no operations are expected in the standby drift, air velocities higher than 0.31 m/s are considered adequate to maintain accessibility (CRWMS M&O 1995a, DCSS-017). The air quantity to satisfy this requirement in a drift diameter of 5.5 m is determined to be 7.37 m^3/s. For a 5.0 m diameter drift, 6.1^{3}m /s is required for maintenance ventilation.

If a delay in emplacement were to occur in a drift, the air flow in that drift will be maintained at 18.78 m^3/s or higher to limit the increase of emplacement drift temperature, and a standby drift could be used as a new emplacement drift and ventilated at the required flow rate for emplacement.

In the late stages of waste emplacement (shown in Figure 8.7.4-5), the emplacement operations will occur in the emplacement drifts near the south end of the repository. The intake air to active emplacement drifts will have to travel a very long distance in the main drifts before reaching the emplacement operations. A significant part of the intake air may be "lost" through leakage to the previously emplaced drifts, due the large number of emplacement drifts connected with the intake airways. The required total air flow volume must be adjusted upward to account for this volume loss and ensure adequate flow to the active area.

8.7.5.3 Ventilation After Completion of Waste Emplacement

After the completion of the simultaneous development and emplacement activities, the barriers which separate the emplacement and development systems will be removed. The maintenance ventilation in the main drifts can be provided by a single ventilation system.

Figure 8.7.5-2 is a conceptual arrangement of the air flow paths throughout the main drifts during the caretaker period. The intake air for the upper block is brought through the North Ramp and then split into two paths:

- Through the East Main, then into the East Main/TBM Launch Main Connector Drift
- Through the North Ramp Extension, then entering the West Main.

Ventilation for the East Main Extension is maintained by an air flow split off the North Ramp Extension airstream. The return air from the TBM Launch Main, East Main and West Main is directed into the central Exhaust Main and exhausted to the surface through the Emplacement Exhaust Shaft.

The maintenance air flow paths for the main drifts in the lower block are also demonstrated in Figure 8.7.5-2. The primary intake air for the lower block is brought from the South Ramp, then directed into the South Lower Block Access Ramp. The Lower Block TBM Launch Main receives air from the Lower Block South Access Ramp. The return air flow of the lower block is exhausted through the Lower Block Exhaust Main which is connected to the Emplacement Exhaust Shaft.

Ventilation for the North Lower Block Access Ramp is maintained by an air flow split off the North Ramp Extension airstream. This air flow will continue to travel to the lower block, and then return to the Emplacement Exhaust Shaft through the Lower Block Exhaust Main.

During the caretaker ventilation period, the Development Exhaust Shaft is arranged to function as a back up intake shaft. It provides ventilation to the Lower Block/Development Shaft Connector Drift during normal maintenance (i.e., inspection and monitoring) activities. If a significate increase in air quantity (for potential emplacement drift cooling or waste retrieval) is required, this back-up shaft can be utilized as an additional major intake airway.

8.7.6 Retrieval Ventilation System

The RDRD (YMP 1994a) requires that the option to retrieve the waste inventory must be maintained (YMP 1994a, 3.2.1.4.B; CRWMS M&O 1995a, Key 016 and 017). To satisfy this objective, the repository underground ventilation system must be designed to maintain the ability to support the waste retrieval activities that may be required.

8.7.6.1 Pre-Retrieval Temperatures of Emplacement Drift

Providing access to emplacement drifts has been identified as the first step in the sequence of subsurface retrieval operations (CRWMS M&O 1994a). A primary concern with respect to emplacement drift access is to ensure that the climate conditions within the drifts will not be so severe as to cause reentry to be impractical. The CDA Document (CRWMS M&O 1995a) specifies that the air temperature in emplacement drifts during retrieval operations shall not exceed 50°C (CRWMS M&O 1995a, DCSS 019). To satisfy the temperature requirement for retrieval activities, ventilation may be utilized to control the emplacement drift temperatures. Since air quantity and

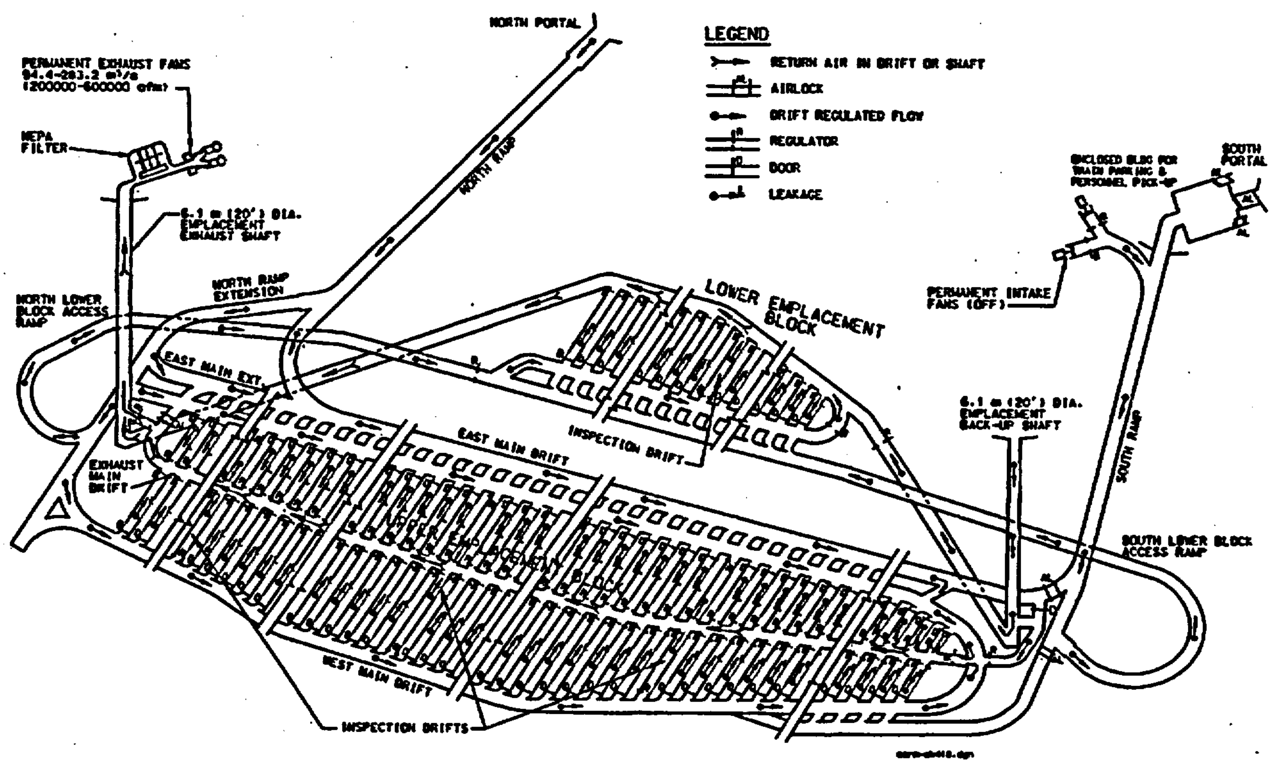

Figure 8.7.5-2. Conceptual Airflow Arrangement During Caretaker Period

time of ventilation needed to provide an acceptable environment will vary significantly with the initial conditions at the beginning of retrieval preparation, it is important to evaluate and identify the pre-retrieval temperatures of emplacement drifts.

The pre-retrieval temperature of emplacement drifts could be significantly affected by the following factors:

Elapsed time from emplacement to start of waste retrieval. After emplacement of the waste packages in an emplacement drift, heat transfer from the waste packages will raise the temperature of the surrounding rock. During this process, the amount of heat exchange and emplacement drift temperature will vary, due to continuous variations in both waste thermal output and heat transfer conditions in the vicinity of the drift. This means that retrieval activities starting at different times would expect to experience different emplacement drift temperatures.

Thermal loading. Rock temperature distributions in the vicinity of emplacement drifts will also vary with different thermal loadings. Several thermal models performed for unventilated emplacement drifts (CRWMS M&O 1995as) have shown that for an areal mass load of 100 MTU/acre, peak drift wall temperatures of 170 to 179°C occurs at 67 to 87 years after emplacement, depending on drift and package spacings. An evaluation for 83 MTU/acre predicted the maximum drift wall temperatures of about 153°C at 52 years after emplacement. These significant differences in both drift-wall temperature and time of occurrence may require different ventilation or cooling capacities if drift reentry for waste retrieval becomes necessary.

Ventilation options. Emplacement drift ventilation may be applied to control the drift temperature. An example presented in previous work (CRWMS M&O 1995at) indicated that if an airflow of 2 m^3/s is used to continuously ventilate emplacement drifts loaded at 100 MTU/acre, about 51 percent of the total heat generated from the waste emplaced in the drift during the preclosure period can be removed. As a result, the magnitude and distribution of the drift temperature would change significantly as compared with the no-ventilation case. The drift temperatures at the beginning of retrieval for previously unventilated and ventilated drifts can be quite different. This indicates that different cooling capacities may be needed to provide acceptable environmental conditions for retrieval activities.

Taking these factors into account, and based on the maximum retrieval period of 100 years, the pre-retrieval temperature conditions in the emplacement drifts have been evaluated for potential retrieval operations at a number of selected times after initial emplacement. Results for various thermal loading scenarios are documented in (CRWMS M&O 1995am).

For the reference thermal load of 83 MTU/acre (CRWMS M&O 1995a, Key 019), the pre-retrieval temperature conditions in unventilated emplacement drifts are described in Figure 8.7.6-1. The thermal analysis models were performed using the ANSYS computer code described previously in

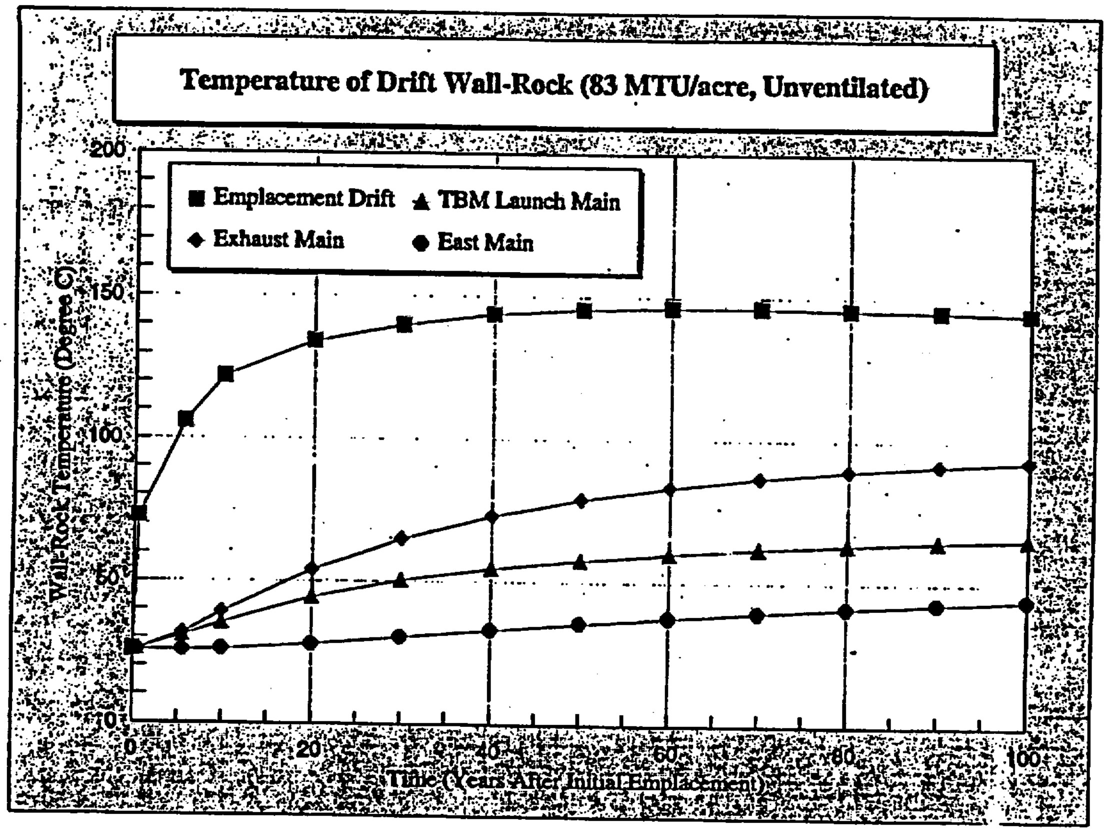

Figure 8.7.6-1. Temperature of Drift Wall Rock (83 MTU/acre, Unventilated Emplacement Drifts)

Section 3.3. Input data were listed in Section 8.7.2.2 (CRWMS M&O 1995a, Key 004, Key 011, EBDRD 3.7.1.J.1, DCSS 015, TDSS 004, TDSS 005 and TDSS 006). Table 8.7.6-1 summarizes the pre-retrieval emplacement drift temperatures at various start times for waste retrieval. These temperature values will be used as a part of the initial conditions for the analysis of emplacement drift blast-cooling in Section 8.7.6.3.

8.7.6.2 Pre-Retrieval Temperatures of Main Drift

The main drifts in the upper block of the repository are the East Main and West Main, TBM Launch Main, and Exhaust Main. In the lower block, the main drifts include the Main, TBM Launch Main, and Exhaust Main.

While few studies have been performed to evaluate the main drift temperature as a function of thermal loading and standoff distance, past repository layouts, such as in the SCP-CDR Report (SNL 1987), have allowed standoff assuming no credit for ventilation to limit the access drift wall temperature to less than 50°C for the first 50 years after waste emplacement. A summary of previous work in this area shows that acceptable standoff distances for vertical borehole and horizontal borehole emplacement concepts range between 28 and 41 m for thermal loadings of approximately 70 to 100 kW/acre (CRWMS M&O 1994a).

Table 8.7.6-1. Pre-Retrieval Temperature of Unventilated Emplacement Drift (83 MTU/acre)

Time to Start of Retrieval (Yr*)	1	5	10	20	30	40	50	60	80	100
Maximum Drift Temperature, °C	97	124	137	146	149	152	153	152	151	149

* Years after initial waste emplacement for a given drift.

An evaluation of unventilated main drift temperatures performed for thermal loadings of 111 and 55 MTU/acre and standoff distance of 44 m, was performed using the V-TOUGH computer code (CRWMS M&O 1994p). The results show that for a thermal loading of 55 MTU/acre, the main drift wall temperature will be below 50°C for 90 years after waste emplacement, and then will increase to 52°C at 100 years. For a thermal loading of 111 MTU/acre, the main drift wall temperature will be below 50°C for 45 years after waste emplacement, and then will increase to 98°C at 100 years. If the results are interpolated for 100 MTU/acre, the main drift wall temperature will be below 50°C for 48 years after waste emplacement, and then increases to 89°C at 100 years.

Results of the recent evaluations on the unventilated main drift temperature for 83 MTU/acre are shown in Figure 8.7.6-1. The temperatures increase from about 26°C at initial emplacement for all main drifts to about 44°C in the East Main, 66°C in the Upper Block TBM Launch Main, and 93°C in the Upper Block Exhaust Main, at 100 years after the start of initial waste emplacement.

It is emphasized that the model results mentioned above did not consider the cooling effect of ventilation air in the main drifts. In fact, ventilation is expected to be maintained in main drifts throughout the entire preclosure period, and a significant amount of heat could be removed by the ventilation air flow. This would significantly reduce the temperature of the main drift walls. An example for 100 MTU/acre thermal load in the *Retrieval Conditions Evaluation* (CRWMS M&O 1995am) demonstrated that the normal ventilation maintained in the main drift can easily remove sufficient heat from the drift wall such that the drift temperature is maintained at 50°C or less.

8.7.6.3 Cooling Analysis for Emplacement Drift

When a drift emplaced with waste is unventilated for an extended period ranging up to 100 years, the heat transfer from the waste to the surrounding rock, mainly through conductive and radiative processes, will cause a large scale increase in drift wall and rock mass temperatures. This is because the drift has been sealed from ventilation and almost all of the energy released from the waste is transferred to its surroundings. As shown previously in Table 8.7.6-1, the pre-retrieval temperatures in an unventilated emplacement drift are expected to be significantly higher than the temperature limits (50 °C) required for equipment access to perform retrieval activities (CRWMS M&O 1995a, DCSS 019). Therefore, emplacement drifts must be cooled prior to drift reentry. Cooling the previously unventilated drifts with large quantities of ambient air just prior to drift reentry is referred to as blast cooling, rapid cooling, or forced-air cooling.

The key factors regarding the feasibility of blast cooling are the required cooling time, air flow rate, and elapsed time to start of blast cooling. During the ACD efforts, blast cooling effects have been evaluated for various thermal loads, air flow quantities and elapsed times to start of cooling. The methods developed for blast cooling analysis and results of these evaluations were presented in several documents (CRWMS M&O 1993f, CRWMS M&O 1994a, CRWMS M&O 1995aq, and CRWMS M&O 1995am).

Figure 8.7.6-2 shows the required time to blast cool previously unventilated emplacement drifts loaded at 83 MTU/acre. The required cooling times were calculated for various air flow quantities (20 to 200 m^3/s) and different elapsed times to start of blast cooling (1 to 100 years after initial waste emplacement). It is shown in the figure that for given air flow quantities, shorter cooling times are required for retrieval starting either within 5 years after waste emplacement (when less heat is stored in the rock), or within the last 40 years of the retrievability period (when waste package heat output has been significantly reduced). Longer cooling times are required for retrieval starting between 10 and 50 years. For an air flow rate of 20 m^3/s or less, it is impossible to reduce the air temperature at drift exit to 50°C within a reasonable cooling time. Feasible ranges of air quantities and cooling times to accommodate practical retrieval schedules are summarized for the three cases evaluated:

Air Quantity (m^3/s)	Cooling Time (Weeks)
40	2.9 - 12.1
60	0.8 - 3.1
80	0.4 - 1.4

Figure 8.7.6-2 also shows that very high air flow rates (~100 - 200 m^3/s) may also be used if a cooling time shorter than 1 week is determined to be necessary. As a point of reference, a flow of 200 m^3/s in a 5.5 m diameter drift containing average obstruction would have a velocity of about 9.5 m/s (21 miles/hour)

The above discussed air quantities and times for blast cooling are based on an 83 MTU/acre case, in which the pre-retrieval temperatures of unventilated emplacement drifts vary from 97 to 153°C during the retrieval period (Table 8.7.6-1). If the maximum allowable emplacement drift temperature of 200°C (CRWMS M&O 1995a, DCSS 023) were considered in the blast cooling calculations, the cooling times would be about 33.6 to 105 weeks for an air flow of 40 m^3/s, 7.6 to 12.1 weeks for 60 m^3/s, 3.3 to 4.4 weeks for 80 m^3/s, and 1.8 to 2.3 weeks for 100 m^3/s.

Effects of refrigerating inlet air for blast cooling have been evaluated for a wide range of air flow rates: 20 - 250 m^3/s (CRWMS M&O 1995aq). It is observed that refrigerating intake air can significantly reduce required cooling time or airflow rate, but is inefficient as far as power consumption is concerned.

8.7.6.4 Air Flow Arrangement for Retrieval Activities

If waste retrieval becomes necessary, ventilation of emplacement drifts is needed to control the drift temperature during the pre-retrieval preparation and retrieval operations. The supply of air to the emplacement drift is expected to be similar to the normal ventilation circuitry arranged for emplacement activities shown in Figure 8.7.4-4. Since the main drifts will be ventilated at all times, the option to provide ventilation for retrieval of waste packages is always available during the 100-year retrievability period. The required quantity of air flow for blast cooling will be directed to the emplacement drift, exhausted through the central Exhaust Main Drift and returned to the surface through the Emplacement Exhaust Shaft. This arrangement allows the equipment (or personnel in off-normal scenario) performing the retrieval activities to be in the up-stream fresh air of the emplacement drift. In case of off-normal conditions when particulate radionuclides are present, the return air will be directed through the HEPA filter system installed near the Emplacement Exhaust Shaft collar (shown in Section 8.7.7.1).

8.7.7 Off-Normal and Accident Conditions Ventilation Considerations

Each emergency situation is unique. Systematic analysis of accident scenarios is an extremely complex subject which generally involves a number of research topics including: developing of an accident scenario, event tree frequency and dose consequence analyses, and planning for emergency responses. Comprehensive study and modeling of accident scenarios require efforts beyond the scope and effort for this repository design stage. This section is intended to provide a preliminary discussion of some generic ventilation considerations for selected accident scenarios.

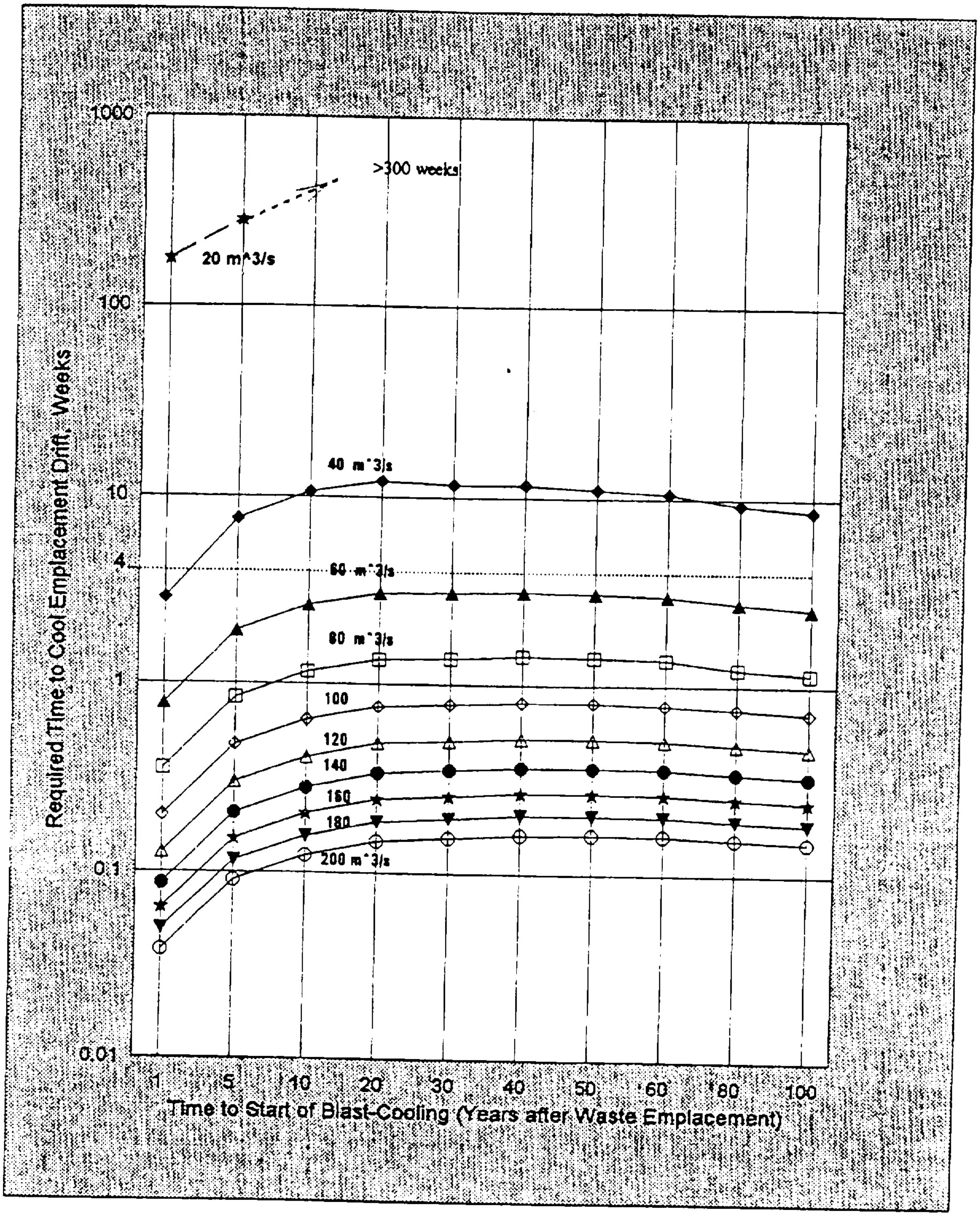

Figure 8.7.6-2. Required Time to Blast Cool Previously Unventilated Emplacement Drift

8.7.7.1 HEPA Filter System

It is required that the ventilation system must control the transport of radioactive particulates and gases within and releases from the underground facility, and it must assure continued function during normal operations and under accident conditions (YMP 1994a, 3.7.5.B.1 and 3.7.5.B.2). In case of off-normal conditions when particulate radionuclides are present in the repository, the return air will be directed through a surface-installed HEPA filter system shown in Figure 8.7.7.1. The filtration system is planned to contain a pre-filtration system to remove the coarse dust and large particulates before the air flow enters the final filtration (HEPA filters). The filtering media of the HEPA filters are replaceable. Two separate filtration units will be installed with one unit as a 100 percent backup of the other. Each unit has a capacity of effectively handling air flows of up to 94.4 m^3/s for velocities of air crossing the filter media of up to 1.27 m/s. HEPA filters are capable of removing 99.99 percent of the particulates with a minimum size of 0.12 microns (Farr 1994). The exhaust air from the repository can be forced into the filtration system by the primary ventilation fan. Each primary fan has a capability of delivering air at a volume flow rate of up to 94.4 m^3/s at a pressure of up to 3.48 kPa. The maximum pressure drop that may be required to course the air into the HEPA filter system should not exceed 2.5 kPa during the entire operational period.

It is important to note that the final decision on whether or not to incorporate HEPA filtration in the repository subsurface ventilation system has not yet been made. HEPA filtration facilities, especially of the size required for this application, are a high cost item. The need (or lack of need) for HEPA filtration facilities will be indicated by the results of accident analyses which have yet to be performed. If these analyses indicate the HEPA filtration is not needed in order to comply with regulatory requirements, they will be dropped from subsequent planning. They are shown here as a conservative measure.

8.7.7.2 Access Between Development and Emplacement Areas

The barriers (isolation air locks) which separate the emplacement and development systems will be composed of bulkheads with airlock doors. The East Main, West Main, Central Exhaust Main and Upper Block TBM Launch Main barriers will be equipped with personal airlock doors. These barriers will be of substantial construction to withstand the relatively high differential air pressures caused by the separate ventilation arrangement described earlier. Passing through the barriers will not be a normal event. Monitoring equipment will be employed to control this interface area.

8.7.7.3 Underground Fires

The most likely source of an underground fire would be a piece of equipment since most of the material brought in the repository will not be flammable. The potential for fire is largely limited to excavation and transportation equipment such as the TBM, muck conveyor, mobile equipment, rolling stock, electrical equipment, power cables and stationary gear boxes. Depending on the location of a fire, the fumes of combustion could be transported throughout a part or the entire underground area by the ventilation air flows. The most effective ways to limit or stop the spread of the products of combustion are to isolate the fire area from the unaffected ventilation areas (until the fire is out), and to extinguish the fire in its early stage.

NOTES

1. PRIMARY EXHAUST FANS WITH SILENCERS. CAPACITY EACH, 94.4 TO 283.2 m^3/s (200,000 TO 600,000 cfm) @ 2 TO 3.48 kPa (8" TO 14" WATER GAGE) PRESSURE. EACH HAS EXTERNAL VARIABLE FREQUENCY MOTOR AND VARIABLE PITCH BLADES.
   FAN 'A' IS NORMAL OPERATION.
   FAN 'B' IS STANDBY.
2. REPLACEABLE AIR FILTERS IN COUNTER FLOW ARRANGEMENT
3. DOOR/GUIDE VANES - CLOSED DURING NORMAL OPERATION.
4. DOOR/GUIDE VANES - OPEN DURING NORMAL OPERATON.

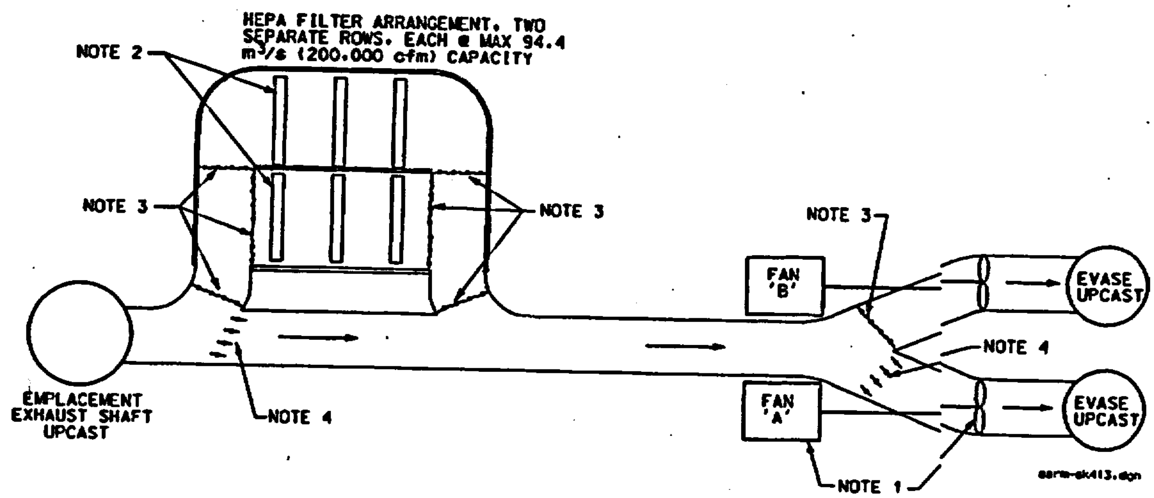

Figure 8.7.7-1. Emplacement Exhaust Shaft Collar/Surface Schematic

A fire associated with a TBM or its trailing gear has the potential to rapidly affect a significant number of underground workers. Since fumes would be carried by the ventilation duct and exhausted into the exhaust shaft, workers could be evacuated through the underground main drifts to the South Portal.

Due to the limited combustible material in the repository, an underground fire is not expected to affect the structural integrity of the facility. All underground openings located upstream of a fire will be used as escape ways. The effects of the fumes will be mitigated by wearing personal protection devices and by designating both primary and secondary escapeways from each working area. Workers will be trained in, and familiar with, the escape routes. Examples of escape routes for a number of typical off-normal scenarios will be provided in Section 8.7.8.

Although fire protection will be provided by the installation of automatic or manual dry chemical extinguishing systems for primary fire fighting on conveyor drives, TBM, and certain other equipment, the potential exists for a fire to spread smoke throughout a considerable section of the repository. In such an emergency situation, entrapped personnel can take refuge in a refuge chamber for a certain period while the situation is corrected. Refuge chambers could also be used by personnel who are trapped underground for reasons other than smoke or fire emergencies.

When a person in the repository is trapped by a fire which prevents escape to the surface, walking towards a refuge chamber may be impaired by smoke and toxic gases. Underground personnel are required by regulation to have self rescue devices to protect them from carbon monoxide gas, but protection is not provided against eye irritating gases, smoke, or an oxygen deficient atmosphere. To alleviate the problem, early detection and alarm systems and early response in case of fire or other emergencies will be part of the repository operating procedures. The early alarm will allow time for personnel to walk or take any other available transportation to the nearest refuge chamber.

8.7.7.4 Rock Falls in Main Drifts

Rock falls in different underground locations could have different effects on the ventilation system, and, thus, require different corrective actions.

A rockfall in the access ramps would be among the most disruptive. The intake air flow would be restricted, causing a rapid increase in fan pressure and corresponding drop in air flow rate. However, due to the large size of the ramps, a rockfall is unlikely to result in complete blockage of the tunnel. Intake air would still travel through the rockfall area and support the operations for removing the blockage. In this event, the air flow quantity that can be delivered to the working faces may not be adequate to meet the operational and personnel needs and the partial ramp blockage would inhibit normal operations. Therefore, underground operations will be stopped and underground personnel evacuated to the surface until the blockage is removed.

Another type of blockage that could have a serious impact on the repository operations is a rockfall in the shafts. If the obstruction occurs during the construction period, the ventilation air can not be rerouted, thus operations will have to be suspended until the blockage is removed. If the obstruction occurs during the caretaker stage, the ventilation intake will be rerouted to other major openings.

8.7.8 Emergency and Escape System

In the event of an underground fire or accidental radionuclide emission/leakage, it is imperative that personnel be able to escape to the surface or to a place of refuge. The repository will have planned escape routes in every phase of the operation. Fire scenarios, site specific availability of refuge chambers, location of established fresh air base, maximum potential walking distance between refuge chambers, ventilation actions and schematics of normal airflow and personnel evacuation directions will be part of personnel training and drill implementation.

In the event the exit routes to the surface are blocked, personnel will have a designated refuge area. The RDRD (YMP 1994a) requires that the repository subsurface ventilation system be designed in compliance with applicable mining regulations, particularly 30 CFR 57 (YMP 1994a, 3.3.6.3.G and 3.7.5.B.7). MSHA regulation 30 CFR 57.11050 requires that a place of refuge shall be provided for every employee who cannot reach the surface from the working place through at least two separate escapeways within a time limit of one hour. These places of refuge must be positioned so that they may be reached by a person within 30 minutes of leaving their work place. In order to meet the MSHA requirement, the maximum distance between refuge chambers or from the furthest work place would be 2,100 m (CRWMS M&O 1995au).

It is an accepted idea in underground mining that entrapped personnel may barricade themselves for protection from fire or smoke. The obvious extension of barricading is to have previously barricaded sites (chambers, shelters, etc.) provided with necessary supplies for survival while awaiting rescue.

A typical refuge chamber is an underground opening provided with a life saving environment. It has a bulkhead and door that will isolate personnel from potentially toxic gases and smoke resulting from a fire. The refuge chambers built during ESF construction will also be used in the repository. Additional refuge chambers will be constructed as needed to have an adequate number in the repository.

8.7.9 Ventilation Equipment Considerations

During the repository ACD efforts, computer models for the complex repository ventilation networks have been established to simulate the ventilation system performance, such as air flow/pressure distributions and main/auxiliary fan operating ranges (CRWMS M&O 1993f, CRWMS M&O 1994a, CRWMS M&O 1995aq, and CRWMS M&O 1995ar).

For the typical ranges of air quantity requirements and the general concepts of air flow distribution evaluated for the repository operations, the ventilation equipment and devices are expected to be similar to those used in conventional underground mining facilities, including main and auxiliary fans, isolation air locks, air regulators, air doors, air locks, ventilation duct or tubing, air quality monitoring devices and dust collectors. This section provides a few examples of repository ventilation equipment considerations.

Emplacement Shaft Exhaust Fans

The conceptual arrangement of the Emplacement Exhaust Shaft collar and surface have been shown previously in Figure 8.7.7-1. Two identical fan units, each complete with silencers and controls, will be installed at the collar of the Emplacement Exhaust Shaft. The second unit is considered to provide a 100 percent back-up of the first unit. Each fan unit will support the ventilation air capacity of the emplacement phase at 94.4 to 283.2 m^3/s. This performance can be delivered by a single stage mine heavy duty vane axial fan similar to the Joy Fan Model M132-79-710. The fan

has a housing of 3.35 m inside diameter, a hub of 2 m in diameter and operates at 710 rpm. The potential maximum quantity of 283.2 m^3/s at 2.5 kPa pressure is used to size the minimum horsepower output of the fan motor. Each primary exhaust fan will need a motor with a minimum power output of 820 kW, as shown in the Joy Fan Curve (Figure 8.7.9-1). The fan blade pitch is adjustable while in motion to deliver performance consistent with system requirements. The fan may also be provided with a variable frequency motor to vary the speed from 500 to 900 rpm. This feature may be needed to allow the fan to deliver a lower air quantity at higher pressure. During operations through the HEPA filters, the same fan will be used (arrangement shown in Figure 8.7.7-1). At lower blade pitch and with an increased speed of up to 880 rpm, the fan will deliver an air flow of 94.4 m^3/s at a total pressure of 3.48 kPa, without stalling . This is sufficient to sustain the fan operation (during an off-normal scenario) to direct the air through the HEPA filters for removal of particulate radionuclides in the return air before releasing it to the atmosphere.

South Ramp Portal Intake Fans

Figure 8.7.9-2 shows the South Ramp Portal and surface arrangement. Two identical fan units, each complete with silencers and controls, will be installed for the repository development phase. The second unit is a 100 percent back-up of the first unit. Each fan unit will provide the ventilation needs for the construction and development of emplacement drifts with air flow quantities ranging from 94.4 to 236 m^3/s. This performance can be delivered by a single stage mine heavy duty vane axial fan similar to the Joy Fan Model M132-79-710. The fan has a housing of 3.35 m inside diameter, a hub of 2 m in diameter, and operates at 710 rpm. The potential maximum quantity of 236 m^3/s at 2 kPa pressure is used to size the motor horsepower output, and this will need a minimum fan motor power of 670 kW, as shown in Figure 8.7.9-3. The fan has adjustable pitch blades while in motion to deliver various air quantities during different stages of development. The physical features of the fans used for the primary development are similar to the primary fans in the Emplacement Exhaust Shaft collar except for the size of the electric motor and controls. This will enhance interchangeability of all spare parts except the fan motor and controls.

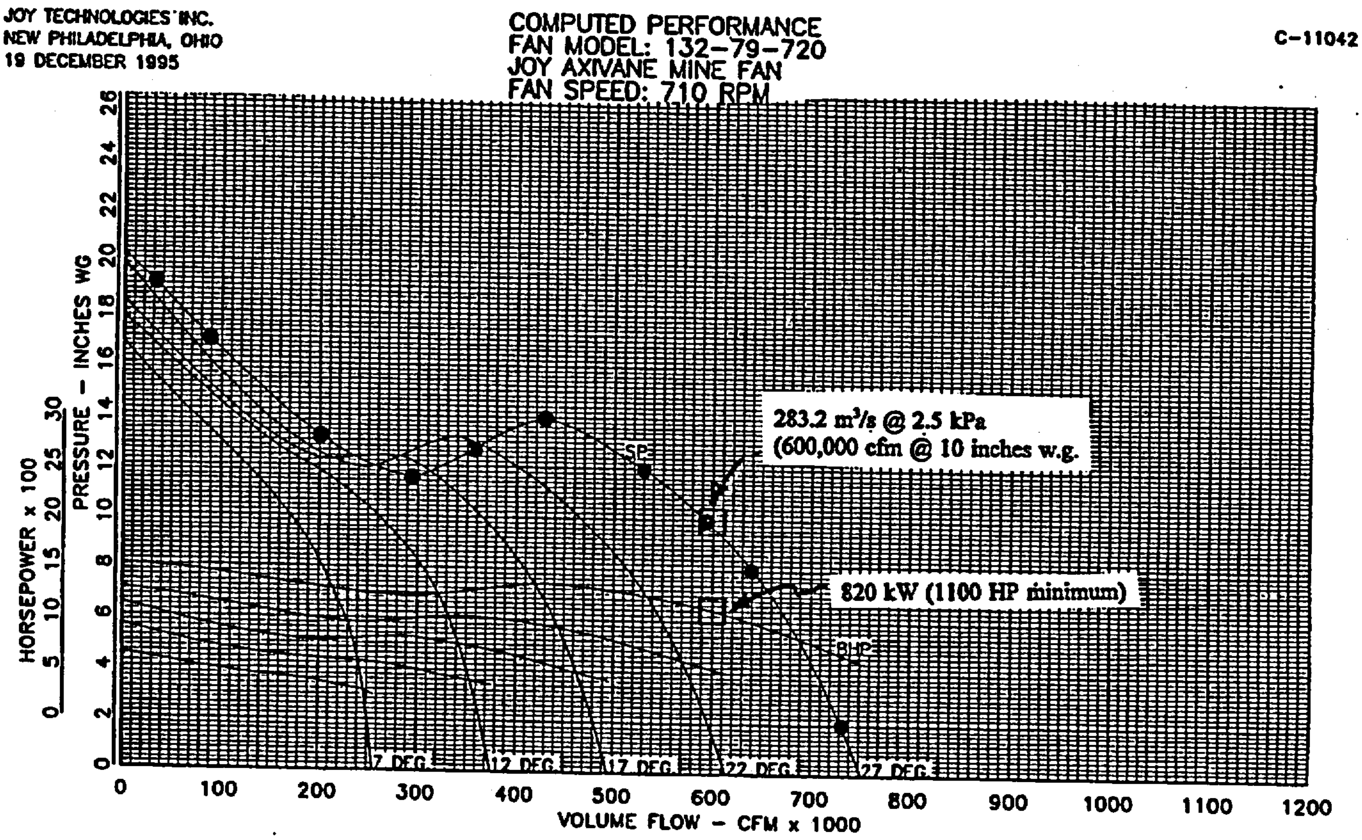

Figure 8.7.9-1. Operating Range of Exhaust Fan for Emplacement System

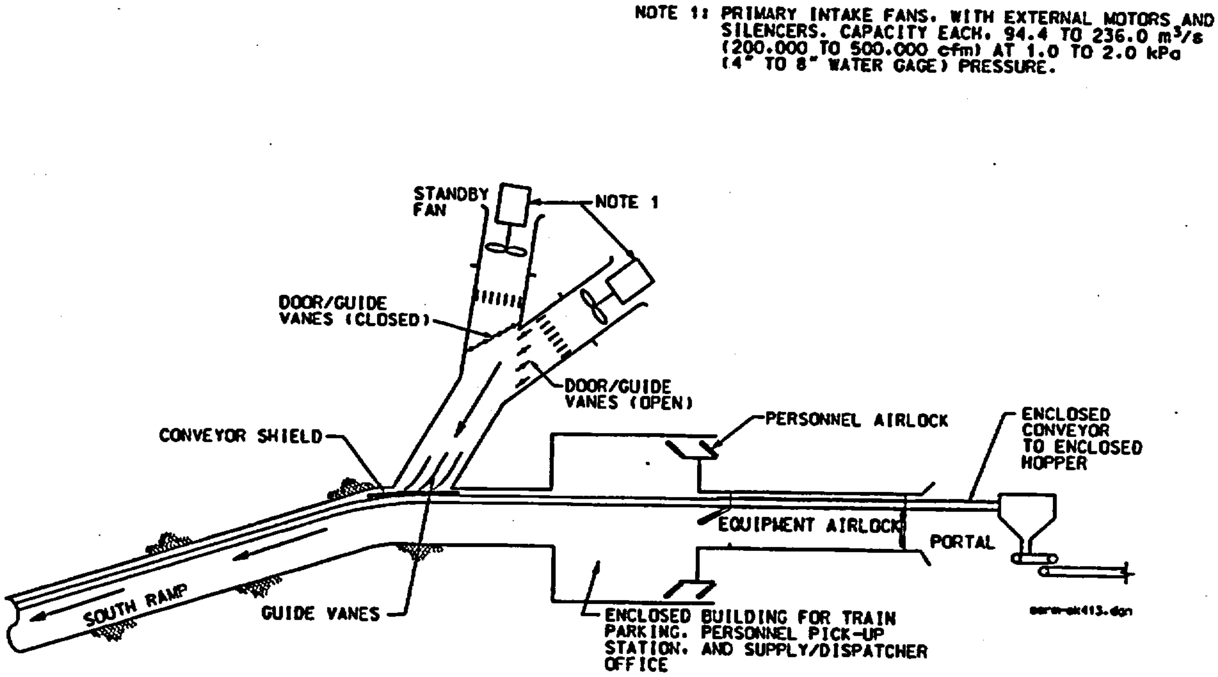

Figure 8.7.9-2. South Ramp Portal Schematic

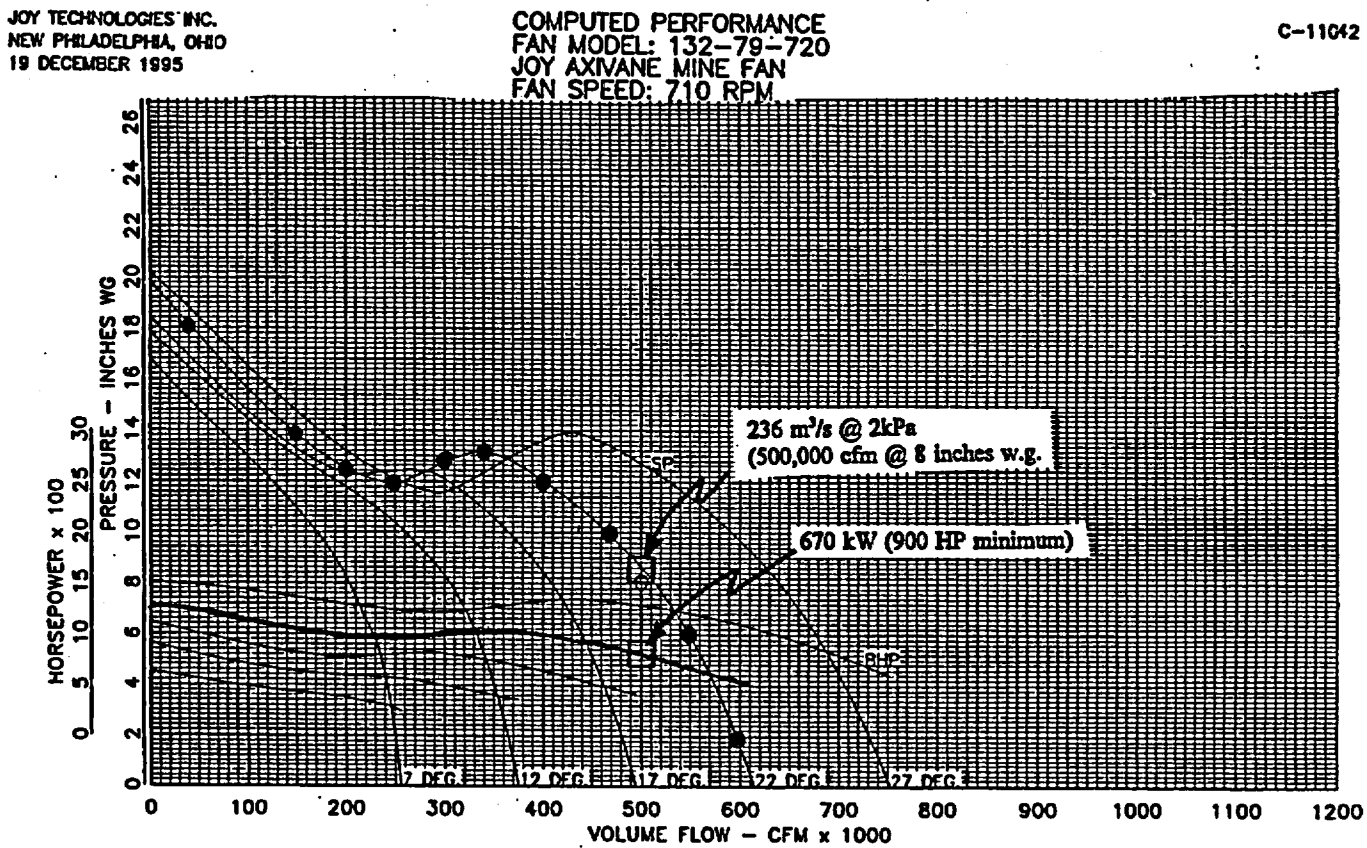

Figure 8.7.9-3. Operating Range of Main Intake Fan for Development System

To insure a relatively stable flow rate and pressure of the intake air flow from the South Ramp, an airlock system will be provided in the vicinity of the South Portal, as shown in Figure 8.7.9.2. The airlock system will serve as a departure station for equipment and personnel transportation to the underground areas. The equipment and personnel airlocks are located in separate areas. All airlocks consist of two air doors in series. Whenever the equipment or personnel is passing through one of the two doors, the other door remains closed to minimize air leakage through the system. The equipment airlock must be designed with an adequate clearance to allow passage of large-sized equipment that fits in the South Ramp transportation envelope.

Auxiliary Ventilation Fans

As discussed earlier in Section 8.7.4, the ventilation for excavations of dead-end headings (i.e., TBM face) will be supported by local auxiliary ventilation systems. Previous repository ventilation studies have evaluated various types of auxiliary ventilation fans, and recommended the use of axivane fans for face ventilation due to their capabilities of providing medium to high pressures at good efficiency. Computer modeling of the ventilation system has shown that the operations in dead-end headings can be supported by local auxiliary ventilation systems equipped with commercially available fans (CRWMS M&O 1993f, CRWMS M&O 1994o, CRWMS M&O 1995aq, and CRWMS M&O 1995ar). For example, the current TBM operations in the ESF are being satisfactorily supported by an auxiliary ventilation system that consists of a series of fans (Joy Fan Model 60-30-1185) installed in a 1.68 m diameter ventilation duct. With an average fan spacing of 840 m, the system is capable of delivering air to the 7.62 m diameter TBM face at an average flow rate of 38 m^3/s.

8.8 EMPLACEMENT DRIFT BACKFILL

The use of backfill in emplacement drifts is not currently planned as part of the engineered barrier system (CRWMS M&O 1995a). However, backfilling of mains, shafts, and ramps is planned at the time of repository closure. This has been the case throughout the course of the ACD effort. However, recent activity in the area of Total System Performance Assessment (CRWMS M&O 1995av) has indicated that emplacement drift backfill, if used, may enhance waste isolation by delaying the release of radionuclides from the system of engineered barriers. A waste isolation strategy, currently under development by the program, also indicates that emplacement drift backfill may be advantageous, but further information is needed before a decision is made to require backfill.

The repository design team has taken action to maintain the option to place backfill in emplacement drifts should it become a program requirement. In anticipation of this requirement, the reference design shows two options for waste package emplacement positioning. In addition to CID, an OCID mode is also shown. Figures of these two modes are contained in Section 8.2.8.7. One of the primary reasons for selecting the off-CID mode is the apparent advantage over the CID mode to place certain types of backfill.

This section has been provided in recognition that, while emplacement drift backfill is not currently required, it was considered prudent to take the steps to maintain this option should it become necessary. A Systems Engineering study is currently underway that is evaluating the use of backfill as one of several engineered barrier system enhancements. Results of this study will help form the basis for a program position on the use of emplacement drift backfill.

8.8.1 Previous Work

Backfilling concepts that have been developed for the Yucca Mountain High-Level Nuclear Repository are largely described in three M&O documents which are briefly discussed below.

In 1993, the study, *Alternatives for Waste Package Emplacement, Retrieval, and Backfill Emplacement* (CRWMS M&O 1993h), discussed the effect of backfill upon the waste packages, loose material for inverts, and design features for the ACD. The effect of backfill on waste packages was described for both small waste packages vertically emplaced in boreholes; and large, horizontal-in-drift emplaced waste packages. The insulating effect of the backfill was examined for each case. Modeling of small, vertical waste packages showed that backfill will cause temperature rise of less than 5°C while larger, horizontal-in-drift emplaced packages will have a temperature rise of 140 to 300°C.

One year later, *Repository Emplacement and Backfill Concepts and Operations Report* (CRWMS M&O 1994q) discussed backfill concepts and operations for material emplacement techniques including dumping, pumping of slurries, pneumatic stowing of solids, and backfilling with concrete; no recommendations were made.

In a Systems Engineering study, *Status Report on Systems Study to Evaluate Technical Basis for Project Decision on Use of Backfill in Emplacement Drifts at the Potential High-Level Nuclear Waste Repository at Yucca Mountain, Nevada* (CRWMS M&O 1995aw), seven backfill functions were defined for twelve generic designs. Four backfilling emplacement methods with two variations of one method were discussed. Among the supporting analyses included in the study were temperature distribution in the drift wall rock, waste package corrosion, backfill and heat effects on relative humidity, and long term dose rates due to radionuclide release.

8.8.2 Design Inputs

8.8.2.1 Requirements

Backfilling, if used, will be designed to meet the requirements and guidelines as set forth by federal statute in DOE and NRC guidelines. Backfilling is not a part of repository sealing as required in 10 CFR 60, but the proposed methodology may be relevant to the placement of material which is used to seal the repository. While the primary functions of seals will be to prevent surface water inflow to the repository, delay radionuclide migration from the repository, and minimize human intrusion into the repository, backfilling may encompass a wider range of requirements.

The regulation, 10 CFR 60.111(b)(2), mentions backfill that could be performed in relationship with waste retrieval or repository closure.

> "This requirement [maintaining the option for waste retrieval for a period of up to 50 years after initiation of waste emplacement operations] shall not preclude decisions by the Commission to allow backfilling part or all of, or permanent closure of, the geologic repository operations area prior to the end of the period of design for retrievability."

The NRC guidelines on backfilling are set forth in the *NRC Draft Regulatory Guide DG-3003* (NRC 1990, pp. 4-7, 4-9, 4-10, 5-2) as follows:

> "Describe the backfilling and sealing system that will be used to permanently close the shafts or ramps. Include the proposed materials for backfilling and sealing, the bases for selection of these materials, methods and equipment for emplacement, and the installation of plugs and bulkheads. Specifically, discuss operational seals and whether or not they will be left in place as part of the post-closure seals."

> "...Discuss methods of construction used for the waste emplacement system, long-term stability of emplacement drifts under repository conditions, and methods and systems for ground support, including backfill materials used around the waste packages."

> "...Describe the backfilling and sealing systems that will be used to permanently close the waste emplacement areas and the remaining portions of the underground facility. Discuss the materials proposed for the systems, the bases for selection of these materials, methods, and equipment with which placement of these materials will be accomplished, and provisions for dealing with sealing of fracture zones, perched water zones, and fault areas."

"...The discussions should include design descriptions of the portions of the underground facility (e.g., the openings and backfill materials) that are considered part of the engineered barrier system; include the provisions provided for retrieval. Backfill materials used in the emplacement drifts and boreholes and other drifts (mains, submains, etc.) should be described, discussing backfill particle size distributions; physical and chemical characteristics; density after emplacement; changes in density and physical and chemical characteristics with time; mechanical, thermal, and thermomechanical properties; emplacement machinery; and capability for retrieval or removal."

The DOE position on backfilling for a geologic repository as stated in *Generic Requirements Document for a Mined Geologic Disposal System* (DOE 1987c, pp. D-14 and D-15) is stated as follows:

"The placement of backfill material before the permanent closure of the repository is an option available to the repository operations management. The placement of backfill material in emplacement rooms or other areas of the repository is specifically permitted provided that all requirements of this statement of position are fulfilled. Nothing in this statement of position shall cause the repository architect/engineer or operations management to assume that repository backfilling before permanent closure is either required or prohibited. However, if early backfilling is part of the planned emplacement operations of the repository, it shall be made part of the design at the time of the license application. Backfilling, if exercised early, must not preclude the possibility of retrieval. Assurance of retrievability from backfilled areas must have occurred during the proof-of-principle retrieval demonstration before the license application. The removal of backfill material for purposes of retrieval shall not affect the integrity of the repository in areas where emplacement will not be disturbed. If waste is to be retrieved from a portion of the repository that has been previously backfilled, the retrieval of any or all of the waste shall be subject to the time guidelines."

Further requirements are set forth in the RDRD (YMP 1994a) with specific reference to the following sections of the RDRD (YMP 1994a):

3.7.6 PERFORMANCE CONFIRMATION REQUIREMENTS

B. Testing. During the early or development stages of construction, a program for in situ testing of such features as borehole and shaft seals, backfill, and the thermal interaction effects of the waste packages, backfill, rock, and groundwater shall be conducted.

F. Backfill Test. A backfill test section shall be constructed to test the effectiveness of backfill placement and compaction procedures against design requirements before permanent backfill placement is begun.

8.8.2.2 Assumptions

Backfilling operations while a future possibility is not required as per Key Assumption 046 which states in the CDA Document (CRWMS M&O 1995a) as follows:

"Current design assumes no backfill in emplacement drifts. Options for backfill will be considered based on ongoing and future backfill studies."

Key Assumption 046 fits the center-in-drift waste emplacement mode described in this MGDS ACD report. Backfilling of the center-in-drift mode is not considered feasible. The backfilling details which have been developed below are presented as a contingency for an unspecified condition or set of circumstances which may arise in the future. For those conditions or circumstances, the OCID is considered the better of several potential waste emplacement modes.

8.8.3 Backfill Operations Description

Backfilling (if considered in the future) in a typical off-center in-drift emplacement drift will utilize a second track which is parallel to the track supporting the waste packages as described in Section 8.8.3.2. Equipment will travel past the emplaced waste packages to the end of the typical emplacement drift and retreat while backfilling to the beginning of the drift. This method of backfilling appears advantageous for operation around the waste packages following a review of currently available equipment systems. In the OCID mode, backfill which is emplaced by dumping material over the waste packages is favored. Pneumatic stowing is considered the better of several methods for backfilling of main drifts and ramps which is integrated with seal construction during closure operations as described in Section 9.4. While pneumatic backfilling may be employed during backfilling of emplacement drifts, dusting and frequent attention by personnel reduce the effectiveness of this method in emplacement drifts.

8.8.3.1 Backfill Considerations

8.8.3.1.1 Subsidence Control

The repository layout geometry (pillar size and spacing) is designed to prevent subsidence as discussed in Section 8.5.3. Backfill is not needed for subsidence control.

8.8.3.1.2 Protection of Waste Packages

Backfilling of emplacement drifts may provide good physical protection against potential waste package damage caused by roof collapse. If the backfill cover over each waste package is sufficient, the impact energy of falling rock will be largely absorbed by the backfill and the rock debris will rest upon the backfill as shown in Figure 8.8.3-1. Even a minimal cover will provide some protection against rocks falling adjacent to the waste packages.

8.8.3.1.3 Performance Enhancement of Waste Packages

Only preliminary assessment has been performed on multiple and single component backfills. Among possible backfill combinations include single component-single layer, multiple component-single layer, multiple layer-single component each layer, and multiple layer-multiple component each layer. Early assessments have indicated that water may be diverted around waste packages by a two layer-single component each layer backfill. This arrangement has been described as a "Richards barrier " (Conca et al. 1995). The loose constituents emplaced in a two layer backfill in theory form a "drip shield" which may provide waste packages with long term protection from corrosion.

The capillary barrier based on the Richards barrier concept requires a double layer backfill which covers the waste package with a gravel-sized material to a minimum depth of one foot and a capping of a sand-sized material to an additional depth of one foot (Conca et al. 1995). Additional conditions which are critical to performance of the barrier include a shallow angle inclination along the interface of the two materials, perturbations along the interface of the two materials not greater than 5 to 10 cms, and sand-sized material which do not penetrate into the gravel-sized material more than three to four gravel-size particle depths.

The weakness of the Richards barrier concept is that multiple layer backfills cannot be constructed within the context of the current underground repository concept. The problem is two-fold; the exacting requirements cannot be met and access is not provided. For various stowing methods (dumping, slinging, or pneumatic stowing), the placement of backfill is too energetic and too erratic for the precise specifications derived from laboratory experimentation (Conca et al. 1995). The available backfill techniques will likely produce the following conditions that invalidate the effectiveness of a two component, stacked backfill:

- Variable slopes for each level of backfill.
- Excessive perturbations along the interface between the two fills.
- Poorly defined interface between two fills due to penetration of the top layer into the bottom layer. Segregation of material constituents by particle size, density, and shape.
- Potential partial exposure of the waste package surface.

In addition, the track that runs parallel to the emplaced waste packages in the OCID mode, and provides access for backfill equipment, is covered by the first layer so that the equipment has no access to apply the second layer.

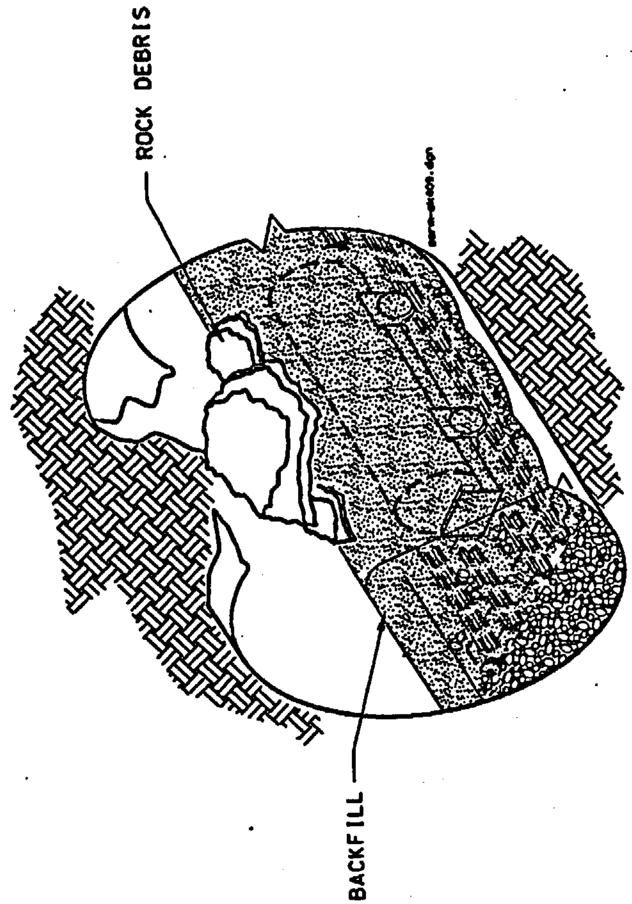

Figure 8.8.3-1. Backfill Protection of Waste Packages

A single layer backfill currently does not appear to provide significant improvement in long term "drip shield " protection to the waste packages nor to radionuclide attenuation (CRWMS M&O 1995av). With the problems associated in constructing a multiple layer (Richards barrier) backfill, it cannot be considered a waste package performance enhancement tool. Thus, some means must be found to enhance the performance of a single layer backfill by either discovering the right single component or combination of multiple components, which, when mixed and emplaced, can enhance performance.

Performance assessments have been limited in evaluating waste package "drip shield" protection by only considering backfill emplacement. Another potential performance enhancement may be the use of a rigid drip shield. Such a structure may be added to the waste package and installed at the time of waste emplacement or installed as a separate unit at the time of closure. This concept has not been considered in performance assessment.

8.8.3.1.4 Prevention/Retardation of Human Intrusion

Human intrusion into the repository will be difficult to prevent, although the depth of the repository and shaft and ramp seals placed at closure will reduce the potential for human intrusion. Backfill placed in the emplacement drifts may significantly slow human intrusion by excavation; although, no backfill material can totally prevent the possibility of human intrusion by determined individuals. Even encasing the waste packages in rock or a rock-like material will not prevent removal of waste packages by over-mining the encasement. Backfill cannot be justified solely upon the basis of human intrusion prevention.

8.8.3.1.5 Personnel Utilization

Though backfilling is largely an equipment-intensive operation, personnel are required for maintaining and operating feeders and conveyors. Underground personnel are generally utilized in backfilling at the point of backfill emplacement and at key locations along the material handling system. The high radiation environment of the emplacement drifts precludes human occupation at the point of backfill emplacement so that remotely operated equipment is expected to be used. Maintenance personnel will be positioned at staging points to repair or perform regular maintenance functions which are well away from high radiation areas.

8.8.3.1.6 Equipment Limitations

Heat and dust are potential conditions which may affect equipment performance. The temperature in unventilated drifts 100 years after waste emplacement has been estimated at 170°C (CRWMS M&O 1995am). The high temperature exceeds the maximum recommended temperature for an electrical drive unit. High temperatures are likely to adversely affect hydraulic over electric or compressed air drives if used on stowing equipment. Therefore, if backfill is to be applied in emplacement drifts, the drifts will first have to be cooled down for equipment access as described in Section 8.7.

8.8.3.1.7 Material Behavior

Backfill mixtures may include any combination of dissimilar materials. Due to various particle characteristics, these dissimilar materials may tend to segregate from the mixture and concentrate to like materials if handled vigorously; thereby, exhibiting various degrees of flowability, consolidation, and dusting.

The flowability of many loose, dry materials tends to be medium to high when dumped. Piles of such materials tend to have a low to medium angle slopes. A material which has loose, dry, small, and round particles will tend to flow to flatter slopes than a material of similar properties which has flattened particles. As crushed tuff is angular in shape, field observations indicate that a pile with 30° sloping sides will likely be attained.

Settlement information is not available for crushed welded tuff. Though most dry, loose, heaped materials tend to consolidate over time, the degree of settlement is unknown.

Dusting to various degrees will occur during normal and off-normal backfilling. Dust particles are generally included in the 0.001 micron (μm) to 100 micron size range. The suspension velocity of 50-micron sized particles which are spherical and have a 0.55 g/cm^3 density is estimated at 0.6 m/s while the same sized spherical particle with a 0.8 g/cm^3 density is 0.8 m/s (Hesketh and Cross 1983). Irregular sized particles of the same size with a 0.8 g/cm^3 density is estimated to become airborne over a range of air speeds from about 0.6 to 2.0 m/s. Once airborne, very small solid particles of less than 15 microns in size tend to settle very slowly. For example, a 10-micron diameter particle with a 2.7 specific gravity may settle as slowly as 0.008 m/s (SME 1973). The screen fractions given for excavated rubble by a 7.62 m TBM (see Table 8.8-1) are undifferentiated below 6 mm (6,000 microns) so that the amount of fines (all material of less than 149 microns) produced is unknown as is the time that particles will remain airborne due to several other characteristics besides size. Dusting is expected to occur during normal backfilling operations as the material is dumped on the waste packages. The backfill material is expected to readily separate by size with fine particles remaining airborne for some unspecified time. As the ventilation flow rate is expected to be minimal, the lateral migration of these particles should not be extensive.

8.8.3.1.8 Waste Package Emplacement and Backfill Cross-Section

Backfill, if required, will be designed to cover the waste packages as shown in Figures 8.8.3-1 and 8.8.3-2 in which the peaked, high portion of the material pile is centered over the cross-section of a typical waste package. The OCID mode of waste emplacement is shown for both figures in which backfilling may be performed from a track parallel to the alignment of the waste package and railcar units. The backfill will spill over the parallel access track as shown in Figure 8.8.3-2.

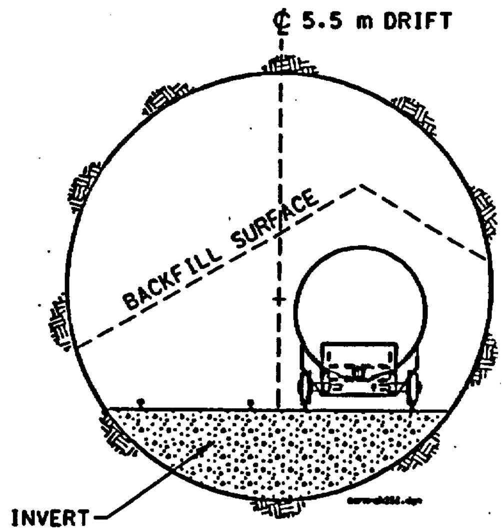

Figure 8.8.3-2 Backfill Profile in OCID Emplacement Drift (Cross-Sectional View)

8.8.3.2 Normal Backfill Operations

Backfill can be emplaced as depicted in Figure 8.8.3-3 by discharging dry material over the centerline of the waste packages starting at the ventilation exhaust drift and progressing to the entrance end of each waste emplacement drift. Material falls to each side and builds up a pile which eventually covers the waste package. The angle of repose is assumed to be approximately 30 degrees which represents the angle that the pile surface will achieve in relation to the drift invert. This angle is common for many materials which are similar to crushed tuff. The material is also assumed to have sufficient flowability to intrude into the space beneath the railcar though some voids are expected to remain beneath each waste package. As the backfill reaches the required depth over each waste package, the point of discharge is moved slowly forward forming a continuous "windrow" all along the length of the emplacement drift.

Dumping will cover the waste packages to an approximate depth of 0.6 m in a 5.5 m diameter drift which is the approximate minimum diameter for opening accommodating an OCID waste emplacement mode. The effective overhead unfilled area will be approximately 34 percent of the initial drift opening. This opening will provide a ventilation flow rate to allow backfilling to be performed without auxiliary ventilation.

Monitoring equipment will be necessary to verify that the waste packages are covered and the depth of the backfill is sufficient. Monitoring must be performed simultaneously with backfilling to verify the condition of the backfill since access back into the drift will be precluded as the track will be covered.

Backfill material will be transported underground by trains comprised of a locomotive and several open, gondola railcars. The railcars will be pulled to car dumps which will unload the gondola railcars and load stower supply cars which will travel to the stowers in the emplacement drifts. Gondola railcars may be side-tracked when stower units are temporarily shut down. The backfill rate will be selected to insure that material falls uniformly about each waste package, dusting is minimized, and stower supply cars can tram sufficient material to provide continuous stowing. Each backfilling unit in creating the continuous "wind row,"will slow its forward advance to allow the top of the pile between waste packages to be even with the pile over the waste packages. A recommended stowing rate of 75 m^3/hr will cover each waste package in about 37 minutes, while the space between waste packages will take somewhat longer. For a backfilling operation conducted on a 2000 hour per year per unit basis, two backfill units, and a backfilling rate of 75 m^3/hr per unit, backfilling will require approximately a 10-year time period unless substantial off-normal conditions are encountered.

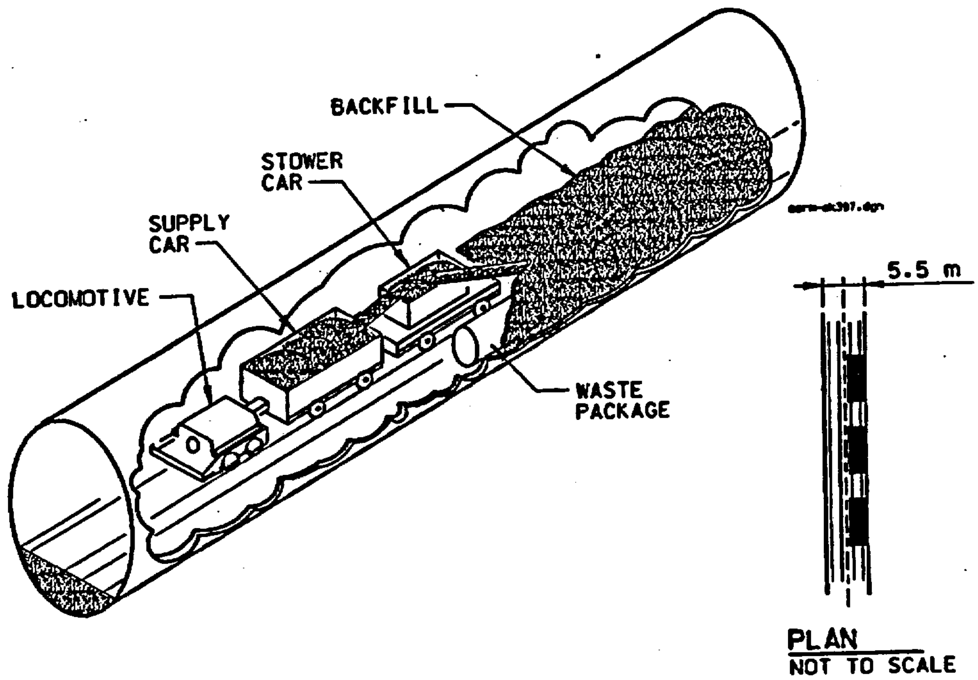

Figure 8.8.3-3. Backfill Stowing in an OCID Emplacement Drift

8.8.3.3 Off-Normal Conditions

Off-normal events may include but are not limited to minor rockfalls and/or displacement of a waste package which occur during the caretaker period. Should a rockfall be substantial, a waste package is damaged, or the overall performance becomes questionable, off-normal retrieval will be performed to remove the waste package and restore the emplacement drift to its original condition, if possible. Otherwise, only such remediation that is required to provide access through the emplacement drift by backfilling equipment will be performed.

8.8.4 Backfill Equipment

8.8.4.1 Backfill Transportation and Handling Equipment

Current planning includes the removal of excavated rock by belt conveyors to a surface stacker and deposition into a large storage pile or into several piles at some undesignated location between the North and South portals. This material will likely be reclaimed for backfilling due to the large amount of material which will be required should backfilling be included in closure operations. After the caretaker period, the tuff in the surface stockpile may need conditioning due to degradation from natural weathering.

A processing facility will be constructed near the South Portal. The processing facility will include screening, crushing, washing (optional), drying (optional), blending (optional) and agglomeration (optional) equipment to condition the material for backfilling. A washing stage is being considered to remove undesirable fines (if required) and treat for microbial infestation. Drying may be included to remove excess moisture and provide additional treatment for microbial infestation.

Agglomeration may be included if multiple components are blended in a "pug mill" mixer and integrated into the backfill. The wide range of possible material constituents having different physical characteristics may require a process to bind the materials together (agglomeration) to prevent separation of various constituents. Supporting facilities including belt conveyors, pan feeders, and various structures will be included. Rubber-tire, front-end loaders and end-dump trucks will provide haulage of the raw backfill material to the processing plant. Trains of locomotives and open, gondola railcars will haul the processed material underground for backfilling.

8.8.4.2 Backfill Stowing Equipment

Normal backfilling equipment consists of a rail-mounted train with locomotive, material supply car(s), and stower car as previously shown in Figure 8.8.3-3. The stower car may be outfitted with a self-propelling drive to provide continuous backfilling while the locomotive is tramming supply cars between the fill site and the stower car. The supply car(s) and the stower car will include open hoppers and cantilevered, elevated conveyors so that multiple supply cars have the capability of chain-feeding the stower car. The conveyor on the stower will be capable of swivelling from side-to-side and elevating up-and-down. The stower conveyor will normally be positioned over the centerline of the waste packages as shown in Figure 8.8.3-3. Sensors will adjust for misalignment of the discharge. Belt conveyors will likely be used on all equipment to provide an adequate throughput so that backfilling can proceed at a timely rate.

8.8.4.3 Remote Handling Considerations

Hostile thermal and radiation conditions existing within the emplacement drifts will necessitate remote control of all backfill operations within the emplacement drifts. Remote-controlled equipment will include operator control stations, wireless communication networks, video monitors, and various sensing devices which have been described in Section 8.6.5. Control elements deemed critical to the safe and successful operation of the backfill equipment can be designed with triple and quadruple redundancy which is typical for modern distribution control systems that employ process safety management strategies. The equipment will be shutdown and removed from the repository for maintenance in the event of malfunction.

8.8.5 Backfill Material

The welded tuff of the Topopah Spring (TSw2) thermal/mechanical unit will be available in large quantity as a result of repository development. This material has favorable properties for backfilling including availability, toughness, and potential radionuclide sorption. The particle size distribution of the tuffaceous rock depends heavily on the method by which the rock is broken. While other material may eventually be added to tuff or replace the tuff, the welded tuff is included herein as a logical based case material. The performance assessment of this material is discussed in Volume III Section 8.1.

For rock broken by disc-cutters mounted on a TBM, the probable particle size distribution based on ESF design (CRWMS M&O 1994r) is given in Table 8.8-1 as shown below.

Table 8.8-1. Excavated Rubble Size by 7.62 Meter TBM

Screen Size (mm)	% Retained (by weight)
+152/-305	10
+76/-152	10
+25/-76	20
+6/-25	30
-6	30

Welded tuff of the TSw2 unit is largely rhyollitic in nature and requires high energy for size reduction. As per testing by Sandia National Laboratories (SNL 1993c), particle breakage occurs by splitting and breaking off edges and corners. The terms cobbles and gravel often denote material which is rounded and uniformly sized. For Yucca Mountain tuff, cobbles and gravel represent only a size description and are likely to be angular with sharp edges. The particle size distribution as shown above compares closely with tuff crushed in a jaw crusher by Sandia and tuff broken with mini-discs by the Colorado School of Mines (SNL 1993c). For both methods of breakage, tuffaceous rock tends to break into particle sizes across a range of cobbles (250 to 64 mm), gravel (64 to 3 mm) and coarse sand size fraction (3 to 2 mm) (SNL 1993c). Even in a jaw crusher in which the discharge opening is varied from 76 to 38 mm, the particle size distribution profile is very similar though the production of fines may be increased by a multiple of two (fines being in the range of particles passing a 35 mesh screen or smaller than about 0.5 mm or 500 microns. The production of excessive fines may require a washing and screening process step to remove these constituents before the material is reintroduced underground to reduce the potential for dusting and undesirable sorting of backfill constituents. Additional study will be required to determine the quantity of fines which may become airborne as the result of backfilling and the need for an intermediate process step.

During removal from the repository, some material degradation in the form of secondary breakage and segregation can be expected due to drops at multiple transition points and to up-down, side-to-side movement while being transported. Additional size degradation due to weathering and separation may occur over the storage period (approximately 100 years) until the material is reclaimed for backfill. Unless extra care is taken to protect the storage pile(s) with top soil and vegetated cover or armored with rip-rap, the processes of natural erosion, settlement, and weathering will most likely change to some degree the overall particle size distribution in the storage pile(s). The backfill material will be sized to conform with either equipment used in normal or off-normal operations. A probable size range will encompass material which will pass through a 38 mm sieve opening but will be retained on a 30 mesh sieve (U.S. Standard Sieve Series) which includes a size gradation from medium gravel to sand particles. Crushing will likely be required to produce sufficient backfill for the repository from excavated tuff due to the amount of oversized material in the tuff stockpile.

The simplest form of material processing may just involve reducing particle sizes in the material prior to reintroduction underground as backfill. More involved material processing may require blending of tuff with other materials, treating the tuff to produce new physio-chemical characteristics, or utilizing completely different materials altogether.

Other potential backfill materials have been tested for use in high level nuclear waste disposal internationally. These materials include charcoal, clays, desiccants (diatomite, dolomite, etc.), metallic minerals, quartz sand, soils, and zeolites. These represent nearly the full range of physical characteristic rock types from light to dense, round to angular, friable to tough, and heat-degradable to heat-resistant. Should any of these materials be used in addition to TSw2 tuff, they will need to be brought to the Yucca Mountain site and stockpiled prior to backfilling. The additional material will be reclaimed simultaneously with the tuff, blended in pug mill (paddle or ribbon mixer) to produce a uniform consistency, and transported underground. Should backfill materials other than tuff be used, then these materials will be reclaimed and transported directly underground. No plans currently exist for the chemical and/or physical treatment of tuff to produce different material characteristics.