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1.3.4 Emplacement Areas of the Subsurface Facility

[NUREG-1804, Section 2.1.1.2.3: AC 3, AC 5, AC 6; Section 2.1.1.6.3: AC 1, AC 2; Section 2.1.1.7.3.1: AC 1; Section 2.1.1.7.3.2: AC 1; Section 2.1.1.7.3.3(II): AC 1, AC 2, AC 3; AC 5, AC 6; AC 9; Section 2.1.1.7.3.3(III): AC 1]

The design of the subsurface emplacement area structures, systems, and components (SSCs) is described in this section, including the emplacement drifts, excavation, ground support system, invert, waste package emplacement pallet, drip shield, and waste package emplacement system. Emplacement drifts are limited to the area between the end of the turnout and the exhaust main.

The subsurface emplacement area is divided into emplacement panels, each of which contains a group of emplacement drifts. Panels vary in size depending on physical and design constraints. The emplacement drifts provide a controlled environment for waste emplacement and monitoring during the preclosure phase. In addition, they provide the environmental setting for waste packages and other engineered barrier components after repository closure. These attributes contribute to the classification of the emplacement drifts as important to waste isolation (ITWI) (Table 1.9-8).

There are two components within the emplacement drift that are classified as ITWI: the drip shield and the waste package. The drip shield is classified as ITWI because it prevents seepage entering the drift from dripping onto the waste packages after repository closure and protects the waste package from direct impact from rockfall (Table 1.9-8). The waste package is also classified as important to safety (ITS), and both the ITS and ITWI classifications for the waste package are discussed in Section 1.5.2.

The only design feature of the emplacement drifts classified as ITWI is the emplacement drift configuration. The emplacement drift configuration constraint states that the emplacement drift excavation shall be circular in cross section with a nominal diameter of 5.5 m. The drift diameter ITWI attribute is related to the kinematics of keyblocks analyzed for drift degradation (rockfall) during the postclosure period.

The transport and emplacement vehicle (TEV) operates inside the emplacement drifts but is not a permanent in-drift feature. The TEV is classified as ITS. This classification is due to the requirements imposed on the TEV to handle the waste package during emplacement operations and the TEV’s role in preventing or mitigating a Category 1 or Category 2 event sequence. The emplacement operations performed by the TEV consist of moving the emplacement pallet and waste package along the emplacement drift and placing the pallet and its waste package at a designated location on the invert structure.

1.3.4.1 Description of Subsurface Facility Emplacement Areas

[NUREG-1804, Section 2.1.1.2.3: AC 3(1), AC 6(1)]

Reported dimensions and sizes for the subsurface excavations are nominal. The drifts are designed to accommodate the emplacement of waste packages, to provide space for cooling the waste packages by means of ventilation, to provide space for monitoring the waste packages during preclosure as a part of the Performance Confirmation Program (Section 4.2.4.1), and to provide space for the installation of drip shields prior to closure. While the length of each emplacement drift varies, each emplacement drift will be built and equipped the same way. After an emplacement drift is accepted and commissioned for emplacement operations and begins accepting waste packages, it becomes a very high radiation area (Section 1.10.2.5).

The emplacement drifts are designed to accommodate as many waste packages as it is physically possible, considering waste package emplacement constraints such as: a nominal spacing between waste packages; thermal seven-waste-package segment and line-load limitations; emplacement drift standoff distances; and, standoff distances for geologic anomalies as applicable. Spacing between waste packages end-to-end is nominally 10 cm. This spacing is one dimension used to meet the temperature limits specified for the repository as provided in Table 1.3.1-2. Thermal constraints consist of limiting the waste package loading in accordance with the emplacement drift loading plan as described in Section 1.3.1.2.5.

Operational equipment inside the emplacement drifts includes the TEV (Section 1.3.4.8) and the remotely operated vehicles used for inspections and monitoring. Additionally, during closure, the drip shield emplacement gantry operates inside the emplacement drift (Sections 1.3.4.7 and 1.3.6). The TEV, the gantry, and other remotely operated vehicles stay inside the emplacement drift only for the necessary duration to execute their function. Vehicle time in the drift is controlled to minimize the effects of heat and radiation on the instrumentation and controls.

The emplacement access doors remain closed and locked (Section 1.3.5.1.4) except during access to the emplacement drifts by the TEV, drip shield emplacement equipment, and drift inspection and performance confirmation equipment. A regulator placed adjacent to the emplacement access doors controls ventilation airflow through the drift (Figure 1.3.5-9). Both doors and regulator are installed in the turnout bulkhead. Airflow from the emplacement drift into the exhaust main is unrestricted. The subsurface ventilation system is designed to maintain repository temperatures at acceptable levels for subsurface operations and to meet the repository thermal management goals described in Sections 1.3.1.2.5 and 1.3.5. Calculations indicate that the temperature of air exiting the emplacement drifts is no more than 99.8°C during normal operations

After all the waste is emplaced, postemplacement monitoring is conducted related to (1) Performance Confirmation Program activities (Chapter 4); (2) maintenance of the openings and repository support systems in adequate condition and working order to emplace the drip shields (Section 1.3.6) and to support retrieval (Section 1.11), if needed; and, (3) continued monitoring of the ventilation system to ensure conformance to the postemplacement heat removal and air quality requirements (Sections 1.3.1 and 1.3.5). The subsurface ventilation system will continue to operate for the remainder of the preclosure period after all the waste is emplaced. The emplacement drifts provide an environment suitable for repository operations, including heat removal through forced ventilation and repository monitoring during the preclosure period, estimated to last up to 100 years. After closure, the emplacement drifts contain the Engineered Barrier System (EBS) components (waste package, waste package emplacement pallet, drip shield, and invert structure) that are evaluated along with the natural barriers for postclosure performance.

1.3.4.2 Emplacement Areas Design Description

[NUREG-1804, Section 2.1.1.2.3: AC 3(1); Section 2.1.1.7.3.3(II): AC 2(4), (5)]

1.3.4.2.1 Design Considerations for Location of the Emplacement Areas

Standoffs—Standoff is a minimum distance to be maintained between specific design features and certain components of the natural barriers. Figure 1.3.4-1 is a simplified representation of the subsurface facility standoffs as applicable to a typical emplacement drift. Design criteria for standoffs affecting the location of emplacement and nonemplacement openings are described in Section 1.3.2.2.1.

The *Underground Layout Configuration for LA* (BSC 2007a, Sections 1, 3.2, and 4.3) invokes the *Underground Layout Configuration* (BSC 2003a) calculation to demonstrate conformance to geologic standoffs and other design constraints imposed on the repository emplacement area locations. More specifically, the layout design relies on the following information from the *Underground Layout Configuration* (BSC 2003a) calculation:

- Geologic setting
- Emplacement drift orientation
- Waste inventory
- Water table standoff
- Perched water standoff
- Geologic fault standoff
- Standoffs from certain geologic units (Section 1.3.2.2.1)
- The repository host horizon
- Overburden cover.

The *Underground Layout Configuration* (BSC 2003a) was developed with the qualified VULCAN software (VULCAN Version 4.0NT, STN: 10044-4.0NT-00) with input from the three-dimensional database from the mountain-scale geologic framework model. Design enhancements performed in the *Underground Layout Configuration for LA* (BSC 2007a) were developed in a MicroStation platform from the VULCAN output file *Subsurfaceladesign_m.dxf* (BSC 2003a, Attachment V). The MicroStation output for the enhanced design was verified (BSC 2007a, Section 4.3 and Attachment VI) to represent the geometric control for the layout configuration as established in the original calculation. The underground layout described in Sections 1.3.1 through 1.3.6 meets the standoffs and geologic constraints (Section 1.3.2.2.1) imposed on the location of the emplacement areas as demonstrated in the *Underground Layout Configuration* (BSC 2003a, Sections 7, 8, 9, and Attachments I through V).

Opening Stability—Location criteria related to opening stability are:

- The emplacement drift azimuth is selected to place the drifts in a stable orientation with respect to the prevailing joint direction (BSC 2007b, Section 4.2.13.8.6).

- The vertical separation between crossing drifts is a minimum of 10 m from the crown of the lower opening to the invert of the upper opening (BSC 2007b, Section 4.2.13.8.1).
- Drifts running parallel are spaced at least three drift diameters apart, centerline to centerline, based upon the diameter of the largest drift (BSC 2007b, Section 4.2.13.8.2).

Emplacement Drift Configuration—The emplacement drift configuration criteria include (BSC 2008a, Section 8.2.1.8):

- The excavated diameter of openings that are used to dispose of waste packages is a nominal 5.5 m to accommodate waste package and drip shield emplacement equipment. Emplacement drifts are excavated with a tunnel boring machine.
- The emplacement drift spacing, centerline to centerline, is a nominal 81 m.
- Emplacement drifts are excavated nominally parallel and the design azimuth is within a range of 70° to 80°.
- The grade of the emplacement drifts is horizontal.

1.3.4.2.2 Design Considerations on Faulting

The location of the repository is in a block defined by block-bounding faults. This block has been the principal focus of site characterization studies. *Bedrock Geologic Map of the Yucca Mountain Area, Nye County, Nevada* (Day et al. 1998) presents a 1:24,000 scale map that includes the structural features near the main block. A detailed three-dimensional interpretation of the geology surrounding the repository area is presented in analyses detailing the construction and interpretation of the geologic framework model, Geologic Framework Model (GFM2000). GFM2000 is a three-dimensional database model of Yucca Mountain geology. The model is one component of the integrated site model and contains information pertaining to the surface topography, rock layers, faults, and boreholes. GFM2000 interfaces with subsurface design software to provide geologic information related to repository design and configuration. GFM2000 is also used to demonstrate that the subsurface repository configuration is compliant with science design constraints driven by hydrologic flow and radionuclide transport modeling.

Fault displacement analyses (BSC 2003b, Sections 4.2 and 7.0) conclude that a 60-m standoff between the main trace of any Quaternary fault with potential for significant displacement and any subsurface opening is effective in reducing the potential impact of fault movements. This standoff considers fractured ground in the proximity of Quaternary faults with potential for significant displacement and uncertainty in the location of the fault at depth. The design constraint is for emplacement drifts to be located a minimum of 60 m from a Quaternary fault with potential for significant displacement (BSC 2008b, Table 1, Derived Internal Constraint 01-05). There is no such constraint for nonemplacement openings.

There are two known Quaternary faults with potential for significant displacement in the immediate vicinity of the repository area: the Solitario Canyon Fault and the Bow Ridge Fault. The Solitario Canyon Fault is the only one of these faults that is close enough to the emplacement areas to warrant consideration of the standoff requirement. The subsurface layout maintains the 60-m standoff to the Solitario Canyon Fault and the Bow Ridge Fault based on current geologic information on their locations (BSC 2003a, Section 7.1.3). During initial construction activities in the Solitario Canyon Fault area, the location of the fault will be confirmed, and the condition of the rock near the fault will be examined. A construction standoff will then be evaluated based on observational data to confirm the design basis (BSC 2003b, Section 7).

The effects of fault displacement on emplacement drifts and other repository openings have been assessed. These effects are described in terms of displacement and stress induced by fault displacement, focusing primarily on the preclosure fault displacement (BSC 2003b, Sections 6.5.1, 6.5.2, and 7). The calculation considers a constant fault displacement, ranging from 1 to 1,000 mm. The largest mean preclosure fault displacement is 320 mm at the Solitario Canyon Fault corresponding to an annual exceedance of 10^{-5}. In this respect, a 1,000-mm fault displacement considered in this assessment bounds the current preclosure fault displacement hazards and extends into the postclosure period (BSC 2003b, Section 7).

Based on the results of the probabilistic seismic hazard analyses for fault displacement and vibratory ground motion at Yucca Mountain, the probability of having a new fault develop within the repository footprint is below the threshold for Category 2 event sequences. Therefore, the impact from such an unlikely scenario has not been considered for the preclosure period (BSC 2003b, Section 7).

The effects of fault displacement on emplacement drifts manifest themselves primarily in terms of reduction to the operational clearance envelope and disturbance to drift stability. Based on the analyses, the induced stresses and rock movement at a distance of 60 m from a fault with a displacement of 1,000 mm are small and have no operational effects on the repository openings and their ground support systems (BSC 2003b, Section 7).

1.3.4.2.3 Summary of Emplacement Area Design Features

Emplacement Drifts—The emplacement drifts are straight tunnels and include the invert structure, ground support, and other infrastructure for operation of the TEV and the drip shield emplacement gantry.

The overall underground layout is developed in a series of emplacement panels (Figure 1.3.4-2). A portion of the initial panel is designed to facilitate early initiation of waste emplacement. This initial emplacement area consists of three emplacement drifts in Panel 1. Separation of this initial emplacement area from construction activities in the rest of the panel is achieved through the deployment of temporary isolation barriers (Section 1.3.5) and other engineering barriers such as access and safeguard and security controls. The division of the repository emplacement areas into panels facilitates separation of development activities from waste emplacement operations.

Emplacement drifts are aligned at a nominal azimuth of 72° to orient the drifts favorably with respect to the prevalent orientation of rock joint sets (CRWMS M&O 1999a, Sections 7 and 8.2). This azimuth orientation improves ground stability and minimizes maintenance of the ground support in the emplacement drifts during preclosure. The azimuth of a drift is the orientation expressed as an angular distance measured from north toward east. In some cases, the emplacement drift orientation is expressed as an azimuth of 72° and in others as 252°, based on the direction of the drift excavation. These two values correspond to the same orientation with respect to north but are measured from starting points at opposite ends of the emplacement drifts. For example, excavation of emplacement drifts in Panels 3E and 4 (Figure 1.3.1-1) is initiated from a southwestern vantage point with respect to the location of the drifts, and the azimuth of the heading is measured clockwise from true north as 72°.

Emplacement drifts are laid out in a parallel pattern and spaced nominally 81 m apart. The pillar is the undisturbed rock between adjacent emplacement drifts. The nominal spacing is determined to prevent thermal interaction between adjacent drifts and to allow drainage of natural percolation and thermally mobilized water within the rock pillars to percolate past the drifts (CRWMS M&O 1999b, Figures 2-1 and 2-3 and Sections 5.1.2 and 6.1.1.1; BSC 2008b, Table 1, Derived Internal Constraint 01-13).

Emplacement drifts are nominally 5.5 m (18 ft) in excavated diameter. Waste emplacement is limited to 800 m of emplacement drift length to ensure ventilation efficiency is maintained. Most emplacement drifts are less than 800 m in emplacement length, with an average emplacement length of slightly over 600 m.

The grade of the emplacement drift shall be nominally horizontal so that overall water drainage is directly into the rock to prevent water accumulation (BSC 2008b, Table 1, Derived Internal Constraint 01-11). Therefore, the invert elevation at the start of each emplacement drift excavation is the same as the corresponding hole through drift invert elevation at the exhaust main. Layout location information for exhaust mains and emplacement drifts is designated at the elevations of the excavated inverts for each.

The underground layout and the geologic units within each panel are shown in Figure 1.3.4-2. This figure also shows the footprint-of-emplacement-area boundary determined by the design considerations discussed above and the standoffs described in Section 1.3.2.2.1. The footprint-of-emplacement-area boundary is defined as the horizontal projection or extent of the volume of host rock suitable for waste emplacement development and meeting repository location criteria and applicable standoffs for the license application design. Utilization of the entire length of the three northernmost emplacement drifts in Subpanel 3-East is limited by the footprint-of-emplacement-area boundary (BSC 2007a, Figure 11). Figure 1.3.4-3 illustrates a typical configuration for an emplacement drift, the intersections to the access main via the turnout, and the intersection to the exhaust main. A typical cross section of an emplacement drift is shown in Figure 1.3.4-4. This cross section illustrates the configuration for a completed drift prior to repository closure, with its components in place. The emplacement drift components shown are: ground support (Section 1.3.4.4), invert structure (Section 1.3.4.5), waste package emplacement pallet (Section 1.3.4.6), waste package (Section 1.5.2), and drip shield (Section 1.3.4.7).

Invert—The lowest point in an underground opening is typically referred to as the invert and the highest point is designated as the crown. A clarification is made because the term "invert" is used in this license application, unless otherwise stated, to include the bottom part of each emplacement drift including the "invert structure." Each emplacement drift has a steel invert structure (Figure 1.3.4-5), which provides a working platform for the emplacement equipment and a bearing surface for the loaded waste package emplacement pallet. The invert structure also includes a layer of crushed tuff ballast placed below and in between the steel structure members (BSC 2007c, Section 6).

Performance Confirmation Thermally Accelerated Drift—The Performance Confirmation Program includes monitoring a thermally accelerated emplacement drift after waste emplacement. The program will monitor near-field conditions of emplacement drift #3 in Panel 1 for a selected period during preclosure. The types of monitoring to be performed in the thermally accelerated drift in Panel 1 require special control of ventilation flow rates to achieve in-drift environmental conditions required by the monitoring program (Section 4.2).

Other subsurface openings used by the Performance Confirmation Program, such as the observation drift and alcove, are located in the nonemplacement areas and are described in Section 1.3.3.1.6.

1.3.4.3 Excavation
[NUREG-1804, Section 2.1.1.2.3: AC 3(1), AC 6(1), (2)]

The emplacement drift excavation activity consists of developing the series of subsurface openings that house waste packages for permanent disposal. The spacing between the openings is selected to meet the thermal performance goals. The method of excavation for the emplacement drifts is by use of a 5.5-m (18-ft) diameter tunnel boring machine, a proven excavation technology that has already been demonstrated at Yucca Mountain. The tunnel boring machine is an electrically powered mechanical excavator that creates a circular opening by advancing a cutter head through the rock. The cutter head rotates across the full diameter of the excavation normal to the axis of the drive. The cutter head has multiple disc cutters that engage the rock face and initiate tensile failure in the rock as the tunnel boring machine applies force by thrusting forward from the grippers. The rock fractures into chips that are scooped up in buckets built into the rotating cutter head, channeled to a conveyor, and removed from the excavation face. A schematic illustration of a typical tunnel boring machine is shown in Figure 1.3.4-6. The use of a tunnel boring machine for excavating the emplacement drifts assures a correct alignment of the drifts and produces a clean bore that facilitates the installation of the ground supports designed for the emplacement drifts. The smoother excavation also improves ventilation efficiency.

Excavation of the emplacement drifts follows the excavation of the access main, the exhaust main, and the excavation and completion of the tunnel boring machine launch chamber within the turnout. The turnout portion between the launch chamber and the emplacement drift is excavated by the tunnel boring machine at the same diameter as the emplacement drift and follows the configuration shown in Figure 1.3.3-13. The tunnel boring machine excavates each emplacement drift at the prescribed azimuth and at a horizontal grade. After the tunnel boring machine breaks through at the exhaust main, its cutter head is partially disassembled, and the machine and components are transported back to the next turnout for excavation of the adjacent emplacement drift. This operation is repeated until all emplacement drifts in a panel are excavated (BSC 2007d, Section 7.2).

Geologic mapping is performed in the emplacement drift during development and after initial ground support has been installed for personnel safety to support engineering analyses and in conformance with the Performance Confirmation Program (Section 4.2.2.1). This includes mapping of fracture and fault zone characteristics, stratigraphic contacts, and lithophysal content in the emplacement drifts. The mapping is performed before installation of the final ground support.

Faults, when found during excavation, will be analyzed as part of the implementation of Procedural Safety Control 25 (PSC 25).

Anomalies could be associated with geologic faults or fault splay zones, zones of unusually large lithophysae, or changes in rock types. The emplacement panels are located to minimize the potential of encountering areas of potentially poor quality rock, but there is a possibility of encountering anomalies because characterization data do not provide complete coverage of the host rock (Section 1.3.4.2.2). In previous characterization excavations such as the Exploratory Studies Facility tunnel and the Enhanced Characterization of the Repository Block Cross-Drift, analyses and operational procedures were put in place to address such an eventuality. Similar analyses and operational procedures implemented during construction of the repository will provide steps to analyze any such problem, maintain or restore excavation alignment, implement mitigation measures to ensure drift stability, and restore an excavated drift cross section. Implementation of these procedures provides assurance of the horizontal and vertical alignment of the drifts, within allowable tolerances, as necessary for installation of the invert structures and rail system. The total drift length available for emplacement includes some excess capacity available as emplacement contingency if needed because of unacceptable rock conditions or any other reason resulting in loss of available emplacement drift length (Section 1.3.2.4.3.1; Table 1.9-10, PSC-25).

Because excavation occurs concurrently with and adjacent to waste package emplacement operations, separation of the subsurface construction activities from the waste emplacement operations is maintained throughout the repository development phase. The repository design uses engineering controls to achieve and maintain this separation, as presented in Section 1.3.5. A combination of engineering and administrative controls is also put in place to maintain access, radiation protection, and safeguard and security controls at the interface points, as applicable (BSC 2008c).

1.3.4.4 Ground Support System

[NUREG-1804, Section 2.1.1.2.3: AC 3(1), AC 6(1), (2); Section 2.1.1.7.3.2: AC 1(2); Section 2.1.1.7.3.3 (II): AC 3(3), AC 5(1) through (10), AC 6(1), (2), (3), (4); AC 9(1), (2)]

The ground support for emplacement drifts consists of 3-m-long Super Swellex-type stainless steel rock bolts set in a square grid pattern at 1.25-m centers, and a 3-mm Bernold-type perforated stainless steel liner. The rock bolts and the steel liner are installed in a 240° arc around the drift periphery and above the invert structure (BSC 2007e, Section 7).

The emplacement drift ground support is classified as non-ITS because it is not relied on to prevent or mitigate a Category 1 or Category 2 event sequence, and it is not ITWI because the total system performance assessment (TSPA) does not take credit for ground support during the postclosure performance period (Tables 1.9-1 and 1.9-9). The emplacement drifts are very high radiation areas after emplacement operations begin. The ground support system is designed to last at least 100 years without planned maintenance even in the severe environmental conditions to be expected in the emplacement drifts. Any necessary maintenance needs triggered by unfavorable inspection results or by off-normal operational conditions will be evaluated taking into full account the information gathered by the inspection and monitoring activities (BSC 2007e, Section 6.6.1.3).

To provide added assurance that ground support will continue to function effectively during its design service life with little or no maintenance, emphasis is placed on reliability of design methods, simplicity of design, materials selection, and consideration of the rock formation properties and variability of those properties throughout the emplacement areas. Repository host-rock physical features and thermal-mechanical properties are summarized in design documents. Inputs to the design from field and laboratory testing include geotechnical data and evaluations of the sufficiency of existing data to support engineering design and performance assessment. The design documentation also includes fracture geometry parameters; rock density and porosity data; intact rock physical, mechanical, and thermal parameters; rock mass quality estimates; and estimated rock mass physical, thermal, and mechanical properties. Ranges or distributions for geotechnical and design parameters, including uncertainties, and spatial and temporal variability are also summarized in the design documentation. Rock properties used for engineering design calculations are presented in Section 1.3.3 (BSC 2007f, Sections 6 and 7; BSC 2007e, Section 6.2).

Where necessary, thermal and mechanical rock properties used in design of the openings, ground support, and thermal-mechanical interactions are reported separately for lithophysal and nonlithophysal rock. Emplacement drifts are located in the two major Topopah Spring Tuff subunit categories that comprise the repository (Section 1.1.5.1): lithophysal tuff, with approximately 80% of the emplacement areas in the lower lithophysal unit and 5% in the upper lithophysal unit, and nonlithophysal tuff, with approximately 10% of the emplacement areas in the middle nonlithophysal unit and 5% in the lower nonlithophysal unit (Figure 1.3.4-2). In the lithophysal rock structure, the reported compressive strength varies as a function of porosity and sample size. The unconfined compressive strength values vary from about 10 MPa to about 30 MPa (Table 1.3.3-2) (BSC 2007e, Sections 4.3 and 6.12, and Table 6-4).

The lithophysal rocks are characterized by approximately 5% to 40% void porosity in the form of lithophysae. The lithophysae are of varying shape, distribution, and size. They average about 10 cm in diameter but can be as large as 1.8 m in diameter. Additionally, the lower lithophysal unit is highly fractured. The fractures that interconnect lithophysae are predominantly vertically oriented with spacing of a few centimeters and trace lengths averaging about 0.3 m.

Physical features and properties for characterization of the rock include rock density, porosity, and fracture geometry. Rock density and porosity data derived from geophysics and laboratory measurements are summarized in design documentation. Site-specific field mapping and measurements are used to determine fracture geometry and orientation, abundance and size distribution of lithophysae, and rock mass quality.

The thermal properties of the Yucca Mountain lithostratigraphic rock units consist of intact and rock mass values of thermal conductivity, specific heat, and coefficient of thermal expansion (BSC 2007e, Tables 6.2 and 6.3). Factors affecting thermal properties include porosity, moisture content, temperature, sample size, fracturing, mineralogy, and loading conditions.

Mechanical properties for both intact rock and rock mass include: (1) elastic properties such as Young's modulus and Poisson's ratio, (2) strength parameters such as compressive and tensile strengths, cohesion, and internal friction and dilation angles used in the Mohr-Coulomb criterion, as well as those used in the nonlinear Hoek-Brown criterion, and (3) stiffness and strength data for rock joints. Intact rock and joint properties are used in a discontinuum modeling approach, while the rock mass properties are used in a continuum modeling approach. Rock mass mechanical parameters for lithophysal rock are summarized in Table 1.3.3-2. Rock mass mechanical parameters for nonlithophysal rock are summarized in Table 1.3.3-3.

The rock mass mechanical behavior of the nonlithophysal units is controlled primarily by the fractures in these units, and the mechanical properties of rock fractures or joints have been identified and documented. These include fracture elastic parameters (normal and shear stiffness), peak and residual strength (friction angle and cohesion), and volumetric behavior (dilation angle). The major factors affecting these parameters include fracture roughness, sample size, surface mineralogy, temperature, and chemical or mechanical degradation of asperities. When deriving rock mass elastic and strength properties for nonlithophysal rock, field-measured fracture and rock conditions are key factors in addition to intact rock properties.

Site-specific field testing includes data from the Single Heater Test, the Drift Scale Test, rock mass mechanical field tests (borehole jack, plate loading, and in situ slot tests), and monitoring of tunnel deformation and steel sets,.

1.3.4.4.1 System Description

System Functions—Maintaining stable repository openings to enhance personnel safety facilitates operations by minimizing maintenance requirements and allows for drip shield installation and inspection. The ground support system functions provide the stable repository openings by providing a drift lining that limits loosening of rock and a keyblock anchoring system that limits rockfall.

Initial Ground Support Description—The initial ground support is used as necessary to provide worker safety until the final ground support system is installed. The initial ground support consists of carbon steel frictional rock bolts, such as split sets, and wire mesh based on industry standard materials (carbon steel). Rock bolts with a length of 1.5 m are installed in a square-grid pattern (minimum of four bolts in each row), with a spacing of 1.5 m in conjunction with wire mesh that has a grade of W2 × W2 and 100-mm center-to-center spacing. The initial ground support is installed in the drift crown only, immediately following excavation. The wire mesh is removed prior to installation of the final ground support, while the initial rock bolts remain in place. The purpose of this initial ground support is to protect personnel from loosened rock during the tunneling process, as well as to protect the geologic mapping personnel that follow behind the tunnel boring machine. Consistent with mining industry practice, field engineering determines the extent of the initial ground support.

Final Ground Support Description—The final ground support is installed prior to the drifts being equipped with electrical and communications equipment and invert structures. Radially oriented friction rock bolts, with faceplates, fasten overlapping perforated steel sheets with approximately 240° coverage around the tunnel above the invert (Figure 1.3.4-7). Friction rock bolts are used to provide a shearing contact or frictional resistance between the rock bolt hole and the bolt surface. This type of bolt is particularly effective in the lithophysal rocks, where the surface contact of the bolt to the bore hole may not be continuous due to the lithophysal voids. The combination of frictional resistance and mechanical interlock generated along the full length of the contact between the friction bolt and the rock provides adequate ground support. The 3-m-long friction-type rock bolts (e.g., Super Swellex-type) spaced at 1.25 m provide adequate factors of safety (1.6 to 11.6) to prevent the dislodging of a rock block as a result of a preclosure seismic event with a mean annual probability of exceedance of 10^{-4} (beyond design basis ground motion (BDBGM) event; see "Seismic Loads" in Section 1.3.4.4.1.2). The design basis for ground support is the DBGM-2 event (mean annual probability of exceedance of 5×10^{-4}), but the design is also checked against an event with a mean annual probability of exceedance of 10^{-4} as part of evaluating design sensitivity to seismic events (BSC 2004a, Sections 6.3.4 and 6.3.5).

The steel liner is composed of 3-mm-thick perforated sheets (i.e., Bernold-type sheets). The steel sheeting provides a confinement to the rock surface around the upper two-thirds of the drift surface, limiting the initiation of loosening or raveling of the rock surface and any subsequent rockfall. This function is particularly important in the lithophysal rocks, where rock block size is small (on the order of inches). The small perforations or slotting of the steel sheet are sufficient to allow air circulation and drying of the rock surface but small enough that most rock particles in the lithophysal rock, where rock block size is small (on the order of inches), cannot pass through the openings.

Calculations show that the combination of rock bolts and steel sheets provides ample support, even in scenarios with blocks in the most unfavorable orientation and with the rock bolts penetrating through the peaks of the unstable blocks, resulting in shorter anchored lengths (BSC 2004a, Sections 6.3.5 and 6.3.6).

Both the friction-type rock bolts and the perforated steel sheets are made of Stainless Steel Type 316. This material is corrosion resistant and is chosen based on the potential corrosion mechanisms that may occur in the repository environment, including dry oxidation, humid-air corrosion, aqueous corrosion, pitting and crevice corrosion, stress corrosion cracking, hydrogen embrittlement, and microbially influenced corrosion. The stainless steel rock bolts and perforated stainless steel sheets are expected to fulfill their functions during the preclosure period without excessive corrosion (BSC 2003c, Sections 7.3 and 7.4).

1.3.4.4.1.1 Design Criteria

Design criteria are specified for ground support to provide worker safety and operational efficiency. These functions are neither ITS nor ITWI. The following criteria are applicable to the design of the ground support system in emplacement drifts:

- The ground support is designed to maintain equipment operating envelopes throughout preclosure for emplacement drifts.
- The initial ground support is designed to accommodate geologic mapping of emplacement drifts. Initial ground support allows direct access to the drift wall for geologic observations and mapping. Installation of final ground support follows after completion of the mapping activities.
- The ground support is designed for the appropriate worst-case combination of in situ, thermal, seismic, construction, and operational loads for the preclosure period.

- The ground support for emplacement drifts considers safety margin in design.
- The ground support uses materials of types and quantities that do not have adverse long-term effects on waste isolation and are accounted for in the performance assessment.
- The ground support is designed to withstand an earthquake with a mean annual probability of exceedance of 5×10^{-4} (DBGM-2).
- The ground support for emplacement drifts is designed to function without planned maintenance during the operational life of the subsurface facility of up to 100 years, while providing for the ability to perform unplanned maintenance in the emplacement drifts on an as-needed basis. However, maintenance will require the temporary relocation of the emplaced waste packages to another emplacement drift. Depending on the location of the affected area and on temporary engineering and administrative controls that could be put in place for personnel protection against radiation, complete evacuation of drift contents may not be necessary to perform maintenance.

Design Considerations—Ground support is a static system interfacing with the natural and engineered environments. It is designed to perform its function in that environment for the entire preclosure period. The environmental conditions presented below are addressed in the design considerations for longevity of the emplacement drift ground support.

The most important environmental conditions in emplacement drifts related to longevity of steel ground support components are temperature, relative humidity, and air and water chemistry. A testing program to conduct corrosion testing of the proposed ground support materials may include a testing alcove or section of the observation drift to be utilized for monitoring the corrosion or degradation of rock bolts (BSC 2008d, Section 3.3).

The drift wall temperature profiles show that the highest temperature of the emplacement drift walls is less than 107°C, which is less than the 200°C limit. The preclosure emplacement drift wall temperature varies from approximately 45°C at 100 m to approximately 91°C at 600 m along the emplacement drift and generally decreases as a function of ventilation time. For an 800-m emplacement drift, the maximum drift wall temperature during preclosure reaches approximately 107°C. The rock bolts and perforated sheets are designed to support the rock over the temperature range described above. Impacts of higher temperatures on ground support have been analyzed and indicate negligible effect on displacement.

Ventilation affects the relative humidity. During the preclosure period, the drifts are ventilated with outside air. Consequently, the relative humidity inside the drift remains low. In the event that ventilation is interrupted, the period of no ventilation and increased relative humidity is short compared to the service life of the ground support and does not impact its performance. The relative humidity inside a bolthole is higher than that inside the emplacement drift. The stainless steel friction-type rock bolts with the specified bolt thickness provide resistance for potential corrosion attack in this high relative humidity environment and preserve performance for the service life of the system during the preclosure period.

Potential corrosion of ground support due to seepage water and air chemistry is also considered in the design of the system. The most important characteristics of seepage water chemistry related to steel corrosion are chloride, sulfate, bicarbonate, and pH. Sulfate and chloride ions are considered to be the most corrosive of the common ions found in naturally occurring waters, with sulfate generally regarded as the most corrosive, while bicarbonate and carbonate ions are considered corrosion inhibitors (Tilman et al. 1984, p. 16). Representative values for the concentrations of chloride, sulfate, and bicarbonate and for pH value in the initial fracture and matrix water are used to evaluate potential corrosion rates, which are factored into the design of the system. The air in the emplacement drifts is composed of outside air drawn from various intake shaft locations at the top of Yucca Mountain and through the three ramps; thus, the composition of the air in these drifts is similar to the composition of the outside air. The ventilation rate of approximately 15 m^3/s in each emplacement drift is the dominant air exchange. This ventilation air rate far exceeds the air exchange rate inside the rock mass. Therefore, emplacement drift air chemistry is nominally outside air that is noncorrosive, and ventilation air chemistry has no discernible impact on the corrosion of ground support components (BSC 2003c, Section 6.2.3).

The analysis of the emplacement drift ground reaction curves and direct modeling of ground support using structural elements within the models is summarized below.

Ground Reaction Curve Analysis—Evaluation of the excavation openings using ground reaction curve analysis shows that the openings equilibrate in a self-supporting mode and the drift remains stable with no further supports required. Thus, the role of ground support is to maintain the excavation surface condition and integrity of the rock mass against loosening or deterioration during the preclosure time period.

Rock Bolt Load Determination—A series of calculations of the estimated loading of friction rock bolts and the associated deformations of the excavations is conducted for the rock mass strength and loading variations. The force-displacement characteristics of the rock bolt structural elements are derived and calibrated from pull tests on friction rock bolts. Straining of the overlapped surface sheeting is derived from the circumferential strain on the opening surface due to predicted radial deformations. From these analyses, in the worst case, the loads are well below the anchorage capacity of the friction rock bolts in both the lithophysal and nonlithophysal rocks. These loads are a small percentage of the loading from in situ and thermal stresses.

1.3.4.4.1.2 Model Selection for Ground Support Analysis

A number of different numerical modeling methods are required for analysis of ground support issues depending on the particular rock type (e.g., lithophysal or nonlithophysal) and the loading conditions (e.g., quasistatic or dynamic) to be examined.

In general, two-dimensional equivalent continuum-based models are used for analysis of lithophysal rocks in which a standard Mohr-Coulomb plasticity material model describes the mechanical response of the rock mass. A two-dimensional continuum model (FLAC V. 4.0. STN: 10167-4.0-00) is used for equivalent continuum parameter studies for cross-sectional analysis of emplacement drifts. The variability of rock mass quality and the associated elastic and strength properties are based primarily on lithophysal porosity. Parametric studies are conducted using a range of properties that reflect the range of rock mass porosities encountered in the Enhanced Characterization of the Repository Block Cross-Drift excavations.

Both two- and three-dimensional equivalent continuum models are used for analysis of the nonlithophysal rock mass but only the two-dimensional continuum (FLAC) model is used for equivalent continuum parameter studies for cross-sectional analysis of emplacement drifts. Rock mass property estimates for the nonlithophysal rock are developed from in situ rock mass classifications using an empirical method. A summary of the modeling methods used for the ground support studies is given in Table 1.3.4-1.

The repository excavations are initially loaded by the in situ gravitational stresses. At Yucca Mountain, the vertical gravitational stress is the maximum component, while the principal horizontal components vary somewhat, depending on the topography.

The stresses applied to the emplacement drifts accounted for in the ground support design include three basic categories: in situ, seismic, and thermal stresses. Construction loads (i.e., tunnel boring machine weight) and operational loads (i.e., emplacement equipment and waste package weights) do not have an impact on the ground support systems.

In Situ Stress—The in situ stress state is measured at the excavation location, showing the vertical component to be the maximum principal stress (s1), which is taken to be equal to the overburden load at that location. The minimum (s3) and intermediate (s2) principal stresses are subhorizontal and oriented at N105E and N15E directions, respectively. The ratio of the minimum principal stress to maximum principal stress (s3:s1) is 0.36, and the ratio of the intermediate principal stress to the maximum principal stress (s2:s1) is 0.62. These values are within the bounding limits used for ground support design.

Seismic Loads—The ground motions associated with an earthquake (a mean annual probability of exceedance of 10^{-4}) are used to determine the impact of seismic shaking on emplacement drift stability. Repetitive seismic loading is also examined for applied ground motions with a mean annual probability of exceedance of 5×10^{-4}. The analyses of drift degradation and rockfall due to seismic loading utilize discrete element analyses to estimate the amount of rockfall that may be caused by seismic ground motions expected at the emplacement drifts. Preclosure seismic hazard analyses are described in Section 1.3.2.5.1. Postclosure drift stability analyses are discussed in Section 2.3.4.

Thermally Induced Stress—Heat generated by the waste packages results in temperature increases in the rock mass surrounding the emplacement drifts. This temperature rise results in thermal expansion of the rock mass surrounding the emplacement drifts and a resultant thermal stress increase that is proportional to the rock mass deformation modulus and thermally induced strain. The thermal stress at maximum temperature is included in the estimation of drift stability.

In addition to the base thermal loading, transient temperature increases caused by ventilation interruption are considered (Section 1.3.5.3). However, transient spikes in temperature above the normal operating temperature ranges (Table 1.3.5-2) do not have an impact on the stability of the emplacement drifts.

1.3.4.4.1.3 Summary of Ground Support Analyses

The excavations have been demonstrated to be self-supporting with safety factors of 2 or greater against collapse modes for the rock mass quality conditions. Therefore, the primary role of ground support at Yucca Mountain is to prevent deterioration and loosening of the rock mass tunnel periphery. The stainless steel components provide sufficient corrosion resistance for the ground support service life during the preclosure period. The ground support system is designed to last at least 100 years without planned maintenance even in the severe environmental conditions expected in the emplacement drifts.

The friction rock bolts and overlapped surface sheeting perform satisfactorily under in situ, thermal, and seismic loads. Design analysis results are within the specified factors of safety.

The surface sheeting is structurally capable of supporting potentially loosened rock between rock bolts and has the deformation capacity to withstand deformation-induced strains during transient loading.

1.3.4.4.2 Operational Processes

The ground support for the emplacement drifts is designed to function without planned maintenance for the preclosure period even in the severe environmental conditions to be found in the emplacement drifts. Benefits of repairs and replacements would be weighed against potential radiological exposures and other operational concerns specific to the situation. However, these repairs and replacements are intended as contingencies and not as planned activities for emplacement drift ground support.

During the preclosure period, observation and instrumentation readings are used as bases for assessing the performance of the ground support and opening stability and as bases for maintenance decisions. The primary assessment method is observation of ground support and tunnel conditions. Because of the environmental conditions related to heat and radiation after waste is emplaced in the drifts, observations are made remotely.

Repair activity in an active emplacement drift would likely require removal of all waste packages from the affected drift prior to any repair work. Repair or maintenance of the ground support involves standard procedures typical of mining or civil tunneling operations. The repair operation typically involves removal of any failed ground support, scaling and removal of loosened rock, and reinstallation of support. Drift conditions are analyzed before a decision to re-emplace waste is made. It is possible that decisions for not emplacing waste packages along a specific area of the emplacement drift are also made.

1.3.4.4.3 Design Codes and Standards

The following codes and standards are applicable to the emplacement drift ground support:

- ASTM A 36/A 36M-05, *Standard Specification for Carbon Structural Steel*
- ASTM A 82-01, *Standard Specification for Steel Wire, Plain, for Concrete Reinforcement*

- ASTM A 276-06, *Standard Specification for Stainless Steel Bars and Shapes*
- ASTM F 432-95, *Standard Specification for Roof and Rock Bolts and Accessories*.

1.3.4.5 Invert System

[NUREG-1804, Section 2.1.1.2.3: AC 3(1), AC 5(3), AC 6(1); Section 2.1.1.7.3.3(II): AC 3(1), (2); Section 2.1.1.7.3.3(III): AC 1(1), (2), (3), (13)]

1.3.4.5.1 System Description

The invert structure consists of two components: the steel invert structure and the ballast fill. Figures 1.3.4-8, 1.3.4-9, and 1.3.4-10 illustrate the design and details for the invert structure components. The ballast fills the voids between the drift rock and the invert steel frame, and the level of the ballast is brought up to the top level of the steel. Steel and crushed tuff ballast materials are selected for the invert components based on structural strength properties, compatibility with the emplacement drift environment, and expected longevity.

The steel invert structure provides a platform that supports the emplacement pallets, waste packages, and drip shields. The steel invert structure also provides a platform that supports the crane rail system for operation of the TEV for emplacement, recovery, and potential retrieval of waste packages, and for operations of the drip shield emplacement gantry and the remotely operated inspection vehicles.

The steel invert structure supports repository preclosure operations that include waste package emplacement, recovery, and potential retrieval during the 100-year preclosure period. The performance of the invert structure will not be affected by corrosion due to the low relative humidity in the emplacement drifts during the preclosure period and the specification of corrosion resistant steel that conforms to ASTM A 588/A 588M-05, *Standard Specification for High-Strength Low-Alloy Structural Steel, up to 50 ksi [345 MPa] Minimum Yield Point, with Atmospheric Corrosion Resistance* (BSC 2007g, Section 4.3.6 and Attachment B).

The steel invert structure consists of transverse beams interconnected to four longitudinal beams (see typical invert plan and elevation in Figure 1.3.4-8). The transverse beams span the width of the drift at the top of the invert section. The transverse beams are bolted to the longitudinal beams. The two outermost longitudinal beams at either end of the invert section are attached to and rest on stub columns that transfer the loads to the substrate rock. The stub columns with base plates are anchored to the drift floor with rock anchors. The outer sections of the transverse beams are terminated on rolled side plates that are also anchored to the drift rock wall with rock anchors (Figure 1.3.4-10). Installation of the steel invert structure includes aligning, shimming, and anchoring the attached stub columns and rolled side plates to the drift rock wall (Figure 1.3.4-9). The waste package emplacement pallet, loaded with a waste package, rests directly on the steel invert structural frame (Figure 1.3.4-8). The steel invert structural frame will also support the drip shield. The invert steel structure is designed to accommodate the relatively small structural displacement expected to occur in the emplacement drifts. Slotted holes are provided at bolt connections, as well as half-inch expansion joints between the rail runway beams and quarter-inch expansion joints between the longitudinal beams (Figure 1.3.4-10) (BSC 2007g, Section 6.1.2).

The steel invert structure is designed for construction loads, waste package emplacement, recovery, and potential retrieval loads, drip shield loads, thermal loads, and seismic loads (BSC 2007g, Section 4.3.2). The crane rails are mounted on the two outer longitudinal beams or rail runway beams. The rails support the operation of the TEV, remotely operated inspection vehicles, and the drip shield gantry. The crane rail is designed in conformance with ASTM A 759-00, *Standard Specification for Carbon Steel Crane Rails*, and following the crane rail tolerance specifications of ASME NOG-1-2004, *Rules for Construction of Overhead and Gantry Cranes (Top Running Bridge, Multiple Girder)*. The crane rail is 171 lb/yd (BSC 2007g, Section 6).

The ballast material is crushed tuff from the repository excavations, processed so it is well-graded material (Figure 1.3.4-8). The ballast material is compacted to minimize long-term settlement. During postclosure, waste package, pallet, and drip shield loads will gradually transfer (due to corrosion of the carbon steel) from the steel invert structure to the invert ballast. A discussion of the postclosure performance of the invert ballast is presented in Section 2.3.4.1. Analyses have been performed to examine the dynamic shaking effects on the invert and the mechanical response of the waste package, pallet, and drip shield. The analyses indicate that these effects are minor and that uneven settlement of the invert ballast from seismic events does not compromise the capability of the drip shield to support static loads, as discussed in FEP 2.1.06.05.0B, Mechanical Degradation of the Invert (Table 2.2-5).

The invert ballast helps maintain the emplaced waste packages in a nominal horizontal position during the postclosure period (BSC 2008b, Table 1, Derived Internal Constraint 02-07).

The invert structural steel frame is prefabricated in modules to facilitate installation of the structure in the emplacement drift. Following installation of the modules, the ballast is placed in lifts and compacted to specifications. Completion of the invert structure assembly is followed by installation and alignment of the crane rails. A third rail that provides electrical power to the TEV, drip shield emplacement gantry, and inspection and performance confirmation vehicles is installed following installation of the invert structure.

Longitudinal expansion joints are provided in the crane rail using a mitered gap. Expansion is accounted for in the longitudinal beam using a gap between the members and longitudinal slotted holes in the splice plates (Figure 1.3.4-10). Expansion in the transverse beams is accounted for by the slotted holes in the top plate connected to the vertical support, as shown in Figure 1.3.4-10.

1.3.4.5.2 Operational Processes

The invert structure is a static component providing a foundation upon which other components are supported. There are no invert operational processes. Emplacement drift invert structures are designed to minimize the need for maintenance during the preclosure period.

1.3.4.5.3 Safety Category Classification

The emplacement drift invert structure is non-ITS because it is not relied on to prevent or mitigate a Category 1 or Category 2 event sequence (Table 1.9-1). The emplacement drift invert structure is not classified as ITWI because no credit is taken for the diffusivity of the invert ballast (Table 1.9-8).

1.3.4.5.4 Administrative or Procedural Safety Controls to Prevent Event Sequences or Mitigate Their Effects

There are no administrative or procedural safety controls applicable to the steel invert structure, crane rail, and ballast to prevent event sequences or mitigate their effects.

1.3.4.5.5 Design Criteria and Design Bases

Design criteria applicable to the invert steel structure are as follows:

- The invert structure is designed for construction loads, waste package emplacement pallet and waste package loads, drip shield loads, thermal loads, and seismic loads.
- The invert structure is designed for the appropriate worst-case combinations of in-place, thermal, seismic, and operational loads.
- The invert structure supports the operational loads from the TEV, remotely operated vehicles, and the drip shield emplacement gantry.
- The emplacement drift invert structures are fabricated of materials that undergo minimal corrosion during the preclosure period.

Design criteria for the steel invert structure are in accordance with *International Building Code 2000* (ICC 2003) and *Manual of Steel Construction, Allowable Stress Design* (AISC 1997).

Design criteria applicable to the invert ballast are that it provides a nominally level surface that supports the drip shield, waste package, and waste package emplacement pallet for static loads and that limits degradation of these EBS components associated with ground motion (but excluding faulting displacements) after closure of the repository (BSC 2008b, Table 1, Derived Internal Constraint 02-07).

1.3.4.5.6 Design Methodologies

The steel invert structure is analyzed using conventional structural design methods (BSC 2007g).

Longitudinal beams and transverse support beams of the steel invert structure are designed with DBGM-2 or 2,000-year-return-period (5×10^{-4} annual exceedance frequency) seismic loads. The TEV rail and rail runway beams are designed with DBGM-1 or 1,000-year-return-period (10^{-3} annual exceedance frequency) seismic loads. Site-specific acceleration response spectra are developed at the repository horizon in the three orthogonal directions, two horizontals and one vertical. Seismic loads for the invert structure are computed based on the equivalent static load method in accordance with the requirements of NUREG-0800 (NRC 1989, Section 3.7.2). Since the lumped mass of the TEV is acting on the top of the crane rails as a single-degree-of-freedom model, the multimode factor is considered as 1.0, and the design acceleration is conservatively taken as the calculated peak spectral acceleration developed for the Yucca Mountain site at the repository elevation of the emplacement drifts (BSC 2007g, Section 4.3.2).

1.3.4.5.7 Consistency of Materials with Design Methodologies

The main components of the invert in the emplacement drifts are structural steel and ballast.

Material for the steel invert structure conforms to ASTM A 588/A 588M-05, *Standard Specification for High-Strength Low-Alloy Structural Steel up to 50 ksi (345 MPa) Minimum Yield Point, with Atmospheric Corrosion Resistance*. This material is selected because it is corrosion resistant and high-strength, low-alloy steel. Structural bolts conform to ASTM A 325-06, *Standard Specification for Structural Bolts, Steel, Heat Treated, 120/105 ksi Minimum Tensile Strength*; or ASTM A 490-06, *Standard Specification for Structural Bolts, Alloy Steel, Heat Treated, 150 ksi Minimum Tensile Strength*.

Crane rails for the TEV consist of ASTM A 759-00, *Standard Specification for Carbon Steel Crane Rails*, carbon steel material (BSC 2007g, Section 4.3.5.1).

Materials in the emplacement drift will also include the third-rail components. Materials for the third rail are commercially available and typically include a copper rail with wear strip and insulator. Specifications will ensure that postclosure requirements for committed materials are satisfied (BSC 2008b, Table 1, Derived Internal Constraint 02-06).

The ballast material for the emplacement drift invert structure is crushed tuff.The ballast material is well graded and compacted.

1.3.4.5.8 Design Codes and Standards

The following codes and standards are applied to the design of the invert steel structure, as shown in Figure 1.3.4-8:

1. Structural steel shapes and plates conform to ASTM A 588/A 588M-05, *Standard Specification for High-Strength Low-Alloy Structural Steel, up to 50 ksi (345 MPa) Minimum Yield Point, with Atmospheric Corrosion Resistance*.

2. The crane rail conforms to ASTM A 759-00, *Standard Specification for Carbon Steel Crane Rails*.

3. Rock anchors for anchoring steel to drift invert conform to ASTM F 432-95 (Reapproved 2001), *Standard Specification for Roof and Rock Bolts and Accessories* (ASTM 1995) (BSC 2007b, Section 4.2.13.7.1).

4. Structural steel bolts conform to ASTM A 325-06, *Standard Specification for Structural Bolts, Steel, Heat Treated, 120/105 ksi Minimum Tensile Strength,* or to ASTM A 490-06, *Standard Specification for Structural Bolts, Alloy Steel, Heat Treated, 150 ksi Minimum Tensile Strength*.

5. Welding is in accordance with the AWS D1.1/D1.1M:2006, *Structural Welding Code—Steel*.

1.3.4.5.9 Design Load Combinations

1.3.4.5.9.1 Loads

A number of loads are considered in the design of the steel invert structure (BSC 2007b, Section 4.2.13.5). Each type of load is described below; the letters in parentheses following the name of the load are used in the load combinations presented in Section 1.3.4.5.9.2.

Dead Loads (D)—Dead loads are those that remain permanently in place and include the weight of framing, permanent equipment, and attachments.

Live Loads (L)—Minimum live construction loads used for the design shall not be less than 500 psf.

Seismic Loads (E)—Longitudinal beams and transverse support beams of the steel invert structure are designed with DBGM-2 or 2,000-year-return-period (5×10^{-4} annual exceedance frequency) seismic loads. The TEV rail and rail runway beams are designed with DBGM-1 or 1,000-year-return-period (10^{-3} annual exceedance frequency) seismic loads (BSC 2007g, Section 3.2.4). In addition, steel invert structures connected to the subsurface emplacement drift walls undergo structural deformations that are imposed and controlled by the tunnel deformations caused by the seismic ground motion. Such actions are termed deformation-controlled and are evaluated and accounted for in the design of steel inverts in emplacement drifts.

Crane Loads (CL)—Since the TEV is a crane-based vehicle, crane supplier's information is used for the equipment weight, wheel loads, and lifted loads for the design of crane rails and supporting structural steel beams. Impact allowances are in accordance with *Manual of Steel Construction, Allowable Stress Design* (AISC 1997, Sections A4.2 and A4.3). The weight of the loaded equipment, such as the TEV, is considered simultaneously with the seismic loads. The horizontal and vertical inertial forces are obtained by multiplying the weight of the equipment by the appropriate accelerations. Design allowances for the crane rail are in accordance with ASME NOG-1-2004, *Rules for Construction of Overhead and Gantry Cranes (Top Running Bridge, Multiple Girder)*. Loads for the TEV control the design of the emplacement drift invert structure.

Waste Package Loads (WP)—For steel invert design, the weight of the Naval Long waste package or the transportation, aging, and disposal (TAD) canister waste package, which are the heaviest waste packages to be emplaced (both have the same weight), are used in the analysis (BSC 2007g, Section 4.3.2). The analysis also considers the load from either of these waste packages collectively with the estimated maximum weight of the waste package emplacement pallet.

Drip Shield Loads (DS)—Drip shields are installed after the completion of emplacement of all waste packages and prior to closure. Drip shield loads are considered in the design of the steel invert structure.

Temperature Loads (T)—The steel invert structure design includes the effects of variations in temperatures. Transient peak drift wall temperature during off-normal events in the emplacement drifts is not expected to exceed 200°C (Table 1.3.1-2). Thermal analyses indicate that, during normal operations, the temperature of the air exiting the emplacement drifts with lengths up to 800 m is no more than 99.8°C. Expansion joints are provided in the longitudinal members of the steel invert structure and the rails in emplacement drifts (BSC 2007h). Expansion joints for the invert steel are designed for temperatures up to 392°F (200°C) to prevent buckling of the steel and potential impacts to waste package emplacement pallet and drip shield positions and alignments within the emplacement drift (BSC 2007g, Section 6.1.2).

Ventilation Pressure Load (P)—Maximum ventilation differential pressure is equivalent to the potential maximum primary fan pressure transmitted when the barrier and turnout bulkheads are closed. This load does not apply to the invert structure design.

1.3.4.5.9.2 Load Combinations

Definitions of standard load terms are included in Section 1.3.2. The following load combinations and allowable stresses are considered in the design of the steel invert structure in emplacement drifts:

- S = D + CL + L + P
- S = D + CL + L + P + T
- S = D + WP + DS + L + P
- S = D + WP + DS + L + P + T
- S = D + CL + L + P + E
- S = D + CL + L + P + T + E
- S = D + WP + DS + L + P + E
- S = D + WP + DS + L + P + T + E.

S is allowable stress, as permitted by *Manual of Steel Construction, Allowable Stress Design* (AISC 1997).

1.3.4.6 Waste Package Emplacement Pallet System

[NUREG-1804, Section 2.1.1.2.3: AC 3(1), AC 6(1), (2); Section 2.1.1.7.3.3(II): AC 3(1), (2); Section 2.1.1.7.3.3 (III): AC 1(1), (2), (3)]

The waste package emplacement pallet supports the waste package during handling, transport, and emplacement during the preclosure period and while emplaced during the postclosure period. The loaded waste package emplacement pallet is lifted from the bottom of the Alloy 22 (UNS N06022) plates.

The waste packages are required to be retrievable during the preclosure period. Therefore, the waste package emplacement pallet is designed to remain in a condition and position such that it can be lifted by the TEV at any time throughout this period.

During preclosure and after closure, the emplacement pallet prevents the waste package from coming into contact with the invert of the drift. For the static design load, the emplacement pallet maintains the waste package emplacement nominal position for at least 300 years and maintains a nominally horizontal waste package emplacement for 10,000 years (BSC 2008b, Table 1, Derived Requirement 08-02). The postclosure analysis of the mechanical performance of the emplacement pallet is addressed in Section 2.3.4.5. Analysis of the performance of the pallet during seismic events indicates that it will deform plastically under impact loading from the waste package but will continue to fulfill its function of supporting the waste package (Sections 2.3.4.1 and 2.3.4.5).

1.3.4.6.1 System Description

There are two sizes of emplacement pallet. One is designed to accommodate all waste package configurations except for 5-DHLW/DOE Short waste packages. A second, short emplacement pallet configuration is specifically developed for the 5-DHLW/DOE Short waste package. The discussions in this section apply to both waste package emplacement pallet sizes unless otherwise specifically noted.

Both sizes of waste package emplacement pallets (Figures 1.3.4-11 and 1.3.4-12) are fabricated from Alloy 22 plates welded together to form the waste package supports. Using the same material on the plates as used in the waste package surface minimizes the potential for galvanic corrosion at the areas of contact between the waste package and the emplacement pallet. A standard nomenclature has been established for referring to the components of the waste package emplacement pallet. This nomenclature is shown in Table 1.3.4-2. Two waste package supports are connected by square Stainless Steel Type 316 tubes to form the waste package emplacement pallet. Each waste package support includes a V-shaped cradle to accommodate all waste package diameters. The emplacement pallet is shorter than the waste packages; therefore, the waste package is supported on the outer corrosion barrier. The waste package is not mechanically attached to the pallet. The fact that the waste package is longer than the emplacement pallet allows the waste packages to be placed end-to-end at close distances without interference from the pallets.

An isometric view of the waste package emplacement pallet supporting a waste package is shown in Figure 1.3.4-13.

1.3.4.6.2 Operational Processes

The waste package emplacement pallet is a means of handling, transporting, and providing long-term support of the waste package. Section 1.3.4.8 provides information regarding operations involving the pallet.

The emplacement drift invert is designed to accommodate the design loads and spatial constraints associated with the emplacement pallet and waste package, as described in Section 1.3.4.5.

The waste package emplacement pallet is designed so as not to need maintenance during preclosure.

The waste package and the emplacement pallet will be monitored in the postemplacement period with the use of remotely operated vehicles. Periodic inspections will be controlled by procedure. A final inspection will be done prior to installation of the drip shields at closure to confirm that the waste packages and pallets have not been impacted by rockfall and that the conditions of these components assumed in TSPA for initiation of the postclosure performance period have not been compromised (BSC 2008b, Table 1, Derived Internal Constraint 03-24).

1.3.4.6.3 Safety Category Classification

The waste package emplacement pallet is classified as non-ITS since it is not relied on to prevent or mitigate the effects of a potential Category 1 or 2 event sequence in waste package drop analyses while being loaded on the pallet at the surface nuclear facilities (Section 1.9).

The waste package emplacement pallet is classified as non-ITWI because it does not have a barrier function and it does not reduce the potential for damage to the waste package during a seismic event. However, the emplacement pallet maintains the waste package in a nominally horizontal emplacement for 10,000 years (BSC 2008b, Table 1, Derived Internal Constraint 08-02). Analysis of the performance of the pallet during seismic events indicates that it will deform plastically under impact loading from the waste package but will continue to fulfill its function of supporting the waste package (Sections 2.3.4.1 and 2.3.4.5). The waste package emplacement pallet also prevents continuous contact between the waste package and differing materials, which prevents galvanic corrosion of the waste package (BSC 2008b, Table 1, Derived Internal Constraint 08-04).

1.3.4.6.4 Administrative or Procedural Safety Controls to Prevent Event Sequences or Mitigate Their Effects

There are no administrative or procedural safety controls associated with the waste package emplacement pallet.

1.3.4.6.5 Design Criteria and Design Bases

1.3.4.6.5.1 Preclosure Requirements for the Waste Package Emplacement Pallet

Discussed below are the preclosure design bases and corresponding design criteria for the waste package emplacement pallet.

Design Basis and Performance Requirement—The waste package emplacement pallet supports the waste package, providing only Alloy 22–to–Alloy 22 contact surfaces.

Design Criterion—Figures 1.3.4-11 and 1.3.4-12 show that each waste package support includes a V-shaped cradle, fabricated from Alloy 22 plates, to accommodate all waste package diameters. This design feature provides the Alloy 22 contact surface for the waste package, which meets the performance requirement.

Design Basis and Performance Requirement—The waste package emplacement pallet retains its form sufficiently to allow lifting of the waste package by the pallet after exposure to applicable loads under normal operating conditions.

Design Criterion—The two normal condition loads for the waste package emplacement pallet are the horizontal lifting of the emplacement pallet loaded with the waste package and the emplacement pallet under the waste package static load as emplaced in the drift. The calculation results for the waste package emplacement pallet lifting shows that the maximum stress intensity (difference between first and third principal stresses) in the pallet due to horizontal lifting is less than the corresponding Alloy 22 yield strength. Therefore, no permanent deformation takes place in the waste package emplacement pallet as a result of a horizontal lift. A second calculation, degraded waste package emplacement pallet static load evaluation, indicates that the maximum stress intensity in the emplacement pallet while loaded with the heaviest waste package is less than the corresponding Alloy 22 yield strength. Therefore, no permanent deformation takes place on the waste package emplacement pallet while emplaced in the drift. The stress and yield strength values at higher temperatures also indicate similar results. Hence, for the lifting and static loads of the waste package on the pallet, the requirement stated above is met.

Design Basis and Performance Requirement—Configuration of the waste package emplacement pallet facilitates emplacement of the waste packages at short distances from each other to facilitate line loading of the drift.

Design Criterion—Figure 1.3.4-13 shows that the pallet is designed for lifting by the plates located below the upper structural tubes. Additionally, the waste package is longer than the emplacement pallet. The combination of these two features removes any physical limit for the minimum spacing between waste packages due to the emplacement pallet design.

1.3.4.6.5.2 Postclosure Requirements for the Waste Package Emplacement Pallet

Discussed below are the postclosure design bases and corresponding design criteria for the waste package emplacement pallet.

Performance Requirement—The waste package emplacement pallet supports the waste package, as needed for TSPA for at least 10,000 years after closure (BSC 2008b, Table 1, Derived Internal Constraint 08-02).

The pallet is evaluated statically loaded with the waste package. The analysis conservatively assumes that the plate thicknesses are reduced in order to include the effects of corrosion during the 10,000 years after closure. The average maximum stress intensity in the pallet due to static waste package load is 276 MPa at room temperature. The corresponding Alloy 22 allowable design stress intensity is 310 MPa. Since the calculated value is less than the allowable value, no permanent deformation takes place on the waste package emplacement pallet. The stress and yield strength values at higher temperatures also indicate similar results. Hence, the performance requirement is met.

Performance Requirement—The waste package emplacement pallet prevents continuous contact of the waste package with anything other than the Alloy 22 waste package emplacement pallet surfaces during and after exposure to the loads defined by the nominal repository performance scenario.

The degraded waste package emplacement pallet static load calculation shows that the pallet components do not experience any permanent deformation. Therefore, the pallet prevents contact of the waste package with anything other than Alloy 22, and the performance requirement is addressed.

1.3.4.6.6 Design Methodologies

The stress magnitudes, deformations, and potential failure mechanisms for the waste package emplacement pallet are evaluated using finite element analysis and the principles of mechanics of materials.

1.3.4.6.7 Consistency of Materials with Design Methodologies

The main function of the emplacement pallets is to support the waste package during emplacement, preclosure, and postclosure periods. This prevents the waste package from coming in contact with the drift invert and, therefore, prevents direct exposure to invert moisture or materials that may induce corrosion. Long-term corrosion resistance is required so that the pallet can perform its structural support function with high reliability for at least 10,000 years after closure. The waste package support material (Alloy 22) provides the long-term corrosion resistance and the means for an identical material contact with the waste package outer corrosion barrier. The connecting stainless steel tubes provide structural strength and also long-term resistance to external loads on the pallet. The general corrosion rate of the stainless steel tubes is low enough for the repository-relevant environments that the tubes will remain structurally sound throughout the preclosure period and the 10,000 years after closure.

1.3.4.6.8 Design Codes and Standards

For manufacturing purposes, appropriate sections of *2001 ASME Boiler and Pressure Vessel Code* (ASME 2001) are used. The following sections of *2001 ASME Boiler and Pressure Vessel Code* (ASME 2001) and other ASME standards are used:

- *2001 ASME Boiler and Pressure Vessel Code* (ASME 2001, Section II)
- *2001 ASME Boiler and Pressure Vessel Code* (ASME 2001, Section III, Division I, Subsection NF/NCA)
- *2001 ASME Boiler and Pressure Vessel Code* (ASME 2001, Section V)
- *2001 ASME Boiler and Pressure Vessel Code* (ASME 2001, Section IX)
- ASME Y14.5M-1994, *Dimensioning and Tolerancing*
- ASME B46.1-1995, *Surface Texture (Surface Roughness, Waviness, and Lay*)
- ASME NQA-1-2000, *Quality Assurance Requirements for Nuclear Facility Applications*, Subparts 2.1 and 2.2.

In addition, welding standards ANSI/AWS A2.4-98, *Standard Symbols for Welding, Brazing, and Nondestructive Examination*, and ANSI/AWS A5.32/A5.32M-97, *Specification for Welding Shielding Gases*, are also used (BSC 2003d, Section 4.1).

1.3.4.6.9 Design Load Combinations

The waste package emplacement pallet structural performance is evaluated in terms of stress magnitudes, deformations, and potential failure mechanisms using finite element analysis and the principles of mechanics of materials (Section 2.3.4.5).

Waste Package Emplacement Pallet Lift—An upper-bound vertical acceleration of 1 m/s^2 (total upward acceleration being 10.81 m/s^2 including gravity) is established for the lifting of the waste package emplacement pallet. However, since the TEV lifts the waste package emplacement pallet at a maximum hoisting speed of 9 ft/min, the vertical acceleration limit established for the waste package emplacement pallet conservatively bounds the hoisting velocity of the TEV.

Horizontal Drop with Waste Package Emplacement Pallet—A discussion of the lifting height limitations that are included in the TEV design to minimize the potential and severity of a drop are included in Section 1.3.3.5.1. Waste package drops for surface and subsurface facilities are described in Section 1.6. Structural analyses ensure that the design bases for the waste package, as defined in Section 1.9, are met.

1.3.4.7 Drip Shield System

[NUREG-1804, Section 2.1.1.2.3: AC 3(1), AC 5(3), AC 6(1), (2); Section 2.1.1.7.3.3(II): AC 1(1); AC 3(1), (2); Section 2.1.1.7.3.3(III): AC 1(1), (2), (3), (11)]

Drip shields are installed over the waste packages as part of the repository closure process. After closure and after the heat produced by the waste package has dissipated, moisture may enter the emplacement drifts in liquid form or as water vapor. The primary function of the drip shield is to divert the liquid moisture that drips from the drift walls around the waste packages and to the drift invert, increasing the longevity and prolonging the structural integrity of the waste packages. The drip shields are designed to link together, forming a single, continuous barrier to advective water flow for the entire length of the emplacement drift. Table 1.3.4-3 summarizes the dimensions and material definitions for the drip shield design.

The design requirements for drip shields include corrosion resistance, as well as structural strength. Corrosion resistance is required so the drip shields can perform their moisture diversion function with high reliability during the postclosure period prior to their structural degradation. The drip shields must also withstand the static loads from rubble resulting from drift degradation (Section 2.2).

1.3.4.7.1 System Description

All drip shields are uniformly sized so that one design can enclose any of the waste package configurations. The drip shield sections are designed to accommodate an interlocking feature to prevent separation between the contiguous segments. This feature consists of an overlapping section with connector guides between the drip shield segments. The minimum lift height required to interlock the drip shield segments is 40 in. for clearance between the two drip shield segments. The drip shield base plates rest on the transverse support beams of the drift invert and inside of the rail runway beams. The drip shield is designed so that, when in its position, it does not contact the emplacement pallet, the waste package, or the rail runway beams (Figure 1.3.4-4).

Details of the drip shield interlocking features and the assembly are shown in Figures 1.3.4-14 and 1.3.4-15. An isometric view of the drip shield is provided in Figure 1.3.4-14.

Several major components comprise the drip shield. A standard nomenclature was established for referring to these components. A description of these components and the standard nomenclature is presented in Table 1.3.4-4.

The drip shield is fabricated from Titanium Grade 7 plates for diversion of dripping water, Titanium Grade 29 for structural support, and Alloy 22 for the base plates to prevent direct contact between the titanium and the steel members in the invert (Table 1.3.4-4). The drip shield top plates and the sidewalls are exposed to direct contact with dripping water or rockfall from the emplacement drift walls. The geometry of these plates is configured so that water is diverted around the waste package and onto the emplacement drift invert section. The interlocking feature of the drip shield includes water diversion rings and connector plates to divert water at the seams between the drip shield segments and around the waste packages to the emplacement drift invert section.

In case of rockfall and subsequent static loads from fallen rocks, the load is transferred from the top plates to the structural support members. Since the drip shield bulkheads and the longitudinal stiffeners are placed directly under the top plate, the vertical load is partially carried by these members. The internal forces and bending moments due to external forces are subsequently transferred to the internal and external support plates, then to the support beams and sidewalls, and, finally, to the emplacement drift invert structure. The base plates prevent potential hydrogen embrittlement of titanium, serving as a barrier between the titanium and the invert steel beams. The titanium components are assembled by welding. However, the Alloy 22 base plates are mechanically attached to the titanium sidewalls by Alloy 22 pins since the two materials cannot be reliably welded together (BSC 2007i, Section 6.1.1).

1.3.4.7.2 Operational Processes

Installation of Drip Shields—Drip shields will be installed as part of closure of the repository. At that time, in-drift environmental conditions are expected to be suitable for use of gantries with some additional cooling required for the longer emplacement drifts. After 50 years of forced ventilation, the average air temperatures are projected to be approximately 50°C and 60°C, respectively, at the end of 600- and 800-m-long emplacement drifts. Figure 1.3.4-16 illustrates the emplacement drift exhaust air temperatures throughout the preclosure period. The air temperatures in the shorter drifts, after 50 years of ventilation, will be at or below the maximum 50°C operating limit for remotely operated equipment (BSC 2008a, Section 22.2.1.2). Air temperatures in the longer drifts will also be acceptable for equipment operation after cooling prior to beginning of drip shield emplacement. The subsurface ventilation system will continue to operate at normal airflow rates during installation of the drip shields after in-drift air temperatures of 50°C or less have been achieved.

Drip Shield Gantry—The drip shield emplacement gantry is designed specifically to install drip shields over waste packages in the emplacement drifts. The drip shield emplacement gantry design, like the TEV (Section 1.3.4.8), is based on nuclear and industrial crane technology. Although the TEV and drip shield gantry have similar drive and control systems, the TEV has a shielded enclosure that lifts the waste package and emplacement pallet while the drip shield gantry has a structural steel frame with lifting beams and hooks that interface with the drip shield. Both the TEV and the drip shield gantry have lifting mechanisms with vertical movement only. Figure 1.3.4-17 shows the drip shield emplacement gantry. The drip shield emplacement gantry has lifting beams that engage brackets attached to the sides of the drip shield. The surface of the drip shield is not handled during emplacement operations. The only contact between the drip shield and the drip shield emplacement gantry is at the lifting brackets.

The lifting mechanism on the drip shield emplacement gantry uses screw jacks to raise the drip shields. The gantry frame is a steel structure designed to support its own weight and the weight of the drip shield. The gantry is self-propelled, with a truck and wheel assembly at each corner of the gantry frame. Drive motor integral disc brakes work in a fail-safe configuration. The electromechanically operated disc brakes are activated by the onboard programmable logic controller (PLC) network, the Central Control Center, or automatically, should loss of power, communication, or control signal occur. Gantry drive motors, screw jack motors, and any other operating components of the gantry are electrically operated and controlled by the onboard PLC network, with remote monitoring from the Central Control Center.

The gantry frame and lifting mechanism dimensions are sized to provide sufficient clearance for the drip shield to be moved over the waste packages when the gantry is traveling along a loaded drift

The drip shield gantry will use a similar electrical and control system and other SSCs as those used by the TEV. Like the TEV, the drip shield emplacement gantry is designed to operate in the environment inside the emplacement drifts, taking into account the temperature of up to 50°C and the design basis radiation environment around the TAD waste package containing 21-PWR fuel assemblies, which is the waste package with the highest potential dose rates (BSC 2008e, Section 3.2.2.3; BSC 2007j, Sections 4.3 and 5; BSC 2007k, Section 6.1.2).

The control system for the drip shield gantry will be similar to the system used for the TEV. Primary control of the drip shield gantry functions will be performed by an onboard PLC network and operators located in the Central Control Center will monitor drip shield emplacement gantry operations and have control override capability for all drip shield gantry functions. The primary source of electrical power for the drip shield emplacement gantry is an electrified third rail system. It is the same electrical supply system that is used by the TEV. Like the TEV, the drip shield emplacement gantry is supplied with dual power pickup mechanisms to ensure a reliable and continuous source of power (BSC 2007j, Section 4.5).

Instrumentation and controls on the drip shield emplacement gantry consist of high-resolution, articulated cameras and a series of high-intensity lights. The gantry is equipped with thermal and radiological sensing instruments. Onboard cabinets and temperature-sensitive components are cooled with air-conditioning units mounted on each equipment cabinet. The gantry is also equipped with a fire protection system that responds automatically if an onboard fire is detected. The gantry fire protection system provides fire event information to the repository fire protection system to annunciate the location and nature of the onboard fire (BSC 2007j, Section 4.5). Radiation shielding for the drip shield emplacement gantry instrumentation will be similar to instrumentation shielding design for the TEV (Section 1.3.3.5.1.5).

In an operational process similar to that described in Section 1.3.3.5.2.1 for the TEV and a waste package, a drip shield is installed in an emplacement drift. Monitoring, communication, and control override capabilities for drip shield gantry functions are performed from the Central Control Center. Moving under supervision of the operators in the Central Control Center, the drip shield emplacement gantry picks up a drip shield at a drip shield staging area and proceeds into the subsurface to the turnout for the designated emplacement drift. The onboard PLC network, monitored from the Central Control Center, then directs the drip shield emplacement gantry into the drift with the drip shield (BSC 2007j, Section 4.5).

The gantry carries the drip shield through the emplacement drift and over the waste packages to emplace the drip shield (BSC 2007l); BSC 2007j, Section 4.1). The design of the drip shields and the drip shield emplacement gantry is such that during normal operations it is not physically possible for the drip shield to contact the waste package while the drip shield is being installed (Figure 1.3.4-18). Because of design and operational similarities with the TEV, a drip shield emplacement gantry equipment malfunction or other off-normal event will be handled in a similar manner as for the TEV and will include an evaluation performed to assess conditions, identify potential hazards, and provide a basis for implementation of a recovery action (BSC 2008e, Section 3.4; BSC 2007j, Section 5).

The emplacement drift invert is designed to accommodate the design loads and spatial constraints associated with emplacement of the drip shields.

1.3.4.7.3 Safety Category Classification

The drip shield prevents or substantially diverts dripping water that could otherwise contact the waste package and protects the waste package against damage by rockfall during the postclosure period. For these reasons, the drip shield is ITWI (Table 1.9-8). However, the drip shield and the drip shield emplacement gantry are non-ITS since neither the drip shield nor the gantry are relied on during preclosure operations to prevent or mitigate any Category 1 or Category 2 event sequences (Tables 1.9-1 and 1.9-7).

1.3.4.7.4 Administrative or Procedural Safety Controls to Prevent Event Sequences or Mitigate Their Effects

There are no administrative or procedural safety controls associated with the drip shields.

1.3.4.7.5 Design Criteria and Design Bases

The characteristics of rockfall affecting the drip shield performance varies with the type of predominant rock types in the repository host rock, as follows:

Rockfall in Nonlithophysal Zone—The potential source of damage to the drip shield in the nonlithophysal zones is rock blocks that can fall from the walls during a seismic event. The potential source of damage to the drip shield considered in the nonlithophysal zone is damage from rock blocks that fall on the drip shield. A description of the mechanical performance of the drip shield subjected to those loading conditions is provided in Section 2.3.4.5.2.2.

Rockfall in Lithophysal Zone—The structural response of the drip shield to the static rock rubble load from fallen host rock generated by tunnel collapse in the lithophysal units has been evaluated with structural response calculations. Those calculations are described in Section 2.3.4.5.2.2.

A discussion of the design bases and corresponding design criteria is provided below.

Performance Requirement—The emplacement drifts accommodate a drip shield structure that protects the waste packages from credible postclosure rockfall.

The performance of the drip shield was examined for (1) general structural stability in the event that emplacement drift collapse has occurred and the resulting rubble loads the drip shield in a quasi-static fashion, and (2) damage resulting from dynamic impact of rock blocks dislodged by a seismic event. The analysis shows that the drip shield maintains structural integrity in a complete collapse of the emplacement drift (Section 2.3.4.5.3) (SNL 2007a, Sections 6.7 and 6.8).

The drip shield mechanical response to rockfall was analyzed (Section 2.3.4.5). The results of the calculation are reported in terms of damaged areas, where the residual stress values exceed 80% of Titanium Grade 7 yield strength. This threshold stress value bounds any form of potential failure due to stress corrosion cracking and surface failures due to localized stress concentrations subsequent to rockfall. A set of representative rock blocks that span the block energy distribution and impact location is selected in order to evaluate the structural response of the drip shield. For each representative block and impact location, a structural response calculation is performed to determine the damage to the drip shield. Results of those damage calculations are described in Section 2.3.4.5.

Performance Requirement—The interlocking drip shields are designed not to separate in order to prevent rocks from impacting the waste package corrosion barrier.

The structural calculations of a drip shield exposed to vibratory ground motion indicate that there is no separation of the drip shields for ground motion events with horizontal peak ground velocity levels up to and including 5.35 m/s corresponding to a 10^{-7} annual probability of exceedance ground motion (Section 2.3.4.3.3.4). The kinematic numerical analyses that demonstrate that drip shield separation does not occur under postclosure seismic vibratory motion are described in Section 2.3.4.5.

Performance Requirement—The drip shield is constructed of corrosion resistant materials and includes corrosion allowance for all surfaces for the expected postclosure performance period longevity.

The drip shield is fabricated from Titanium Grade 7 for the top and sidewall plates, Titanium Grade 29 for the structural stiffeners, and Alloy 22 for the base plates. The maximum corrosion of these materials for the performance period of the drip shield after closure is taken into consideration by reducing the related material thickness in the structural calculations. Titanium Grade 29 has a higher rate of corrosion when compared to Titanium Grade 7, but Titanium Grade 29 is still highly resistant to corrosion. The corrosion loss over a 10,000-year period for Titanium Grade 29 was determined to be less than 1 mm—the corrosion allowance for drip shield exposed surfaces. Corrosion analysis results for Titanium Grades 7 and 29 are presented in *General Corrosion and Localized Corrosion of the Drip Shield* (SNL 2007b, Sections 6.1[a] and 6.2[a]). The structural adequacy of these materials, including the effects of corrosion, is demonstrated through the results of the rockfall response of the drip shield. Hence, the performance requirement is met.

Performance Requirement—The interlocking drip shields prevent water dripping from the rock from contacting the waste packages.

The geometry of the drip shield is such that the dripping water is diverted around the waste package and onto the emplacement drift invert. Hence, the performance requirement is met.

1.3.4.7.6 Design Methodologies

The drip shield component of the EBS is a unique component, and, as such, there are no established industry practices for its design. As a result, the structural performance of the drip shield is evaluated in terms of postclosure functions and postulated postclosure events. The stress magnitudes, deformations, and potential failure mechanisms are evaluated using finite element analyses and the principles of mechanics of materials. These finite element analyses allow verification of the design performance in the changing emplacement drift environment during the postclosure period, including possible drift degradation and seismic ground motions (SNL 2007c, Sections 6.4 and 6.5).

The structural analysis methods are used to predict margin to failure by ductile tearing. Appropriate fracture mechanics and toughness values of the drip shield materials are considered in the evaluation of potential brittle fracture. A combination of ductile and brittle failure has been considered. The drip shield materials, in general, are characterized by ductile behavior. If mixed-mode failure (i.e., a combination of ductile tearing and crack propagation) is identified for the drip shield materials, specifications are developed with allowable flaw sizes that ensure that drip shield failure due to crack propagation is prevented. This design approach is mainly derived from the fact that failure by fracture is governed by both material susceptibility (fracture toughness) and maximum permitted flaw size.

Evaluation of Repository Components Exposed to Vibratory Ground Motion—The motion of repository components, namely waste package, waste package emplacement pallet, and drip shield, due to a seismic event is evaluated using both two-dimensional discrete element and three-dimensional finite element representation with either a velocity or an acceleration time history as an externally applied load.

The analysis of waste package, waste package emplacement pallet, and drip shield mechanical response to vibratory motion from a postclosure seismic event is described in Section 2.3.4.5.

1.3.4.7.7 Consistency of Materials with Design Methodologies

There are no applicable codes and standards that govern the selection of materials for use in the drip shield components. The selection of the drip shield materials is dependent on the mechanical properties and long-term corrosion performance of the drip shield plates and sidewalls and the structural strength of the support structure. A mechanism for generating hydrogen can occur through the galvanic coupling between the titanium drip shield surface and the emplacement drift steel structural invert components. The likelihood of galvanic coupling is minimized by a design feature, Alloy 22 base plates, that serves as a barrier between the titanium and the invert structure steel beams. The titanium components are assembled by welding, and welds are subsequently stress-relieved.

One of the main functions of the drip shield is to divert the water that drips from the emplacement drift walls around the waste packages and to the invert section, prolonging the longevity and structural integrity of the waste packages. Hence, corrosion resistance is required so that the drip shields can perform their water diversion function with high reliability for their period of postclosure performance. As such, Titanium Grade 7 was selected for the drip shield plates and sidewalls. The general and localized corrosion behavior of Titanium Grade 7 was evaluated and provides the basis for selection of this material.

The design requirements for the drip shield also include structural strength. Structural strength is required so that the drip shield can protect the waste package against damage by rockfall resulting from drift wall degradation. The drip shields must also withstand the static loads from fallen rocks while limiting contact with the waste package. The structural performance of the drip shield under such conditions was evaluated, and postulated postclosure events are summarized in Section 2.3.4.5. The high strength characteristics of the Titanium Grade 29 were the basis of selecting it as the drip shield structural material for these mechanical load conditions.

Details of the fabrication of the drip shield are described in *Yucca Mountain Project Engineering Specification Prototype Drip Shield* (BSC 2007m). The drip shield assembly, including the lifting feature assemblies, are stress relieved after completion of fabrication work and final machining. The drip shield assembly and lifting feature assemblies are furnace heated for stress relief at a prescribed temperature and duration, followed by cooling by air.

All drip shield fabrication welds are visual-examination-tested to meet the nondestructive examination requirements. All Alloy 22 and titanium full-penetration welds are radiographically and ultrasonically examined. Welds using *ASME Boiler and Pressure Vessel Code*, Section III, Subsection NC requirements (ASME 2001) are examined with the liquid-penetrant method in conformance with the code.

1.3.4.7.8 Design Codes and Standards

Codes and standards applicable to the design and fabrication of the drip shield are listed in Section 1.3.2 (Table 1.3.2-5)

1.3.4.7.9 Design Load Combinations

Drip Shield Emplacement Gantry—Gantry crane supplier's information is used for the crane weight, wheel loads, and lifted loads for the design of crane rails and supporting structural steel beams. Impact allowances are in accordance with *Manual of Steel Construction, Allowable Stress Design* (AISC 1997, Sections A4.2 and A4.3). The weight of the loaded crane is considered simultaneously with the seismic loads. The horizontal and vertical inertia forces are obtained by multiplying the weight of the crane by the appropriate accelerations (BSC 2007b, Section 4.2.13.5).

Geometry of Collapsed Drift—The dislodging of rock blocks that may occur due to seismic activity or drift collapse during postclosure results in external pressure on the drip shield from rock rubble. This loose rock load is taken into account to prevent or limit impacts to the waste package in the structural performance of the drip shield (BSC 2004b, Section 6.4)).

Rock Geometry for Rockfall Analysis—The rock block shapes, sizes, and velocities used in drip shield mechanical analyses are described in Section 2.3.4.5.

1.3.4.8 Waste Package Emplacement System

[NUREG-1804, Section 2.1.1.2.3: AC 3(1), AC 6(1), (2); Section 2.1.1.6.3: AC 1(2)(c), (h), (i), (m), AC 2(2); Section 2.1.1.7.3.1: AC 1(1), (2), (3); Section 2.1.1.7.3.3(II): AC 1(1), AC 2(3), (6), AC 9(1), (2)]

This section describes the process for emplacing waste packages in the subsurface drifts. Emplacement is the last step in the operational process of moving waste packages from the surface facilities into the subsurface. Movement of the waste packages from the surface facilities into the subsurface repository is described in Section 1.3.3.5.

1.3.4.8.1 System Description

As discussed in Section 1.3.3.5, the TEV is the specialized, crane rail-based transporter designed to safely move waste packages from the surface facilities into the subsurface facility for emplacement. The TEV transports an individual waste package from the surface facilities into the subsurface on an emplacement pallet, places the waste package and pallet at a designated location in an emplacement drift, and returns to the surface facilities to repeat the process.

If waste package retrieval is required, the emplacement operation is performed in reverse order, using the TEV to remove waste packages from the emplacement drift and transport them to the surface facilities or to an alternate or contingency emplacement drift. Waste package retrieval would be initiated with the removal of the waste package emplaced nearest the emplacement drift entrance. The waste package emplacement process does not allow the lifting of one waste package over another, so the waste packages would be removed in reverse sequence to emplacement. Potential retrieval operations are further discussed in Section 1.11.

Operational interfaces between the waste package emplacement and retrieval system and repository facilities are described in Section 1.3.3.5.2.4.

1.3.4.8.1.1 Transport and Emplacement Vehicle Design Description

The TEV is designed to accommodate the waste packages and associated emplacement pallets to be placed in the repository. The functions of the emplacement and retrieval system are designed to support the throughput described in Section 1.2.1. A more detailed system description of the TEV is presented in Section 1.3.3.5.1. Figures 1.3.3-39 and 1.3.3-40 present a simplified general arrangement and plan and elevation views of the TEV.

1.3.4.8.1.2 Fire Protection

Fire protection is integrated into the design of the TEV and related support systems. As discussed in more detail in Section 1.3.3.5.1.4, a fire protection system on the TEV provides automatic fire protection by monitoring, detecting, annunciating, and suppressing any fires that occur in the TEV shielded cabinets that house the communications and electronic controls equipment. Additional information regarding fire protection is presented in Section 1.4.3. Maintenance activities will be conducted in accordance with plans and procedures described in the repository Maintenance Program. Information regarding the Maintenance Program is presented in Section 5.6.

1.3.4.8.2 Operational Processes

Emplacement operational processes and considerations are discussed in this section. These operational processes are to be specifically defined prior to operations. TEV emplacement functions will be performed in accordance with procedures developed to address normal operations and off-normal events. If an off-normal event did occur, an evaluation would be conducted to assess recovery options and develop an implementation strategy (BSC 2007n, Section 3.1). In addition to operational processes, TEV emplacement operations will be supported by a maintenance program that includes monitoring, routine and preventive maintenance, and inspections to ensure performance within design specifications. Maintenance activities will be conducted in accordance with plans and procedures described in the repository Maintenance Program. Information regarding the Maintenance Program is presented in Section 5.6.

1.3.4.8.2.1 Operational Overview

The TEV receives the waste package and emplacement pallet assembly at the surface facilities loadout area. Once the waste package emplacement pallet is lifted inside the TEV and the shielded enclosure doors have been closed and locked, the loaded TEV travels into the subsurface to the turnout for the designated emplacement drift. After passing through the turnout (Section 1.3.3.5.2.1), the TEV enters the emplacement drift and proceeds to the selected emplacement location. The operating speed for the TEV when carrying a waste package is 150 ft/min (1.7 mph). This rate of speed is described in industry guidance as the design rated load speed and is considered a safe operating speed for gantry cranes carrying loads similar in weight to the waste packages carried by the TEV (ASME NOG-1-2004, *Rules for Construction of Overhead and Gantry Cranes (Top Running Bridge, Multiple Girder)*, Table 5333.1-1). Additionally, the operating speed of 150 ft/min (1.7 mph) does not cause a waste package breach in the event of collision (Sections 1.6 and 1.7).

At the selected emplacement location, the TEV is designed to emplace a waste package at a nominal spacing of 10 cm from a previously emplaced waste package. The operating methodology used to achieve this spacing interval is described in the emplacement drift loading plan (Section 1.3.1). When the waste package and pallet are lowered onto the invert structure, the TEV moves away from the emplaced waste package. The TEV returns to the drift entrance and proceeds through the subsurface to the surface facilities to begin another waste package transportation and emplacement cycle. The waste package emplacement operations are illustrated in Figures 1.3.4-19 and 1.3.4-20.

1.3.4.8.2.2 Operational Sequence

The following sequence presents TEV operations required for waste emplacement and retrieval, if needed, within the emplacement drift. The steps for transporting waste packages from the surface nuclear facilities to the emplacement drifts are presented in Section 1.3.3.5.2.1.

Waste Emplacement Operations—Operational steps for waste package emplacement within the emplacement drifts include (BSC 2008e, Section 2.5):

1. After traveling along the emplacement drift at a normal operating speed of 150 ft/min, the TEV nears the designated emplacement location and stops. The TEV rail brakes are set and the shielded enclosure doors are unlocked and fully opened.

2. The rear shielded door is raised, and the shielded enclosure base plate is extended before the TEV moves forward to the designated waste package emplacement location.

3. The TEV advances at a crawl speed, nominally 15 ft/min, to a predetermined position that is relative to a previously emplaced waste package. Operation of the positioning instrumentation is checked. Positioning instrumentation may include: drive shaft speed monitoring encoders, range detection indicators, and cameras for visual monitoring.

4. The speed of the TEV is decreased further, and the TEV proceeds forward at a slow crawl speed, nominally 1.5 ft/min, until the designated emplacement location for the onboard waste package and emplacement pallet is reached. Operational requirements for positioning a waste package include a nominal spacing distance of 10 cm from the previously emplaced waste package (BSC 2008a, Section 14.2.2.2).

5. When the waste package is confirmed as correctly positioned by the operators in the Central Control Center, the TEV screw jacks are raised slightly from a lowered parked position to engage the lifting features and support the weight of the shielded enclosure. The transportation shot bolts are retracted to the unlocked position. These shot bolts extend from the TEV chassis and support the weight of the shielded enclosure during waste package transport. After the shot bolts are retracted, the shielded enclosure is lowered, placing the waste package and pallet on the emplacement drift invert structure. The weight indicators for the screw jacks are monitored to confirm that the waste package and emplacement pallet are not being supported by the TEV lifting features.

6. After placing the waste package and emplacement pallet, the TEV moves away from the emplaced waste package and pallet at a slow crawl speed, nominally 1.5 ft/min. The

TEV stops at a predetermined distance that is sufficient to allow proper operation of the shielded enclosure doors and the base plate.

7. The shielded enclosure is raised to the travel height and the transportation shot bolts are extended into the locked position, allowing the screw jacks to be lowered into a parked position that transfers the weight of the shielded enclosure onto the shot bolts. This action reduces vibrations transmitted from the rails during movement of the TEV.

8. The base plate is retracted and the rear shield door is lowered, mechanically preventing movement of the base plate. The shielded enclosure front doors are closed and locked. When these actions are completed, the TEV returns, at normal operating speed, through the emplacement drift and turnout to the emplacement access doors.

Waste Retrieval Operations—Normal retrieval is the reverse of the waste emplacement process through the point at which the TEV exits the subsurface (Section 1.11).

Waste Package Recovery—Recovery of specific waste packages may be required to address concerns related to off-normal conditions. Unlike retrieval, which is based on a program decision to remove all waste packages, a recovery action is implemented to restore or maintain normal emplacement operations. If a recovery action becomes necessary, an evaluation would be conducted to assess recovery options and an implementation strategy would be developed.

1.3.4.8.2.3 Transport and Emplacement Vehicle Operational Controls

Operating requirements will be incorporated as the design of the TEV control system evolves for modes and conditions such as startup, normal operations, shutdown, off-normal operation, and other system operations.

The TEV control system is based on proven technologies that can be implemented with several layers of functional and physical redundancies. Control system reliability and availability are increased by providing backup electrical power and employing varied technologies that are not susceptible to similar failures from a single cause (Section 1.4.2.1). The onboard control system includes the PLC which implements the monitoring and control functions on the TEV. The environment within the emplacement drifts may warrant supplemental shielding of components or selection of radiation-hardened components, as applicable (BSC 2008e, Sections 3.2.1.40.1 and 3.3.15).

Shielded and insulated cabinets protect the heat- and radiation-sensitive instrumentation, and solid-state air-conditioning units regulate the cabinet temperature. Built-in fire detection automatically activates fire suppression systems should an onboard fire be detected in the communications and electronic control cabinets (Sections 1.3.3.5.1.4 and 1.3.3.5.1.5).

1.3.4.8.2.4 Monitoring Processes

The TEV video monitoring and control system provides operators at the Central Control Center with real-time visual information about the operating environment and vehicle performance. The focus of the monitoring and control process will be on the precise movements needed during waste package emplacement. The video monitoring system installed on the TEV will include video cameras and a series of high-intensity lights. The video monitoring information and images are provided to the Central Control Center via the repository communications system. Through this interface, monitoring and control information for the emplacement and retrieval system is provided on the digital control and management information system human machine interface console in the Central Control Center. The information provided to the console may include but is not limited to (Section 1.4.2):

- Graphic representation of equipment and operations
- TEV location and positioning information
- Video images of the operations to aid operators in the control process
- Status indications and operator messages concerning emplacement and retrieval operations
- Audible and visual alarms indicating off-normal operation
- Data collection, trending, and reporting of emplacement and retrieval operations parameters.

1.3.4.8.2.5 In-Drift Positioning of Waste Packages

Waste package positioning during emplacement maintains a minimum standoff of 15 m (49 ft) between the end of the last waste package and the centerline of the exhaust main and a minimum of 1.5 m (5 ft) between the end of the turnout and the first waste package. More specific information regarding these standoffs is provided in Section 1.3.2.4.3.3.

The emplacement operating procedures will specify the safety control measures that will be implemented to orient (position) the waste packages within the emplacement drift consistent with the initial condition assumptions and requirements identified in the preclosure safety analysis. This procedural safety control, PSC-25, will be implemented by either (1) completing an analysis that confirms a fault cannot credibly lead to a breach of the waste package during the preclosure period, or (2) confirming waste package emplacement positions are a minimum standoff distance from the outer boundary of fault locations (Table 1.9-10, PSC-25).

Positioning instrumentation on the TEV confirms that the standoff distances are achieved and provides this information to the Central Control Center to allow the operators to supervise and control the waste package positioning process (BSC 2003a, Section 6.3; BSC 2008e, Sections 2.5.4 and 3.2.1.39).

Emplacement operating criteria also require that waste packages be emplaced with a nominal spacing of 10 cm between them. This spacing interval is driven by thermal management requirements which specify that the local average line-load in the emplaced repository will not exceed 2.0 kW/m and no waste package will exceed a thermal output of 18 kW. Additionally, waste package emplacement will be such that other relevant thermal limits will not be exceeded, including mid-pillar temperature, drift wall temperature, waste package temperature, and cladding temperature (BSC 2008b, Table 1, Derived Internal Constraints 05-02 and 05-03).

Instrumentation mounted on the TEV provides monitoring and control capabilities to the Central Control Center for the positioning process and confirms that the spacing distance is achieved. The waste package positioning instrumentation provides real-time spacing information to the operators in the Central Control Center and allows them to provide commands to the TEV to implement the equipment actions needed to place the waste package at the designated location. Measuring equipment and video components will be selected to support system operability and reliability (BSC 2008e, Sections 2.5.4, 3.2.1.41.3, and 3.3.15).

Evaluations of spacing measurement instrumentation systems have identified several methodologies with capabilities for meeting waste package positioning requirements (BSC 2008e, Section 2.5.4). Specific requirements and design features for the waste package positioning instrumentation and operational process will be addressed through the component development process described in Section 1.3.2.7.

1.3.4.8.3 Safety Category Classification

The waste package transportation and emplacement system design complies with the classification requirements of the preclosure safety analysis. The TEV is classified as ITS. More information regarding the safety category classification is provided in Section 1.3.3.5.3.

1.3.4.8.4 Administrative or Procedural Safety Controls to Prevent Event Sequences or Mitigate Their Effects

Information regarding procedural safety controls to prevent event sequences or mitigate their effects is provided in Section 1.9. One preclosure procedural safety control has been identified for the waste package emplacement process (Table 1.9-10). The procedural safety control (PSC-25) is related to standoff distances for waste package emplacement. Implementation of PSC-25 is discussed in Section 1.3.4.8.2.5.

1.3.4.8.5 Design Criteria and Design Bases

The nuclear safety design bases for ITS SSCs and features are derived from the preclosure safety analysis presented in Sections 1.6 through 1.9. The nuclear safety design bases identify the safety function to be performed and the controlling parameters with values or ranges of values that bound the design. The nuclear safety design bases and design criteria for the TEV are discussed in Section 1.3.3.5.5 and presented in Table 1.3.3-5.

1.3.4.8.6 Design Methodologies

Design methodologies for the waste package transportation and emplacement system utilize proven and established nuclear crane and industrial crane rail-based technologies. More information regarding design methodologies is provided in Section 1.3.3.5.6.

1.3.4.8.7 Consistency of Materials with Design Methodologies

Materials selected for the design of equipment and components that are part of the waste package transportation and emplacement system are considered based on the range of anticipated operating conditions. More information regarding consistency of materials with design methodologies is provided in Section 1.3.3.5.7.

1.3.4.8.8 Design Codes and Standards

Demonstration of assurance that ITS functions will be performed as required by TEV features will be achieved by following established codes and standards that prescribe how the components are to be designed, fabricated, and tested. More information regarding design codes and standards is provided in Section 1.3.3.5.8.

1.3.4.8.9 Design Load Combinations

Codes and standards are the basis for the TEV equipment design loads (ASME NOG-1-2004, Section 4130). More information regarding design load combinations is provided in Section 1.3.3.5.9.

1.3.4.9 Conformance of Design to Criteria and Bases

[NUREG-1804, Section 2.1.1.7.3.1: AC 1(1)]

The TEV operates in the emplacement areas and is classified as ITS. The information related to conformance of the TEV to its design criteria and preclosure nuclear safety design bases has already been included in Section 1.3.3.6 and Table 1.3.3-5. The subsurface facility has no other SSC in the emplacement areas with an ITS classification.

Table 1.3.4-5 includes postclosure nuclear safety design bases and associated derived internal constraints that apply to subsurface facility emplacement SSCs. This table includes summarized information on conformance of the SSC designs to the design criteria and design considerations related to the postclosure control parameters and constraints and on implementation controls to ensure conformance with the postclosure nuclear safety design bases.

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Table 1.3.4-1. Summary of Numerical Models Used for Emplacement and Nonemplacement Drift Ground Support Analyses

Rock Type	Comment	Model
Nonlithophysal	Rock mass behavior controlled by fracture geometry	Three-dimensional continuum (FLAC3D) model for equivalent continuum parameter studies of drift and drift/shaft intersections
		Two-dimensional continuum (FLAC) model for equivalent continuum parameter studies for cross-sectional analysis of emplacement drifts
		Three-dimensional discontinuum (3DEC) model for analysis of drift intersections
Lithophysal	Rock mass behavior controlled by lithophysal porosity and dense fracturing	Two-dimensional continuum (FLAC) model for equivalent continuum parametric studies

Table 1.3.4-2. Standard Nomenclature for Waste Package Emplacement Pallet Components

Preferred Terminology	Acceptable for Clarity or Brevity	Description
Waste Package Support	Alloy 22 Piers	Alloy 22 structures that cradle the waste package during handling, emplacement, preclosure, and postclosure; also provide lifting points for handling the emplacement pallet loaded with the waste package during handling, emplacement, and potential retrieval
Stainless Steel Tubes	Longitudinal Stiffeners and Tubes	Stainless steel tubes that keep the waste package supports aligned during handling, emplacement, potential retrieval, and postclosure

Table 1.3.4-3. Drip Shield Design Detail

Item	Detail
Material	
• 15-mm water diversion surfaces	Titanium Grade 7 (UNS R52400)
• Structural members	Titanium Grade 29 (UNS R56404)
• Base	Alloy 22 (UNS N06022)
Dimensions	
• Height	113.630 in. (overlap end) 111.071 in. (butt end)
• Width	99.806 in. (overlap end) 99.437 in. (butt end)
• Length	228.543 in.
• Weight	11,000 lbs

Table 1.3.4-4. Standard Nomenclature for Drip Shield Components

Preferred Terminology	Acceptable for Clarity or Brevity	Description
Drip Shield Top Plate	Drip Shield Plate 1	The plate that covers the top of the drip shield (Titanium Grade 7)
Drip Shield Sidewall	Drip Shield Plate 2	The vertical plate on either side of the drip shield (Titanium Grade 7)
Internal Support Plate	NA	Support plate located at the drip shield corner below the top plate (Titanium Grade 7)
External Support Plate	NA	Support plate located at the drip shield corner on the outer surface of the sidewall (Titanium Grade 7)
Drip Shield Connector Plate	Connector Plate	Plates designed to connect one drip shield to another (Titanium Grade 7)
Water Diversion Ring	Drip Shield Connector Guide	Structural connector rings located below the connector plates (Titanium Grade 7)
Bulkhead	NA	The structural support member located under the top plate that spans from one sidewall to the other (Titanium Grade 29)
Longitudinal Stiffener	Bulkhead Longitudinal Stiffener	The structural support member located under the top plate that runs in longitudinal (axial) direction (Titanium Grade 29)
Support Beam	NA	High-strength vertical beam located on the outer surface of the sidewall (Titanium Grade 29)
Base	Base Plate	Base plate (Alloy 22) mechanically attached to the bottom of the sidewalls

NOTE: Figure 1.3.4-14 provides component identification.
NA = not applicable.

Table 1.3.4-5. Summary of Conformance of Subsurface Facility Design to Postclosure Control Parameters—Emplacement Areas

Structure, System and Component	Postclosure Control Parameter		Relevant to ITWI	Design Criteria/Configuration	Postclosure Procedural Safety Control
	Parameter Number and Title	Values, Ranges of Values or Constraints			
Subsurface Facility	01-01 Repository Geographic and Geologic Location (Controlled Interface Parameter)	The location of the subsurface facility of the repository within the footprint of the emplacement area boundary and the repository host horizon within the lithostratigraphic detail shall be controlled through the configuration management system (Section 5).	No	Design considerations for locating the emplacement areas are described in Section 1.3.4.2.1. Location and configuration of the subsurface facility of the repository is as illustrated in Figure 1.3.4-2.	NA
Subsurface Facility	01-02 Repository Layout (Controlled Interface Parameter)	The general layout and configuration of the subsurface facility, including shafts, portals, ramps, mains, emplacement drifts, observation drifts, and other subsurface features, and waste package nominal endpoint coordinates, elevations, and available drift lengths shall be controlled through the configuration management system (Section 5).	No	The design description of the general layout of the subsurface facility design is presented in Sections 1.3.3 and 1.3.4.	NA
Subsurface Facility	01-03 Repository Geologic Location (Controlled Interface Parameter)	The repository areas, emplacement area by geologic unit, fault intersection coordinates, and borehole locations shall be controlled through the configuration management system (Section 5).	No.	The design descriptions of the repository areas, geologic units, fault intersections and borehole locations is presented in Sections 1.3.3 and 1.3.4.	NA

Table 1.3.4-5. Summary of Conformance of Subsurface Facility Design to Postclosure Control Parameters—Emplacement Areas (Continued)

Structure, System and Component	Postclosure Control Parameter		Relevant to ITWI	Design Criteria/Configuration	Postclosure Procedural Safety Control
	Parameter Number and Title	Values, Ranges of Values or Constraints			
Subsurface Facility	01-04 Repository Elevation – Standoff from Water Table	The base of the emplacement drifts shall be located at least 120 m above the maximum elevation of the present-day water table. Note: Based on its current location, the maximum elevation of the present-day water table beneath the emplacement area is approximately 850 m above sea level. Thus the minimum elevation of the base of the emplacement drifts shall be 970 m above sea level.	Yes	The design of the repository identifies the lowest elevation for a repository opening at approximately 1,022 m above mean sea level (Section 1.3.1.1).	NA
Subsurface Facility	01-05 Repository Standoff from Quaternary Fault	The emplacement drifts shall be located a minimum of 60 m from a Quaternary fault with potential for significant displacement.	No	The repository design has located the emplacement openings with a minimum standoff of 60 m from a Quaternary Fault with potential for significant displacement (Section 1.3.2.2.1).	NA
Subsurface Facility	01-06 Repository Elevation – Overburden Thickness	The overburden thickness (i.e., the distance from the top of each emplacement drift to the topographic surface) shall be a minimum of 200 m.	Yes	The repository design has located the emplacement drifts a minimum vertical distance of 200 m from the topographic surface (Section 1.3.2.2.1)	NA
Subsurface Facility	01-07 Repository Standoff from Perched Water	The emplacement drifts shall be located a minimum of 30 m from the top of the Tptpv2 (Topopah Spring Tuff Crystal-poor Vitric Zone) because perched water may occur at the base of the Topopah Spring Tuff Unit.	No	The repository design has located the emplacement openings with a minimum standoff of 30 m from the top of the Tptpv2 (Topopah Spring Tuff Crystal-poor Vitric Zone) which is at the base of the Topopah Spring Tuff Unit (Section 1.3.2.2.1)	NA

Table 1.3.4-5. Summary of Conformance of Subsurface Facility Design to Postclosure Control Parameters—Emplacement Areas (Continued)

Structure, System and Component	Postclosure Control Parameter		Relevant to ITWI	Design Criteria/Configuration	Postclosure Procedural Safety Control
	Parameter Number and Title	Values, Ranges of Values or Constraints			
Subsurface Facility	01-08 Orientation of Emplacement Drifts	The emplacement drifts will be nominally parallel. The design azimuth shall be the same for all emplacement drifts and shall be within a range of 70° to 80°.	No	The layout design provides emplacement drifts within each emplacement panel that are nominally parallel to each other as illustrated in Figure 1.3.4-2. The layout of the emplacement drifts is presented in Section 1.3.4.2.3 and incorporates azimuths of 72° for emplacement drifts.	NA
Subsurface Facility	01-10 Emplacement Drift Configuration	The emplacement drift excavations shall be circular in cross section with a nominal diameter of 5.5 m.	Yes	The emplacement drift opening design sizes the opening at a nominal 5.5 m. This and additional characteristics are illustrated in Figure 1.3.4-4.	NA
Subsurface Facility	01-11 Emplacement Drift Gradient	The grade of the emplacement drifts shall be nominally horizontal so that overall water drainage is directly into the rock to prevent water accumulation.	No	The layout design information presented in Section 1.3.4.2.3 includes a nominally horizontal grade for the emplacement drifts as described in Section 1.3.4.2.	NA
Subsurface Facility	01-13 Emplacement Drift Spacing	The subsurface facility shall be designed to locate the emplacement drifts nominally 81 m apart to prevent thermal interaction between adjacent drifts and to allow drainage of thermally mobilized water within the rock pillars to percolate past the drifts.	No	The layout design information, including a nominal spacing of 81 m for all 108 emplacement drifts is illustrated in Figure 1.3.3-8.	NA

Table 1.3.4-5. Summary of Conformance of Subsurface Facility Design to Postclosure Control Parameters—Emplacement Areas (Continued)

Structure, System and Component	Postclosure Control Parameter: Parameter Number and Title	Postclosure Control Parameter: Values, Ranges of Values or Constraints	Relevant to ITWI	Design Criteria/Configuration	Postclosure Procedural Safety Control
Subsurface Facility	01-14 Verification of Design Rock Properties	The emplacement openings shall provide for postexcavation investigations of each drift that will be conducted under the Performance Confirmation Program. The objective of postexcavation investigations is to verify that host rock properties are bounded by the rock properties described within the in situ observations and model assumptions used in postclosure analyses. Postexcavation investigations will include geologic mapping to confirm that fracture geometric variability and initial rock properties are within the model input parameter range used in rockfall calculations.	No	Design and installation of the emplacement drift ground support will provide for geologic mapping activities before the emplacement walls are covered with final ground support materials that may impede visual inspections and observations (Section 1.3.4.4). The postexcavation investigations, including geologic mapping to verify design rock properties are presented in Section 4.2.2.	NA
Subsurface Facility	01-15 Design of Ground Support System (Controlled Interface Parameter)	The design and materials used for ground support shall be controlled through the configuration management system (Section 5).	No	The design of ground support for emplacement drifts includes materials that will not have a detrimental effect on repository performance. The ground support design for emplacement drifts includes 3-m-long Super Swellex-type stainless steel rock bolts set in a square grid pattern at 1.25-m centers, and a 3-mm Bernold-type perforated stainless steel liner. The rock bolts and the steel liner are to be installed in a 240° arc around the drift periphery and above the invert structure. The ground support system is described in Section 1.3.4.4 1.3.4.4.	NA

Table 1.3.4-5. Summary of Conformance of Subsurface Facility Design to Postclosure Control Parameters—Emplacement Areas (Continued)

Structure, System and Component	Postclosure Control Parameter: Parameter Number and Title	Postclosure Control Parameter: Values, Ranges of Values or Constraints	Relevant to ITWI	Design Criteria/Configuration	Postclosure Procedural Safety Control
Subsurface Facility	01-16 Air Circulation through Ground Support	The permanent ground support shall be perforated to allow air circulation between the host rock and the in-drift environment.	No	The ground support design of the emplacement drifts as specified in Section 1.3.4.4.1 is perforated stainless steel sheeting around the perimeter of the drift (upper 240°) with openings of adequate size to allow air circulation between the steel liner and the drift wall.	NA
Subsurface Facility	01-17 Emplacement Drift Ground Support	(a) The emplacement drift ground support system shall prevent raveling or rockfall in the emplacement drifts that could induce residual tensile stresses in the waste package above 257 MPa. (b) In the event the ground support system fails, the waste packages that come into contact with fallen rock or ground support materials shall be inspected for surface damage and remediated as required prior to closure.	No	(a) The ground support design presented in Section 1.3.4.4 includes rock bolts for prevention of detachment of large key blocks, as well as coverage of the drift wall above and on the sides of the waste packages to prevent rubble from falling on the waste packages or accumulating on the invert surface.	(b) If fallen rock or ground support is found, inspections will be performed on the waste package surface for damage.
Subsurface Facility	01-18 Unheated Drift Length	As boundary conditions for the thermal-hydrologic model in the postclosure, in the event that access main and exhaust main drifts are backfilled, areas at both ends of the emplaced waste will be free of backfill. The two areas will be a minimum of 15 m long and their combined length will total a minimum of 75 m. Note: Emplacement areas will not be backfilled (see Parameter 05-04).	No	The repository design does not include backfill in the access or exhaust mains. Repository backfill is limited to those openings that connect the emplacement area to the surface, mainly ramps and shafts (Section 1.3.6.1). On the access main side of the emplacement drifts, the design maintains an unobstructed turnout as illustrated in Figures 1.3.3-13 and 1.3.3-34.	NA

Table 1.3.4-5. Summary of Conformance of Subsurface Facility Design to Postclosure Control Parameters—Emplacement Areas (Continued)

Structure, System and Component	Postclosure Control Parameter: Parameter Number and Title	Postclosure Control Parameter: Values, Ranges of Values or Constraints	Relevant to ITWI	Design Criteria/Configuration	Postclosure Procedural Safety Control
Subsurface Facility	01-20 Repository Standoff from Paintbrush Nonwelded Hydrogeologic Unit	The minimum distance between the top of each emplacement drift and the base of the Paintbrush nonwelded hydrogeologic unit shall be 100 m.	Yes	The repository design has located the emplacement openings with a minimum standoff of 100 m from the base of the Paintbrush nonwelded hydrogeologic unit (Section 1.3.2.2.1).	NA
Subsurface Facility	01-21 Minimum Thickness of the Paintbrush Nonwelded Hydrogeologic Unit above the Repository	The minimum thickness of the Paintbrush nonwelded hydrogeologic unit above the repository shall be 10 m.	Yes	The repository design has located the emplacement openings in areas overlayed by the Paintbrush nonwelded hydrogeologic unit with a minimum formation thickness of 10 m (Section 1.3.2.2.1).	NA
Subsurface Facility	01-22 Repository Standoff from Calico Hills Nonwelded Hydrogeologic Unit	The minimum distance between the base of each emplacement drift and the top of the Calico Hills nonwelded hydrogeologic unit shall be 60 m.	No	The repository emplacement openings have been located with a minimum standoff of 60 m from the top of the Calico Hills nonwelded hydrogeologic Unit (Section 1.3.2.2.1).	NA

Table 1.3.4-5. Summary of Conformance of Subsurface Facility Design to Postclosure Control Parameters—Emplacement Areas (Continued)

Structure, System and Component	**Postclosure Control Parameter**		**Relevant to ITWI**	**Design Criteria/Configuration**	**Postclosure Procedural Safety Control**
	Parameter Number and Title	**Values, Ranges of Values or Constraints**			
Emplacement Drift Configuration	02-01 As-Emplaced Waste Configuration (Controlled Interface Parameter)	The configuration for the emplaced waste packages shall be controlled through the configuration management system (Section 5).	No	The process for emplacing the waste packages and maintaining the configuration of their emplacement are described in Section 1.3.4.8.2. This process includes the operational and monitoring controls related to the in-drift positioning of the waste packages. Design considerations for emplacement of sequences of waste packages in a drift for thermal management purposes are described in Section 1.3.1.2.5.	NA
Emplacement Drift Configuration	02-02 As-Emplaced Waste Package Drip Shield Configuration (Controlled Interface Parameter)	The minimum distance from the top of the waste package to the interior height of the drip shield shall be controlled through the configuration management system (Section 5).	No	The in drift component design shows minimum vertical distance between the waste package surface and the interior surface of the drip shield varies from 14 in. for the 5-DHLW/DOE SNF Short waste package to 27 in. for the 2-MCO/2-DHLW waste package.	NA
Emplacement Drift Configuration	02-04 Invert and EBS Components In Situ Stress and Thermal Response	The invert and EBS components shall be designed to accommodate at least a 10-mm displacement to account for potential in situ stress and thermal response.	No	The design of the emplacement drift invert structure allows for thermal loads resulting from potential peak temperatures of 200°C (392°F) (BSC 2007g, Section 6.1.2) to accommodate the 10-mm displacement due to in situ stress and thermal response. The design description for the invert structure is described in Section 1.3.4.5.	NA

Table 1.3.4-5. Summary of Conformance of Subsurface Facility Design to Postclosure Control Parameters—Emplacement Areas (Continued)

Structure, System and Component	Postclosure Control Parameter: Parameter Number and Title	Postclosure Control Parameter: Values, Ranges of Values or Constraints	Relevant to ITWI	Design Criteria/Configuration	Postclosure Procedural Safety Control
Emplacement Drift Configuration	02-05 EBS In-Drift Materials Interactions	EBS materials shall be inert relative to each other so that physical contact between EBS materials minimizes dissimilar material interaction mechanisms. The waste package outer corrosion barrier shall not contact EBS components other than the Alloy 22 support surfaces of the pallet.	No	Design criteria for material characteristics and configurations to establish conformance with this requirement are included in design specifications for EBS components in Sections 1.3.4.5 (Invert System), 1.3.4.6 (Waste Package Emplacement Pallet), 1.3.4.7 (Drip Shield System), and 1.5.2 (Waste Package).	NA
Emplacement Drift Configuration	02-06 EBS Material Interactions – Copper	(a) For the as-emplaced configuration, the drip shields and waste packages shall not contact any copper that may be present in other EBS components such as parts of the emplacement vehicle rail system. (b) The total mass of elemental copper per meter of emplacement drift shall be less than 5.0 kg/m.	No	(b) Specifications identified in Section 1.3.4.5.7 will ensure the as-emplaced configuration meets these constraints. The only emplacement drift component containing copper that has been identified in preliminary estimates of committed materials is the third-rail conductor (Table 1.3.6-1). Emplacement drift configuration will preclude contact between the drip shield or waste package with the third rail.	(a) Verification of conformance to this requirement will be done, at the time of closure, by developing procedures that will include inspecting the as-built configuration of emplacement drift EBS components and third-rail component to ensure no waste package or drip shield contact with copper materials is possible.

Table 1.3.4-5. Summary of Conformance of Subsurface Facility Design to Postclosure Control Parameters—Emplacement Areas (Continued)

Structure, System and Component	Postclosure Control Parameter		Relevant to ITWI	Design Criteria/Configuration	Postclosure Procedural Safety Control
	Parameter Number and Title	Values, Ranges of Values or Constraints			
Emplacement Drift Configuration	02-07 Emplacement Drift Invert Function	The emplacement drift invert (ballast) shall provide a nominally level surface that supports the drip shield, waste package, and waste package emplacement pallet for static loads and that limits degradation associated with ground motion (but excluding faulting displacements) after closure of the repository.	No	The design of the invert ballast will carry the loads from the waste package emplacement pallets, the waste packages, and drip shields. The invert ballast helps maintain the emplaced waste packages in a nominal horizontal position during the postclosure period as identified in Section 1.3.4.5.1. The design loads analyzed in the invert design are discussed in Section 1.3.4.5.9.	NA
Emplacement Drift Configuration	02-08 Invert Materials (Controlled Interface Parameter – Item a only)	(a) The components and materials used in the invert and for the gradation and placement of the invert ballast material shall be controlled through the configuration management system (Section 5). (b) The invert material will be carbon steel and crushed tuff. The crushed tuff shall have properties consistent with the repository host rock excavated by mechanical means.	No	(a) and (b) The composition of the invert materials are illustrated in Figure 1.3.4-9, and described in Section 1.3.4.5.7.	NA
Emplacement Drift Configuration	02-10 Emplacement Drift Invert Configuration (Controlled Interface Parameter)	The general configuration, plan, and details of the emplacement drift invert shall be controlled.	No	The general configuration of the emplacement drift invert is illustrated in Figures 1.3.3-8 and 1.3.4-9.	NA

Table 1.3.4-5. Summary of Conformance of Subsurface Facility Design to Postclosure Control Parameters—Emplacement Areas (Continued)

Structure, System and Component	Postclosure Control Parameter		Relevant to ITWI	Design Criteria/Configuration	Postclosure Procedural Safety Control
	Parameter Number and Title	Values, Ranges of Values or Constraints			
Emplacement Drift Configuration	05-01 Waste Package Handling and Emplacement	Waste package handling and emplacement activities shall be monitored through appropriate equipment. An operator and an independent inspector shall verify proper waste package installation.	No	NA (Background information: The operational and monitoring controls on the waste package emplacement system are presented in Sections 1.3.4.8.2.3 and 1.3.4.8.2.4, respectively. Design of monitoring equipment, instrumentation, and sensors that are part of the transport and emplacement vehicle and that are needed to satisfy this requirement is described in Section 1.3.4.8.2.5.)	The waste package handling and emplacement procedures will be developed and include requirements for monitoring during handling. Verification of waste package handling will be done by an operator from the remote CCCF location with the use of high-resolution cameras and electronic sensors. An independent inspector will verify the adequacy of the emplacement.
Emplacement Drift Configuration	05-02 Waste Package Spacing	Adjacent waste packages in a given emplacement drift shall be emplaced 0.1 m (nominal) apart, from the top surface of the upper sleeve of one waste package to the bottom surface of the lower sleeve of the adjacent waste package.	No	NA (Background information: The design of the TEV is to emplace a waste package at a nominal spacing of 10 cm from a previously emplaced waste package as presented in Section 1.3.4.8.2.1.)	The waste package emplacement procedures will be developed and include emplacement limitations to be met. Monitoring equipment, instrumentation, and sensors that are part of the TEV are used to control this operation. The controls and instrumentation needed to satisfy this requirement are described in Section 1.3.4.8.2.5.
Drip Shield	07-01 Drip Shield Design (Control Interface Parameter)	The drip shield dimensions and characteristics shall be controlled through the configuration management system (Section 5).	No	The design of the drip shield including dimensions, characteristics, and material definitions are provided in Section 1.3.4.7.7, Figure 1.3.4-15, and Table 1.3.4-3.	NA

Table 1.3.4-5. Summary of Conformance of Subsurface Facility Design to Postclosure Control Parameters—Emplacement Areas (Continued)

Structure, System and Component	Postclosure Control Parameter		Relevant to ITWI	Design Criteria/Configuration	Postclosure Procedural Safety Control
	Parameter Number and Title	Values, Ranges of Values or Constraints			
Drip Shield	07-02 Drip Shield Design and Installation	(a) The drip shield shall be designed to interlock and overlap in a manner that prevents a liquid drip path from above the drip shield to the waste package. (b) The drip shield handling and emplacement activities shall be monitored through appropriate equipment. An operator and an independent inspector shall verify proper drip shield installation. Records demonstrating compliance shall be maintained.	Yes	(a) The design of the details of the drip shield interlocking features and the assembly are provided in Figures 1.3.4-14 and 1.3.4-15. The interlock feature that prevents a liquid path from above the drip shield to the waste package is described in Section 1.3.4.7.1.	(b) The drip shield placement procedures will be developed and include handling requirements that include verification of proper drip shield interlocking mechanism compliance during installation. This operation will be performed by independent operators in the CCCF using remote equipment. Installation discussion is in Table 1.3.6-3. Drip shield handling and emplacement activities are described in Section 1.3.4.7.2.)
Drip Shield	07-04 Drip Shield Materials and Thicknesses	The drip shield shall be constructed of Titanium Grade 7, with a minimum thickness of 15 mm. The drip shield structural material shall be manufactured of Titanium Grade 29.	Yes	The design of the drip shield materials and thicknesses are provided in Table 1.3.4-3	NA
Drip Shield	07-07 EBS Drip Shield/ Emplacement Drift Invert Materials Interactions	Alloy 22 bases shall be attached to the drip shield to preclude titanium contact with the invert (including transport equipment rails).	Yes	The design of the Alloy 22 base plate attachment will preclude the contact of the titanium portion of the drip shield with the steel members in the invert. The description of the design configurations is provided in Section 1.3.4.7.1 and in Figure 1.3.4-14.	NA

Table 1.3.4-5. Summary of Conformance of Subsurface Facility Design to Postclosure Control Parameters—Emplacement Areas (Continued)

Structure, System and Component	Postclosure Control Parameter		Relevant to ITWI	Design Criteria/Configuration	Postclosure Procedural Safety Control
	Parameter Number and Title	Values, Ranges of Values or Constraints			
Drip Shield	07-08 Drip Shield Seismic Performance (Controlled Interface Parameter)	The drip shield design shall be controlled such that during a seismic event it resists separation through failure of the DSC connector guides, the DSC left/right support beams, and the left/right support beam connectors. Note: Compliance with the postclosure performance aspects of the drip shield within this constraint is demonstrated in postclosure analyses (only).	No	A description of the structural calculations, which indicate that there is no separation of the drip shields for ground motion events with peak ground velocity levels up to and including 5.35 m/s corresponding to a 10^{-7} annual probability of exceedance ground motion as identified in Section 1.3.4.7.5, are provided in Section 2.3.4.3.3.4.	NA
Drip Shield	07-09 Drip Shield Fabrication	The drip shield shall be fabricated in accordance with standard nuclear industry practices, including material control, welding, weld flaw detection and repair and heat treatment.	Yes	The fabrication specification will require that procedures developed by the fabricator be developed consistent with standard nuclear industry practices, for the subject constraints, for the applicable codes and standards listed in Table 1.3.2-5.	NA
Drip Shield	07-10 Drip Shield Fabrication Weld Inspections	The drip shield full-penetration fabrication welds shall be nondestructively examined by visual, liquid penetrant, and ultrasonic testing for flaws. Fillet welds shall be inspected by means of liquid penetrant and visual testing for flaws. All flaws larger than code standards shall be repaired.	Yes	The nondestructive inspection of the drip shield fabrication welds using liquid penetrant and visual examination testing per the constraint will be provided in the procurement specification to the fabricator. These requirements are consistent with applicable codes and standards as listed in Table 1.3.2-5.	NA

Table 1.3.4-5. Summary of Conformance of Subsurface Facility Design to Postclosure Control Parameters—Emplacement Areas (Continued)

Structure, System and Component	**Postclosure Control Parameter: Parameter Number and Title**	**Postclosure Control Parameter: Values, Ranges of Values or Constraints**	**Relevant to ITWI**	**Design Criteria/Configuration**	**Postclosure Procedural Safety Control**
Drip Shield	07-11 Drip Shield Fabrication Welding Flaws	The welding techniques for the fabrication welds shall be constrained to gas metal arc welding, except for short-circuiting mode, and automated gas tungsten arc welding. Welding flaws will be repaired in accordance with written procedures that have been accepted by the design organization prior to their usage.	Yes	The procurement specification shall constrain the welding techniques for the drip shield fabrication welds per the constraint. Requirements for the correction of drip shield fabrication welding flaws will be included in the procurement specification to the fabricator. The applicable codes and standards are listed in Table 1.3.2-5 The procurement specification will require that such weld flaw procedures be approved by the repository design organization prior to their use.	NA
Drip Shield	07-12 Drip Shield Fabrication Weld Materials	(a) All drip-shield welding shall be conducted in accordance with standard nuclear industry practices. (b) For Titanium Grade 7 to Titanium Grade 7 welds, Titanium Grade 7 weld filler material shall be used. For Titanium Grade 29 to Titanium Grade 29 welds, Titanium Grade 29 shall be used. For Titanium Grade 7 to Titanium Grade 29 welds, Titanium Grade 28 weld filler shall be used.	Yes	(a) and (b) The fabrication specification will require that procedures developed by the fabricator be developed consistent with these requirements and with standard nuclear industry practices for the applicable codes and standards listed in Table 1.3.2-5. Additionally requirements for the fabrication specification will include the specific material requirements of part (b) of the subject constraint.	NA

Table 1.3.4-5. Summary of Conformance of Subsurface Facility Design to Postclosure Control Parameters—Emplacement Areas (Continued)

Structure, System and Component	Postclosure Control Parameter: Parameter Number and Title	Postclosure Control Parameter: Values, Ranges of Values or Constraints	Relevant to ITWI	Design Criteria/Configuration	Postclosure Procedural Safety Control
Drip Shield	07-13 Drip Shield Heat Treatment	After fabrication, the drip shield assembly and lifting feature assemblies shall be stress-relieved. After completion of all required fabrication work except for the final machining, the drip shield assembly and lifting feature assemblies shall be treated for stress-relief. The drip shield assembly and lifting feature assemblies shall be furnace-heated for stress relief at 1,100°F +/- 50°F for a minimum of 2 hours. To prevent pickup of hydrogen, a slightly oxidizing atmosphere shall be used; air-cooling is allowed.	Yes	The fabrication specification will require that the specific stress relief requirements of the subject constraint be performed. The drip shield system is discussed in Section 1.3.4.7	NA
Drip Shield	07-14 Drip Shield Handling	a) The drip shield shall be handled in accordance with standard nuclear industry practices to minimize damage, surface contamination, exposure to adverse substances, and impacts. b) Drip shield installation shall be controlled and monitored through appropriate equipment to minimize possible waste package/drip shield damage and/or misinstallation. Installation shall include the use of equipment with an alarm, an operator, and an independent checker. Records demonstrating compliance shall be maintained.	Yes	NA	(a) The drip shield placement procedures will be developed and require handling of the drip shield that will minimize damage, surface contamination, exposure to adverse substances, and impacts as presented in Section 1.3.4.7.2. (b) The procedures will require actions to minimize misinstallation. Placement of the drip shields will be inspected, and records developed, remotely from the CCCF by two independent operators. An alarm showing potential misalignment between successive drip shields will be developed to support the installation process.

Table 1.3.4-5. Summary of Conformance of Subsurface Facility Design to Postclosure Control Parameters—Emplacement Areas (Continued)

Structure, System and Component	Postclosure Control Parameter: Parameter Number and Title	Postclosure Control Parameter: Values, Ranges of Values or Constraints	Relevant to ITWI	Design Criteria/Configuration	Postclosure Procedural Safety Control
Drip Shield	07-15 Drip Shield Thermal Expansion Constraint	To account for volume increase of corrosion products, the drip shield shall not be constrained laterally or longitudinally, or rigidly mounted to the invert. Drip shield connectors will be designed to allow thermal expansion without binding to 300°C.	No	The design of the drip shield contains an allowance for both the volume increase of corrosion products and thermal expansion without binding of up to 300°C. The drip shield rests on the steel invert structure and it is not constrained laterally by any EBS component or invert structure component. The drip shield will be longitudinally constraining by the adjacent drip shields on either side as the drip shields are mechanically interlocked when emplaced. Figure 1.3.4-4 illustrates the placement of the drip shield in the emplacement drift.	NA

Table 1.3.4-5. Summary of Conformance of Subsurface Facility Design to Postclosure Control Parameters—Emplacement Areas (Continued)

Structure, System and Component	Postclosure Control Parameter: Parameter Number and Title	Postclosure Control Parameter: Values, Ranges of Values or Constraints	Relevant to ITWI	Design Criteria/Configuration	Postclosure Procedural Safety Control
Drip Shield	07-16 As-Emplaced Waste Configuration —Waste Package / Drip Shield Clearance (Controlled Interface Parameter)	The minimum distance from the top of the waste package to the interior height of the drip shield shall be controlled through the configuration management system (Section 5).	No	The in drift component design shows minimum vertical distance between the waste package surface and the interior surface of the drip shield varies from 14 in. for the 5-DHLW/DOE SNF Short waste package to 27 in. for the 2-MCO/2-DHLW waste package.	NA
Waste Package Emplacement Pallet	08-01 Emplacement Pallet Design (Controlled Interface Parameter)	The emplacement pallet dimensions and characteristics shall be controlled through the configuration management system (Section 5).	No	Dimensions for the standard waste package emplacement pallet are provided in Figure 1.3.4-11, and dimensions for the short waste package emplacement pallet are provided in Figure 1.3.4-12. Design characteristics (i.e., system description) of the waste package emplacement pallet are discussed in Section 1.3.4.6.1.	NA

Table 1.3.4-5. Summary of Conformance of Subsurface Facility Design to Postclosure Control Parameters—Emplacement Areas (Continued)

Structure, System and Component	Postclosure Control Parameter: Parameter Number and Title	Postclosure Control Parameter: Values, Ranges of Values or Constraints	Relevant to ITWI	Design Criteria/Configuration	Postclosure Procedural Safety Control
Waste Package Emplacement Pallet	08-02 Emplacement Pallet Function	For the design static load, the emplacement pallet shall maintain the waste package emplacement nominal position for at least 300 years and shall maintain a nominally horizontal waste package emplacement for 10,000 years.	No	The design of the drift, invert and pallet each contribute to the capability of the waste package emplacement pallet to maintain the waste package in a nominal position for 300 years and a nominally horizontal position for 10,000 years considering static loads. The emplacement drifts will be excavated at a horizontal grade as described in Sections 1.3.4.3. The steel invert structure supports repository preclosure operations that include waste package emplacement, recovery, and potential retrieval and the invert ballast helps maintain the emplaced waste packages in a nominal horizontal position as described in Section 1.3.4.5.1.	NA

Table 1.3.4-5. Summary of Conformance of Subsurface Facility Design to Postclosure Control Parameters—Emplacement Areas (Continued)

Structure, System and Component	Postclosure Control Parameter: Parameter Number and Title	Postclosure Control Parameter: Values, Ranges of Values or Constraints	Relevant to ITWI	Design Criteria/Configuration	Postclosure Procedural Safety Control
Waste Package Emplacement Pallet	08-03 Emplacement Pallet Fabrication and Corrosion Allowance (Controlled Interface Parameter – Item (a) only)	(a) The emplacement pallet material properties shall be controlled through the configuration management system (Section 5). (b) The emplacement pallet shall be fabricated of Alloy 22 plates and square stainless steel tubes. (c) The contacts between the waste package and emplacement pallet shall be Alloy 22. (d) The corrosion allowance for the Alloy 22 components shall be at least 2 mm. (e) The corrosion allowance for the stainless steel components shall be at least 2 mm. (f) The mechanical properties at 150°C or higher shall be used for postclosure analysis.	No	(a), (b), and (c) Fabrication and construction of the waste package emplacement pallet will control contacts between the waste package and emplacement pallet and are described in Section 1.3.4.6.1 per the subject constraints of (a) and (c). The waste package emplacement pallet design will be configured per the subject constraint in (b) and is shown in Figure 1.3.4-11. (d), (e), and (f) Design conforms with corrosion allowances and mechanical properties of the materials at the stated temperature.	NA
Waste Package Emplacement Pallet	08-04 EBS Materials Interactions – Emplacement Pallet Function	EBS materials shall be inert relative to each other so that physical contact between EBS materials minimizes dissimilar material interaction mechanisms. The emplacement pallet shall be designed such that, for the nominal scenario (e.g., not seismic or igneous), the waste package outer corrosion barrier shall not contact EBS components other than the Alloy 22 support surfaces of the pallet.	No	Design criteria controlling fabrication and construction of the waste package emplacement pallet and design of contacts between the waste package and emplacement pallet are described in Section 1.3.4.6.1. EBS materials used in the fabrication of waste package emplacement pallet are described in Section 1.3.4.6.7. The standard and short waste package emplacement pallets are shown in Figures 1.3.4-11 and 1.3.4-12.	NA

Table 1.3.4-5. Summary of Conformance of Subsurface Facility Design to Postclosure Control Parameters—Emplacement Areas (Continued)

Structure, System and Component	Postclosure Control Parameter: Parameter Number and Title	Postclosure Control Parameter: Values, Ranges of Values or Constraints	Relevant to ITWI	Design Criteria/Configuration	Postclosure Procedural Safety Control
Waste Package Emplacement Pallet	08-05 Waste Package and Emplacement Pallet Static Stresses	The tensile stresses imposed on the Alloy 22 components of both the waste package and the emplacement pallet shall be less than 257 MPa (the approximate stress corrosion cracking threshold for Alloy 22).	No	Analyses demonstrating that tensile stresses imposed on Alloy 22 components of both the waste package and emplacement pallet are less than 257 MPa are discussed in Section 1.5.2.6.1.8.	NA

NOTE: See Table 1.9-9 for additional information on postclosure analyses control parameters.

Source: BSC 2008b, Table 1.

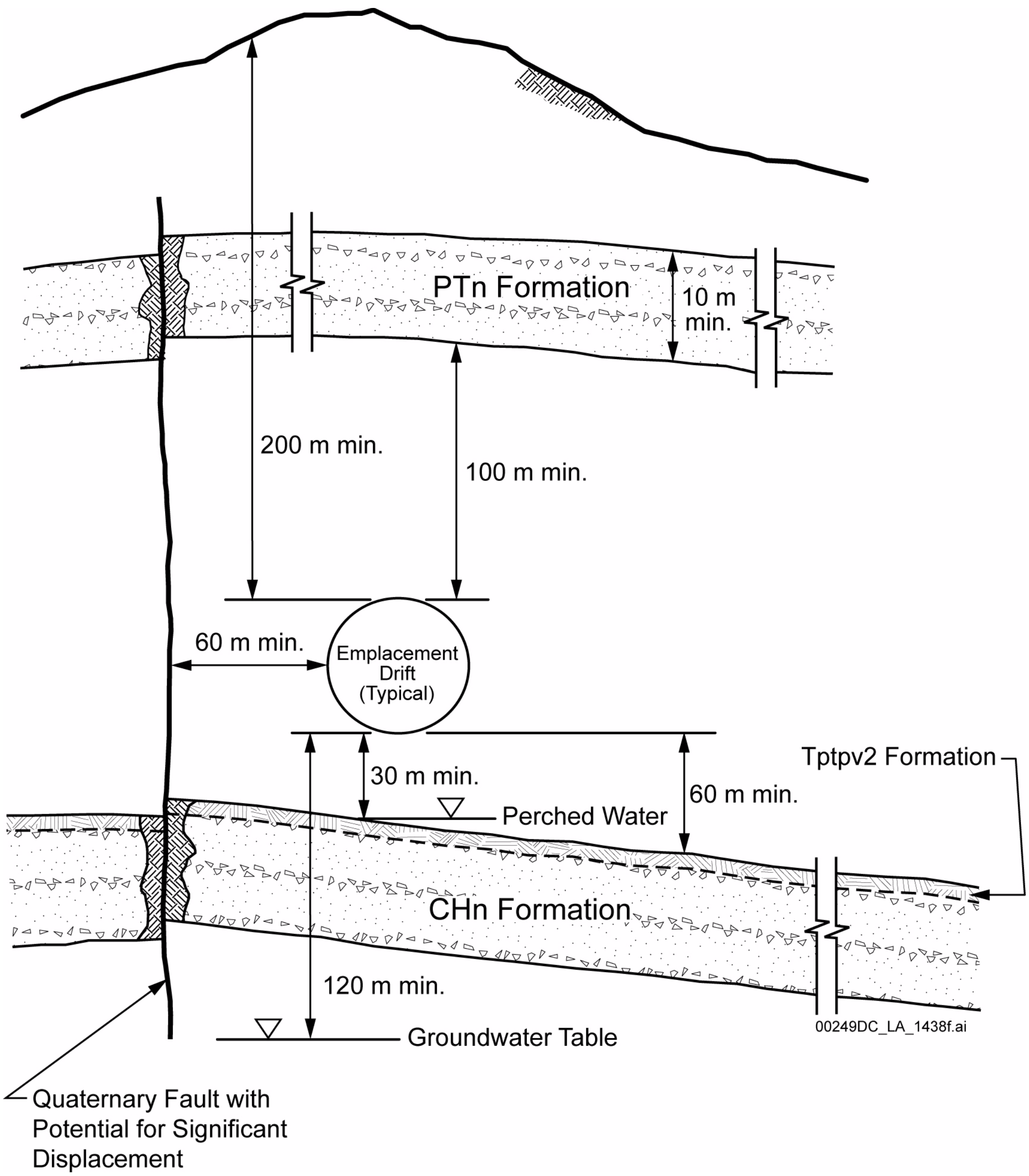


Figure 1.3.4-1. Simplified Representation of the Subsurface Facility Standoffs as Applicable to an Emplacement Drift

NOTE: Drawing is not to scale.
Tptpv2 = Topopah Spring Tuff crystal-poor vitric zone; CHn = Calico Hills nonwelded unit; PTn = Paintbrush nonwelded unit.

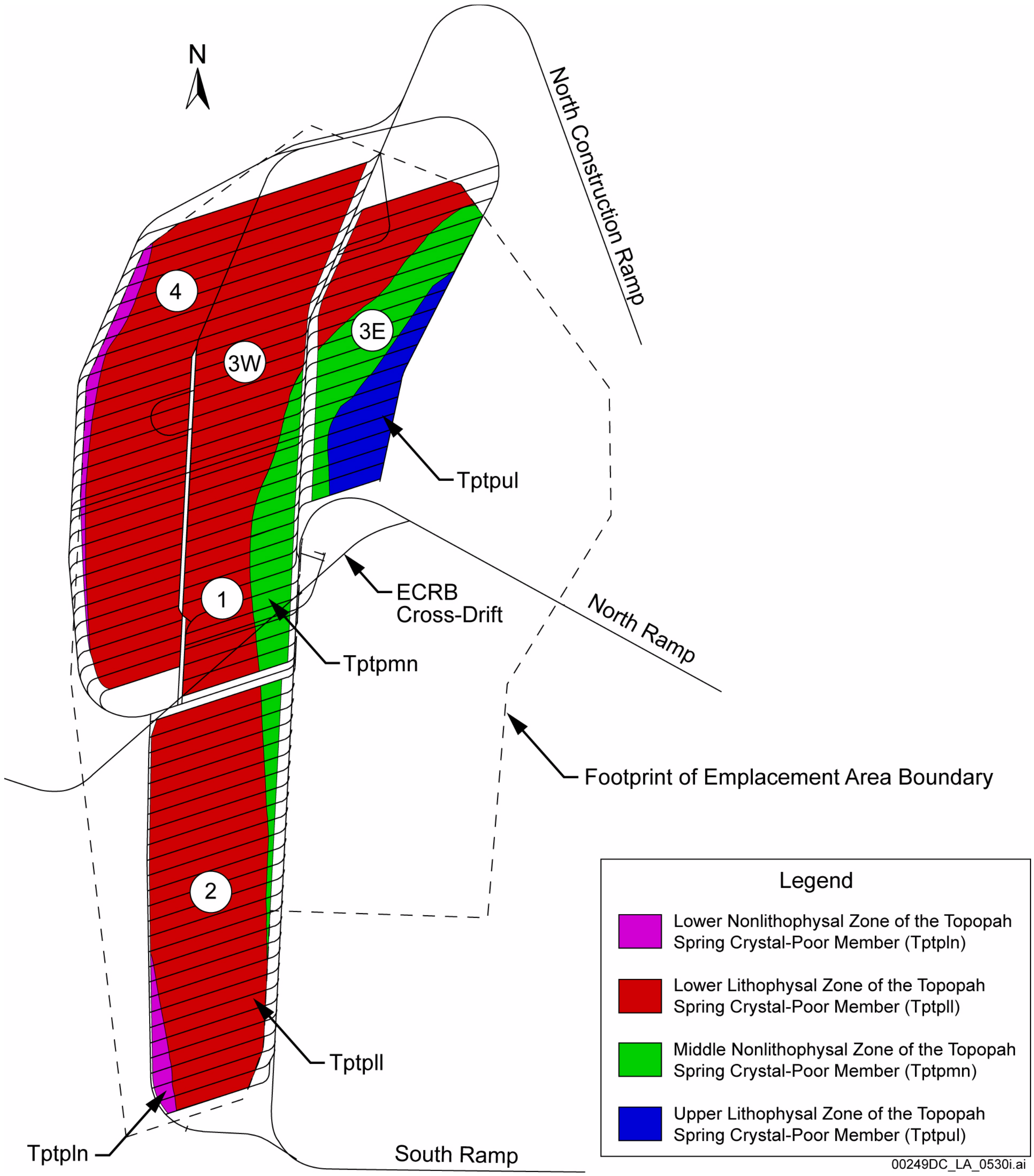
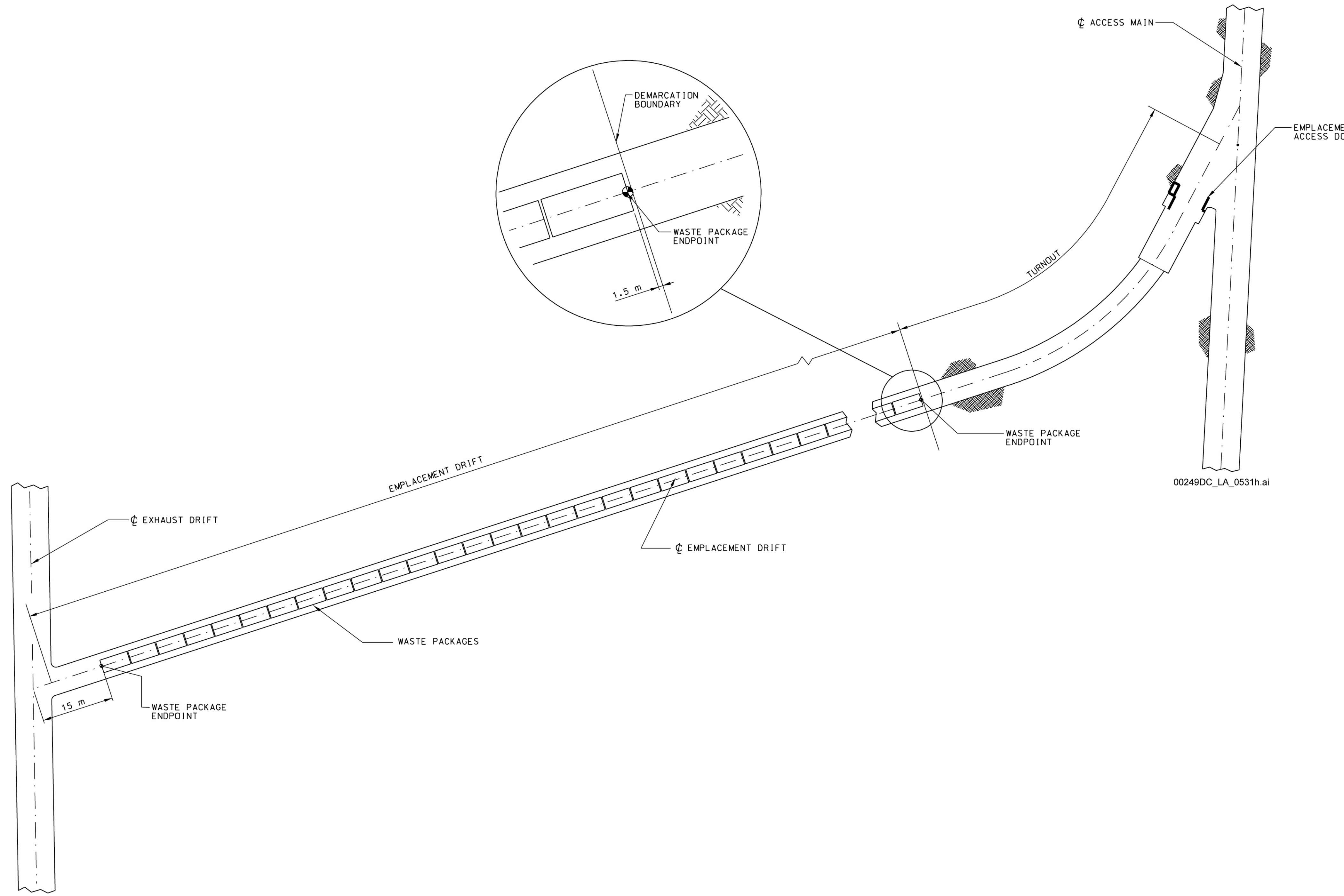


Figure 1.3.4-2. Underground Layout Configuration and Geologic Units by Panel



NOTE: Emplacement drift—turnout demarcation boundary is 5.0 ft (1.5 m) from the Waste Package Endpoint. The waste package standoff distance to the centerline of the exhaust main is 49 ft (15 m).

The VULCAN model (Section 1.3.4.2.1) uses geometric control points and centerlines as the basis for the underground layout. In the VULCAN model the emplacement drift end point is the centerline intersection of the exhaust main and the emplacement drift. However, the end of the emplacement drift is where the emplacement drift excavation breaks through into the exhaust main excavation. Available emplacement drift length (drift length available for waste package emplacement) is determined by subtracting the applicable standoffs, the 15-m offset measured from the exhaust main centerline and the 1.5-m offset from the end of the turnout.

The following emplacement drifts in Panel 2 are affected at the exhaust end of the drift by the following operational standoffs applicable in addition to the 15-m offset (the operational standoff is provided in parentheses for each affected drift): 2-17 (5 m), 2-18 (10 m), 2-19 (10 m), 2-20 (11 m), 2-21 (11 m), 2-22 (11 m), and 2-23 (6 m).

Figure 1.3.4-3. Typical Emplacement Drift Configuration

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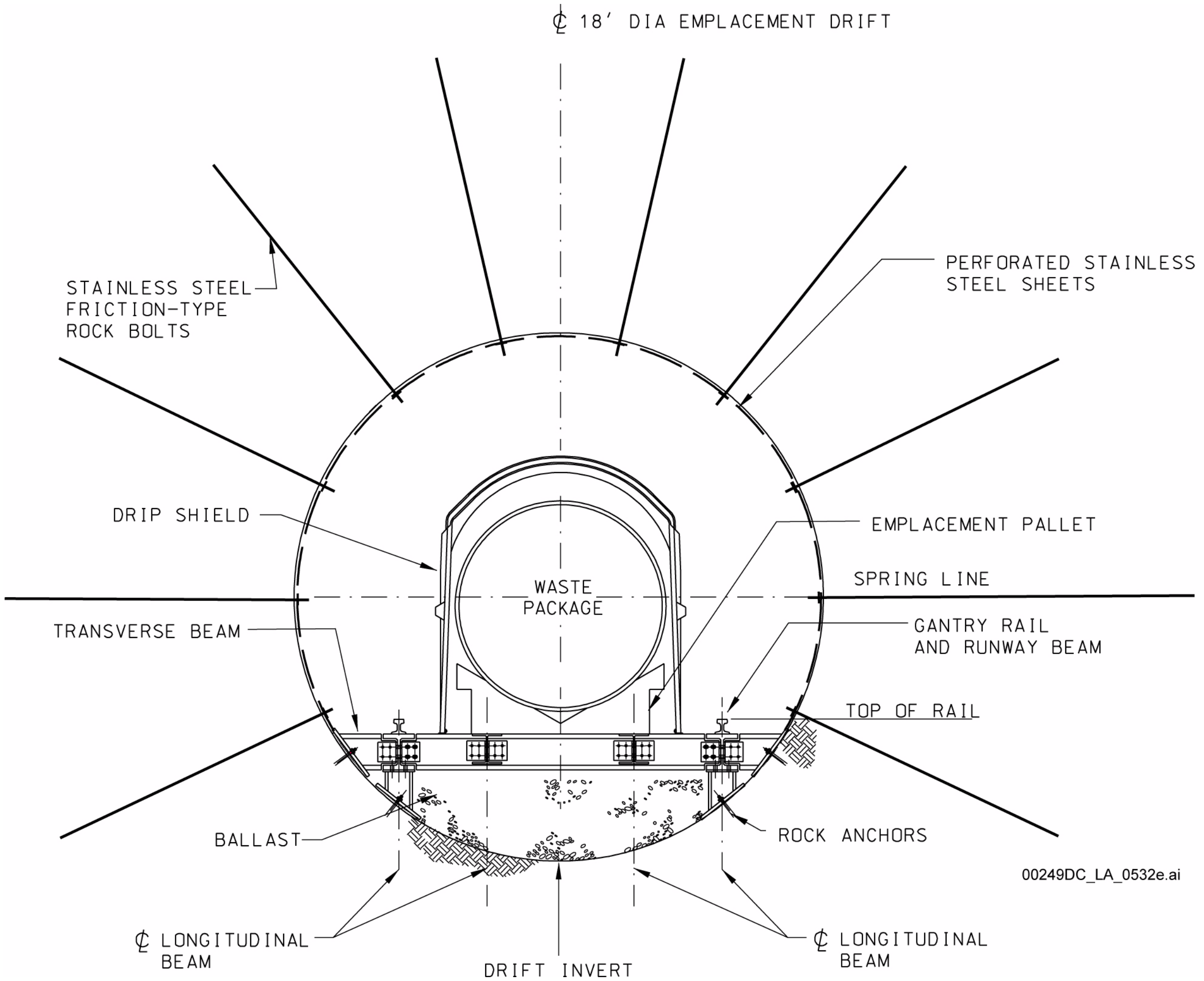


Figure 1.3.4-4. Typical Emplacement Drift Cross Section

NOTE: The spring line is a horizontal line passing through the center of the tunnel.

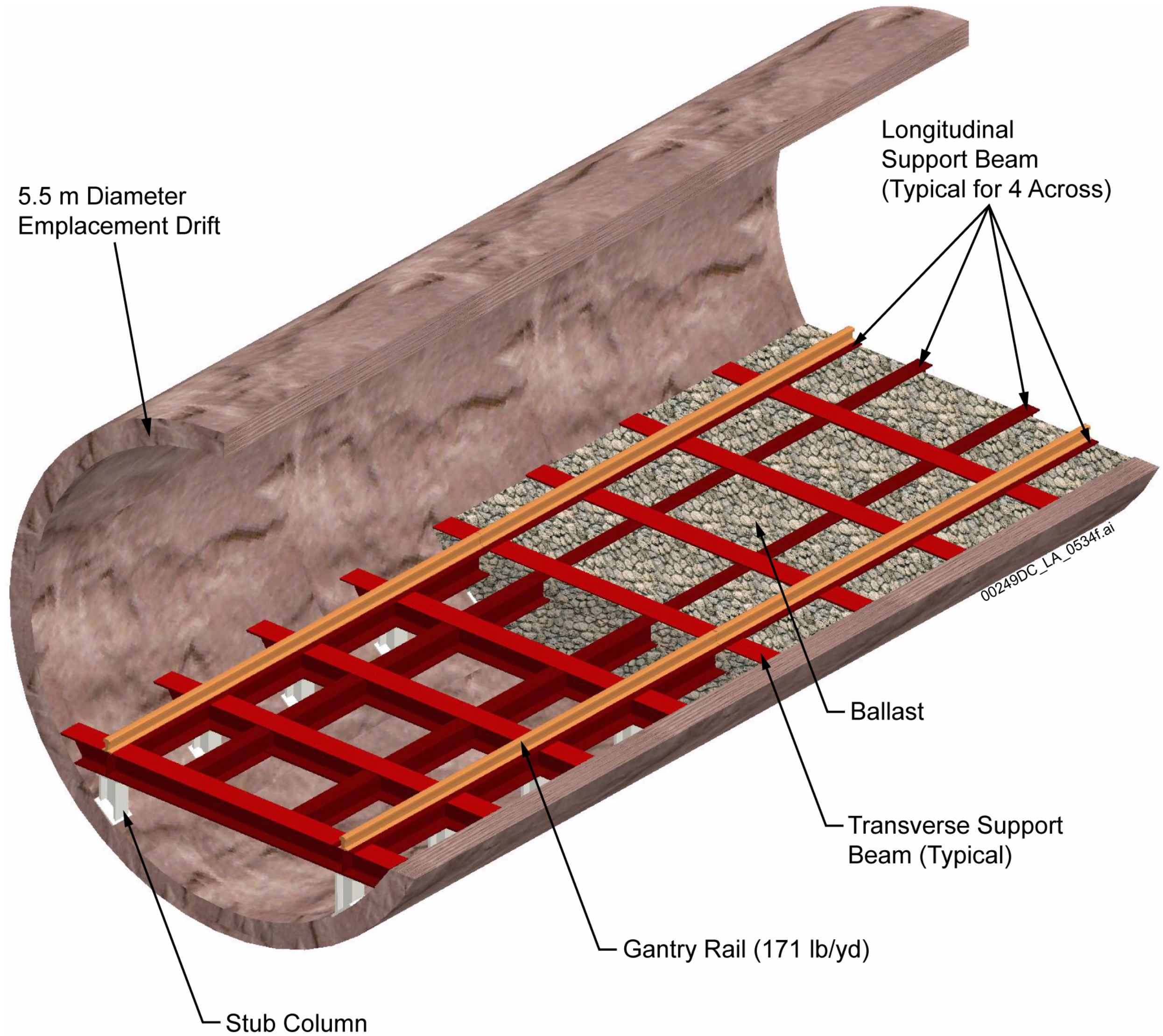
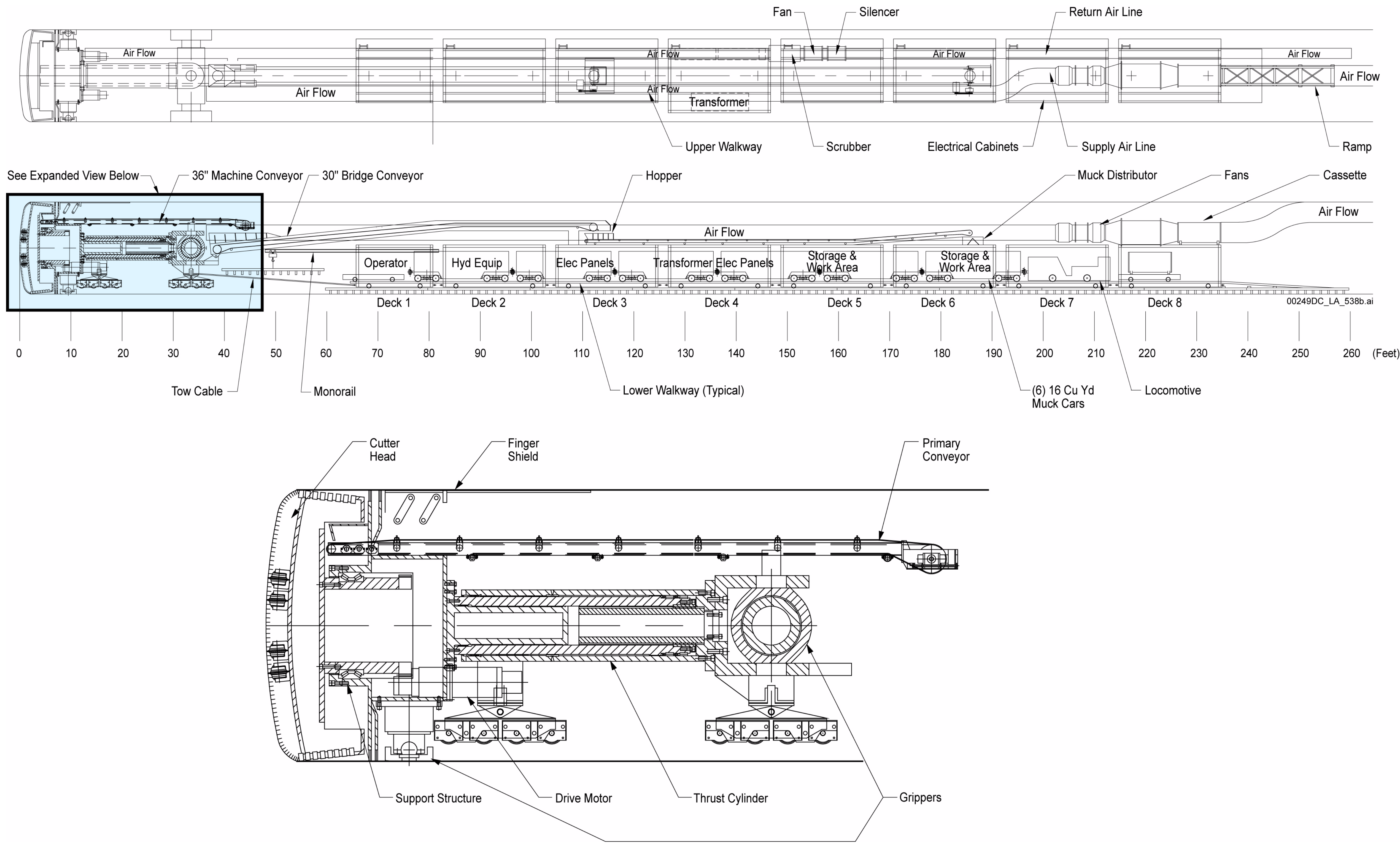


Figure 1.3.4-5. Emplacement Drift Steel Invert

NOTE: The third rail detail is not included.
Ballast shown partially to illustrate configuration of the invert steel structure.



NOTE: Elec = electrical; Hyd = hydraulic.

Source: Colorado School of Mines 2004, Figures 2-4, 3-6, and Attachment 1.

Figure 1.3.4-6. Conceptual Tunnel Boring Machine for the Emplacement Drift

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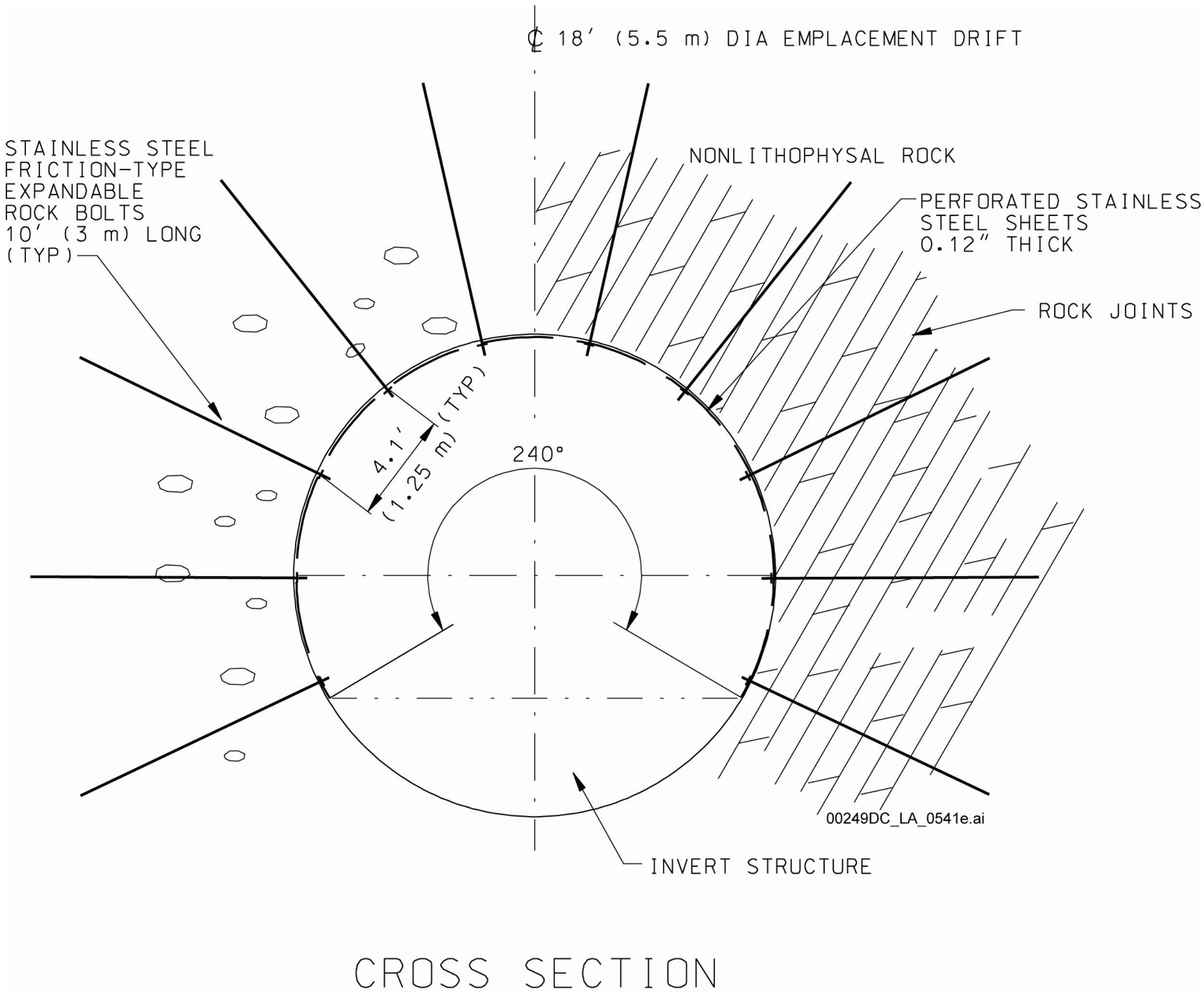

Figure 1.3.4-7. Schematic of Typical Emplacement Drift Permanent Ground Support

NOTE: Emplacement drift ground support design is the same for openings in lithophysal and nonlithophysal rock. Rock symbols are for illustration purposes only and not intended to depict the rock characteristics or fracture orientation.

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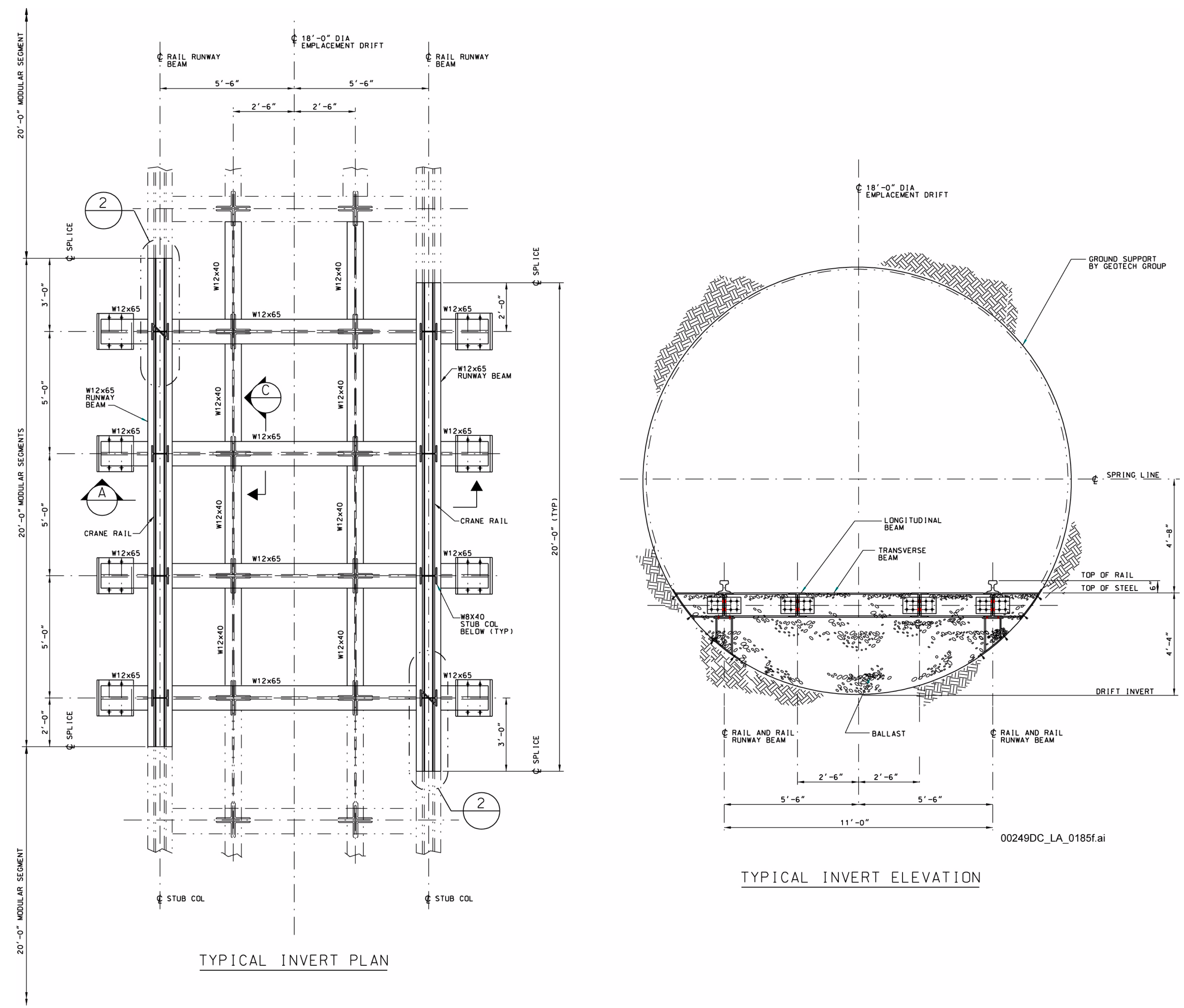

Figure 1.3.4-8. Emplacement Drift Invert—Plan and Elevation

NOTE: SHT = sheet.

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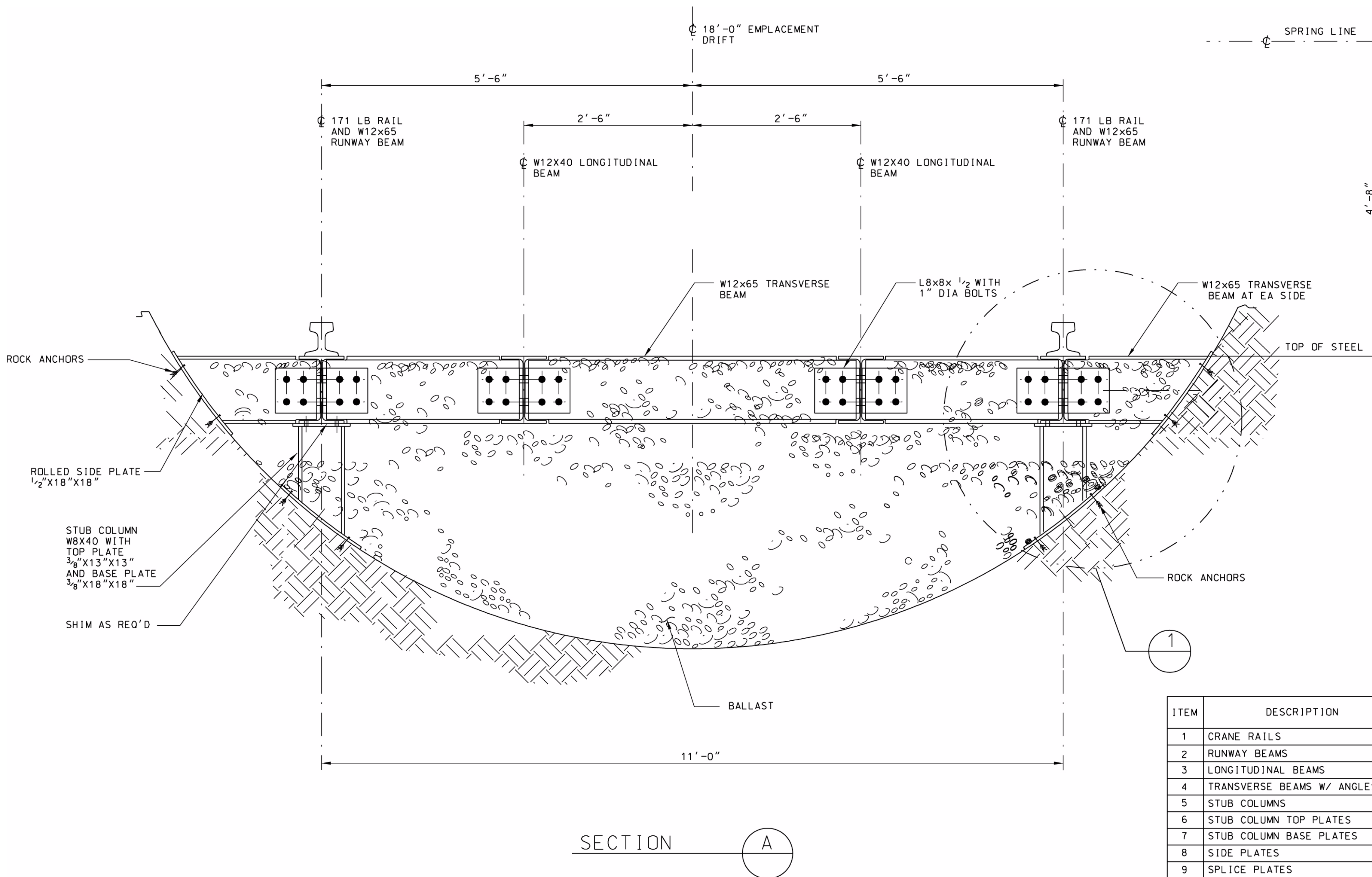

COMMITTED MATERIALS

ITEM	DESCRIPTION	SIZE	MATERIAL	WEIGHT LBS./FT	REMARKS
1	CRANE RAILS	171 lb/yd	ASTM A759	114	2 RAILS
2	RUNWAY BEAMS	W12x65	ASTM A588, GR. 50	130	2 BEAMS
3	LONGITUDINAL BEAMS	W12x40	ASTM A588, GR. 50	80	2 BEAMS
4	TRANSVERSE BEAMS W/ ANGLES	W12x65	ASTM A588, GR. 50	247	SPACED AT 5'OC
5	STUB COLUMNS	W8x40	ASTM A588, GR. 50	23	2-SPACED AT 5'OC
6	STUB COLUMN TOP PLATES	3/8"x13"x13"	ASTM A588, GR. 50	7	2-SPACED AT 5'OC
7	STUB COLUMN BASE PLATES	3/8"x18"x18"	ASTM A588, GR. 50	14	2-SPACED AT 5'OC
8	SIDE PLATES	1/2"x18"x18"	ASTM A588, GR. 50	18	2-SPACED AT 5'OC
9	SPLICE PLATES	1/2"x8"x16.5"	ASTM A588, GR. 50	4	4 PLATES
10	STRUCTURAL BOLTS	1" DIA	ASTM A325	34	15.6 BOLTS / FT
11	ROCK ANCHORS	1" DIA	STAINLESS STEEL	9	3.2 BOLTS / FT
	TOTAL STEEL			680 **	
12	BALLAST	VARIES	CRUSHED TUFF	5717**	* 46 CUBIC FT / FT

* TOTAL GROSS SECTIONAL AREA OF BALLAST IS 46 SQ FT. AVERAGE NET SECTIONAL AREA OF THE BALLAST IS 46 SQ FT. AVERAGE NET SECTIONAL AREA OF STEEL IS 1 SQ FT.

** WEIGHT (LB / FT) = + OR - 10% OF TABLE LISTED WEIGHT.

00249DC_LA_0184f.ai

NOTE: F. S. = far sight; NA = not applicable; N. S. = near sight; PL = plate.

Figure 1.3.4-9. Emplacement Drift Invert—Steel Frame and Ballast Details

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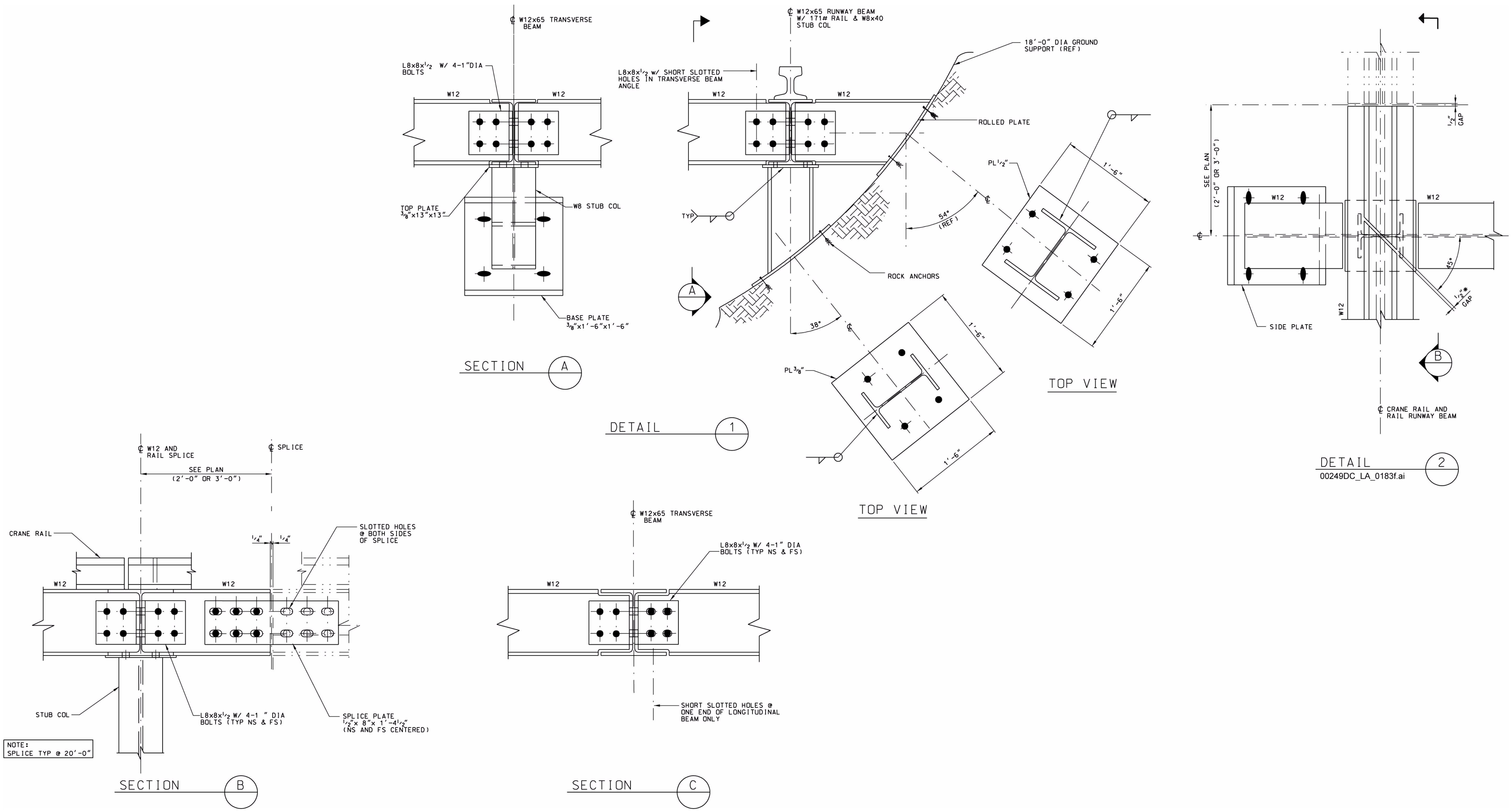

NOTE: F. S. = far sight; N. S. = near sight.

Figure 1.3.4-10. Emplacement Drift Invert—Steel Structure Details

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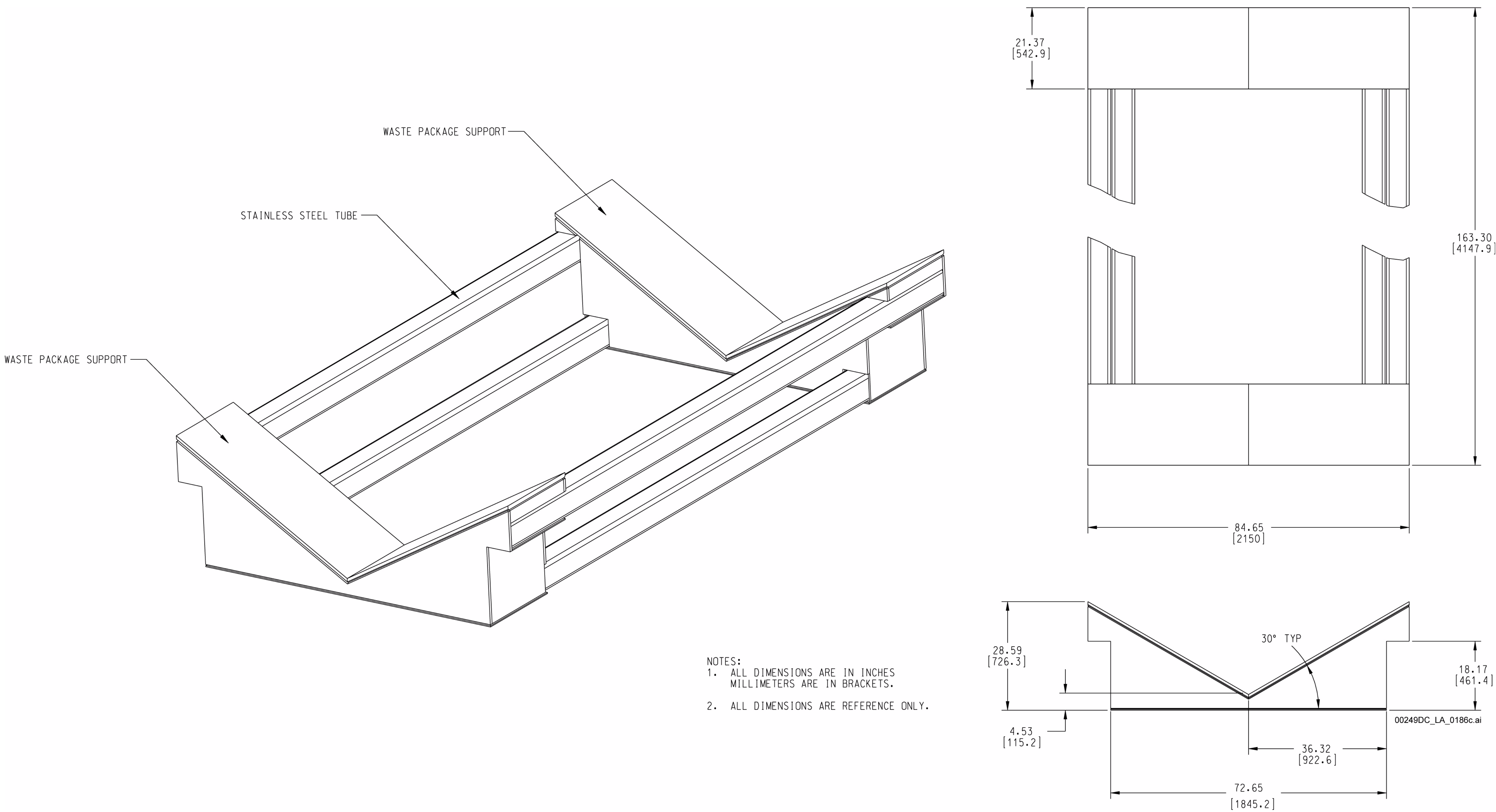

Figure 1.3.4-11. Standard Waste Package Emplacement Pallet

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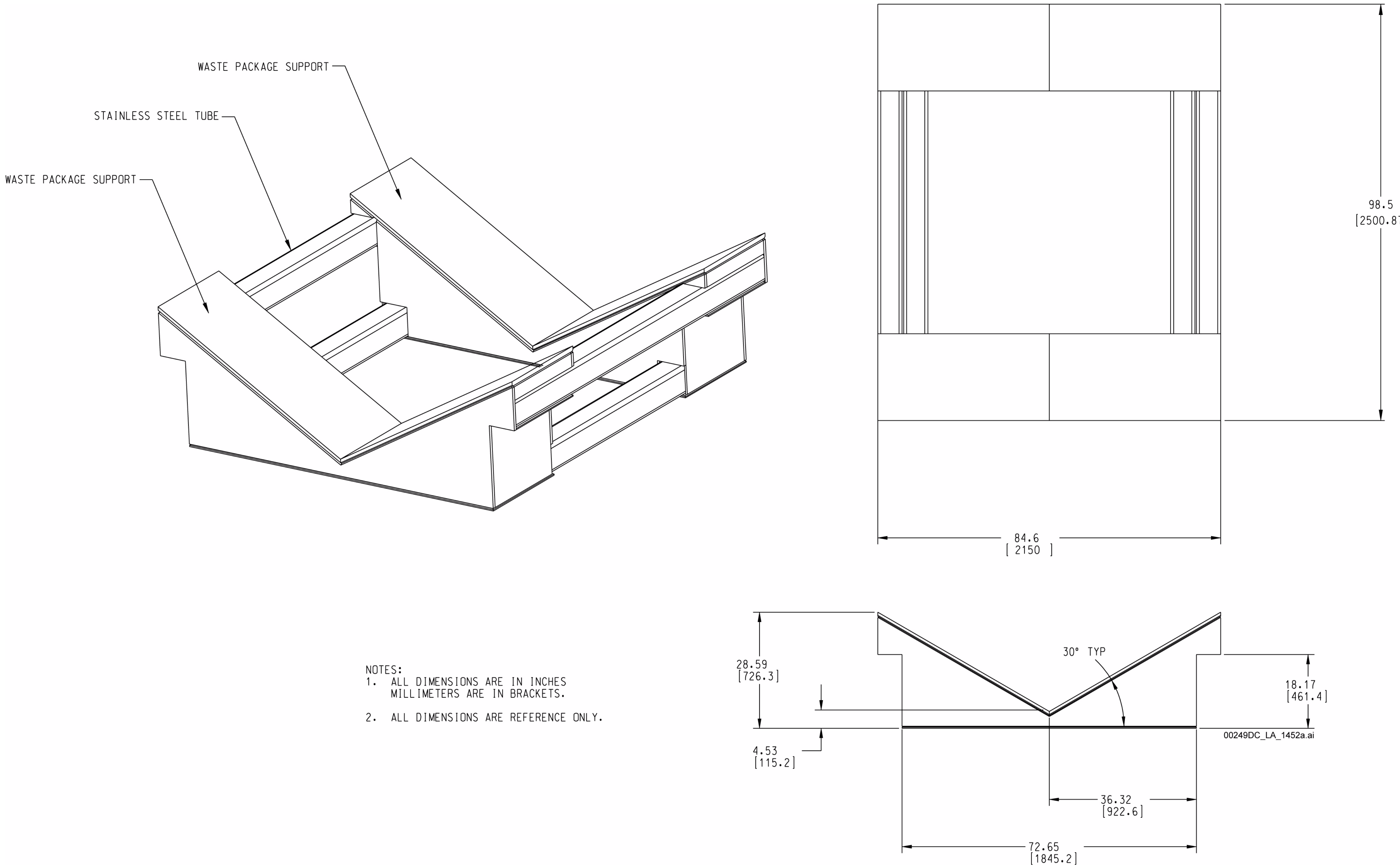

Figure 1.3.4-12. Short Waste Package Emplacement Pallet

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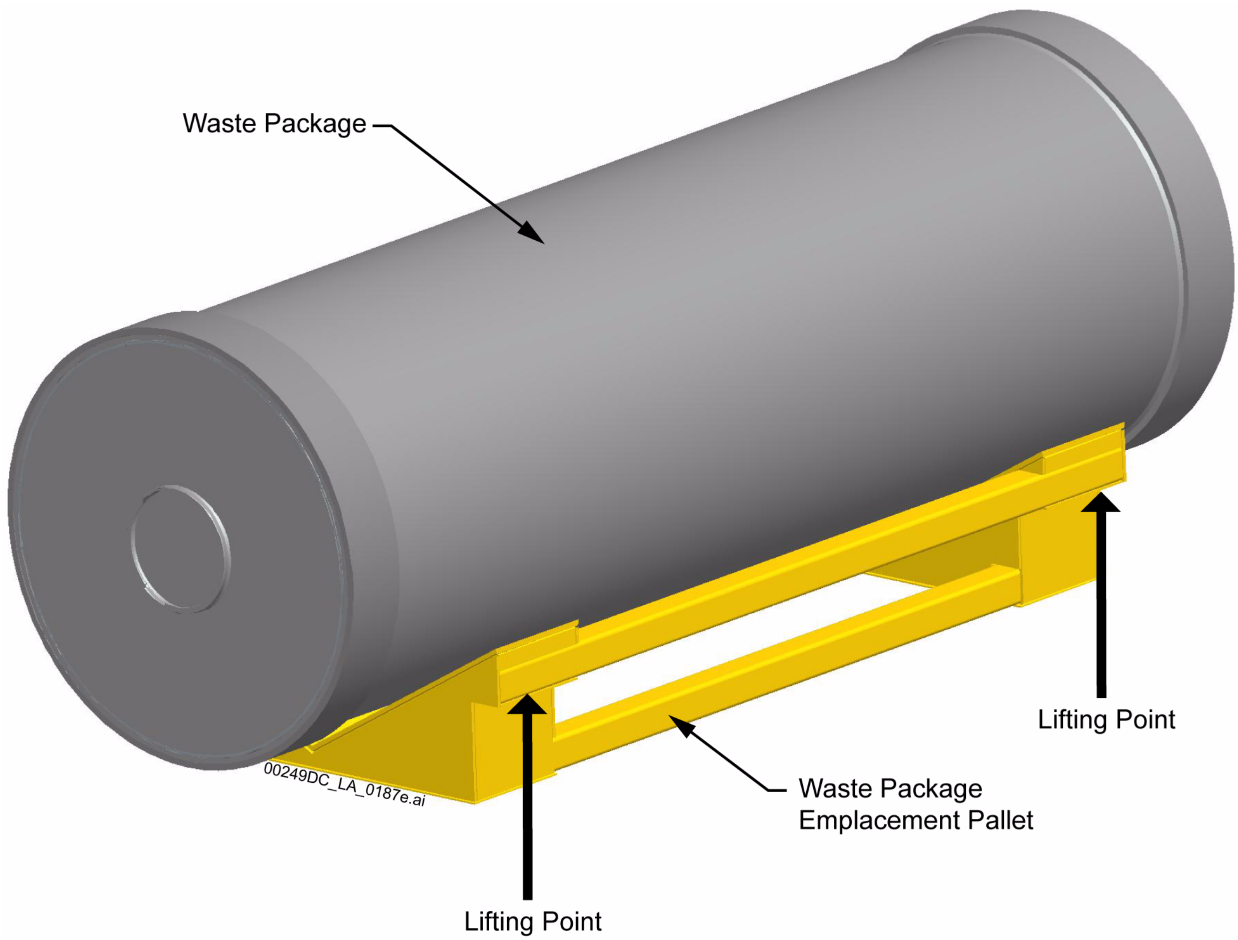

Figure 1.3.4-13. Emplacement Pallet Loaded with Waste Package

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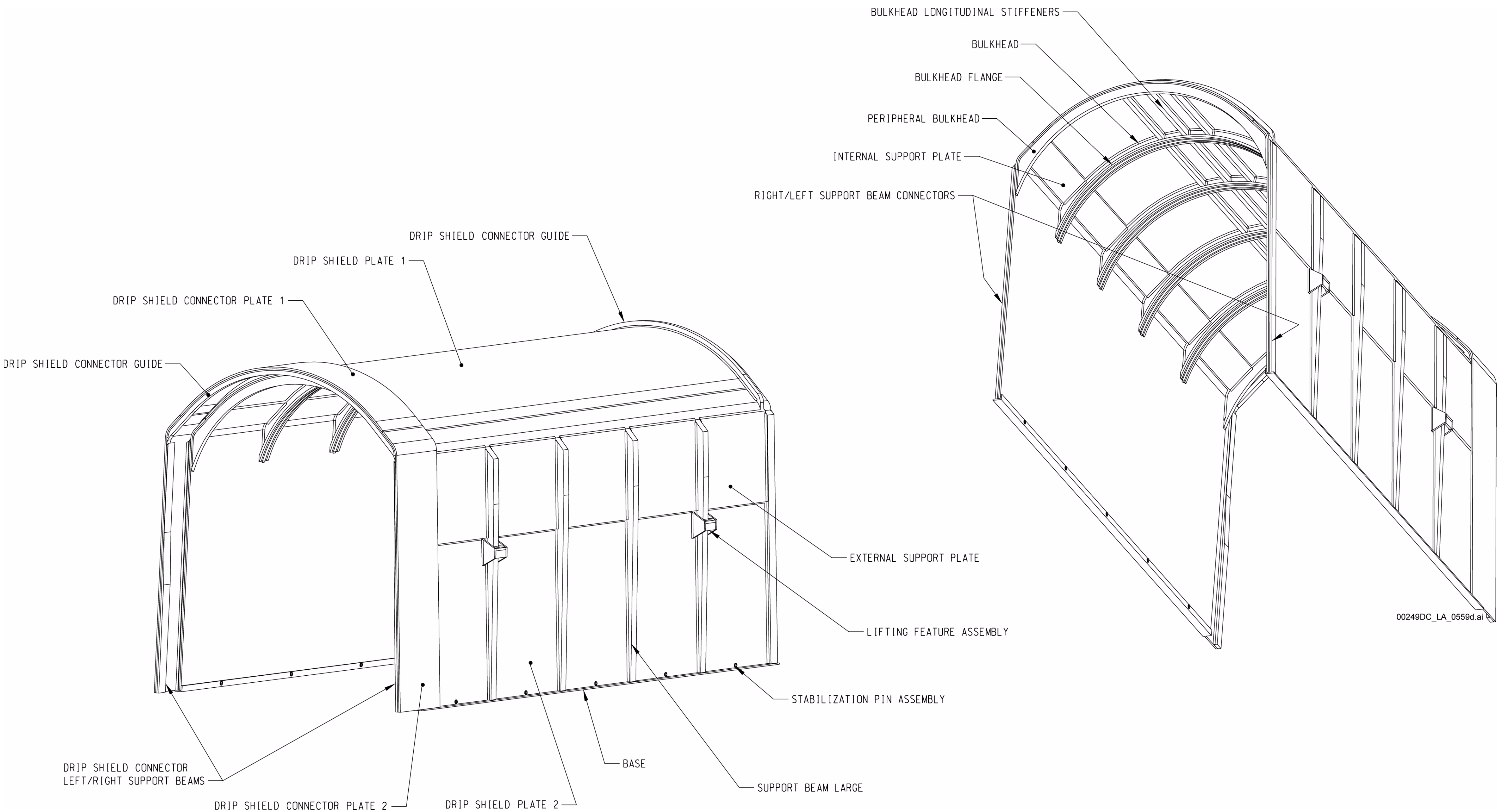

Figure 1.3.4-14. Interlocking Drip Shield

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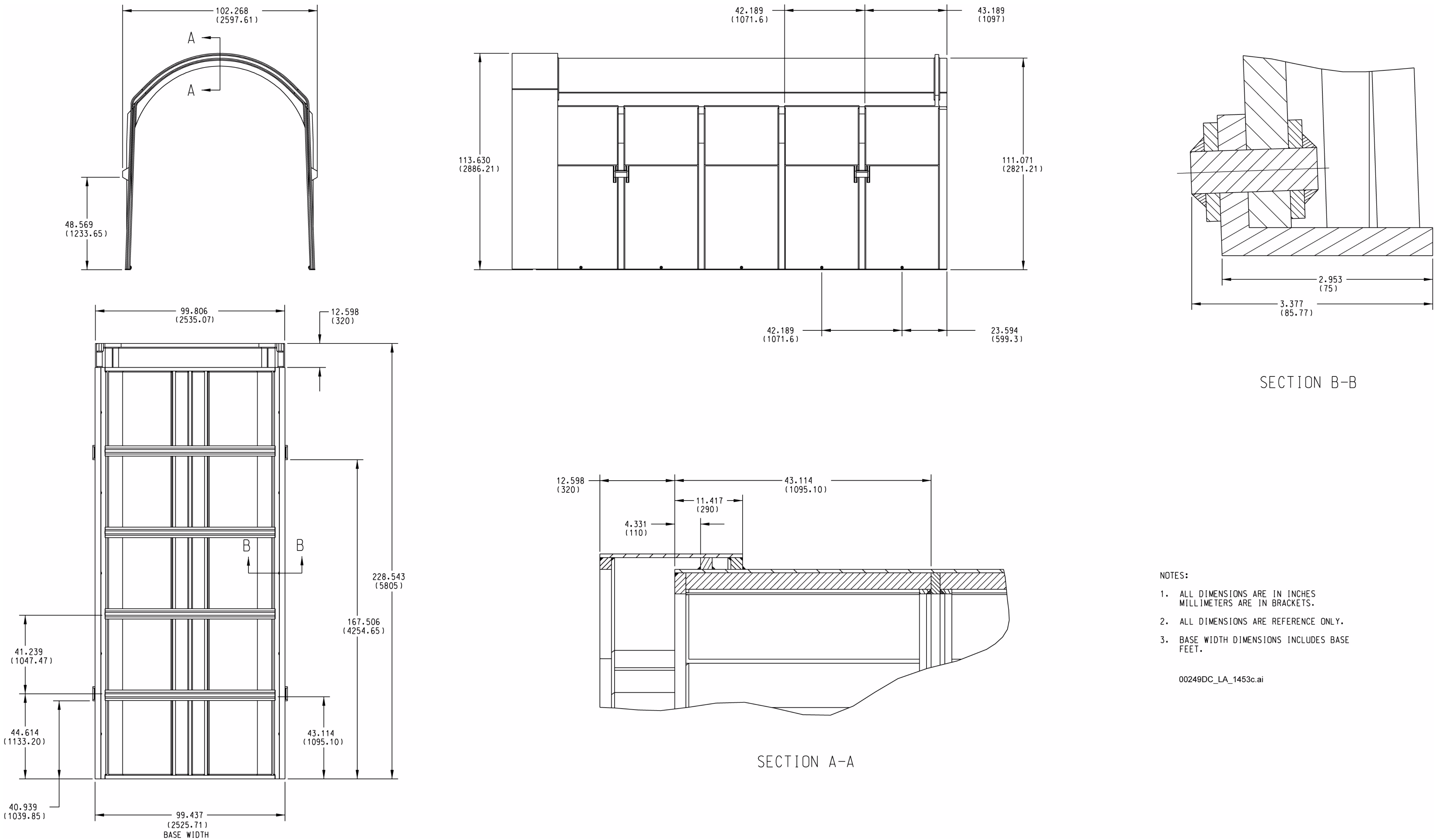

Figure 1.3.4-15. Drip Shield Structural Details

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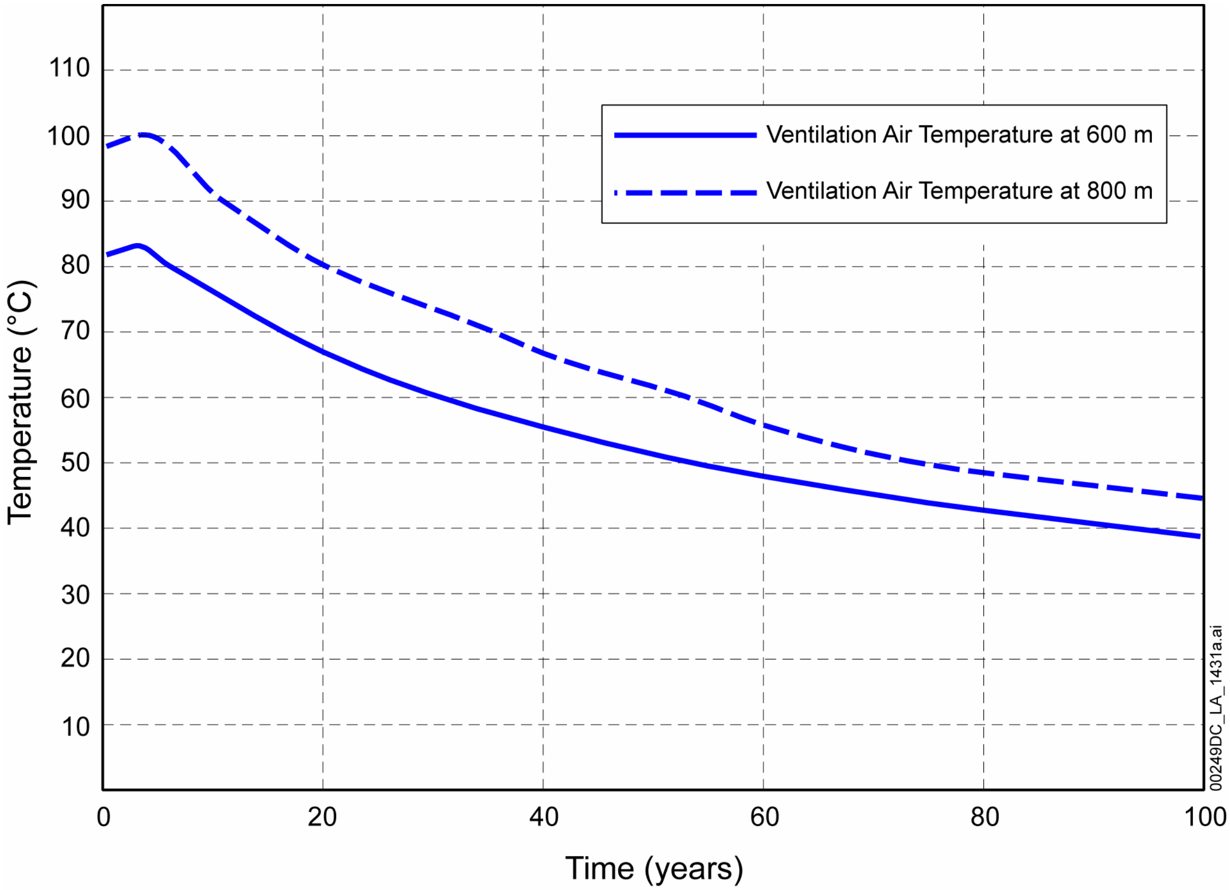


Figure 1.3.4-16. Emplacement Drift Exhaust Air Temperatures as a Function of Time and Distance from the Drift Inlet (Full Drift) for Drifts Loaded with a Thermal Line Load of 2.0 kW/m

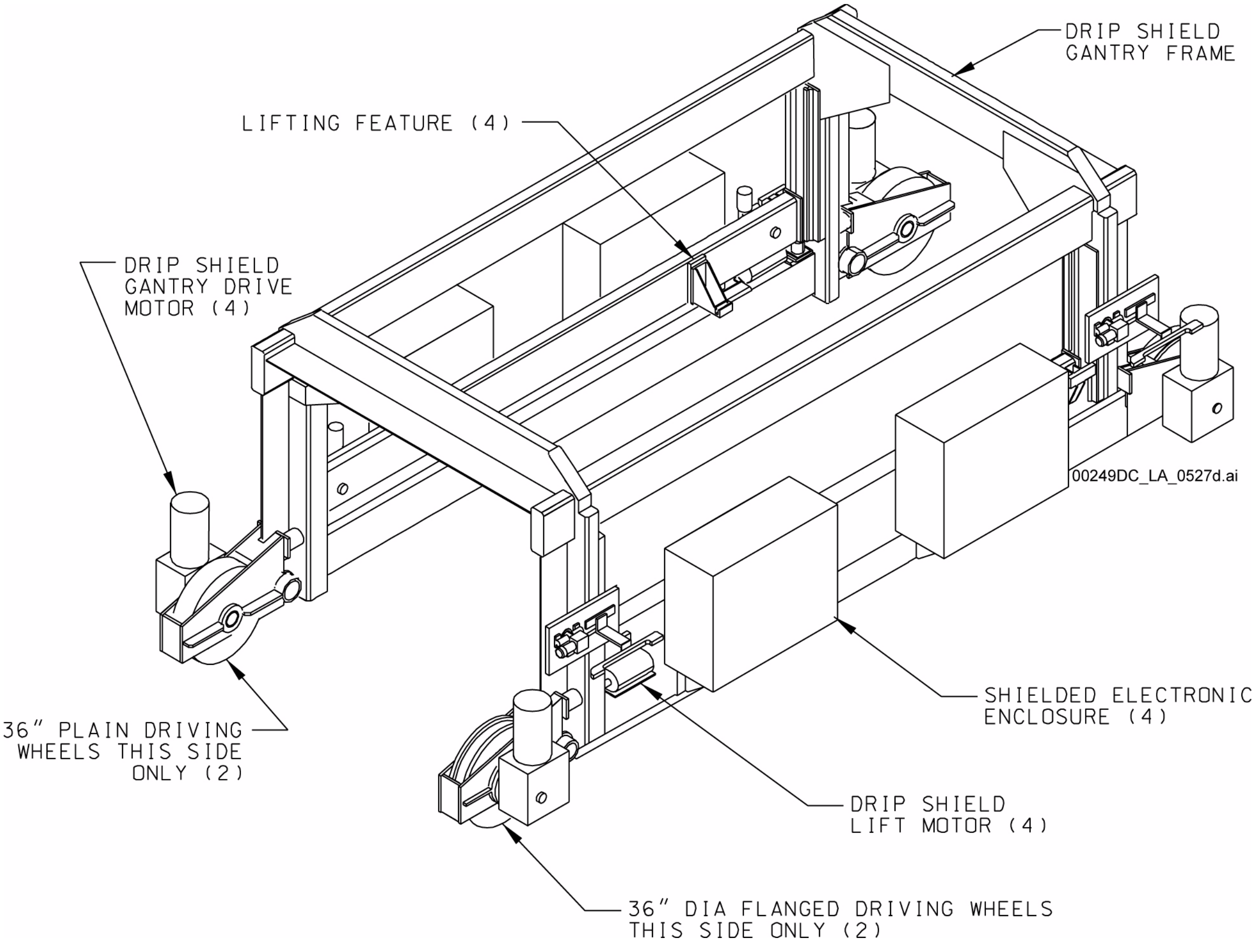
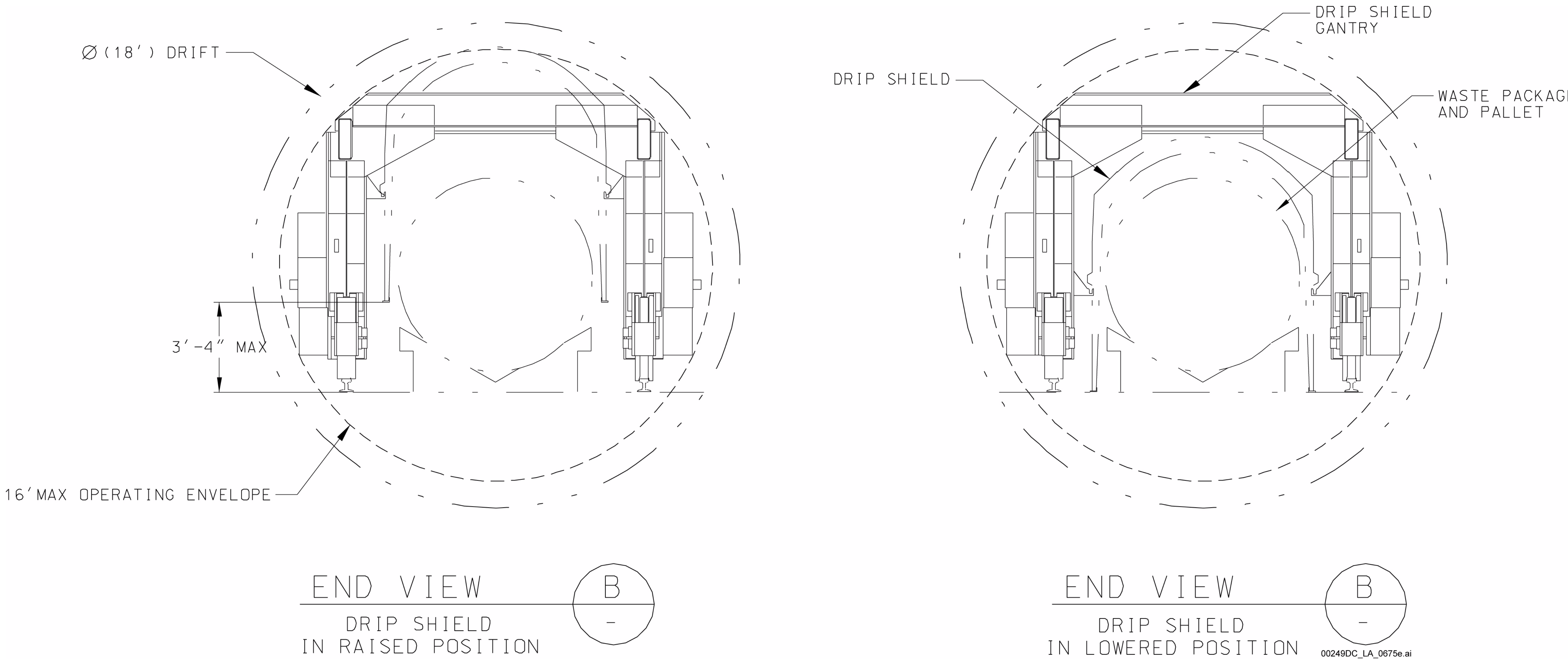


Figure 1.3.4-17. Drip Shield Emplacement Gantry

NOTE: Third rail is not shown.



NOTE: Third rail is not shown.

Figure 1.3.4-18. Emplacement Drift Configuration for Drip Shield Emplacement

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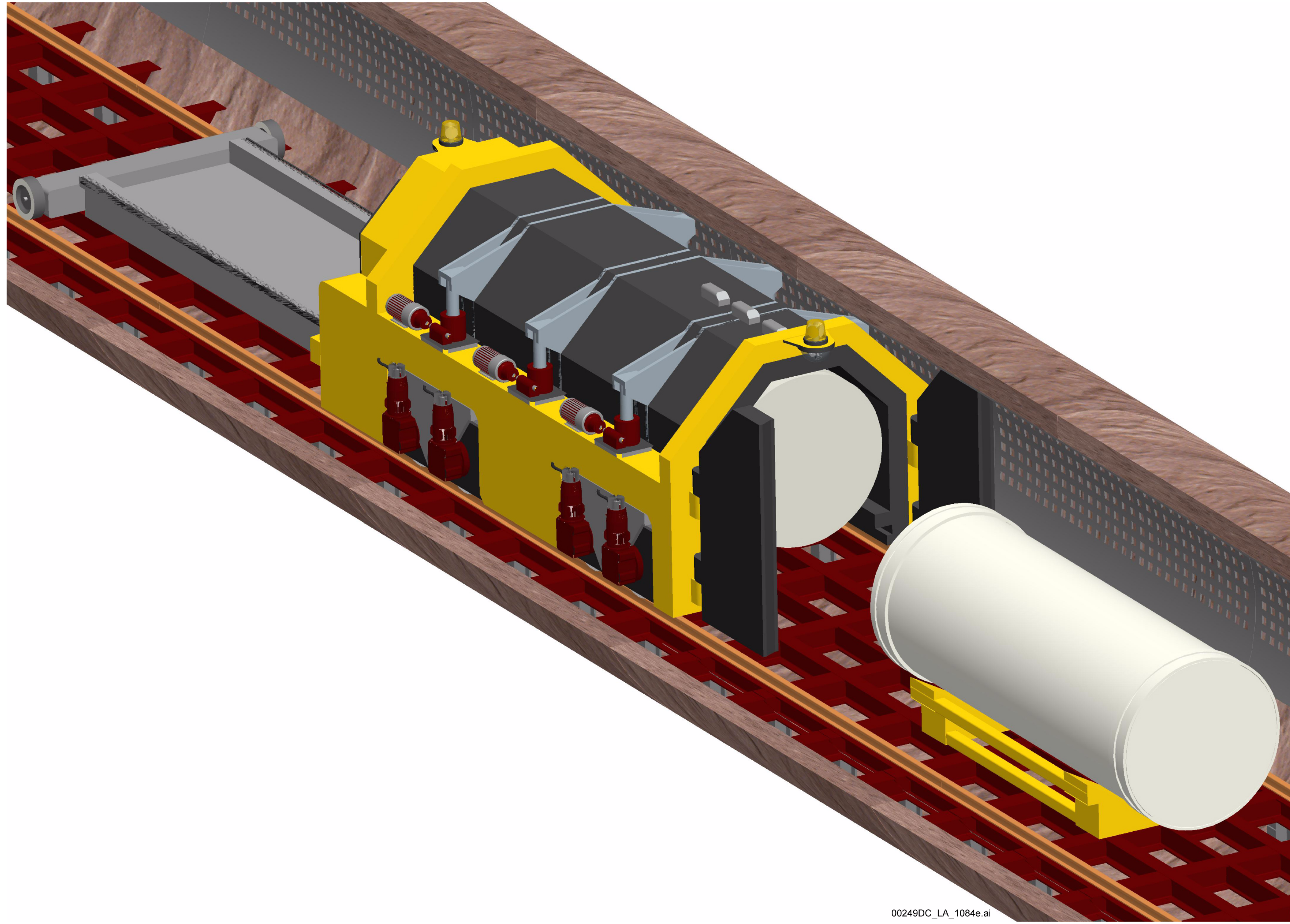

NOTE: A more specific presentation of the Transport and Emplacement Vehicle configuration is provided in Figures 1.3.3-39 and 1.3.3-40. Third rail is not shown.

Figure 1.3.4-19. Conceptualized Representation of Waste Package Emplacement Operations

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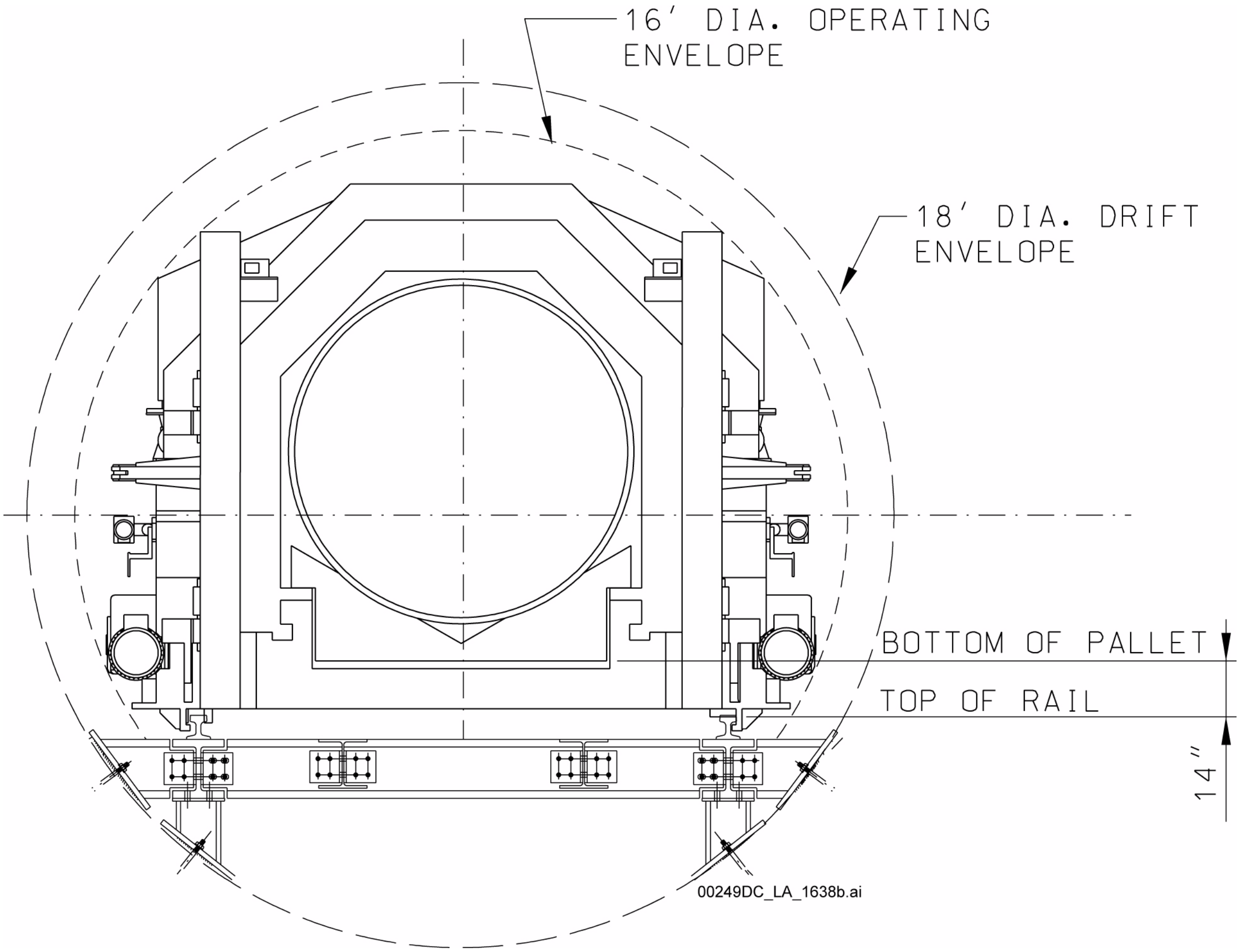

Figure 1.3.4-20. Transport and Emplacement Vehicle with Waste Package in the Emplacement Drift

NOTE: The plan view (B) of the above end view is depicted in Figure 1.3.3-40.
Third rail is not shown.

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FIGURES

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1.3.5 Subsurface Facility Ventilation

[NUREG-1804, Section 2.1.1.2.3: AC 3, AC 6; Section 2.1.1.7.3.1: AC 1; Section 2.1.1.7.3.2: AC 1; Section 2.1.1.7.3.3(II): AC 2, AC 3, AC 7]

The subsurface facility design includes openings that connect the surface to the waste package emplacement areas for the purpose of providing ventilation to those areas. These openings are directly or indirectly connected to the access mains or to the exhaust mains so that together they form a continuous path of airways for the subsurface ventilation system. The path of some of the airways is permanently divided at certain locations by isolation barriers. These permanent isolation barriers separate the outside ambient air intake and distribution airways from the heated air collection and exhaust airways. The subsurface facility is thus divided into thermal zones, the intake air zone and the exhaust air zone, with the emplacement drifts being the connecting conduits where heat is exchanged. The emplacement drifts contain the waste packages that generate the heat being removed by the subsurface ventilation system. The subsurface ventilation system operates throughout the preclosure period under this thermal-zone concept. When the repository reaches full emplacement, the entire subsurface facility is operated with one subsurface ventilation system in place. That system uses all the intake and exhaust ventilation airways described in the design, and it distributes air from the intake air zone into the emplacement drifts and removes heated air from the emplacement drifts into the heated air zone and out to the surface. The continuous forced ventilation to the emplacement drifts for an extended period after emplacement of waste packages provides heat removal that is considered as part of the bases for postclosure analyses.

The configuration of the subsurface facility ventilation system changes over time as the facility is developed into a fully-loaded repository. During initial construction of the repository and before waste package emplacement begins, the subsurface ventilation system is used as a single system that only supports construction operations through a limited number of available airways. At this stage of development, a continuous underground airway path has not been established, so the construction ventilation system uses air ducts to supply and exhaust construction air out of dead-end excavations and, in this way, maintains the supply air separate from the exhaust air. Dust, fumes, and naturally occurring radon gas are removed with the exhaust air from the excavation areas. In the development areas there are also outside ambient air intake airways and exhaust airways that become part of the repository operations ventilation system when the ventilation airway path is established as the new drifts are commissioned for waste emplacement.

During the time period when repository development and emplacement activities occur concurrently, the intake and exhaust thermal zones described in the previous paragraphs are divided into two areas with separate ventilation systems operating on either side of a set of temporary isolation barriers. As the initial emplacement drifts are commissioned and before they are turned over for waste package emplacement, temporary isolation barriers are placed at the access mains to separate the intake air from one source going into the emplacement drifts from the intake air from a different source being distributed to the development areas, and to effectively separate development activities from active waste emplacement areas. Temporary isolation barriers are also placed in the exhaust mains to separate the heated exhaust air being removed from the emplacement drifts from the air on the development side of the barrier, and to effectively separate the construction activities from the waste emplacement areas. Additional temporary isolation barriers are placed in a similar fashion as more emplacement drifts are completed and made ready for waste emplacement, and the previously installed temporary isolation barriers are removed so that there is only one set of functional temporary isolation barriers at any time separating the construction activities from the waste emplacement activities in a particular panel.

The development ventilation system uses temporary fans installed at the intake shaft openings that force air into the development areas. The emplacement ventilation system uses permanent fans installed at the exhaust shaft openings that draw air from the emplacement areas. The isolation barriers separating the two systems are thus exposed to a relative pressure differential created by a positive pressure on the development side and a negative pressure on the emplacement side of the barrier. This pressure differential induces airflow from the development side to the emplacement side if there is any leakage across the barrier. Airflow across the barriers is controlled by two bulkheads that are part of the isolation barrier and that function together as an airlock structure. Bulkhead doors are activated on either side of the isolation barrier for passage by personnel.

The design of the subsurface facility ventilation system is described in this section. The subsurface ventilation system is classified as not important to safety (non-ITS) because it is not relied upon to prevent or mitigate any Category 1 or 2 event sequences (Sections 1.7 and 1.9, and Table 1.9-1). The system is also not important to waste isolation (non-ITWI) (Table 1.9-8) because repository thermal goals and postclosure thermal performance can be achieved without relying on the ventilation system for periods of at least 30 days for naval SNF canisters or even longer for other waste forms. The typical role that ventilation systems routinely perform in assuring confinement of radiological material is not a function required from the subsurface ventilation system. With respect to nonnuclear safety considerations, the subsurface ventilation system plays an important life safety role in conforming to appropriate life safety codes (i.e., applicable parts of the Occupational Safety and Health Administration and Mine Safety and Health Administration as administered by the U.S. Department of Energy (DOE) through implementation of 10 CFR 851 regulations).

Bases for Classification of the Subsurface Ventilation System—The classification of the subsurface ventilation system is predicated on the capability of the repository to withstand temporary ventilation system failures without the system being needed to prevent or mitigate the occurrence of an event sequence or being the cause of an event sequence. Since neither of these cases occurs, the system is classified as non-ITS (Table 1.9-1). The system does not contribute significantly to postclosure barrier performance and therefore, is classified as non-ITWI (Table 1.9-8).

The subsurface ventilation system operates continuously and removes decay heat from the waste packages in order to meet the thermal limits of the waste forms, the waste packages and the host rock. The continuous operation also assures that the initial thermal conditions for the postclosure safety analyses are established during the preclosure operating and monitoring periods. In terms of the loss of ventilation, short-duration interruptions in the continuous operation of the ventilation system do not adversely affect the ability to establish the repository postclosure thermal conditions because of the small changes in thermal energy transferred to the host rock during such events. However, the loss of subsurface ventilation for short durations could impact repository operations, so it is incumbent that the subsurface ventilation system be restored promptly.

The operational limits that the subsurface ventilation system must maintain are as follows:

- Commercial spent nuclear fuel (SNF) cladding temperature must not exceed a maximum temperature of 350°C upon emplacement and must not exceed 570°C for off normal conditions.

- The drift wall temperature must not exceed 200°C during both normal and off normal conditions.

- The naval SNF canister surface temperature inside a waste package must, at no time during the preclosure or postclosure period, exceed a naval SNF canister thermal envelope defined by the time-temperature plot shown in Figure 1.3.1-8. If the envelope is exceeded during preclosure, the DOE and the Naval Nuclear Propulsion Program will evaluate if any adverse effects have occurred to the naval SNF. The postclosure portion of the envelope will not be exceeded if the naval waste package is placed in accordance with the naval SNF waste package operational thermal loading limits for emplacement described in Section 1.3.1.2.5, and ventilation is maintained for the preclosure period, allowing for short-duration interruptions, so that the naval SNF canister surface temperature stays within the thermal envelope shown in Figure 1.3.1-8.

Section 1.3.1.2.5 describes how repository operations will be conducted to ensure that the above limits and other thermal management constraints will be met. The evaluations described in Section 1.3.5.3.2 show that for short-duration subsurface ventilation losses, where short duration is defined as 30 days or less, the above limits are not violated.

The subsurface ventilation system is designed so that it can handle potential ventilation failures without exceeding thermal limits and assure restoration of operations within a 30-day period, providing additional margin to the thermal limits. This restoration is assured by the following subsurface ventilation system features and margins:

- Supplemental cooling provided by natural ventilation

- Excess installed capacity with dual fan installations at each exhaust shaft

- Ability for rapid fan replacement with spare fans and parts stocked on site, and a maintenance capability available on site

- Low probability of overall power loss (Section 1.4.1)

- Dual power lines and backup generators for both surface and subsurface operations

- Standby diesel power generators connected and available to three exhaust fans, and connections for mobile backup diesel generators at all the exhaust shaft pads

- Rock formations suitable for stable underground openings, even if unsupported

- Ground support system designed to withstand a DBGM-2 ground motion (Sections 1.3.3.3 and 1.3.4.4)
- Capability to maintain ventilation flow through partially blocked drifts
- Ability to track waste packages during operations to identify and remediate waste packages that have been exposed to off-normal loss of ventilation events resulting in exposures over the thermal basis.

Subsurface off-normal events impacting ventilation are discussed in Section 1.3.5.3.2.

1.3.5.1 System Description

[NUREG-1804, Section 2.1.1.2.3: AC 3(1), AC 6(1), (2); Section 2.1.1.7.3.2: AC 1(1); Section 2.1.1.7.3.3(II): AC 2(1), AC 3(4), AC 7(2) to (4)]

As previously mentioned, subsurface ventilation consists of two operationally independent and separate systems during the period of time when there is concurrent development and emplacement. After development activities cease and when all the emplacement drifts are commissioned, there is only one subsurface ventilation system. Before complete repository development is achieved, isolation barriers physically separate the development areas from the emplacement areas. This arrangement allows concurrent development of emplacement drifts on one side of the isolation barriers and waste emplacement in operational emplacement drifts on the other side of the isolation barriers. The two areas have independent airflow networks and fan systems that operate concurrently. The development ventilation system uses fans installed on the intake shafts to force air into the development areas of the underground. Typically, during development, the development areas exhaust air is discharged through either the South Portal or the North Construction Portal, depending on the location of the area being developed. The emplacement ventilation system uses fans installed on the exhaust shafts to draw air from the emplacement areas. Generally, intake air for the emplacement areas is supplied through the intake shafts no longer used for development and through the North Portal and other portals no longer used for development. This configuration ensures that if one system shuts down, the flow direction of potential leakage across the isolation barriers is maintained toward the emplacement areas. In the case of a complete power failure in which the ventilation systems on both sides of the isolation barrier are not functioning, a natural ventilation airflow on the emplacement side, driven by the thermal energy from the waste packages, maintains flow in the same direction as the forced ventilation (BSC 2007a, Section 7; BSC 2005, Section 7).

1.3.5.1.1 System Function

The subsurface ventilation system provides fresh air for personnel and equipment and supports thermal management goals by cooling the emplacement drifts. The subsurface ventilation system is designed to handle both normal and off-normal situations in the operational phases of the repository.

The subsurface ventilation system is illustrated in Figure 1.3.5-1 and system components are described further in this section. This diagram is representative of a partially developed emplacement panel with concurrent development and emplacement activities. On the emplacement side, air regulators are indicated at the entrance to the emplacement drifts (turnout bulkheads) and fan isolation louvers at the fan locations (exhaust shafts). The diagram also illustrates the three types of isolation barriers and identifies instrumentation for monitoring environmental and airflow parameters for system operations. Type A and Type B isolation barriers separate the emplacement area from the development area. These separated areas have individual and unique ventilation systems. Type C isolation barriers separate fresh-air airways from exhaust-air airways containing heated air.

1.3.5.1.2 System Location and Functional Arrangement

The subsurface ventilation system components include ventilation fans, emplacement access doors and regulators, isolation barriers, and instrumentation for control and monitoring of the system. The subsurface openings used by the ventilation system include the ramps, access mains, turnouts, emplacement drifts, shaft access drifts, and shafts. Although the system ventilates the underground, some of the structures, systems, and components (SSCs) are located on the surface.

The ventilation system connects the emplacement areas to the surface through the ramps, access and exhaust mains, shaft access drifts, and shafts. Locations of these design features are illustrated in Figure 1.3.5-2. Section 1.3.3 describes the ramps, shafts, access and exhaust mains, and other nonemplacement areas and openings. Section 1.3.4. describes the emplacement drifts.

The subsurface facility ventilation system is designed to support repository thermal management goals by maintaining subsurface air, near-field rock strata, and engineered-barrier component temperatures below preclosure limits (Table 1.3.1-2). The system also removes enough heat generated by the waste packages during preclosure to ensure repository temperature limits after closure (Table 1.3.1-2) are not exceeded. The subsurface ventilation system provides a nominal airflow of 15 m^3/sec to each loaded emplacement drift for a minimum duration of 50 years after last waste emplacement for the total system performance assessment (TSPA) thermal reference case (Section 1.3.1.2.5). The system is designed to operate for a nominal period of 100 years throughout subsurface development, waste emplacement, postemplacement monitoring, and closure (BSC 2008a, Sections 4.3.2 and 6.2). The flow rate and duration have been demonstrated to work with efficiencies of 85% to 90% in terms of heat removal during the preclosure period, for the nominal and higher analyzed thermal loading plans (Section 1.3.1.2.5) proposed for the repository (SNL 2007, Section 7; SNL 2008a, Sections 6.1.2 and 6.1.3). The total ventilation duration of 100 years from the start of emplacement until repository closure allows for completion of waste emplacement prior to the 50-year nominal emplacement period, while assuring that the ventilation period assumed as part of the estimated limiting waste stream demonstration (Section 1.3.1.2.5) of a representative waste stream emplacement is met.

1.3.5.1.3 Subsystems and Major Components

The primary components of the subsurface ventilation system for the emplacement areas include ramps, intake shafts and their access drifts, access mains, turnouts, turnout bulkheads with emplacement access doors and airflow regulators, emplacement drifts, exhaust mains, isolation barriers, exhaust shafts and their access drifts, exhaust fans, ventilation instrumentation, and monitoring equipment to control the system. The subsurface emplacement ventilation equipment and instrumentation are standard commercial-grade components.

The primary components of the subsurface ventilation system for the development areas include ramps, access mains, intake shafts and their access drifts, intake fans, dust control equipment, auxiliary fans, ductwork, instrumentation, and controls. Intake fans, dust control equipment, auxiliary fans, ductwork, instrumentation, and controls are standard, commercial-grade components.

Ventilation volumetric flow rates for the subsurface development and emplacement ventilation systems are based on the considerations of airflow for minimum breathing air requirements for personnel, equipment operations, and air quality control. Thermal management is an additional consideration and the limiting consideration for the emplacement area ventilation system in terms of determining airflow rates and durations of ventilation. The system is designed to operate with the incoming air characteristics listed in Table 1.3.5-1 and to control underground component temperatures to the limits stated in Table 1.3.1-2.

The subsurface ventilation system is designed to operate throughout the subsurface development and waste emplacement phases and during the postemplacement monitoring and repository closure operations, a period of nominally 100 years. The subsurface ventilation system operates for a minimum period of 50 years after final waste emplacement to achieve the repository thermal conditions for initiation of the postclosure phase for the TSPA thermal reference case (Section 1.3.1.2.5) and for nominally 100 years to support repository operations through closure.

As discussed in Sections 1.3.1.2.5 and 2.3.5.4.3, the analysis for the postclosure thermal reference case for TSPA included the assumption of instantaneous emplacement of all waste packages, followed by 50 years of preclosure ventilation (SNL 2008b, Section 5.2.3). This approach was further analyzed for sensitivity to waste package emplacement sequences with an estimated limiting waste stream (SNL 2008a, Section 6.1.2). The estimated limiting waste stream was selected from simulations of waste stream scenarios that considered constraints imposed by the contracts between the DOE and the nuclear power utilities, and the operational processes of waste selection, canisterization, and transport to the repository (BSC 2006). The estimated limiting waste stream represented waste packages to be received at the repository for a period of approximately 35 years (depending on emplacement sequence), with each waste package having its own thermal decay function based on the radionuclide inventory it contains. Thermal power for waste packages to be shipped to the repository for the emplacement sequence analyses was set higher (22.0 kW) than for the TSPA thermal reference case (SNL 2008a, Section 6.1.2). Operational thermal loading limits for the emplacement sequences analyzed with a ventilation efficiency of 86% were as follows: (1) limit mid-pillar rock temperatures to 96°C or lower; (2) limit emplacement drift thermal line load to 2.0 kW/m averaged over any adjacent seven waste packages; and, (3) limit waste package power at emplacement to 18.0 kW (SNL 2008a, Section 6.1.3). Results of the emplacement sequence analyses indicate that for far-field thermal effects, the effects of variability among waste packages (decay history, ventilation time) are negligible. Thus, the postclosure reference case defines the thermal envelope for far-field analyses. For near-field effects, the impact of emplacement sequence on all postclosure temperature limits was found to be acceptable for normal (uncollapsed) conditions (SNL 2008a, Section 6.1.7). Additional information is provided in Section 2.3.5.4.3 and the associated features, events, and processes (Section 2.2). The results of the analyses (SNL 2008a, Section 6.3) demonstrate that the preclosure ventilation rate and duration are satisfactory for preclosure and postclosure thermal management objectives, given the potential variability in waste package emplacement sequences that may be experienced at the repository.

The subsurface emplacement ventilation system maintains acceptable ranges of normal operating temperatures (Table 1.3.5-2) for the subsurface environment throughout preclosure. A single set of normal temperatures cannot be used to characterize the subsurface facility operations phase. There are normal ranges for habitable areas of the facility and for areas where it is suitable to use mechanical equipment with operational thermal limitations. Uninhabitable areas and areas that have limited equipment operation have a higher range of normal temperatures.

Analyses demonstrate that, although the subsurface ventilation system is operated to maintain repository temperatures at acceptable operational levels during the preclosure period and to maintain an adequate margin for temperature limits listed in Table 1.3.1-2, the temperature limits are not exceeded during system shutdowns of limited duration, up to 30 days, resulting from power failure, fan failure and replacement, or from partial airflow blockage due to rockfall (Section 1.3.5.3). The analyses show that there is sufficient time to restore the system or portions of the system to normal operating conditions before incurring the risk of exceeding the temperature limits (BSC 2007b, Section 7.5).

1.3.5.1.3.1 Fan Installations

The exhaust fan installations are located at the surface openings of exhaust shafts for emplacement area ventilation. Typically, for an emplacement side exhaust shaft, there are two fans operating in parallel, sized to provide the desired airflow. The fans provide the design basis airflow with margin. The fans are variable pitch, axial flow, and are driven by variable-speed motors. These characteristics allow flexibility to supply air to a varying number of emplacement drifts as emplacement operations advance to successive drifts and panels over time and as the number of loaded drifts increases. Airflow rates through individual emplacement drifts are controlled with airflow regulators located in the turnout bulkheads at the entrances to the turnouts. The design includes louvers at each fan for isolation purposes, for single-fan operation as the air volume requirements vary during waste emplacement operations, or for ventilation system maintenance. The fans are sized to provide a range of airflow rates that accommodate heat removal and other operational needs for a fully loaded repository. Airflow rates to a single drift can be varied from zero to a maximum of 100,000 cfm (47 m^3/s). The airflow rate provided to a fully loaded drift is a nominal 32,000 cfm (15 m^3/s) for the range of acceptable emplacement drift thermal line loads up to 2.0 kW/m.

The total power required for the ventilation fans at each exhaust shaft for the preclosure period is approximately 1,800 hp, or 900 hp per fan. Three of the exhaust fans will be connected to diesel standby power generators (Section 1.4.1.1.1.3). Additionally, exhaust fan installations will be provided with connections for mobile diesel backup power generators to maintain repository airflow patterns during a major network power failure or during a power supply interruption to the subsurface facility.

Figure 1.3.5-3 shows the exhaust fan configuration. The shaft collar designs accommodate both development and emplacement use. For example, exhaust shaft 2 in Panel 2 is used as a supply air shaft (intake) during development of the panel, as described in Section 1.3.5.1.3.2.

The design of the exhaust fan installations includes applicable seismic and environmental design criteria to ensure their continued function and readiness to support operations (Section 1.3.2). In a large-diameter exhaust shaft where normally two fans operate simultaneously, if one fan fails or is off-line for maintenance, the second fan remains operational and produces approximately 70% of the required air volume; therefore, it will not be necessary to curtail repository operations if a ventilation fan is down for repairs or maintenance for short durations. With multiple ventilation shafts, each having two fans, a single fan down for maintenance does not have a major impact on the repository airflow volume. The small-diameter exhaust shafts normally operate only one fan, so the second fan provides 100% of the required airflow rate if the other fan is shut down for repairs or maintenance (Section 1.3.5.3.1).

The ventilation fans are located at the exhaust shaft collar in the heated air stream; however, the operating temperatures (Table 1.3.5-2) do not require special equipment. The fans provided in the design can withstand the operating conditions that they will be exposed to at the shaft outlets (high temperatures), so there is no need for additional equipment to mitigate or improve those operating conditions, and temperature-sensitive equipment such as the electric motors are located outside the airstream. The fans are made of steel and cast alloy blade assemblies. The shaft collar ductwork is constructed of steel and is designed within applicable structural and hazard requirements (Section 1.3.5.4).

The intake fans are located on the surface and connected to intake shafts for development area ventilation. When development of an area is complete and ready for turn over to emplacement operations, the intake fans are no longer needed and can be removed. Figure 1.3.5-4 shows the intake shaft configuration. Fan characteristics for the development side may be similar to those discussed for the fans on the emplacement side. The operational mode for each system is different. The development side fans are configured to force air into the subsurface while the emplacement side fans are configured to draw heated air from the subsurface. Auxiliary fans and ducting are also used in the subsurface excavations to direct fresh air into advancing excavation fronts and to remove dust-laden air away from the excavation fronts to be scrubbed or filtered prior to discharge to the surface.

1.3.5.1.3.2 Isolation Barriers

The ventilation system uses isolation barriers located in the access mains and exhaust mains to separate emplacement areas from development areas (temporary), or to separate the intake airways from the exhaust airways in the emplacement areas (permanent). The following types of barriers are used in the repository.

- **Type A**—Barrier between the development and emplacement ventilation systems that does not permit emergency egress

- **Type B**—Barrier between the development and emplacement ventilation systems that permits emergency egress

- **Type C**—Barrier between intake airflow and exhaust airflow.

During the development phase, isolation barriers Type A and Type B are installed in the access and exhaust mains to separate the development ventilation system from the emplacement ventilation system. The two separate ventilation systems create two distinct fire areas, and the barriers are fire rated for a minimum of three hours (BSC 2007c, Section 7.1.3). Type A and Type B isolation barriers are located on a temporary basis and are moved as the development and construction effort progresses. The Type B isolation barrier bulkheads (two) form an airlock chamber, and both bulkheads have a door for emergency egress for escape purposes. Isolation barrier monitoring functions are included for monitoring ventilation pressure and door status. These functions are monitored from the Central Control Center.

The third type of isolation barrier (Type C) is installed between the intake air and exhaust air flow paths, ensuring that access to high-radiation and high-temperature areas is not possible and that exhaust airflow does not recirculate. Access ports for deployment of remotely controlled inspection devices may be made available at some of the Type C barriers for conducting inspections of ground support systems in the nonaccessible exhaust mains and exhaust shaft access drifts (BSC 2008b, Section 6.2.1). The Type C barriers are permanent because they remain in place for the entire period of ventilation and after final emplacement. Type C isolation barrier locations are shown in Figure 1.3.5-5.

Isolation barrier bulkheads and turnout bulkheads are designed with penetration openings for flexibility to maintain the operability of the repository. Allowance for penetrations includes crane rail, electrical wiring for power and instrumentation, and other utilities that will be required as needed. Flexibility for future penetrations will be accommodated by empty openings appropriately sealed in the isolation barrier bulkheads. Bulkheads for temporary and permanent barriers are mostly of the same size.

Figure 1.3.5-5 shows an isometric view of the subsurface ventilation system for a fully developed repository, with the intake airways differentiated from the exhaust airways to illustrate the effect of the permanent isolation barriers. In contrast, Figures 1.3.5-6 and 1.3.5-7 illustrate concurrent development and emplacement ventilation systems during development of Panel 1 and Panel 2. These figures illustrate the role of temporary and permanent isolation barriers, separation between development and emplacement zones within a single panel, and typical airflow circulation patterns for the concurrent but separate operations.

Relocation Sequence for Isolation Barriers—Isolation barriers are typically relocated in sets of two. Each isolation barrier structure consists of two bulkheads spaced a sufficient distance apart to form an airlock chamber between the two bulkheads. The length of the airlock chamber is dependent on the specific application. The typical general arrangements for the Type A, B, and C isolation barriers are illustrated in Figure 1.3.5-8. Location of the isolation barriers in the access mains will also be coordinated with location of the electrical equipment alcoves such that there is no impact to their intended functions. A set will typically consist of a Type A barrier in the exhaust main and a Type B barrier in the access main, located at directly opposite sides of the emplacement panel. Panels 1 and 2 are used in Figures 1.3.5-6 and 1.3.5-7 to illustrate the basic steps involved in the relocation of isolation barriers to maintain separation of the development and emplacement sides at all times. These figures also provide good examples of how the functions of some of the ventilation openings change over time, such as in the case of the Enhanced Characterization of the Repository Block (ECRB) shaft that is initially used for Panel 1 as an air intake to support construction but as emplacement advances, becomes an exhaust airway for Panels 1 and 2. The sequence of barrier relocations shown in Figures 1.3.5-6 and 1.3.5-7 is conceptual because a detailed construction sequence has not yet been developed.

As described in Section 1.3.1, development of the initial operating capability for the repository includes commissioning of the first three drifts in Panel 1 for waste emplacement. Figure 1.3.5-6 is a simplified schematic of the ventilation system configuration for this initial operating capability. A set of isolation barriers is placed in the access and exhaust mains between emplacement drifts 1-3 and 1-4. These isolation barriers separate emplacement operations in drifts 1-1 to 1-3 from continuing development activities in the rest of Panel 1. Air supply for drifts 1-1 to 1-3 is provided through the North Portal and North Ramp. These openings also provide air to the observation drift and observation alcove extending below the emplacement horizon. A bulkhead and airflow regulator at the entrance of the observation drift control air flow into the drift, and a sealed bulkhead at the end of the observation drift separates it from the heated air of the Panel 1 exhaust main. Another isolation barrier is installed at the connector drift to the future area for Panel 3-West. This isolation barrier will facilitate future development activities north of the connector drift, maintaining separation of the future activity from the emplaced waste in Panel 1. Heated air from emplacement drifts 1-1 to 1-3 is removed through exhaust shaft 1 connected to the Panel 1 exhaust main via a short shaft access drift. Figure 1.3.5-6 also illustrates an excavated drift, future emplacement drift 1-4, as part of the excavation for the initial operating capability. This drift allows intake air provided through the ECRB shaft to circulate around the development area of Panel 1 and completes the connection of this temporary intake airway to the access main from where it is exhausted through the South Ramp and South Portal. The ECRB shaft is connected to the ECRB Cross-Drift, which is connected to the Panel 1 exhaust main through a ventilation raise and two raise access drifts. The emplacement and development ventilation system configurations described in this paragraph will remain in place until a second set of isolation barriers is installed in the northern portion of Panel 2, and until the next set of emplacement drifts is commissioned.

In this conceptual sequence of repository development, the next drifts to be commissioned for waste emplacement are the last three drifts in Panel 1 and the first two drifts in Panel 2. Figure 1.3.5-7 illustrates the advancement of emplacement activities from Panel 1 into the northern portion of Panel 2. This advancement requires the placement of isolation barriers in the access main and exhaust main of Panel 2 between drifts 2-2 and 2-3. Similar to the strategy with drift 1-4 in Panel 1's initial operating capability, drift 2-3 would have to be excavated prior to closing the second set of isolation barriers so that ventilation air can be circulated around the Panel 2 development area from a source different from the North Portal. That new source of intake air is intake shaft 2 connected to the access main of Panel 2 through a shaft access drift. Air from the development areas south of the second set of isolation barriers flows to the South Ramp and is exhausted through the South Portal. Other required changes to the emplacement and development ventilation system configurations prior to removal of the first set of isolation barriers in Panel 1 are (1) installation of a set of fans at the ECRB shaft to convert it from a temporary development intake shaft into a permanent exhaust shaft; and (2) excavation of a shaft access drift connecting the ECRB shaft station to the Panel 2 exhaust main. Closing of the second set of isolation barriers makes Panel 1 and the first two drifts in Panel 2 a continuous waste emplacement area with the North Portal as the intake air source, and exhaust shaft 1 and the ECRB shaft as the exhaust airways. The first set of isolation barriers from Panel 1 are then removed. The isolation barrier on the access main from set 1 can be relocated to the set 2 access main location between drifts 2-7 and 2-8; however, the isolation barrier from the Panel 1 exhaust main can not be reused because it is of a smaller size (18 ft) than what is required for the exhaust main set 2 location (25 ft). This pattern of leap-frogging the sets of isolation barriers continues in a southward direction in Panel 2 until the entire panel is developed. The shaft at the southern end of Panel 2 can be initially used as an intake airway. After all the drifts in Panel 2 are developed, a permanent isolation barrier (Type C) is installed at the southern end of the perimeter main drift of the panel, thus creating a boundary between the access main and the exhaust main for the southern portion of the panel. As waste emplacement advances southward in the panel, additional air exhaust capacity is required, so exhaust fans are installed at the shaft at the southern end of the panel and it becomes exhaust shaft 2. At that point, intake air for Panel 2 is provided from intake shaft 2 and the South Portal and exhaust air is drawn out through the ECRB shaft and exhaust shaft 2. After all the temporary isolation barriers in Panel 2 are removed, the access main will be connected without interruption to both the North and South Portals, with the combined air intake through both portals and intake shaft 2 supplying intake air to the Panel 1 and Panel 2 emplacement areas.

The permanent electric power, permanent crane rail, third-rail power system, and data and communication systems will be installed up to and across the isolation barriers to allow activation of these services in the expanded emplacement areas with a minimum of construction effort. The disconnection point to isolate the communication lines and electrical feeds will occur in an appropriate junction box or terminal apparatus located in the vicinity of the isolation barrier bulkheads. Details and requirements for separation and isolation of the utility systems will be included in the construction specifications. Some utility systems may be isolated on the emplacement side of the isolation barriers while others will be isolated in a construction area on the development side.

The process described above limits the work activities in the emplacement side of the isolation barriers to a controlled disassembly of the bulkhead from its structural frame and its removal via rail car on the access main side, or via rail car, rubber tire or track equipment on the exhaust main side. Design and fabrication of the bulkhead structures will include features that allow for a continued installation of emplacement rail and electric power up to or across the isolation barrier bulkheads. When completed, the isolation barriers bulkheads will be sealed to minimize air leakage and to provide a fire barrier between the development and emplacement sides.

Each time an isolation barrier is relocated, the boundaries for the development and emplacement ventilation areas change, and both systems are rebalanced. The design of the subsurface ventilation system and the selection of the isolation barrier locations take those boundary changes into consideration.

1.3.5.1.3.3 Turnout Bulkheads, Emplacement Access Doors, and Airflow Regulators

Turnout bulkheads, emplacement access doors, and airflow regulators control the ventilation airflow to the emplacement drift. The doors and regulator are located in the turnout bulkhead, which is the main structure in the turnout to support these pieces of equipment. The turnout bulkhead is constructed of steel and occupies the cross-sectional area of the turnout. The bulkhead is structurally designed for the expected differential pressures across the bulkhead from normal operations. Sealant is used around the periphery of the turnout bulkhead to minimize leakage of air. Figure 1.3.5-9 shows the location and configuration of the turnout bulkhead and emplacement access doors. The turnout bulkhead is located close to the junction of the turnout and the access main, as close to the access main as possible in order to minimize the potential radiation dose rate at the door location.

Figure 1.3.5-10 shows the emplacement access doors and airflow regulator locations. The steel emplacement access doors within the turnout bulkhead accommodate the waste package transport and emplacement vehicle clearance envelope. The gaskets on the emplacement access doors are located on the intake side or within reach from the intake side of the door to facilitate inspection, maintenance, and replacement. Equipment that requires maintenance, such as electrical or instrumentation equipment, is also placed outside the intersection of the mains and turnouts to reduce potential radiation exposure.

Figures 1.3.5-11 and 1.3.5-12 illustrate the concepts for the mechanisms that activate the emplacement access doors and the instrumentation and controls for the operation. Figure 1.3.5-13 shows the concept for the type of airflow regulator that will be utilized and the associated controls and instrumentation.

1.3.5.1.4 System Interfaces

The subsurface development ventilation system interfaces with the repository subsurface facility openings, electrical, communications, safety and health, fire protection, and monitoring systems to provide adequate airflow for personnel underground. The system design considers dust, diesel particulates, and other potential airborne contaminants, heat control, and naturally occurring radon. The subsurface emplacement ventilation system interfaces with the electrical, communications, monitoring and control systems, performance confirmation, safeguards and security, fire protection, and environmental safety and health systems to ensure thermal goals are satisfied and access to emplaced waste is controlled.

The emplacement access doors provide restricted personnel and equipment access to the turnouts and to the emplacement drifts. Dose rates from emplaced waste packages in the emplacement drifts are expected to range from 57 rem/hr at 1 m from the waste package in the axial direction facing the turnouts to approximately 1,100 rem/hr on the surface in the radial direction (sides) of emplaced waste packages. The emplacement drift and adjacent portion of turnout inside the emplacement access doors will be treated as a very high radiation area (Section 5.11) in accordance with 10 CFR 20.1602 and Regulatory Guide 8.38. The emplacement access doors function as the access point, or entrance, to the very high radiation area. As such, the emplacement access doors also serve as the access control mechanism by remaining locked, except during periods of access, to prevent unauthorized or inadvertent access to the area controlled as the very high radiation area within the emplacement drift and turnout.

Specific subsurface ventilation system interfaces and interface functions are summarized as follows:

- Digital Control and Management Information System (Section 1.4.2)
  - Compile and relay ventilation component information to Central Control Center
  - Report fan and controls status to Central Control Center
  - Data storage for ventilation monitoring equipment
  - Video and voice communications

- Electrical Power System (Section 1.4.1)
  - Power supply to construction and emplacement ventilation components
  - Power supply to ventilation instrumentation and monitoring components
  - Standby backup power supply for three exhaust fans and connections at all exhaust shaft locations for mobile diesel backup generators
- Electrical Power Support System (Section 1.4.1)
  - Ventilation system requirements for cable raceways and grounding
  - Lightning protection on main fans
- Emplacement Drift (Section 1.3.4)
  - Emplacement access doors prevent access to areas controlled as very high radiation areas
  - Preclosure airflow control and regulation supports thermal management
- Emplacement and Retrieval System (Sections 1.3.3.5 and 1.11)
  - Ventilation structures accommodate equipment envelopes
  - Provide proper airflow to ensure equipment operating temperature limits are met
- Environmental and Meteorological Monitoring System
  - Support effluent monitoring from the subsurface repository exhaust system
  - Meteorological data
- Fire Protection System (Section 1.4.3)
  - Fire detection
  - Fire suppression
  - Fire rating of isolation barriers and doors
  - Emergency egress and evacuation
  - Refuge station location and design
  - Smoke and combustion by-product removal
  - Main fan control and component control for emergency management
- Performance Confirmation Program (Section 4)
  - Provide ventilation to observation drift and alcove, and to other alcoves and niches, as applicable
  - Coordination of ventilation needs for test drift(s)

- Plant Services System
  - Water requirements for subsurface development dust control
- Radiation and Radiological Monitoring System
  - Access control to radiologically controlled areas
  - Accommodate radiological monitoring instrumentation
  - Personnel tracking and exposure records
- Safeguards and Security System
  - Access control and alarms at emplacement access doors and isolation barriers
- Subsurface Development (Section 1.3.1)
  - Development ventilation system supplies airflow to development operations
  - Shaft and drift construction sequencing to maintain fresh air
  - Openings are sized to support ventilation requirements.

1.3.5.1.5 System Maintenance Considerations

The subsurface ventilation system will be maintained to support a nominal service life of 100 years. The subsurface facility ventilation system will be maintained and rebalanced as needed to ensure required ventilation flow rates are maintained throughout the preclosure period.

Fan monitoring information includes vibration, bearing temperature, pressure, and airflow rate and temperature. The motors are also monitored. Maintenance will be performed in accordance with manufacturer guidelines. In large-diameter exhaust shaft installations, if one fan fails or is off-line for maintenance, the second fan can remain operational and produce approximately 70% of the original airflow volume. In small-diameter shaft installations, either of the two installed fans can provide 100% of the required airflow rates. In addition, the fans are all located on the surface and are easily accessible for maintenance.

The emplacement access doors are part of the subsurface ventilation system because of the impact a door operational failure could have on the balance of the ventilation system. Radiation control personnel have control of opening the doors and granting emplacement drift access per established administrative control (Section 5.11). The emplacement access doors require periodic inspection. The turnout bulkhead and frame are designed to require minimal maintenance. Components are modular and are designed for ease of replacement, if needed. Seals, bearings, and electronics are industrial grade.

No routine maintenance activities are planned on the door actuators. The actuators are planned to operate a few hundred times at each turnout, since approximately 100 waste packages are emplaced in each drift. After waste emplacement occasional activation of the doors will be required for remotely-operated monitoring equipment access, and for inspections and maintenance as needed. The actuators are tested remotely to determine operational readiness and, if found to be inoperable, can be replaced if emplacement drift access is required. The failure rate of the actuators is expected to be low because of the low frequency of use and the simplicity of their design. Door actuators are to remain operational throughout the preclosure period to support performance confirmation and retrieval activities, as needed.

Scheduled maintenance is planned for the regulators. The regulator components are located on the access main side of the turnout bulkhead to prevent unnecessary radiation exposures for routine maintenance, calibration, inspection, and repair. The modular components are expected to be a bolted design to facilitate repair or replacement.

Standard commercially available instrumentation (temperature, pressure, and flow rate) will be used, and the manufacturer recommendations will be followed for maintenance, calibration, and testing. Multiple instrumentation devices are incorporated into the monitoring system; these allow for error checking by operators of individual sensors incorporated into the redundant system (Figure 1.3.5-1).

1.3.5.2 Operational Processes and Procedures
[NUREG-1804, Section 2.1.1.2.3: AC 3(1), AC 6(1), (2)]

Subsurface ventilation system components will be inspected and maintained to keep the system fully functional and in a continuous operating mode for the duration of the preclosure period. Components requiring maintenance at the fan pads and underground are readily accessible to facilitate inspections, maintenance and repairs. Instrumentation will be utilized to monitor the major electrical and mechanical components so that conditions indicative of potential failures can be detected and mitigated. Components exposed to heat and radiation are designed to withstand the environmental conditions of their locations. The gasket material on the emplacement access doors, for example, will have a high-radiation exposure rating (greater than 1,000 rad) to ensure that it lasts the life of the preclosure period. The emplacement access door and regulator components, such as actuators and louvers, will require regular maintenance and inspection. These components are modular and designed to facilitate replacement, if necessary. The subsurface ventilation components in the turnouts will be located on the access main side of the turnout bulkhead to prevent unnecessary radiological exposures to personnel performing routine inspection, maintenance, calibration, and repair. The isolation barrier bulkheads are of modular construction and can be accessed and repaired. Ventilation airflow separation and regulation at the isolation barrier can still be maintained during bulkhead repairs by installing a temporary airlock compartment to the companion bulkhead (Figure 1.3.5-8).

Operational procedures for the subsurface ventilation system including inspection and maintenance activities will be developed and implemented in accordance with the program described in Section 5.6. Operational interfaces of concurrent development and emplacement ventilation systems are developed by analyzing the ventilation design aspects of a single emplacement panel. Panel 1 is chosen since it is the first panel to be used for emplacement.

Figure 1.3.5-14 presents ventilation flow diagrams for development and emplacement ventilation. Figure 1.3.5-15 is a schematic representation of Panel 1 during concurrent development and emplacement operations. These two figures use alphabetic designators to denote the different design features that can be traced directly from the flow diagram to the schematic representation of the ventilation system operations in Panel 1.

Development and emplacement in Panel 1 require the isolation of several existing openings to route the airflow and to separate access to the different areas. Starting at the North Ramp, an isolation barrier blocks the entrance to the ECRB Cross-Drift to control the interaction of the airways. The ECRB Cross-Drift is initially used (for initial operating capability) as a development intake airway when connected to the ECRB shaft and to Panel 1 drifts not included in the initial operating capability. Later on, when the ECRB shaft becomes an exhaust shaft, the ECRB isolation barrier becomes a permanent barrier separating the North Ramp intake air from the Panels 1 and 2 exhaust air. Farther downstream, in the vicinity of where the North Ramp meets the access main, an isolation barrier is installed in the connector drift (short drift connecting the Panel 1 access main to the future access main for Panel 3 to the north) to isolate Panel 1 emplacement operations from future development activities in Panel 3. This isolation barrier will be removed during commissioning of the emplacement drifts in that area of Panel 3 (initial drifts to be emplaced in Panel 3-West). Continuing from the access main and along Emplacement Drift 1-1 to the beginning of the Panel 1 exhaust main, there is another isolation barrier in the connector drift between Panel 1 and the future Panel 4. This barrier will isolate Panel 1 exhaust air from the future development activities in Panel 4. This isolation barrier will be removed during commissioning of emplacement drifts in that area of Panel 4. Figure 1.3.5-15 also shows the first set of temporary isolation barriers to be deployed in Panel 1. These two isolation barriers are deployed in the access main and exhaust main between emplacement drifts 1-3 and 1-4 to separate the construction of drifts 1-4 through 1-6 from the emplacement of waste in drifts 1-1 through 1-3. The schematic in Figure 1.3.5-15 shows this, as well as the roles of the ECRB Cross-Drift shaft and the South Portal as the intake and exhaust ports for Panel 1 development, respectively, while the North Portal and exhaust shaft 1 provide intake and exhaust airways for the emplacement side, respectively.

The components in the local ventilation box in the airflow diagram presented in Figure 1.3.5-14 identify a concept of temporary ventilation systems set up during construction to provide air circulation and dust collection at the excavation fronts. These systems also help in removal of radon gas that is released from the rock as the excavation equipment exposes the strata to atmospheric pressure and an open air environment. Figure 1.3.5-16 presents a typical arrangement for such a local ventilation system that could be used for excavation of the emplacement drifts using an 18-ft diameter tunnel boring machine. In the case of the tunnel boring machine excavation as illustrated in this figure, high-pressure water spray nozzles are provided at the cutter head to mitigate dust generation. Flexible ducting, dust extractors, and dust collectors are also provided to reduce airborne dust in the areas of the excavation and behind the tunnel boring machine where personnel are deployed performing multiple duties. Ducting is used to draw fresh air from the intake airway, in this case the access main, and to release the air extracted from the construction front back to the airway.

The design of the subsurface ventilation system includes monitoring to satisfy requirements for personnel safety, system operations, operation of other systems such as the waste emplacement and retrieval system and the drift inspection equipment, and to provide information needed by other repository activities, such as the Performance Confirmation Program.

The basic requirements of the subsurface ventilation system monitoring and controls are related to the functions listed below:

- The status, display, and command override functions of subsurface ventilation systems that support fire and worker protection, such as dampers and fan controls, are accessible from the fire command center.
- The emplacement access doors control access to the emplacement drifts.
- Emplacement drift environmental conditions are at temperatures and relative humidities that support the performance of the repository.
- To be within the acceptable range for the remotely operated repository equipment, the system maintains emplacement drift air temperatures at 50°C or below in the emplacement drift during transport and emplacement vehicle (TEV) and gantry operations. TEV operations are described in Section 1.3.4.8, and drip shield emplacement gantry operations are described in Section 1.3.4.7.
- The subsurface ventilation system provides airflow control to individual emplacement drifts.

The repository ventilation is controlled through the operation of the surface based exhaust fans and the regulators located in the turnout bulkheads for individual emplacement drifts. The airflow through the exhaust fans can be adjusted using either variable frequency drives on the motors to vary the rotational speed of the fan or with adjustable pitch blades. The surface fans are equipped with louvers for the sole purpose of isolating the fan when performing maintenance. In the small-diameter exhaust shaft installations where one fan is typically on standby, the idled fan would be isolated (louver closed). The airflow through the emplacement drifts can be adjusted using the regulator located in the turnout bulkhead. Both the position and status of the regulator and the emplacement access doors are monitored remotely. The airflow through the regulator is also remotely monitored, and the regulator can be remotely adjusted to achieve the required airflow. Regulators and fans can also be adjusted manually.

The airflow regulator instrumentation includes air velocity, airflow volume (calculated), temperature, and humidity, and it provides for manual overrides. The instrumentation is linked to the Central Control Center and interfaces with the digital control and management information system to provide real-time monitoring, adjustment, and recording of the ventilation conditions for each emplacement drift.

The airflow distribution through the repository is continuously monitored and automatically controlled by the digital control and management information system. As the airflow requirements vary over time or as changes in performance are detected, changes in system setpoints or operation can be evaluated and implemented remotely through the digital control and management information system.

The airflow regulator louvers are interlocked with the emplacement access door position indicators so that when an emplacement access door is opened, causing a temporary airflow anomaly, the regulator louvers do not adjust for the temporary decrease in airflow.

The Type C isolation barrier prevents a ventilation bypass in the system between intake and exhaust airways. Access from the development side is limited to the area between the bulkheads. Security personnel will control access into the emplacement area, and such access will only be allowed in case of an emergency. Personnel from the emplacement side may exit through both isolation barrier bulkheads in case of emergency (BSC 2008c, Sections I.4.1.3 and P.2.1.1).

1.3.5.2.1 Emplacement Access Door Operation

Emplacement access doors are opened in opposite rotational directions. That is, as one door opens inward toward the emplacement drift, its complementary door opens outward toward the access main. This design feature uses the force exerted on the face of the doors from the pressure of the ventilation system to aid in the movement of one door of the tandem set, while opposing the movement of the opposite door. The door closest to the access main always opens toward the access main. This configuration is advantageous based on the geometry of the turnout.

Before the TEV accesses the turnout and before the emplacement access doors are opened, radiological access controls (as discussed in Section 5.11) and engineering controls (as discussed in this section and in Section 1.3.3.5) are in place to provide positive access control and prevent unauthorized or inadvertent access to the very high radiation areas in the drift and turnout.

1.3.5.2.2 Airflow Regulator Operation

The airflow regulator located within the turnout bulkhead is the principal component for regulating airflow rates to the emplacement drift. Figures 1.3.5-9 and 1.3.5-10 show the location and general configuration of the airflow regulator. The louver opening within the regulator is adjustable and normally open but is also capable of closing.

Regulators designed for application in extreme environmental conditions and for many industrial settings are installed. Due to the location of the regulators in the turnout, the repository environment to which the regulators are exposed is similar to those for other industrial applications. The expected temperature and radiation environment at the turnout bulkhead location is considered mild to moderate (Table 1.3.5-2 and Figure 1.3.3-13).

The functionality criteria for the regulator located at each emplacement drift include an adjustable opening, seals capable of full closure to limit air bypassing the regulator, and handling of a nominal airflow rate of 32,000 cfm (15 m^3/s), as well as a larger flow rate up to 100,000 cfm (47 m^3/s) for cooling purposes. The regulators are electronically controlled to maintain the nominal airflow rate of 32,000 cfm (15 m^3/s) per drift and can be adjusted to increase or decrease the flow rate as needed for other operational purposes such as additional cooling of the drift if needed for equipment incursions or mitigation of off-normal events, or to compensate for variables, such as drift length and drift thermal loading. The regulators can operate in automatic or manual mode.

Reliability criteria include proper functioning of the regulator, with planned maintenance and replacement, over the preclosure period of up to 100 years. The regulators have a minimal number of moving parts, and common commercial parts, so that maintenance or replacement is facilitated.

The subsurface ventilation system is used for repository decay heat removal. The ability built into the system to modify flow rates and distribution patterns to meet the cooling demand for different applications during normal and off-normal situations also provides operational flexibility as repository operational conditions change.

The variable-speed fans, dual-fan installations, and adjustable regulators provide the means to vary emplacement drift airflow rates to meet thermal requirements. Fresh air from the access main enters the emplacement drift as regulated by an automated regulator located in the turnout bulkhead of each emplacement drift. The air volume required is minimal at the start of the emplacement operations and gradually increases as waste packages are loaded in an emplacement drift. When an emplacement drift is fully loaded, the design basis airflow rate to maintain thermal goals in the natural and engineered barriers is 32,000 cfm (15 m^3/s). This airflow rate is the basis for the ventilation system design.

1.3.5.3 Safety Category Classification

[NUREG-1804, Section 2.1.1.2.3: AC 3(1), AC 6(1), (2); Section 2.1.1.7.3.3(II): AC 2(1), AC 7(5), (6)]

The subsurface ventilation system is neither ITS nor ITWI because the system does not prevent or mitigate an event sequence in the preclosure period and does not contribute to a significant barrier function in the postclosure period.

The system is required to maintain thermal limits that assure the performance of the host rock and to protect the commercial SNF cladding and naval SNF properties. Maintaining the host rock temperature below 200°C assures that elevated temperatures do not adversely affect the strength properties of the rock. Prevention of damage to the commercial SNF is assured by maintaining the cladding temperature of the commercial SNF below 350°C for normal operations and below 570°C for off-normal operations. Maintaining the appropriate time and temperature relationship, for example, as shown in Figure 1.3.1-8, ensures that the properties of the naval SNF used for preclosure and postclosure safety analyses are not adversely affected as discussed in Section 1.5.1.4 of the Naval Nuclear Propulsion Program Technical Support Document. Establishing a maximum 30-day time period in which to restore subsurface ventilation ensures flexibility for subsurface operations. The operational approach, however, is to resolve outages as soon as practical. The thermal effects and consequences of a shutdown of forced ventilation for the subsurface facility are discussed in Section 1.3.5.3.1.

Although the rock properties and cladding behavior are considered in preclosure and postclosure safety analysis, exceeding these limits does not affect the safety classification of the subsurface ventilation system. The non-ITS classification for the subsurface ventilation system includes the isolation barriers, which are not relied on for limiting or preventing dose exposure to personnel working on the development side of the repository. However, the isolation barriers constitute a physical barrier to prevent access to high radiation areas in the exhaust mains, in addition to their ventilation function.

1.3.5.3.1 Events Leading to Ventilation Shutdown

A forced (mechanical) ventilation shutdown to one or more emplacement drifts would require one or more of the following events to occur:

- Mechanical failure of exhaust fans
- Power failure to exhaust fans including loss of transmission lines
- Closure of ventilation control regulators
- Collapse and blockage of a portion of an emplacement drift or its supply or exhaust airways.

The ventilation fans located on exhaust shafts are designed as two fans operating in parallel for the large diameter shafts. Small diameter shafts are also equipped with dual fans, but only one fan is operational at any given time. In a parallel fan arrangement, if one fan fails or is taken off-line for maintenance purposes, the remaining fan produces approximately 70% of the original airflow volume of the two fans operating together. Because the repository layout has multiple exhaust and intake shafts, each with two fans, a shutdown of a fan does not have a major impact on the repository airflow volume and does not affect the ability of the ventilation system to supply each emplacement drift with sufficient airflow to meet the repository temperature limits.

In the event of loss of normal power to all of the exhaust fans, ventilation air circulation through the emplacement drifts is supplied from two sources. First, three exhaust fans are provided with standby backup power supplies. Additionally, all exhaust shaft surface pads are equipped with connections for mobile diesel backup generators. Second, air circulation throughout the repository continues due to thermal gradient. The air in the emplacement drifts is heated from the waste packages. This heating decreases the density of the air, creating buoyancy-driven natural convection currents in which hot air is exhausted from shafts and cool, fresh air is drawn into the repository through the ramp and intake shafts. Natural ventilation airflow rates have been calculated to be about 50 % of the forced ventilation flow rate during the preclosure period, for fully loaded emplacement drifts. For a partially loaded emplacement drift, analyses show that it would take a length of approximately 120 m of emplaced waste to develop sufficient natural ventilation pressure to assure flow (BSC 2005, Section 7). Once natural ventilation pressure has been established in the first emplacement drift, natural ventilation airflow will continue to occur and is further enhanced as more waste packages are added throughout the remaining emplacement drifts.

Ventilation control regulators for the emplacement drifts are located in each turnout bulkhead. The air pressure and flow rate at each bulkhead are monitored, and the regulators are positioned automatically to control airflow at the desired level. With a loss of power, the control regulators fail as-is, in the current position, allowing natural airflow resulting from thermal convection currents to proceed through the emplacement drifts. In the event that it is necessary during a loss of power event to open the emplacement access doors, it is possible to manually open the emplacement access doors by removing a locking pin, once the appropriate radiological protection and security controls are in place.

Numerical modeling of the preclosure stability of emplacement drifts under in situ, thermal, and seismic loading indicates that unsupported emplacement drifts are stable with only minor collapse possible from combined thermal and seismic effects (Sections 1.3.3.3 and 1.3.4.4). Considering the emplacement drift ground support, which consists of closely spaced stainless steel rock bolts and stainless steel surface sheeting, a collapse that substantially prevents airflow through a drift is not expected during the preclosure period (Section 1.3.5.3.2.3).

1.3.5.3.2 Analysis of Thermal Effects from a Ventilation Shutdown

Analyses of loss of ventilation include the following off-normal cases:

- A worst-case analysis of a complete shutdown of ventilation, with no credit taken for natural convection
- A more realistic analysis in which ventilation shutdown occurs and cooling is through natural convection
- Reduction in ventilation flow rates due to obstructions in an emplacement drift or in a supply or exhaust airway.

1.3.5.3.2.1 Complete Ventilation System Shutdown without Natural Convection Cooling

Numerical simulations examined the impact of a subsurface ventilation shutdown with no natural convective cooling on the drift wall, waste package surface, and fuel cladding temperatures for the 2.0 kW/m emplacement drift linear heat load and a maximum waste package initial heat output of 18.0 kW. Previous analyses of subsurface ventilation shutdown scenarios for a drift thermal line load of 1.45 kW/m showed that ventilation shutdown cases with no natural convection and occurring 1 year after the beginning of emplacement resulted in the most conservative or bounding cases in terms of potentially exceeding repository temperature limits (Table 1.3.1-2). Results of the numerical simulations for such an off-normal case for the higher drift thermal line load of 2.0 kW/m are presented in Figure 1.3.5-17 for the waste package arrangement defined in Table 1.3.5-3. The maximum temperatures as reported in Figure 1.3.5-17 correspond to the location of waste package 6 in the waste package segment in Table 1.3.5-3. The simulation results show that at 30 days after loss of ventilation the peak waste package surface temperature is 244°C. The waste package surface temperature reaches the limit of 300°C at 162 days after loss of ventilation. The drift wall reaches 176.7°C at 28.6 days after loss of ventilation and reaches the limit of 200°C at 55.3 days after loss of ventilation. Simulation results of thermal response for the waste package and waste package internal components for the same off-normal loss of ventilation case are shown in Figure 1.3.5-18. The results show that cladding temperatures stay well below 570°C for the extended period simulated without ventilation.

1.3.5.3.2.2 Complete Ventilation System Shutdown with Natural Convection Cooling

Figure 1.3.5-19 shows the time-versus-temperature curve after emplacement for the naval SNF canister in a waste package with natural convection considered. The upper curve shows the thermal response for a naval SNF canister contained in a naval waste package with a thermal power of

12.9 kW (at the time of emplacement) emplaced between two commercial SNF waste packages with thermal power of 11.8 kW each, and within a seven-waste-package segment with a line load of 1.45 kW/m. The naval SNF waste package is analyzed as being placed at the center of the seven-waste-package segment. The upper curve shows repository closure taking place approximately 50 years after emplacement of the package. Since the emplacement thermal power limit for the naval waste package is 11.8 kW, this result (performed at 12.9 kW) thermally envelopes the naval SNF canister surface temperature inside a waste package after emplacement of a naval SNF waste package in accordance with naval SNF waste package emplacement operational thermal loading limits. As discussed in Section 1.3.1.2.5, the Naval Nuclear Propulsion Program uses this thermal envelope to evaluate naval SNF canisters that have an overall maximum thermal power of 11.8 kW and a maximum peak axial heat load of 5.0 kW/m to confirm that the naval SNF is not adversely affected by the thermal conditions.

Since the naval waste package has an emplacement operational thermal loading limit (Section 1.3.1.2.5) that requires placement of nearby waste packages to be lower in thermal output than most packages (11.8 kW versus 18.0 kW), the potential exists for an error to occur during emplacement. Accordingly, analyses have been performed to evaluate the potential misplacement of a high-thermal power commercial SNF waste package next to a naval waste package to determine whether the operational limit of 30 days for subsurface ventilation restoration is adequate. Evaluation of the emplacement system controls and human performance in the emplacement process show that the total probability of misplacement over the preclosure period of two high-thermal power commercial SNF waste packages within a naval seven waste package segment is 1×10^{-5} (BSC 2008d, Section 7.3). The case, however, of a single 18.0 kW-thermal power commercial SNF waste package being misplaced next to a naval waste package could occur. To be conservative, misplacement of the maximum possible thermal-power commercial SNF waste package (22.0 kW), was evaluated and the resulting thermal response curve is shown in Figure 1.3.5-19 (lower curve). Allowing for natural convection cooling, the results demonstrate a less-limiting temperature profile (i.e., the peak temperatures of the misplacement analysis during the preclosure and postclosure periods do not exceed the peak temperatures of the reference curve and the profile of the misplacement curve follows generally the same profile as the reference curve).

A different misplacement case is possible where a naval SNF waste package with a thermal power of 11.8 kW is mistakenly placed in a seven-waste-package segment loaded to the commercial SNF operational thermal loading limits (commercial SNF waste packages with a maximum thermal power of 18.0 kW and a drift load not to exceed 2.0 kW/m). Allowing for natural convection cooling, the naval SNF canister thermal response from an emplaced 11.8 kW naval SNF waste package with a peak axial thermal load of 4.45 kW/m is represented by the lower curve in Figure 1.3.5-20 (the upper curve in the figure represents the naval SNF canister thermal reference envelope that is also presented in Figure 1.3.5-19). The thermal response shown in Figure 1.3.5-20 identifies margin as well as no exceedance of the naval SNF canister time-temperature reference envelope. The margin indicates that an analysis that would include a maximum peak axial thermal load of 5.0 kW/m for the naval SNF waste package would likely have a response below the thermal reference envelope as well. This analysis will be completed prior to emplacement of a naval waste package with a peak axial thermal load that exceeds 4.45 kW/m, to show conformance with the thermal limits for preclosure and postclosure. Evaluation of the emplacement system controls and human performance in the emplacement process show that the probability of a misplacement of a naval SNF waste package into a seven-waste-package segment loaded to the commercial SNF operational thermal loading limits, combined with a misplaced commercial SNF waste package that exceeds 11.8 kW, is 6×10^{-6} (BSC 2008d, Section 7.3).

Both misplacement scenarios described above take credit for natural convection ventilation, which will not be present until the first 120 m of the first drift have been loaded (BSC 2005, Section 7). In the initial 120-m section of drift, unlike the misplacement cases described above, a single misplacement (placement of a commercial SNF waste package that exceeds a thermal power of 11.8 kW next to a naval SNF waste package with a thermal power greater than 8.5 kW, or placement of a naval SNF waste package with a thermal power greater than 8.5 kW in a seven-waste-package segment loaded to the commercial SNF operating thermal loading limit of 2.0 kW/m) could lead to an unacceptable naval SNF canister temperature profile as compared to the thermal reference envelope in Figures 1.3.5-19 and 1.3.5-20. The probability of such a misplacement has been calculated and is very small (2×10^{-5} over the preclosure period) (BSC 2008d, Section 7.3).

An analysis of natural convection for a fully loaded emplacement drift estimated the natural convective airflow rates for the repository during a mechanical ventilation shutdown. A sustained power outage to ventilation fans could result in loss of forced ventilation to the subsurface facility. Analysis of the natural convection potential of a fully loaded drift during the preclosure period indicates that, in the absence of forced ventilation, airflow rates of about 6.4 to 10.1 m^3/s will be maintained across the emplacement drifts, for drifts loaded to 1.45 and 2.0 kW/m, respectively. Therefore, natural ventilation alone provides sufficient airflow for a fully loaded drift to ensure that the fuel cladding temperature limit (the overall controlling temperature limit) is not exceeded even during an extended power outage.

The results indicate that for the realistic case of natural convection, the 30-day time limit is adequate. Furthermore, the emplacement of naval SNF waste packages has been analyzed for an 18-year emplacement period, with natural convection cooling considered. Longer emplacement periods for the naval SNF waste packages are feasible given the margin identified in these calculations or possible adjustments to the operational thermal loading limits for the naval SNF waste packages.

1.3.5.3.2.3 Ventilating Partially Obstructed Emplacement Drifts

The potential for rockfall in emplacement drifts during preclosure, resulting only from the combined effects of thermal and seismic loading, is minor. A partial obstruction of an emplacement drift was analyzed. This analysis assumed an unsupported emplacement drift, even though ground support will be used throughout the emplacement drifts during the preclosure period. The calculations show that the ventilation system is capable of maintaining normal system airflow rates through an emplacement drift that is approximately 94% obstructed by rockfall in a localized area. Therefore, even in the event of unexpected rockfall, the ventilation system is capable of maintaining airflow through emplacement drifts. The analysis accounts for supply or exhaust airway collapse or obstruction indirectly as a loss in heat removal potential.

Analyses of drift degradation indicate that blockage of emplacement drifts by rockfall is not likely during the preclosure period in drifts located in either the nonlithophysal or the lithophysal rock (BSC 2004, Section 6). Stability analyses of unsupported drifts in lithophysal rock based on a seismic event with a mean annual exceedance probability of 1×10^{-4} (occurring once in 10,000 years), indicate that rockfall is most likely in the form of rubble than as a wedge-type failure during the preclosure period. The resulting volume of rockfall was estimated at 0.19 m^3 per linear kilometer of drift (BSC 2004, Table 6-49). Any potential rockfall during preclosure in areas of lithophysal rock would be associated with small loosening and unravelling rock pieces, which can be prevented with the perforated stainless steel sheet liner proposed for the emplacement drifts.

Stability analyses of unsupported drifts in nonlithophysal rock based on a seismic event with a mean annual exceedance probability of 1×10^{-4} (occurring once in 10,000 years), predicted the heaviest key block to be 2.72 metric tons. Assuming a cube-shape for this key block, it would have an approximate dimension of 1 m per side (BSC 2004, Table 6-20). A rock bolt such as those specified for the emplacement drifts ground support design would have enough holding capacity, whether it is calculated for the anchorage force of the bolt or the shear resistance force along the interface between the bolt and the key block, to prevent the 2.72-metric-ton block from falling. From these results, it can be determined that, even if the prescribed ground supports failed, the volume of rockfall estimated for these rockfall events in lithophysal or nonlithophysal rock would not be sufficient to completely obstruct a 5.5-m diameter emplacement drift.

Analyses performed with the UDEC model (BSC 2004, Section 6.4) for emplacement drifts located in lithophysal rock, assuming an unsupported condition (no ground support), estimated no rockfall for rock mass in Categories 2 to 5 (Table 1.3.3-2) when subjected to ground motions with an annual exceedance probability of 1×10^{-4}. Similar analyses performed for Category 1 rock mass, the weakest lithophysal rock mass, resulted in minor spalling (BSC 2004, Figure 6-120). Category 1 lithophysal rock is only found sporadically at the repository level as demonstrated by geologic mapping results for the Enhanced Characterization of the Repository Block Cross-Drift, where less than 3% of the rock in that drift was rated as Category 1 (BSC 2007d, Sections 6.3 and 6.4.4).

1.3.5.3.3 Summary of Ventilation Loss Analyses Results

The analysis of loss of forced ventilation airflow to the emplacement drifts shows that no temperature limits are exceeded for durations of at least 30 days for the commercial SNF, codisposal, and naval SNF waste packages; therefore, there would be sufficient time to take reasonable steps to restore forced ventilation airflow.

1.3.5.3.4 Considerations for Potential Radioactive Releases from the Subsurface Facility

Normal operations at the subsurface facility involve the transport and placement of waste packages that are closed and sealed. A breach of a waste package and leakage of radioactive material from a waste package have been identified as a beyond Category 2 event sequence during preclosure. No Category 1 or 2 event sequences have been identified for operations of the subsurface facility (Sections 1.7 and 1.8).

There are three mechanisms that could generate potential airborne releases of radioactive materials during normal operations of the subsurface facility:

- Resuspension of radioactive contamination from the external surfaces of the emplaced waste packages
- Neutron activation of ventilating air inside the emplacement drifts
- Neutron activation of removable host rocks (rock dust) inside the emplacement drifts.

Section 1.8.2.2 discusses the methodology and results for these potential releases, and it has been determined that any resulting radiological doses would not exceed the regulatory limits of 10 CFR 63.111 (a)(2). Therefore, the subsurface ventilation system is not required to prevent or mitigate releases from the subsurface and no filtration is included in the subsurface ventilation system design. Furthermore, the subsurface ventilation system is designed such that airflow direction is away from normally occupied underground openings and into the exhaust airways.

1.3.5.4 Design Codes and Standards
[NUREG-1804, Section 2.1.1.2.3: AC 3(1); Section 2.1.1.7.3.1: AC 1(5); Section 2.1.1.7.3.3(II): AC 7(1), (6)]

Steel structures, such as the isolation barriers and the emplacement access doors, are designed in accordance with the allowable stress design method of *Manual of Steel Construction, Allowable Stress Design* (AISC 1997; BSC 2007e, Section 4.2.13.2.4).

The subsurface ventilation system is classified as non-ITS. Therefore, subsurface ventilation system SSCs located at the surface, such as fan structures, including steel, concrete pads, foundations, and footings, are designed to International Building Code Seismic Use Group I or II, depending on hazard occupancy rating (Section 1.3.2 and Table 1.3.2-2). In accordance with *International Building Code 2000* (ICC 2003), each structure is provided with complete lateral- and vertical-force-resisting systems capable of providing adequate strength, stiffness, and energy dissipation capacity to withstand the design earthquake ground motions within the prescribed deformation limits. Applying the seismic design parameters to the fan installations ensures that there is no structural failure of the components because of a seismic event. The fans may trip off because of vibration sensors but can be restarted after verification of the cause and after equipment inspection.

The cabling and other electrical components of the subsurface ventilation system are designed to minimize fire hazards by complying with requirements in NFPA 1, *Uniform Fire Code,* and NFPA 801, *Standard for Fire Protection for Facilities Handling Radioactive Materials*.

Other codes and standards applicable to the subsurface ventilation system are:

- *TLVs and BEIs, Based on the Documentation of the Threshold Limit Values for Chemical Substances and Physical Agents & Biological Exposure Indices* (ACGIH 2006).
- Air pollutants (carbon monoxide, lead, nitrogen dioxide, ozone, sulfur oxides, and particulate matter)—Releases from underground shall not exceed the limits of the National Ambient Air Quality Standards (40 CFR Part 50).
- Diesel Use—Mobile diesel-powered equipment used underground in atmospheres other than gassy operations shall comply with applicable standards as regulated by DOE in accordance with 10 CFR Part 851, such as the Federal Mine Safety and Health Act of 1977.
- Construction area—Shall have reversibility in ventilation in conformance with applicable standards, such as the Occupational Safety and Health Administration (29 CFR 1926), as regulated by DOE in accordance with 10 CFR Part 851.
- MIL-STD-1472F, Change Notice 1, 2003, *Human Engineering*.
- ACI 318-02/318R-02, *Building Code Requirements for Structural Concrete (ACI 318-02) and Commentary (ACI 318R-02)*.
- *The Electrical Engineering Handbook* (Dorf 1993).
- *Manual of Steel Construction, Allowable Stress Design* (AISC 1997).

1.3.5.5 Conformance of Design to Criteria and Bases
[NUREG-1804, Section 2.1.1.2.3: AC 3(1)]

The subsurface ventilation system is classified as non-ITS (Table 1.9-1); therefore, there are no preclosure nuclear safety design bases to be satisfied by this system.

The subsurface ventilation system is classified as non-ITWI (Table 1.9-8), however, there are requirements derived from postclosure nuclear safety design bases considerations that relate to the design of the subsurface ventilation system because of the role the system plays in the repository meeting postclosure conditions consistent with the analyzed repository total system performance. Table 1.3.5-4 presents the derived requirements from postclosure nuclear safety design basis considerations that relate to the subsurface ventilation system, related design criteria considerations, and types of controls, either configuration management or procedural safety, that will be implemented to ensure the parameter conditions and characteristics that contribute significantly to barrier performance are established or maintained.

1.3.5.6 General References

ACGIH (American Conference of Governmental Industrial Hygienists) 2006. *TLVs and BEIs, Based on the Documentation of the Threshold Limit Values for Chemical Substances and Physical Agents & Biological Exposure Indices*. Cincinnati, Ohio: American Conference of Governmental Industrial Hygienists. TIC: 258915.

ACI 318-02/318R-02. 2002. *Building Code Requirements for Structural Concrete (ACI 318-02) and Commentary (ACI 318R-02)*. Farmington Hills, Michigan: American Concrete Institute. TIC: 252731.

AISC (American Institute of Steel Construction) 1997. *Manual of Steel Construction, Allowable Stress Design*. 9th Edition, 2nd Revision, 2nd Impression. Chicago, Illinois: American Institute of Steel Construction. TIC: 240772.

BSC (Bechtel SAIC Company) 2004. *Drift Degradation Analysis*. ANL-EBS-MD-000027 REV 03. Las Vegas, Nevada: Bechtel SAIC Company. ACC: DOC.20040915.0010.

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BSC 2007b. *Drift Wall Thermal Response to Loss of Ventilation.* 800-00C-WIS0-00400-000-00A. Las Vegas, Nevada: Bechtel SAIC Company. ACC: ENG.20070314.0001.

BSC 2007c. *Subsurface Fire Exposure Calculation.* 800-M0C-FP00-00100-000-00A. Las Vegas, Nevada: Bechtel SAIC Company. ACC: ENG.20070726.0020.

BSC 2007d. *Subsurface Geotechnical Parameters Report*. ANL-SSD-GE-000001 REV 00. Las Vegas, Nevada: Bechtel SAIC Company. ACC: ENG.20070115.0006.

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BSC 2008b. *Ground Support Maintenance Plan.* 800-30R-SSD0-00100-000-00C. Las Vegas, Nevada: Bechtel SAIC Company. ACC: ENG.20080215.0001.

BSC 2008c. *Yucca Mountain Repository Concept of Operations.* 000-30R-MGR0-03000-000 REV 002. Las Vegas, Nevada: Bechtel SAIC Company. ACC: ENG.20080312.0029.

BSC 2008d. *Waste Package Misplacement Probability.* 000-PSA-MGR0-02500-000-00A. Las Vegas, Nevada: Bechtel SAIC Company. ACC: ENG.20080124.0006.

BSC 2008e. *Postclosure Modeling and Analyses Design Parameters*. TDR-MGR-MD-000037 REV 02. Las Vegas, Nevada: Bechtel SAIC Company. ACC: ENG.20080108.0002.

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Federal Mine Safety and Health Act of 1977. 30 U.S.C. 801 et seq.

ICC (International Code Council) 2003. *International Building Code 2000*. Falls Church, Virginia: International Code Council. TIC: 251054; 257198.

MIL-STD-1472F, Change Notice 1. 2003. *Human Engineering*. Washington, D.C.: U.S. Department of Defense. TIC: 256247.

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NFPA 801. 2003. *Standard for Fire Protection for Facilities Handling Radioactive Materials*. 2003 Edition. Quincy, Massachusetts: National Fire Protection Association. TIC: 254811.

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SNL 2008a. *Postclosure Analysis of the Range of Design Thermal Loadings.* ANL-NBS-HS-000057 REV 00. Las Vegas, Nevada: Sandia National Laboratories. ACC: DOC.20080121.0002.

SNL 2008b. *Multiscale Thermohydrologic Model.* ANL-EBS-MD-000049 REV 03 ADD 02. Las Vegas, Nevada: Sandia National Laboratories. ACC: DOC.20080201.0003.

Table 1.3.5-1. Emplacement Drift Inlet Air Properties, Weighted Averages at Exploratory Studies Facility Station 28+93

Air Property	Weighted Average
Dry Bulb Temperature	75°F (23.82°C)
Wet Bulb Temperature	51.7°F (10.94°C)
Relative Humidity	19.22%

NOTE: Air temperatures represent a 4-year average of actual underground temperatures as measured at the Exploratory Studies Facility tunnel. These averages are used in the analyses in lieu of diurnal or seasonal inputs.

Table 1.3.5-2. Normal Range of Air Temperatures for Subsurface Facility

Subsurface Facility Area	Air Temperature Range (°C)	Comment
Access mains (habitable) Turnouts (uninhabitable)	7 to 31	None.
Fully loaded emplacement drifts (uninhabitable)	23 to 100	In-drift air temperatures vary per these parameters: location in drift (low values near drift entrance), emplacement drift length, and years of ventilation. Note: In-drift air temperatures are maintained below 50°C when emplacement equipment is operating.
Exhaust mains, shaft access drifts, and shafts (uninhabitable)	Up to 100	Temperatures in these areas vary with extent of emplacement in a given area or panel and with years of ventilation.
Exhaust fans	100 maximum	The temperatures at the shaft collar will be equal to the temperature of the air exhausting from the emplacement areas, or slightly lower due to cooling of the air in the vertical ascent through the shaft.

Table 1.3.5-3. Twelve Waste Package Segment Used in Numerical Simulations of Subsurface Ventilation Shutdown Cases, with Waste Package Order of Emplacement in the Segment and Initial Heat Loads

Waste Package Number	Waste Package Type	Initial Heat (kW)
12[a]	TAD	3.042
11	5-Long	0.637
10	TAD	18.009
5	TAD	11.557
4	TAD	11.557
2	TAD	18.009
1	5-Long	0.637
3	TAD	14.955
6	TAD	18.009
7	5-Short	9.470
8	TAD	11.557
9	TAD	18.009
13[a]	5-Long	0.319

NOTE: [a]half waste package.
TAD = transportation, aging, and disposal; 5-Long = 5-DHLW/DOE Long Codisposal;
5-Short = 5-DHLW/DOE Short Codisposal.

Table 1.3.5-4. Summary of Conformance of Subsurface Facility Design to Postclosure Control Parameters—Subsurface Ventilation

Structure, System and Component	**Postclosure Control Parameter**		**Relevant to ITWI**	**Design Criteria/Configuration**	**Postclosure Procedural Safety Control**
	Parameter Number and Title	**Values, Ranges of Values or Constraints**			
Subsurface Facility - Closure	02-03 Committed Materials	During construction of the emplacement drifts, and operation and closure of the repository, administrative controls will be imposed to prevent impact on waste isolation from materials used, lost, or left in the repository. These controls will be supported by technical evaluation. The following constraints will be imposed on the administrative control of tracers, fluids, and materials; construction materials; and committed materials: Parts (a) through (c): Controls related to the use of approved tracers, fluids, and materials during construction, operation, and closure are addressed in Table 1.3.6-3. d) Concrete dust generation shall be kept to a minimum through the use of surface coatings and / or the use of dust suppression and ventilation control during concrete installation and/or removal. e) Controls related to the use of approved tracers, fluids, and materials during construction, operation, and closure are addressed in Table 1.3.6-3.	Yes	Part (d) – Concrete dust generation is likely during repository development activities, during emplacement and postemplacement as a result of maintenance of invert structures and ground support in nonemplacement areas, and during closure as a result of removal of noncommitted cementitious materials in the shafts, ramps, access mains, turnouts, invert structures, and miscellaneous slabs. Dust suppression and emission controls will be controlled by the development contractors through contract specifications and contractual special conditions. Dust suppression measures will also be enforced during emplacement and postemplacement for any concrete dust generating activities in the repository. Dust suppression and mitigation considerations during closure of the repository will be developed and incorporated into the closure design to be submitted as part of the license amendment application to close the repository.	Part (d) – Procedures will be developed that will control the operation of the subsurface ventilation system to assist in the control of concrete dust generation. This will be accomplished by providing localized controls in areas where concrete work is being done. Such controls may include the use of air ducting to remove dust-laden air, or dust scrubbers and air filters to trap the dust before it gets carried out into the repository airways. Dust suppression through the use of inflatable barriers, foam coatings and surfactants may also be used as the activity demands.

Table 1.3.5-4. Summary of Conformance of Subsurface Facility Design to Postclosure Control Parameters—Subsurface Ventilation (Continued)

Structure, System and Component	Postclosure Control Parameter		Relevant to ITWI	Design Criteria/Configuration	Postclosure Procedural Safety Control
	Parameter Number and Title	Values, Ranges of Values or Constraints			
Emplacement Drift Ventilation	06-01 Duration of Ventilation	The duration of the ventilation period shall be a minimum of 50 years after final emplacement.	No	NA (Background information: Operational criteria for the subsurface ventilation system is described as part of the thermal management discussion in Section 1.3.1.2.5. As stated in Section 1.3.5.1.3, the thermal management plans demonstrate the ability to utilize varying ventilation periods. The demonstration case for thermal loading that is described in Section 1.3.1.2.5, provides for a ventilation period of 65 years. Accordingly, thermal management planning will include a minimum 50 year ventilation duration after final waste package emplacement. The design of the subsurface ventilation system and its components, as described in Section 1.3.5.1, has the capability to provide continuous ventilation to each of the repository emplacement drifts at nominal rates of 32,000 cfm for a minimum of 50 years after waste emplacement is complete.)	Procedures controlling the thermal management plan and waste package loading plan will include the requirement of a minimum of 50 years of ventilation, following the final waste package emplacement as part of the calculation for thermal loading.

Table 1.3.5-4. Summary of Conformance of Subsurface Facility Design to Postclosure Control Parameters—Subsurface Ventilation (Continued)

Structure, System and Component	Postclosure Control Parameter		Relevant to ITWI	Design Criteria/Configuration	Postclosure Procedural Safety Control
	Parameter Number and Title	Values, Ranges of Values or Constraints			
Emplacement Drift Ventilation	06-02 Drift Wall Temperature	The maximum preclosure emplacement drift wall temperature shall not exceed 200°C to avoid possible adverse conditions (e.g., mineralogical transitions, rock weakening).	No	The calculations performed in support of the thermal loading plan assures that the emplacement drift wall temperature limits of the subject constraint are not violated. The thermal management approach is described in Section 1.3.1.2.5 with supporting postclosure analyses described in Section 2.3.5.4.3. The subsurface ventilation design will provide the ventilation flow rates and durations as required by these analyses, as described in Section 1.3.2.4.5.2.	NA
Emplacement Drift Ventilation	06-03 Waste Package Temperature Limit	The waste package surface temperature shall be kept below 300°C for the first 500 years and below 200°C for the next 9,500 years to eliminate postclosure issues (i.e., phase stability). Note: Compliance with this constraint after repository closure is demonstrated in postclosure analyses (only). Parameters 05-03, 06-01, and 06-06 support compliance with this constraint during both the preclosure and postclosure periods.	Yes	The calculations performed in support of the thermal loading plan assures that the waste package surface temperature limits of the subject constraint are not violated. The thermal management approach is described in Section 1.3.1.2.5 with supporting postclosure analyses described in Section 2.3.5.4.3. This requirement is represented as one of the thermal management criteria for the repository as stated in Table 1.3.1-2 and as a design criterion for the subsurface ventilation system in Section 1.3.2.4.5.2.	NA

Table 1.3.5-4. Summary of Conformance of Subsurface Facility Design to Postclosure Control Parameters—Subsurface Ventilation (Continued)

Structure, System and Component	Postclosure Control Parameter		Relevant to ITWI	Design Criteria/Configuration	Postclosure Procedural Safety Control
	Parameter Number and Title	Values, Ranges of Values or Constraints			
Emplacement Drift Ventilation	06-05 Maximum Temperature of HLW Glass Canisters – Ventilation	The maximum HLW glass temperature shall be less than 400°C.	No	The calculations performed in support of the thermal loading plan assures that the HLW glass temperature limits of 400°C are not violated. The thermal management approach is described in Section 1.3.1.2.5 with supporting postclosure analyses described in Section 2.3.5.4.3. The subsurface ventilation design will provide the ventilation flow rates and durations as required by these analyses, as described in Section 1.3.2.4.5.2	NA
Emplacement Drift Ventilation	06-06 Average Airflow Rate for Preclosure Ventilation of Emplacement Drifts	During the preclosure phase, the nominal inlet airflow rate per emplacement drift shall be 15 m^3/sec. The range of airflow rate in a given drift shall be 15 m^3/sec ± 2 m^3/sec, based on integrated ventilation efficiency and drift length.	No	The design of the subsurface ventilation system will provide airflow rates per the subject constraint. These airflow rates are consistent with the thermal loading management approach described in Section 1.3.1.2.5 with supporting postclosure analyses described in Section 2.3.5.4.3. The subsurface ventilation design will provide the ventilation flow rates and durations as required by these analyses, as described in Section 1.3.2.4.5.2	NA

NOTE: NA = not applicable.

Source: Table 1.9-9; BSC 2008e, Table 1.

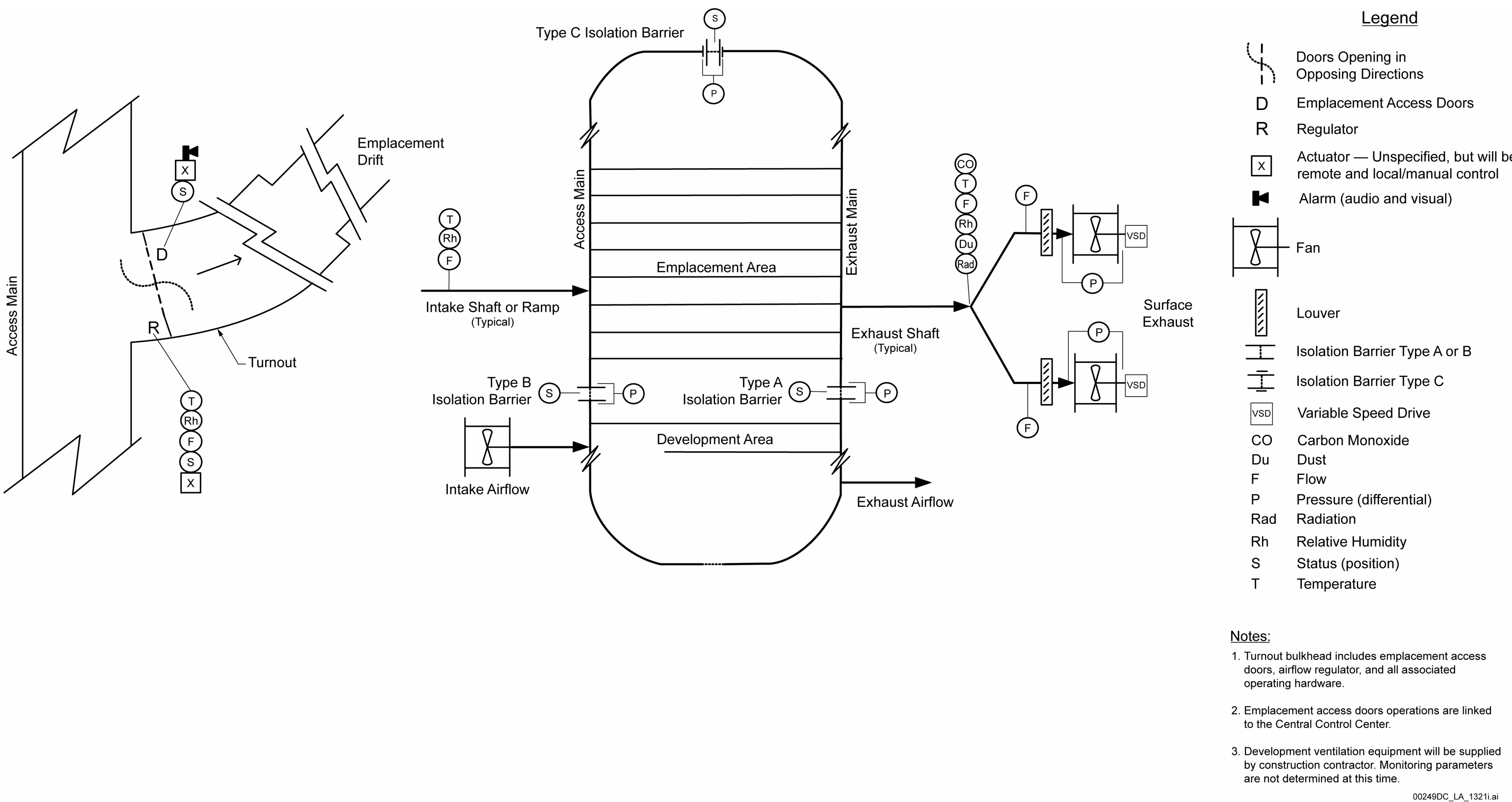

Figure 1.3.5-1. Subsurface Ventilation System and Instrumentation Diagram

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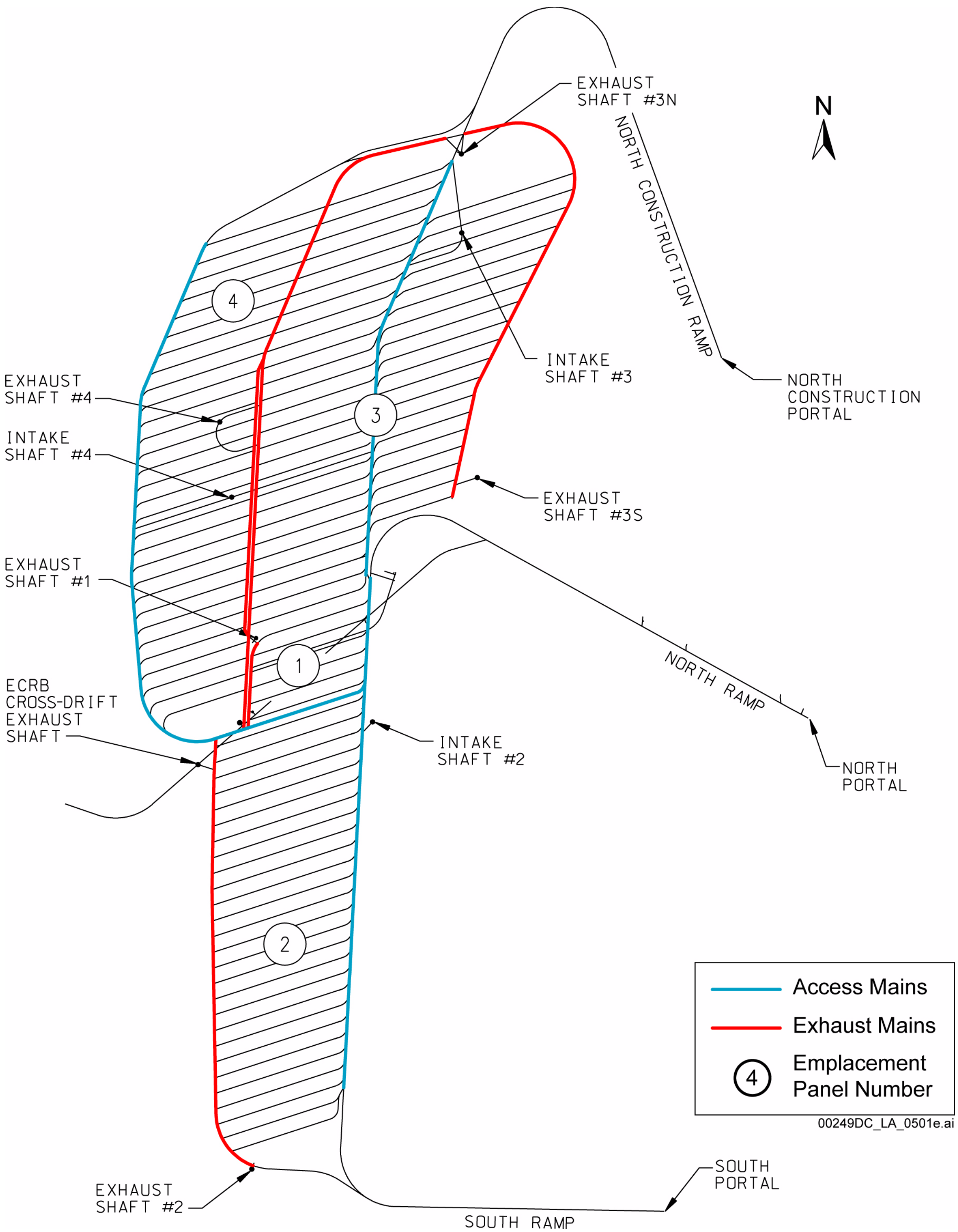

Figure 1.3.5-2. Underground Layout and Location of Ramps and Shafts

NOTE: The North Construction, North, and South Ramps serve as intake airways in conjunction with the intake ventilation shafts.

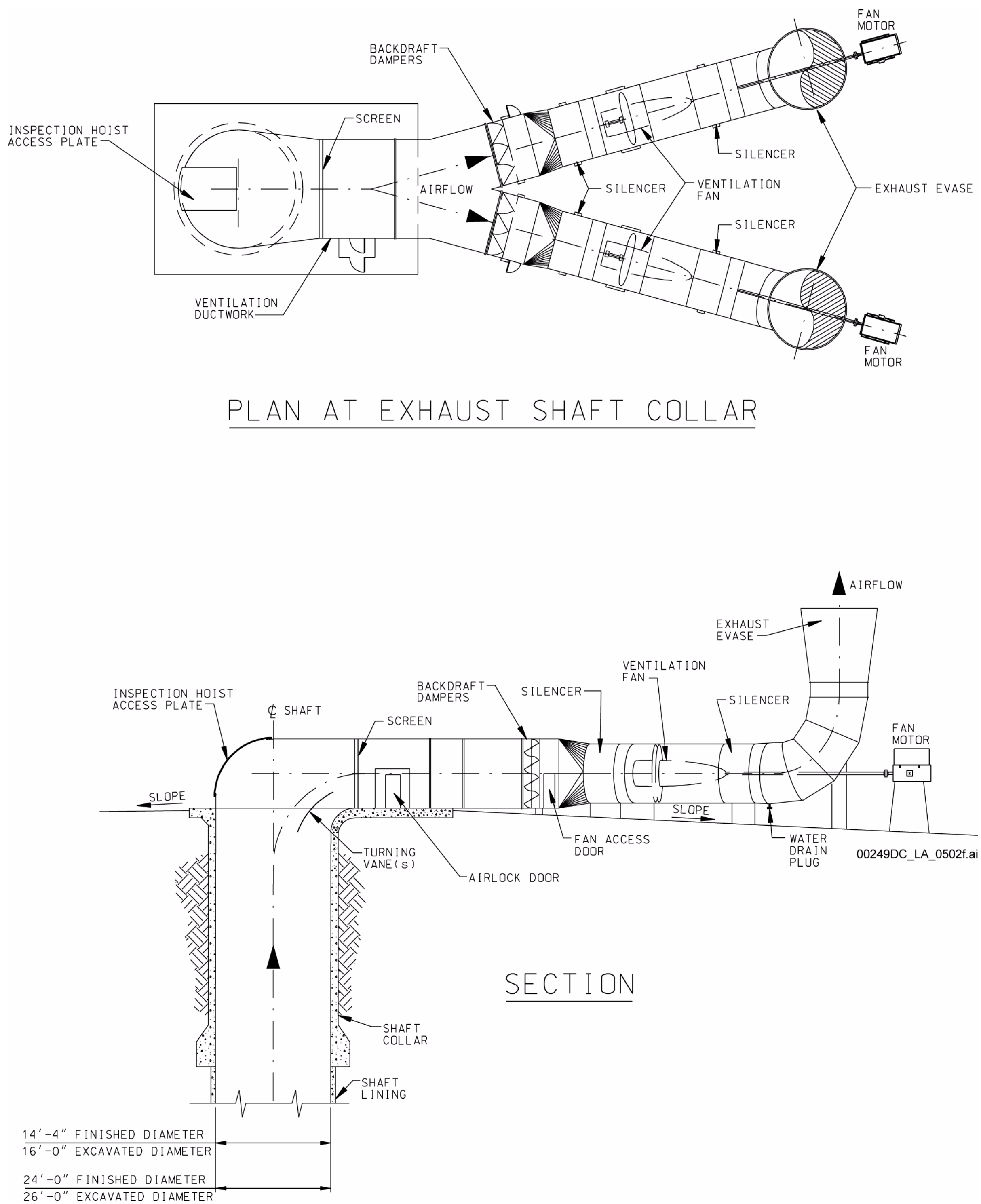

Figure 1.3.5-3. Typical Exhaust Fan Installation Configuration, Section and Plan View

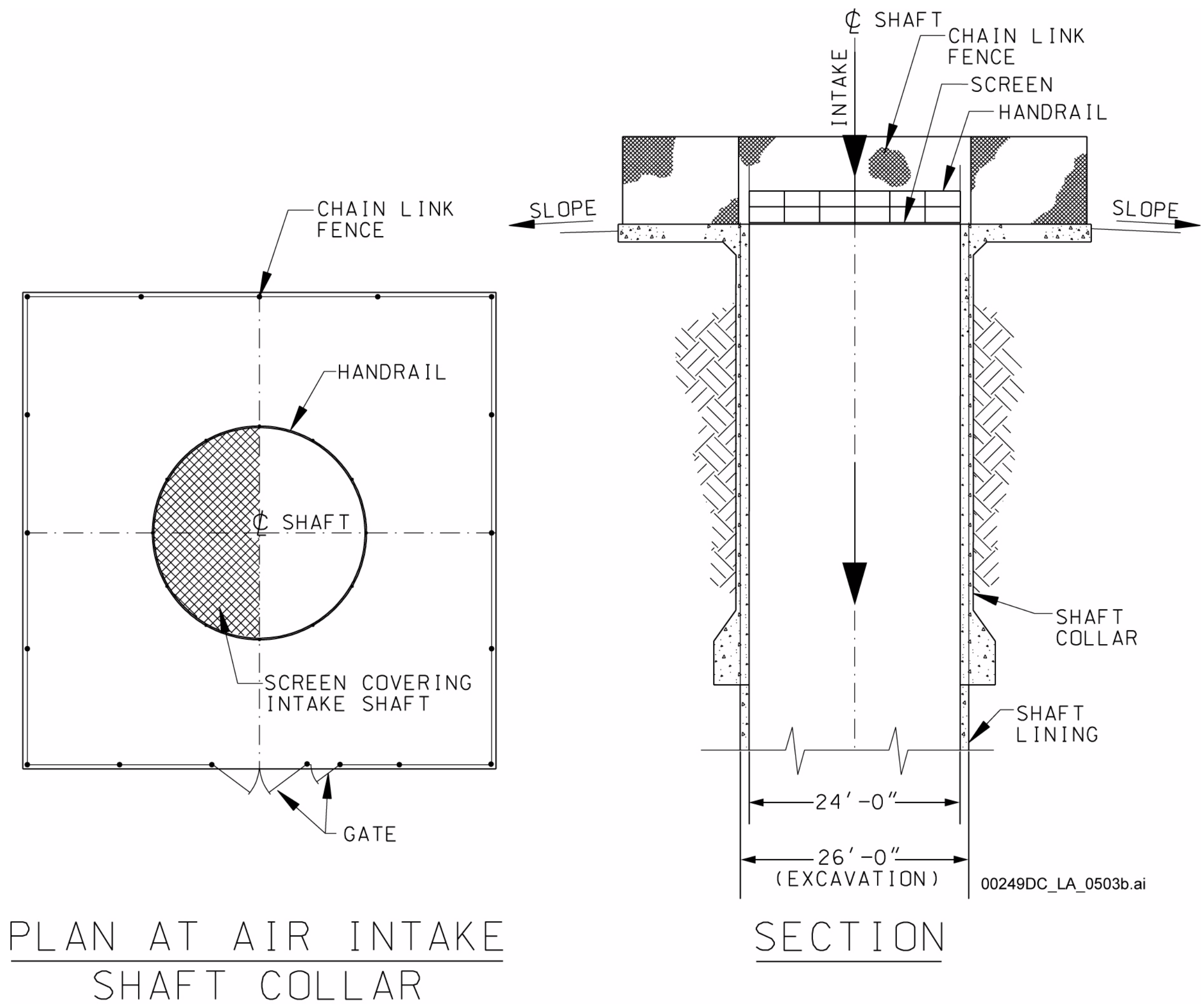

Figure 1.3.5-4. Typical Intake Shaft Configuration, Section and Plan View

NOTE: Intake fan installation detail is not shown. Intake fan installation details will be provided by construction contractor.

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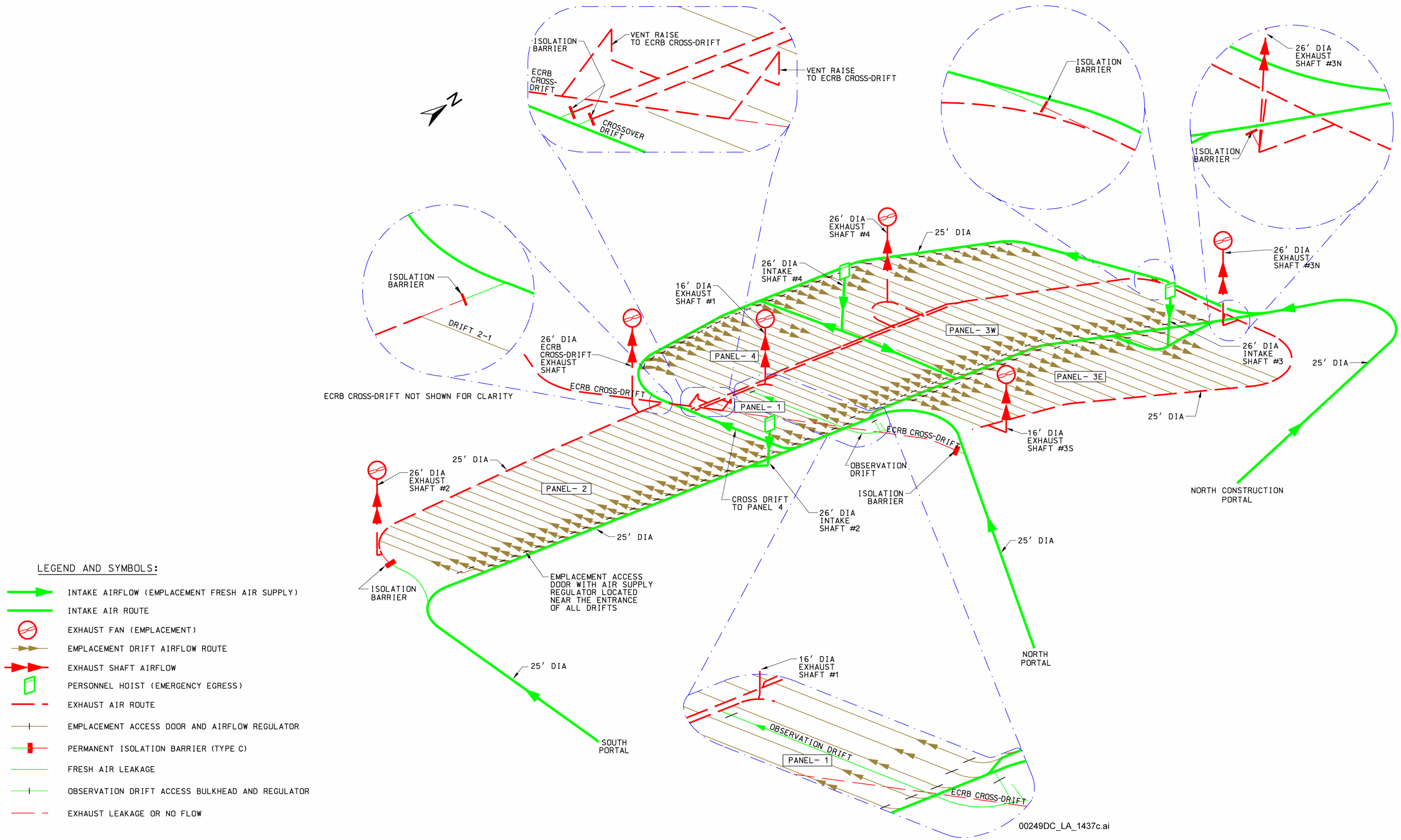

Figure 1.3.5-5. Subsurface Repository Ventilation System at Full Emplacement

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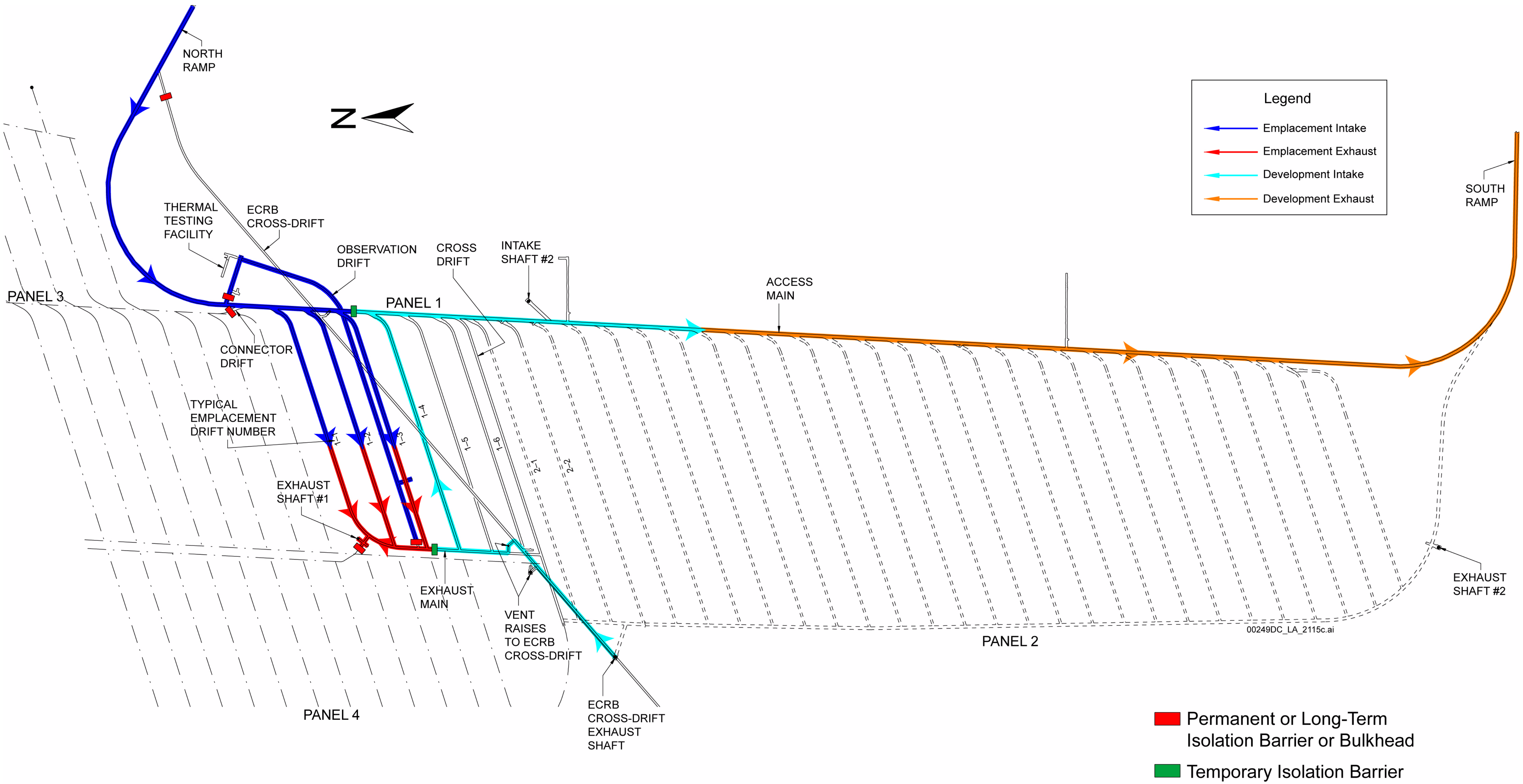

NOTE: The observation drift is only equipped with ventilation bulkheads and not isolation barriers.

Source: BSC 2008a, Figure 16.

Figure 1.3.5-6. Concurrent Development and Emplacement Operations in Panel 1 (Initial Operating Capability)

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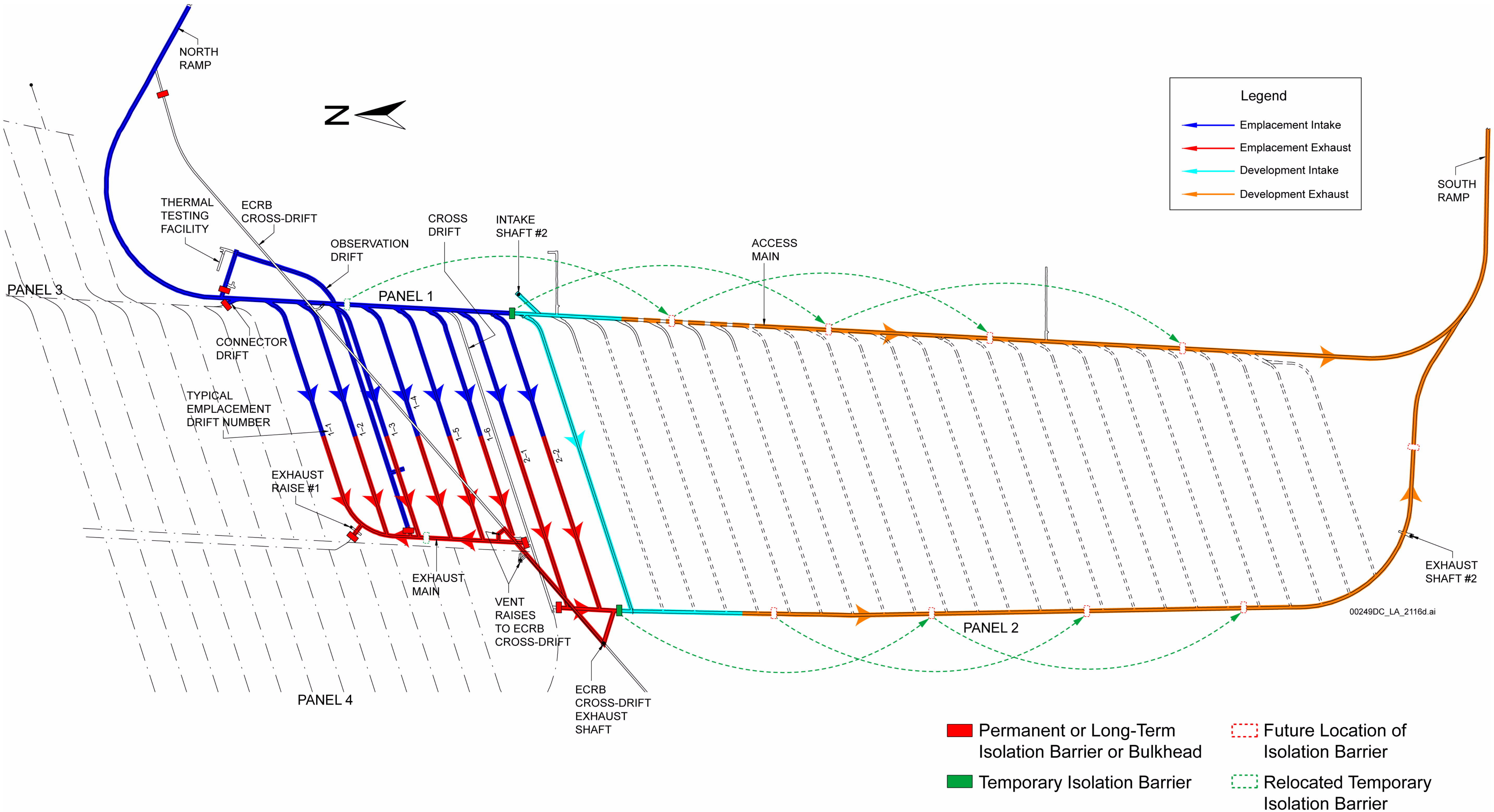

NOTE: The observation drift is only equipped with ventilation bulkheads and not isolation barriers.

Figure 1.3.5-7. Concurrent Development and Emplacement Operations in Panel 2 (Panel 1 Fully Loaded)

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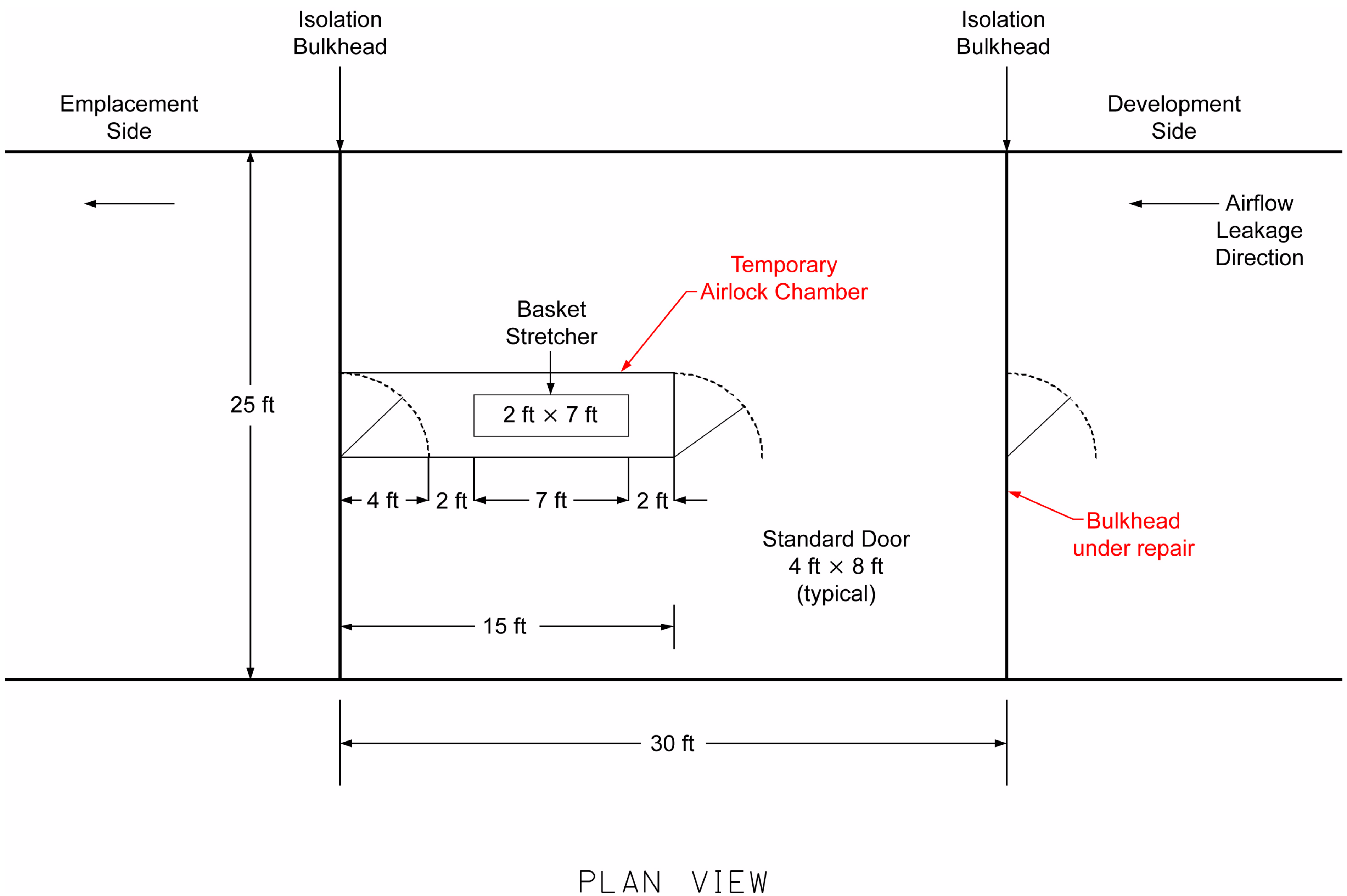

NOTE: Temporary airlock chamber connected to the bulkhead on the left side of this figure is only necessary when the other bulkhead is not functional as illustrated in this figure.

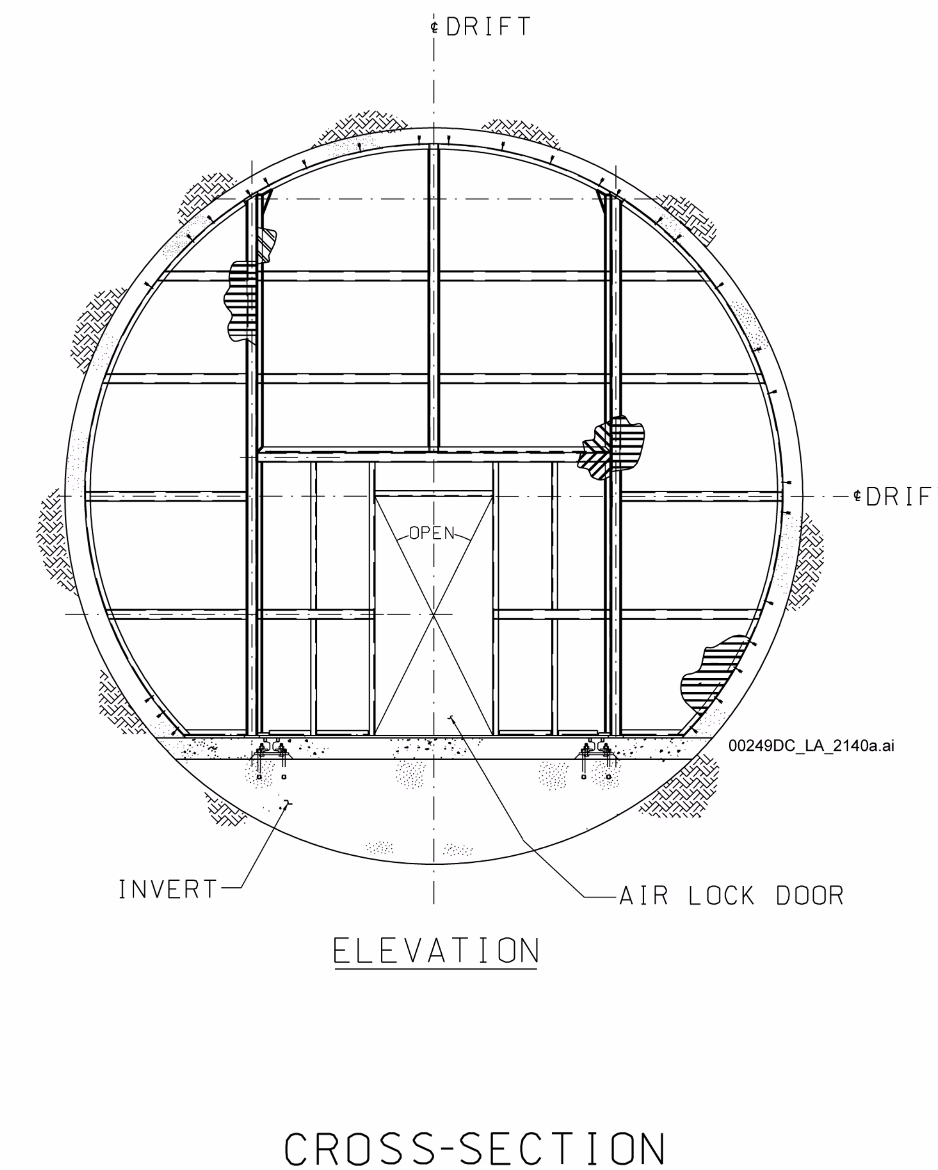

Figure 1.3.5-8. Isolation Barriers Types A, B, and C—General Arrangements

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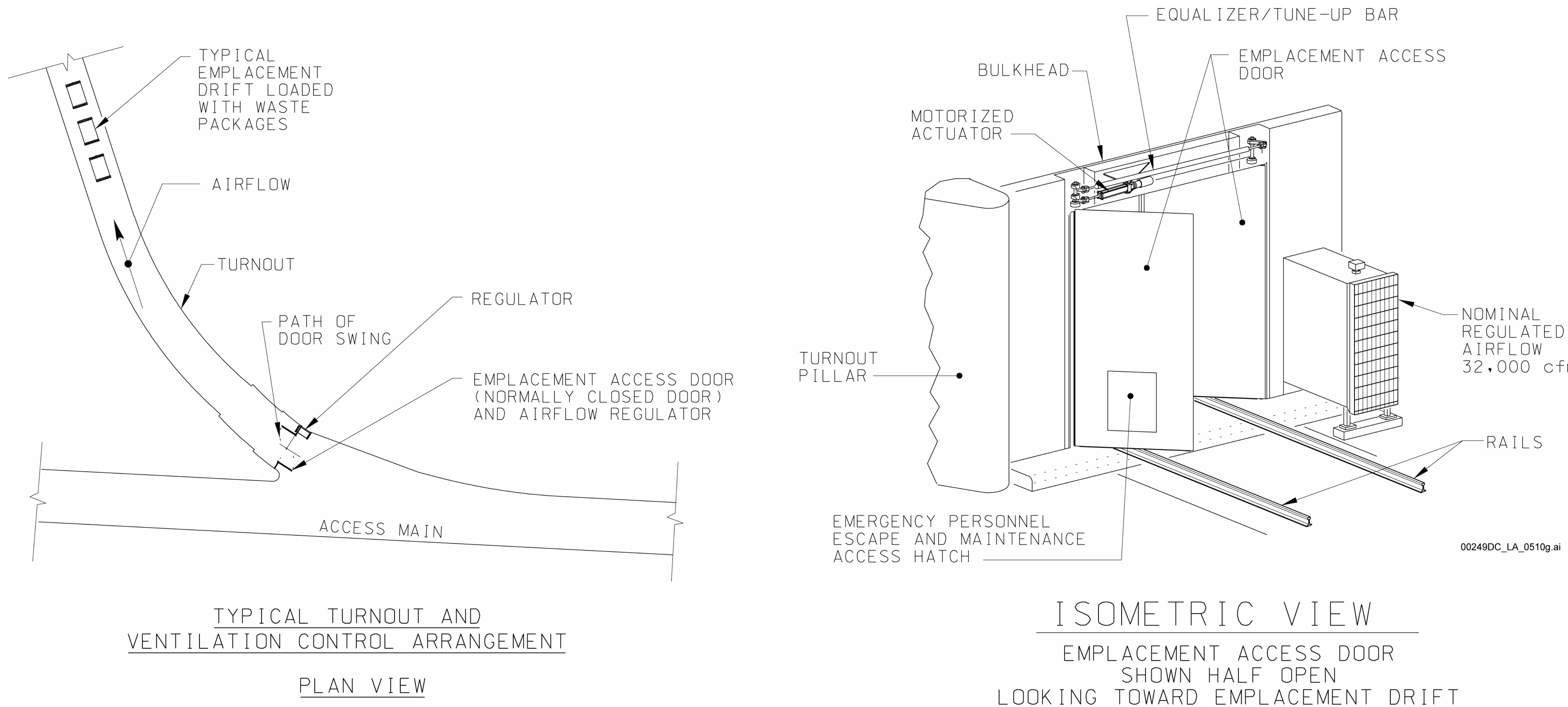

Figure 1.3.5-9. Turnout Bulkhead and Emplacement Access Doors

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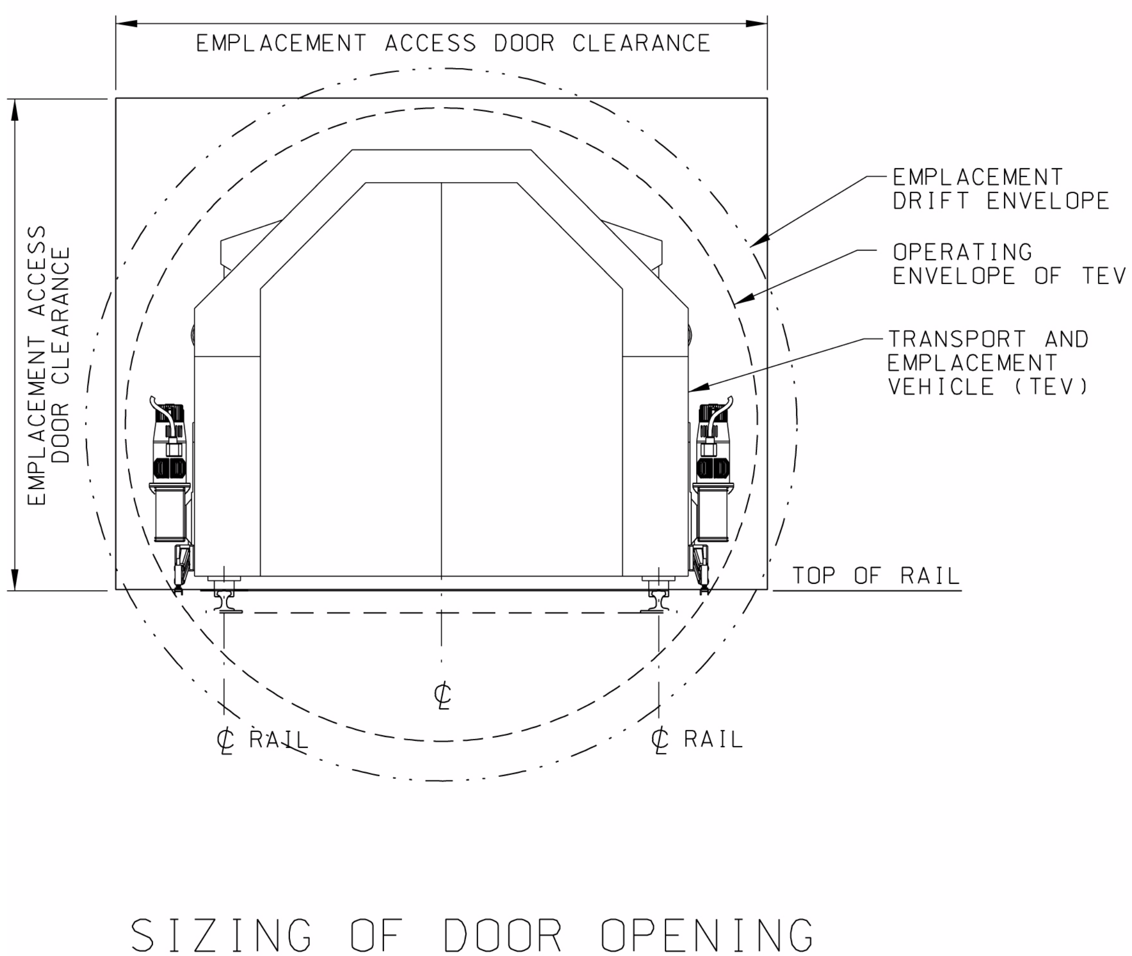

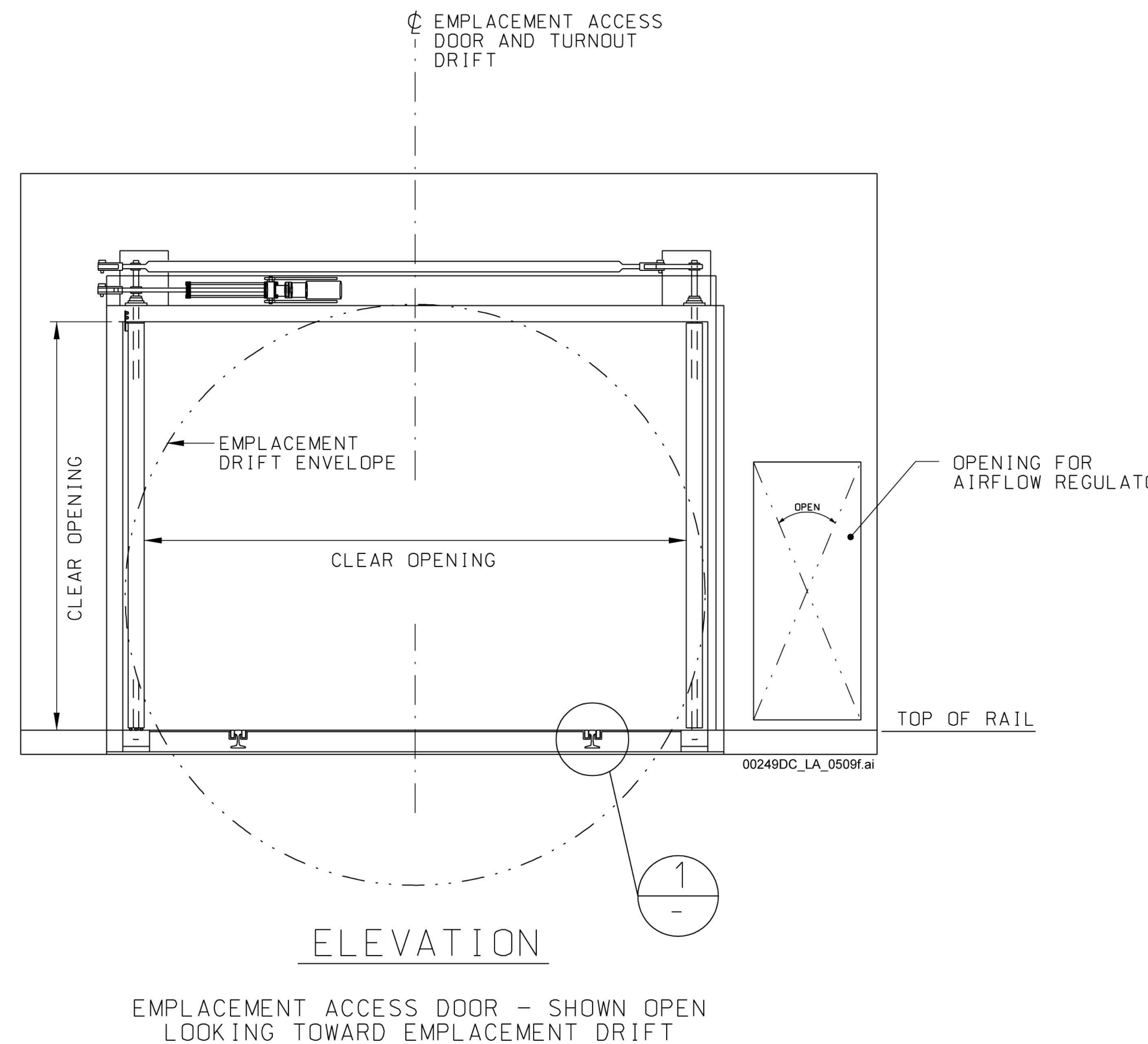

NOTE: Detail 1 called out in Elevation View is shown in Figure 1.3.5-11.

Figure 1.3.5-10. Typical Turnout Bulkhead and Emplacement Access Door Dimensions

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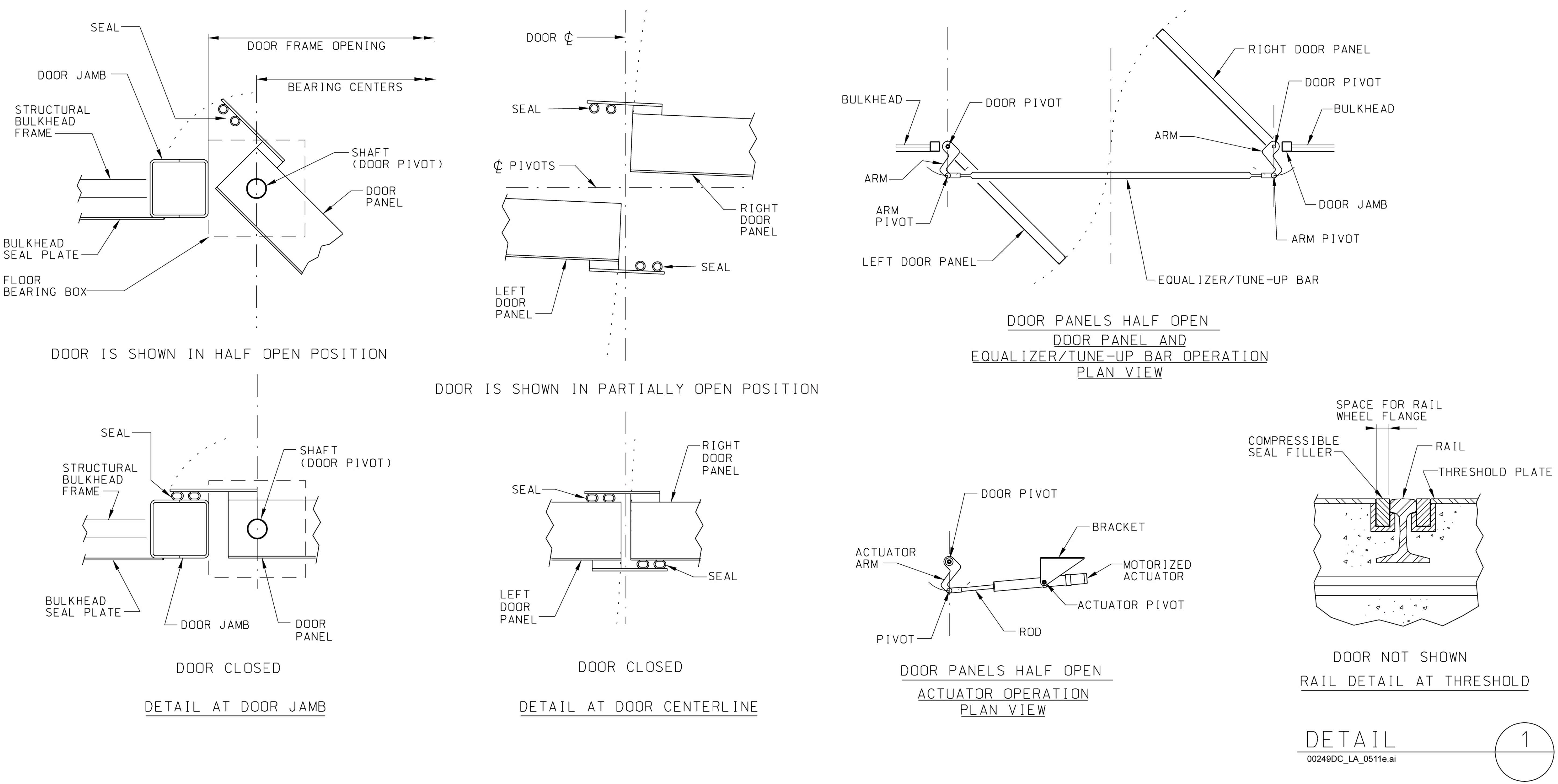

NOTE: Location for Detail 1 is shown in Figure 1.3.5-10, Elevation View.

Figure 1.3.5-11. Emplacement Access Doors—Counter Opening Arrangement

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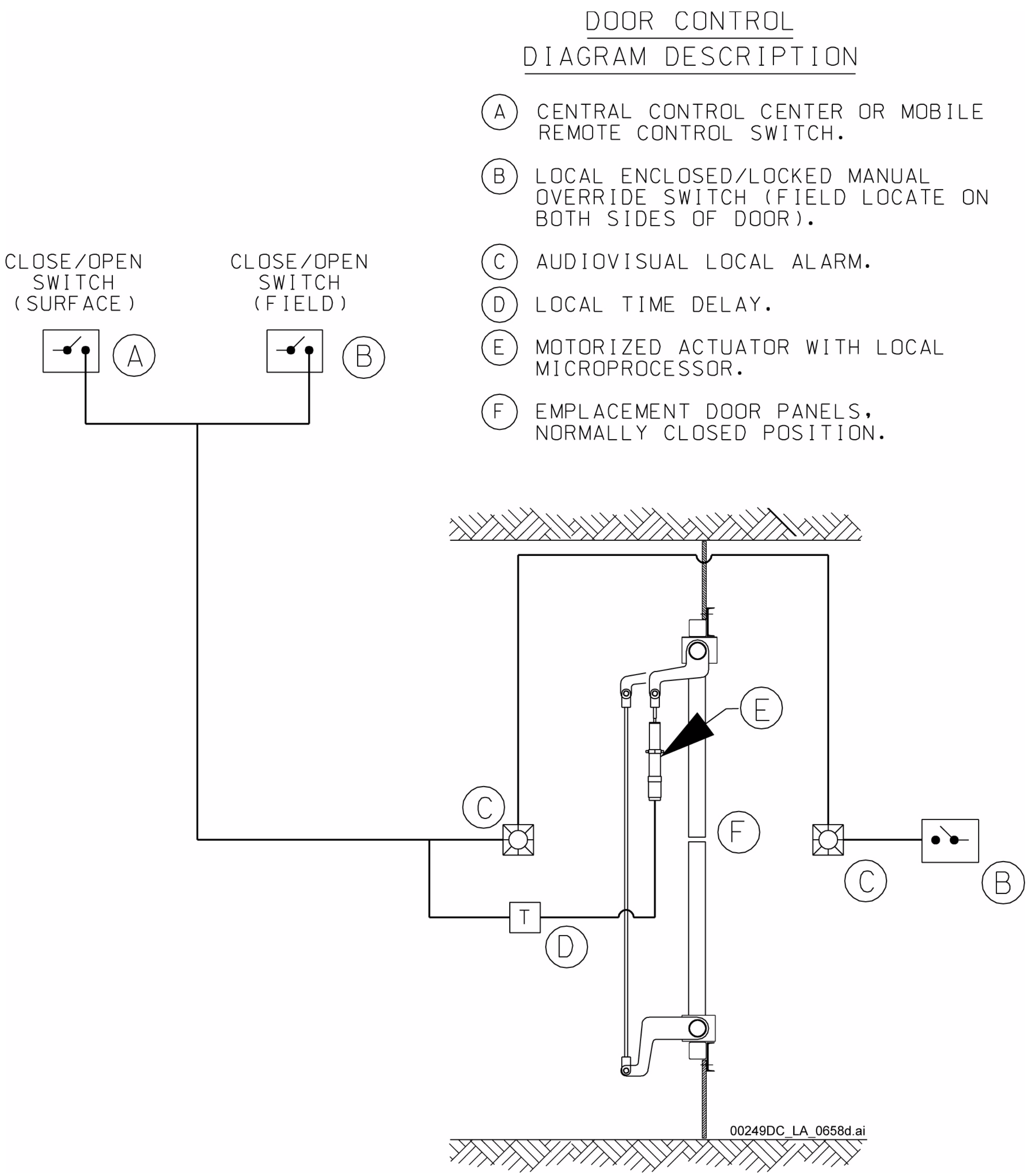

Figure 1.3.5-12. Emplacement Access Door Instrumentation and Controls

NOTE: The purpose of the surface remote control switch is to prevent the emplacement access doors from being opened from underground without Central Control Center Facility action. The local enclosed/locked manual override switch works in conjunction with the surface remote control switch to provide locked controls for the emplacement access doors at each location. The audiovisual alarm provides a strobe and audible signal when the door is about to open. The time delay works in conjunction with the alarm. The motorized actuator and microprocessor indicate the status and action of the door-opening mechanism. The emplacement access door panels aid in monitoring the positions (status) of the emplacement access doors.

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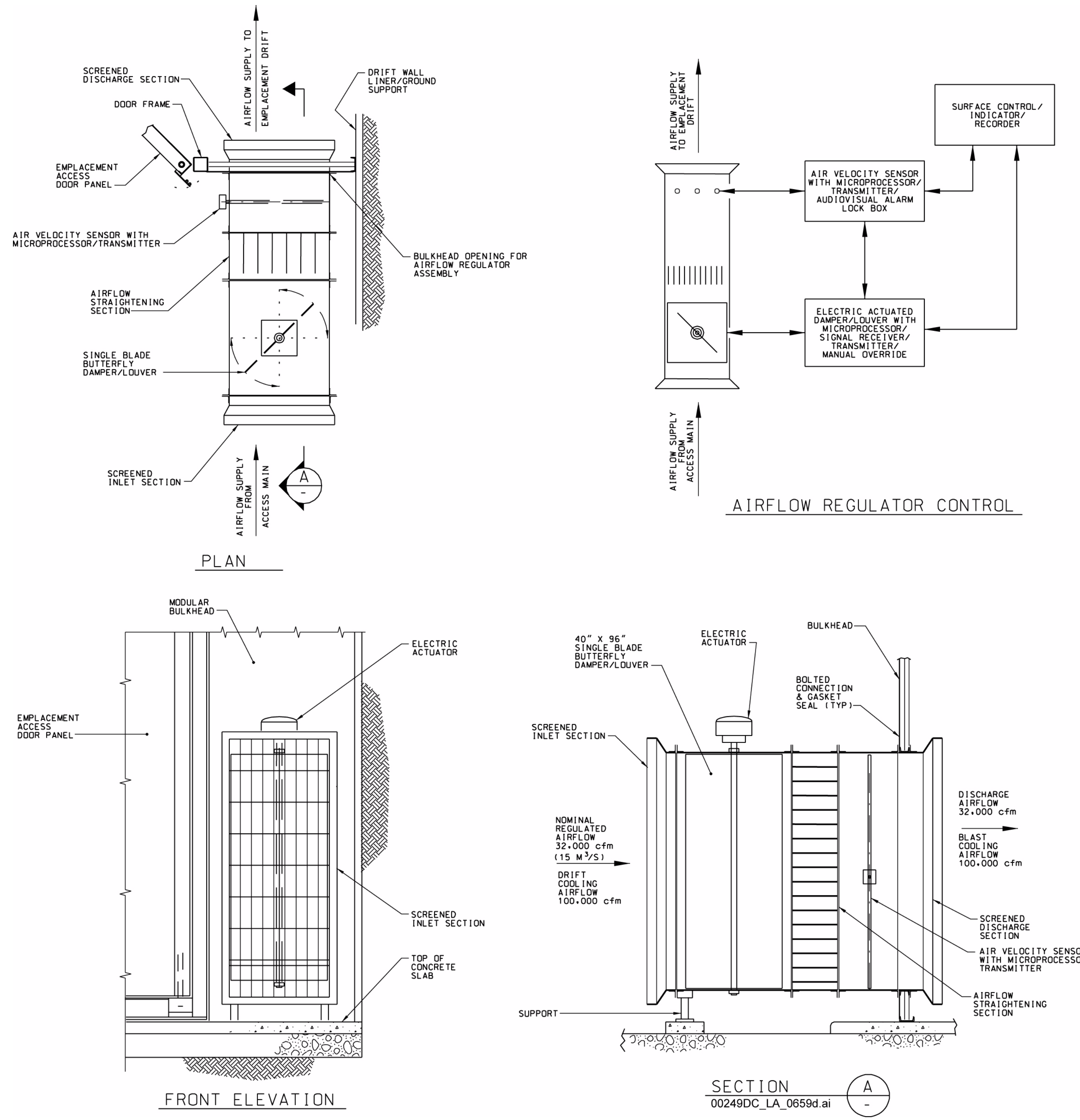

Figure 1.3.5-13. Example of Butterfly-Type Airflow Regulator

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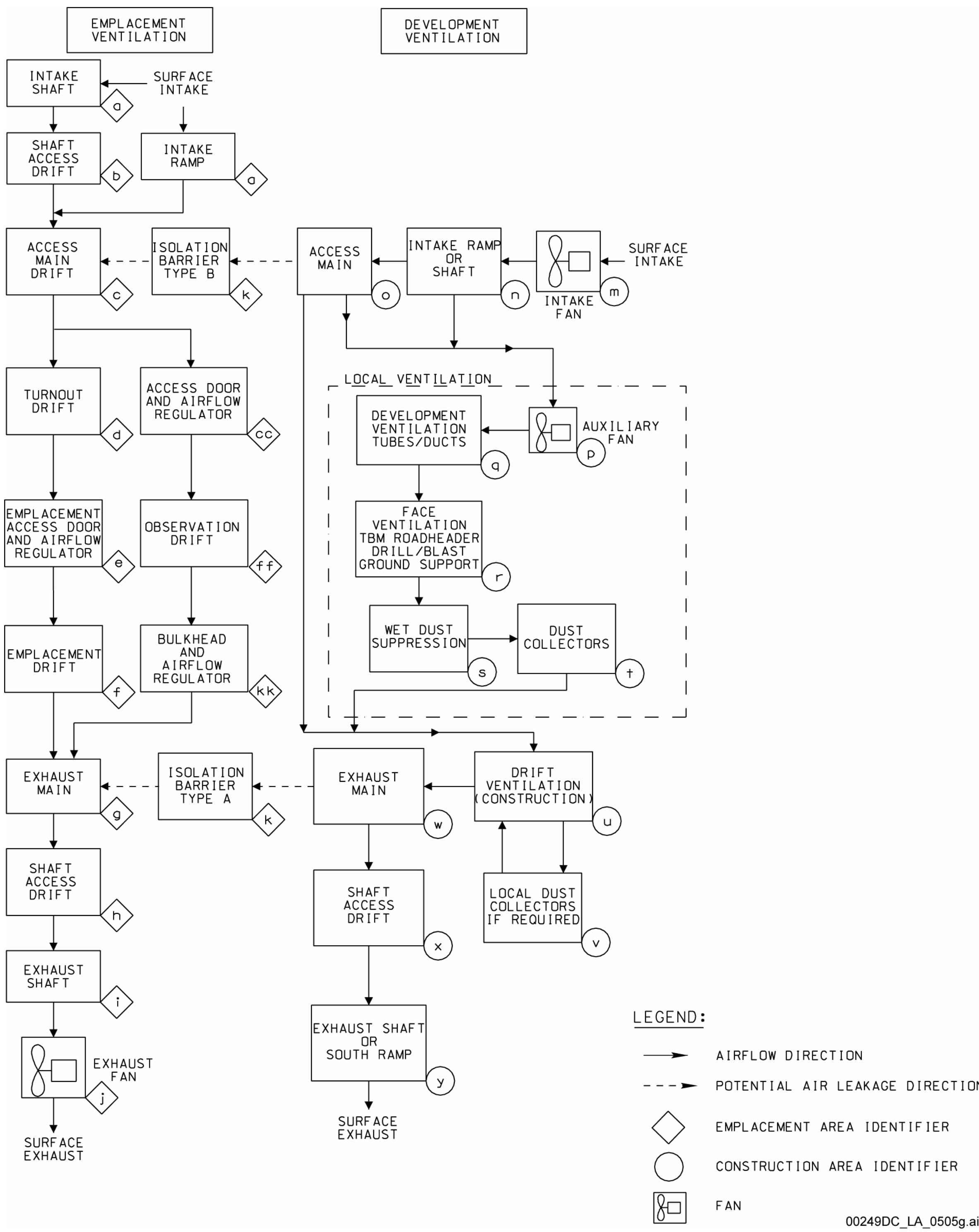

Figure 1.3.5-14. Subsurface Ventilation Flow Diagrams for Development and Emplacement Sides

NOTE: Letters in diamonds and circles refer to features or locations also used in Figure 1.3.5-15 for the emplacement and development sides, respectively.
TBM = Tunnel boring machine.

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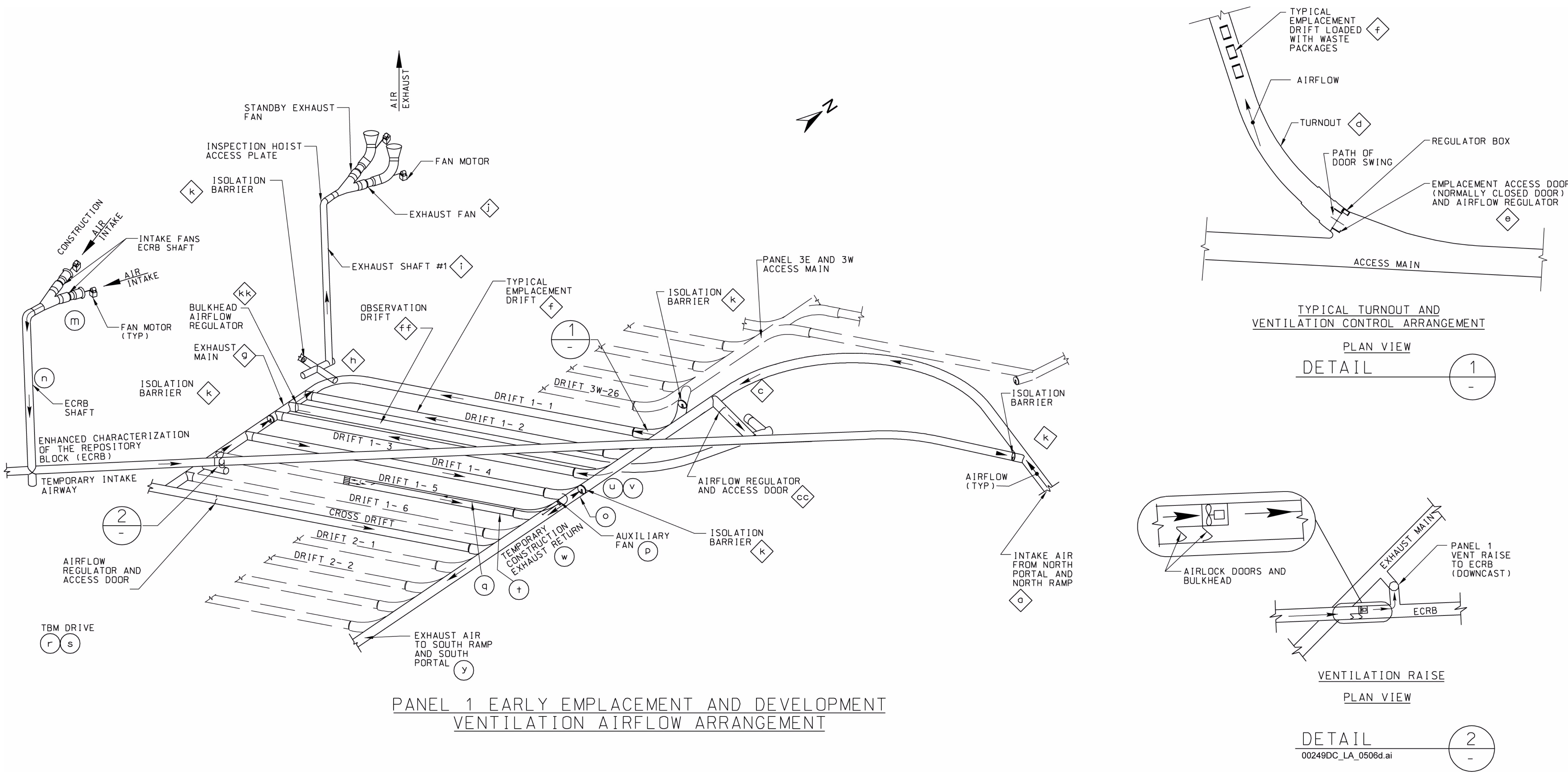

Figure 1.3.5-15. Subsurface Ventilation Schematic for Panel 1 Development and Emplacement Sides

NOTE: TBM = Tunnel boring machine.

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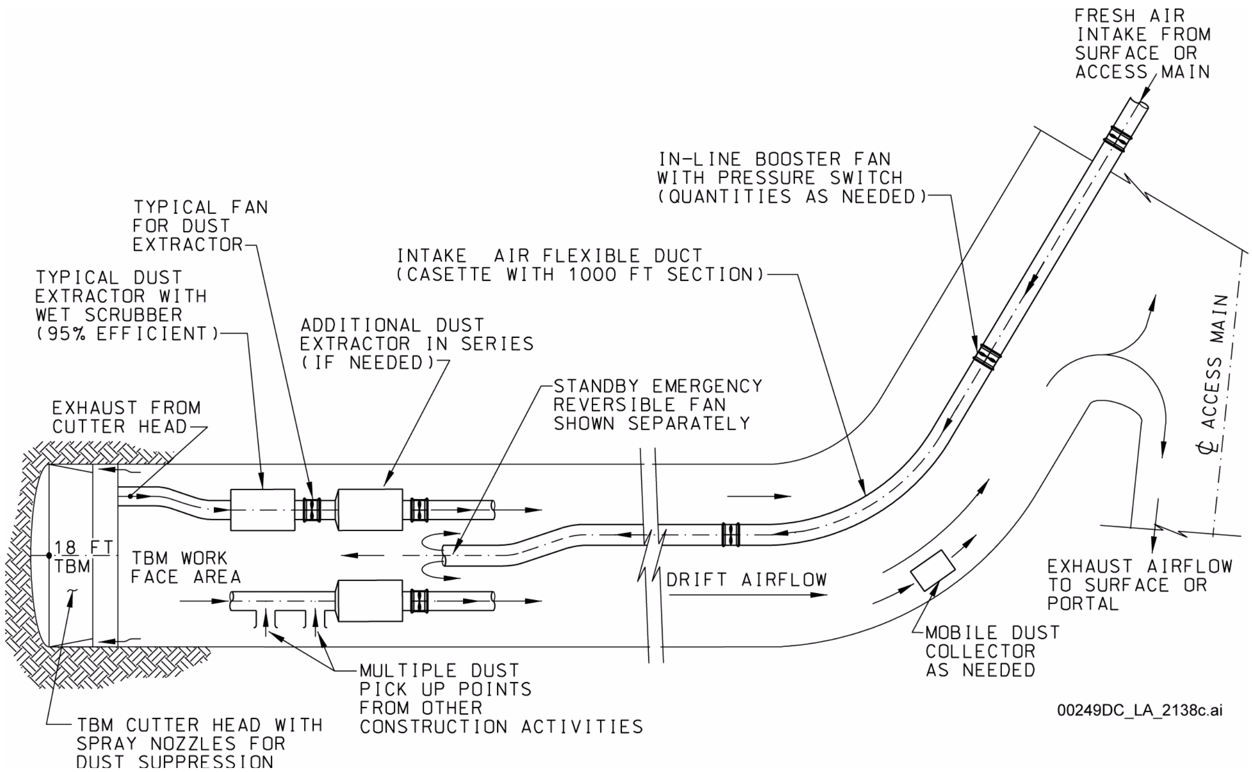

Figure 1.3.5-16. Typical Local Ventilation Arrangement for the Tunnel Boring Machine Excavation

NOTE: TBM = tunnel boring machine.

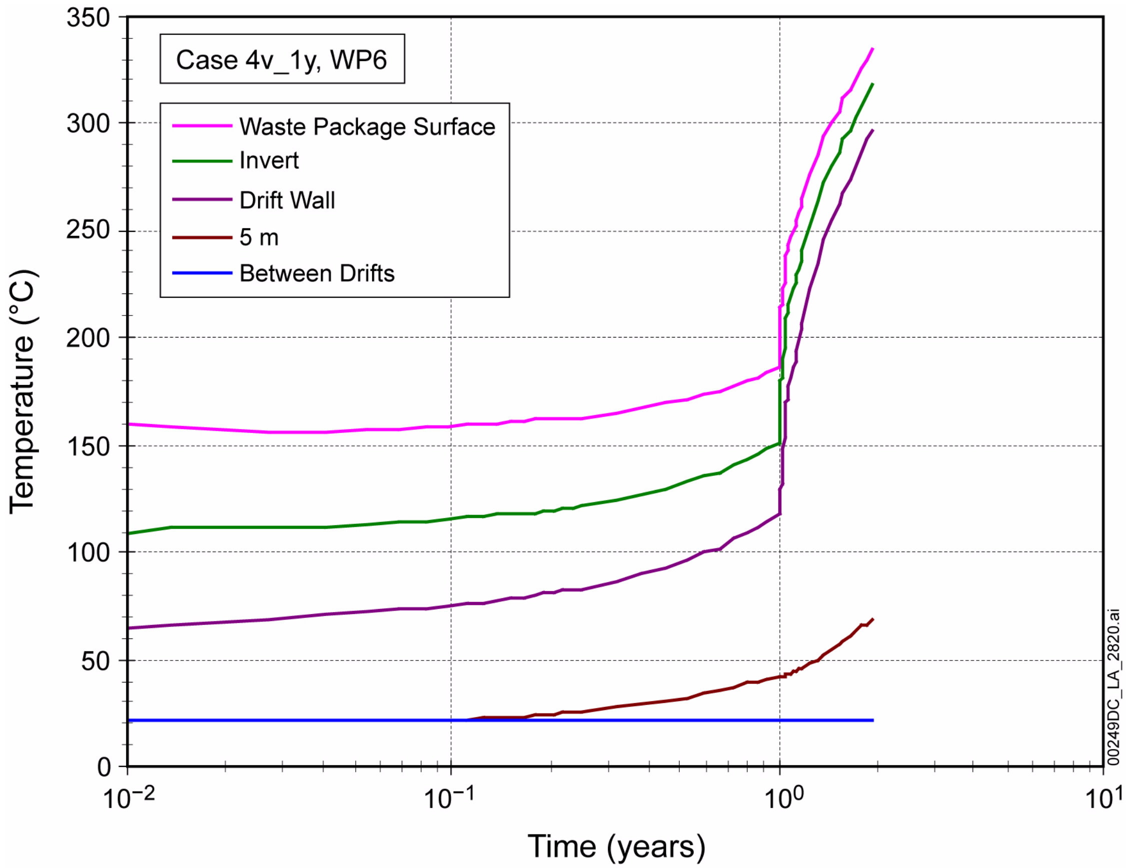

Figure 1.3.5-17. Peak Temperature Histories for Emplacement Drift Wall and EBS Components Adjacent to the Location of the Hottest Waste Package (WP6), for the Numerical Simulation of Forced Ventilation Shutdown Occurring One Year After Beginning of Emplacement, Without Natural Convective Cooling and Without Resumption of Forced Ventilation

NOTE: WP = waste package; Invert = emplacement drift invert structure; 5 m = simulated rock temperature 5 meters from the emplacement drift wall; Between Drifts = simulated mid-pillar rock temperature; Case 4v_1y = case analyzed as described in Section 1.3.5.3.2.1; WP6 = location of waste package #6 listed in Table 1.3.5-3 and indicative of the location in the waste package segment for which temperatures are provided in figure.

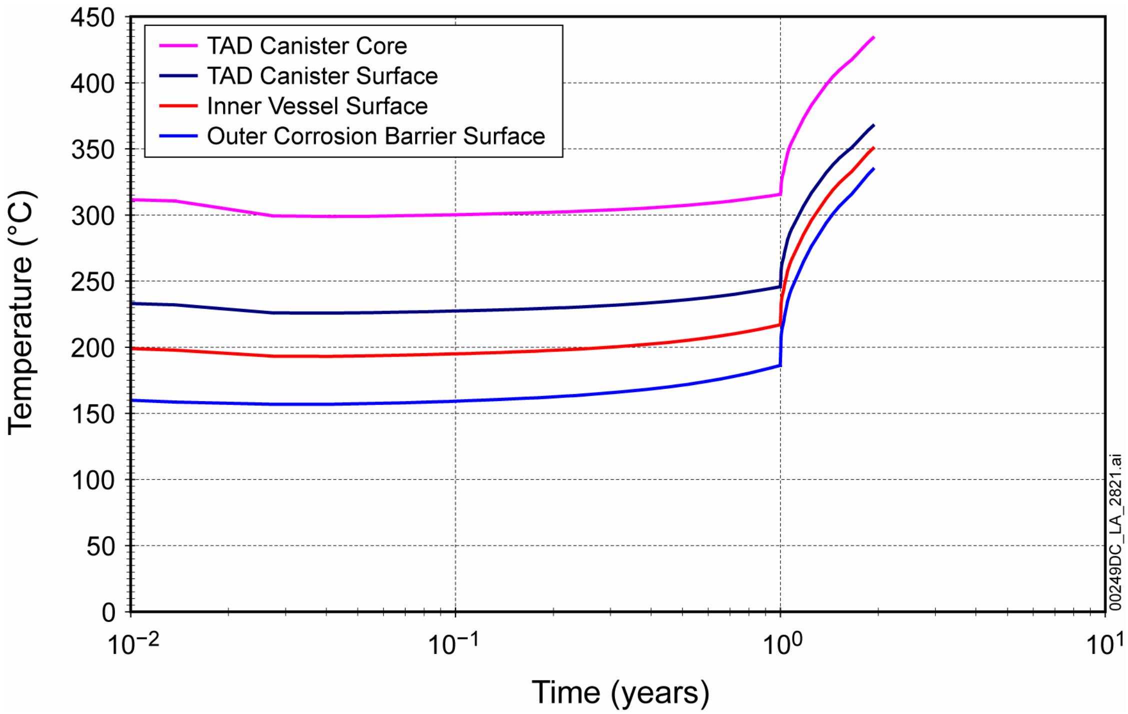

Figure 1.3.5-18. Temperature Histories for an 18.0-kW TAD Waste Package, Case 4v_1y Boundary Conditions

NOTE: TAD = transportation, aging, and disposal container; OCB = outer corrosion barrier; Case 4v_1y = case analyzed as described in Section 1.3.5.3.2.1.

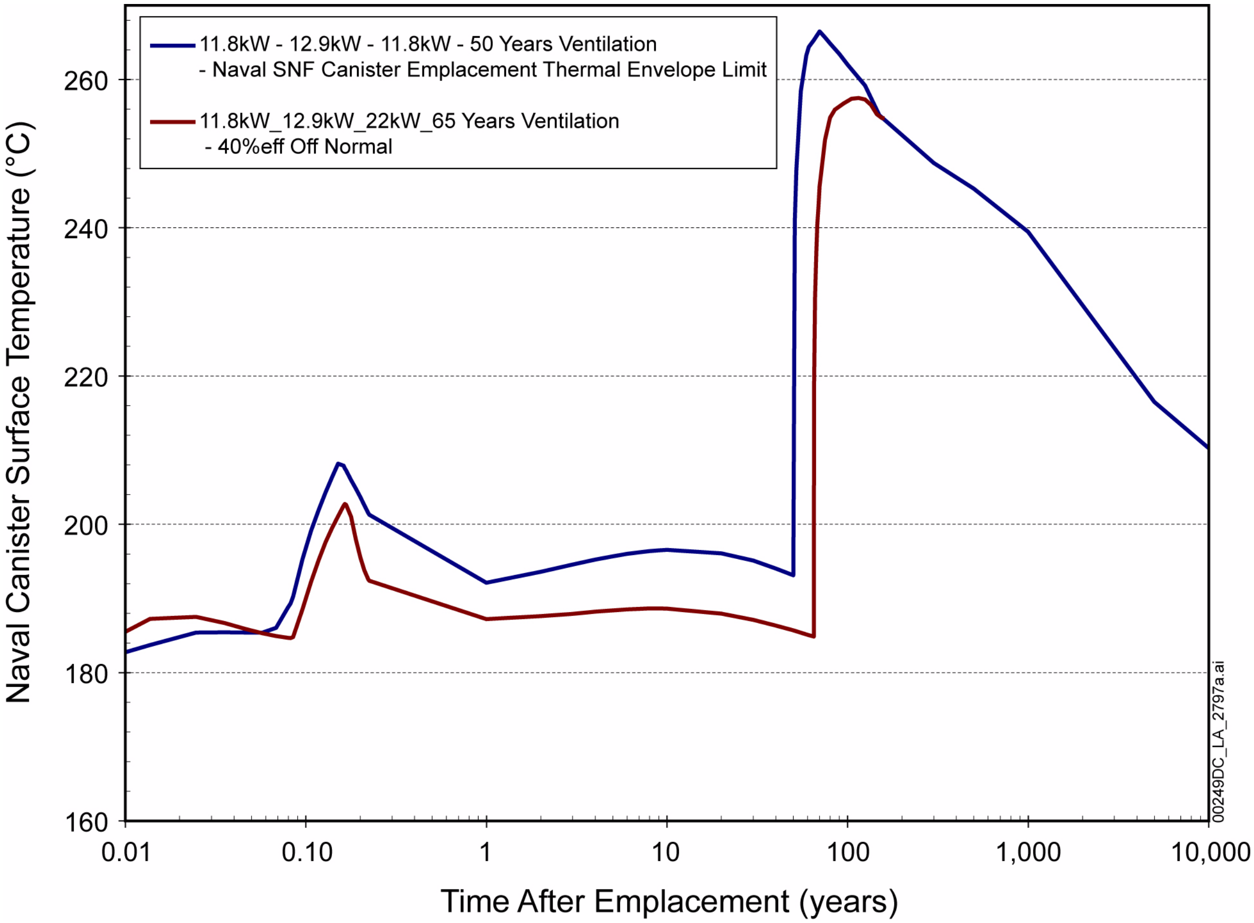

Figure 1.3.5-19. Naval SNF Canister Surface Temperature Comparison—Misplacement of a 22.0-kW Commercial SNF Waste Package in a 1.45-kW/m Naval Drift Segment Loaded with One 12.9-kW Naval SNF Waste Package, with 40% Natural Ventilation Efficiency During Preclosure and with Occurrence of an Off-Normal Condition

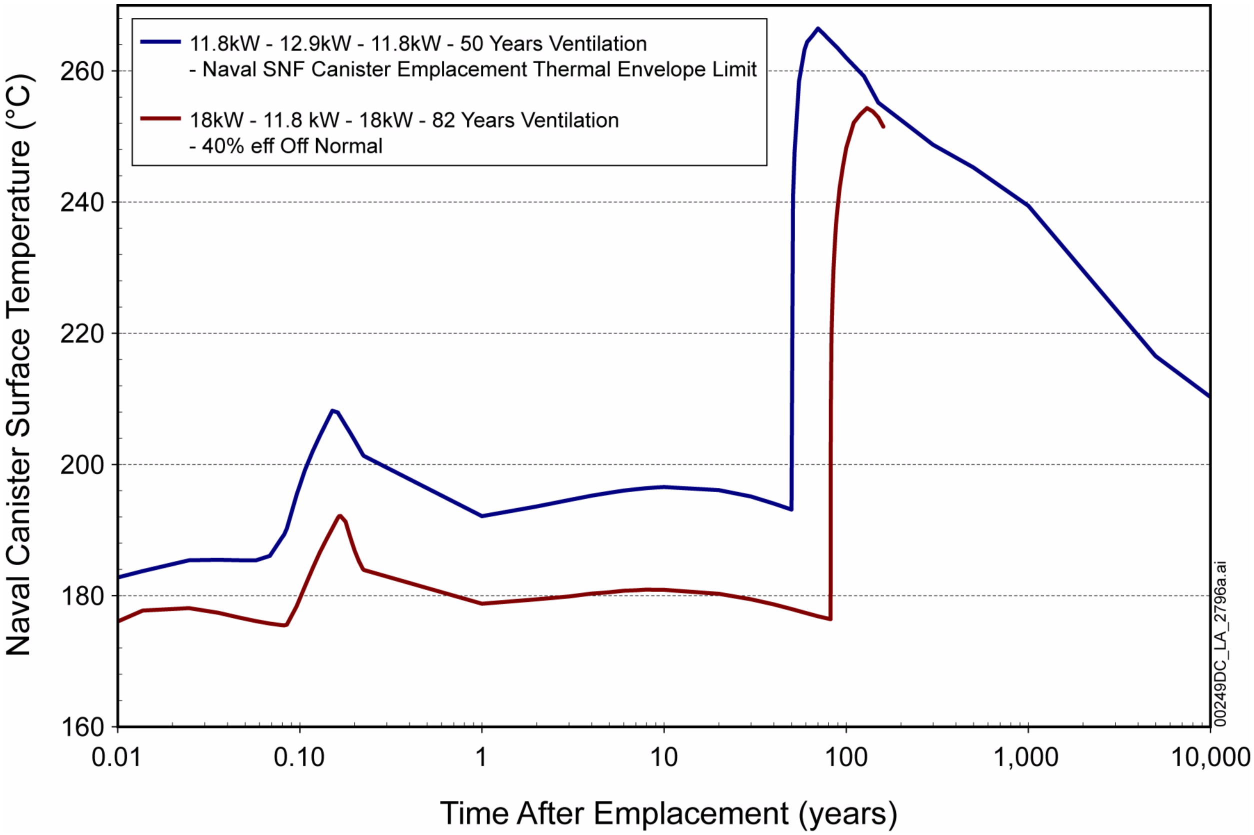

Figure 1.3.5-20. Naval SNF Canister Surface Temperature Comparison—Misplacement of an 11.8-kW Naval SNF Waste Package in a 2.0-kW/m Commercial SNF Drift Segment with 40% Natural Ventilation Efficiency During Preclosure and with Occurrence of an Off-Normal Condition

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1.3.6 Subsurface Facility Closure

[NUREG-1804, Section 2.1.1.2.3: AC 3, AC 6; Section 2.1.1.7.3.2: AC 1; Section 2.1.1.7.3.3(III): AC 1]

This section describes the subsurface facility closure including: inspection of waste packages, installation of drip shields, removal of noncommitted materials, placement of backfill in ramps and shafts, and site restoration.

1.3.6.1 Closure Processes

[NUREG-1804, Section 2.1.1.2.3: AC 3(1), AC 6(1), (2); Section 2.1.1.7.3.3(III): AC 1(12)]

The final phase of the repository preclosure period is the closure of the subsurface facility. Closure consists of the following activities:

- Installation of drip shields
- Removal of noncommitted materials from the subsurface facility
- Placement of backfill in ramps and shafts
- Regrading of affected areas and installation of surface monuments
- Final site restoration.

Installation of the drip shields will be initiated after the U.S. Nuclear Regulatory Commission has issued a license amendment to close the repository in accordance with 10 CFR 63.51. The drip shield design is described in Section 1.3.4.7. The equipment and the process for installation of the drip shields are also discussed in Section 1.3.4.7.

The repository's postclosure nuclear design basis that addresses closure of boreholes located within or near the footprint of the repository block (BSC 2008a, Table 1, Derived Internal Constraint 09-03) is satisfied by backfilling the boreholes with materials compatible with the host rock materials, and plugging the boreholes at the surface. The time of closure for each borehole will be determined on a case-by-case basis.

The closure process also involves removal of items outside the emplacement drifts that could have an impact on long-term repository performance. These items are designated as noncommitted materials in the nonemplacement areas and are subjected to conformance with the repository's postclosure nuclear safety design bases. These items include most concrete, miscellaneous steel structures, turnout bulkheads and emplacement access doors, electrical equipment and cables, and rails. The approach to be used for removal of noncommitted subsurface materials and planned decommissioning activities is described in Section 1.3.6.1.3. The operating philosophy for the emplacement drifts is to ensure that at closure no removal of materials or remediation is expected within the drift in order to close. That is, the emplacement drifts are maintained in a ready to close condition at all times, except for installation of the drip shields.

Repository backfill is limited to openings that connect the emplacement areas to the surface, mainly the ramps and the shafts, and it is not required for performance of the engineered barriers (Table 1.9-8). The backfilling strategy requires interface with the subsurface ventilation system to regulate and adjust airflow, as needed, and to control dust. The ventilation system has the flexibility to support backfilling operations. Placement of backfill also requires interface with removal and transportation of noncommitted materials. Ducted ventilation systems and dust filters installed to support closure will be utilized to ventilate dead-end work spaces being backfilled and to limit migration of dust into the emplacement drifts.

Subsequent to backfilling of shafts, the surface-based ventilation equipment and ancillary facilities will be dismantled, and the shaft collars will be removed to allow surface restoration. The surface terrain will be restored to as close to natural conditions as practicable (BSC 2008b, Section 6.6).

Closure structures, systems, and components (SSCs) are classified as non-ITS. The drip shields are classified as important to waste isolation (ITWI) because of their role in protecting the waste package during postclosure from rockfall and water seepage into drifts (Table 1.9-8).

General Sequence of Closure Activities—Figure 1.3.6-1 presents a general flow diagram of the subsurface facility closure activities. Generally, closure activities in the repository that rely on the crane rail transportation system would begin in the emplacement areas farthest away from the North Portal. Closure activities would then work towards the North Portal, successively implementing the closure activities while allowing for fully functional transportation and ventilation systems to be available to the work areas until work is completed in a section of a given panel. Sections of invert, crane rail, and electrical equipment and cables will be removed in nonemplacement areas no longer needing rail transportation, such as in areas adjacent to emplacement drifts where all the drip shields have been installed. Removal of noncommitted materials will be done via the South and North Construction Portals using other means of transportation. The exhaust fans will continue normal operation throughout the closure period until the drip shields have been installed and the noncommitted materials have been removed at the repository level (BSC 2008b, Section 6). Operational procedures and controls for SSCs described in Sections 1.3.1 through 1.3.5 will govern closure operations as applicable to SSCs active during the closure phase.

Initiation of closure activities in emplacement drifts is preceded by inspection of the emplaced waste packages to ensure that no unacceptable damage has occurred to waste packages in areas where ground support may have failed and/or rockfall may have occurred (BSC 2008a, Table 1, Derived Internal Constraint 03-24). If damage to any waste package is found, it will be evaluated with respect to potential impact on postclosure performance, and mitigation measures such as waste package repair or repackaging of the waste will be implemented if necessary.

Installation of drip shields will proceed from one emplacement drift to the next within a panel. The direction of advance of drip shield emplacement in a given panel is a function of materials traffic coordination. During emplacement of the drip shields, noncommitted materials will be removed from the repository during the same period of time. Coordination of this work will be done to ensure safe operation of the repository while minimizing schedule impacts. The drip shield emplacement gantry uses the same crane rail as the transport and emplacement vehicle; therefore, the crane rail operational support systems would have to be kept fully functional along the transportation routes except in the sections of access mains and turnouts serving emplacement drifts with drip shields already in place.

Prior to removal of noncommitted materials, the respective areas and materials would be surveyed and sampled to determine the potential presence of radioactive contamination. If contamination is found, decontamination and dismantlement methods will be implemented for the safe handling and disposal of the contaminated materials.

Once the drip shields are installed in a contiguous group of emplacement drifts within a panel, removal of noncommitted materials in their respective turnouts and in the adjacent sections of access main can begin following standard construction demolition methods with the appropriate controls in place for dust suppression and for spread of contamination, as applicable. Some of these controls may include deployment of inflatable isolation barriers to minimize dust-laden airflow into the emplacement drifts adjacent to areas in the turnouts where demolition activities are taking place. Additional controls for worker radiological protection and safeguards and security will be provided with design documentation for the license amendment to close the repository.

After completion of drip shield installations and removal of noncommitted materials, the exhaust fans can be turned off and dismantled. Backfilling of the ramps and shafts can then be initiated. Backfill work fronts in the ramps and shafts will require local ventilation systems with dual ducting for air supply and air removal and dust control equipment. Backfill placement in shafts or ramps can be done sequentially or concurrently since the ramps and shafts are physically separated from each other and have no operational interfaces at this stage of closure. Backfill operations for each shaft or ramp would have their own access and support systems, including separate ventilation systems.

Once placement of backfill in the ramps and shafts is completed, surface restoration and installation of permanent repository monuments take place.

1.3.6.1.1 Final Inspection of Waste Packages

In conformance with the postclosure design bases for repository closure, the waste packages that have come in contact with fallen rock or ground support materials will be inspected prior to installation of the drip shields. Damage to the waste package corrosion barrier must be checked to ensure that scratches are less than 1.6 mm (1/16 in.) in depth and that deformations such as dents do not leave residual tensile stresses greater than 257 MPa (BSC 2008a, Table 1, Derived Internal Constraint 03-24).

The final inspection of the emplacement drifts ground support and waste packages will be performed with a remotely operated inspection gantry that uses the same rail, power feed, and communications systems as the drip shield emplacement gantry. The inspection gantry will also monitor the general condition of other emplacement drift components such as the waste package emplacement pallet and the condition of the crane rail in preparation for deployment of the drip shield emplacement gantry.

If a waste package is found to exceed the postclosure design bases damage limitations noted above, a remediation plan will be developed specific to the findings from the inspection. Such remediation may include removal of the damaged waste package for repair or replacement of the damaged corrosion barrier. Depending on the location of the damaged waste package in the drift, this operation may involve the temporary relocation of all the waste packages in front of the damaged waste package in the affected drift and placing the waste packages back in the drift at the conclusion of remediation and in conformance with the original in-drift loading plan (Section 1.3.1.2.5). Enough excess emplacement drift capacity will be available at closure for the relocation of the unaffected waste packages while remediation of the damaged waste package takes place.

1.3.6.1.2 Installation of Drip Shields

Equipment and methodology for installation of the drip shields are described in Section 1.3.4.7.2.

1.3.6.1.3 Removal of Noncommitted Materials from the Subsurface

Other than materials to be removed at closure, materials of potential concern to repository postclosure performance fall into two categories: (1) those materials that are brought into the repository environment as components of the engineered SSCs and that are proposed to become permanent fixtures of the repository, and (2) spurious materials and materials that unintentionally or inadvertently may get left behind after construction and operation activities but that are not a part of the engineered SSCs. The materials in the first category, such as most of the materials installed in the emplacement drifts and selected materials installed in nonemplacement openings, are designated as committed materials and are evaluated for their overall impact on long-term repository performance through performance assessment analyses. The types and quantities of these committed materials are controlled throughout the design, construction, and operational phases of the repository so that they are not exceeded beyond the limits analyzed in the performance assessment analyses (BSC 2008a, Table 1, Derived Internal Constraint 02-03). A preliminary inventory of these committed materials is presented in this section (Tables 1.3.6-1 and 1.3.6-2). The second category of materials designated as nondesign or undesirable committed materials originates mainly as residues from operation of construction or maintenance equipment and related activities, and they include such materials as organic residues from diesel equipment operations; maintenance materials such as lubricants, oils, cleaning solvents, anti-freeze liquids; organic residues from explosive materials; and dust control substances and additives. The nondesign committed material types and quantities are estimated and their potential impact to repository long-term performance is evaluated on an ongoing basis throughout repository lifetime, through the Site Performance Protection Evaluation Program to determine their status as committed or to be removed (FEP 1.1.02.03.0A) (Section 2.2, Table 2.2-1).

Materials and equipment not committed as permanent features of the repository will be removed from the nonemplacement areas of the subsurface at closure. In general, the items to be removed include:

- Mobile and fixed equipment
- Concrete inverts
- Electrical items, such as a third-rail conductor, cable, wire, conduit, cable tray, and electrical equipment
- Communication items, such as antennae, feeder cable, and fiber-optic cable
- Miscellaneous steel structures, turnout bulkheads, and emplacement access doors

- Ventilation equipment and structures
- Refuge chamber material
- Steel rails, switches, and other rail components.

Removal of the ventilation equipment and structures, in addition to the items installed underground, includes the surface-based components, such as the shaft collars, fans, ductwork, electrical equipment, and other appurtenances located around the shaft surface openings, to allow for shaft pads surface restoration.

Ground support materials in the turnouts, ramps, and access and exhaust mains will not be removed because of concerns for the safety of personnel who would be involved in that removal. Rock bolts and other temporary ground support installed during construction of the shafts will become committed materials because their removal would be impractical. The concrete and shotcrete shaft lining materials are all removed at closure. Removal of the cementitious-material liners and placement of backfill in the shafts are done sequentially in length increments from bottom to top. The backfill materials in the shafts and ramps also become committed materials. The concrete ground support in the shafts will be removed in short sections of shaft. The short sections will be backfilled and the process repeated until the backfill reaches the surface. Materials that will remain underground after closure of the repository will become committed materials. Preliminary estimates of committed materials in the emplacement and nonemplacement areas of the repository are listed in Tables 1.3.6-1 and 1.3.6-2. Quantities of committed materials at closure have been evaluated for their effect on postclosure performance in Chapter 2. The license amendment for closure of the repository will identify the maximum quantities of committed materials approved to be left within the repository.

Radiological controls will be required during some closure activities. Management practices for decontamination and dismantlement as discussed in Section 1.12 for surface facilities will also be applied as appropriate for the subsurface facility closure activities.

Decontamination and dismantlement activities for readiness of the subsurface facility for closure will parallel similar activities described in Section 1.12 for the surface facilities. However, the levels of contamination for the subsurface facility at closure are expected to be minimal. These activities that will be performed either throughout repository lifetime or in advance of decontamination and dismantlement activities will include, generally:

- Implementation of as low as is reasonably achievable principles for worker protection
- Characterization of potentially contaminated areas
- Development of plans and designs for contamination removal
- Development of mitigation measures to prevent or minimize the spread of contamination

- Development of plans and designs for removal and disposal of noncommitted materials
- Implementation of waste management practices in conformance with project requirements.

Specific equipment, methods, and designs to be utilized for decontamination and dismantlement activities in the subsurface facility will be identified in the license amendment application for closure of the repository.

A radiation health and safety program to be implemented during closure of the subsurface facility will be consistent with the components of the program for the surface facilities as described in Section 1.12.3.9.

Removal of noncommitted materials in the turnouts includes invert steel, rail, turnout bulkhead, emplacement access doors, air regulator, electrical equipment and cables, and instrumentation. These demolition and removal activities will occur in close proximity to the emplacement drifts and will require additional radiological worker protection measures, possibly including some temporary shielding. Other closure activities described in this section occur in repository locations distant from the emplacement drifts and will not require additional radiological worker protection measures.

1.3.6.1.4 Placement of Backfill

Backfill material for the ramps and shafts will meet material and placement specifications to be provided prior to initiation of closure operations.

Backfilling operations will consist of a surface preparation plant, a stockpile/loading component, and a conveyance system to the area being backfilled. Crushed tuff from the repository excavation will be reclaimed from the muck stockpiles and processed to the specifications for backfill material and placement to be developed during preparation of the license amendment to close the repository. It is anticipated that the preparation plant will include a crusher, a screen plant to provide graded fill, and a stacker. Screen analyses of previously excavated materials at Yucca Mountain show that the tunnel boring machine muck is fairly well graded, but crushing will be required for larger flat rock pieces typically produced by the tunnel boring machine's disc cutters. Crushing and screening of the muck to produce the desired gradation range will provide an optimal engineered backfill (BSC 2008b, Section 6.3).

Backfill materials for the ramps and shafts may require additional treatment to achieve the desired hydraulic conductivity properties of the backfill in certain areas. Some of this additional treatment may include mixtures of bentonite, sand, and other crushed materials (BSC 2008b, Section 6.4).

1.3.6.1.4.1 Placement of Backfill in Ramps

Backfill in the ramps provides long-term stability of the openings and prevents human intrusion into the waste emplacement areas.

Figure 1.3.6-2 shows a conceptual representation of the backfilling operations in the ramps.

Placement of the backfill in the ramps can be accomplished by pneumatic stowing as shown in Figure 1.3.6-2, by simple hydraulic push plates, or using an archimedean screw type of device. The backfill emplacement machine will be self-propelled and will have a roof shield for personnel protection when steel sets are being removed. To operate efficiently, the backfill emplacement machine will have the capabilities to be conveyor-fed and to place and compact the backfill over the entire tunnel cross section (BSC 2008b, Section 6.3). Backfilling of the ramps will require a ducted ventilation system to provide fresh air and to remove exhaust air.

The total volume of backfill material for the ramps has been estimated as 472,887 yd^3 (BSC 2008b, Table 2).

1.3.6.1.4.2 Placement of Backfill in Shafts

Backfill in the shafts provides long-term stability of the openings and prevents human intrusion into the waste emplacement areas.

The shafts will be backfilled starting from the bottom and progressing to the top. A section of the shaft concrete liner will be removed and that section backfilled. Concrete removal and backfilling continue until the shaft is filled (BSC 2008b, Section 6.4).

Figure 1.3.6-3 illustrates the typical conceptual design of equipment that will be used for backfilling of shafts.

Gravity will facilitate the conveyance of the backfill material to the shaft bottom by use of a "slick line." Figure 1.3.6-3 shows a typical shaft galloway setup common to the mining industry. After the concrete liner and shaft furnishings are removed from a section of shaft, backfill will be delivered to the shaft bottom, leveled, and compacted. The material leveling and compacting can be accomplished by typical construction equipment hoisted in and out of the shaft or mounted on the galloway (BSC 2008b, Section 6.4).

The total volume of backfill material for the shafts has been estimated as 176,748 yd^3 (BSC 2008b, Table 2).

1.3.6.1.5 Regrading and Site Restoration

As stated in *Final Environmental Impact Statement for a Geologic Repository for the Disposal of Spent Nuclear Fuel and High-Level Radioactive Waste at Yucca Mountain, Nye County, Nevada* (DOE 2002, Section 2.1.2.4), the repository site reclamation includes restoring the site to as near its preconstruction condition as practicable, including the recontouring of disturbed surface areas, surface backfill, soil buildup and reconditioning, site revegetation, site water course configuration, and erosion control, as appropriate.

Subsequent to site restoration, several items are listed in 10 CFR 63.51 as further requirements to permanently close the repository. These include:

- Preservation of records (Section 5.2)
- Installation of monuments (Section 5.8)
- Continued oversight of the repository (Section 5.8).

1.3.6.2 Operational Processes

Operational interfaces are described in Section 1.3.1.3. Operational processes for closure activities will be developed and implemented in accordance with Section 5.6.

Operational processes for drip shield emplacement gantry operations are described in Section 1.3.4.7.2.

The removal of noncommitted materials from the subsurface facility is described in Section 1.3.6.1.3, and the general practices for implementing decontamination and dismantlement of the subsurface facility will be similar to those practices described in Section 1.12 for the surface facilities.

The placement of backfill in ramps and shafts is discussed in Sections 1.3.6.1.4.1 and 1.3.6.1.4.2, respectively.

Regrading and site restoration are described in Section 1.3.6.1.5.

1.3.6.3 Safety Category Classification

Repository backfill and the drip shield emplacement gantry are not important to safety (ITS) since they are not relied upon to prevent or mitigate any Category 1 or 2 event sequences. The drip shield is classified as ITWI (Table 1.9-8) because it prevents water contact with the waste packages and protects waste packages from rockfall damage.

1.3.6.4 Procedural Safety Controls to Prevent Event Sequences or Mitigate Their Effects

There are no procedural safety controls that are directly applicable to closure activities. Table 1.3.6-3 provides information on controls that will be put in place during closure activities to ensure conformance of these activities with postclosure nuclear safety design bases.

1.3.6.5 Design Criteria and Design Bases

Subsurface facility closure SSCs are non-ITS because none of the closure activities can cause a Category 1 or 2 event sequence. Section 1.3.2.4 describes the design criteria applicable to the closure activities.

1.3.6.6 Design Methodologies

Section 1.3.2.5 provides the design methodologies applicable to the closure activities.

1.3.6.7 Consistency of Materials with Design Methodologies

The materials used in the closure activities are consistent with the design criteria and methodologies discussed in Section 1.3.2.

1.3.6.8 Design Codes and Standards
[NUREG-1804, Section 2.1.1.2.3: AC 3(1)]

Codes or standards specifically related to design of closure SSCs will be identified when the designs are finalized and submitted with the license amendment application for closure of the repository. Specific criteria related to civil structures, materials, and geotechnical engineering will be used, as appropriate.

1.3.6.9 Design Load Combinations

Section 1.3.2.8 discusses applicable structural load combinations for subsurface closure SSCs.

1.3.6.10 Conformance of Design to Criteria and Bases
[NUREG-1804, Section 2.1.1.7.3.2: AC 1(1)]

The subsurface facility closure SSCs are classified as non-ITS; therefore, there are no preclosure nuclear safety design bases to be satisfied by this system or process.

There are several derived internal constraints from postclosure nuclear safety design basis considerations that relate to the design of the subsurface facility closure SSCs and activities because of the role they play in the repository meeting postclosure conditions consistent with the analyzed total system performance. Table 1.3.6-3 presents the derived internal constraints from postclosure nuclear safety design basis considerations that relate to the subsurface facility closure SSCs and activities, related design criteria considerations, and the types of controls that will be put in place to ensure conformance with postclosure control parameter values and derived internal constraints.

1.3.6.11 General References

BSC (Bechtel SAIC Company) 2008a. *Postclosure Modeling and Analyses Design Parameters*. TDR-MGR-MD-000037 REV 02. Las Vegas, Nevada: Bechtel SAIC Company. ACC: ENG.20080108.0002.

BSC 2008b. *Closure Design Calculation*. 800-KMC-MGR0-00200-000-00E. Las Vegas, Nevada: Bechtel SAIC Company. ACC: ENG.20080808.0002.

DOE (U.S. Department of Energy) 2002. *Final Environmental Impact Statement for a Geologic Repository for the Disposal of Spent Nuclear Fuel and High-Level Radioactive Waste at Yucca Mountain, Nye County, Nevada*. DOE/EIS-0250. Washington, D.C.: U.S. Department of Energy, Office of Civilian Radioactive Waste Management. ACC: MOL.20020524.0314 through MOL.20020524.0320.

YMP (Yucca Mountain Site Characterization Project) 2001. *Reclamation Implementation Plan*. YMP/91-14, Rev. 2. Las Vegas, Nevada: Yucca Mountain Site Characterization Office. ACC: MOL.20010301.0238.

Table 1.3.6-1. Repository Committed Materials in Emplacement Drifts—Summary of Preliminary Estimates

Feature	Material	Estimated Unit Quantity	Estimated Total Quantity	Comment
Initial Ground Support—Rock Bolts	Carbon steel split set rock bolts with plates	9.1 kg/m	615,763 kg	—
Initial Ground Support—Welded Wire Mesh	Carbon steel	9 kg/m	0	Carbon steel welded wire mesh will be removed to allow installation of perforated steel sheets.
Final Ground Support—Rock Bolts	Stainless steel friction-type rock bolts with plates	98 kg/m	6,653,458 kg	—
Final Ground Support—Perforated Sheets (Bernold Type)	Stainless steel	374.4 kg/m	25,428,157 kg	—
Invert Steel Structure, Runway Beams, and Crane Rail but Excluding Anchor Rock Bolts	Carbon steel	671 lb/ft	149,511,040 lb	Based on total length of emplacement drifts (67,915 m)
Invert Steel Structure Anchor Rock Bolts	Stainless steel	9 lb/ft	2,005,364 lb	Based on total length of emplacement drifts (67,915 m)
Invert Third Rail and Supports	Copper and stainless steel	Copper: Less than 5 kg/m Stainless steel: see comment	Less than 339,575 kg See comment	Material types and quantities selected through design will be compatible with TSPA committed materials approval process.[a]
Invert Third Rail Insulator	See comment	See comment	See comment	Material types and quantities selected through design will be compatible with TSPA committed materials approval process.[a]
Invert Ballast	Crushed tuff	46 ft^3/ft	10,249,639 ft^3	Based on total length of emplacement drifts (67,915 m)
Waste Package Emplacement Pallet—Standard	Stainless steel	724.0 kg ea.	7,189,320 kg	Based on 9,930 standard pallets
Waste Package Emplacement Pallet—Standard	Alloy 22 (UNS N06022)	1,290.0 kg ea.	12,809,700 kg	Based on 9,930 standard pallets
Waste Package Emplacement Pallet—Short	Stainless steel	432.0 kg ea.	495,504 kg	Based on 1,147 short pallets
Waste Package Emplacement Pallet—Short	Alloy 22	1,290.0 kg ea.	1,479,630 kg	Based on 1,147 short pallets

Table 1.3.6-1. Repository Committed Materials in Emplacement Drifts—Summary of Preliminary Estimates (Continued)

Feature	Material	Estimated Unit Quantity	Estimated Total Quantity	Comment
Waste Package Emplacement Pallet—Standard and Short	Weld metal	See comment.	See comment.	Weld metal quantities are included in quantities calculated for individual metals.
Drip Shield—Plates and Connector Guides	Titanium Grade 7 (UNS R52400)	3,646.0 kg ea.	41,677,426 kg	Number of drip shields is based on the estimated number of waste packages of the different types, multiplied by their average lengths (9,930 × 5.716 m + 1,147 × 3.697 = 61,000.34 m), a 10-cm spacing between waste packages, and the net length of the drip shield considering the maximum interlocking overlap distance (5.805 – 0.320 = 5.485 m). A total number of drip shields is obtained as [61,000.34 + (9,930 + 1,147) × 0.1] / 5.485 = 11,323. An allowance of an extra drip shield per emplacement drift is added for a grand total of (11,323 + 108) = 11,431. Weld metal quantities for the drip shields are included in quantities calculated for individual metals.
Drip Shield—Structural Members	Titanium Grade 29 (UNS R56404)	1,142.0 kg ea.	13,054,202 kg	
Drip Shield	Weld metal	See comment.	See comment.	
Drip Shield—Base	Alloy 22	109.0 kg ea.	1,245,979 kg	

NOTE: [a]Materials selection and quantities shall conform with postclosure constraint 02-03 in Table 1.3.6-3.
TSPA = total system performance assessment.

Table 1.3.6-2. Repository Committed Materials in Nonemplacement Openings—Summary of Preliminary Estimates

	Feature	Material	Estimated Unit Quantity	Estimated Total Quantity	Comment
Portals	NA	—	—	—	—
Ramps	Ground Support—Rock Bolts	Grouted carbon steel rock bolts with plates	Varies	1,073,862 kg	—
	Ground Support—Welded Wire Mesh	Carbon steel	Varies	306,538 kg	—
	Ground Support—Cement Products	Cement grout	Varies	308,575 kg	—
	Ground Support—Cement Products	Shotcrete	Varies	21,342,124 kg	—
Access and Exhaust Mains	Ground Support—Rock Bolts	Grouted carbon steel rock bolts with plates	Varies	2,489,884 kg	—
	Ground Support—Rock Bolts	Carbon steel split sets with plates	Varies	143,181 kg	—
	Ground Support—Welded Wire Mesh	Carbon steel	Varies	1,130,986 kg	—
	Ground Support—Cement Products	Cement grout	Varies	684,582 kg	—
	Ground Support—Cement Products	Shotcrete	0	0	—
Access Main—Turnout Intersections	Final Ground Support—Rock Bolts	Grouted carbon steel rock bolts with plates	350.42 kg/m	1,362,491 kg	—
	Lattice Girder	Carbon steel	230 kg/m	894,046 kg	—
	Final Ground Support—Concrete and Shotcrete	Cement grout	Varies	419,765 kg	—
	Final Ground Support—Cement Products	Shotcrete	Varies	26,591,140 kg	—

Table 1.3.6-2. Repository Committed Materials in Nonemplacement Openings—Summary of Preliminary Estimates (Continued)

	Feature	Material	Estimated Unit Quantity	Estimated Total Quantity	Comment
Turnouts	Initial Ground Support—Rock Bolts	Carbon steel split sets with plates	Varies	67,981 kg	—
	Final Ground Support—Rock Bolts	Grouted carbon steel rock bolts with plates	Varies	180,431 kg	—
	Final Ground Support—Welded Wire Mesh	Carbon steel welded wire mesh	5.31 kg/m^2	79,228 kg	—
	Final Ground Support—Cement Products	Cement grout	Varies	82,681 kg	—
	Final Ground Support—Rock Bolts	Stainless steel friction-type rock bolts with plates	98 kg/m	607,594 kg	—
	Final Ground Support —Welded Wire Mesh	Stainless steel	5.41 kg/m^2	386,163 kg	—
Exhaust Main—Emplace ment Drift Intersections	Final Ground Support—Rock Bolts	Grouted carbon steel rock bolts with plates	223 to 270.8 kg/m	394,478 kg	—
	Final Ground Support —Cement Products	Cement grout	Varies	121,533 kg	—
	Final Ground Support—Cement Products	Shotcrete	Varies	5,645,407 kg	—
Shaft and Raise Access Drifts	Ground Support—Rock Bolts	Grouted carbon steel rock bolts with plates	Varies	589,826 kg	—
	Ground Support—Rock Bolts	Carbon steel split sets with plates	Varies	12,548 kg	—
	Ground Support—Welded Wire Mesh	Carbon steel	Varies	267,363 kg	—
	Ground Support—Cement Products	Cement grout	Varies	162,170 kg	—
	Ground Support—Cement Products	Shotcrete	0	0	—
Shaft and Raises	Ground Support—Rock Bolts	Carbon steel split sets with plates	Varies	97,412 kg	—

Table 1.3.6-2. Repository Committed Materials in Nonemplacement Openings—Summary of Preliminary Estimates (Continued)

	Feature	Material	Estimated Unit Quantity	Estimated Total Quantity	Comment
Observation Drift, Alcoves, and Miscellaneous Openings	Ground Support—Rock Bolts	Grouted carbon steel rock bolts with plates	Varies	153,786 kg	—
	Ground Support—Welded Wire Mesh	Carbon steel	Varies	69,164 kg	—
	Ground Support—Cement Products	Cement grout	Varies	42,283 kg	—

NOTE: NA = not applicable.

Table 1.3.6-3. Summary of Conformance of Subsurface Facility Design to Postclosure Control Parameters—Repository Closure

Structure, System and Component	**Postclosure Control Parameter**		**Relevant to ITWI**	**Design Criteria/Configuration**	**Postclosure Procedural Safety Control**
	Parameter Number and Title	**Values, Ranges of Values or Constraints**			
Subsurface Facility - Closure	02-03 Committed Materials	During construction of the emplacement drifts, and operation and closure of the repository, administrative controls will be imposed to prevent impact on waste isolation from materials used, lost, or left in the repository. These controls will be supported by technical evaluation. The following constraints will be imposed on the administrative control of tracers, fluids, and materials; construction materials; and committed materials: a) Material not technically evaluated and determined acceptable prior to the permanent closure of the repository will be removed from subsurface facilities prior to permanent closure. b) Committed materials that are proposed to remain in the underground repository following permanent closure will be technically evaluated and determined acceptable prior to use. c) Administrative controls will include accounting and inspection, as appropriate to confirm that controls on the approved tracers, fluids, and material quantities and compositions are met. d) Controls related to dust generation are addressed in Table 1.3.5-4. e) Tracers, fluids, and materials that may be used during construction, operation, or closure shall be controlled.	No	Part (a)—The design includes estimates of the materials used in the emplacement drifts and nonemplacement openings. These materials are included as committed materials, as listed in Tables 1.3.6-1 and 1.3.6-2.	Parts (b), (c), and (e)—Procedures will be developed to control and evaluate materials not already controlled by the design that are used in the subsurface facility during the preclosure period.

Table 1.3.6-3. Summary of Conformance of Subsurface Facility Design to Postclosure Control Parameters—Repository Closure (Continued)

Structure, System and Component	Postclosure Control Parameter: Parameter Number and Title	Postclosure Control Parameter: Values, Ranges of Values or Constraints	Relevant to ITWI	Design Criteria/Configuration	Postclosure Procedural Safety Control
Waste Package – Final Inspection	03-24 Waste Package Surface Damage Prior to Closure	The emplacement drift ground support system shall be inspected prior to drip shield installation. Waste packages that have come in contact with fallen rock or ground support materials will be inspected to ensure the damage to the waste package corrosion barrier that displaces material (i.e., scratches) shall be limited to 1/16 in. (1.6 mm) in depth. Modifications to the waste package corrosion barrier that deform the surface, but do not remove material (i.e., dents), shall not leave residual tensile stresses greater than 257 MPa.	Yes	NA (Background information: Design criteria applicable to inspection of ground support in emplacement drifts are included in Sections 1.3.4.4.1 and 1.3.4.4.2. Design considerations for final inspection of waste packages at closure, prior to drip shield installation, are included in Section 1.3.4.7.2. Design criteria relevant to safeguarding the waste package corrosion barrier and applicable to closure activities (final inspection) are related to the removal, remediation, and re-emplacement of damaged waste packages as stated in Sections 1.3.2.3 and 1.3.4.8.)	Procedures will be developed that will control the final inspection, prior to placement of drip shields, of the emplacement drift ground support and waste packages. The inspection will be performed with a remotely operated inspection gantry from the CCCF to inspect for the limitations imposed by the subject constraint. Repairs, if needed will be controlled by procedures per the limitations of the subject constraint.
Emplacement Drifts	05-04 No Backfill in Emplacement Drifts	Engineered backfill shall not be present in the space between the drip shield and the drift wall.	No	No design requirements incorporate placement of backfill in the emplacement drifts (i.e., not included in the repository closure design).	NA

Table 1.3.6-3. Summary of Conformance of Subsurface Facility Design to Postclosure Control Parameters—Repository Closure (Continued)

Structure, System and Component	Postclosure Control Parameter		Relevant to ITWI	Design Criteria/Configuration	Postclosure Procedural Safety Control
	Parameter Number and Title	Values, Ranges of Values or Constraints			
Drip Shield – Installation Inspection	07-02 Drip Shield Design and Installation	(a) The drip shield shall be designed to interlock and overlap in a manner that prevents a liquid drip path from above the drip shield to the waste package. (b) The drip shield handling and emplacement activities shall be monitored through appropriate equipment. An operator and an independent inspector shall verify proper drip shield installation. Records demonstrating compliance shall be maintained.	Yes	(a) The design of the drip shield interlocking features and the assembly are provided in Figures 1.3.4-14 and 1.3.4-15. The ability of the interlock feature that describes the capability to prevent a liquid path from above the drip shield to the waste package is described in Section 1.3.4.7.1. (Background: Part (b) Drip shield handling and emplacement activities are described in Section 1.3.4.7.2.)	Part (b) Procedures will be developed that will control drip shield handling and emplacement activities. The placement of drip shields will be controlled remotely from the CCCF, using the drip shield emplacement gantry, and will be verified and documented by two independent operators.
Subsurface Facility - Closure	09-01 Closure of Shafts and Ramps	Closure of the shafts shall include backfilling for the entire depth of the opening. Closure of ramps shall include backfilling along the entire length of the opening.	No	Design criteria for this activity are defined in Section 1.3.6.1.4. Backfill methods for ramps and shafts are illustrated in Figures 1.3.6-2 and 1.3.6-3, respectively. The extent of the backfill used in both the shafts and ramps will preclude human or animal access to the waste because it would entail a substantial effort to remove or bypass this material over the entire length of the opening.	NA

Table 1.3.6-3. Summary of Conformance of Subsurface Facility Design to Postclosure Control Parameters—Repository Closure (Continued)

Structure, System and Component	Postclosure Control Parameter		Relevant to ITWI	Design Criteria/Configuration	Postclosure Procedural Safety Control
	Parameter Number and Title	Values, Ranges of Values or Constraints			
Subsurface Facility - Closure	09-03 Closure of Boreholes	Site investigation boreholes within or near the footprint of the repository block will be backfilled with material compatible with the host rock and plugged.	No	NA (Background information: Closure of boreholes will be performed with material compatible with the host rock. DOE will determine at the time of borehole closure if regulations apply to borehole closure. Timing of closure of boreholes will be determined on a case-by-case basis because some boreholes will continue to be used during the emplacement and postemplacement phases (i.e., seismic instrumentation boreholes). Where applicable, some boreholes will be closed and plugged prior to excavation of the emplacement drifts to minimize impacts on the excavation. If this timing is not possible for some boreholes, closure may be postponed until after excavation or even until closure of the repository.)	Procedures will be developed for the purpose of controlling the closure of boreholes and for tracking closure activities. These procedures will require that site investigation boreholes within or near the footprint of the repository block will be backfilled with material compatible with the host rock and plugged.

Table 1.3.6-3. Summary of Conformance of Subsurface Facility Design to Postclosure Control Parameters—Repository Closure (Continued)

Structure, System and Component	Postclosure Control Parameter		Relevant to ITWI	Design Criteria/Configuration	Postclosure Procedural Safety Control
	Parameter Number and Title	Values, Ranges of Values or Constraints			
Subsurface Facility - Closure	09-04 Reclamation of Lands Disturbed by Repository	Lands disturbed by the repository shall be reclaimed to ensure that there are no preclosure disturbances that will impact postclosure performance.	Yes	NA (Background information: Lands disturbed by the repository will be reclaimed following the *Reclamation Implementation Plan* (YMP 2001, Section 1) as established in *Final Environmental Impact Statement for a Geologic Repository for the Disposal of Spent Nuclear Fuel and High-Level Radioactive Waste at Yucca Mountain, Nye County, Nevada* (DOE 2002, Sections 2.1.2.4, 4.1.3.2, 4.1.3.3, and 4.1.4.4).)	Design will be developed that will ensure that no postclosure performance impacts caused by the preclosure operations remain prior to closure of the repository. Procedures for the repository surface restoration will be developed in support of a license amendment to close the repository, and they will conform to applicable design criteria at the time of closure, and to the bounding conditions for land restoration established through the *Final Environmental Impact Statement for a Geologic Repository for the Disposal of Spent Nuclear Fuel and High-Level Radioactive Waste at Yucca Mountain, Nye County, Nevada* (DOE 2002).

NOTE: See Table 1.9-9 for additional information on postclosure analyses control parameters.
CCCF = Central Control Center Facility; DOE = U.S. Department of Energy; NA = not applicable.

Source: BSC 2008a,Table 1.

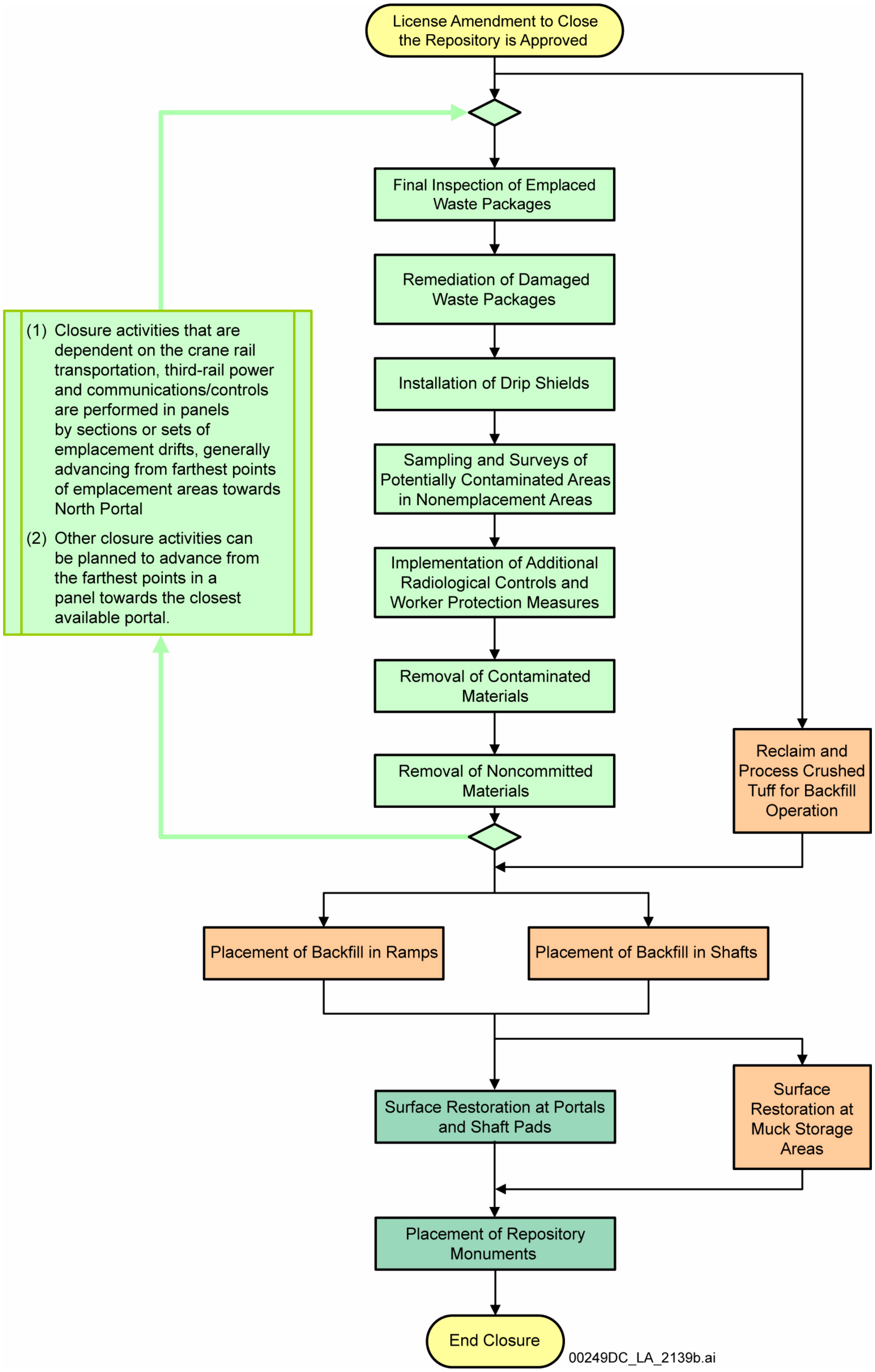

Figure 1.3.6-1. General Sequence of Repository Closure Activities

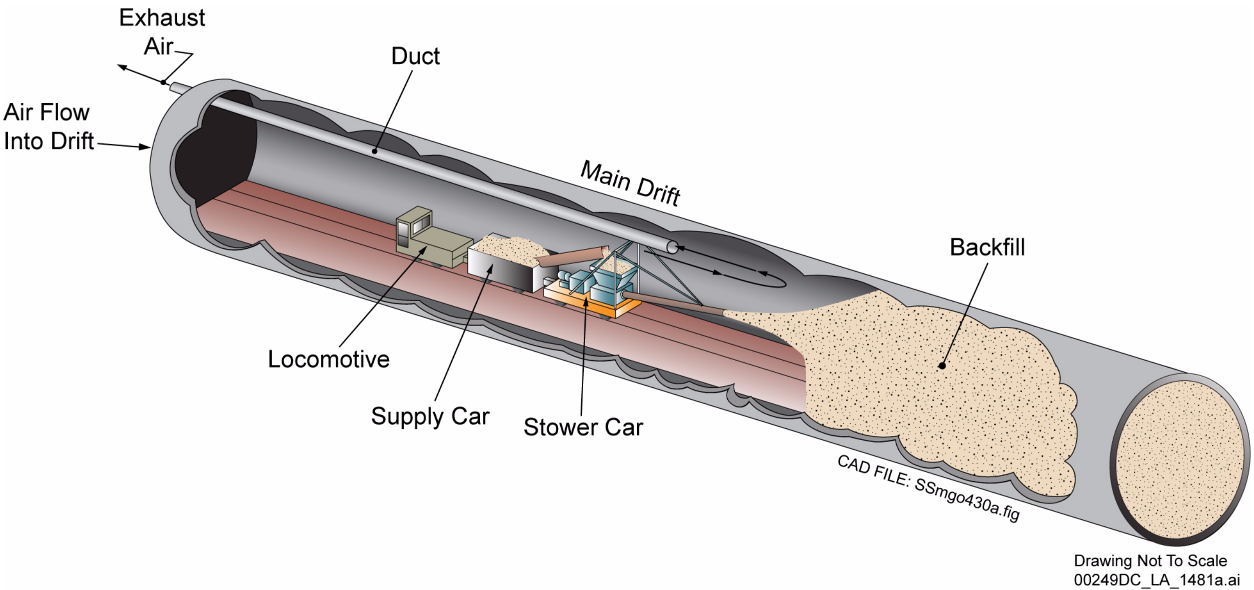

Figure 1.3.6-2. Conceptual Arrangement for Placement of Backfill in Ramps

NOTE: Repository closure activities include backfilling of the ramps with granular material. This figure portrays a conceptual approach by which such operation can be accomplished.

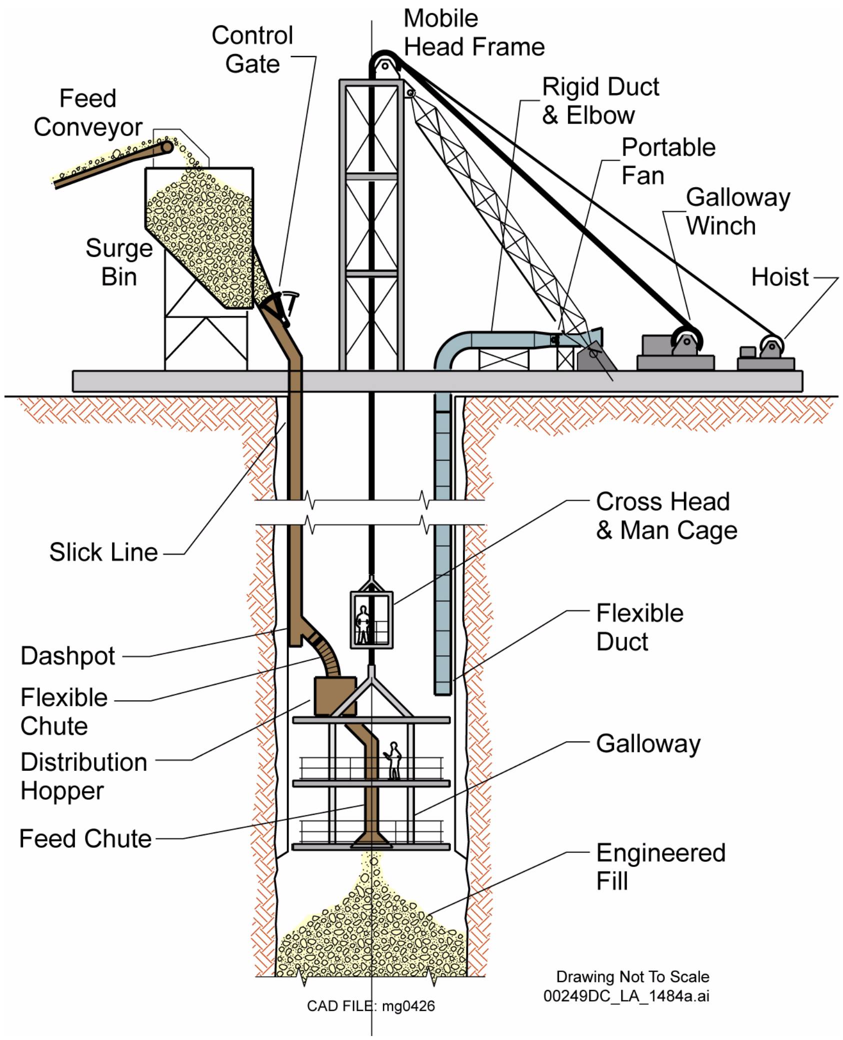

Figure 1.3.6-3. Conceptual Arrangement for Placement of Backfill in Shafts

NOTE: Intake and exhaust shafts will be backfilled with granular material as part of the repository closure activities.

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