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1.3 SUBSURFACE STRUCTURES, SYSTEMS, AND COMPONENTS AND OPERATIONAL PROCESS ACTIVITIES

This section discusses subsurface structures, systems, and components and operational activities. Topics discussed include a subsurface operations overview, general subsurface design considerations, nonemplacement areas of the subsurface facility, emplacement areas of the subsurface facility, subsurface facility ventilation, and subsurface facility closure.

This section presents the details of how structures, systems, and components built into the facility and operated within the facility perform their functions in conformance with a prescribed safety strategy. Safety considerations that are addressed in this section are:

- Providing configuration and location of emplacement drifts that support repository postclosure performance
- Creating a suitable underground environment for the engineered barriers and their preclosure and postclosure performance
- Providing the infrastructure and support systems for safe operation of the waste package transportation and emplacement equipment
- Maintaining facility readiness for a safe waste package retrieval operation, should that action be undertaken
- Safely closing the repository.

The information presented in this section addresses the requirements of 10 CFR 63.21(c) by providing a general description of the structures, systems, and components and the operational activities of the geologic repository operations area. The information presented in this section also addresses requirements for description of the repository safety analysis, as stated in 10 CFR 63.112; requirements for design to support performance confirmation activities, as stated in 10 CFR 63.111(d); and, requirements for repository performance objectives after closure as stated in 10 CFR 63.113.

This section also provides information that addresses specific acceptance criteria in Sections 2.1.1.2 (Description of Structures, Systems, Components, Equipment, and Operational Process Activities), 2.1.1.6 (Identification of Structures, Systems, and Components Important to Safety, Safety Controls, and Measures to Ensure Availability of the Safety Systems), and 2.1.1.7 (Design of Structures, Systems, and Components Important to Safety and Safety Controls) of NUREG-1804. The following table lists each subsection of this section and the corresponding regulatory requirements and acceptance criteria from NUREG-1804 that are addressed in that subsection.

SAR Section	Information Category	10 CFR Part 63 Reference	NUREG-1804 Reference
1.3.1	Subsurface Operations Overview	63.21(c)(2) 63.21(c)(3) 63.112(a)	Section 2.1.1.2.3: Acceptance Criterion 3 Acceptance Criterion 6 Section 2.1.1.7.3.1: Acceptance Criterion 1 Section 2.1.1.7.3.2: Acceptance Criterion 1 Section 2.1.1.7.3.3(II) Acceptance Criterion 2 Acceptance Criterion 4
1.3.2	General Subsurface Design Considerations	63.21(c)(2) 63.21(c)(3) 63.112(a) 63.112(e) 63.112(f)(2)	Section 2.1.1.2.3: Acceptance Criterion 3 Section 2.1.1.6.3: Acceptance Criterion 1 Section 2.1.1.7.3.1: Acceptance Criterion 1 Section 2.1.1.7.3.2: Acceptance Criterion 1 Section 2.1.1.7.3.3(II): Acceptance Criterion 1 Acceptance Criterion 2 Acceptance Criterion 3 Acceptance Criterion 4
1.3.3	Nonemplacement Areas of the Subsurface Facility	63.21(c)(2) 63.21(c)(3) 63.111(d) 63.112(a) 63.112(e) 63.112(f)(2)	Section 2.1.1.2.3: Acceptance Criterion 3 Acceptance Criterion 5 Acceptance Criterion 6 Section 2.1.1.6.3: Acceptance Criterion 1 Acceptance Criterion 2 Section 2.1.1.7.3.1: Acceptance Criterion 1 Section 2.1.1.7.3.2: Acceptance Criterion 1 Section 2.1.1.7.3.3(II): Acceptance Criterion 1 Acceptance Criterion 2 Acceptance Criterion 3 Acceptance Criterion 4 Acceptance Criterion 5 Acceptance Criterion 6 Acceptance Criterion 8 Acceptance Criterion 9

SAR Section	Information Category	10 CFR Part 63 Reference	NUREG-1804 Reference
1.3.4	Emplacement Areas of the Subsurface Facility	63.21(c)(2) 63.21(c)(3) 63.111(d) 63.112(a) 63.112(e) 63.112(f)(2) 63.113(b) 63.113(c)	Section 2.1.1.2.3: Acceptance Criterion 3 Acceptance Criterion 5 Acceptance Criterion 6 Section 2.1.1.6.3: Acceptance Criterion 1 Acceptance Criterion 2 Section 2.1.1.7.3.1: Acceptance Criterion 1 Section 2.1.1.7.3.2: Acceptance Criterion 1 Section 2.1.1.7.3.3(II): Acceptance Criterion 1 Acceptance Criterion 2 Acceptance Criterion 3 Acceptance Criterion 5 Acceptance Criterion 6 Acceptance Criterion 9 Section 2.1.1.7.3.3(III): Acceptance Criterion 1
1.3.5	Subsurface Facility Ventilation	63.21(c)(2) 63.21(c)(3) 63.112(a)	Section 2.1.1.2.3: Acceptance Criterion 3 Acceptance Criterion 6 Section 2.1.1.7.3.1: Acceptance Criterion 1 Section 2.1.1.7.3.2: Acceptance Criterion 1 Section 2.1.1.7.3.3 (II) Acceptance Criterion 2 Acceptance Criterion 3 Acceptance Criterion 7
1.3.6	Subsurface Facility Closure	63.21(c)(2) 63.21(c)(3) 63.112(a)	Section 2.1.1.2.3: Acceptance Criterion 3 Acceptance Criterion 6 Section 2.1.1.7.3.2: Acceptance Criterion 1 Section 2.1.1.7.3.3(III): Acceptance Criterion 1

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1.3.1 Subsurface Operations Overview
[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 4]

This section provides an overview of the subsurface facility portion of the repository. It describes the major subsurface structures, systems, and components (SSCs) and equipment and the activities associated with transporting the loaded and sealed waste packages from the handling facilities on the surface to the designated disposal location in an emplacement drift. This description includes the physical movement of the loaded waste package using the waste package transport and emplacement vehicle (TEV).

The detailed discussions of subsurface operations and closure are contained in Sections 1.3.3 to 1.3.6. The design of the subsurface facility SSCs conforms to the requirements, criteria, and considerations described in Section 1.3.2. Section 1.3.3 describes the subsurface facility SSCs that are located in the nonemplacement areas of the facility or that operate in those areas. Section 1.3.4 describes the emplacement areas of the subsurface facility and the SSCs that are located or that operate within those areas. Section 1.3.5 describes the subsurface facility ventilation system, and its SSCs and their operation, with an emphasis on system operations in the emplacement areas of the facility. Section 1.3.6 describes the SSCs that are part of closure of the repository and their operations during closure.

Operations in the subsurface facility are preceded by a period of initial construction defined by the period of time between receipt of construction authorization to the time of first waste emplacement. The period of operations for the subsurface facility starts with the first waste emplacement and has been determined to be nominally 100 years. This period of time, also referred to as the preclosure period for the repository, accommodates the durations for the following operational phases:

- Repository development concurrent with waste emplacement: 24 years
- Waste package emplacement: up to 50 years (concurrent with development for 24 years)
- Waste package ventilation: up to 100 years following emplacement of the first waste package and a minimum of 50 years after last emplacement
- Waste package retrieval: can be initiated anytime during the preclosure period, and the retrieval operation will be of reasonable duration
- Postemplacement monitoring: continuous from first emplacement until a license amendment to close the repository is issued.

1.3.1.1 Major Subsurface Facility Structures and Equipment
[NUREG-1804, Section 2.1.1.2.3: AC 3(1)]

The subsurface facility consists of nonemplacement areas as described in Section 1.3.3, and of emplacement areas, as described in Section 1.3.4. The emplacement areas include four distinct emplacement panels containing the emplacement drifts. The emplacement drifts and panels will be developed over a period of several years, with waste emplacement operations occurring concurrently with repository development. Development activities for the initial emplacement areas, designated as part of the initial operating capability for the repository, include development and commissioning of the first three emplacement drifts in Panel 1 and the systems and ancillary nonemplacement excavations required to support the initial emplacement operations. The subsurface facility scope of work for the development of the initial operating capability is summarized in Section 1.3.1.2.7.3.

The emplacement panels of the subsurface facility are located in the Topopah Spring Tuff, a thick layer of rock at the bottom of the Paintbrush Group. The emplacement drifts of the repository are located more than 200 m below the surface and more than 180 m above the present-day saturated zone beneath Yucca Mountain (BSC 2007a, Section 7.6). The lowest point of the repository layout is approximately at elevation 1,022 m and corresponds to the bottom of the Exhaust Shaft #3N in the northern part of the layout (BSC 2003, Table 7; BSC 2007a, Table 8). This lowest repository elevation is approximately 172 m above the postulated highest present-day water table elevation in the repository area. The lowest emplacement drift invert is approximately at elevation 1,037 m (Emplacement Drift #3-1W), which is approximately 187 m above the postulated highest present-day water table elevation in the repository area (BSC 2007a, Table 14). Figure 1.3.1-1 provides a plan view of the subsurface facility. Information on surface topography, geology, stratigraphy of the rock formations, and site characterization information for the repository is described in Section 1.1. Hydrogeologic, thermal, and mechanical properties of the rock formations are also presented in GI Section 5 and in Sections 1.1, 2.1, and 2.3. The subsurface facility consists of the emplacement drifts, turnouts, North Ramp, access mains, exhaust mains, performance confirmation observation areas, and ventilation system intake and exhaust shafts. Also shown are the South Ramp and North Construction Ramp that are used for the phased construction of the emplacement drifts, while loaded waste packages are transported down the North Ramp to disposal locations in completed emplacement drifts. All three portals and ramps are used as ventilation airways during concurrent development and emplacement and after full repository development (Section 1.3.5).

The major piece of equipment associated with the transport and emplacement of the waste packages is the waste package TEV (Section 1.3.3.5).

When the license amendment to close the repository is issued, the subsurface facility will be prepared for permanent closure. The structures and components added to the subsurface facility for postclosure performance include the drip shields and backfill in all the shafts and ramps (Section 1.3.6). Placement of backfill is preceded by removal of noncommitted materials from nonemplacement openings (BSC 2007b, Section 6.2).

The designs of the subsurface facility and SSCs conform to preclosure nuclear safety design bases as listed in Table 1.9-7 and to postclosure analyses control parameters as listed in Table 1.9-9. Section 1.3.1.4 contains cross-references to other sections with information on conformance of the design solutions for the subsurface facility and SSCs to their respective design criteria and design bases. Section 1.3.2 describes the design considerations applied to the designs of the different subsurface SSCs to ensure that their functions are performed in conformance to their respective nuclear safety design bases. Development of the preclosure nuclear safety design bases follows the preclosure safety analysis methodology described in Sections 1.6 through 1.9. Development of the postclosure analyses control parameters and derived requirements and constraints is described in Section 2.1 and additional detail is provided in *Postclosure Modeling and Analyses Design Parameters* (BSC 2008a).

The following paragraphs provide an overview of the major subsurface facility SSCs. Table 1.3.1-1 lists the major subsurface facility excavations and the functions, sizes, and geometry of the openings.

Figure 1.3.1-2 illustrates the overall repository site plan and the location of the subsurface facility with respect to other repository facilities.

Emplacement Drifts—As described in Section 1.3.4, the emplacement drifts are horizontal, 5.5-m nominal diameter circular drifts, spaced in a parallel pattern, center to center, at nominally 81 m (Sections 1.3.2.4.3.5 and 1.3.4.2.1), and driven through the host rock by a tunnel boring machine. The emplacement drifts are, on average, approximately 604 m in emplacement length, with no drift longer than 780 m in emplacement length (BSC 2007a, Attachment IV). The layout of the subsurface facility encompasses an area that can accommodate approximately 108 similarly equipped emplacement drifts, with a total available emplacement length of 65,209 m (40.6 mi.) (BSC 2007a, Table 10; BSC 2003, Section 8.8). The total emplacement length includes space allowance for some contingency capacity (Section 1.3.2.4.3.1). The width of the rock pillar between emplacement drifts is selected to provide a heat sink and a drain path for percolating water and for water in the rock mobilized by the decay heat of the waste packages. The ground support for the emplacement drifts is a system of stainless steel rock bolts and a drift-wall liner consisting of perforated stainless steel sheets bolted in place against the rock wall to limit raveling and rockfall during preclosure. The drift diameter is large enough to permit the installation of the drift invert structure to serve as a horizontal surface for supporting the emplacement pallet with its waste package and to provide space for the movement of the TEV and the placement of the drip shield. Each emplacement drift is provided with power and communication capabilities for the TEV (Section 1.3.3.5).

The turnout between the emplacement drift and the access main is sized and shaped to permit the movement of the TEV, while also providing a natural shield against radiation streaming into the access main. Although the emplacement drift is higher than the access main in order to prevent water flow into the drift, the turnout rises at a gentle grade to a flat at-grade transition into the emplacement drift to allow smooth and uninterrupted travel of the TEV into the emplacement drift (Section 1.3.3.1.4). Each emplacement drift is connected to the ventilation system via the access main and turnout and the exhaust main. The turnout cross section transitions from an irregular rectangular shape near the access main into a circular shape past the tunnel boring machine launch chamber (Figure 1.3.3-13). The circular section of the turnout is excavated by the tunnel boring machine and has the same diameter as the emplacement drift. At the beginning of the turnout and adjacent to the access main, there is a bulkhead with the emplacement access doors. The bulkhead also houses an airflow control regulator for adjusting the ventilation flow into each emplacement drift (Section 1.3.5.1.3.3).

The subsurface layout includes a contingency emplacement drift length that is available if rock conditions encountered during excavation in any emplacement drift anywhere in the repository preclude emplacing of waste packages in a section of drift. Conditions that may be encountered that may preclude emplacement of waste packages in sections of a drift, such as geologic anomalies, are discussed in Section 1.3.4.3. General requirements or criteria for avoiding or selecting a standoff distance from geologic anomalies of different types are not defined except for standoffs from Quaternary faults with potential for significant displacement (Section 1.3.2.4.3.2) (BSC 2008a, Table 1, Derived Internal Constraint 01-05). The only such faults known to be within or near the repository area are the Solitario Canyon and the Bow Ridge Faults, and the layout design conforms to the prescribed standoff for both of these faults. If other such faults are encountered during excavation of the emplacement drifts, appropriate waste package standoffs will be determined on a case-by-case basis depending on ground conditions (Table 1.9-10, PSC 25). There is a specific criterion for naval waste packages that requires an 8.2-ft (2.5-m) minimum emplacement standoff distance from mapped faults with vertical displacements greater than 6.5 ft (2 m) (BSC 2008b, Section 8.2.1.23). The postclosure classification Table 1.9-8 (footnote d) also identifies this requirement. The contingency emplacement drift length included in the layout design ensures that the repository has sufficient capacity to accommodate the statutory limit of 70,000 MTHM.

Nonemplacement Excavations—The major nonemplacement excavations and structures are described in Section 1.3.3 and summarized below.

North Ramp—The North Ramp and its portal connect the surface facilities to the subsurface facility. The North Ramp is the only ramp used for the emplacement of waste packages. Access to the repository emplacement areas through the North Ramp will be controlled at the North Portal. The access control at the North Portal and access control procedures are described in Section 1.3.1.2. The North Portal (top of concrete elevation) is located at 3,683.95 ft above mean sea level (Figure 1.3.3-1). The portal is protected from stream flooding by water diversion and control structures. Furthermore, the North Ramp entrance approach is sloped up at about 2% so that surface runoff water from areas adjacent to the North Portal cannot flow into the North Ramp and, subsequently, into the emplacement drifts (Figure 1.3.3-5). The existing Exploratory Studies Facility (ESF) ramp slopes down to the emplacement horizon elevation at a 2.15% slope. The slope of the repository's North Ramp (upgraded ESF North Ramp) will be approximately the same. The ground support for the ramp is a system of fully grouted rock bolts, steel fiber-reinforced shotcrete, and lattice girders as necessary for roof control (BSC 2007c, Section 6.5.4.1). The crane rails for the TEV are fastened to anchor bolts embedded in a reinforced concrete slab poured over the existing invert structure, and the power is supplied through a third-rail system (Section 1.3.3.4.1).

Access Mains—There are three access mains that are the interface between the North Ramp and the emplacement drifts. They are the access main for Panels 1 and 2, the access main for Panels 3E and 3W, and the access main for Panel 4 (Figure 1.3.1-1). The access mains continue the rail, communications, and power system for the TEV to the turnouts. The access mains are connected to the emplacement drifts by turnouts that accommodate the turning radius of the TEV. The access mains also serve to supply ventilation for the emplacement drifts. The ground support for the access mains is a system of fully grouted rock bolts and heavy-gage wire mesh. At the turnout–access main intersections, the ground support includes fully grouted rock bolts with steel fiber–reinforced shotcrete and lattice girders, as necessary, to provide additional support for the larger excavated spans (BSC 2007c, Section 6.5.4.1).

Exhaust Mains—There are four distinct exhaust mains that collect the ventilation flow from the emplacement drifts and direct the air to the exhaust shafts that discharge to the environment at the surface (Figure 1.3.1-1). These are: the exhaust main for Panel 1, which is of a smaller diameter than the other exhaust mains; the exhaust main for Panel 2; the exhaust main for the "East" subpanel of Panel 3 (3E); and the exhaust main serving subpanel 3W and Panel 4. The latter main splits into two parallel exhaust mains in the middle portion of the panels to allow drift development in Panel 4 while waste is being emplaced in subpanel 3W. The exhaust mains are not equipped with permanent invert structures, rails, communications, or power for transportation equipment, nor is there a turnout between the emplacement drift and the exhaust main. The emplacement drifts connect directly to the exhaust mains. There is no door at the exhaust main end of the emplacement drift. The ground support for the exhaust mains is a system of fully grouted rock bolts and heavy-gage wire mesh. Intersections between the exhaust mains and emplacement drifts have fully grouted rock bolts with steel fiber–reinforced shotcrete, and lattice girders as necessary for roof span control (BSC 2007c, Section 6.5.4.1).

Shafts—A design description of the shafts is provided in Section 1.3.3 and a description of their role in the subsurface ventilation system is provided in Section 1.3.5. The repository is connected to the surface and ambient air through three intake shafts, three ramps, and six exhaust shafts, including four large-diameter (26-ft) exhaust shafts and two small-diameter (16-ft) exhaust shafts. The shafts are excavated by mechanical and/or drill and blast methods and lined with concrete. At the top of each exhaust shaft is a fan enclosure with two installed exhaust fans. Typically, the two fans will be operating simultaneously at each large-diameter exhaust shaft, while only one fan will be operating at any time at each of the smaller-diameter shafts (BSC 2008c, Section 6.2.1).

North Construction and South Ramps—These two ramps provide access for the ongoing construction of the full complement of emplacement drifts while loaded waste packages are transported down the North Ramp to completed emplacement drifts. These ramps are constructed with a similar configuration as the North Ramp with respect to prevention of stormwater from entering the ramps. Radiation protection, security, and isolation barriers are erected between the operational portion of the subsurface facility and those portions under construction to protect the operating facility from construction-initiated hazards and the construction workers from the radiological hazards of the emplacement drifts. Access to the repository emplacement areas from the development areas will be controlled at the isolation barriers (BSC 2008d, Sections 6.1, I4.1.3, and P2.1.2). Once development is completed, the ramps will serve as intake airways for the subsurface ventilation system (BSC 2008c, Section 6.3 and Figure 11).

Transport and Emplacement Vehicle—Waste package transportation and emplacement operations are performed by the self-propelled TEV. Descriptions of the TEV equipment and their safety systems are presented in Sections 1.3.3 and 1.3.4. The TEV is a crane rail-based transporter with a shielded enclosure that carries the loaded waste packages and emplacement pallets from the surface Initial Handling Facility (IHF) and Canister Receipt and Closure Facilities (CRCFs) to designated locations in the emplacement drifts. The TEV is remotely controlled and monitored by operators in the Central Control Center. Power for the TEV is provided by a third rail or insulated conductor. For loading or unloading a waste package and pallet, the TEV opens front shielded enclosure doors, lifts a rear shield door, and extends a shielded enclosure base plate. These actions allow the TEV to position itself over the waste package and emplacement pallet and lift it during loading, or position itself during emplacement to unload the waste package and pallet. After loading or unloading operations, the TEV shielding components are retracted, closed, and locked for travel to or from the emplacement drift. While stationary or in transit, the TEV holds the pallet and its waste package within the locked shielded enclosure. Safety features, equipment functions, and operational sequences for the TEV are described in Section 1.3.3.5 (BSC 2008e, Section 2.5).

Subsurface Ventilation System—The subsurface ventilation system facilities, equipment, and operations are described in Section 1.3.5. The subsurface ventilation system provides ventilation airflow through the emplacement drifts during the emplacement period, for a period of time after emplacement until successful completion of the Performance Confirmation Program, and through closure activities. Variable speed fans are installed at the surface openings of the exhaust shafts. The shafts, shaft access drifts, access mains, turnouts, and exhaust mains are the airways for the ventilation system. Regulators in the turnout bulkheads are adjusted to provide the required ventilation flow to each emplacement drift. Isolation barriers are used to separate the ventilation flow that is directed to the operating emplacement drifts from the ventilation that is provided to the development areas (BSC 2008c, Section 6).

Closure SSCs—The design characteristics for the drip shields and their emplacement equipment are described in Section 1.3.4.7.2. Section 1.3.6 describes the installation of drip shields as part of the repository closure process. The drip shields are part of the Engineered Barrier System (EBS) considered in the postclosure performance of the repository. The drip shields prevent or substantially reduce the potential for seepage water from contacting the waste packages and protect the waste packages from rockfall due to drift degradation. The drip shields will be installed during the preparation for permanent closure, which occurs after the license amendment to close the repository is approved. The drip shields are made of corrosion-resistant titanium alloys. The drip shields interlock with adjacent drip shields to form a continuous cover over the waste packages. The drip shields are designed with structural components to withstand potential rockfall of a certain weight or characteristics (Section 1.3.4.7.5) (BSC 2008a, Table 1, Derived Internal Constraints 07-01 through 07-04 and 07-07 through 07-16; BSC 2007b, Section 6.2).

Placement of backfill in selected nonemplacement excavations is part of the repository closure activities described in Section 1.3.6. After the installation of the drip shields, the ramps and shafts will be backfilled. Backfill provides long-term stability of the openings and prevents human intrusion.

Engineered Barrier System SSCs—The designs of the subsurface facility closure SSCs conform to the postclosure analyses control parameters as listed in Table 1.9-9. Section 1.3.1.4 includes cross-references to other sections with information on conformance of the closure feature designs to their respective design criteria and design bases. Section 1.3.2 describes the design criteria applied to the designs of the subsurface closure SSCs to ensure that their functions are performed in conformance with their respective postclosure analyses control parameters. Development of the postclosure nuclear safety design bases and derived requirements and constraints is described in Section 2.1 and additional detail is provided in *Postclosure Modeling and Analyses Design Parameters* (BSC 2008a).

The subsurface facility includes the EBS SSCs: the emplacement drifts (Section 1.3.4), the emplacement drift invert structure (Section 1.3.4.5), the waste package emplacement pallet (Section 1.3.4.6), the waste package (Section 1.5.2) that contains the waste form (Section 1.5.1), and the drip shield (Section 1.3.4.7). The waste package is the important to safety and important to waste isolation component that provides the primary containment of radionuclides to ensure isolation from the environment. The waste package functions include resistance to corrosion, containment, and criticality prevention. Waste canisterization, and design and fabrication of the waste package as described in Sections 1.5.1 and 1.5.2, respectively, will ensure compliance with the applicable design bases and derived requirements described in Section 1.9. The subsurface facility, including its operating systems, provides an adequate environment during the preclosure and postclosure periods for the EBS SSCs to perform their intended functions.

1.3.1.2 Subsurface Facility Operations

[NUREG-1804, Section 2.1.1.2.3: AC 3(1), AC 6(1), (2); Section 2.1.1.7.3.1: AC 1(1), (5); Section 2.1.1.7.3.3 (II): AC 2(1), AC 4(1), (2), (3)]

Operational procedures for the subsurface facility will be developed and implemented in accordance with the Conduct of Operations Plan.

1.3.1.2.1 Support Operations in the Subsurface Facility

1.3.1.2.1.1 Access Control Operations

The North Portal is the main access point for the emplacement areas of the subsurface facility. Access for waste emplacement, maintenance, and emplacement drift startup activities will be controlled at the North Portal Access Control Point. The North Portal Access Control Point will house the equipment and personnel that will control these activities.

The North Portal Access Control Point will provide controlled ingress to and egress from the North Portal of the subsurface through a double-fenced enclosure. The North Portal Access Control Point serves as a security checkpoint to ensure that only necessary personnel and materials enter the subsurface area. Radiological and security inspections of vehicles will be conducted at the station. Personnel will enter through the building where a series of checks will ensure they are qualified and equipped for subsurface entry. Upon exit, a portal monitor will check for personnel contamination. The North Portal Access Control Point will also provide administrative space for the personnel assigned to the facility.

An accurate accounting of personnel and their location in the subsurface must be kept at all times for emergency management purposes.

Accounting of materials entering the subsurface must be maintained due to the limitations on engineered or nonengineered materials that will remain in the repository after closure. Therefore, materials (e.g., tools, lubricant) entering the subsurface will be logged and removal of those materials will be verified through inventory controls.

Entry of nuclear materials into the subsurface constitutes a change in material control and accounting balance areas. When a TEV loaded with a waste package reaches the North Portal Access Control Point, the TEV is brought to a stop at a preprogrammed point inside the gated inspection area. At this time, the Material Control and Accounting person will take custody of the waste package and record its entrance into the subsurface, confirm the waste package identity, and confirm the intended emplacement location. Waste package identity will be obtained from the TEV loading records. Security confirms that there are no occurrences of off-normal events that may prevent emplacement. Prior to the departure of the TEV from the North Portal Access Control Point, verification is made that all personnel and equipment in the subsurface transportation route to be used by the TEV are sheltered and that the right-of-way is clear. After off-loading the waste package, the TEV will return to the North Portal Access Control Point and stop at a programmed point to be inspected for contamination by swipe or smear test by radiological control personnel before being released for maintenance or reloading (BSC 2008d, Appendix H). Confirmation that the waste package has been emplaced and that the TEV is empty will be obtained from the Central Control Center.

1.3.1.2.1.2 Personnel

There will be required training for subsurface access (e.g., subsurface worker training, subsurface familiarity training, first aid training). Worker qualification may be required for some subsurface tasks. Worker training and qualification will be per the process described in Section 5.3.

Entering the subsurface facility is a transition from a clean area to a potentially contaminated (C2) and radiation (R2) area. When a loaded TEV is present, the emplacement side of the subsurface facility is controlled as an R4 area. A radiological work permit is required for entry. There will be a general radiological work permit that addresses entry for routine activities. Other entries may require specific radiological work permits for the task. Each person preparing to enter the subsurface will sign the appropriate radiological work permits and will wear the dosimetry specified by the radiological work permits. Radiation doses and exposures will be controlled per the Operational Radiation Protection Program described in Section 5.11.

Personnel and equipment leaving the subsurface will be surveyed to be free of contamination prior to exiting the radiologically controlled area. A radiological technician or health physics technician will be available to assist personnel and survey vehicles and equipment.

An industrial health and safety technician will verify each shift that the subsurface atmosphere and environmental conditions are safe for entry.

There will be two means of communication with personnel in the subsurface. These will be a public address system and a handheld radio for each person (BSC 2008d, Appendix H).

1.3.1.2.1.3 Task-Specific Activities

Personnel supporting repository operations requiring access to the subsurface repository will also pass through the North Portal Access Control Point.

Personnel associated with startup of the emplacement drifts after turnover from construction to operations will also access the subsurface repository through the North Portal Access Control Point. All the personnel, materials, and equipment will be beyond the TEV route and will be impacted only if they require egress during TEV movement.

The list below provides an example of personnel entering the subsurface facility and the tasks that will be performed. On a routine basis, it is reasonable to expect that the following personnel will enter the subsurface (BSC 2008d, Appendix H):

- Security officers for a walk down of the facility (number of officers and frequency of walk downs are per security procedure)
- One industrial health and safety technician to verify life safety conditions (each shift)
- One radiological technician for surveys and swipes (each shift)
- One operator for a rail walk down and inspection (each shift)
- Two operators for general housekeeping and cleaning the invert (each shift)
- Four maintenance personnel for electrical and mechanical preventive maintenance (each shift)
- One operator or mining engineer for ground support inspection (each shift)
- One safety professional for observations and walk downs (each shift)
- One supervisor for walk downs, job inspections, and miscellaneous tasks (each shift)
- Approximately six personnel for startup of an emplacement drift (as needed)
- One quality control person for maintenance activities verification, weld verification, and miscellaneous tasks (as needed)
- Material control and accounting personnel enter the subsurface facility before and after a waste package emplacement to affix and remove tamper indicating devices at the emplacement access doors and to perform annual inventory
- One quality assurance person for audits and observations (several times per week)
- Several personnel as allowed for tours (as defined and allowed by the U.S. Department of Energy (DOE))
- Other personnel for corrective maintenance, construction/operations barrier installation and removal, and miscellaneous tasks (as needed).

1.3.1.2.1.4 Personnel Transportation

The specific method of mechanized transportation of workers from the surface to the subsurface areas has not yet been defined. Any vehicle chosen for operation in the subsurface will be electric, either functioning from the third rail or battery powered. Rail-based vehicles, rubber-tire-based vehicles, or both may be employed. There may be larger vehicles to carry multiple personnel and smaller vehicles that transport only one or two personnel. It is also likely that specialized maintenance vehicles, equipped with toolkits and other maintenance supplies, will be utilized.

Movement of general transportation equipment must be coordinated with TEV movement. These interface activities will be covered in the operations plan-of-the-day and will be coordinated with the Central Control Center for TEV operations so that access to general transportation equipment can be properly controlled from the North Portal Access Control Point (BSC 2008d, Appendix H).

1.3.1.2.1.5 Maintenance Activities

Subsurface repository maintenance vehicles will also enter the repository though the North Portal Access Control Point. All vehicles and personnel will be “tagged” and controlled while in the subsurface by the subsurface inventory control system. Maintenance activities will be completed under a radiological work permit. All activities with the exception of emergent events will be scheduled and coordinated with the TEV waste package emplacement activities. All maintenance materials entering the tunnel will be approved and logged. Excess, damaged, or replaced materials are returned to the North Portal Security Access Control Station from the subsurface repository to ensure all noncommitted materials are accounted for (BSC 2008d, Appendix H).

1.3.1.2.1.6 Monitoring Activities

There are two general types of monitoring to be accomplished in the subsurface facility: operational monitoring (e.g., the radon, radiation monitoring, and dust measurements taken for the health and safety of workers) and performance confirmation monitoring (e.g., monitoring a fault for displacement). Some measurements, such as relative humidity, can be used for both operations and performance confirmation.

The main operational monitoring activities that will occur underground are (BSC 2008d, Appendix I):

- Ventilation system airflow monitoring (airflow velocity, barometric pressure, air temperature, humidity, airborne particulates, carbon monoxide, and airborne radioactive materials)
- Emplacement access door monitoring
- Subsurface ventilation fan monitoring
- Ground support monitoring
- Monitoring of other major passive systems such as invert structures and rail, and isolation barriers.

Emplacement Drift Postemplacement Inspections—After the initiation of emplacement of waste packages, human access to the emplacement drifts will not be permitted. During this time, as part of the Performance Confirmation Program, the drifts will be remotely monitored and inspected for drift environmental conditions and waste package integrity. This activity will be conducted periodically, on a scheduled basis, to detect any indications of rockfall, drift degradation, or instability within the drifts that may require unplanned maintenance. The inspection frequency will be specified as the details of repository design are developed (BSC 2008f, Section 6.1.1).

Monitoring and inspecting emplacement drifts after the emplacement of waste packages may be accomplished using acoustic or seismic tomography, or both, to help detect rockfall. Remotely operated observation vehicles will be used for visual inspections and material sampling. Remote observations by video camera will be made of the drift wall stainless steel liner for possible water seepage, drift degradation areas, and ground support component failure (indicators of ground support failure include sagging or torn stainless steel sheeting and rock particles on the invert or waste packages). The drift floors will be observed for rockfall debris and the waste packages will be inspected for damage in areas where ground support failure and rockfall may have occurred. The volume of any observed rockfall debris will be estimated, and the condition of the waste packages will be assessed. This monitoring and inspection activity will be conducted on a scheduled basis, and it will provide the information necessary for evaluating drift degradation effects and ground support deterioration, and for the possible need for retrieving any damaged waste packages (BSC 2008f, Section 6.1.1).

Accessible Openings—Many nonemplacement repository openings will be safe and accessible for human entry. These openings include the portals and access ramps, access mains, ventilation intake shafts/raises and accesses, portions of the emplacement drift turnouts, and the performance confirmation observation drift including test alcoves. The accessible openings also include the existing ESF facilities (i.e., alcoves) and part of the Enhanced Characterization of the Repository Block (ECRB) Cross-Drift. During repository operations, qualified personnel will (subject to normal operational control procedures) periodically visually inspect these accessible nonemplacement openings, by direct observation, for the deterioration of ground support components and drift degradation effects. For the inspection of ventilation intake shafts, an inspection device deploying a camera will be used. These direct observations will be supplemented by in situ measurements of rock deformation and opening stability provided by geotechnical instrumentation. This information will form the basis for evaluating the need for repairs of the ground support system. A schedule of regular inspections by qualified personnel will be implemented, maintenance reports will be prepared, and any necessary repairs will be identified and performed (BSC 2008f, Section 6.3).

Inaccessible Openings—Nonemplacement openings that are inaccessible for human entry during the preclosure period are the exhaust mains, exhaust shaft access drifts, exhaust shafts, and turnouts. High temperatures and potential high radiation levels characterize these areas. These areas will require remote monitoring and visual inspection for any degradation and ground support deterioration, using a remote observation vehicle equipped with a video camera. Visual indications of problematic conditions include failed or buckled liner segments in exhaust shafts, and failed ground support components and rockfall in exhaust mains. A schedule of regular inspections will be implemented and will form the basis for determining whether any maintenance will be required in these inaccessible openings (BSC 2008f, Section 6.2).

1.3.1.2.1.7 Off-Normal Response Activities

Off-normal is a term used to define an occurrence or condition outside the bounds of routine operations but within the range of analyzed conditions for the SSC. The requirements for worker health and safety, as low as is reasonably achievable operations, and minimizing radiation releases are not reduced during off-normal events. Handling off-normal events requires procedures and controls specific to that operation, and are developed for that specific situation. Ventilation during off-normal operations may need to be modified and will be included in off-normal response planning.

Examples of off-normal events that may occur in the subsurface facility during the emplacement phase include the following (BSC 2008d, Appendix I):

- Any manned operation conducted in an exhaust main, in an exhaust shaft, or in a partially or fully loaded emplacement drift (any such action will be preceded by cooling of affected drift and relocation of waste packages to another drift). The present concept of operations does not provide for manned operations in a partially or fully loaded emplacement drift, or active exhaust mains or shafts. Manned operations in a partially loaded emplacement drift may be possible, after all the proper safety and radiological protection measures have been put in place. Such instances will be analyzed on a case-by-case basis considering all risks and observing as-low-as-is-reasonably-achievable principles.
- Loss of construction or emplacement ventilation due to fan failure or power loss
- A rockfall blocking an opening
- A subsurface fire
- A general power failure shutting down the ventilation system
- A TEV failure.

Emplacement Area Emergency Egress and Refuge—Escape from the repository will be the primary survival strategy for emergency off-normal events. The type and location of the off-normal event will influence emergency escape from the repository emplacement areas. The locations of the work area(s) in relation to the event, configuration of the repository, and ventilation airflow are crucial parameters influencing emergency escape and response planning. Identified escapeways are access mains leading to intake ventilation shafts, the North Ramp and Portal, the South Ramp and Portal, and the North Construction Ramp and Portal. When the potential exists for escape to be unachievable, refuge will become the survival strategy (BSC 2008d, Appendix P).

The repository Fire Protection Program (Section 1.4.3), and current and more detailed fire hazards analyses (BSC 2007d) provide policies, procedures, and criteria for emergency escapeways and refuge to protect the subsurface personnel and property. These are “living” documents and will require revision to account for each stage of the emplacement area development and operation.

Most off-normal events would not be life threatening but the disruption of normal system operations may make it desirable to evacuate the subsurface facility. For example, power loss to the ventilation fans and subsequent ventilation loss is not an immediate life threat to subsurface personnel, however if the system cannot be restored within a specified time, the subsurface will be evacuated because the operational ventilation requirements cannot be met. An analysis of each SSC in the repository emplacement area to determine contributing factors concurrent with the fire hazards analyses following detailed design will help establish credible events and appropriate responses, and define evacuation criteria and procedures for subsurface repository emplacement area operations.

Emergency Egress through Isolation Barriers—Escape from a construction area through an exhaust main isolation barrier is not allowed, as the passage would be into a radiation area having high temperature emplacement exhaust air.

Access main isolation barriers offer the opportunity for their utilization as an emergency egress, shelter, or refuge. Penetration of this barrier is allowed for personnel safety actions. Further analysis of emergency egress has recognized that the isolation barriers can be modified to provide emergency egress, shelter, or refuge from both sides of the isolation barriers, enhancing life safety for both construction and operations personnel. Doing this will allow personnel emergency egress through the first bulkhead of the isolation barrier and allow them to take shelter or refuge in the area between the bulkheads.

Any emergency or off-normal event will be monitored in the Central Control Center and the North Portal Access Control Point. The construction or operations responder's responsibility is resolution of safety, health physics, and radiological concerns regarding entrance from or into either side of the barrier, as governed by procedure (BSC 2008d, Appendix P).

1.3.1.2.2 Waste Package Transportation

The North Portal is the waste package transportation access to the subsurface facility. The North Portal is connected by crane rail to the IHF and to the CRCFs. The individual sealed waste packages of spent nuclear fuel (SNF) and high-level radioactive waste (HLW) are loaded at these surface facilities on emplacement pallets and are loaded into the TEV for transport into the subsurface facility. The TEV carries each waste package on its emplacement pallet to the emplacement drift via the North Ramp, access mains, and turnout (BSC 2008d, Appendix I).

The block diagram in Figure 1.3.1-3 identifies the primary operations involved in transferring waste packages from the surface facilities into the subsurface facility and emplacing them in the emplacement drifts. Figure 1.3.1-4 is an illustration of the turnout between the access main and a typical emplacement drift. It shows the interaction of the TEV with the emplacement access doors. These operations are also discussed in more detail in Sections 1.3.3.5 and 1.3.4.8.

Minimum and maximum travel distances for waste package transportation are to Panels 1 and 4, respectively (Figures 1.3.3-10 and 1.3.3-11). The minimum one-way distance traveled by the TEV from the North Portal to reach the first turnout in Panel 1 is approximately 2,760 m. The maximum one-way distance traveled by the TEV from the North Portal to reach the last turnout in Panel 4 is approximately 7,200 m. The travel time will depend on controls and conditions encountered along the different routes, such as the number of switches that have to be activated for each route. The operating speed for a loaded TEV is 150 ft/min (1.7 mph), so the approximate rolling times for the minimum and maximum distances provided above, not including stops and delays, would be approximately 60 to 160 minutes, respectively.

Once the waste package on an emplacement pallet is loaded and enclosed within the shielded enclosure, the TEV exits the surface facility. As it travels from the surface facility to the North Portal, the TEV moves through surface rail switches to ensure that it is correctly oriented for entry into the emplacement drift (Figures 1.3.3-10 and 1.3.3-11). Sections 1.3.3.1.2 and 1.3.3.5.2 provide detailed descriptions of the transportation routes and TEV operations, respectively. After the TEV enters the North Portal and the subsurface environment, it travels down the North Ramp to the access main. At the turnout, the TEV stops and waits for the emplacement access doors to open. The emplacement access doors are activated from the Central Control Center after clearance to proceed has been received from the radiological control personnel in charge of securing access to the emplacement drifts. The TEV, operated remotely and monitored by the Central Control Center operators, enters the turnout when the emplacement access doors have been opened. The emplacement access doors are closed after the TEV passes and the TEV proceeds to the emplacement drift for emplacement of the waste package (BSC 2008e, Section 2.5).

1.3.1.2.3 Waste Package Emplacement

Detailed descriptions of the waste package transportation and emplacement equipment and operations are presented in Sections 1.3.3.5 and 1.3.4.8, respectively. After entering the emplacement drift, the TEV proceeds to the designated waste package emplacement location. As it approaches the location, the TEV stops, opens the front shielded enclosure doors, lifts a rear shield door, and extends a shielded enclosure base plate. The TEV moves forward to the designated emplacement location to the end of the drift or adjacent to a previously placed waste package. The onboard waste package positioning system guides the TEV to the specific waste package location. Once the TEV is in position, the emplacement pallet with the waste package is lowered onto the steel invert structure and the placement location and spacing of the waste package are confirmed. The TEV then moves back and away from the emplaced waste package, raises the shielded enclosure, retracts the shielded enclosure base plate, and lowers the rear shield door, closes and locks the front shielded enclosure doors, and proceeds out the emplacement drift toward the turnout. At the turnout, the TEV stops until the emplacement access doors are opened so that it can proceed into the access main, then to the North Ramp, and back to the surface. The TEV is radiologically surveyed upon reaching the North Portal Access Control Point to ensure no contamination levels above regulatory requirements are present (BSC 2008e, Section 2.5).

1.3.1.2.4 Subsurface Facility Ventilation Operations

Ventilation air is used to cool the emplacement drifts during preclosure by removing the decay heat from the waste packages (BSC 2008c, Section 6).

The subsurface ventilation system supports thermal management goals by cooling emplacement drifts. Operationally, waste package thermal loading will be controlled in the surface facilities to meet the thermal limits described in the following section. Heat removal from the waste packages in the emplacement drifts will be controlled by regulating subsurface ventilation and by adjusting the duration of ventilation prior to beginning closure operations of the repository to establish the initial conditions for the total system performance assessment (TSPA) analyses.

The emplacement ventilation system is designed to operate under both normal and off-normal situations, such as a potential partial blockage in a drift.

In the emplacement ventilation system, airflow is drawn through the subsurface by fans located on the surface at the top of the exhaust shafts. Ambient air enters the ramps and intake shafts and is distributed either directly from the ramps to the access mains or through intake shaft access drifts to the access mains. Fresh air from the access mains passes through the turnout bulkhead airflow regulators into the turnouts and then enters the emplacement drifts. Automated regulators located in the turnout bulkheads control the airflow distribution into the emplacement drifts. Air flows from the emplacement drifts directly to the exhaust mains. The airflow travels from the exhaust main to the exhaust shafts through shaft access drifts. The surface-based fans draw air through the exhaust shafts to the surface where it is discharged to the atmosphere. High-efficiency particulate air filters are not required at the subsurface facility ventilation exhaust points to the surface since there are no Category 1 or 2 event sequences that can lead to a breach of a waste package in the subsurface. There are no normal operations in the subsurface facility that require filtered ventilation for radiological control purposes. Calculations on resuspension of potential contaminated material from the surface of the waste packages and radiological activation of air and dust particles also show that high-efficiency particulate air filters are not required for normal operations (Section 1.8.2.2.2).

In the event of a subsurface ventilation system malfunction causing loss of airflow to the emplacement drifts, a period of 30 days has been selected as a reasonable period of time to perform repairs and to restore the system to normal operation. The analysis of the thermal effects resulting from a loss of forced ventilation, therefore, was based on a time period of 30 days. Although subsurface ventilation will be restored as soon as practicable, a maximum 30-day operational limit has been established for loss of forced ventilation.

Section 1.3.5.3.2 describes the assessment of repository thermal effects due to different potential scenarios leading to loss of subsurface ventilation and provides additional justification for implementation of the 30-day operational limit for loss of forced ventilation. The electrical power distribution grid for the subsurface facility (Section 1.3.3.1.8) includes backup power feeds for the subsurface exhaust fans as an extra measure to prevent extended operational interruptions due to loss of electric power.

The subsurface ventilation system design is described in Section 1.3.5.

1.3.1.2.5 Thermal Management

This section provides a summary of analyses that demonstrate the subsurface facility performs thermal management operations in compliance with the repository thermal requirements. Thermal management operations during preclosure set the repository thermal conditions for conformance with postclosure performance requirements. The information presented also demonstrates available flexibility in operations to ensure compliance with the requirements under anticipated normal operations and under constraints and uncertainties related to the repository waste stream.

Requirements and Objectives—Thermal management of the waste packages is required to maintain integrity of engineered barrier components and to ensure natural or altered conditions of the host rock conform to conditions analyzed for long-term repository performance (Section 2.3.5.4.3). Thermal management activities performed in the surface facilities that are relevant to SNF forms, SNF canisters, and SNF handling prior to sealing of the waste packages are described in Section 1.2. Thermal management activities that are relevant to sealed waste packages during their transport to the subsurface, at emplacement, and during the preclosure period of the repository are described in this section and Sections 1.3.2, 1.3.4, and 1.3.5.

The emplacement of waste packages is controlled through a loading plan that determines waste package loading sequences and interfaces with the repository operations to maintain temperatures within prescribed limits during the preclosure period. In the preclosure period, these operations establish the initial conditions for closure so that, upon termination of ventilation at closure, the thermal loading in the repository results in temperature transients during the thermal pulse that are consistent with the conditions as analyzed in the repository performance assessment described in Section 2. The thermal pulse is the general rise and drop in temperature in the mountain after ventilation ceases and as the waste thermal decay and heat dissipation take place over thousands of years after closure.

Table 1.3.1-2 lists the repository subsurface temperature limits. During the preclosure period, the emplacement drifts are supplied with outside air at a sufficient flow rate to maintain the bulk exhaust temperature within an acceptable operating range (Table 1.3.5-2). The exhaust air temperatures for individual drifts vary with intake air temperature, drift length, heat load, ventilation flow rate, and years of ventilation.

Analyses conducted for the subsurface facility considered the following thermal parameters as conditions for design of underground SSCs:

- Maximum waste package thermal power at emplacement: 18.0 kW (BSC 2008a, Table 1, Derived Internal Constraint 05-03)

- Maximum linear heat load at emplacement over the length of a seven-waste-package segment: 2.0 kW/m (BSC 2008b, Section 8.2.1.5; BSC 2008a, Table 1, Derived Internal Constraint 05-03)

- Nominal spacing between adjacent waste packages, averaged over a seven-waste-package segment: 10 cm (BSC 2008a, Table 1, Derived Internal Constraint 05-02)

- Calculated thermal energy density of any seven adjacent as-emplaced waste packages: not to result in exceeding a thermal-energy-density index (temperature) of 96°C at the midpillar (between adjacent emplacement drifts), adjusted to account for host-rock thermal conductivity and hydrologic conditions in the host rock (BSC 2008a, Table 1, Derived Internal Constraint 05-03).

The seven-waste-package segment as modeled in the TSPA thermal loading reference case is an arrangement of six whole waste packages and two half waste packages (figuratively forming a total of seven waste packages), consisting of different types of codisposal and SNF waste packages with different thermal power content. These packages are arranged such that the thermal profile over the entire length of the emplacement drift is fairly uniform, thus preventing the development of pronounced thermal gradients along the axis of emplacement. In the repository thermal management studies the seven-waste-package segment is designated as a unit cell (Section 2.3.5.4.1) and is presented as a representative depiction of package-to-package thermal variability. It is also used to describe the basis for the seven waste package running-average as a drift loading rule meeting the constraints of the 96°C midpillar thermal-energy-density index (temperature) and the 2.0 kW/m thermal line-load average (Section 2.3.5.4.3).

The operational flexibility inherent in the subsurface ventilation system, coupled with flexibility in ventilation operation duration, allows for a range of thermal operating conditions (BSC 2007e, Section 6.2; SNL 2008a, Section 6; BSC 2001, Tables II-5, III-7, and V-5) that meet the repository preclosure and postclosure temperature limits. Operational process flexibility in the surface handling facilities and the surface aging capability are also considered in analyzing waste emplacement options in the subsurface facility.

From a thermal management perspective, closure of the repository is permissible when the thermal conditions of the repository are such that the thermal pulse does not cause any of the temperature limits in Table 1.3.1-2 to be exceeded. The limiting condition in achieving repository thermal goals is the waste package thermal energy density. The waste package thermal energy density is specific to preclosure ventilation efficiency and duration and to the host rock thermal diffusivity, and is used to control midpillar temperature. The midpillar temperature is shown to be limiting such that the other postclosure temperature limits are met if this criterion is satisfied.

The following discussion provides information on methods and approaches used to establish the thermal management strategy for the repository. Recognizing that flexibility must be maintained in the receipt, handling, aging, and emplacement of the waste, the following items were considered in developing the strategy:

- Variability in the waste stream
- Postclosure analyses and limits related to waste emplacement
- The estimated limiting waste stream, as a representative waste stream considering available commercial SNF inventory and accepting it at a relatively high thermal output
- Simulation of a specific waste package emplacement sequence using the WPLOAD V. 2.0 software
- The emplacement drift loading plan.

The methodology for thermal management of the waste stream was applied to a representative waste stream for the purposes of demonstrating the flexibility of the repository in receiving and emplacing the 70,000 MTHM SNF and HLW inventory.

Variability of the Waste Stream—The waste stream that will ultimately be received at the repository is dependent on a number of factors, most of which are variable. These factors include the following:

- Availability of waste at the generator sites at the time of pickup, and whether the generator is a commercial utility or one of the government sites such as Idaho National Laboratory, Savannah River, or Hanford
- Availability of waste that conforms to acceptance criteria for waste receipt at the repository, including parameters such as commercial SNF initial enrichment, exposure and thermal content
- Availability of the allocated quantity of waste that is supposed to be received in a given year from each site
- Availability of a transportation cask fleet that satisfies the waste stream demands and the shipping schedule.

Both the commercial utility sites and the government sites plan for management of their SNF and HLW far in advance of likely pick up by the DOE, and create projections of what they are likely to deliver each year. The DOE considers those individual projections for development of the overall waste stream projection for the repository, but like each of the above factors, the projections from the individual sites are also subject to change. Accordingly, it is necessary for the DOE to develop flexibility to accept a wide spectrum of waste streams in order to bound the eventual waste deliveries so that the repository capabilities can be managed for acceptance of a wide range of waste characteristics.

A key variable in determining the nuclear and thermal characteristics of the waste stream is the capability of the transportation, aging, and disposal (TAD) canister, as it will be used for transportation of approximately 90% of the commercial SNF. The TAD canister holds 21-PWR assemblies or 44-BWR assemblies. However, the thermal capability of the TAD canister as well as its capability to meet radiation dose limits have been left to the cask vendors to determine for their designs as design bases or criteria for certification under 10 CFR Part 71 regulations in the form of performance specifications for the canister. Since the DOE does not define acceptance criteria for the waste except as identified in 10 CFR Part 961, the loading curves developed when the TAD canisters are loaded become the primary control of the overall waste stream characteristics, including thermal power output.

The actual waste stream that will be received and emplaced during operation of the repository will likely differ from any waste stream analyzed but the analyses that support the thermal loading approach provide flexibility to accept a wide range of waste streams. Those analyses (BSC 2006a; SNL 2007a; SNL 2008a) have identified flexibility in receipt, handling, aging, and emplacement that make it possible to deal with the variables just described.

Postclosure Analyses and Limits Related to Emplacement of Waste—The postclosure thermal reference case comprises a representative inventory of wastes to be received at Yucca Mountain, and a representative arrangement of waste packages for use by TSPA. The arrangement is a repeating sequence of seven waste packages that is used to represent waste package variability in simulations for TSPA (SNL 2008b). Figure 1.3.1-5 shows this repeating segment. The thermal line load of the postclosure reference case for TSPA is 1.45 kW/m, averaged over the length of the seven-waste-package segment. This segment line load is developed as a representative thermal load including decay characteristics of commercial SNF with an average of 38 GWd/MTU exposure at approximately 23 years time out of reactor (SNL 2007b, Section 7[a]).

The postclosure reference case includes the assumption of instantaneous emplacement of all waste packages in the year 2067, with the thermal loading characteristics described above (all waste emplaced at once with the equivalent of a 1.45 kW/m drift thermal linear load in 2067), followed by 50 years of preclosure ventilation (SNL 2008b, Sections 5.2.3, 5.2.3[a], and 5.4.2[a]) prior to initiating closure activities. Since the nuclear and thermal characteristics of SNF and HLW are dependent on the start and duration of exposure, a selection for initial emplacement of November 2016 was made for the purposes of analysis. The stylized postclosure reference case with the assumption of instantaneous emplacement of all of the waste in 2067, with the associated composite decay heat curve and 50 years of ventilation after emplacement, envelopes for purposes of repository performance assessment, the more realistic composite decay heat curve based on modeling the waste placed in the repository one drift at a time with post emplacement ventilation periods of 50 years or longer. This conservatism is sufficient to show that, by the time of repository closure in 2117, the total amount of decay heat not removed by ventilation for various alternative thermal loading schemes is represented by, or bounded by, the postclosure reference case analyzed for TSPA based on 50 years of ventilation heat removal.

Therefore, the TSPA modeling bases provides the bases for evaluation of the thermal response of the host rock during postclosure using the stylized modeling of the seven-waste-package segment. The assessment of the hydrogeologic, geomechanical, and geochemical responses to the anticipated range of thermal loading as described in Section 2.3.5.4.3 shows that for the nominal case (uncollapsed emplacement drifts), only minor changes are needed to represent the anticipated range of thermal loading in the TSPA model feeds, and that designation of features, events, and processes as included or excluded (Section 2.2) does not change.

The Estimated Limiting Waste Stream—Sensitivity analyses were performed with alternative thermal loading schemes with linear heat loads ranging from 1.45 to 2.0 kW/m, to determine their effects on midpillar temperatures, drift-wall temperatures, and waste package temperatures. Results of the sensitivity analyses were favorable for use of the higher linear thermal loads at emplacement (younger or higher burnup commercial SNF) and showed the feasibility of meeting the repository thermal limits (Table 1.3.1-2) for thermal loading conditions higher than the TSPA thermal reference case. The study also showed that the midpillar temperature limit is a more important constraint on thermal loading than drift-wall temperature (SNL 2007a, Sections 6 and 7), and it helped define the parameters and approach to be used in follow-up repository thermal analyses as follows (Section 2.3.5.4.3): (1) performing a postclosure study, including evaluation of impacts to the TSPA and its modeling basis; (2) establishing the feasibility of using a measure of waste package thermal energy density to control thermal loading; and, (3) leading to controls on loading of the repository that will be conceptually similar but based on more detailed analyses.

A postclosure thermal study was performed to further define the thermal envelope and analyze the postclosure response of the repository to a representative TAD and codisposal canister waste stream as analyzed in multiple waste, aging, and emplacement scenarios. An initial phase of analyses was performed using an engineering study to determine a range of possible waste streams and to select a representative, limiting waste stream (designated as the estimated limiting waste stream) for further analysis (BSC 2007f). A second phase of analyses followed to determine the local thermal loading conditions associated with the estimated limiting waste stream (BSC 2007g), and the geomechanical, geochemical, and hydrogeologic responses of the repository host rock to these loading conditions (SNL 2008a). The estimated limiting waste stream utilizes waste deliveries in conformance with the commercial utility contracts, but is developed only as a representative case, since the actual waste receipt is yet to be determined. The postclosure thermal study analyzed the estimated limiting waste stream as two distinct emplacement sequences with different midpillar index of thermal energy density constraints to study effects of drift-scale variability on in-drift temperatures. The process of selection of these emplacement sequences is described below. Two hotter locations from these emplacement sequences were identified based on developed criteria, and the corresponding limiting waste package heat output and arrangement were selected. The loading rules used to simulate emplacement ensured that all locations, including the two hotter ones selected for analysis, satisfied the repository limits for midpillar, drift-wall, and waste package surface temperatures.

Decay curves for the waste packages forming the estimated limiting waste stream (codisposal and TAD canisters) were developed (BSC 2007g), and were used in the analysis of the range of design thermal loadings (SNL 2008a, Appendix B) described in Section 2.3.5.4.3.

An underlying assumption in the early stages of development of the postclosure range of design thermal loading calculations, based on preceding work (BSC 2007f; SNL 2007a; SNL 2007c), was that by meeting the midpillar temperature limit, the drift-wall and waste-package temperature limit conditions would also be met. This limit was confirmed for the two hotter locations (segments of the estimated limiting waste stream derived emplacement sequence), and is generally applicable to all applications of the loading rules (SNL 2008a, Section 5.1). The postclosure thermal study was a demonstration of the approach to thermal management, not the actual implementation proposed for repository operations. The actual implementation will occur on a drift-by-drift basis when a specific waste stream and resulting waste packages can be identified and each emplacement drift analyzed for loading.

The estimated limiting waste stream used by the postclosure analysis of the range of thermal loadings study was selected from the preceding engineering study (BSC 2007f) by applying the following criteria (SNL 2008a):

- TAD canisters can be shipped as hot as 22.0 kW, which corresponds to the current limit on licensed transportation casks of similar capacity.
- Youngest fuel available will be shipped first from the utilities, with a minimum age of 5 years-out-of-reactor.
- Ninety percent of the commercial SNF will be packaged at the utility sites in TAD canisters containing 21-PWR and 44-BWR assemblies.
- Ten percent of the commercial SNF will be shipped as uncanistered fuel assemblies.

- Pickup rates will be stepped in quantity up to a maximum of 3,000 MTHM per year by the fifth year and thereafter.
- DOE SNF and HLW will be delivered as needed for repository emplacement operations.

Shipping the commercial SNF hotter than the 18.0 kW waste package limit was considered acceptable because of the capability built into the repository design to age the commercial SNF on the surface until the emplacement thermal power limit was met. Figure 1.3.1-6 illustrates how the resulting linear power load and decay curve for the selected estimated limiting waste stream case compares to the TSPA reference case. The curve for the reference case has been shifted by 17 years in the figure for more direct comparison with the estimated limiting waste stream overall average line load, and indicates the possibility of accelerating the assumed schedule for repository operations and closure while meeting postclosure thermal limits.

To assess the impact of any loading plan alternative on the midpillar temperature, a simplified two-dimensional thermal conduction calculation was used with a ventilation efficiency of 86% (i.e., 86% of waste heat removed during preclosure), for consistency with previous studies, to calculate an index of thermal energy density for each waste package. The calculation took into account the time-varying thermal output, and the thermal properties of the host rock, to represent the contribution of each package to midpillar temperature. The index of thermal energy density for any particular waste package is defined as the resultant peak midpillar temperature if the entire repository were loaded with packages that have those specific characteristics (SNL 2008a, Section 6.1.3). The midpillar temperature curve increases within a few hundred years after closure of the repository, and is then flat near the peak. This behavior is useful because the index of thermal density for waste packages can then be compared, or averaged together, without concern for the time at which the peak occurs for each waste package. Approximately half of the waste packages in the estimated limiting waste stream have an index of thermal energy density that exceeds the limit of 96°C. Those waste packages will have to be emplaced with, and adjacent to, cooler packages so that the local peak midpillar temperature is limited to 96°C or below.

The effort of the range of design thermal loading study then focused on developing a method to use the running average of midpillar index values as a loading rule for generating emplacement sequences from the estimated limiting waste stream that would meet the midpillar temperature criterion (SNL 2008a, Section 6.1.3). The seven-waste-package running average approach works in maintaining the midpillar temperature at or below the limit everywhere in the repository because: (1) seven packages correspond approximately to the pillar half-width (40.5 m), which is sufficient to blend the individual responses of the closest packages; and (2) the running-average approach is applied everywhere in the repository, at every possible waste package position. If all the waste packages in the repository have a midpillar index less than the midpillar temperature limit (which is not the case), then it is obvious that the midpillar limit will be met everywhere. However, the same condition is also met if the local, running-average index of thermal energy density is less than the midpillar temperature limit, even if some individual waste packages have index values that exceed the limit (SNL 2008a, Section 6.1.3).

Two emplacement sequences were generated from the estimated limiting waste stream, applying the different applicable loading rules. These realizations are designated the 85/4 case and the 96/2 case, as defined below (SNL 2008a, Section 6.1.3):

- 85/4 Case—Limits the midpillar index of thermal energy density for the seven-waste-package running average to a midpillar temperature of 85°C and allows an initial (prior to beginning emplacement) surface capacity for aging equivalent to 4 years of waste receipt at the repository.

- 96/2 Case—Limits the midpillar index of thermal energy density for the seven-waste-package running average to a midpillar temperature of 96°C and allows an initial surface capacity for aging equivalent to 2 years of waste receipt at the repository.

Aging of some of the incoming commercial SNF is necessary in both cases to accommodate TAD canisters shipped to the repository with thermal powers above 18.0 kW, and to have buffer capacity to balance throughput capability of the different processes involved in the handling and packaging of the waste. In particular, the initial buffer size (2 or 4 years of waste receipt) allows a wider range of commercial SNF to be available during the first few years of emplacement, when receipt rates are relatively low. The 85/4 case represents the coolest attainable thermal loading condition, in an average sense, and it is equivalent to the overall average midpillar index for the estimated limiting waste stream using the mean value of (wet) thermal conductivity for the lower lithophysal host-rock unit. In the 85/4 case, the codisposal waste packages (cooler) are distributed throughout the emplacement drifts, while in the 96/2 case approximately half of the codisposal waste packages are emplaced later, after the commercial SNF waste packages are emplaced (BSC 2007g).

The range of design thermal loading study also analyzed the drift-wall temperatures as part of the geochemical, geomechanical, and geohydrologic assessment of the range of design thermal loading by calculating a drift-wall index of energy density similar to how it was done for estimating the midpillar index. Results of those assessments are presented in Section 2.3.5.4.3. The resulting peak drift-wall temperature was calculated as approximately 160°C (less than the repository limit of 200°C), demonstrating that the drift-wall temperature limit is met. Drift-wall temperature for the estimated limiting waste stream overall average line load is shown in Figure 1.3.1-7 (SNL 2008a, Section 6.3.2.4). If the drift-wall temperature limit of 200°C is met, then the waste package surface temperature limit of 300°C will also be met for uncollapsed drift conditions because the calculated difference between waste package surface and drift-wall temperatures is generally less than 50°C and always less than 100°C. Results of cases previously analyzed for similar thermal conditions (BSC 2006b, Section 7) validated this assertion (SNL 2008a, Section 6.1.5).

Although credit for integrity of commercial SNF cladding is not taken for TSPA, a cladding temperature limit criterion (350°C) is still identified, and is met for the anticipated range of thermal loading based on the estimated limiting waste stream. Calculations (BSC 2008g, Section 6.2.1.16; BSC 2008h) have shown that the limit is not exceeded for waste packages with a thermal output of 11.8 kW. The estimated limiting waste stream includes waste packages with a thermal output of as much as 18.0 kW at emplacement. Whereas the previous studies did not evaluate for this higher output with sufficient ventilation (75 years is the maximum used in the previous analyses), the peak postclosure temperature is less than the peak preclosure temperature. The ventilation times for commercial SNF waste packages in the 85/4 and 96/2 emplacement sequences are approximately

70 years or longer. Thus, if the waste packages are loaded such that the arrangement of fuel assemblies limits preclosure cladding temperature to 350°C or less, then this limit will be met during postclosure (SNL 2008a, Section 6.1.6).

Thermal performance of emplacement sequences developed in the postclosure study of the range of design thermal loading was evaluated with a three-dimensional finite-element computer code. Four scenarios were simulated based on two time frames, preclosure and postclosure. The preclosure time frame includes heat removal by forced ventilation and the postclosure time frame assumes no ventilation. The simulation results show that all emplacement scenarios analyzed satisfy the preclosure and postclosure repository thermal requirements. Thermal results for the warmest condition simulated in the four scenarios are presented in Figure 1.3.1-7. Figure 1.3.1-7 (Part a) shows the thermal profile at the drift with the peak drift-wall temperature and Figure 1.3.1-7 (Part b) shows a history of drift-wall temperature adjacent to the hottest waste package simulated (SNL 2008a, Section 6.3.2.4).

An important finding of the postclosure study of the range of design thermal loading is that the overall average thermal line load for the estimated limiting waste stream is slightly cooler than the TSPA reference case (Figures 1.3.1-5 and 1.3.1-6). Although the preclosure ventilation periods differ in duration, the far-field thermal effects are closely comparable (SNL 2008a, Section 7.1).

WPLOAD V. 2.0 Analysis—To provide a more detailed simulation of a specific waste package emplacement sequence, the estimated limiting waste stream was analyzed using the WPLOAD V. 2.0 computer model. The WPLOAD V. 2.0 model uses a two-dimensional representation of the rock layer stratigraphy to determine the rock temperature history resulting from a specified heat flux into the drift wall. The unit flux pulse temperature response is then used in WPLOAD V. 2.0 to calculate temperature history at the midpillar rock location and at the drift wall. This method of calculating the midpillar temperature history is conservative because the cooling effects of water movement and vaporization within the rock are not taken into consideration in the two-dimensional conduction-only model (BSC 2007e, Section 4.3). The postclosure range of design thermal loading study concludes that apparent midpillar temperatures (conduction only) are up to 20°C higher than predicted by thermal-hydrologic models (SNL 2008a, Section 6.2). Therefore, additional waste package heat output can be accommodated in thermal-hydrologic simulations, corresponding to a calculated conduction-only temperature increase of up to 20°C, while still meeting the 96°C midpillar temperature limit. Thus, the WPLOAD approach can be used with a target temperature greater than 96°C while ensuring a drainage pathway exists through the midpillar location. To partially compensate for the conduction-only conservatism in the WPLOAD V. 2.0 calculation method, the upper limit of peak midpillar temperature was set at 99°C, instead of 96°C, for the analysis of the estimated limiting waste stream. The 99°C limit was selected because that was the coldest midpillar temperature limit at which all waste packages could be successfully emplaced under the conduction-only model. However, since there is up to a 20°C margin due to the neglected thermal-hydrologic effects, emplacement at 99°C conservatively ensures that the actual midpillar temperature is less than 96°C. A lower limit of 90°C, instead of 85°C, was also imposed on peak midpillar temperature in order to strategically maximize the HLW canister availability in later emplacement years and avoid using this cooler waste too early in the emplacement sequence (BSC 2007e, Sections 6.2.3 and 6.4).

A simulation was developed that considered the estimated limiting waste stream as time-phased waste deliveries to the repository. Upon receipt of the waste, it was handled, aged, or emplaced as appropriate to satisfy the repository thermal limits (Table 1.3.1-2).

The estimated limiting waste stream was then evaluated with the WPLOAD V. 2.0 model to determine whether each arriving TAD canister would be emplaced or aged upon receipt.

The following criteria were considered for selecting a TAD canister-bearing waste package for emplacement:

- Maximum emplacement limit of 18.0 kW per waste package
- Maximum line load limit of 2.0 kW/m
- Seven-waste-package segment thermal energy density that results in a midpillar thermal-energy-density index (temperature) of 99°C or less (as discussed above, this limit on the calculation method used by the WPLOAD V. 2.0 model meets the postclosure limit of 96°C)
- Nominal throughput capabilities for waste package closure at the CRCFs and the IHF
- Availability of the TEV for transport and emplacement of waste packages when completed by the CRCFs or the IHF.

Thermal envelopes for the naval SNF canister have been calculated for loss of ventilation events for both the handling of the naval SNF canisters in the IHF and naval SNF waste packages in the subsurface facility. The naval SNF canister temperature during handling of the naval SNF canister following receipt in the IHF, must be kept at or below 320°F during normal operations and below 400°F in the event of a 30-day interruption in ventilation. Normal handling and loading operations of the naval SNF canister in the IHF have been analyzed and results of those analyses are described in Section 1.2.3.4.

Specific operational thermal loading limits are used to limit the maximum naval SNF canister surface temperatures imposed on the naval SNF canister during normal or off normal operations following emplacement. Figure 1.3.1-8 forms the basis for acceptable operation with a naval waste package following emplacement. Normal handling, emplacement, and postemplacement operations of the naval SNF waste package in the subsurface facility will be performed so that the naval SNF canister temperature will stay within the thermal envelope shown in Figure 1.3.1-8, and off-normal conditions will be managed so that the canister temperature will stay within the same thermal envelope. The Naval Nuclear Propulsion Program uses this thermal envelope to evaluate naval SNF canisters that have a maximum overall thermal power of 11.8 kW and maximum peak axial heat load of 5.0 kW/m, and confirms that the naval SNF is not adversely affected by the thermal conditions (BSC 2007h, Section 6.2.1.3; BSC 2006c, Table 3). Therefore, the properties or characteristics of the naval SNF as used in the preclosure and postclosure analyses are preserved. Accordingly, with these tailored operational thermal loading limits for naval SNF waste packages, normal operations and loss of ventilation do not impact long term performance. Evaluations of potential misplacement of commercial waste packages that could potentially violate the naval SNF operational thermal loading limits during emplacement are described in Section 1.3.5.3.2.1.

The operational thermal loading limits for emplacing the naval SNF waste packages are more restrictive than the thermal limits for commercial SNF. These limits are (BSC 2008b, Section 8.2.1.5):

- Maximum emplacement thermal power of 11.8 kW
- A naval waste package cannot be emplaced in a seven-waste-package segment that contains another waste package with a thermal power in excess of 11.8 kW
- Maximum emplacement thermal line load of 1.45 kW/m for any seven-waste-package segment containing a naval SNF waste package.

Postclosure constraint 05-03 also identifies these naval SNF waste package operational thermal loading limits.

Although the maximum emplacement thermal power of naval waste packages will be 11.8 kW per waste package, the results of calculations that resulted in information shown in Figure 1.3.1-8 are based on a naval waste package with thermal power of 12.9 kW and a peak axial thermal load of 5.0 kW/m for the canister.

The naval SNF canisters will be received and packaged in the IHF at a rate of up to 24 canisters per year. The calculation for receipt and emplacement of waste has shown that the naval SNF can be accommodated with the proposed emplacement drift loading approach (BSC 2007e, Sections 6 and 7). No naval SNF will be staged at the Aging Facility.

The results of the WPLOAD V. 2.0 simulation as shown in Table 1.3.1-3 confirmed the results presented previously from the postclosure study of the range of design thermal loadings (SNL 2008a), demonstrating that emplacement of the 70,000 MTHM inventory allocated to the repository is possible and can be done in conformance with the preclosure and postclosure temperature limits (Table 1.3.1-2) in approximately 35 years. The calculation also demonstrated that the 63,000 MTHM of commercial SNF could be received in approximately 25 years, and emplacement of the full inventory may extend an additional 10 years, for a total waste packaging and emplacement period of approximately 35 years. Aging pad capacity was also estimated for this case, with a total capacity of less than 1,200 TAD canisters required at any given time (BSC 2007e, Section 7). A total capacity of 2,500 spaces is available for aging to account for additional potential variability in the waste stream received.

The examination of the estimated limiting waste stream with the WPLOAD V. 2.0 calculation method demonstrates the flexibility available to the repository, through its surface and subsurface facilities, to handle the waste stream variability that is likely to be experienced with the actual waste delivery sequence.

A simplified flow chart of the process involved in defining the repository waste stream and its characteristics, how that information is used for selecting the “estimated limiting waste stream” sequences, and to demonstrate acceptance and emplacement of the waste within the thermal and postclosure performance constraints is presented in Figure 1.3.1-9.

Emplacement Drift Loading Plan—The postclosure study of the range of design thermal loading and corroboration of those results with the WPLOAD V. 2.0 calculation indicate that the repository waste stream in the future, once characteristics of the waste to be emplaced are known for a specific emplacement drift or sets of emplacement drifts, can be managed effectively to meet the repository thermal limits (Table 1.3.1-2). The process of selecting a specific location for emplacement of a waste package within a drift will be defined in the emplacement drift loading plan. The use of each available waste package location is based on waste packages that are available for emplacement at a given time and on their thermal characteristics. The loading plan for each drift will specify waste characteristics, waste package emplacement locations, and ventilation duration. The plan will then show how preclosure and postclosure performance requirements will be met.

While in the surface handling facilities and prior to any underground emplacement considerations, each waste package is surveyed and inspected per procedures described in Section 1.2 to ensure that waste package surface contamination, if detected, is below the allowable threshold for emplacement. The surface of the waste package is also inspected for signs of damage that may affect its long-term performance (Section 1.2.4.2.4.2) in conformance with waste package surface damage postclosure criteria (BSC 2008a, Table 1, Derived Internal Constraint 03-18). Waste packages that are rejected as a result of these inspections are sent back for additional surface restoration or for repackaging or refurbishment if surface damage is unacceptable. Damaged pallets are also repaired or replaced (BSC 2008a, Derived Internal Constraint 03-20).

Type, size, and thermal power of a waste package, as determined through reactor and TAD canister loading records, are the primary variables for determining an emplacement location. As described below, waste packages are loaded so that their thermal power and thermal energy density do not exceed the specified limits at emplacement. Waste packages are emplaced at a nominal spacing of 10 cm from waste package to waste package.

The emplacement location for each waste package is determined based on seven-waste-package averages of thermal characteristics.

When the repository opens, more realistic waste receipt schedules can be developed consistent with the contractual requirements and once the utilities provide shipping plans. The sequence of waste packages received at the repository, as described in the estimated limiting waste stream (BSC 2006a) represents an estimate of what the repository waste stream may be like if contractual agreements with utilities, utility company priorities in shipping spent fuel, and other variables stay relatively consistent with the assumptions used. Although it is likely those variables will change in the future, the established computational methods can be applied with the revised information to represent how each drift will be loaded. Likewise, the analytical methods developed with the range of design thermal loading study (SNL 2008a) or enhancement of those methods, as well as the WPLOAD V. 2.0 model discussed above, are readily available for DOE to analyze the revised repository waste streams. A customized loading plan that meets overall repository thermal goals and applicable emplacement standoffs and constraints will be developed for each emplacement drift, once more definitive shipping schedules for spent fuel from the different utilities and other sources are provided. Analyses to ensure that naval SNF canister thermal limits are met will likewise be conducted for those drifts including naval SNF waste packages. Furthermore, each emplacement drift will be analyzed in an as-emplaced basis to demonstrate compliance with the TSPA bases.

Figure 1.3.1-10 illustrates a simplified representative process that will be used in the future for analyzing the loading plan for specific emplacement drifts, once the waste characteristics and available waste package inventory are known. In this representative process, a drift loading model that includes the appropriate process modules will be utilized to estimate the emplacement drift loading plan for each drift.

Figure 1.3.1-11 is a simplified representation of the emplacement drift loading process that incorporates the emplacement drift loading plan developed through the drift loading model.

Emplacement drift loading records will be kept and maintained in accordance with procedures described in Section 1.2.1.4.3.

In summary, acceptable thermal performance in the subsurface facility is ensured based on the following:

- An operational loading plan and process for determining an acceptable location for each waste package in their respective emplacement drift, for the expected waste forms and canisters to be delivered to the repository. This loading plan considers the thermal characteristics and limitations of each waste package, the integrated line thermal load for the emplacement drift, and the time remaining from emplacement to repository closure.
- Forced ventilation of the repository for a minimum of 50 years after emplacement of the last waste package.
- Availability of natural ventilation in the repository in the event of a temporary interruption of forced ventilation prior to repository closure.
- Availability of sufficient backup support systems and repair capability to restore forced ventilation within 30 days.

1.3.1.2.6 Repository Performance Monitoring

The in situ testing portion of the Performance Confirmation Program (Chapter 4) is implemented in the subsurface facility. The subsurface facility design includes one emplacement drift in Panel 1 for use in the Performance Confirmation Program as a test drift for studies of accelerated heating and cooling cycles with actual waste packages. Subsurface observation facilities, an observation drift and an alcove located beneath the performance confirmation test drift, are used to deploy instrumentation into the host rock to monitor the response of the natural barrier to waste emplacement.

1.3.1.2.7 Concurrent Development and Emplacement Operations

Subsurface development includes excavation of underground openings, as well as installation of ground support, infrastructure fixtures, testing, and commissioning of emplacement drifts. Repository emplacement and development activities occur concurrently, except during initial construction in Panel 1 and after the completion of the last panel. This period of initial construction is directed toward making available for waste emplacement the first three emplacement drifts in Panel 1 (BSC 2007i, Section 6.1). Isolation barriers are erected between the development and emplacement areas. These separated areas have individual and unique ventilation systems. A pressure differential is maintained between the two systems. The emplacement area has a negative air pressure relative to the atmosphere, while the development area has a positive pressure. The pressure differential ensures that airflow leakage between the systems is into the emplacement areas (BSC 2008c, Section 6). These features of the subsurface ventilation system are discussed in Section 1.3.5.

The layout for the emplacement drifts is based on a phased approach to development that supports the start of waste emplacement operations after initial construction. Concurrent, but separate, drift development and waste emplacement will continue until development is completed (approximately 24 years).

1.3.1.2.7.1 Sequence of Development and Operations

The subsurface layout is designed to be constructed in a four-panel sequence (Figure 1.3.1-1):

- **Panel 1**—The initial emplacement panel is located within the central section of the overall layout. The North Portal and the North Ramp are used for access to the repository horizon. Panel 1 supports initial waste emplacement.

- **Panel 2**—The second panel is developed at the south end of Panel 1, using the South Portal and the South Ramp for construction while emplacement continues in Panel 1 via the North Ramp.

- **Panel 3**—While Panel 2 is being constructed, the North Construction Portal and associated ramp will be developed, providing access for the construction of Panels 3 and 4. Panel 3 is developed to the immediate north of Panel 1. Panel 3 is divided into two subpanels, 3E and 3W, both accessed from the central access main extending from the North Construction Ramp.

- **Panel 4**—Panel 4 is developed to the west of Panel 3, extending to the western limit of the repository footprint. The northern portion of Panel 4 shares a common exhaust main with Panel 3 and will be constructed and turned over concurrently with the northern portion of Panel 3 (Subpanel 3-West).

1.3.1.2.7.2 Separation of Development from Operations

Each panel requires a specific amount of development work, including excavation and furnishing of access and exhaust mains, shafts, turnouts, and emplacement drifts. The general excavation process of a panel begins with the excavation of the access and exhaust mains, followed by the excavation of the ventilation shafts, and finally the turnouts and emplacement drifts. As the emplacement drifts within a panel become available to accept waste, the emplacement drifts are isolated from the ongoing development construction by installing isolation barriers (Section 1.3.5.1.3.2). The concurrent development and emplacement continue in this way until the repository is fully developed.

1.3.1.2.7.3 Development of the Initial Operating Capability

The first three emplacement drifts in Panel 1 must be completed in order to achieve initial operating capability and support initial waste emplacement. Development activities will also include completion of the nonemplacement openings needed to support waste emplacement. These activities include upgrades to existing facilities to be utilized by the repository for the initial operating capability.

The major activities that need to be completed for initial operating capability are (BSC 2007i, Appendix A, Table A1):

- **Tunnel Boring Machine Excavation**—An 18-ft-diameter tunnel boring machine will excavate four emplacement drifts, the Panel 1 exhaust main, and the access main cross-drift to Panel 4.

- **Drill and Blast or Roadheader Excavations**—Non-tunnel boring machine excavations include portions of six turnouts, the Observation Drift and Test Alcove, miscellaneous access drifts, electrical alcoves, and ventilation drifts.

- **Vertical Shaft Construction**—Construction of the ECRB Cross-Drift exhaust shaft, exhaust shaft 1, and an internal ventilation raise from Panel 1 to the level in the ECRB Cross-Drift.

- **Ground Support Installations**—These installations will include: (1) initial and final ground supports in three emplacement drifts (only the initial ground support is included in initial operating capability for the fourth drift); (2) ground support upgrades in the North Portal, North Ramp, and in approximately 1,100 ft of access main (existing ESF tunnel past emplacement drift 1-4); (3) support for the ventilation shafts and raise (rock bolts and concrete lining); and, (4) supports for miscellaneous openings (shaft and raise access drifts, exhaust main, observation drift and alcove, and electrical and communications equipment alcoves or niches).

- **Invert Structures, Rail, Electrical and Communications Equipment, and Ballast Construction**—Placement of concrete invert in the ESF North Ramp and 1,100 feet of access main. Place concrete and steel in three turnouts. Place invert steel and ballast in three emplacement drifts. Place TEV crane rail from the North Portal to the end of each of the three finished emplacement drifts. Completion of the transportation routes and the emplacement drifts will include installation of invert structures, crane rail, and TEV support systems consisting of electric power and communications. Invert structures for the North Ramp, access main and portions of the turnouts from the access main past the launch chamber are cast-in-place concrete structures with embedded rail supports. Invert structures in the circular sections of the turnouts and in the emplacement drifts are carbon steel frames supported on and bolted to the rock, with crushed tuff ballast filling in the spaces between the top of the invert structure and the drift rock wall and invert. Crane rail in the circular sections of the turnouts and in the emplacement drifts are installed on running beams attached to the invert steel structure. Third-rail power feeds are also attached to supports bolted or welded to the invert steel structure. The invert structure, rail, third-rail, and communications hardware along the access main will be installed past the isolation barriers that separate the initial operating capability emplacement area from the rest of Panel 1.

- **Ventilation Bulkheads and Isolation Barriers—**Installation of five isolation barriers, three emplacement access doors, and two ventilation bulkheads in the observation drift beneath Panel 1.

- **Surface Shaft Facility—**Construction of support structures, security fence, and permanent items at exhaust shaft 1. Development work for the initial operating capability will include installation of two ventilation fans at exhaust shaft 1, including: the associated motors, control systems, transformers, and other components; security fence; and, monitoring, instrumentation, and control systems.

The excavation of horizontal openings for the initial operating capability include approximately 18,000 linear ft for an excavated volume of approximately 318,000 yd^3. The excavation of vertical openings for the initial operating capability include approximately 2,500 linear ft for an excavated volume of approximately 62,400 yd^3 (BSC 2007i, Appendix A, Tables A1.1-1 and A1.2-1).

Support Systems—Design criteria, design considerations, and design descriptions for initial operating capability SSCs described in the following paragraphs are the same as described for similar structures in the subsurface facility and included in Sections 1.3.2 through 1.3.5.

Bulkhead Construction—Development activities for the initial operating capability will include the installation of three long-term isolation barriers on openings that connect the initial operating capability openings with existing facilities (ECRB Cross-Drift) or with future repository excavation areas (connector drift to Panel 3 area from access main, and connector drift to Panel 4 area from exhaust shaft 1). The openings to be excavated for initial operating capability and the isolation barrier locations are illustrated in Figure 1.3.1-12. There will also be two isolation barriers separating the initial operating capability emplacement area from the rest of Panel 1; one located on the access main and another on the exhaust main in opposite sides of the panel between drifts 1-3 and 1-4. All isolation barriers consist of dual bulkheads with airlock chambers in between the bulkheads.

Single bulkheads will also be installed at each of the three turnouts. These bulkheads include the emplacement access doors and the ventilation air regulator for each drift.

The observation drift excavation is connected to the air intake (North Ramp access main) through the existing heated drift test alcove at one end, and to the Panel 1 exhaust main at the other end. It is necessary to install a ventilation bulkhead at the intake end to regulate airflow into the observation drift and alcove, and another bulkhead at the opposite end to isolate the observation drift from the heated air in the exhaust main.

Special Considerations—A discussion of aspects of the initial operating capability development work, or work items in the Panel 1 area that are not included in the initial operating capability scope of work are as follows:

- **Turnout Excavations—**All of the non–tunnel boring machine excavated portions of the turnouts in Panel 1 will be excavated as part of the initial operating capability scope to minimize impacts from blasting shock on the isolation barriers, if those portions of the turnouts are excavated by drill and blast methods.

- **ECRB Cross-Drift—**Location of the ECRB Cross-Drift isolation barrier may be moved to a point farther to the southwest to avoid the area where the ECRB Cross-Drift crosses over the access main. This area has a concentration of boreholes connecting these openings which are conduits for air leakage, so placing the barrier farther west towards the center of the panel would avoid the boreholes.

- **Tunnel Boring Machine Removal—**The tunnel boring machine used for excavating the ECRB Cross-Drift was mothballed at the western end of the excavation. Removal of the tunnel boring machine is not part of the initial operating capability scope of work. This work will be accomplished during repository closure.

- **Access Main Cross-Drift to Panel 4 Area—**This excavation is included in the initial operating capability scope to complete the perimeter drifts for Panel 1, which are all excavated with the same 18-ft-diameter tunnel boring machine. This excavation is done to take advantage of the availability of the tunnel boring machine, and it facilitates subsequent development activities in adjacent areas of the repository without impacting emplacement activities in Panel 1.

1.3.1.2.7.4 Concurrent Development Hazards

Development operations, including all repository excavation and construction activities up to and including commissioning of the drifts for emplacement, will be controlled so that they are isolated from surface and subsurface repository facilities, support systems, and operations to preclude proximity interactions with waste receipt, handling, emplacement, or retrieval operations.

Isolation barriers separate the development activities from the emplacement activities in the subsurface facility. In order for a development activity to impact emplacement activities, these barriers would have to be breached. The isolation barrier is designed to withstand planned development and emplacement activities, and, therefore, any breaching would have to be the result of an off-normal event. Five types of events have the potential to breach the isolation barrier: fires, explosions, runaway trains and equipment, flooding, and air leakage across the barrier. The hazards analyses for the isolation barriers include scenarios involving equipment that could potentially be used in the construction side of the barrier, such as trains that are typically used for transportation of construction materials underground and for the haulage of excavated rock. Administrative procedures ensure explosives are used in a controlled manner to avoid any situation where the explosives could cause a direct challenge to waste package integrity or emplacement drift integrity. Such controls address limits on the types and amounts of explosive materials to be used and when and where they may be used relative to ongoing waste package emplacement activities.

The repository is a DOE facility and it is subject to 10 CFR Part 851, the DOE worker safety and health protection regulation. Part 851 incorporates by reference 29 CFR Part 1910 and Part 1926, as applicable, but OSHA has no regulatory authority at the repository. The DOE has exercised its authority under Section 4(b) of the OSHA regulations to self-regulate worker safety and health at the site.

Fires—The design basis fire for the development area is defined as a maintenance railcar fire lasting 3 hours. The fire-resistance rating of the isolation barrier is set at a minimum of 3 hours. In the case of such a fire, emplacement activities would be halted until development conditions are returned to normal (BSC 2007j, Section 7.2.3).

Accidental Explosion Due to Blasting Agent—To limit the potential for an explosion impacting emplacement operations, controls will be set to limit fuel sources, and administrative controls will be applied. Sources of a potential explosion are blasting agents or explosives and accumulations of flammable gas.

Explosives will be utilized in the construction of the repository. Accidental detonation of a blasting agent or explosive, although unlikely, is considered as a possibility. To ensure that construction activities do not interfere with repository operations, construction activities are physically isolated from the emplacement operations by isolation barriers and distance. Additionally, administrative controls will limit the use of explosives in proximity to the isolation barriers.

Storage, handling, underground transportation, and use of explosives will conform to DOE worker safety and health protection regulations.

Administrative controls common to the mining and tunneling industries that will be implemented include:

- Prohibiting storage of explosives near bulkheads or ventilation controls
- Prohibiting electrical cables or energized equipment near explosive storage magazines
- Requiring locks on explosive storage magazines
- Limiting the capacity of explosive storage magazines and transportation boxes to only the material required for a shot or to complete a shift
- Limiting the size of explosive rounds and the proximity to isolation barriers.

Should an explosion occur that damages an isolation barrier, emplacement activities will be halted until the isolation barrier is repaired.

Accidental Explosion of Flammable Gas—Flammable gases may also be present within the repository. Sources of flammable gases are bottled fuel, such as acetylene, and products of chemical reactions, such as hydrogen produced during battery charging. Administrative controls, including locations and quantities of bottled fuel and ventilation requirements for battery charging, will be established to limit the possibility of an accidental ignition of flammable gas accumulations.

The repository will conform to DOE worker safety and health protection regulations for cutting and welding, which require site-specific fire protection plans addressing use of flammable gases and liquids, and for underground ventilation, to specifically address the ventilation practices required to minimize the potential for the accumulation of explosive gases.

Administrative controls and physical controls common to the tunneling and mining industry that will be put into place include:

- Proper ventilation of battery charging stations
- Frequent inspections of underground areas by qualified people for gas accumulations.

Should an explosion of flammable gas occur, emplacement activities would be halted until normal conditions are restored.

Runaway Equipment—Mechanical breaching of an isolation barrier due to runaway equipment, such as a railcar, is possible. This type of isolation barrier breach may be limited by the use of a derailer on any tracks leading into an opening with an isolation barrier or administrative controls limiting operations. Additionally, a crash barrier may be placed in front of each isolation barrier to decrease the potential impact of a runaway vehicle. Administrative and physical controls may also be used to limit the speed of subsurface vehicles. If a runaway event occurs and causes a breach of an isolation barrier, emplacement activities would be halted until the breach is repaired.

Flooding—Rupture of water pipes installed to support construction could result in water accumulation in isolation barrier areas. Limited quantities of water may penetrate or infiltrate around the bulkhead and reach the emplacement side. If such a breach of the barrier occurs, water flow can be controlled by manually activating the stop valves in the water lines or by having pumps available to respond to water accumulations. Emplacement operations will be halted until conditions are returned to normal. Due to the higher elevation of the emplacement drifts, water cannot flow into the emplacement drifts from either the access mains or the exhaust mains.

Isolation Barrier Leakage—The isolation barrier is designed to separate the emplacement ventilation system from the development ventilation system. The development ventilation is a supply system, while the emplacement ventilation is an exhaust system, so, if there is leakage across an isolation barrier, the airflow direction is from the development side to the emplacement side. This design ensures that air potentially contaminated from emplacement activities would not impact development activities.

Because of this potential for barrier leakage, it would be possible for smoke and/or fumes to migrate to the emplacement side of the barrier in the event of a fire or explosion. Regular inspection and maintenance of the barriers will be performed to limit this possibility. Emplacement activities will be halted until the smoke and fumes are dissipated and the source is extinguished.

1.3.1.2.8 Waste Retrieval Operations

Section 1.11 provides a description of the waste retrieval plans. Waste retrieval operations, if that option is exercised, take place in the subsurface facility using the same or similar SSCs as those used for waste package transportation and emplacement.

The expected operational concepts within the subsurface facility for retrieving the waste packages are those performed in the waste emplacement process, but in reverse order. The retrieval process starts with cooling the emplacement drift with sufficient volumes of ambient air to bring the emplacement drift air temperature down to a level suitable for equipment operation. Next, the TEV retrieves the waste package and emplacement pallet. The TEV moves each retrieved waste package to the surface facilities or to an alternate staging area for further disposition.

1.3.1.2.9 Repository Closure Operations

When the license amendment to close the repository is issued, the openings connecting the repository level to the surface will be backfilled and the repository will be closed following the process described in Section 1.3.6. The closure activities begin with the emplacement of the drip shields. The drip shields are installed inside the emplacement drifts as a continuous cover over the waste packages. A drip shield emplacement gantry is used for this operation. This phase of closure requires full ventilation capabilities to maintain equipment environmental conditions. Completion of drip shield emplacement is followed by removal of noncommitted materials in the nonemplacement areas of the repository. Closure activities continue with placement of backfill in the access ramps and shafts and conclude with restoration where the repository openings meet the surface. Boreholes that may serve as conduits of water to the emplacement areas will be backfilled and capped during the repository development phase. Any boreholes drilled after completion of development will be backfilled and capped prior to closure. At the end of the closure phase, permanent monuments and markers are installed on the surface at the geologic repository operations area and site to identify the repository location, history, and contents (Section 5.8) (10 CFR 63.51).

Materials and equipment that are not committed as permanent features of the nonemplacement areas of the repository are removed at closure. Committed materials are defined as materials installed during construction and used during operations of the repository and that remain underground after repository closure. Committed materials estimates (Section 1.3.6.1.3) are developed for the emplacement areas and for the nonemplacement areas and are considered in the repository performance assessment (Table 2.2-3, Parameter 02-03). Quantities and composition of committed materials in the emplacement drifts are monitored and recorded during construction, operations, and closure to ensure they remain within the estimates addressed in the repository performance assessment analytical bases (BSC 2008a, Table 1, Derived Internal Constraint 02-03).

1.3.1.3 Subsurface Facility Interfaces with Facilities and Systems *[NUREG-1804, Section 2.1.1.2.3: AC 6(1), (2)]*

The subsurface facility interfaces directly with the following repository facilities and systems, described in the sections below.

1.3.1.3.1 Facilities

Initial Handling Facility and CRCF 1, 2, and 3—The subsurface facility accepts waste packages from the IHF and from the CRCF 1, 2, and 3.

Heavy Equipment Maintenance Facility and Miscellaneous Repository Facilities—Waste package transportation and emplacement equipment and other support equipment are maintained at miscellaneous repository facilities.

1.3.1.3.2 Major Systems

Waste Packages (Section 1.5.2)—The subsurface facility provides space for the disposal of waste packages.

Waste Emplacement (Sections 1.3.3 and 1.3.4) and Retrieval (Section 1.11)—The subsurface facility provides the openings and the infrastructure for this system to operate underground.

Performance Confirmation (Chapter 4)—The subsurface facility provides the openings and the infrastructure for performance confirmation activities.

1.3.1.3.3 Infrastructure Systems

Digital Control and Management Information (Section 1.4.2)—This system provides the infrastructure, hardware, and software for operational controls of subsurface equipment.

Environmental and Meteorological Monitoring (Section 1.4.2)—This system monitors environmental parameters in the underground environment and around the repository site.

Radiation and Radiological Monitoring (Section 1.4.2)—This system monitors radiation throughout the repository facilities.

Site-Generated Radioactive Waste Management (Section 1.4.5)—This system collects, processes, and disposes of site-generated radiological waste, including any such waste potentially generated in the subsurface facility.

Nonradioactive Waste Management (Section 1.4.5)—This system collects, processes, and disposes of nonradioactive waste found or brought into the subsurface facility.

Electrical Power (Section 1.4.1)—This system provides power sources for subsurface facility operations.

Electrical Support (Section 1.4.1)—This system provides electrical power distribution within the subsurface facility to support individual equipment electrical current type and load requirements.

Plant Services (Section 1.4.4)—This system provides miscellaneous support services to the subsurface facility, such as water service and equipment maintenance.

Communications (Section 1.4.2)—This system provides infrastructure, hardware, and software for operational and emergency communications underground.

Fire Protection (Section 1.4.3)—This system provides and manages fire detection and protection equipment in the subsurface facility.

Safeguards and Security (GI Section 3)—This system provides access control features and administrative procedures for the subsurface facility to comply with repository safeguards and security requirements.

Subsurface Ventilation (Section 1.3.5)—This system provides the structures, equipment, and repository operation to maintain the subsurface facility air quality, quantity, and rates needed to support operations and thermal management goals.

Additional information on subsurface SSC interfaces within the subsurface facility and with other repository facilities and systems are described in the individual design descriptions in Sections 1.3.3 through 1.3.6.

1.3.1.3.4 Interfaces During Repository Development

Turning over of completed emplacement drifts from development to operations will be an ongoing interface activity throughout the subsurface repository development phase. This process, referred to as emplacement drift commissioning, will go on for several years. The major activities included in drift commissioning are as follows (BSC 2008d, Section 4.3):

Inspection and Turnover of Emplacement Drift SSCs—This activity will include final inspections of all structures within a drift, such as ground support, invert steel and ballast, crane rail, and third rail conductor. The successful turnover acknowledges that the construction, installations, and inspections have been performed in conformance with approved engineering drawings, codes, and specifications. The areas to be released will have been demonstrated to comply with the applicable license specifications.

Functional Testing of Emplacement Drift SSCs—Functional tests are the responsibility of the startup organization with assistance from the operations organization so that operations personnel can become familiar with equipment and systems (Section 5.5). This activity will include system functional testing, such as the rail system for a group of emplacement drifts.

Cold Integrated System Testing—These tests will verify the overall functionality and operating procedures of the emplacement drift using simulated waste packages. This testing will cover the complete waste package transportation and emplacement cycle from loading of the TEV at the surface facilities to retrieving of a surrogate waste package from the subsurface.

Hot System Testing—Once a license amendment to receive and posses nuclear waste is received from the U.S. Nuclear Regulatory Commission, hot testing or initial startup operations will begin. Hot testing will demonstrate the ability, using actual operating procedures, to emplace waste packages.

Other important subsurface operational interface activities that will take place during the development phase will include: construction blasting, isolation barrier removal and relocation, offsite deliveries of potentially committed materials, emergency response, site-generated waste management, and safeguards and security (BSC 2008d, Section 4.2).

1.3.1.4 Conformance of Design to Criteria and Bases

[NUREG-1804, Section 2.1.1.7.3.1: AC 1(5), (9); Section 2.1.1.7.3.2 AC 1(1)]

Summaries of safety functions and the associated nuclear safety design bases and design criteria satisfied by the design of subsurface components classified as important to safety, are presented in Section 1.3.3 (Table 1.3.3-5).

Summaries of parameters related to the design of the subsurface facility and SSCs with postclosure-derived requirements, and pertinent to this section, are presented in Table 1.3.1-4. Table 1.3.1-4 contains information on the type of control, either configuration management or procedural safety, that will be implemented to ensure the parameter conditions and characteristics that contribute significantly to postclosure performance are established or maintained.

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Table 1.3.1-1. Types of Openings and Overall Excavation Summary for the Underground Layout

Heading	Description	Size of Opening and Geometry		Plan Length	
		(m)	(ft)	(m)	(ft)
Emplacement Drifts	Repository for waste packages.	5.5 diameter	18 diameter	67,915[a]	222,781
Turnouts	Opening connecting access main to the emplacement drift. Note: The turnout cross-sectional areas vary in shape and dimensions for each of the areas of the turnout designated as: rail turnout segment, turnout bulkhead segment, launch chamber, turnout curve, and TEV alignment segment (Figure 1.3.3-13).	Varies	Varies	10,954	35,901
North Construction Ramp	Construction access and ventilation airway to the emplacement areas.	7.62 diameter	25 diameter	2,884	9,462
ESF Tunnel (North Ramp, South Ramp, and Main Drift Connecting the two ramps)	Existing excavations that will become part of the repository. The North Ramp provides access to the emplacement areas and is utilized as an intake airway. The South Ramp provides construction access and is also utilized as an intake airway. The main drift connecting the two ramps becomes the access main for Panels 1 and 2.	7.62 diameter	25 diameter	7,877	25,843
Access/Exhaust Main[b]	Access to emplacement areas and ventilation airways.	7.62 diameter	25 diameter	16,991	55,746
Exhaust Main (Dual)	Dual exhaust mains allow construction in one panel concurrent with waste emplacement operations in adjacent panel.	7.62 diameter	25 diameter	1,516	4,975
Exhaust Main (Panel 1)	Smaller diameter exhaust main for Panel 1 excavated with same tunnel boring machine used for excavating emplacement drifts.	5.5 diameter	18 diameter	555	1,820
Access Main Offset Drift	Access main extension parallel to the southern end of the access main for Panel 2.	7 × 7	23 × 23	143	469
Connector Drift (Panel 1)	Drift connecting access main for Panels 1 and 2 with access main for Panels 3E and 3W.	7 × 7	23 × 23	58	189
Cross Drift to Panel 4	Drift connecting access main for Panels 1 and 2 with access main for Panel 4.	5.5 diameter	18 diameter	900	2,951

Table 1.3.1-1. Types of Openings and Overall Excavation Summary for the Underground Layout (Continued)

Heading	Description	Size of Opening and Geometry		Plan Length	
		(m)	(ft)	(m)	(ft)
Observation Drift and Observation Alcove (Panel 1)	Excavation used for installing instrumentation, monitoring and testing equipment used in Performance Confirmation Program.	5 × 5	16 × 16	1,011	3,317
Panel 3 Exhaust Main Access	Construction access from Panel 4 access main, north end, to the Panel 3W exhaust main.	7 × 7	23 × 23	200	656
Exhaust Raise Access Drift	Opening to access exhaust raise from exhaust main.	5 × 5	16 × 16	221	726
Ventilation Raise to ECRB Cross-Drift Access	Opening to ECRB Cross-Drift raise from exhaust main in Panel 1.	3.7 × 3.7	12 × 12	23	75
Ventilation Raise to ECRB Cross-Drift (Panel 1)	Vertical excavation to ECRB Cross-Drift from Panel 1 exhaust main.	3.75 diameter	12 diameter	29	95
Ventilation Raise Access at ECRB Cross-Drift	Opening to access ventilation raise from ECRB Cross-Drift.	3.7 × 3.7	12 × 12	23	75
Access to ECRB Cross-Drift Raise	Opening to access exhaust raise to ECRB Cross-Drift from Panel 4.	7 × 7	23 × 23	30	99
Ventilation Raise to ECRB Cross-Drift (Panel 3)	Vertical excavation to ECRB Cross-Drift from Panel 4 used as an exhaust airway.	8 diameter	26 diameter	29	95
ECRB Cross-Drift Access to Raise	Opening to access ventilation raise from ECRB Cross-Drift.	7 × 7	23 × 23	27	88
ECRB Cross-Drift Widening	Widening of the ECRB Cross-Drift to the shaft in the ECRB Cross-Drift in the vicinity of Panel 4.	7 × 7	23 × 23	318	1,042
Intake/Exhaust Shaft	Vertical excavations used as intake and exhaust airways from repository horizon to surface.	8 diameter	26 diameter	2,499	8,199
Exhaust Shaft	Small diameter airway in Panels 1 and 3.	5 diameter	16 diameter	635	2,082
Intake Shaft #4 Access Drift	Opening connecting intake shaft to access main.	7.62 diameter	25 diameter	1,384	4,541
Exhaust/Intake Shaft Access Drift	Drifts connecting exhaust shafts to exhaust mains and intake shafts to access mains.	8 × 8.5	26 × 28	1,812	5,946

Table 1.3.1-1. Types of Openings and Overall Excavation Summary for the Underground Layout (Continued)

Heading	Description	Size of Opening and Geometry		Plan Length	
		(m)	(ft)	(m)	(ft)
Construction Shaft Access (Panel 3)	Construction opening connecting Panel 3 Exhaust Main to Exhaust Shaft #1.	5 × 5	16 × 16	31	102
Assembly/Disassembly Chambers	25-ft-diameter tunnel boring machine startup chambers in multiple locations.	11 × 11	36 × 36	240	787

NOTE: [a]Value reported is the total excavated length of emplacement drifts. This total excavated length, after the appropriate standoff distances and other applicable constraints are applied to each emplacement drift, results in 65,209 m of total available emplacement length for the repository (BSC 2007a, Tables 9 and 10; BSC 2003, Section 8.8).
[b]Excavation data provided for "Access/Exhaust Main" only includes new construction. North Ramp, South Ramp, and existing portion of ESF tunnel that becomes an access main are not included in the "Access/Exhaust Main" excavation quantities because they are existing openings (see fourth item in table). The opening sizes are nominal and other variations of excavation sizes and dimensions may also exist. All excavation information is obtained from first source (BSC 2007a) except for the excavation information for the existing ESF openings (CRWMS M&O 1996).

Source: BSC 2007a, Table 9; CRWMS M&O 1996, Figure 3.

Table 1.3.1-2. Repository Subsurface Facility Temperature Limits

Parameter	Limit	Period of Applicability
Rock temperature at midpillar	96°C maximum	Preclosure and Postclosure
Emplacement drift-wall temperature	200°C maximum	Preclosure and Postclosure
Waste package surface temperature	300°C for first 500 years 200°C for the next 9,500 years	Preclosure and Postclosure
Commercial SNF cladding temperature upon emplacement[a] Commercial SNF cladding maximum temperature	350°C 570°C for off-normal and accident conditions	Preclosure and Postclosure Preclosure
HLW waste form temperature	400°C	Preclosure and Postclosure
Naval SNF canister temperature	See Figure 1.3.1-8	Preclosure and Postclosure

NOTE: [a]The 400°C normal temperature limit for commercial SNF cladding applicable to the surface facilities (BSC 2008b, Section 11.2.2.4) is invoked as also applicable while transporting the waste packages for emplacement by the TEV.

Source: BSC 2008b, Sections 11.2.2, 12.2.2, and 22.2.1; BSC 2008a, Table 1, Derived Internal Constraints 04-05, 04-06, 05-03, 06-02, 06-03, 06-04, 06-05; BSC 2008i, Figure 7.

Table 1.3.1-3. Estimated Limiting Waste Stream Characteristics and Emplacement Sequence Results

Input Parameters	
Commercial SNF waste stream	ELWS YFF5 22.0 kW
DOE SNF and HLW stream	On-demand
Repository host rock (Tptpll) layer thermal properties used to determine midpillar rock temperature	Global-mean value of thermal conductivity
Repository host rock (Tptpll) layer thermal properties used to determine drift wall temperature	10th-percentile value of thermal conductivity
Upper limit on waste package thermal power at emplacement	18.0 kW
Upper limit on emplacement drift linear thermal power at emplacement	2.0 kW/m
Upper limit on peak midpillar temperature[a]	99°C
Lower limit on peak midpillar temperature[a]	90°C
Year to begin accepting waste	2017
Year of repository initiation of closure	2117
Results	
Number of emplacement drifts used	91
Year to finish emplacement	2052
Required aging pad capacity	1,134 TAD Canisters

NOTE: [a]The reported "peak midpillar temperature" in this table corresponds to the bounding temperature at the midpillar, as calculated in the conduction-only two-dimensional model used to support the engineering studies of the estimated limiting waste stream. The midpillar temperature is also referred to as the "index of thermal energy density" or "thermal-energy-density index" when resulting from the thermal energy density associated with a seven-waste-package segment or "unit cell" (Section 1.3.1.2.5).
ELWS = estimated limiting waste stream; YFF5 = waste package sequence identified as the estimated limiting waste stream.

Source: BSC 2007e, Table 11, Case 3a.

Table 1.3.1-4. Summary of Conformance of Subsurface Facility Design to Postclosure Control Parameters—Thermal Management

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**			
Waste Package	03-11 Waste Package Decay Heat (Controlled Interface Parameter)	The postclosure design basis waste package decay heat shall be controlled through the configuration management system (Section 5).	No	NA (Background information: The decay heat characteristics for waste forms contained within the waste packages are used in calculations supporting Section 1.3.1.2.5, Thermal Management.)	Decay heat characteristics for the waste inventory are captured in qualified information received as part of the waste title transfer and are used for calculating emplacement drift loading plans for individual drifts. These calculations will be performed once the specific waste to be placed in waste packages which will then be emplaced in specific drifts is identified. The process for developing emplacement drift loading plans is described in Section 1.3.1.2.5.

Table 1.3.1-4. Summary of Conformance of Subsurface Facility Design to Postclosure Control Parameters—Thermal Management (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	05-03 Waste Package Thermal Limits	The waste package emplacement shall be within an envelope such that the emplacement of waste packages does not exceed the other relevant thermal limits of mid-pillar temperature, drift wall temperature, waste package temperature, and cladding temperature. In addition, the local-average line-load (over any seven-waste-package segment) in the emplaced repository will not exceed 2.0 kW/m, and no waste package shall exceed thermal output of 18 kW. Finally, the calculated thermal energy density of any seven adjacent as-emplaced waste packages shall be controlled such that the temperature shall not exceed 96°C at the mid-pillar, calculated using mean host-rock thermal properties and representative saturation levels for wet and dry conditions. In addition, the thermal loading limits for the naval SNF waste packages are lower than the thermal limits for commercial SNF. These limits are (BSC 2008b, Section 8.2.1.5): • Maximum emplacement thermal power of 11.8 kW. • A naval waste package cannot be emplaced in a seven-waste-package segment that contains another waste package with a thermal power in excess of 11.8 kW. • Maximum emplacement thermal line load of 1.45 kW/m for any seven-waste-package segment containing a naval SNF waste package.	Yes	NA (Background information: This requirement is integrated into the thermal management criteria for the repository as stated in Table 1.3.1-2; as design criteria that ensure that 70,000 MTHM can be emplaced within the repository thermal limits; and, as design criteria for the subsurface ventilation system in Section 1.3.2.4.5.2. The thermal energy density criterion is used to develop and demonstrate the ability to maintain repository thermal limits by emplacing waste packages in a seven waste package segment. This analytical process is described in Section 1.3.1.2.5.)	Waste Package Loading plans will be developed using the methodology described in Section 1.3.1.2.5. The loading plans, when implemented, will result in emplaced sequences of waste packages that satisfy the midpillar temperature criterion. This ensures conformance with the repository thermal limits during preclosure and postclosure.

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

Source: BSC 2008a, Table 1.

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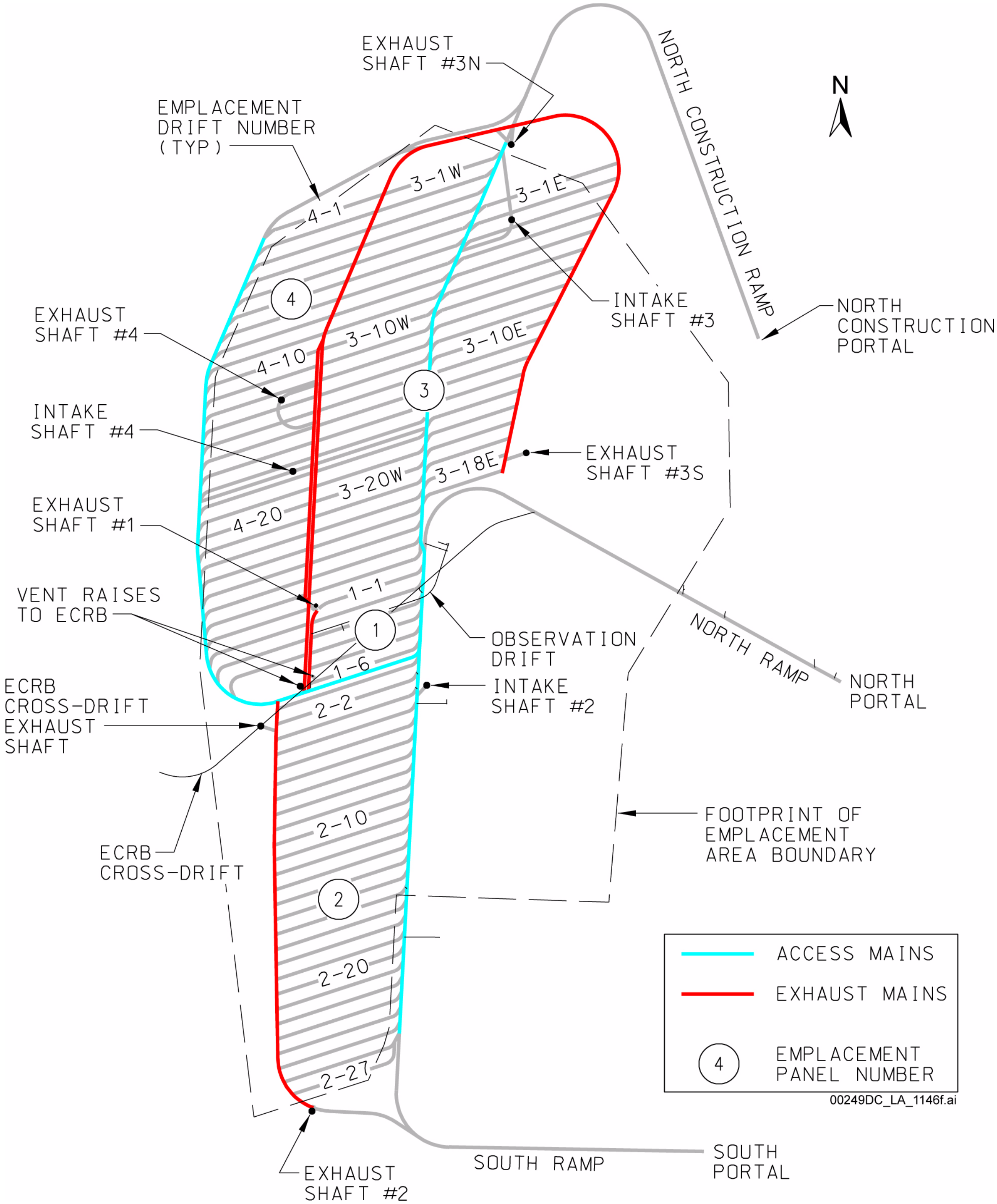

Figure 1.3.1-1. Subsurface Facility Layout

NOTE: The "footprint of emplacement area boundary," shown in the figure as a dashed-line boundary, defines the boundary of the area meeting the location-relevant design control parameters identified in Table 1.9-9, in particular, control parameters 01-01, 01-04, 01-05, 01-06, 01-07, 01-20, 01-21, and 01-22. The general use of the term repository footprint or footprint as used in Chapter 2 corresponds to the layout of the emplacement drifts characterized by the waste package nominal end-point coordinates defined by control parameter 01-02.

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NOTE: Grid is in feet and based on the Nevada State Plane coordinate system, central zone, North American Datum of 1927 (NAD 27).

Figure 1.3.1-2. Overall Repository Site Plan

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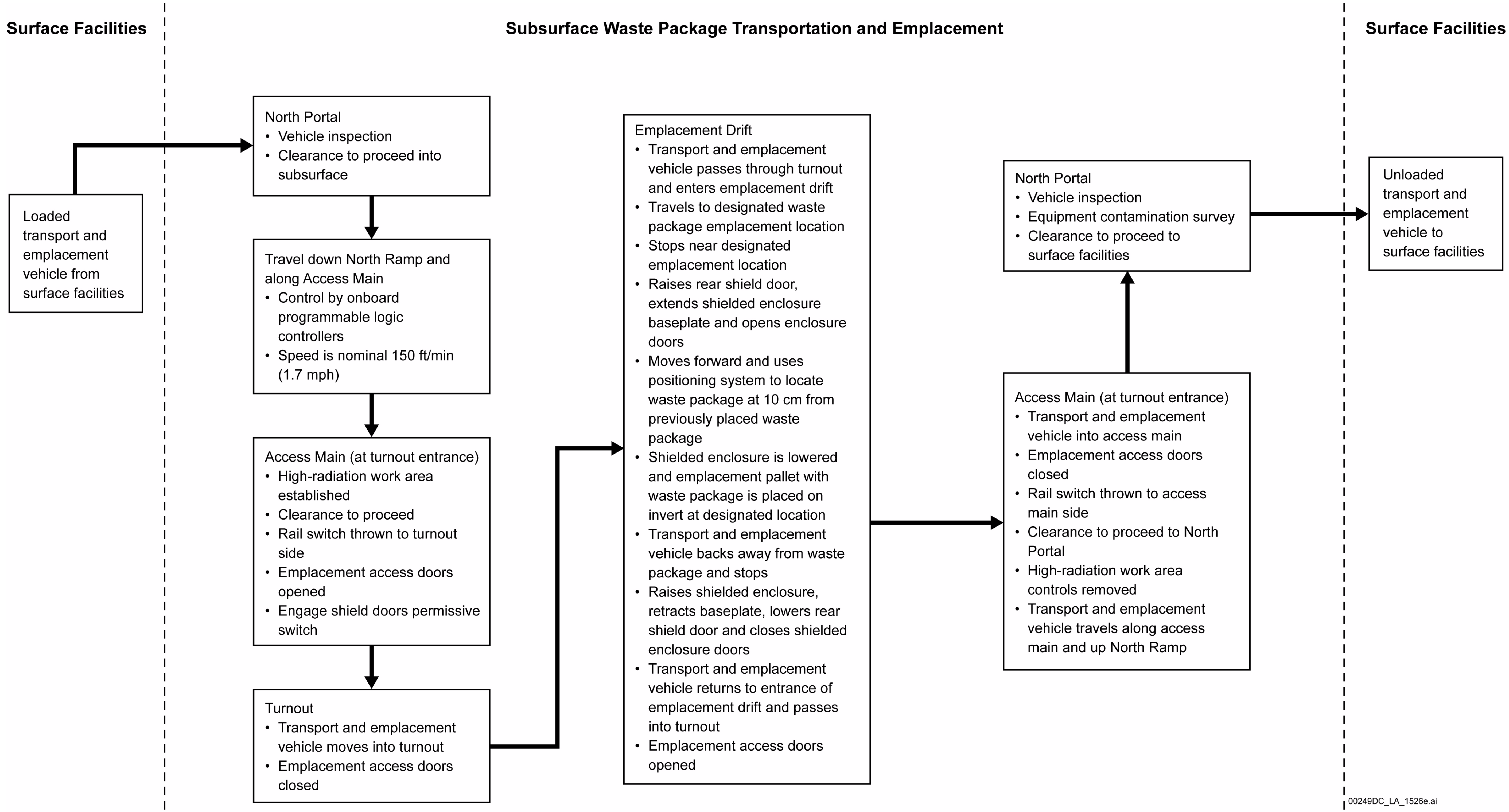

NOTE: Electric power supplied from third rail throughout surface and subsurface facilities.

Figure 1.3.1-3. Subsurface Waste Package Transportation and Emplacement Block Flow Diagram

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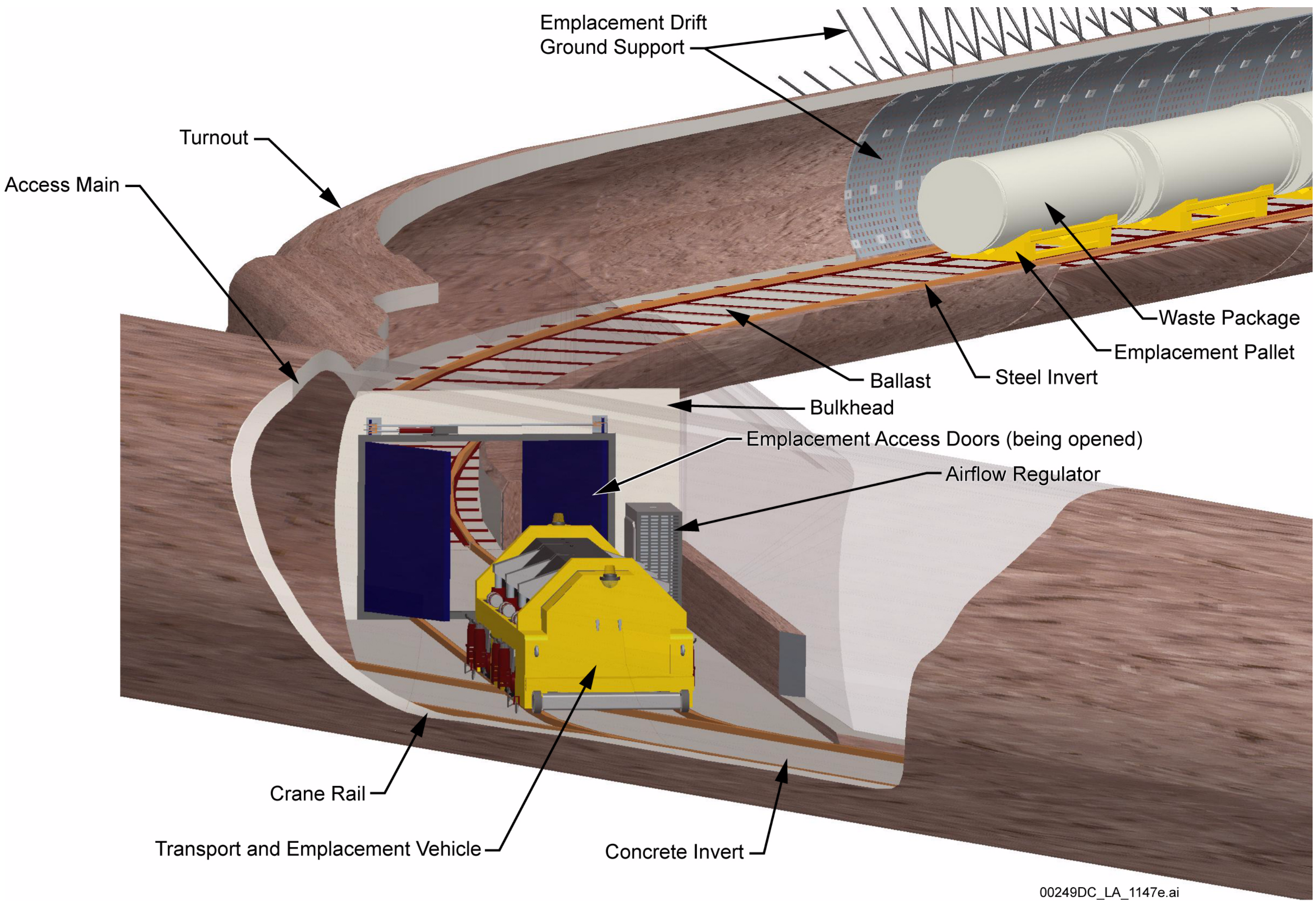


Figure 1.3.1-4. Illustration of Turnout, and Waste Package Transportation and Emplacement Equipment

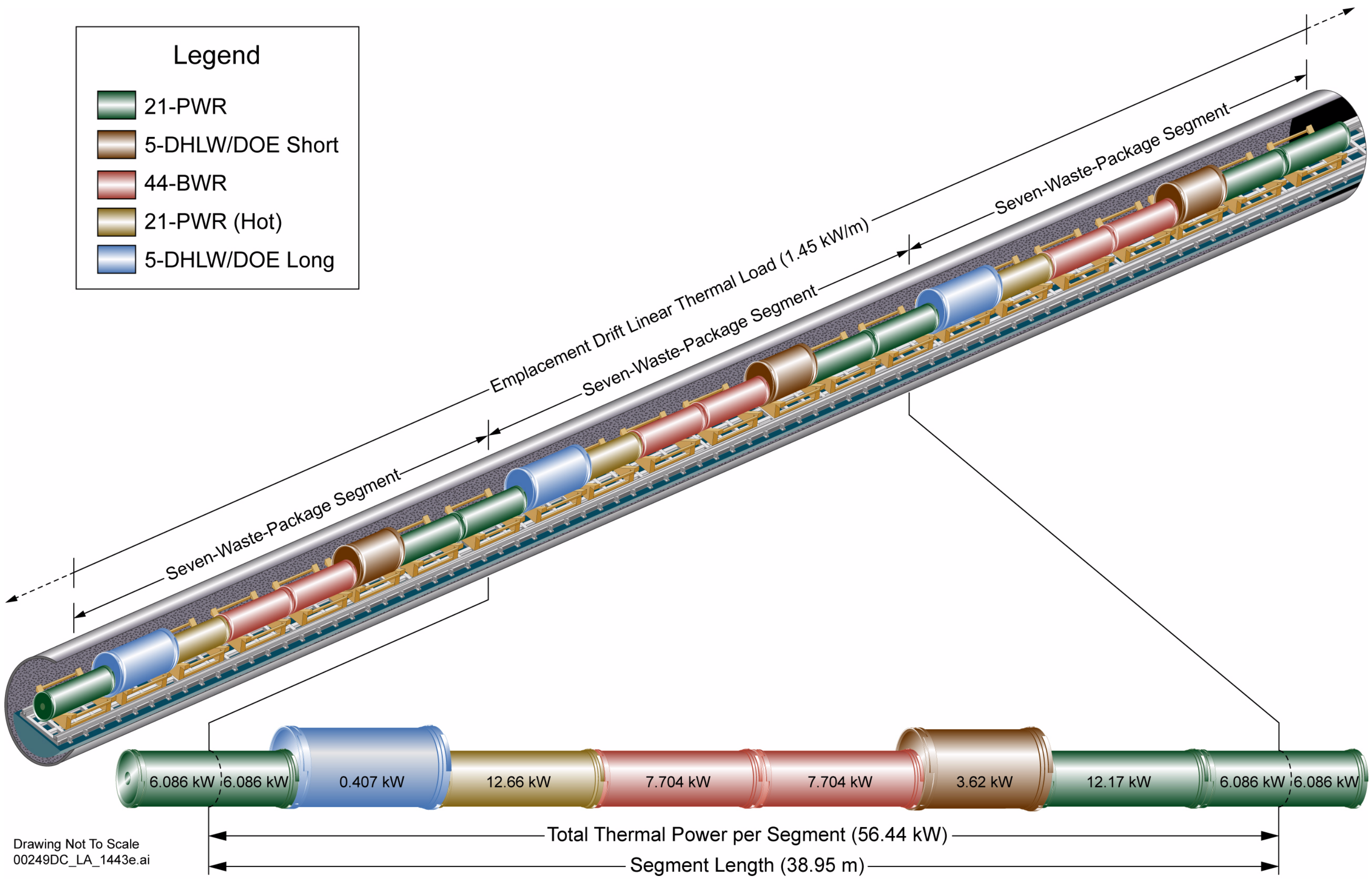


Figure 1.3.1-5. Representation of Contiguous Waste Package Segments Emplaced in a Drift for the TSPA Reference Case Thermal Line Load

NOTE: The segment length includes a nominal 10-cm space between waste packages. "Hot" denotes a 21-PWR waste package loaded above the nominal 21-PWR thermal power.
BWR = boiling water reactor; DHLW = defense high-level radioactive waste; PWR = pressurized water reactor.

Source: SNL 2007b, Section 7.1[a] and Tables 7-3[a], 7-4[a], and 7-5[a]; SNL 2008b, Table 6.2-6[a].

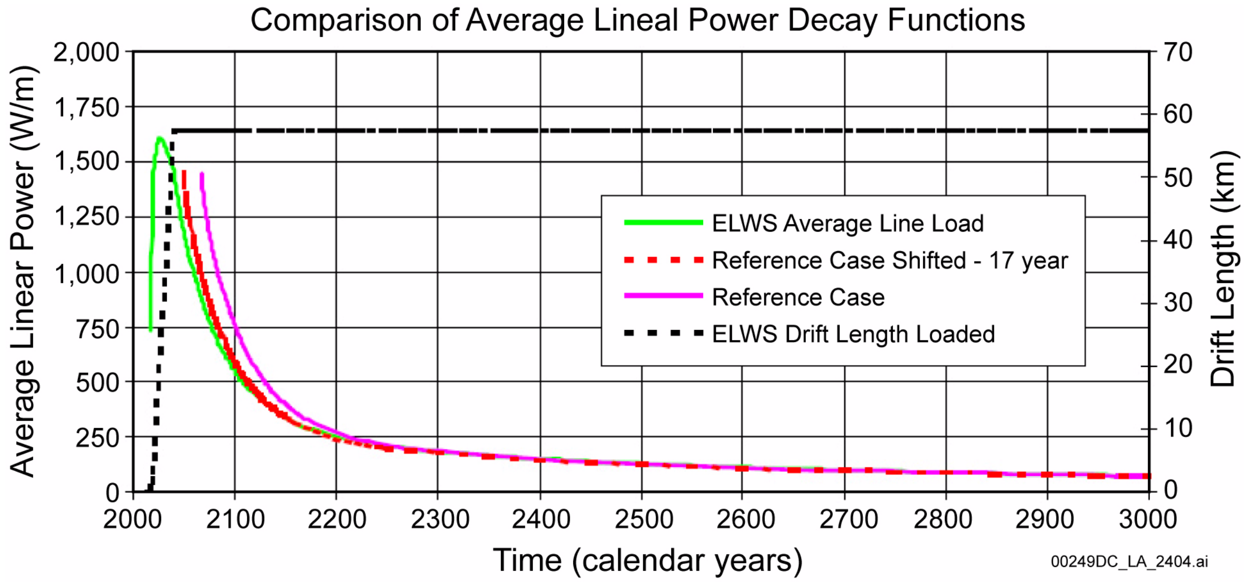
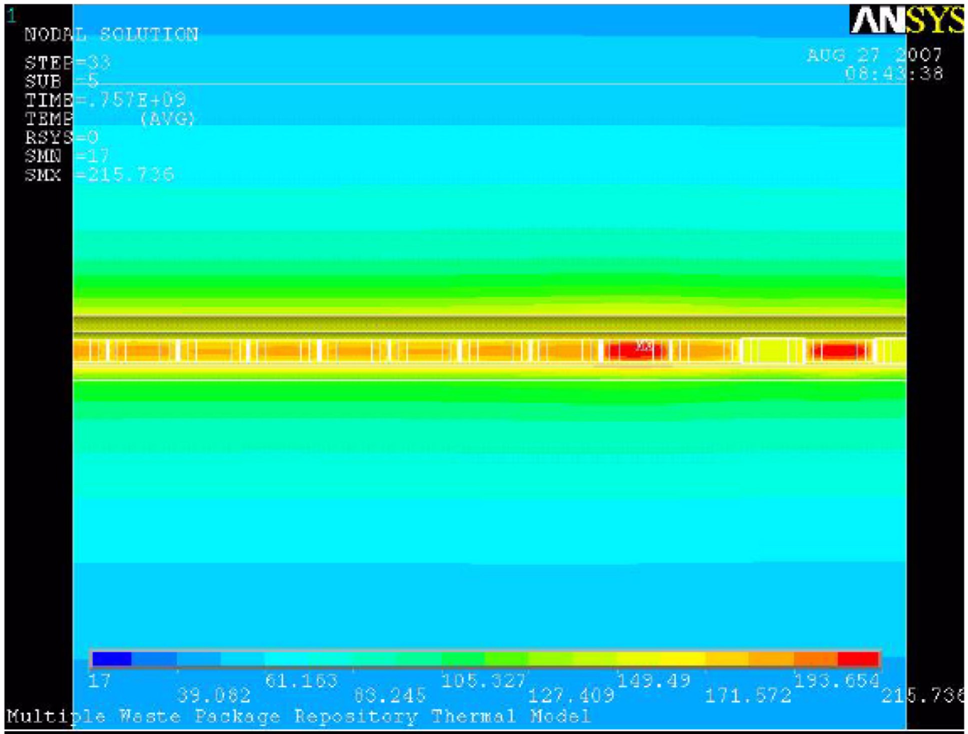


Figure 1.3.1-6. Comparison of Linear-Load Power Functions between the Estimated Limited Waste Stream Case and the TSPA Reference Case

NOTE: ELWS = Estimated Limited Waste Stream.

Source: SNL 2008a, Figure 6.1-1.

(a) Thermal Profile in Drift with the Peak Drift-Wall Temperature, Scenario 4



(b) Hottest Drift-Wall Temperature History, Scenario 4

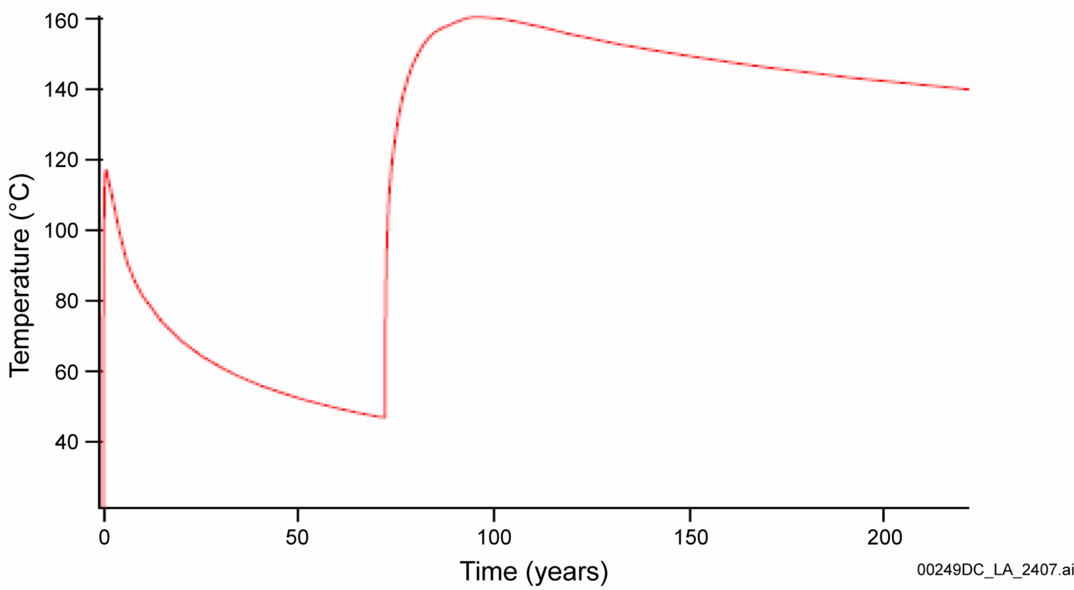


Figure 1.3.1-7. ANSYS Model Results for Warmest Emplacement Drift

NOTE: This result is calculated for the 10th percentile value of thermal conductivity for the lower lithophysal (Tptpll) host rock unit. ANSYS refers to ANSYS V. 8.0.

Source: SNL 2008a, Figures 6.3-14 and 6.3-15.

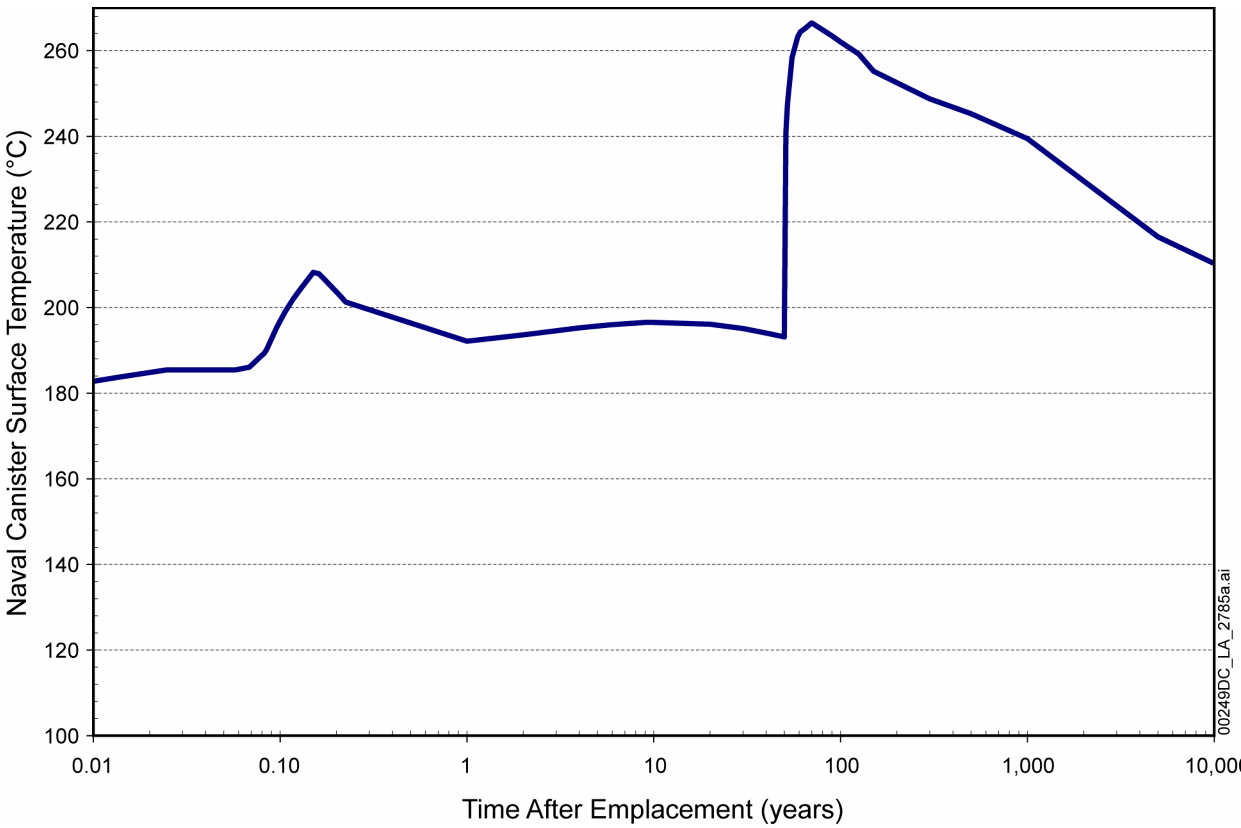


Figure 1.3.1-8. Thermal Envelope for Naval SNF Canister Surface Temperature in Emplacement Drift (Preclosure and Postclosure)

NOTE: Calculation results represented by this thermal envelope curve correspond to a naval SNF canister with a thermal power of 12.9 kW and a peak axial thermal load of 5.0 kW/m for the canister, contained in a waste package and emplaced in a seven-waste-package segment between two commercial SNF waste packages with a thermal power of 11.8 kW each. The naval SNF seven-waste-package segment has a thermal line load of 1.45 kW/m. The thermal envelope curve includes the thermal transient resulting from a 30-day loss of ventilation during the preclosure period, and the more pronounced thermal transient after forced ventilation is shut down and the repository is closed.

Source: BSC 2008i, Figure 7.

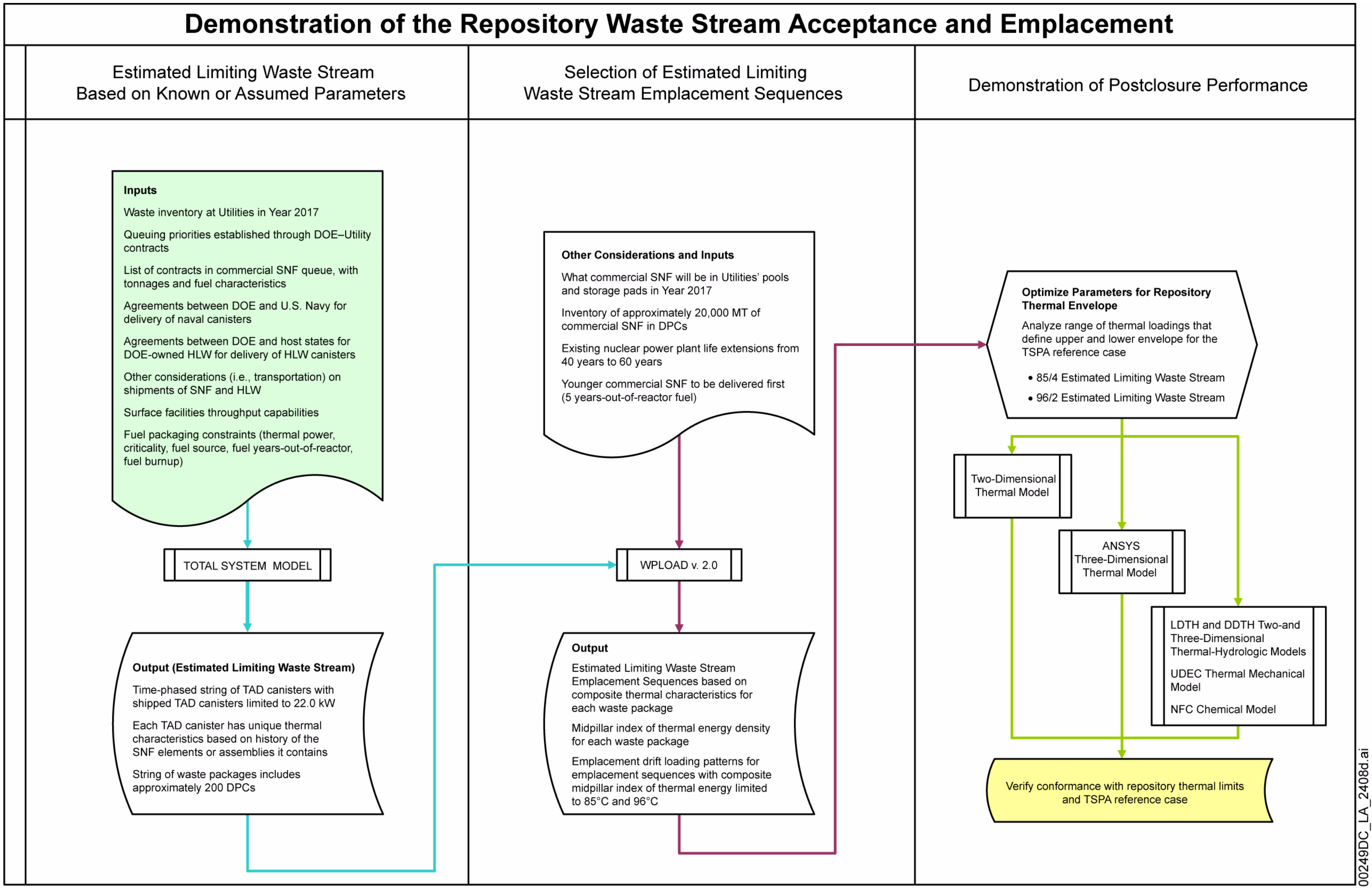


Figure 1.3.1-9. Demonstration of the Repository Waste Stream Acceptance and Emplacement

NOTE: The term ANSYS refers to ANSYS V. 8.0, the term WPLOAD refers to WPLOAD V. 2.0. DDTH = three-dimensional, discrete-heat-source, drift-scale, thermal-hydrologic; DPC = dual-purpose canister; LDTH = two-dimensional, line-averaged-heat-source, drift-scale, thermal-hydrologic; NFC = near-field chemistry; UDEC = universal distinct element code.

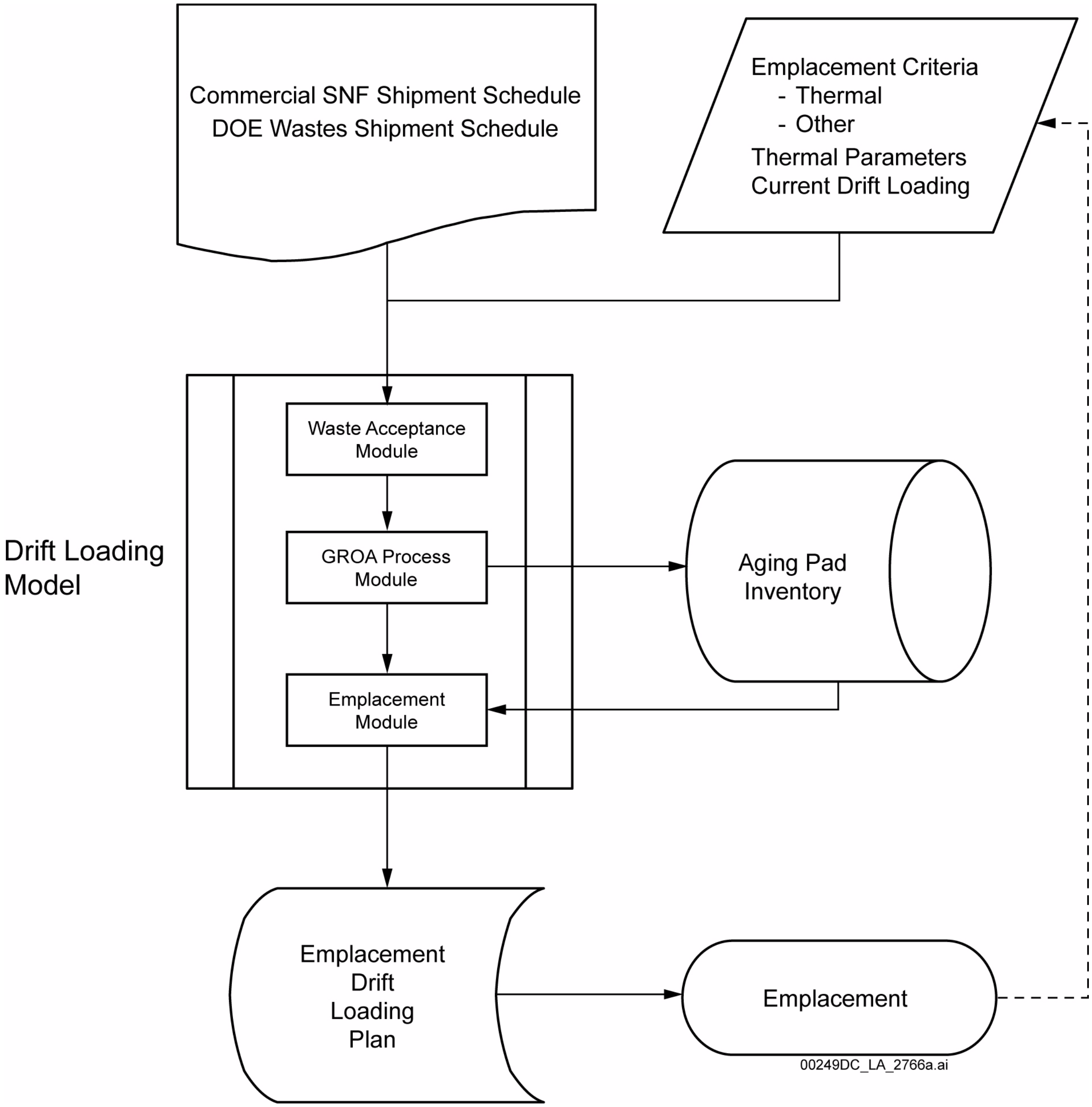


Figure 1.3.1-10. Representation of Emplacement Drift Loading Model

NOTE: This composite figure represents concepts described throughout Section 1.3 and it is not directly traceable to a single reference document. For Emplacement Drift Loading Plan details, see Figure 1.3.1-11.
GROA = geologic repository operations area.

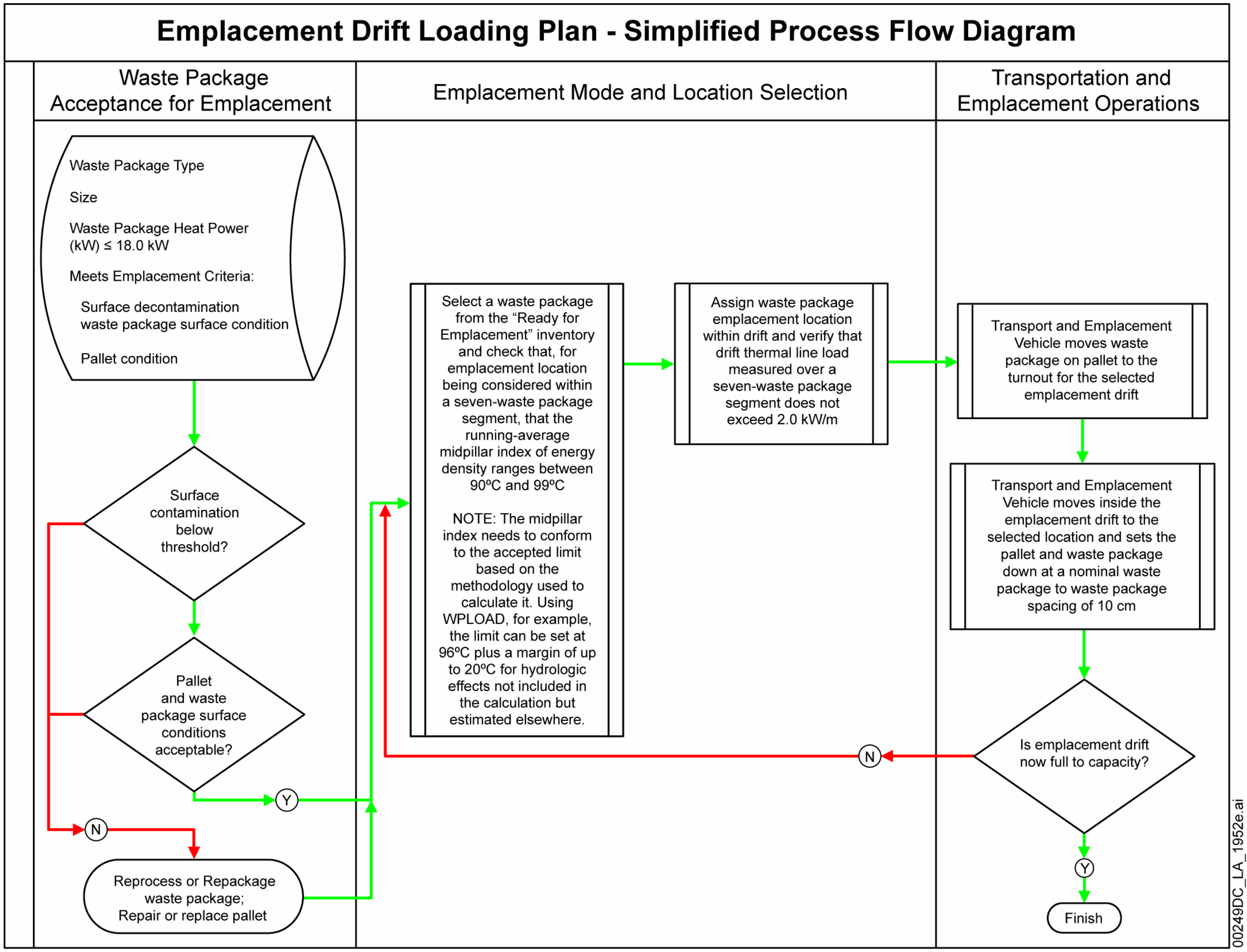


Figure 1.3.1-11. Process Flow Diagram of Emplacement Drift Loading Plan

NOTE: This composite figure represents concepts described throughout Section 1.3 and it is not directly traceable to a single reference document. WPLOAD = WPLOAD V. 2.0.

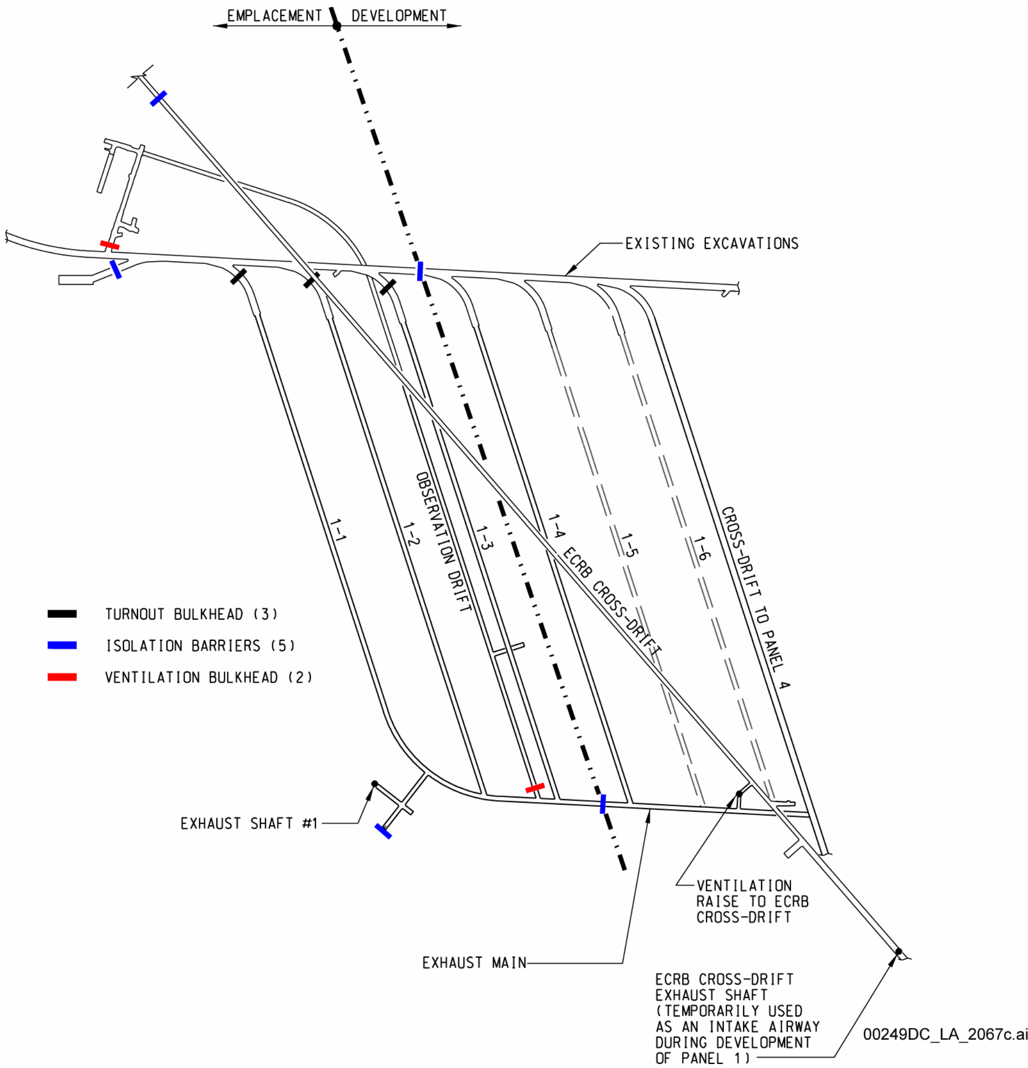


Figure 1.3.1-12. Initial Operating Capability Excavation and Bulkhead and Isolation Barrier Locations

Source: BSC 2007i, Figure A1.5-1.

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TABLES

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1.3.2 General Subsurface Design Considerations

[NUREG-1804, Section 2.1.1.2.3: AC 3; Section 2.1.1.6.3: AC 1; 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 4]

The general design considerations, methodologies, and solutions that are applicable to the repository subsurface facility and its structures, systems, and components (SSCs), both important to safety (ITS) and non-ITS, are discussed in this section. The subsurface facility includes ITS SSCs, important to waste isolation (ITWI) SSCs, and non-ITS and non-ITWI SSCs. The development of the design bases for each category of SSC evolves from different processes, as follows:

1. The nuclear safety design bases for the subsurface facility ITS SSCs and their safety functions are developed through preclosure safety analyses (Sections 1.6 to 1.9). These design bases are translated into control parameters and constraints that ensure that the design bases for those ITS SSCs are met. Designs of the subsurface ITS SSCs satisfy their design bases and relevant design criteria, thus ensuring that their functions are performed safely.

2. The nuclear safety design bases for the subsurface ITWI SSCs and their functions are developed through postclosure performance analyses (Chapter 2) that analyze direct or indirect contributions of natural and engineered barrier components to the repository postclosure performance. Scientific analyses and modeling determine how well the natural barrier components and Engineered Barrier System (EBS) components (individual subsurface ITWI SSCs) contribute to the overall repository performance as verified in the integrated total system performance assessment (TSPA) model. The individual analyses, as well as the integrated model, result in the formulation of postclosure nuclear design bases that translate into control parameters and constraints that must be met by the subsurface ITWI and non-ITWI SSCs and their interfaces with the natural barriers. Designs of the subsurface facility and its EBS components, and interactions with the natural barriers meet these direct and derived requirements and conditions, ensuring conformance with the repository postclosure nuclear design bases, thus resulting in satisfactory contributions to postclosure repository performance.

3. Design bases for subsurface non-ITS and non-ITWI SSCs evolve from calculations and analyses based on functional and performance expectations for those SSCs, from application of industry standards, and from established design practice. These design bases translate into design requirements and criteria that ensure the designs of non-ITS and non-ITWI SSCs meet their expected functionality and performance.

The design concepts used to ensure that the subsurface facility and associated ITS SSCs perform their credited safety functions are also described in this section. The considerations, methodologies, and design solutions for the non-ITS and non-ITWI SSCs are further discussed in Sections 1.3.3 to 1.3.6. The subsurface facility is designed for a nominal service life of 100 years, including the periods of waste emplacement, postemplacement ventilation, and monitoring, until repository closure.

Additionally, the design methodologies, considerations, and solutions incorporate experience from the methods employed for commercial nuclear facility design, industry codes and standards endorsed by the U.S. Nuclear Regulatory Commission (NRC), and proven technology in use at NRC-licensed facilities.

Several terms that relate to performance are used throughout this section and other sections of Section 1.3. The following statements clarify the intended use of the different performance-related terms: (1) "postclosure performance assessment" is used for individual SSCs to discuss their individual performance attributes during postclosure; (2) if referring to the entire repository, the words are usually preceded by "total system" or, alternatively, "TSPA" is used (TSPA includes the combined performance of the engineered barriers as well as the natural barriers around and beyond the repository limits); and (3) "repository performance" and "repository postclosure performance" are equivalent to "total system performance," as in TSPA.

1.3.2.1 General Design Approach
[NUREG-1804, Section 2.1.1.2.3: AC 3(1); Section 2.1.1.6.3: AC 1(1)]

The general approach to safety in the design of the subsurface facility SSCs is summarized in this section.

External Hazards and Natural Phenomena—Components of the subsurface facility, mainly the mobile equipment that travels from the subsurface facility to the surface facilities, that are exposed to external hazards and natural phenomena when traveling from the surface facilities to the subsurface are designed to withstand the potential effects of external events stemming from natural phenomena and man-made hazards. Where external hazards have the potential to propagate an undesirable effect to a subsurface SSC, the SSCs are designed to withstand the hazard (e.g., an earthquake). Using this design approach prevents or provides mitigation for Category 1 or Category 2 event sequences that could be caused by external hazards (Sections 1.7 and 1.8).

Shielding—The transport and emplacement vehicle (TEV) is the subsurface SSC that handles waste packages. The TEV incorporates radiation shielding and other engineered controls to protect workers and the public from potential exposures to radiation and to achieve the goal of maintaining radiological doses as low as is reasonably achievable. The TEV is designed for remote operation or operation behind shielded design features (Section 1.10).

Fire Protection—Subsurface SSCs are constructed of noncombustible and heat-resistant materials to the extent practical. Fire barriers within the subsurface facility are designed to contain fires within the area of origin, preventing exposure to adjacent areas of the facility. Fire protection systems are provided to detect and effectively suppress fires. Details on the fire barriers and the fire detection and suppression systems are presented in Section 1.4.3.

Fire hazard analyses are prepared for the subsurface facility within the restricted area, in accordance with Regulatory Guide 1.189. Facility safety, fire, and explosion hazards are addressed in the fire hazard analyses. A listing of the fire hazard analyses performed is presented in Section 1.4.3.

Criticality Safety—Prior to repository closure, subsurface nuclear criticality safety is assured by the commercial SNF and U.S. Department of Energy (DOE) SNF canisters and waste package designs (Sections 1.5.1 and 1.5.2). The canisters and waste package designs provide a barrier to moderators in the subsurface during preclosure. As described in Section 1.14, the waste package contents are expected to remain subcritical at all times. Prior to waste package failure during the postclosure period, the waste package provides an additional barrier to criticality by excluding moderators. The intact waste package fabricated and loaded as designed is subcritical under fully flooded conditions (SNL 2008a, Section 6). The commercial SNF and DOE SNF canisters also provide a combination of fissile material limits, geometry control, and fixed neutron-absorber materials, as needed.

The subsurface facility and mechanical handling SSCs are designed to handle only sealed waste packages. Sealed waste packages are designed such that drops, collisions, and other handling impacts within their design bases cannot lead to event sequences that result in a nuclear criticality (Section 1.14).

Mechanical Handling Equipment—Subsurface SSCs used to lift, handle, transport, or emplace waste packages incorporate design features to minimize the potential for drops, collisions, and other types of mechanical impacts to waste packages. The TEV incorporates design features to ensure a high degree of reliability with a low likelihood of failure. These include redundant or diverse design features for load-bearing components and braking systems. In addition to a travel route that is defined by the arrangement of the crane rails, the travel path of the TEV within the subsurface facility is controlled to minimize the potential for collisions. Design features incorporated into the TEV to prevent collisions include a non-ITS collision avoidance system and physical stops. More information regarding the design features of the TEV is presented in Section 1.3.3.5.1.

Classification of SSCs—Repository subsurface SSCs are functionally classified based on their ITS and ITWI attributes.

Subsurface ITS SSCs are those SSCs whose function is (Section 1.9.1):

- To provide reasonable assurance that waste packages can be received, handled, emplaced, and retrieved without exceeding the requirements of 10 CFR 63.111(b)(1) for normal operations and Category 1 event sequences.
- To prevent or mitigate Category 2 event sequences that could result in radiological exposures exceeding the values specified in 10 CFR 63.111(b)(2) to any individual located on or beyond any point on the boundary of the site.

SSCs that contribute significantly to the performance of any of the three barriers (Upper Natural Barrier, EBS, and Lower Natural Barrier), are classified as ITWI. Section 2.1 identifies those SSCs associated with the natural and engineered barriers whose function is to provide reasonable expectation that spent nuclear fuel (SNF) and high-level radioactive waste can be disposed in conformance with the requirements of 10 CFR 63.113(b) and (c) as ITWI. The methodology for classification of ITWI SSCs is described in *Postclosure Nuclear Safety Design Bases* (SNL 2008b), and the parameters needing controls (procedural or configuration management) to satisfy postclosure nuclear safety design bases are included in Table 1.9-9. These documents also describe derived requirements and constraints from the postclosure design bases. The SSCs classified as ITWI that are part of the subsurface facility design are the emplacement drifts and the drip shield. The design bases for the ITWI SSCs are listed in Table 1.9-8.

The methodology used to classify ITS SSCs is described in Section 1.9. The only SSC classified as ITS that is part of the subsurface facility design or that operates within the subsurface facility is the TEV. The nuclear design bases for the subsurface facility ITS SSCs are listed in Table 1.9-7.

1.3.2.2 Design Considerations

[NUREG-1804, Section 2.1.1.2.3: AC 3(1); Section 2.1.1.7.3.1: AC 1(1), (2), (3), (5), (9)]; Section 2.1.1.7.3.3(II): AC 1(2); AC 2(4)]

1.3.2.2.1 General Layout of the Subsurface Facility

The subsurface facility layout incorporates the following considerations on locational and standoff constraints that affect the location of the emplacement areas (Section 1.9).

- Locating emplacement drifts and turnouts within the repository footprint and host horizon. The repository footprint is defined as the horizontal projection or extent of the volume of host rock suitable for waste emplacement development and meeting all repository location criteria and applicable standoffs for LA design (BSC 2003, Section 5.1.1.1; BSC 2007a, Section 4.3.1). These criteria ensure that these subsurface openings are located within the Yucca Mountain area and in the host rock formations analyzed in the postclosure performance models. As a result, the location of the subsurface openings supports an ITWI function (BSC 2008a, Table 1, Derived Internal Constraints 01-01, 01-02, and 01-03). The emplacement drifts are located within the repository host horizon. The repository host horizon is located within the lower part of the TSw1 thermal mechanical unit, corresponding to the upper lithophysal (Tptpul) lithostratigraphic unit of the Topopah Spring Tuff (Tpt), and the TSw2 thermal mechanical unit, corresponding to the middle nonlithophysal (Tptpmn), lower lithophysal (Tptpll), and lower nonlithophysal (Tptpln) lithostratigraphic units of the Topopah Spring Tuff (Figure 1.1-60). Establishing this vertical location of the repository, a complete description of the location of the emplacement areas can be made within the characterized area. It also establishes a standoff distance of at least 200 m to the ground surface and locates the repository in characterized rock suitable for waste disposal.

- Establishing a minimum 120 m vertical standoff between the present-day water table and the repository horizon. The water table is at least 170 m below the repository horizon at the present time based on mapped piezometric contour elevations. This requirement maintains separation between the repository horizon and the water table under potential future (wetter) climates that could cause the water table to rise. This requirement supports the TSPA analysis basis on groundwater table location. The worst-case postulated water table elevation based on historical records and analyses of geohydrologic information is approximately 850 m. A potential rise of the water table in future wetter climates of 120 m could potentially raise the water table to an elevation of approximately 970 m above mean sea level in the area of the repository (BSC 2008a, Table 1, Derived Internal

Constraint 01-04), although the repository host horizon would still be at least 50 m above this potential future water table rise.

- Establishing a minimum 30 m standoff between the inverts of the emplacement drift openings and the top of the Topopah Spring Tuff crystal-poor vitric zone (Tptpv2). Perched water may occur at the base of the Topopah Spring Tuff. This requirement limits vaporization of the perched water and supports the TSPA analysis basis by limiting the amount of water that could be mobilized and interact with the emplacement drifts (BSC 2008a, Table 1, Derived Internal Constraint 01-07).

- Maintaining a minimum Paintbrush nonwelded (PTn) unit thickness of 10 m above the repository horizon. In addition, maintaining a minimum 100-m standoff between the base of the PTn unit and the crowns of the emplacement drifts. These requirements ensure that sufficient thickness of the PTn unit exists above the repository to limit concentrated flows (fracture flow) before they reach the repository horizon and to limit alteration of the permeability (due to heating) of the PTn hydrogeologic unit. These requirements support the TSPA analytical basis by protecting the integrity of rock properties beneficial to the repository.

- Establishing a minimum 60-m standoff between the Calico Hills nonwelded (CHn) unit and the inverts of the emplacement drift openings. This standoff requirement limits chemical alteration (due to heating) of the CHn hydrogeologic unit. This requirement supports the TSPA analytical basis by protecting the integrity of rock properties beneficial to the repository.

- Establishing a minimum 60 m standoff between a Quaternary fault with potential for significant displacement and repository emplacement openings. This requirement reduces the effects of potential fault movement on the waste packages. This requirement supports both ITS and ITWI functions by limiting the potential impact of rockfall and ground displacement on the waste packages (BSC 2008a, Table 1, Derived Internal Constraint 01-05).

- Establishing a minimum of 200 m overburden thickness above the emplacement areas. This establishes a minimum vertical distance from the emplacement drifts to the topographic surface (BSC 2008a, Table 1, Derived Internal Constraint 01-06) for purposes of waste isolation and minimization of thermal impacts to the surface environment.

The subsurface facility layout design includes 108 emplacement drifts located in one horizon. The layout includes emplacement contingency allowance. The contingency allowance is provided as excess excavated emplacement drift length in case emplacement capacity is lost in emplacement-designated areas due to the potential presence of geologic anomalies or localized areas of highly fractured rock (Section 1.3.4.3).

The first emplacement panel to be constructed (Panel 1) is also the smallest, consisting of six emplacement drifts. The small size and location of this panel facilitates commissioning of the initial three drifts and initiation of waste emplacement activities. The balance of the emplacement drifts in

Panel 1 will be developed concurrently with waste emplacement operations. During concurrent operations, separation is maintained between the development and emplacement areas by the use of isolation barriers at the access and exhaust mains, and by personnel access control and safeguards and security controls at the North Portal, thus providing complete separation of access, transportation, and ventilation systems for the two areas (Sections 1.3.1.2.7.3 and 1.3.5.1.3.2).

The major types of excavations for the subsurface facility are portals, ramps, access mains, turnouts, emplacement drifts, exhaust mains, shafts, and shaft access drifts. These excavations and the design considerations for the layout of the subsurface facility are described in Sections 1.3.3 and 1.3.4.

The emplacement drifts are the openings where waste packages are emplaced. The turnouts are nonemplacement openings that connect the access mains with the emplacement drifts (Figures 1.3.3-13 and 1.3.3-14). There is a difference in elevation between the invert for the access main and the invert for the adjacent emplacement drift, with the latter being higher. The turnout bridges this elevation difference by gradually ramping up from the access main elevation to the emplacement drift elevation to provide an at-grade transition from the turnout to the emplacement drift.

1.3.2.2.2 Thermal Design Considerations

Thermal management is supported by the design of the underground layout, waste package loading, emplacement drift loading, and heat removal during the preclosure period. The layout design provides space and configuration for emplacement of the waste packages to minimize thermal impact on the natural barriers and to enhance moisture flow past the emplacement horizon. Design criteria and controls for loading of the waste forms in the transport, aging, and disposal canister and the waste package ensures conformance with individual waste package thermal power limits. The design of the waste package, and its internal canisters, enhance heat transfer to the outer surface of the waste package. Emplacement drift loading design ensures that the waste package heat load is distributed along the length of the drift in conformance with the emplacement drift loading plan described in Section 1.3.1.2.5. The subsurface ventilation design provides sufficient airflow to each emplacement drift to maintain temperatures for the engineered barrier components and drift walls below specified maximum limits throughout the preclosure period. The repository temperature limits for the subsurface facility are described in Section 1.3.1.2.5 (Table 1.3.1-2). Emplacement drift and exhaust air temperatures (Table 1.3.5-2) are maintained such that a temporary loss of forced-air ventilation does not result in exceedance of the maximum off-normal temperature limits. The outdoor ambient temperature range for design of subsurface facility SSCs is from 2°F to 116°F.

1.3.2.2.3 Equipment Qualification

The Equipment Qualification Program provides the framework to evaluate the ability of active ITS SSCs to perform their safety functions under their applicable environmental, seismic, and event sequence conditions. The Equipment Qualification Program is described in Section 1.13.

The only subsurface equipment that is classified as ITS and has been identified as a candidate for equipment qualification is the TEV. An equipment qualification program for the TEV will be implemented to ensure that it will be able to perform its intended safety functions.

The TEV design is based on proven technology for nuclear and industrial cranes as adapted for the purpose of transporting and emplacing waste packages in a combination of surface and underground environments. The information presented in Section 1.13 addresses the assessment of equipment operating environments based on the guidelines and standards used in the equipment qualification process. The primary focus of the equipment qualification program for the subsurface will be on confirming that the TEV design and procured ITS SSCs meet regulatory and performance requirements. The equipment qualification program for the TEV will be prepared and implemented to confirm that the following requirements are met:

- Ensure the ability of the TEV to perform its intended safety functions under applicable environmental, seismic, and event sequence conditions
- Ensure the availability, reliability, and component-aging management of the TEV
- Ensure the TEV is suitable for the application
- Verify the adequacy of the design through a combination of modeling, analyses, and testing to demonstrate compliance with codes and standards for similar or analogous equipment previously qualified, reviewed, and accepted by the NRC.

1.3.2.3 Design of Subsurface Mechanical Handling Equipment

[NUREG-1804, Section 2.1.1.2.3: AC 3(1); Section 2.1.1.6.3: AC 1(2)(c), (h), (m); Section 2.1.1.7.3.1: AC 1(1), (2), (3), (4); Section 2.1.1.7.3.3(II): AC 1(3)]

Various pieces of mechanical handling equipment such as the TEV, drip shield gantry and maintenance and inspection vehicles will operate in the subsurface facility. However, only the TEV handles waste packages and performs ITS functions. Therefore, the TEV is classified as ITS. Although other pieces of subsurface mechanical handling equipment are required to support operations, they are classified as non-ITS. Due to the significance of TEV functions and performance in carrying out waste package transportation and emplacement processes, the discussion in this section focuses only on the nuclear safety design bases requirements for TEV functions that are ITS. Requirements for TEV design, operational, and environmental considerations are addressed in Section 1.3.3.5. A discussion of the drip shield gantry design is presented in Section 1.3.4.7.2. Specific design configurations for maintenance and inspection vehicles have not yet been defined, however, usage of such equipment is addressed in the discussions for related functional areas and operations.

Non-ITS equipment, both mobile and fixed, has been evaluated for the potential of a seismically induced or operational interaction that could adversely impact the ability of an ITS SSC to perform its safety function. System interactions that include the potential for such adverse effects are evaluated in the preclosure safety analyses and are shown to not result in event sequences that exceed regulatory limits, or they are prevented by design or operational controls (Sections 1.6, 1.7, 1.8 and 1.9).

The TEV is a crane-rail-based transport assembly designed as a Type 1, single-failure-proof crane in accordance with accepted industry codes and standards (ASME NOG-1-2004, Section 1150). The TEV is designed to accommodate the weight and size of the anticipated loads, including the heaviest and largest waste package with its emplacement pallet. Although the TEV is based on proven and commercially available technology, project-specific functions and performance requirements are such that this SSC represents a first-of-a-kind application of existing technology. Design features for the project-specific equipment designs that are part of the TEV are advanced through a process that evaluates codes and standards and identifies supplemental requirements to address nonstandard design areas. This design development process is described in Section 1.3.2.7. Design functions and features for the TEV and its SSCs that are classified as ITS are described in the following section and in Sections 1.3.3.5 and 1.3.4.8 (BSC 2008b, Sections 3.1, 3.2, and 3.3). Operational processes for the TEV are discussed in Section 1.3.3.5.2.

The primary purpose of the TEV is to transport and emplace waste packages in a manner that prevents a waste package breach. A secondary purpose for the TEV is for use in waste package retrieval as discussed in Section 1.11. The TEV primary objective is accomplished by establishing design requirements that identify performance levels that must be met by TEV design features and operational controls to limit or prevent the effects of potential event sequences that could lead to a waste package breach during transport. Information used to define design requirements that address potential event sequences is based on hazards analyses and event sequence evaluations performed through the preclosure safety analyses process. This information is provided in Sections 1.6 and 1.7. Design criteria that support development of the TEV, together with the design bases, are presented in Table 1.3.3-5.

The design requirements for the TEV that address the nuclear safety design bases are presented in the following discussion with design solutions for implementing the requirements.

1.3.2.3.1 Nuclear Safety Design Basis Requirements

The preclosure safety analyses credit the TEV with performing ITS functions and meeting the performance criteria listed in Section 1.9. The TEV design requirements have been established to ensure performance of the identified ITS functions as defined in the nuclear safety design bases developed for the preclosure safety analysis. Two preclosure procedural safety controls (PSC-10 and PSC-25) have been identified for the waste package transportation and emplacement system (Table 1.9-10).

The following discussion addresses the nuclear safety design bases requirements applicable to the TEV and summarizes the design approach for satisfying each requirement. More information regarding the nuclear safety design bases and the preclosure safety analyses is presented in Sections 1.6, 1.7, 1.8 and 1.9.

Runaway—The probability of runaway of a TEV that can result in a potential breach of a waste package shall be less than or equal to 2.0×10^{-9} per transport (Section 1.9; Table 1.3.3-5, HE.SS.01).

The TEV SSCs that address this requirement include the drive motors and integral disc brakes, gearboxes, driveshafts, wheels, and rail brakes (BSC 2008c, Section 5.1). As recommended by ASME NOG-1-2004 (Section 5333.1) for a crane load of 50 to 99 tons, the speed of the TEV will not exceed a design-rated load “fast” speed of 150 ft/min (1.7 mph) with a design tolerance of ±10%. Drive motors and gearboxes are sized and selected to achieve but not exceed this speed, which is within the design bases limit, even during descent of the North Ramp, which has a downgrade of 2.15% (BSC 2008b, Sections 3.1.1 and 3.2.1.32). The component development process described in Section 1.3.2.7 will be applied to define TEV performance and operational requirements for operations on the North Ramp.

The motors selected for the main drive are coupled with high ratio gearboxes which limit the TEV from traveling faster than the identified operating speed of 150 ft/min. When power to the drive motors is reduced, the high gear ratios of the gearboxes provide rotational drag and cause the TEV to slow. If a loss of power to the TEV occurs, the drive motors stop, the high gear ratios of the gearboxes slow or stop the TEV, and the integral disc brakes in the drive motors are automatically applied. This action prevents movement of the TEV wheels. Additionally, the TEV has two rail brakes, which are applied automatically during a loss of power. The rail brakes are also applied when the TEV is parked (BSC 2008b, Sections 3.1.1, 3.3.3, and 3.3.4).

The integral disc brake for each drive motor minimizes the potential of a TEV runaway. The brakes are applied by a command to slow or stop, and also upon loss of power. The integral disc brakes are released electrically and applied mechanically and operate on the fail safe principle that when the electrical supply is interrupted for any reason, the brake is applied automatically. The TEV rail brakes also operate on the fail safe principle and are applied automatically upon loss of power. The brake system design allows the TEV to meet the requirement to minimize the potential for a runaway through mechanical limitations (BSC 2008b, Sections 3.1.1, 3.2.1.33, 3.3.3, and 3.3.4).

Inadvertent Door Opening—The mean probability of inadvertent TEV door opening shall be less than or equal to 1.0×10^{-7} per transport (Section 1.9; Table 1.3.3-5, HE.SS.02).

This nuclear safety design bases requirement is addressed through a series of interlocks and hardwired switches to minimize the potential for an inadvertent opening of the TEV shielded enclosure front doors or the rear shield door. The TEV design incorporates ITS SSCs to address this requirement, including the rear shield door actuators, shielded enclosure front door locks, circuitry for hardwired interlock, and the interlock switch. The shielded enclosure front door locks are designed to remain locked and in place during a collision or derailment. The circuitry for the shielded enclosure front door locks and the rear shield door is designed such that unlocking and movement of the doors can only be accomplished within dedicated areas. An ITS switch on the TEV is hardwired in the circuitry. An external stationary actuating arm, which is located in the waste package loadout rooms of the surface nuclear facilities and inside the subsurface facility turnouts, mechanically engages and actuates the ITS switch as the TEV passes by its location. The shielded enclosure front door locks cannot be unlocked and the rear shield door cannot be raised until the ITS switch has been actuated. The hardwired ITS switch ensures that opening of the shielded enclosure front doors and raising of the rear shield door can occur only in the loadout rooms of the surface nuclear facilities and in the turnouts or the emplacement drifts. These are controlled limited access areas (BSC 2008b, Sections 3.1.3, 3.2.1.7, and 3.3.15).

Derailment—The mean frequency of derailment of the TEV at the loadout station due to the spectrum of seismic events shall be less than or equal to 1.0×10^{-4}/yr (Section 1.9). This nuclear safety design bases requirement is applicable during waste package loading in the IHF and CRCF surface nuclear facilities (Table 1.3.3-5, HE.IH.01 and HE.CR.01).

To meet the nuclear safety design bases requirement to protect against derailment of the TEV during loading of a waste package and ensure that TEV performance during a seismic event is in accordance with ASME NOG-1-2004 (Section 4457) requirements for a Type 1 crane, seismic restraints are included in the design of the underside of the TEV chassis. These restraints consist of "L" shaped fabrications of sufficient size and capacity to limit the vertical lift of the TEV off the rails during a seismic event. The fabrications are located at the front and the back of the TEV, positioned on the outer side of both rails, and placed so that the leg of the "L" shape projects under the railhead on each side (Figure 1.3.3-41) (BSC 2008b, Figure 45 and Sections 3.1.2, 3.1.3, and 3.4.9).

Tipover—The mean frequency of tipover of the TEV due to the spectrum of seismic events shall be less than or equal to 2.0×10^{-6}/yr (Section 1.9) while the TEV is operating in repository surface and subsurface areas (Table 1.3.3-5, HE.IH.02, HE.CR.02, and HE.SS.03).

The approach for addressing this nuclear safety design bases requirement is based on a design concept that minimizes the potential for tipover of the TEV through a design configuration that incorporates a wide vehicle profile and a low center of gravity. The design of the TEV includes the use of an 11-ft-wide track which is as wide as practicable considering the emplacement drift operating envelope of 16 ft. During transport, the TEV carries the waste package at a nominal height that does not exceed 14 in. from the top of rail to the bottom of the emplacement pallet. This design configuration ensures stability of the TEV throughout the waste package transportation and emplacement process (BSC 2008b, Sections 3.1.2, 3.4.9 and 3.4.10; BSC 2007b).

The TEV includes design features to minimize the probability of events that may lead to a tipover, such as derailment. Reducing the possibility of derailment reduces the potential for tipover. A design concept developed to minimize the potential for derailment and a tipover of the TEV includes the use of double-flanged wheels which are designed to prevent wheel climb when the TEV travels around a curve. One side of the TEV is equipped with double flanged wheels while the wheels on the opposite side of the TEV are left plain. This wheel configuration allows the TEV plain wheels to shift laterally on the rail, as needed, while the flanged wheels guide the TEV around the curve. A geometric assessment performed for this wheel configuration indicates that, in the center of the 200-ft curve, the flanges of the double flanged wheels have sufficient clearance to minimize the potential for wheel climb. As a result, derailment does not occur (Section 1.3.3.5.1). Another design feature to minimize the potential for a tipover of the TEV is a chassis and base-plate design that limits the distance a TEV wheel could drop if a derailment did occur. The bottom faces of the TEV chassis and the bottom face of the base plate are at the same level and are only two inches above the top of the rail. This design configuration ensures that the maximum drop of the TEV is limited to two inches plus the depth of the wheel flanges, nominally one inch. If such an event occurs, design features at the bottom faces of the chassis and the bottom face of the base plate will sit on the rails and will support the TEV (BSC 2008b, Sections 3.1.2, 3.4.9, and 3.4.10). Derailment is considered during a runaway and tipover event sequence and does not result in a waste package breach (Section 1.7).

Waste Package Ejection—The mean frequency of ejection of a waste package from the TEV due to the spectrum of seismic events shall be less than or equal to 2.0×10^{-4}/yr (Section 1.9) while the TEV is operating in repository surface and subsurface areas (Table 1.3.3-5, HE.IH.03, HE.CR.03, and HE.SS.04).

The TEV shielded enclosure front shield door locks and rear shield door are designed and constructed to restrain the front shield doors and base plate during a DBGM-2 seismic event. The front shield door locks are designed to remain locked and in place during a collision or derailment (including tipover) without resulting in a Category 1 or Category 2 event sequence (BSC 2008b, Sections 3.2.1.5, 3.2.1.6 and 3.2.1.7).

The locks for the shielded enclosure front doors are similar in design to the transportation shot bolts used to carry the weight of the shielded enclosure during waste package transport (Section 1.3.3.5.1.1). Two electrically-activated door lock actuators are mounted on one front shield door. Each actuator drives a shot bolt into a hole in a structural feature mounted to the other door. The steel shot bolts used for the front shield door locks are of sufficient cross-sectional area and tensile strength to withstand the loading conditions associated with a DBGM-2 seismic event (BSC 2008b, Sections 3.2.1.5, 3.3.8, and 3.3.12).

The shielded enclosure front shield doors, door drives, hinges and locks are designed and constructed in accordance with the recommendations of *Design Guides for Radioactive Material Handling Facilities and Equipment* (Doman 1988). The guidance provided relates to shield doors, anticipated load combinations, considerations for the design of hinges, door drive systems, and safety devices (BSC 2008b, Section 3.3.12).

1.3.2.3.2 Design, Operational and Environmental Requirements

General design requirements that support TEV operational and environmental capabilities and functions necessary to carry out waste package transportation and emplacement processes are discussed in Section 1.3.3.5.

1.3.2.4 Design of Subsurface Facility Structures, Systems, and Components

[NUREG-1804, Section 2.1.1.2.3: AC 3(1); Section 2.1.1.7.3.1: AC 1(1), (2), (4), (9); Section 2.1.1.7.3.3(II): AC 1(3); AC 3(1), (2)]

1.3.2.4.1 Subsurface Electrical Distribution Criteria and Design Considerations

The subsurface facility electrical distribution system and equipment have been classified as non-ITS. Electrical distribution for the development side of the facility is supplied by a main transformer that is separate from the main transformer for the emplacement side of the facility. Demand loads and power interruptions in the development side will have no effect on the emplacement side. The subsurface ventilation fans on the emplacement side will work continuously throughout the preclosure period and the design includes provisions for backup power in case of loss of primary power. There are no provisions for backup power for the waste package transportation and emplacement operations as the waste package and workers will be safe if the TEV is stopped during transport underground. The repository electrical distribution design description is included in Section 1.4.1. Specific electrical distribution design information applicable to the subsurface facility is summarized in Section 1.3.3.

Design criteria and codes and standards applicable to the major electrical distribution components and service are as follows (BSC 2007c, Section 4.3.1):

- Electrical system design complies with NFPA 70, *National Electrical Code* (with the tentative interim amendment) and NFPA 70E-2004, *Standard for Electrical Safety In the Workplace*.

- Electrical system design provides for the safe distribution of power and complies with NFPA 101, *Life Safety Code* (with its errata and tentative interim amendments).

- Electrical design of power generation, transmission and distribution complies with the applicable requirements of 29 CFR 1910, *Labor: Occupational Safety and Health Standards Section 269, Electrical Power Generation, Transmission and Distribution*. This requirement includes, as part of the energy control program that energy-isolating devices for machines and equipment are designed to accept a lockout device, and the components are substantial enough to prevent removal without the use of excessive force and provide for a safe or off position.

- Electric power system design provides for fire protection requirements that comply with NFPA 1, *Uniform Fire Code* and NFPA 801, *Standard for Fire Protection for Facilities Handling Radioactive Materials*.

- The electrical system design provides margin to accommodate future load growth for electrical equipment like transformers, switchgear, load centers, motor control centers, and raceways.

- The electrical system design voltage regulation is based on ANSI C84.1-1995, *Electric Power Systems and Equipment—Voltage Ratings (60 Hz)*.

- The subsurface facility power supply voltages are in accordance with the following schedule per IEEE Standard 141-1993:

  – 13.8 kV, 60 Hz, 3-phase, 3-wire, resistance grounded neutral
  – 4.16 kV, 60 Hz, 3-phase, 3-wire, resistance grounded neutral
  – 480 V, 60 Hz, 3-phase, 3-wire, solidly grounded neutral
  – 480/277 V, 60 Hz, 3-phase, 4-wire, solidly grounded neutral
  – 208/120 V, 60 Hz, 3-phase, 4-wire, solidly grounded neutral
  – 240/120 V, 60 Hz, 1-phase, 3-wire, solidly grounded neutral
  – 125 V DC battery system voltage.

- Electric distribution cable is designed in accordance with IEEE Standard 525-1992, *IEEE Guide for the Design and Installation of Cable Systems in Substations*. The 15-kV and 5-kV power cables are shielded and are either a single conductor or a triplexed Class B stranded copper conductor, with a 133% insulation level, rated for continuous operation at

90°C, 130°C for emergency overload operation, and 250°C for short circuit conditions in accordance with the applicable Insulated Cable Engineers Association standard.

- Utilization cables for 480 V power, 277 or 208/120 V lighting, 480 V motor feeder and 120 V control cables are single conductors, copper, rated 600 V, and 75°C. The conductor is hard-drawn, solid or stranded copper. All power and control wiring is solid or stranded copper flame-retardant, moisture and heat-resistant or heat-resistant thermoplastic and insulated to 75°C.

1.3.2.4.2 Subsurface Facility Communications Criteria and Design Considerations

The subsurface facility communications will be integrated with the repository communications through a common synchronous optical network (SONET) communications backbone. The backbone network is expandable so that it can grow as the repository is developed. The network backbone will be set up in loops so that signals from a single point in the network can reach the central control center through two different routes. Consequently, in the subsurface facility where an incident in one portal, access ramp, or access main may disrupt the loop locally, the network would still be functional through an alternate portal-ramp access main route.

The repository communications network will support all the subsurface facility's operations through network routing, local area networking, virtual local area networks, network management, communications security, emergency communications, alarm notification, public address, video monitoring, closed-circuit television, telephone, radio, and wireless communications. Design criteria and characteristics applicable to the respective communications network components are as follows (BSC 2007c, Section 4.3.7):

- The subsurface facility communications will be transported on a common SONET communications backbone in accordance with T1.105-2001, *Synchronous Optical Network (SONET)—Basic Description Including Multiplex Structure, Rates, and Formats* (including supplement T1.105a-2002).

- All network communications comply with internet protocols as required by RFC 791, *Internet Protocol, DARPA Internet Program Protocol Specification* (Postel 1981a), and RFC 793, *Transmission Control Protocol, DARPA Internet Program Protocol Specification* (Postel 1981b).

- The communications networks and network services are centrally managed from a network operations center in accordance with RFC 1155, *Structure and Identification of Management Information for TCP/IP-Based Internets* (Rose and McCloghrie 1990).

- Emergency communications are provided with capabilities to support onsite emergency response and establish communications with outside organizations during repository emergencies.

Design descriptions for the repository communications system are included in Section 1.4.2. Section 1.3.3 contains a brief description of the communications network architecture for the subsurface facility, and Section 1.3.3.5 includes additional information on communications and controls for the subsurface waste package transportation and emplacement equipment.

1.3.2.4.3 Mining

1.3.2.4.3.1 Criteria and Design Considerations for Sizing of Emplacement Areas

The subsurface facility emplacement areas are sized to accommodate the statutory limit of 70,000 MTHM of SNF and high-level nuclear waste. The capacity of the emplacement areas includes some contingency to handle potential geologic anomalies that may impede utilization of sections of emplacement drifts and allows for a standard waste package standoff distance at the end of each emplacement drift (Figure 1.3.4-3). There is no firm contingency criterion established, such as a percentage or quantity allowance.

The capacity of each emplacement drift will depend on what types of waste packages are emplaced in the drift, based on the lengths of those waste package types and emplacement constraints encountered in the specific drift. That information will be available when the emplacement drift is built and drift-specific loading information is available (Section 1.3.1.2.5).

The adequacy of the overall sizing of the emplacement areas is verified by considering the estimate of number of waste packages to be emplaced. The estimate is based on the packaging of different types of waste forms in transportation, aging, and disposal canister-bearing waste packages, in naval waste packages, and DOE codisposal waste packages. There are two estimates of number of waste packages: one estimate based on the most current waste stream inventories, and one estimate based on the waste stream inventory used as the basis for the 2006 license application design baseline (BSC 2007d, Section 3.1.2 and Table 6.2-3). The estimates vary because of the sensitivity of the parameters used by each estimate for their respective purposes, and because of the method and data sources utilized. The waste package inventory for the estimated limiting waste stream (Section 1.3.1.2.5) estimated a total of 10,324 waste packages (BSC 2007e, Table 12). The waste package estimate based on the waste stream baseline for the waste package emplacement pallet and drip shield estimates of committed materials for the TSPA analyses resulted in a total inventory of 11,077 waste packages (BSC 2007d, Tables 6.2-3 and I-1).

The underground layout includes a total emplacement drift excavated length of 67,915 m, of which 65,209 m are available for emplacement (Table 1.3.1-1). The weighted-average length for a waste package based on the 2006 waste stream baseline is 5.5069 m. Adding 10 cm for the average package-to-package spacing and dividing the available emplacement drift total length by this sum (5.6069 m) results in an approximate repository capacity of 11,630 waste packages, which is approximately the same number of waste packages used by TSPA (11,629) (Section 2.3.7.4).

The underground layout can accommodate both waste package estimates. Using an average length of 600 m for an emplacement drift, the underground layout would have approximately 5 or 12 contingency drifts for the higher- or lower-range estimates. The number of contingency drifts estimates are approximate because they do not include potential length deductions due to drift-end effects (drift lengths at the ends where only a fraction of a package length can be accommodated).

1.3.2.4.3.2 Faulting

The repository design provides for a minimum 60 m standoff between a Quaternary fault with potential for significant displacement and repository emplacement openings. This standoff is designed to reduce the potential effect of fault movement on EBS components. Section 1.1 provides an overview of geologic faults in the repository area.

The Solitario Canyon Fault is the only known Quaternary fault with potential for significant displacement near the repository emplacement area. The Bow Ridge Fault, another Quaternary fault with potential for significant displacement, is not in the immediate vicinity of the repository emplacement area but it crosses the North Ramp near the North Portal (CRWMS M&O 1998, Table 8-1).

Repository excavations other than emplacement drifts may be located with less than 60 m standoff only if a site impact evaluation determines that the location is justified and the potential damages due to displacement would not result in failure to meet the requirements in 10 CFR 63.111(a). This evaluation would consist of a potential damage assessment in areas located within the standoff distance. This option is provided because of the complexity of effects of Quaternary faults with potential for significant displacement on the repository design and performance. There is a precedent for crossing a major Quaternary fault by the existing Exploratory Studies Facility excavation as documented in *Geotechnical Characterization of the North Ramp of the Exploratory Studies Facility* (Brechtel et al. 1995, Section 4).

1.3.2.4.3.3 Standoffs

Standoff general criteria (Section 1.3.2.2.1) are defined to limit the extent of the subsurface layout to avoid potential natural hazards, such as major faults or water-bearing strata, and to establish margin for portions of the natural barrier that may be impacted by the thermal, mechanical, or chemical effects ensuing from repository thermal pulses (Section 2.3.5). Section 1.3.2.2.1 lists the standoff general criteria for the emplacement drifts. Requirements for standoff distances from faults specific to naval waste packages are described in Section 1.3.1.1.

1.3.2.4.3.4 Excavation Stability

The excavation stability general criteria are listed in Section 1.3.4.2.1.

1.3.2.4.3.5 Emplacement Drift Configuration

The following are emplacement drift configuration general criteria:

- The excavated diameter of emplacement drifts used to dispose of waste packages is a nominal 5.5 m. This criterion establishes an envelope for use in designing emplacement drift fittings and mobile equipment that uses the emplacement drifts. The emplacement drift diameter and the layout of the emplacement drifts are controlled postclosure design parameters because they ensure that performance is consistent with rockfall and drift modeling (Table 1.9-9).

- The emplacement drift spacing (centerline to centerline) is a nominal 81 m. This drift spacing promotes drainage of thermally mobilized water and will increase the thermal independence of individual drifts. The emplacement drift spacing is a controlled postclosure design parameter because it ensures that performance is consistent with thermal and seepage modeling (Table 1.9-9).

- The grade of the emplacement drifts is nominally horizontal. The purpose of this criterion is to ensure that any water entering the emplacement drift wall will not collect in pools and so that water drains into the rock uniformly along the length of the drift through the invert.

- The emplacement drifts are oriented at a nominal 30° from the dominant joint set for the lithophysal and nonlithophysal rock units of the repository horizon. This criterion provides optimum orientation of the emplacement drift alignments for overall stability (formation of potential rockfall keyblocks) and seepage. The 30° offset from the dominant joint sets results in an azimuth in the range of 70° to 80° for the emplacement drifts.

1.3.2.4.3.6 Portal Flood Protection

The portals are designed with the following features to preclude flooding of the subsurface facility due to the maximum precipitation and the probable maximum flood:

- The portal and shaft collar openings are protected from the probable maximum flood event. Areas around the repository openings are also graded to prevent surface storm runoff from entering the emplacement drifts and shaft openings during times of excessive rainfall.

- The surface gradient at the portal openings and shaft collars slopes away from the openings to prevent surface runoff from rain or spills from entering the openings.

1.3.2.4.4 Design of Geotechnical Structures, Systems, and Components

1.3.2.4.4.1 Ground Support

Ground support SSCs for the repository are classified as non-ITS (Table 1.9-1). The design of a ground support system for both emplacement and nonemplacement openings (Sections 1.3.4.4 and 1.3.3.3, respectively) involves selecting components and materials based on the preclosure functions and performance requirements, service life, and postclosure effects on waste isolation (Section 1.3.6.1.3). A ground support system includes the initial and final ground support. The stability of supported underground openings is analyzed and demonstrated by using numerical modeling and applicable closed-form solutions and is documented in design calculations. Ground support design includes maintenance strategy and plan considerations.

1.3.2.4.4.2 Ground Support Design Methods

Ground support designs are based on analyses that utilize a full range of rock mass thermal-mechanical properties, loading conditions, and potential rock mass strength degradation by carrying out comprehensive scoping analyses. The ground support design for emplacement drifts and nonemplacement openings involves both empirical and analytical methods.

Empirical methods are used for assessing the needs for ground support, as well as being a practical guide for the ground support system selection.

Analytical methods, mainly numerical methods, are used to analyze the stability of unsupported emplacement drifts and nonemplacement openings, as well as to predict the performance of associated ground support components subjected to load combinations from in situ, thermal, and seismic loads.

The emplacement drifts and nonemplacement openings are analyzed for structural stability for both conditions: with and without ground supports. The openings at Yucca Mountain are expected to be stable without the need of ground support, under the prescribed design loads and for seismic events applicable to preclosure, for the duration of the preclosure period (Sections 1.3.3.3.1 and 1.3.4.4.1). Ground supports are added for personnel protection and for additional reliability of the openings in an operational facility (control of spalling, prevention of key block detachments, and mining safety practice).

The numerical methods utilize finite difference computer codes that evaluate stress and response conditions for every element in the model, providing comprehensive assessments of the openings and their ground support components' performance when subjected to different load combinations.

Subsurface openings and their ground support components are monitored and tested during and after installation to ensure that their performance conforms to design expectations. As a minimum, the openings and ground support components are monitored for opening convergence, ground support and rock temperatures, and ground support load conditions in order to establish that design limits are not exceeded. These monitoring activities are performed throughout the repository operating period if the ground support is accessible. Ground support designs consider the repository environmental conditions during preclosure and incorporate corrosion-resistant materials in areas where maintenance activities may be constrained because of high temperatures and high radiation (Sections 1.3.3.3 and 1.3.4.4).

1.3.2.4.4.3 Ground Support General Requirements

The following are ground support general requirements for both emplacement drifts and nonemplacement openings:

- The ground support system is designed to maintain adequate equipment operating envelopes through closure for emplacement drifts, turnouts, access and exhaust mains, intake and exhaust shafts, the North Ramp, and North Portal.

- The ground support system accommodates geologic mapping of emplacement drifts and nonemplacement openings.

- Ground support components are designed for the most severe condition based on applicable load combinations of in situ, thermal, seismic, construction, and operational loads for their locations.

- Ground support uses materials having acceptable long-term effects on waste isolation.

- Ground support is designed to prevent rockfall that could potentially result in personnel injury during the operational period. This criterion satisfies industry standards for personnel to safely operate within the facility.

- The ground support for emplacement drifts and inaccessible nonemplacement areas is designed to function without planned maintenance during the operational life, while providing for the ability to perform unplanned maintenance in emplacement drifts and inaccessible nonemplacement areas on an as-needed basis.

- The subsurface facility accommodates the maintenance of accessible nonemplacement openings.

1.3.2.4.5 Ventilation

The subsurface ventilation system design considers the following criteria on flammable and combustible materials (BSC 2007c), Section 4.9.3):

- The subsurface ventilation system is designed to limit the consequences of fire in accordance with Regulatory Guide 1.189, Section C4.1.4.

- Fan houses, fan bulkheads for main and booster fans, and air ducts connecting main fans to shaft openings are constructed of noncombustible materials.

- Stored flammable or combustible materials at the surface are kept more than 100 ft away from underground access openings.

- Internal combustion engines, except diesel-powered engines on mobile equipment used in the development areas, are prohibited underground.

Subsurface ventilation components located in the exhaust airway openings such as: exhaust main isolation barriers; exhaust fans and ancillary equipment at the exhaust shafts such as ducts and fan-isolation louvers are designed to withstand high temperature conditions for extended periods. Normal exhaust air temperature could approach 100°C for the longest (800 m) emplacement drifts and exceed 80°C for the average length (600 m) emplacement drifts (Figure 1.3.4-16) (BSC 2008d, Section 6.3).

The turnout bulkheads and fan-isolation louvers are designed to withstand the additional air pressure from high-volume drift cooling airflow.

The design of the subsurface ventilation system is consistent with the criteria, codes, standards, and specifications used in the underground mining industry.

1.3.2.4.5.1 Ventilation Pressures

The subsurface ventilation facility is designed to have two separate and independent systems for the ventilation of the emplacement and development areas, for the years when concurrent development and emplacement occurs. The two separate systems are created by placing temporary isolation barriers in the access and exhaust mains at locations where a given emplacement panel can be partitioned into sets of drifts that are ready for emplacement from the balance of drifts in the panel that are being excavated and equipped for emplacement. These temporary isolation barriers are movable to allow for the turn-over of sets of completed drifts from development to emplacement. After the repository development is complete, the temporary and movable isolation barriers separating the two systems are no longer necessary and the repository ventilation system reverts to one system. In addition to the temporary isolation barriers, the subsurface ventilation system uses permanent isolation barriers to separate the network of intake airways from the network of exhaust airways, thus creating thermal zones within the system, the ambient air (intake) zone, and the heated air (exhaust) zone with the active emplacement drifts being the connecting conduits between these thermal zones (Section 1.3.5). The air pressure differential between the development side and emplacement side of the subsurface repository is maintained to ensure that airflow leakage travels from the development side (supply positive pressure system) to the emplacement side (exhausting negative pressure system) of the subsurface repository. The isolation barriers and their bulkheads and doors are designed for the maximum ventilation differential pressure load, in addition to the dead and seismic loads. Maximum ventilation differential pressure is equivalent to the potential maximum primary fan pressure transmitted when the barrier and turnout bulkheads are closed. Intake and exhaust shaft collars are designed for the maximum internal air pressure.

The distributions of ventilation pressure throughout the subsurface facility are calculated for normal repository operating conditions. The balanced pressure loss, airflow rate, and airway resistance for each subsurface airway show that the subsurface ventilation system design is capable of maintaining the required air pressure differences and directing the needed amount of airflow to desired locations.

The natural ventilation pressures generated by the waste package heat load in the repository are also evaluated for the airways in the subsurface facility. The waste package heat in the repository generates sufficient natural ventilation pressures to assist the main fans in moving the underground ventilation air through the exhaust mains and shafts.

A breach of a waste package and leakage of radioactive material from a waste package have been identified as beyond Category 2 event sequences (Section 1.7). Other potential radioactive materials in the subsurface are the resuspended radioactive contamination from the external surfaces of the waste packages and air and dust that have been neutron activated. Analyses indicate that the potential releases of these materials are below regulatory limits and do not require additional engineered controls, such as high-efficiency particulate air filters, for exhaust air released to the environment (Section 1.8).

1.3.2.4.5.2 Thermal

The subsurface ventilation system is designed considering the repository subsurface facility temperature limits listed in Table 1.3.1-2. The key ventilation parameters, including airflow quantity, airflow allocations, shaft sizes, and ventilation arrangement for various development stages, are designed to ensure sufficient airflow for heat removal. Emplacement drift and exhaust temperatures are maintained such that a temporary loss of forced ventilation does not result in any temperature limit for off-normal transient conditions being exceeded (Section 1.3.5.3.2).

1.3.2.4.6 Design of Civil and Structural Structures, Systems, and Components

Structures and structural components of the subsurface facility are designed according to the design criteria discussed below.

1.3.2.4.6.1 Groundwater

The groundwater level does not impose any additional design requirements because it will not be encountered during the tunnel boring and shaft sinking operations. The water table is in excess of 170 m below the repository horizon at the present time for the worst postulated case. Although local and perched water may be encountered, such conditions in the drifts and shafts can be managed during construction and operations, but are not expected to occur and the drifts and shafts are expected to be dry.

1.3.2.4.6.2 Frost Line

The surface based structures (e.g., ventilation fan foundations, North Portal Security Access Control Station) are designed to withstand a potential penetration frost-line depth of 10 in.

1.3.2.4.6.3 Seismic Design Bases

Seismic loads applicable to preclosure for the various subsurface structural SSCs are based on the seismic design basis ground motions (DBGMs) and seismic use group importance factors described in Section 1.3.2.5.1.

1.3.2.4.6.4 Materials

Materials used for civil and structural components in the emplacement drifts are limited to those that do not have an adverse effect on postclosure performance (Section 1.3.6.1.3). The materials in the emplacement drift invert structures are steel and ballast. Crushed tuff generated from the tunnel boring machine excavations is evaluated for its suitability for use as ballast material for the emplacement drift invert. Design specifications will describe the requirements for the ballast material, placement, and compaction to support the design basis. Contingent on the method ultimately selected by the subsurface transportation equipment design-fabrication contractor, the third rail conductor to be utilized to supply power to the TEV may include other types (i.e., copper and insulator material) and quantities of materials that will have to be analyzed to verify that the impact of proposed materials on postclosure performance is acceptable.

Structural steel for the invert structure in emplacement drifts 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 2007c, Section 4.2.13.3.1).

Other applications in nonemplacement areas, including platforms, bulkhead plates, stiffeners, and miscellaneous steel, conform to the following standards, with a minimum yield stress of 36 ksi. Higher strength and corrosion-resistant materials are used if required by the design (BSC 2007c, Section 4.2.13.3.1):

- ASTM A 36/A 36M-05, *Standard Specification for Carbon Structural Steel*
- ASTM A 992/A 992M-06a, *Standard Specification for Structural Steel Shapes*
- ASTM A 500-03a, *Standard Specification for Cold-Formed Welded and Seamless Carbon Steel Structural Tubing in Rounds and Shapes*.

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*. Bolts for platforms and stairs conform to ASTM A 307-04, *Standard Specification for Carbon Steel Bolts and Studs, 60,000 psi Tensile Strength*. Structural connections are bearing-type connections, except where slip-critical connections are essential.

Anchor bolts at a minimum conform to ASTM A 307-04, *Standard Specification for Carbon Steel Bolts and Studs, 60,000 psi Tensile Strength*, with a minimum yield strength of 36 ksi.

Welding electrodes conform to AWS D1.1/D1.1M:2006, *Structural Welding Code—Steel*, Table 3.1.

Reinforced concrete structures are not used in the emplacement drifts. Concrete structures used in nonemplacement areas conform to the following material properties:

- Concrete compressive strength, based on 28-day strength, is 4,000 psi minimum in conformance with ASTM C 150-05, *Standard Specification for Portland Cement*.
- Reinforcing steel is deformed bars conforming to ASTM A 615/A 615M-06a, *Standard Specification for Deformed and Plain Carbon Steel Bars for Concrete Reinforcement*, or ASTM A 706/A 706 M-06a, *Standard Specification for Low-Alloy Steel Deformed and Plain Bars for Concrete Reinforcement*, Grade 60, with a minimum yield stress of 60,000 psi.
- Welded wire fabric conforms to ASTM A 185/A 185M-06, *Standard Specification for Steel Welded Wire Reinforcement, Plain, for Concrete*.

Nonshrink grout, where used in nonemplacement areas, is based on Type K Portland cement, in conformance with ASTM C 150-05, cement silica fume (ASTM C 1240-05, *Standard Specification* *for Silica Fume Used in Cementitious Mixtures*), super plasticizer, and admixtures (ASTM C 494/C 494M-05a, *Standard Specification for Chemical Admixtures for Concrete*).

1.3.2.4.6.5 Corrosion Effects

Steel corrosion in mines is usually caused by sulfuric acid that results from the oxidation of sulfide phases. This type of aggressive corrosion is not expected to be present in the emplacement drifts because no sulfides have been observed in the repository host formation. Significant aqueous corrosion in general is not expected to occur during the preclosure period because of low relative humidity. Due to the low relative humidity expected in the preclosure drift environment, any seepage entering into a drift would tend to evaporate. Salt brines are generated from local groundwater due to the evaporative concentration of chlorides and bromides. Since the presence of these brines can cause rapid corrosion, they are evaluated in the selection and design for the invert support steels. Also, materials used in the repository are resistant to microbially influenced corrosion in a subsurface environment. The steel invert structure in emplacement drifts is corrosion resistant, conforming to ASTM A 588/A 588M-05. Alternatively, an allowance for corrosion can be made in the thickness of the steel invert section by increasing the thicknesses beyond what is required structurally to allow for potential material degradation due to corrosion during the preclosure period in emplacement drifts.

1.3.2.4.6.6 Reinforced Concrete Structures

Reinforced concrete structures are designed in accordance with ACI 318-02/318R-02, *Building Code Requirements for Structural Concrete (ACI 318-02) and Commentary (ACI 318R-02)*.

1.3.2.4.6.7 Steel Structures

Steel structures are designed in accordance with the allowable stress design method using *Manual of Steel Construction, Allowable Stress Design* (AISC 1997) and *Specification for Structural Steel Buildings*, *Allowable Stress Design and Plastic Design, June 1, 1989, with Commentary* (AISC 1989). Proportioning and detailing for seismic loads meet the additional requirements of ANSI/AISC 341-02, *Seismic Provisions for Structural Steel Buildings*, Part III.

1.3.2.4.6.8 Permanent Subsurface Railway Design

The subsurface facility railway for the TEV crane rail is designed in conformance with ASTM A 759-00, *Standard Specification for Carbon Steel Crane Rails*, and in conformance with crane-rail tolerances specified in ASME-NOG-1 2004, *Rules for Construction of Overhead and Gantry Cranes (Top Running Bridge, Multiple Girder)*), and for the prescribed TEV loads and design load combinations (BSC 2007f, Sections 4.3, 6, and 7). The subsurface crane rail is an integrated rail system that connects the emplacement areas to the Initial Handling Facility and Canister Receipt and Closure Facility buildings where the waste packages are loaded and sealed.

Switches for the 11-ft centerline-to-centerline crane rail are designed specifically for TEV operational requirements, and are similar to switch design features identified in American Railway Engineering and Maintenance of Way Association standards (AREMA 2006) and rail design requirements and tolerances specified in ASTM A 759-00 and ASME NOG-1-2004.

1.3.2.4.6.9 Surface Structures That Are Part of Subsurface Facility

The principal structural surface-based SSCs that are part of the subsurface facility include the following:

- Portals
- North Portal Security Access Control Station
- Fan housings and foundations for shafts
- Head frames and their supporting foundations
- Fan pads electrical equipment
- Hoist houses.

1.3.2.4.7 Design of Fire Protection Systems, Structures, and Components

The subsurface fire-protection design consists of the following systems: fire water (development side only), explosion protection, fire suppression, fire detection, fire alarm, fire notification, and fire barrier (BSC 2007g, Section 6.1.2). Detailed descriptions of these systems are included in Section 1.4.3.

The fire barrier subsystem consists of physical fire-rated barriers that separate the emplacement areas from the development areas. In addition to providing fire-rated barriers, the barriers function as ventilation separators, and safeguard and security barriers (BSC 2007g, Section 6.1.2.5).

The development subsystems are temporary systems that are removed when a developed section is prepared for emplacement activities and turned over to operations. Fire hazards are significantly greater during development activities because of higher transient combustible loading. The higher combustible loading exists because of construction equipment, such as the tunnel boring machines, roadheaders, and load-haul-dump underground haulers. This equipment introduces electrical power supply cables, diesel fuel, rubber tires, hydraulic fluids, and general lubricants into the subsurface. Another hazard is the use of blasting materials for excavation activities (BSC 2007h, Section 4.3.1).

Fire hazards in the emplacement areas are more limited than in the development areas. Maintenance work in the emplacement areas introduces welding gases brought in for maintenance, which are managed under the combustible material control program. Battery explosion prevention on backup power systems in mobile equipment, such as the TEV, primarily relies on proper battery selection. Batteries are selected to minimize hydrogen offgassing. Battery charging is performed in well-ventilated areas and preferably on the surface. Construction explosives will neither be transported through nor stored in the emplacement areas. The surface fire water subsystem does not provide water to the emplacement areas since no fixed fire-suppression sprinkler system will be installed in those areas. If installed during development, the sprinkler system will be removed during commissioning activities. Fixed and transient fuel loads in the emplacement areas are very low. Fixed loading is primarily electrical and instrument cables, and transient loading is primarily in the mobile equipment (batteries and electrical equipment). Mobile equipment operating in the emplacement areas is equipped with onboard fire detection and suppression systems. However, the design of the TEV and other subsurface rolling stock will ensure that the severity of credible fires is controlled without taking credit for fire suppression systems and will not result in a waste package breach (BSC 2008b, Section 3.2.1.4; BSC 2007g, Section 6.1.2).

1.3.2.4.8 Design for Waste Retrieval

The subsurface facility design preserves the option to retrieve any or all of the emplaced waste throughout the preclosure period. The repository ground support, ventilation, rail, and other support systems are designed to remain effective for up to 100 years after the initiation of waste emplacement such that the occurrence of rockfall or anticipated off-normal events do not preclude retrieval.

The specific surface facilities needed to support waste retrieval will depend on various factors that can only be determined when a decision for waste retrieval is made. Detailed plans for retrieved waste handling and storage will be developed when the need for retrieval is identified. The specific design and operational plans needed will depend upon the reasons for retrieval, consideration of any associated hazards, and consideration of regulations applicable at the time. Approaches for waste retrieval processes, operations, equipment, and compliance with preclosure performance objectives are discussed in Section 1.11.

1.3.2.4.9 Construction in Phases: Panel Sequencing

The subsurface facility is divided into four waste emplacement panels (Figure 1.3.1-1), which will be developed in sequence to coincide with the receipt of waste. The panel sequence planned for excavation, construction, and waste emplacement is as follows:

- Panel 1
- Panel 2
- Panel 3E and Panel 3W, alternately developed and emplaced
- Panel 4.

The development of each of these panels includes access and exhaust mains, shafts, turnouts, and emplacement drifts. The general excavation process of a panel begins with the excavation of the access and exhaust mains, followed by the excavation of the ventilation shafts, and, finally, the construction of turnouts and emplacement drifts. Before the emplacement drifts within a panel are made available to accept waste, the emplacement drifts are isolated from the adjacent development activities by installing isolation barriers at the access and exhaust mains (Section 1.3.5). Emplacement will occur concurrently with a major portion of the development work, and will continue after completion of development until the inventory of 70,000 MTHM has been emplaced.

Construction starts with Panel 1, accessed from the existing Exploratory Studies Facility tunnel (North Portal). Excavation and construction of emplacement drifts will proceed from north to south in Panel 1. This panel has six emplacement drifts and one exhaust shaft. It uses the North Portal–North Ramp as the intake airway for the emplacement side and the Enhanced Characterization of the Repository Block Cross-Drift shaft temporarily as an initial intake airway for the development side of Panel 1. Three emplacement drifts are included for initial emplacement while development of the remaining drifts in the panel continues concurrently with that operation. The observation drift in Panel 1 (Section 1.3.3) will also be commissioned concurrently or prior to commissioning of the initial drifts. Isolation barriers will be constructed to separate the initial emplacement area from the continuing construction in Panel 1. The repository construction schedule is discussed in GI-2.1.

After Panel 1, Panel 2 is the next panel excavated. This panel is accessed from the existing South Portal. Excavation and construction of emplacement drifts proceed from north to south in Panel 2. This panel has 27 emplacement drifts, two exhaust shafts, and one intake shaft.

After Panel 2, Panels 3E and 3W are the next panels excavated. These panels share a common access main and are excavated alternately from south to north. Construction of the North Construction Portal and North Construction Ramp, five ventilation shafts, and the excavation of access and exhaust mains are completed before waste emplacement in Panel 3 begins. The emplacement drifts for these two panels are filled alternating from east to west, retreating from the south to the north. These panels have a combined total of 45 emplacement drifts.

Panel 4 is excavated concurrently with Panel 3. Construction access to Panel 4 is through the North Construction Portal. Waste emplacement in Panel 4 is finished last. The emplacement drifts in Panel 4 are filled from the south to the north. This panel has 30 drifts.

1.3.2.4.10 Design for Repository Closure

Designs for repository closure features and items specific to the subsurface facility are described in Section 1.3.6. The subsurface facility closure design includes features that prevent human intrusion and that promote the long-term isolation of the emplaced waste. Closure also includes completion of the EBS, such as installation of the drip shields, and incorporation of backfill in the ramps and shafts to prevent human intrusion.

1.3.2.5 Design Methodologies for Subsurface Structures, Systems, and Components *[NUREG-1804, Section 2.1.1.7.3.2: AC 1(1), (2), (4)]*

1.3.2.5.1 Seismic Design

Seismic loads applicable to preclosure for the various subsurface SSCs are based on the seismic DBGMs and seismic use group importance factors summarized in Tables 1.3.2-1 and 1.3.2-2. Seismic conditions used for analyzing postclosure performance of the EBS SSCs (i.e., waste package emplacement pallet, waste package, and drip shield) are described in Section 2.3.4.

Seismic Data Sources—Seismic ground motion data generated during the period 2003–2004 (BSC 2004) were primarily used in subsurface design analyses while supplemental seismic ground motion data generated during the late 2007 and early 2008 (BSC 2008e) were used to determine potential impacts on ground support and structures designed to the 2003-2004 ground motions data.

Seismic Ground Motion Time Histories—Ground support design analyses use seismic ground motions in the forms of seismic velocity time histories in both horizontal and vertical directions corresponding to an annual probability of exceedance event of 5×10^{-4} as DBGM-2. Seismic velocity histories corresponding to an annual probability of exceedance event of 1×10^{-4} are used as beyond DBGMs to address the sensitivity of drift stability and ground support behavior to potential seismic events. These velocity waves are converted to stress waves corresponding to the primary wave (P-wave) and shear wave (S-wave) for their applications to full dynamic analyses of drift stability and ground support adequacy (BSC 2007i; BSC 2007j; BSC 2008f). Ground motion time histories corresponding to annual probability of exceedance events of 1×10^{-3}, 5×10^{-4} and 1×10^{-4} for both the 2003-2004 and 2007-2008 data sets are shown in Figures 1.3.2-1 through 1.3.2-6.

Seismic Response Spectra—Response spectra in the forms of plots of spectral acceleration vs. frequency, corresponding to annual probability of exceedance events of 1×10^{-3}, 5×10^{-4} and 1×10^{-4} for both the 2003-2004 and 2007-2008 data sets are illustrated in Figures 1.3.2-7 through 1.3.2-12. Response spectra are used for quasi-static analyses of structures such as invert structures (BSC 2007f), but are not used for ground support design analyses.

For structural SSCs designed to *International Building Code 2000* (ICC 2003) as listed in Table 1.3.2-1, the applicable seismic load is calculated from spectral accelerations by the following method: (1) the maximum considered earthquake ground motion is taken as that motion represented by an acceleration response spectrum having a 2% probability of exceedance within a 50-year period (2,500-year return period); (2) since site-specific accelerations are available for events with 1,000-year, 2,000-year, and 10,000-year return periods, a graphical approximation of the accelerations for the 2,500-year return period is made; (3) then, a two-thirds factor is applied, as allowed by the code, to obtain the seismic accelerations equivalent to approximately a 500-year return period seismic event (BSC 2007c, Section 6.1.10.2.2; BSC 2007k, Section 6).

Non-ITS structures located at the surface that are part of the subsurface facility (e.g., fan pads) are seismically designed to the appropriate *International Building Code 2000* (ICC 2003) seismic use group (Table 1.3.2-2).

In addition, structures connected to the drift walls are designed for structural deformations imposed by tunnel deformations caused by the seismic ground motion.

Seismic Hazard Levels—Seismic ground motions corresponding to a mean annual probability of exceedance of 5×10^{-4} (or 2,000 year return period) are used as a basis for determination of the effects of seismic ground motions on: (1) stability of emplacement drifts and nonemplacement openings; and (2) performance of ground support systems. Seismic ground motions corresponding to an annual probability of exceedance event of 1×10^{-4} (or 10,000-year return period) are also considered as part of examining the sensitivity of drift stability and ground support behavior to potential seismic events (BSC 2008g, Section 4.3; BSC 2007i; BSC 2007j; BSC 2008f). In addition, in support of the preclosure safety analyses for Category 2 events, the following events are analyzed: seismic ground motions for an annual exceedance probability event of 1×10^{-5} (or 100,000-year return period) are used for assessing rockfall events in nonemplacement drifts where the TEV travels; and, seismic loads for annual exceedance probability events of 2×10^{-6} (or 500,000-year return period) and 1×10^{-6} (or 1,000,000-year return period) are used for predicting rockfall events in emplacement drifts for the first 50 years of repository operations (BSC 2008h, Section 3.2.1) and throughout the 100-year preclosure period (BSC 2007i, Section 6.11); BSC 2008g, Section 6.9), respectively. Seismic ground motion data corresponding to an annual exceedance probability of 1×10^{-3} (or 1,000-year return period) are not used in ground support design analyses.

Table 1.3.2-3 lists sources for the original (2003-2004) and supplemental (2007-2008) seismic ground motion data (ground motion time histories, response spectra, and seismic hazard curves).

1.3.2.5.2 Criticality Design

Evaluation of preclosure criticality safety in the subsurface facility is discussed in Section 1.14.2.3.3.6.

1.3.2.5.3 Shielding Design

The methods used in shielding analyses to support the repository design are consistent with those of commonly accepted shielding calculations and appropriate for the radiation types, geometries, and materials analyzed. The analytical tools include computer codes that use Monte Carlo, deterministic transport, and point-kernel integration techniques for the various shielding cases encountered in the repository design (BSC 2007c, Section 4.10.1.6). The principal computer code used for shielding analysis, MCNP, is supplemented by other shielding codes such as SCALE. A more detailed discussion of shielding design is presented in Section 1.10.3.

The design of shielding for the protection of workers against radiation considers normal operations and Category 1 event sequences. Shielded cabinets protect the radiation-sensitive electrical and electronic components. The radiation shielding designed for the equipment operating in the emplacement drift protects the equipment from the design basis radiation environment around the transportation, aging, and disposal waste package containing 21-PWR fuel assemblies, which is the waste package with the highest dose rates (BSC 2007l, Table 2).

1.3.2.5.4 As Low as is Reasonably Achievable Design Methodology

As low as is reasonably achievable guidelines described in Section 1.10.2 are implemented to maintain personnel exposures to radiation as low as is reasonably achievable.

1.3.2.5.5 Consistency of Materials with Design Methodologies

The materials of construction for subsurface repository SSCs comply with the industry codes and standards listed for each SSC in their respective design description sections.

1.3.2.6 Performance and Documentation of Design Analyses
[NUREG-1804, Section 2.1.1.7.3.3(II): AC 1(2)]

Structural, thermal, shielding, confinement, and decommissioning analyses are performed for ITS and ITWI SSCs to ensure that:

- Values of material properties have documented technical bases and are consistent with site-specific data.
- Loads and load combinations are consistent with normal operations and conditions resulting from Category 1 and Category 2 event sequences.
- Analytical methods, models, and codes are appropriate for the conditions analyzed and are properly benchmarked, as appropriate.

- Technical bases for assumptions are defined and are based on accepted engineering practice.
- The designs and analyses for SSCs demonstrate that these SSCs have sufficient capability to withstand normal, Category 1 event sequence, and Category 2 event sequence loadings, as appropriate.

These factors are considered in each design analysis for ITS and ITWI SSCs and are documented as part of the respective design analyses and calculations.

Software codes used for aiding in design analyses and calculations for subsurface ITS and ITWI SSCs are acquired or developed, modified, and maintained in a planned and traceable manner in accordance with software configuration management procedures. The software meets Quality Assurance Program requirements. The software verification and validation activities are planned, performed, and documented for each software code, for changes to software, or for those system configurations that are determined to impact the software. Furthermore, each software code is evaluated to ensure both its appropriateness for the applications used in analyses and its usage within the range of verification and validation.

1.3.2.7 Design Codes and Standards
[NUREG-1804, Section 2.1.1.7.3.3(II): AC 1(1), (3)]

Industry codes and standards used in the design of the TEV are listed in Table 1.3.2-4. The consensus codes and standards listed for the TEV are typically used for design of nuclear and industrial crane systems and equipment and have been evaluated as applicable for design of the TEV SSCs and features that perform ITS functions (BSC 2008b, Section 3.3). The codes and standards applicable to the design and fabrication of ITWI SSCs are listed in Table 1.3.2-5.

Studies to identify applicable codes and standards and to determine the extent of applicability are performed to address areas of nonstandard design that include components and design configurations that do not have standard industry practices or codes and standards. Application of industry codes and standards, where available, provides established performance levels and service factors based on equipment usage and performance (BSC 2008c, Section 1).

The TEV SSC designs are based on proven and commercially available technology. However, portions of some designs represent first-of-a-kind application of existing technology. If only partial application of an applicable code or standard is possible due to project-specific performance or functional requirements or a new application of an existing technology, it will be necessary to develop supplemental requirements to augment the applicable code or standard. This process is addressed through further evaluation of applicable codes and standards to ensure each ITS performance requirement is met. When a performance requirement is not fully satisfied, a difference is highlighted and evaluated. This gap analysis identifies the supplemental requirements needed and also identifies the specific areas of nonstandard design. The iterative process of refining the requirements will continue as the design progresses (BSC 2008c, Section 1; BSC 2008i, Section 1; BSC 2008j, Section 2).

If the gap analysis concludes that a performance requirement for an SSC classified as ITS cannot be fully satisfied through application of a code or standard or supplemental requirement, additional activities are performed to satisfy the performance requirement. This process includes refinement of design requirements to meet ITS reliability, safety, and performance goals and identifies the means for demonstrating that SSCs that do not have established code and standard requirements can be relied upon to perform the ITS functions identified in the nuclear safety design basis (Section 1.9). Activities will include any or all of the following: calculations, modeling, iterative failure mode and effects analysis and fault-tree analysis, and testing on components and systems. Testing for the TEV will include bench testing of selected individual components and will include factory acceptance testing of the complete TEV (BSC 2008i, Sections 2, 4, and 5; BSC 2008j, Sections 3, 8, and 9).

Documentation is developed for design verification and the subsequent development of performance specifications, test specifications, and test procedures to ensure the SSCs can meet their performance criteria (BSC 2008j, Sections 1 and 10).

1.3.2.8 Design Loads and Load Combinations

[NUREG-1804, Section 2.1.1.2.3: AC 3(1); Section 2.1.1.7.3.1: AC 1(1), (2), (4), (5), (9); Section 2.1.1.7.3.3(II): AC 1(1), (2), (3); AC 4(5)]

Postclosure related loads are evaluated in Section 2.3.4 for mechanical loads and in Section 2.3.5 for thermal considerations. The following loads and load combinations are considered in the design of the subsurface ITS and non-ITS mechanical and structural SSCs.

1.3.2.8.1 Dead Loads

Dead loads are those loads that remain permanently in place and include the weight of framing, permanent equipment, and all attachments.

1.3.2.8.2 Live Loads

Live loads (L) are those loads that are superimposed by the use and occupancy of the building or structure. Live load (L_0) is defined as the live load expected to be present during an earthquake event. A live load (L_0) equal to 25% of the minimum uniform design live loads specified below may be used. Minimum live loads used for the design are not less than the following:

- Platforms, walkways, and stairs:
- Uniform live load: 100 psf
  - Concentrated load: 1,000 lbs
  - These loads are concurrent. Concentrated load is applied to maximize moment and shear.

- Construction loads:
  - Construction loads for the steel invert structure: 500 psf
  - Loads near shafts:

    Minimum traffic load near shafts: H20 Truck Loading (AASHTO 2005)
    Minimum surcharge load: 300 psf
    Minimum laydown load near shafts: 250 psf.

1.3.2.8.3 Seismic Loads

Seismic loads for the design of the SSCs are the inertia loads that are generated resulting from the seismic ground motion accelerations described in Section 1.3.2.5.1.

1.3.2.8.4 Transport and Emplacement Vehicle Loads

The loaded TEV, which includes the crane weight, wheel loads, and lifted loads, is used for the design of crane rails and supporting structural steel beams. The design allowances are in accordance with ASME NOG-1-2004, *Rules for Construction of Overhead and Gantry Cranes (Top Running Bridge, Multiple Girder)*. The weight of the loaded TEV (which will not exceed 300 tons) is considered simultaneously with the seismic loads. The horizontal and vertical inertia forces are obtained by multiplying the weight of the TEV by the appropriate accelerations (BSC 2007f, Sections 3 and 4).

1.3.2.8.5 Waste Package Loads

Waste package characteristics and the maximum loaded waste package weights are evaluated. For design of SSCs subject to waste package loads, the maximum weight of the waste packages (nominal 178.2 kips or 81.0 tons for the Naval Long waste package) is used, and maximum weight of the pallet (nominal 5.5 kips or 2.5 tons for the long pallet) supporting the waste package is also included (BSC 2007f, Section 4.3).

1.3.2.8.6 Drip Shield Loads

Drip shields in the emplacement drifts are planned to protect the waste packages from rockfall and water intrusion after closure. Natural degradation processes affect the structural integrity of the drip shield. The drip shield performs this function for thousands of years as identified in Sections 2.3.4 and 2.3.6. Drip shields will be installed after the completion of emplacement of all waste packages and prior to closure. Drip shield loads (nominal 11.0 kips or 5.0 tons distributed along drip shield base plates) are considered in the steel invert structure design (BSC 2007f, Section 4.3).

1.3.2.8.7 Ventilation Pressure Loads

Isolation barriers, steel bulkheads, and emplacement access doors are designed for the ventilation differential pressure load (maximum pressure differential of 15 in. water gauge), in addition to the dead and seismic loads. Maximum ventilation differential pressure considered is equivalent to the potential maximum primary fan pressure transmitted when the barrier and turnout bulkheads are closed. Intake and exhaust shaft collars are designed for the maximum internal air pressure (7.5 in. water gauge).

1.3.2.8.8 Temperature Loads

The design of SSCs includes the effects of loads based on the variations in temperatures for their intended locations. The peak exhaust air temperature in the emplacement drift approaches 100°C (Figure 1.3.4-16) during normal operations, for the longest emplacement drift length (BSC 2008d, Section 6.3). The peak design temperature for SSCs in the emplacement drifts and turnout is 200°C, allowing for temperatures that could be reached during off-normal events, for short durations (30 days or less). Expansion joints are provided in the longitudinal members of the steel invert structure and rails in the emplacement drifts.

1.3.2.8.9 Load Combinations

Application methodology for design load combinations for the different subsurface facility SSCs varies depending on the SSC being analyzed. Standard design practices are used as much as possible; however, the analyses of some structural components, such as dynamic analysis of the waste package emplacement pallet or drip shield, are conducted with three-dimensional numerical simulation models, such as finite-element codes, which apply design loads to the component elements being analyzed within a prescribed set of boundary conditions. Performance of ground support designs in the subsurface environment are also analyzed for the different applicable load combinations in a comprehensive manner, using finite-element and finite difference codes that apply and distribute the applicable loads throughout the rock media and subsurface openings being analyzed. Selected design loads and load combinations used for the major subsurface systems are explained in the respective sections for those systems.

1.3.2.8.9.1 Structural Steel Structures

Load combinations for the design of steel invert structures in emplacement drifts are described in Section 1.3.4.

Other structural steel structures and components designated as non-ITS SSCs are designed in accordance with the following load combinations of the *International Building Code 2000* (ICC 2003, Section 1605.3.2) and conform to the requirements of *Manual of Steel Construction, Allowable Stress Design* (AISC 1997):

$$S = D + L$$
$$S = D + L + P + T$$
$$S = D + L + 0.7E$$
$$S = D + L + P + T + 0.7E$$
$$S = 0.9D + 0.7E$$

where

S	=	Allowable stress as permitted by *Manual of Steel Construction, Allowable Stress Design* (AISC 1997) method
D	=	dead load
L	=	live load
E	=	seismic load
P	=	ventilation pressure load
T	=	temperature load.

1.3.2.8.9.2 Reinforced Concrete Structures

Reinforced concrete structures are not used in the emplacement drifts. Concrete structures used in the nonemplacement areas are designated as non-ITS SSCs and are designed in accordance with the following load combinations, conforming to the requirements of the *International Building Code 2000* (ICC 2003):

$$U = 1.4D$$
$$U = 1.2D + 1.6L$$
$$U = 1.2D + 1.2T + 1.6L$$
$$U = 1.2D + 1.0L + 1.0E$$
$$U = 1.2D + 1.2T + 1.0L + 1.0E$$
$$U = 0.9D + 1.0E$$

where

U	=	Required strength per *International Building Code 2000* (ICC 2003)
D	=	dead load
L	=	live load
T	=	temperature load
E	=	seismic load.

1.3.2.8.9.3 Equipment

Design of the subsurface mobile equipment includes the consideration of various load combinations. Equipment dead load includes equipment substructure, blocks and wheels, and baseplates, where applicable. Also included in dead load are equipment and component shielding. Live load includes equipment movable components and assemblies and the dynamic effects of their operation, wind loads, and seismic-induced loads. Service factors are applied to equipment load combinations per appropriate code guidelines. More information regarding design loads for the waste package transportation and emplacement equipment is presented in Section 1.3.3.

1.3.2.9 Conformance of Design to Criteria and Bases

The tables that contain the cross-references of SSCs nuclear safety design bases, for both preclosure and postclosure considerations, to the corresponding design criteria considerations and control parameters and constraints that ensure the nuclear safety design bases are met are included in Section 1.3.1, Subsurface Operations Overview, and in the subsurface facility design description sections, Sections 1.3.3 through 1.3.6.

1.3.2.10 General References

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ASTM A 307-04. 2004. *Standard Specification for Carbon Steel Bolts and Studs, 60,000 psi Tensile Strength*. West Conshohocken, Pennsylvania: American Society for Testing and Materials. TIC: 258703.

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Table 1.3.2-1. Seismic Design Requirements for Structures, Systems, and Components

Structures, Systems, and Components	Seismic Design Basis
Steel Invert Structures in Emplacement Drifts Analyzed for Seismic Loads with Loaded TEV	DBGM-1
Steel Invert Structures in Emplacement Drifts Analyzed for Seismic Loads without TEV Loads	DBGM-2
Isolation Barriers, Steel Bulkheads, and Emplacement Access Doors in Access Mains and Turnouts	IBC
Steel and Concrete Invert Structures in Turnouts, Access Mains, and North Ramp	IBC
Muck Handling Structures	IBC
Steel Platforms and Walkways at Repository Horizon	IBC
Supports for the Utilities	IBC
Shaft Collars	IBC
Portal Structures and Foundations	IBC
Miscellaneous Structures and Foundation Pads at Rock Surface above Repository Horizon	IBC
North Portal Security Access Control Station	IBC
Ground Support in Nonemplacement Openings	DBGM-2
Ground Support in Emplacement Drifts	DBGM-2 Beyond DBGM also used for sensitivity analyses and drift degradation analyses

NOTE: IBC = International Building Code (ICC 2003).

Table 1.3.2-2. Seismic Use Group and Importance Factors of Structures, Systems, and Components Designed to International Building Code

Seismic Use Group	Importance Factor	SSCs Designed to International Building Code
I	1.0	Non-ITS SSCs for standard occupancy
II	1.25	SSCs that represent substantial hazard to human life
III	1.5	Essential or hazardous SSCs

Table 1.3.2-3. Seismic Design Input Sources for Location B, Repository Level

Seismic Design Input	Annual Probability of Exceedance	Seismic Data Source (2003-2004)	Seismic Data Source (2007-2008)
Time Histories	1×10^{-3}	BSC 2004	BSC 2008e
	5×10^{-4}	BSC 2004	BSC 2008e
	1×10^{-4}	BSC 2004	BSC 2008e
	1×10^{-5}	BSC 2004	NA
	1×10^{-6}	BSC 2004	NA
Response Spectra	1×10^{-3}	BSC 2004	BSC 2008e
	5×10^{-4}	BSC 2004	BSC 2008e
	1×10^{-4}	BSC 2004	BSC 2008e
Hazard Curve	1×10^{-2} to 1×10^{-8}	NA	BSC 2008e

NOTE: NA = not applicable.

Table 1.3.2-4. Codes and Standards and Regulatory Guidance Documents Used in the Design of Subsurface Important to Safety Structures, Systems, and Components

Codes and Standards and Regulatory Guidance Documents	Applicability
ASME NOG-1-2004, *Rules for Construction of Overhead and Gantry Cranes (Top Running Bridge, Multiple Girder)* • Section 4000, "Requirements for Structural Components" • Section 5000, "Mechanical" • Section 6000, "Electrical Components" • Section 7000, "Inspection and Testing"	ITS TEV and Non-ITS Drip Shield Gantries[a]–consensus standard for nuclear overhead and gantry cranes
CMAA 70-2000, *Specifications for Top Running Bridge and Gantry Type Multiple Girder Electric Overhead Traveling Cranes*	ITS TEV, extensively used throughout ASME NOG-1-2004 for standard gantry crane design requirements
Design Guides for Radioactive Material Handling Facilities and Equipment (Doman 1988).	ITS TEV interlocks and locking safety features

NOTE: [a]ASME NOG-1-2004 is also used for design of the drip shield gantry.

Table 1.3.2-5. Codes and Standards and Regulatory Guidance Documents Used in the Design of Subsurface Important to Waste Isolation Structures, Systems, and Components

Codes and Standards and Regulatory Guidance Documents	Applicability
NUREG-0612, *Control of Heavy Loads at Nuclear Power Plants* (NRC 1980)	Structural requirements for lifting and handling large loads
2001 ASME Boiler and Pressure Vessel Code (including 2002 addenda) (ASME 2001, Section II, Part D, Table NF-2)	Drip shield Titanium Grade 7– Density (ρ)
Properties and Selection: Nonferrous Alloys and Special-Purpose Materials (ASM International 1990, Table 20, p. 620)	Drip shield Titanium Grade–Density (ρ)
2001 ASME Boiler and Pressure Vessel Code (including 2002 addenda) (ASME 2001, Section II, Part D, Table Y-1)	Drip shield Titanium Grade 7–Yield Strength (S_y)
2001 ASME Boiler and Pressure Vessel Code (including 2002 addenda) (ASME 2001, Section II, Part B, SB-265, Table 1)	Drip shield Titanium Grade 7–Ultimate Tensile Strength (S_u); percentage elongation
2001 ASME Boiler and Pressure Vessel Code (including 2002 addenda) (ASME 2001, Section II, Part D, Table TM-5)	Drip shield Titanium Grade 7–Elastic Modules (E)
2001 ASME Boiler and Pressure Vessel Code (including 2002 addenda) (ASME 2001, Section II, Part D, Table TE-5)	Drip shield Titanium Grade 7–Mean Coefficient of Thermal Expansion
2001 ASME Boiler and Pressure Vessel Code (including 2002 addenda) (ASME 2001, Section II, Part D, Table NF-1)	Drip shield Titanium Grade 7–Poisson's Ratio (ν)
Properties and Selection: Nonferrous Alloys and Special-Purpose Materials (ASM International 1990, Table 21, p. 621)	Drip shield Titanium Grade 7–Poisson's Ratio (ν)
Properties and Selection: Nonferrous Alloys and Special-Purpose Materials (ASM International 1990, Table 20, p. 620)	Drip shield structural members Titanium Grade 29–Density (ρ)
2001 ASME Boiler and Pressure Vessel Code (including 2002 addenda) (ASME 2001, Section II, Part B, SB-265, Table 3)	Drip shield structural members Titanium Grade 29–Yield Strength (S_y)
2001 ASME Boiler and Pressure Vessel Code (including 2002 addenda) (ASME 2001, Section II, Part B, SB-265, Table 1)	Drip shield structural members Titanium Grade 29–Ultimate Tensile Strength (S_u); percentage elongation
Properties and Selection: Nonferrous Alloys and Special-Purpose Materials (ASM International 1990, Table 21, p. 621)	Drip shield structural members Titanium Grade 29–Elastic Modulus (E)
Properties and Selection: Nonferrous Alloys and Special-Purpose Materials (ASM International 1990, Table 20, p. 620)	Drip shield structural members Titanium Grade 29–Mean Coefficient of Thermal Expansion
Properties and Selection: Nonferrous Alloys and Special-Purpose Materials (ASM International 1990, Table 21, p. 621)	Drip shield structural members Titanium Grade 29–Poisson's Ratio (ν)
2001 ASME Boiler and Pressure Vessel Code (including 2002 addenda) (ASME 2001, Section II, Part B, SB-575, Section 7.1)	Drip shield Alloy 22 (UNS N06022) base and stabilization pin–Density (ρ)
2001 ASME Boiler and Pressure Vessel Code (including 2002 addenda) (ASME 2001, Section II, Part D, Table Y-1)	Drip shield Alloy 22 base and stabilization pin–Yield Strength (S_y)

Table 1.3.2-5. Codes and Standards and Regulatory Guidance Documents Used in the Design of Subsurface Important to Waste Isolation Structures, Systems, and Components (Continued)

Codes and Standards and Regulatory Guidance Documents	Applicability
2001 ASME Boiler and Pressure Vessel Code (including 2002 addenda) (ASME 2001, Section II, Part D, Table U)	Drip shield Alloy 22 base and stabilization pin–Ultimate Tensile Strength (S_u)
2001 ASME Boiler and Pressure Vessel Code (including 2002 addenda) (ASME 2001, Section II, Part B, SB-575, Table 3)	Drip shield Alloy 22 base and stabilization pin–Percentage elongation
Properties and Selection: Stainless Steels, Tool Materials and Special-Purpose Metals (ASM 1980, p. 143)	Drip shield Alloy 22 base and stabilization pin–Poisson's Ratio (v) for Alloy 625 is used for Alloy 22[a]

NOTE: [a]The rationale for using the Alloy 625 Poisson's ratio (v) for Alloy 22 is documented in *Naval Long Waste Package Vertical Impact on Emplacement Pallet and Invert* (BSC 2007m, Section 3.2.2).

Source: BSC 2007n, Section 4.1.2 and Table 1.

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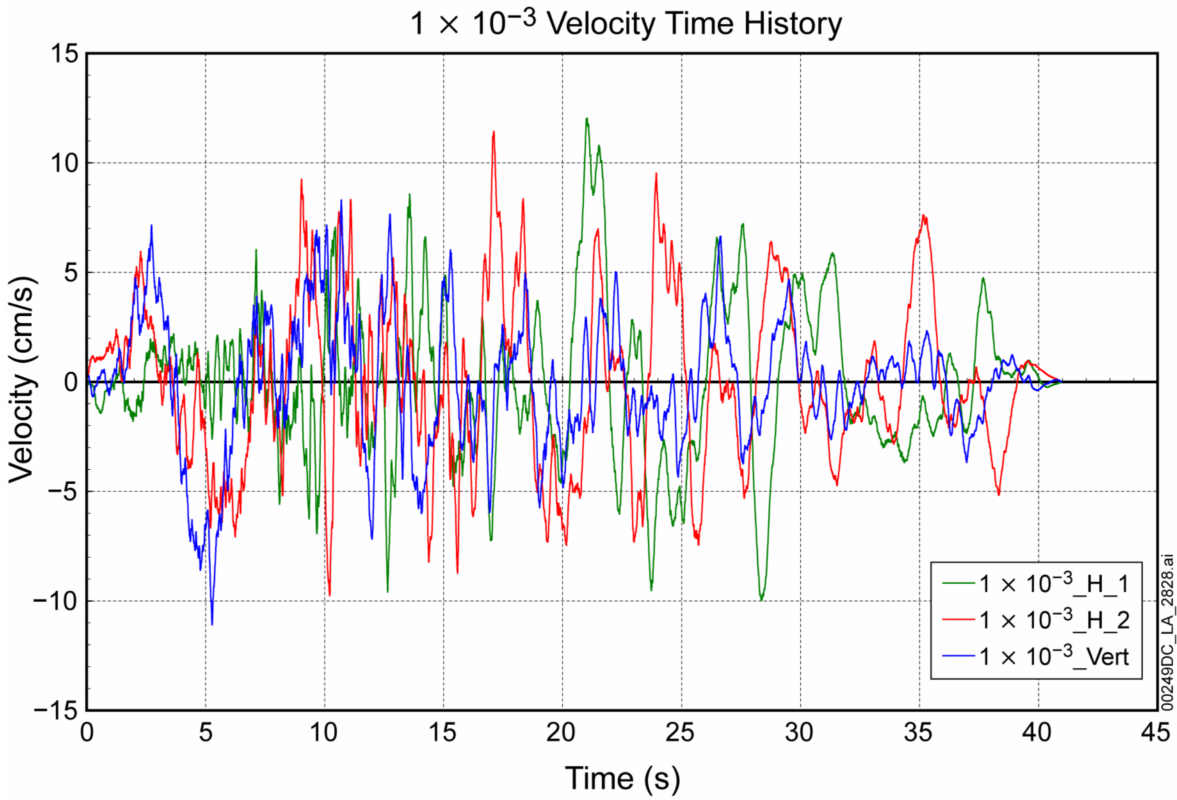

Figure 1.3.2-1. Seismic Time Histories for Location B (Repository Level) for a Seismic Event with an Annual Exceedance Probability of 1×10^{-3}, from the 2003–2004 Data Set

NOTE: H_1 = horizontal ground velocity 1; H_2 = horizontal ground velocity 2; Vert = vertical ground velocity.

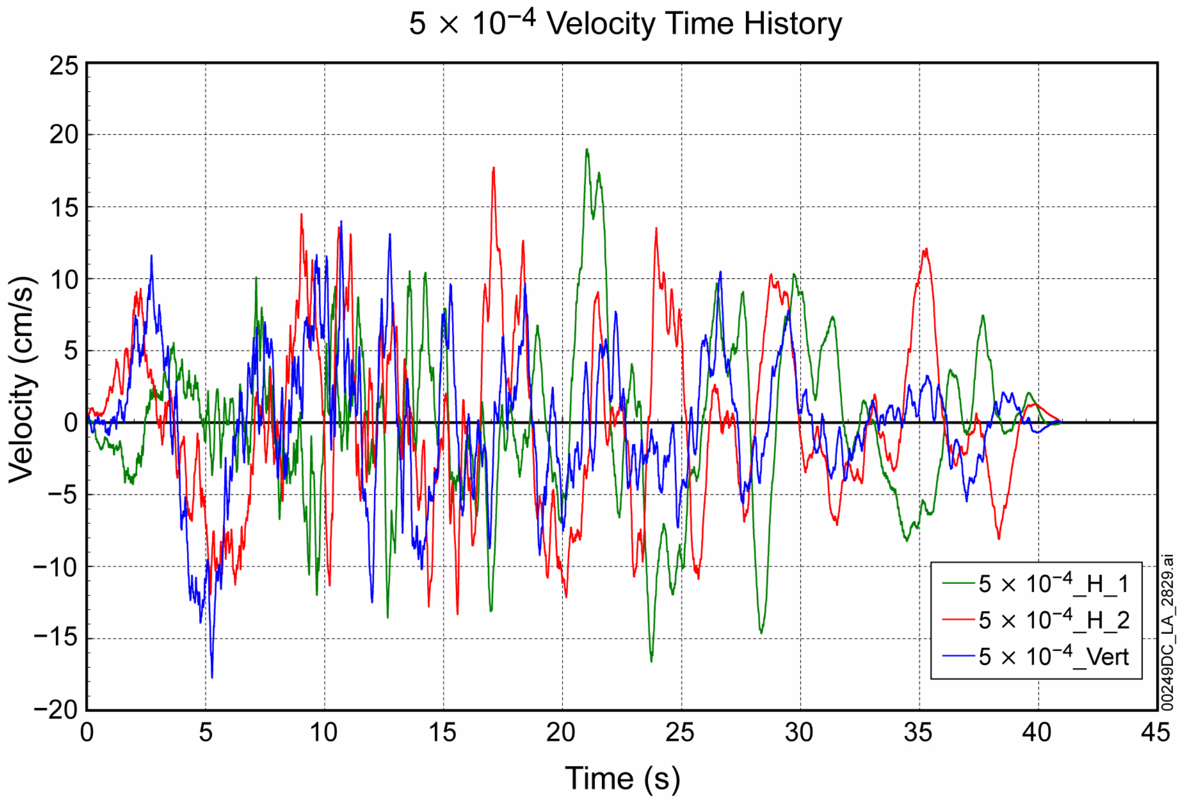

Figure 1.3.2-2. Seismic Time Histories for Location B (Repository Level) for a Seismic Event with an Annual Exceedance Probability of 5×10^{-4}, from the 2003-2004 Data Set

NOTE: H_1 = horizontal ground velocity 1; H_2 = horizontal ground velocity 2; Vert = vertical ground velocity.

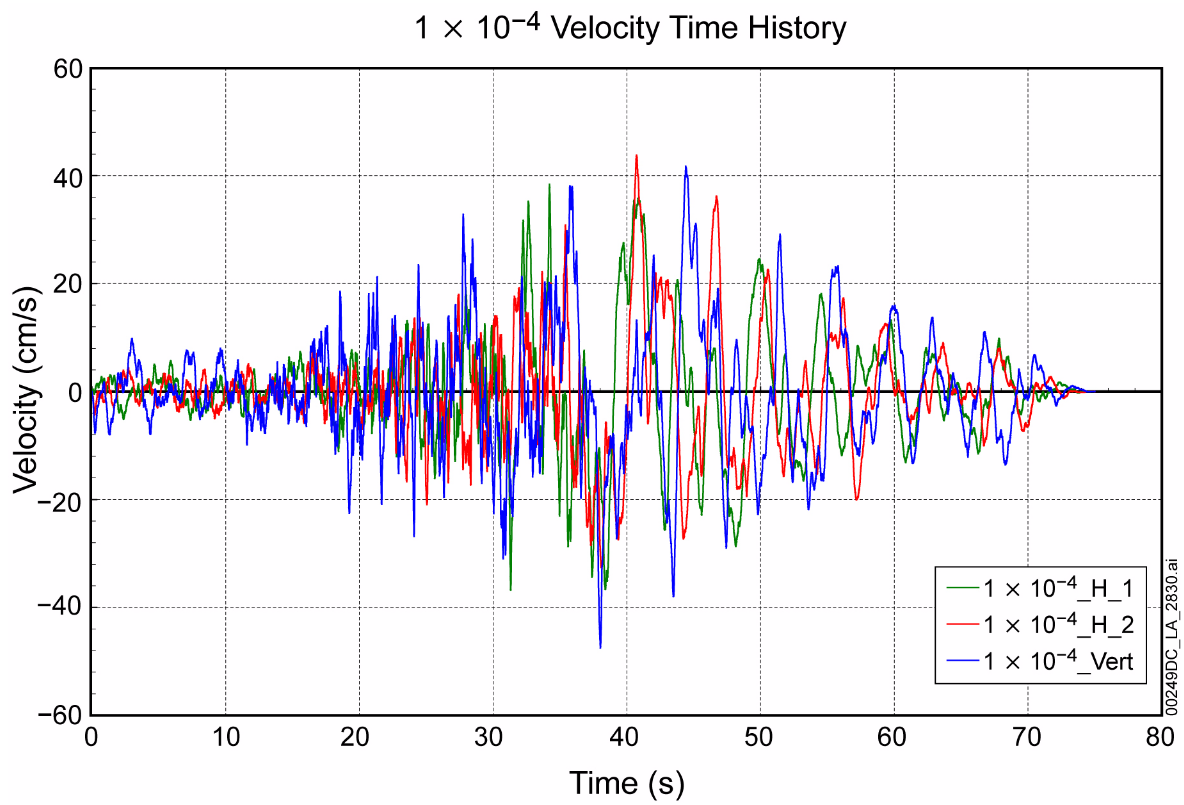

Figure 1.3.2-3. Seismic Time Histories for Location B (Repository Level) for a Seismic Event with an Annual Exceedance Probability of 1 × 10^{-4}, from the 2003–2004 Data Set

NOTE: H_1 = horizontal ground velocity 1; H_2 = horizontal ground velocity 2; Vert = vertical ground velocity.

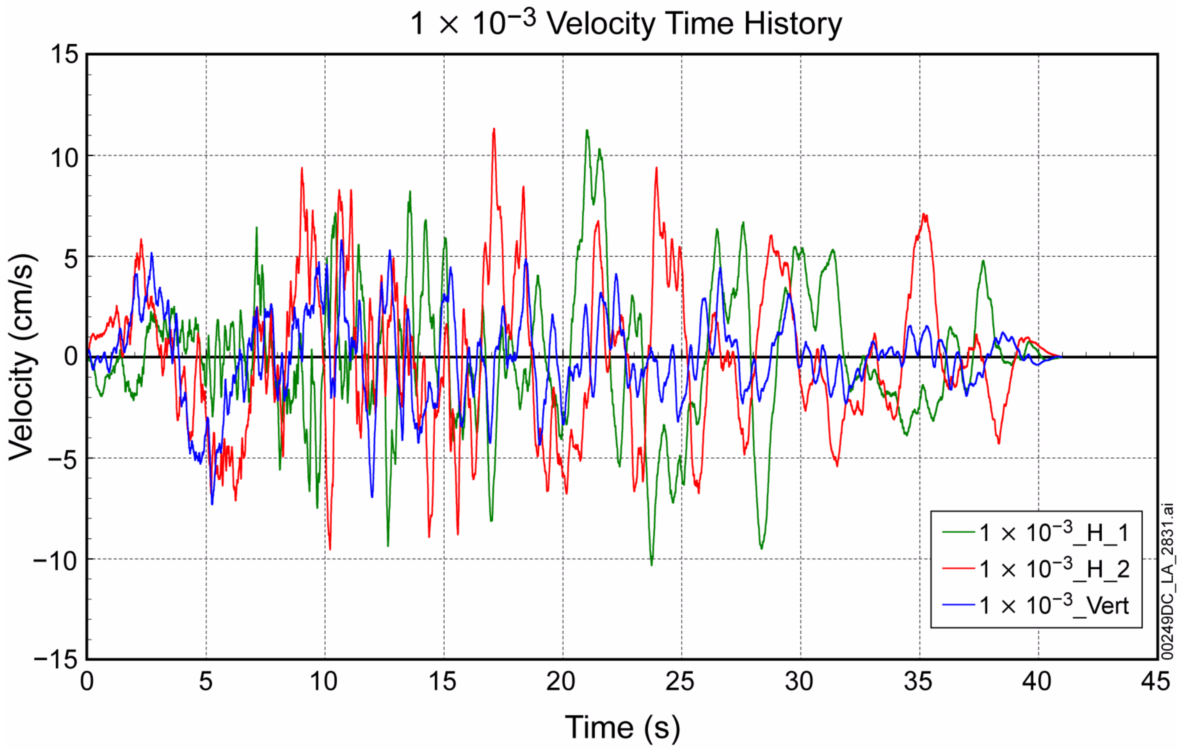

Figure 1.3.2-4. Seismic Time Histories for Location B (Repository Level) for a Seismic Event with an Annual Exceedance Probability of 1 × 10^{-3}, from the 2007–2008 Data Set

NOTE: H_1 = horizontal ground velocity 1; H_2 = horizontal ground velocity 2; Vert = vertical ground velocity.

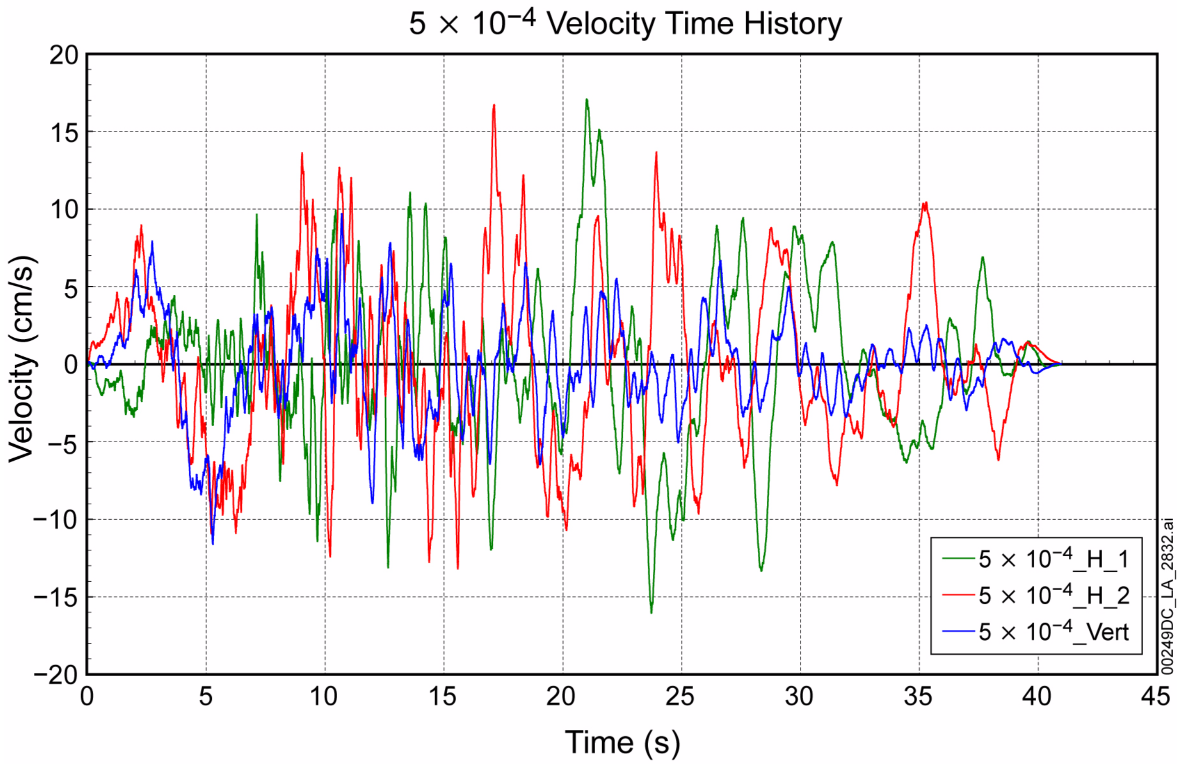

Figure 1.3.2-5. Seismic Time Histories for Location B (Repository Level) for a Seismic Event with an Annual Exceedance Probability of 5×10^{-4}, from the 2007–2008 Data Set

NOTE: H_1 = horizontal ground velocity 1; H_2 = horizontal ground velocity 2; Vert = vertical ground velocity.

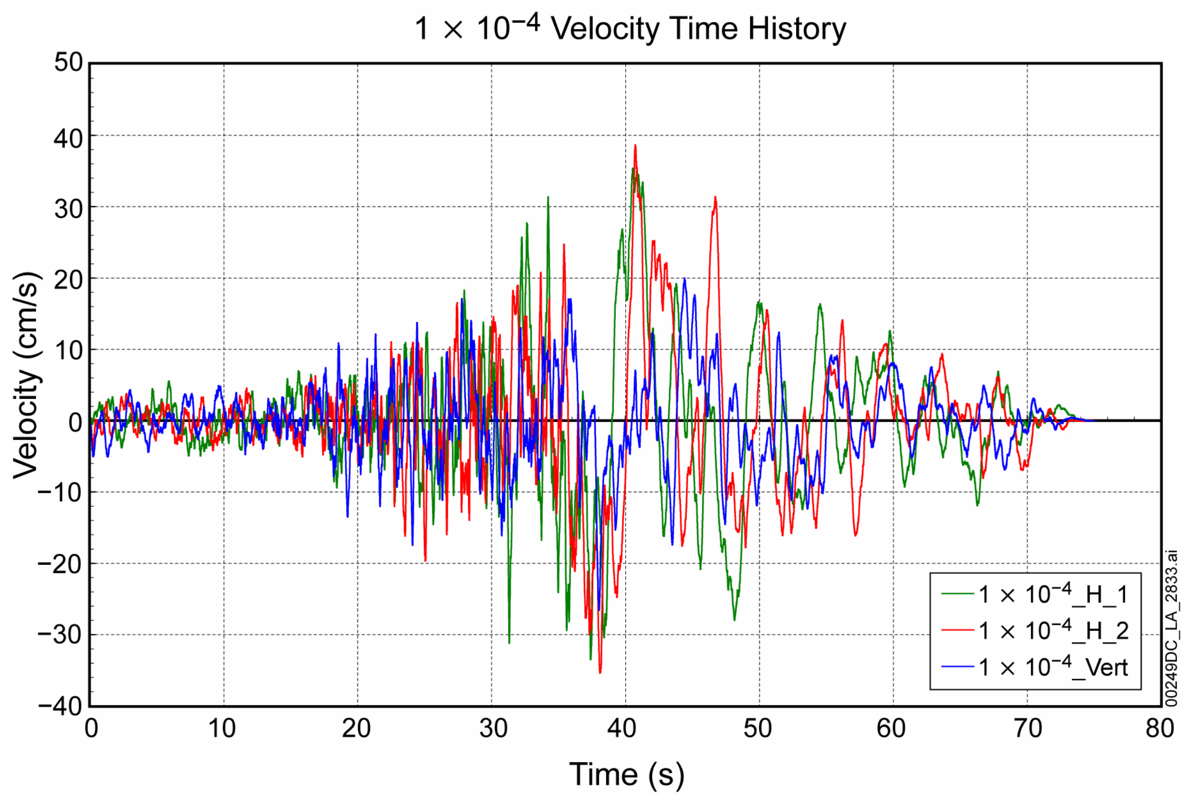

Figure 1.3.2-6. Seismic Time Histories for Location B (Repository Level) for a Seismic Event with an Annual Exceedance Probability of 1×10^{-4}, from the 2007–2008 Data Set

NOTE: H_1 = horizontal ground velocity 1; H_2 = horizontal ground velocity 2; Vert = vertical ground velocity.

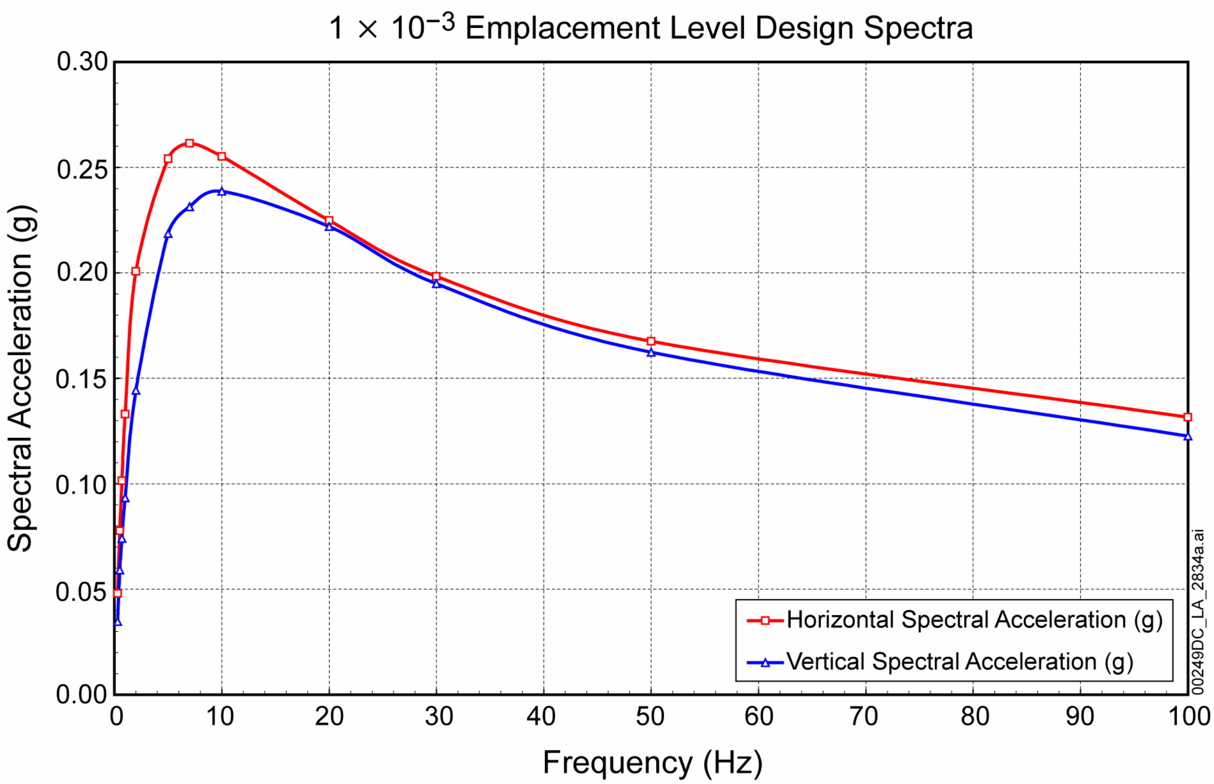

Figure 1.3.2-7. Seismic Response Spectra for Location B (Repository Level) for a Seismic Event with an Annual Exceedance Probability of 1×10^{-3}, from the 2003–2004 Data Set

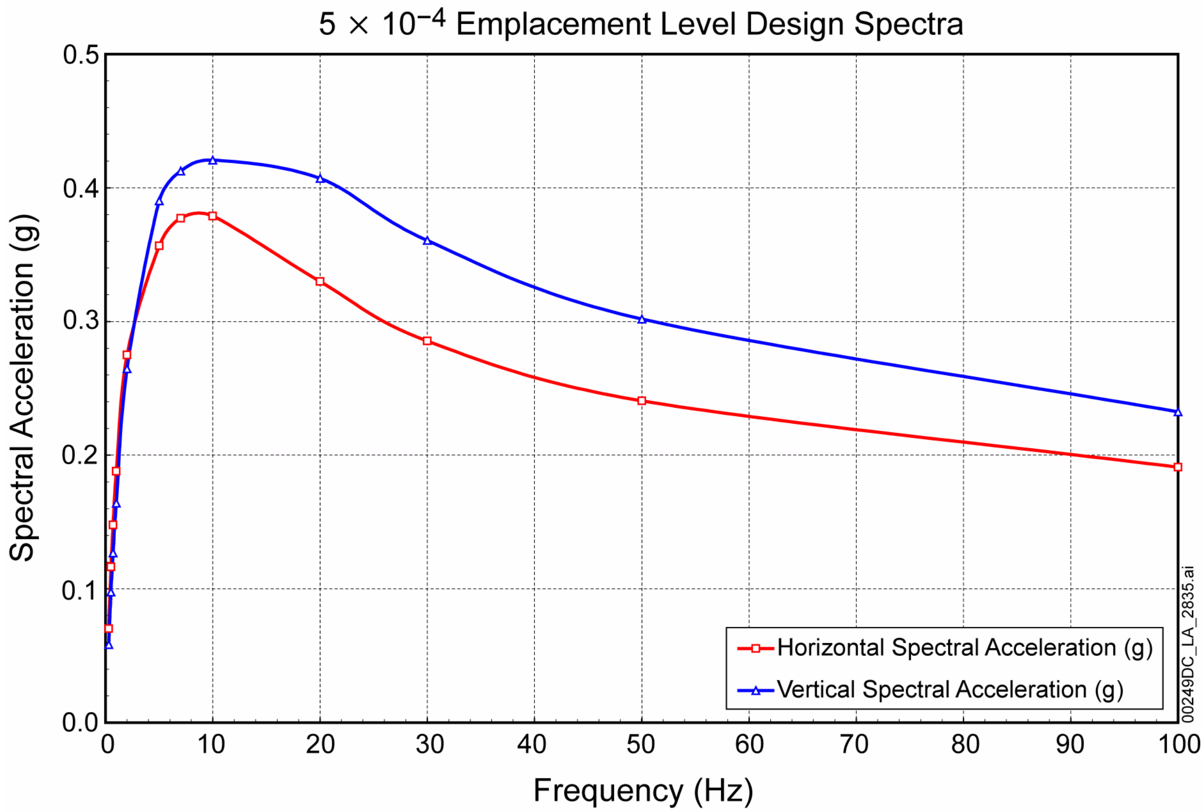

Figure 1.3.2-8. Seismic Response Spectra for Location B (Repository Level) for a Seismic Event with an Annual Exceedance Probability of 5×10^{-4}, from the 2003–2004 Data Set

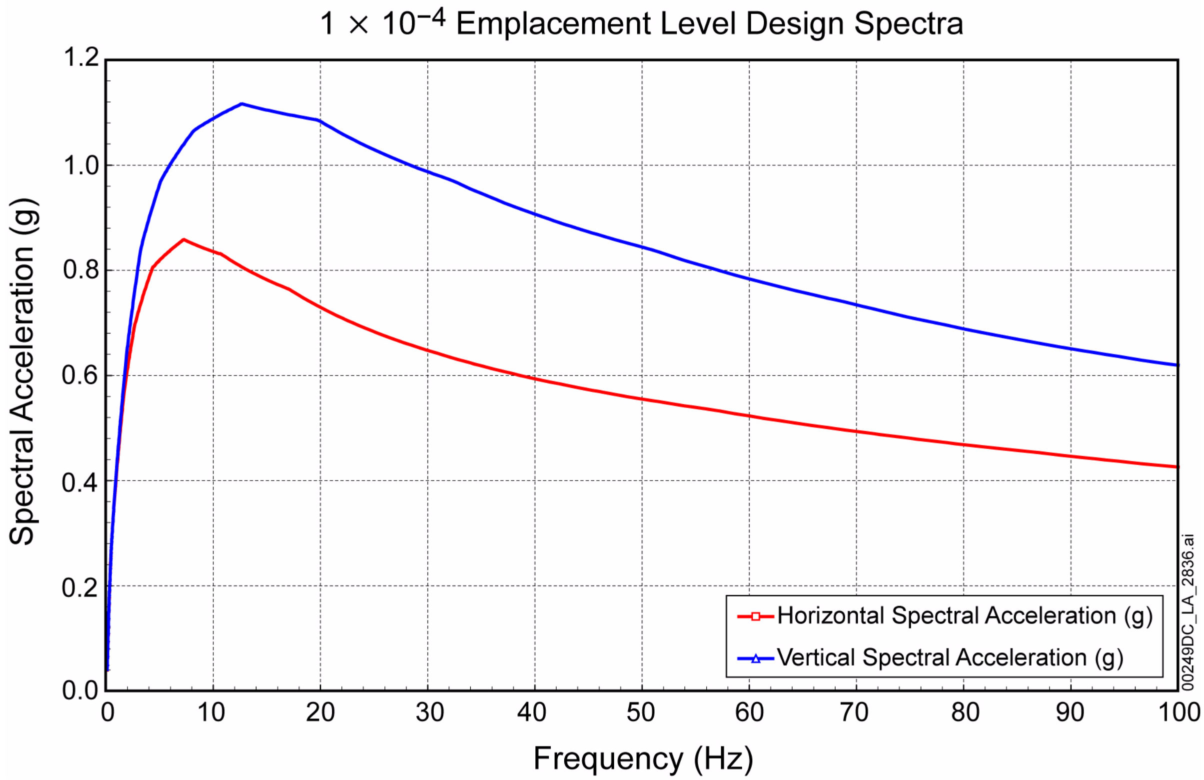

Figure 1.3.2-9. Seismic Response Spectra for Location B (Repository Level) for a Seismic Event with an Annual Exceedance Probability of 1×10^{-4}, from the 2003–2004 Data Set

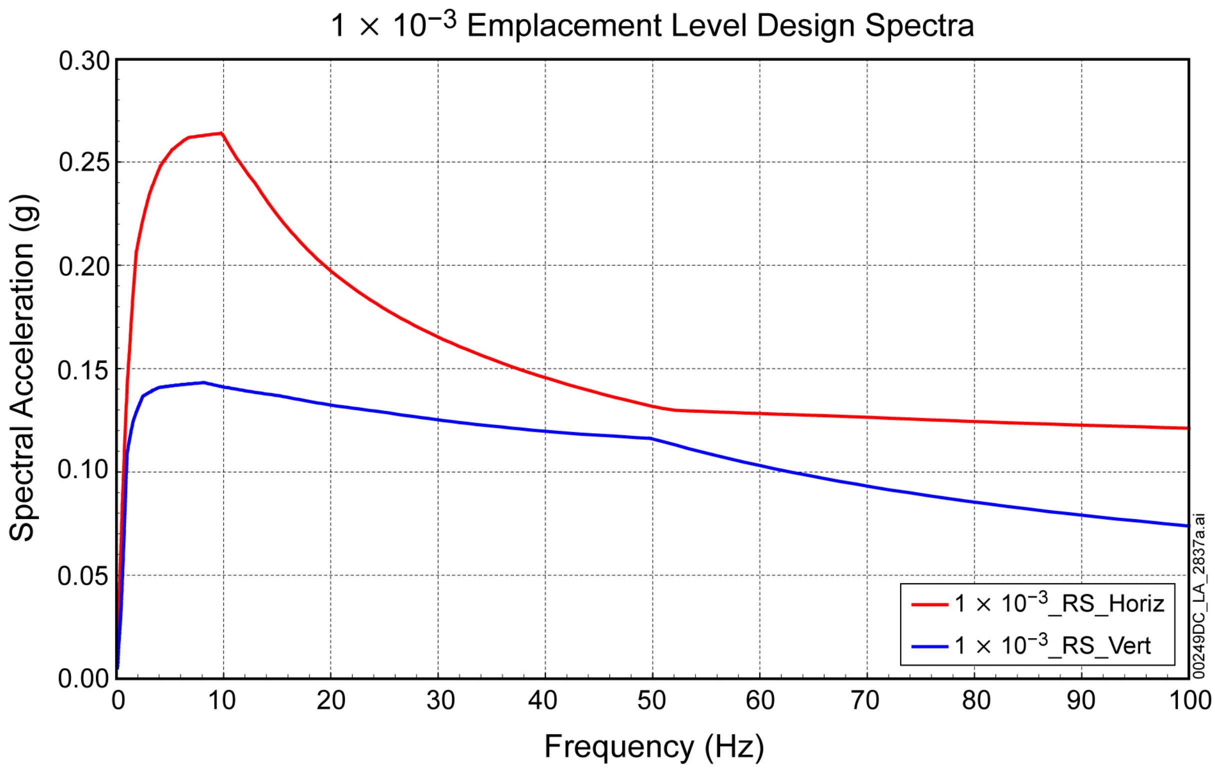

Figure 1.3.2-10. Seismic Response Spectra for Location B (Repository Level) for a Seismic Event with an Annual Exceedance Probability of 1×10^{-3}, from the 2007–2008 Data Set

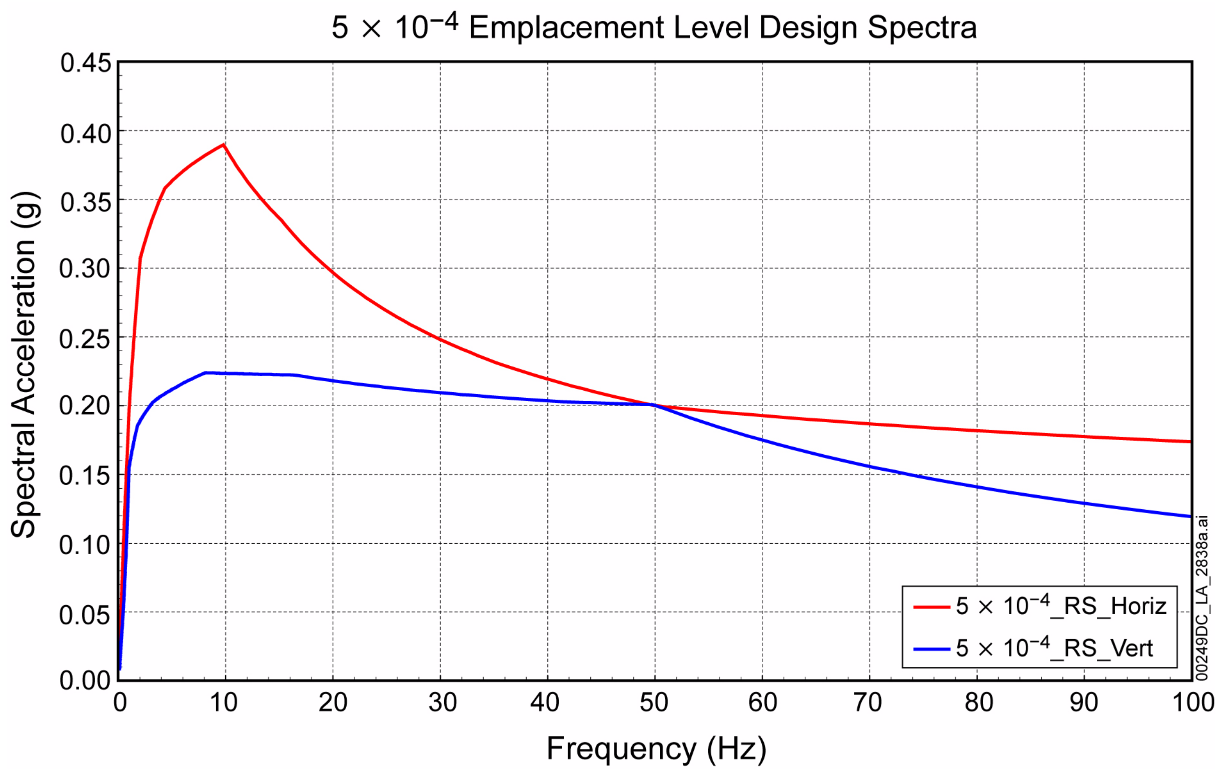

Figure 1.3.2-11. Seismic Response Spectra for Location B (Repository Level) for a Seismic Event with an Annual Exceedance Probability of 5×10^{-4}, from the 2007–2008 Data Set

NOTE: RS_Horiz = horizontal spectral acceleration; RS_Vert = vertical spectral acceleration.

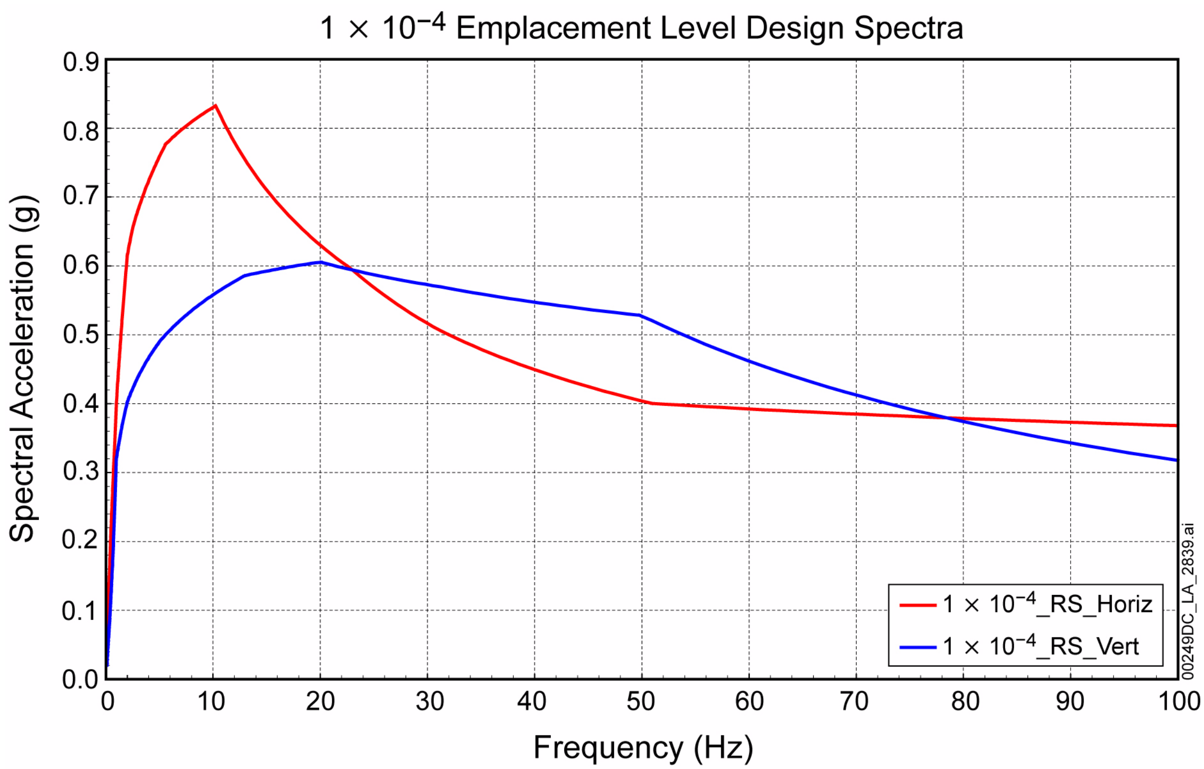

Figure 1.3.2-12. Seismic Response Spectra for Location B (Repository Level) for a Seismic Event with an Annual Exceedance Probability of 1×10^{-4}, from the 2007–2008 Data Set

NOTE: RS_Horiz = horizontal spectral acceleration; RS_Vert = vertical spectral acceleration.

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1.3.3 Nonemplacement 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 4, AC 5, AC 6, AC 8, AC 9]

The nonemplacement areas of the subsurface facility include all underground openings and their structures, systems, and components (SSCs), except for the emplacement drifts and their structures and components. They also include surface-based structures and equipment immediately adjacent to subsurface SSCs or directly over the subsurface facilities of the repository. The following are the major features of the repository nonemplacement areas:

- North Portal Access Control Point
- Shaft surface pads including ventilation fans and ancillary equipment
- Subsurface electrical distribution and electrical equipment alcoves
- Subsurface communications network
- North Portal and North Ramp and their structures and equipment
- South Portal and South Ramp and their structures and equipment
- North Construction Portal and North Construction Ramp and their structures and equipment
- Access mains and their structures and equipment
- Turnouts and their structures and equipment
- Exhaust mains and their structures and equipment
- Intake and exhaust shafts and their structures and equipment
- Shaft access raises and access drifts
- Performance confirmation observation drift and observation alcove in Panel 1.

The transport and emplacement vehicle (TEV) rail extensions from the North Portal to the Canister Receipt and Closure Facilities (CRCFs), the Initial Handling Facility (IHF), and to the Heavy Equipment Maintenance Facility are considered to be part of the surface facilities (nuclear facilities and balance of plant facilities, respectively). The excavated muck conveyance facilities and muck storage areas are considered to be part of the surface facilities. The construction support facilities adjacent to the North Portal, South Portal, and North Construction Portal are considered to be temporary and part of the surface facilities. The electrical distribution to support development activities and the ventilation equipment to be installed on the intake shaft pads during repository development (and not yet turned over to the repository for emplacement operations) are considered to be temporary and not part of the subsurface facility emplacement areas.

The nonemplacement areas of the subsurface facility provide access and infrastructure for the major repository systems operating underground and facilitate the disposal of waste packages. The design of the nonemplacement areas is described in this section, including openings that provide access to the subsurface emplacement areas, ventilation openings, performance confirmation openings, electrical and communications equipment, excavation, ground support and invert systems, and the waste package transportation system.

The nonemplacement areas of the subsurface facility provide the following functions during the preclosure phase:

- Access and infrastructure for repository development, primarily through the North Construction Portal and South Portal.

- Access and infrastructure to support waste package transportation and other operations, primarily through the North Portal, North Ramp, access mains, and turnouts. The same transportation access and infrastructure are available for waste package retrieval, should that action become necessary.

- Underground openings as infrastructure for the subsurface ventilation system, primarily the portals, ramps, access and exhaust mains, intake shafts and exhaust shafts, and shaft access drifts.

- Underground openings as infrastructure for performance confirmation activities, primarily an observation drift and observation alcove, and miscellaneous alcoves for seepage and seismic monitoring (Sections 4.2.1 and 4.2.2).

- Access and infrastructure for installation and distribution of repository electrical, communication systems, monitoring and alarm systems, and personnel refuge and emergency evacuation systems.

Openings and structures in the subsurface facility nonemplacement areas (e.g., electrical and communications equipment for the North Portal, North Ramp, access mains, and turnouts) support operations or functions for the only important to safety (ITS) component, the TEV.

Openings and structures in the subsurface facility nonemplacement areas also support functions that are important to postclosure performance, such as thermal management and closure of shafts and ramps (openings used as ventilation airways and their structures, such as the portals, ramps, access mains, turnouts, exhaust mains, shaft access drifts, and shafts).

1.3.3.1 Nonemplacement Areas Design 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), (2); Section 2.1.1.7.3.3(II): AC 1(3), AC 2(5), AC 8(1), AC 9(1)]

The North Portal, North Ramp, access mains, and turnouts are nonemplacement openings utilized to reach the emplacement drifts. These nonemplacement openings are classified as non-ITS because they are not relied upon to prevent or mitigate Category 1 or 2 event sequences (Table 1.9-1).

1.3.3.1.1 Portals and Ramps

The repository uses the existing Exploratory Studies Facility (ESF) excavations: the North Portal and North Ramp, the South Portal and South Ramp, and the main drift connecting both ramps at the repository level. Prior to initiation of waste emplacement, the North Portal, the North Ramp, and the main drift connecting to the turnouts for Panel 1 will be upgraded from construction support facilities to facilities used to access the emplacement drifts (Section 1.3.1.2.7.3). The North Portal and the main drift will require refitting work that includes installing final ground support, installing new invert sections and rail over the existing invert structures, removing construction utilities, and installing emplacement electrical distribution and communications equipment.

At the onset of excavation and construction of the repository, the North Portal serves to support construction activities needed to prepare the initial drifts in Panel 1 for emplacement. Development of the remaining drifts in Panel 1 will continue concurrent with initial emplacement operations. After development of the initial drifts and prior to the start of emplacement operations, the North Portal, North Ramp, and access main up to the isolation barriers between the emplacement and development sides of the subsurface facility will be configured for emplacement operations.

The North Portal serves as the only opening through which waste packages are transported underground for emplacement. Should retrieval of waste packages be undertaken (Section 1.11), this portal would serve as the access for waste package transportation using the same, or similar, subsurface equipment and facilities as used for waste emplacement but in reverse order. The North Portal, in addition to supporting emplacement activities, continues to serve as a fresh air intake opening to the emplacement ventilation system through closure of the repository. This portal also supports closure operations.

In addition to the North and South Portals and North and South Ramps, the subsurface design includes a new construction ramp and portal designated as the North Construction Ramp and North Construction Portal. The latter facilities are needed for construction access to the northern emplacement areas. Design information provided herein for the existing ramps and portals includes upgrades for permanent ground support, upgrades to the invert sections to support transportation system requirements, and upgraded electrical distribution and communications equipment to support emplacement operations.

Plan views for the North Portal, South Portal, and North Construction Portal designs are shown in Figures 1.3.3-1, 1.3.3-2, and 1.3.3-3, respectively. The North Construction Portal opening provides sufficient cross-sectional area to accommodate final assembly and startup of the tunnel boring machine used for excavation of the North Construction Ramp and the access and exhaust mains in the northern part of the repository.

The portal designs satisfy requirements for protecting the repository against stormwater and floodwater incursions into the underground facility. The portal openings are located above the design basis flood elevations or are protected against the rise of floodwaters by containment and diversion structures. Additionally, the areas around the openings are graded to prevent stormwater runoff from entering the repository (Section 1.1.4.3.2).

The purpose of the ramps is to connect the surface facilities to the subsurface. The as-built ramp grade of the ESF North Ramp is 2.15%, as shown in Figure 1.3.3-4. This grade starts at the portal and ramp interface, as illustrated in Figure 1.3.3-5, and continues until the ramp merges with the access main. The grade of the repository North Ramp, after installation of the permanent repository invert structure, will be approximately the same. The portal and ramp interface detail for the South Portal and the North Construction Portal are shown in Figures 1.3.3-6 and 1.3.3-7, respectively.

The ramp design for the North Ramp meets requirements for safe transportation of waste packages using a crane rail–based transporter, as discussed in Section 1.3.3.5.1. The ramp designs for the South Ramp and the North Construction Ramp meet the requirements for access by construction equipment and for removal of excavated rock.

1.3.3.1.2 Access Mains

The access mains connect to the ramps and provide pathways for access to the turnouts, transportation, and ventilation. The purpose of the access mains is to serve as transport routes and airways for emplacement operations.

Functions for the access mains are to:

- Provide access, infrastructure, transportation, ventilation, and support systems to the active waste emplacement areas of the underground repository separate from areas under development.

- Accommodate power and communications for SSCs operating underground.

Figure 1.3.3-8 illustrates the underground layout with the access mains identified. These mains connect to the North Ramp to provide access from the surface facilities to the emplacement areas. The access mains directly connect to the turnout for each emplacement drift to allow waste emplacement. Figures 1.3.3-9 to 1.3.3-11 illustrate the access mains that serve the different emplacement panels and their characteristics such as length, stationing, orientation, grades, and radius of curvature.

The access mains are excavated with a tunnel boring machine to a 7.62-m (25-ft) diameter except for the access main cross-drift to Panel 4, which is excavated to a 5.5-m (18-ft) diameter. Figure 1.3.3-12 shows a typical finished cross section of a 7.62-m diameter access main with the concrete invert, rail, and other basic infrastructure in place.

The subsurface waste package transportation routes identified in Figures 1.3.3-9 to 1.3.3-11 correlate to the sequence of emplacement into panels as they are being developed. The operational steps involved in transporting the waste packages from the surface nuclear facilities into the subsurface for emplacement are described in Section 1.3.3.5.2 (BSC 2007a, Figure 1 and Section 6.2).

TEV operations throughout the waste package transportation and emplacement process will be monitored and controlled remotely by operators from the Central Control Center. This oversight and control capability allows the operators in the Central Control Center to provide initiating commands to the programmable logic controller (PLC) on board the TEV to implement preprogrammed equipment actions (Section 1.3.3.5.2.3). Power to the TEV during the waste package loading, transportation, and emplacement cycle will be provided by a third-rail system (Section 1.3.3.4.1).

Travel of the loaded TEV from the North Portal to the entrance of the designated turnout will occur with the TEV oriented in such a way that its shielded doors face the emplacement drift when it approaches the respective turnout. Orientation of the TEV for the different emplacement routes is shown in Figures 1.3.3-10 and 1.3.3-11 and described below. The TEV uses a set of rail switches located at the surface to get into the proper orientation for each of the transportation routes.

The Panel 1 turnouts are oriented toward the northeast (Figure 1.3.3-10) so the TEV is oriented with the shielded doors facing the North Portal as it enters the repository so that as it approaches the emplacement area, it has a direct approach to those turnouts.

The Panel 2 turnouts are also oriented toward the north (Figure 1.3.3-10) so the travel and approach of the TEV to the turnouts is directly into the turnout as described for Panel 1.

All the turnouts for Panel 3–West are oriented toward the north and located north of the North Ramp intersection with the access main (Figure 1.3.3-11). The TEV travels down the North Ramp with the shielded doors at the front. After entering the access main past the North Ramp intersection, it stops, reverses direction of travel, and enters the connector drift to the access main for Panel 3. It then travels north past the destination turnout, stops, and reverses travel direction again to proceed to enter the turnout with the shielded doors facing the emplacement drift. As the TEV travels from the Panel 1 access main into the connector drift to Panel 3, one rail switch will be activated where the connector drift meets the access main. A second rail switch will be activated where the connector drift meets the Panel 3 access main.

The Panel 3–East turnouts are oriented toward the south (Figure 1.3.3-10). When traveling to these turnouts and going into the North Portal, the TEV travels with the shielded doors to the back and follows the same maneuvers as described for Panel 3–West, past the connector drift and into the Panel 3 access main. When it enters the Panel 3 access main, its shielded doors face the turnout entrances, and it is ready to proceed into the emplacement drifts.

The Panel 4 turnouts are oriented to the south, but the access to these turnouts is from the south and follows a continuous route from the North Portal (Figure 1.3.3-11). Travel and approach of the TEV to these turnouts takes place with the shielded doors at the front all the way from the North Portal to the emplacement drifts. A rail switch will be activated at the intersection of the Panel 1 access main with the access main cross-drift to Panel 4 so that the TEV can continue travel towards the Panel 4 access main.

The TEV can travel in either direction so the return trips to the surface nuclear facilities follow a reverse order as the respective trips from the surface nuclear facilities to the underground panel areas, with the different rail switches discussed above being positioned in the proper settings for continued TEV travel from the different panels towards the North Ramp. The TEV will be oriented with the shielded enclosure doors facing forward prior to entering the surface nuclear facilities. TEV operational processes are described in more detail in Section 1.3.3.5.2.1.

1.3.3.1.3 Exhaust Mains

The exhaust mains are typically a continuation of the access mains 7.62-m (25-ft) excavated bore, as shown in Figure 1.3.3-8. One exception is the exhaust main for Panel 1, which is excavated with a 5.5-m (18-ft) diameter, as an extension of the emplacement drift 1-1 excavation. Panel 1 has a limited number of emplacement drifts, so the smaller exhaust main is adequate for the design airflows. The boundary between the access main and its contiguous exhaust main is the isolation barrier. The isolation barrier separates the ambient temperature intake air from the hotter exhaust air from the emplacement areas. Additional information on the isolation barriers is provided in Section 1.3.5.

The exhaust mains connect the end of the emplacement drifts to the exhaust shafts via the shaft access drifts and serve to remove hot ventilation air from the repository during preclosure.

Functions of the exhaust mains are as follows:

- Support repository thermal management strategies and compliance with repository thermal performance requirements
- Provide return airways for ventilation of emplacement areas
- Provide remote access to infrastructure SSCs for inspection and maintenance.

Figure 1.3.3-8 shows the locations of the exhaust mains. The exhaust mains for Panels 1, 2, and 3–West define the western boundaries for those panels, while the exhaust mains for Panels 3–East and 4 define the eastern boundaries for those panels. There are two parallel exhaust mains for some length between Panels 3 and 4 that allow concurrent development in Panel 4 and emplacement in adjacent emplacement drifts in Panel 3. This arrangement is necessary to maintain the exhaust of ventilation air from Panel 3 separate from construction equipment and personnel in Panel 4 during concurrent development and emplacement operations in this area. A similar arrangement for Panel 1 has its exhaust main parallel to a portion of the exhaust main for Panel 4. This dual-exhaust main arrangement is also necessary for carrying out construction activities in Panel 4 adjacent to a waste-loaded Panel 1.

The exhaust mains are provided with ground support. The exhaust mains may also be provided with a basic invert structure (i.e., temporary fill used as a construction equipment running surface and that may be removed or left in place after construction, contingent on impact evaluation of the fill material as a committed material) to facilitate mobile equipment access, and may be provided with temporary utilities only during the construction phase.

1.3.3.1.4 Turnouts

The turnouts connect the emplacement drifts to the access mains. They also house facilities and equipment that control access and ventilation to the emplacement drifts.

These openings represent a key design feature in the underground layout because their configuration and features facilitate operations of principal repository systems, such as waste transportation and emplacement and ventilation. The configuration of each turnout varies with location, but all turnout configurations meet the same design criteria listed in this section. Figure 1.3.3-13 represents a typical turnout plan view for Panel 1. This typical plan view is used to explain the turnout design criteria and how the general turnout design satisfies those criteria.

The curvature and length of the turnout are designed so that there is no direct line of radiation shine from any emplaced waste package to the access main. The last-emplaced waste package is the predominant contributor to the dose rates in the turnout and access main areas, amounting to over 95% of the total.

The turnout design configuration presented in Figure 1.3.3-13 consists of the following segments:

- **Rail Turnout Segment**—This is the turnout segment that intersects with the access main and where the turnout rail switch and frog are located. This segment has a finished grade of 1.35%. A typical cross section of this segment excavation is shown in Figure 1.3.3-13. The invert structure in this segment is reinforced concrete.

- **Turnout Bulkhead Segment**—This segment is adjacent to the rock pillar between the turnout and the access main, and it contains the turnout bulkhead, emplacement access doors, airflow regulator, and instrumentation. The invert structure in this segment is also reinforced concrete at a finished grade of 1.35%.

- **Tunnel Boring Machine Launch Chamber**—This segment has a narrower width than the previous segment, with excavated cross sections for both illustrated in Figure 1.3.3-13. Set up of the tunnel boring machine for excavation of the rest of the turnout and the emplacement drift is done in this chamber where the rock pillar has sufficient thickness to withstand the pressure of the tunnel boring machine grippers as it starts excavating (BSC 2007b, Section 6.2). The invert structure is in reinforced concrete and the finished grade transitions from 1.35% to 1.75%.

- **Turnout Curve**—This segment is circular in cross section except that the cross section is notched at the bottom to accommodate the invert structure as illustrated in Figure 1.3.3-13. The notched area progressively gets smaller in this and the next segment, and eventually disappears as the invert structure depth is increased and the entire structure is contained within the circular opening. The invert structure in this segment and the next segment is carbon steel and ballast with a finished grade of 1.75%. The steel structure in both segments is supported on stud columns and rests on the rock floor.

- **TEV Alignment Segment**—This segment is straight and aligned with the emplacement drift axis to facilitate positioning of the TEV for waste package emplacement. The finish grade for the invert structure in this segment is 0.0%, the same as that of the emplacement drift invert structure.

Figure 1.3.3-13 provides the calculated dose rates at the various locations in the turnout and access main areas with the bounding transportation, aging, and disposal (TAD) waste package loaded with 21-PWR spent nuclear fuel (SNF) assemblies and design basis SNF specification. There is no credit taken for any shielding by the emplacement access doors at the entrance of the turnout. The dose rates, for packages to be emplaced in the subsurface, are due mainly to primary gamma radiation originating from SNF assemblies contained in the waste packages. The combined contribution of neutron and secondary gamma radiation is relatively small (about 1% of the total).

The minimum 200-ft turning radius for the turnout design is sufficient to maneuver the TEV safely around the curve.

The turnout designs also accommodate an invert structure and rail that meets transportation load requirements, emplacement access doors to meet requirements for limited access to the emplacement drifts, and a regulator for regulation of emplacement drift ventilation (Figure 1.3.5-9).

The inverts for the emplacement drift and for the access main are at different elevations, so the turnouts also provide a transition zone to facilitate the continuity of the rail from the access mains into the emplacement drift at a gentle upward gradient. This gradient also prevents the flow of any water in the access mains from being diverted into the emplacement areas. Figure 1.3.3-14 shows the elevation interfaces between the access mains, the turnouts, and the emplacement drifts. The elevations for each emplacement drift, turnout, and access main intersection vary throughout the repository, depending on location. Figure 1.3.3-14 illustrates the elevations for two emplacement drifts at opposite sides of the access main for Panels 3–East and 3–West. The offset in elevations is due to the fact that the turnouts for Panel 3–East face a southwest direction at the intersection with the access main, while the turnouts for Panel 3–West face a northeast direction at the intersection. Thus the turnouts intercept the access main at different points. The access main slopes down to the north so the turnouts facing northeast intercept the access main at a lower elevation than the turnouts facing southwest. Despite these variations, the elevation difference between each emplacement drift invert and the "point of switch" for its turnout (at the access main) are kept constant as illustrated by dimensions "B" in Figure 1.3.3-14.

1.3.3.1.5 Shafts

The shafts are vertical excavations that provide a connection between the emplacement areas and the surface. These openings have the primary function to provide conduits for ventilation air, either by conveying fresh air from the surface to the underground or by exhausting air to the surface. The intake shafts have secondary functions as access ways for materials handling and for personnel emergency evacuation.

The subsurface ventilation design relies on the North Ramp, the North Construction Ramp, the South Ramp, and on shafts as airways to bring in fresh air and to exhaust air from the subsurface facility.

The shaft locations are determined based on suitable surface topography for collar locations and to approximately balance the ventilation for the different airflow volume requirements from each emplacement area. When fully developed, the overall ventilation system consists of three shafts and three ramps on the intake side and six shafts on the exhaust side. Shaft access drifts connect the access and exhaust mains to the shafts. Figure 1.3.3-8 shows the location of the three ramps and nine shafts used by the ventilation system. Table 1.3.3-1 lists the characteristics of the shafts. Other internal vertical excavations designated as raises, typically of shorter length, are used to connect exhaust airways located at different levels. The repository design includes two such features and they are associated with connections of the Panel 1 and Panel 4 exhaust mains to the Enhanced Characterization of the Repository Block (ECRB) Cross-Drift exhaust shaft (see detail on ventilation raises in Figure 1.3.5-5). Exhaust shafts 1 and 3-South handle lower airflow volumes based on the overall repository ventilation balance, so their finished diameters are smaller (14.36 ft) compared to the standard size exhaust shaft with a finished diameter of 24 ft.

Figure 1.3.3-15 shows typical elevation views of the shaft collars for the shafts. Figure 1.3.3-16 shows elevations of typical shafts. Figure 1.3.3-17 shows a conceptual layout of an exhaust shaft fan pad with the ventilation fans and ancillary equipment in place. Additional design information on systems associated with the shafts is provided in Section 1.3.5.

1.3.3.1.6 Performance Confirmation Openings

As a part of the Performance Confirmation Program described in Chapter 4, in situ testing and monitoring will be conducted in the area of Emplacement Drift 3 of Panel 1. An observation drift and alcove to accommodate performance confirmation activities will be excavated starting from the existing Thermal Test Alcove in the ESF, extending under Panel 1, and ramping up and connecting with the exhaust main on the opposite side of the panel (Figures 1.3.3-18 and 1.3.3-19). The observation drift runs below and parallel to Emplacement Drift 3, offset approximately 20 m (66 ft) to the north. The offset provides stability to the pillar between the drifts, while minimizing disturbance around the emplacement drift, and still allows for the placement of relatively short, accurately positioned boreholes for monitoring in the near-field rock environment. The alcove is located below the emplacement horizon, a minimum of 10 m (33 ft) from crown to invert (i.e., from the top of the alcove excavation to the bottom of the emplacement drift excavation), in order to maintain pillar stability. The location of the observation drift allows for monitoring the rock below and to the north of Emplacement Drift 3. The alcove provides monitoring coverage for the rock to the south of Emplacement Drift 3. The combination of the observation drift and alcove provides access to nearly half the perimeter of Emplacement Drift 3.

The observation drift and observation alcove are supported by the subsurface ventilation system during the development and emplacement phases. During emplacement, air is directed from the Panel 1 access main via the Thermal Test Facility and into the observation drift. Control of the ventilation to these facilities is through bulkheads positioned at each end of the observation drift. Both bulkheads contain airflow regulators similar to the turnout bulkhead installations, described in Section 1.3.5.1.3.3. The first bulkhead, or access bulkhead, is also equipped with a set of doors for equipment and personnel access. Personnel access through the second bulkhead into the Panel 1 exhaust main will be prohibited because of the thermal and radiation hazards. The second bulkhead is shown in Figures 1.3.3-18 and 1.3.3-19. Fresh air source is the North Portal that feeds the North Ramp, access main, Thermal Test Facility, and observation drift and alcove (Figure 1.3.5-6). The observation alcove is ventilated from the observation drift air supply by using a standard fan and vent line installation. The observation drift and observation alcove are designated as a stand-alone fire zone protected by automatic and manual fire detection and alarm systems and equipped with portable fire extinguishers. In addition, the observation drift may contain a dedicated, self-contained refuge station.

The subsurface facility will also include seepage alcoves that will be excavated off the access mains or the ECRB Cross-Drift to measure seepage in the unsaturated zone. One seepage alcove will be located in the Topopah Spring Tuff middle nonlithophysal zone, and another seepage alcove in the Topopah Spring Tuff crystal-poor lower lithophysal zone. Fracture mapping data will be used during the early development phases of the repository to locate the alcoves, to ensure that the selected test locations provide good spatial coverage of the targeted geologic units (Section 1.3.2.2 and Figure 1.1-60).

The design of the performance confirmation openings located in the nonemplacement areas of the subsurface facility meets the following functional requirements:

- Provides observation drift and alcove for construction of boreholes and installation of equipment to monitor the emplacement drifts near-field rock environment and to confirm geotechnical and design parameters and thermal-mechanical response of the repository

- Provides allowances for installation of two seepage alcoves in support of the Performance Confirmation Program

- Provides vertical separation between crossing drifts to a minimum of 10 m (33 ft) from the crown of the lower opening to the invert of the upper opening.

1.3.3.1.7 Alcoves and Niches

Underground alcoves and niches serve the basic function of providing space for various equipment and operations away from the main lines of traffic. Alcoves and niches are small excavations of various sizes and shapes and are typically excavated off the access mains. Some of the equipment housed in alcoves and niches includes electrical, communications, and monitoring equipment.

Major alcoves and niches that have been identified for the subsurface facility are:

- Performance confirmation alcove to be used for deploying instrumentation and equipment for monitoring the host rock in the vicinity of the initial emplacement drifts in Panel 1 (Section 4.2.1). Host-rock near-field coupled processes monitoring will be accomplished by utilizing boreholes extended from the observation drift or alcove toward a thermally accelerated drift.

- Two alcoves for measuring seepage rates and characteristics in the lithophysal and nonlithophysal rock units of the unsaturated zone, for seepage potentially flowing into the emplacement horizon (Section 4.2.1.2). Seepage alcoves will be sealed with a bulkhead and not ventilated.

- Electrical, controls, and communications equipment alcoves and niches to be located along the access mains at halfway points between turnouts to minimize radiation dose exposure to inspection and maintenance personnel. The location for the electrical equipment alcoves (subsurface electrical stations) are shown in Figure 1.4.1-6. Communications equipment will be deployed in electrical equipment alcoves.

1.3.3.1.8 Electrical Service Distribution

Section 1.4.1 describes the electric power distribution for the subsurface facility. The repository electrical main single line diagram is included as Figure 1.4.1-1. Electrical power distribution to the underground is through the North Portal for support of emplacement operations, through the South and North Construction Portals for support of development, and aboveground for power distribution to the intake and exhaust shaft surface pads.

As illustrated in Figure 1.4.1-2 (sheet 5 of 6), outside electric power to the subsurface is provided by two 13.8 kV main switchgear buses (A and B) located near the North Portal. These main switchgear buses distribute power via overhead distribution lines to the South Portal and the North Construction Portal, and through buried conduit banks to the North Portal. Overhead distribution lines also go to the shaft pads to power the subsurface ventilation fans and ancillary equipment as illustrated in Figure 1.4.1-2 (sheet 2 of 6).

Electrical Distribution to Emplacement Areas—The 13.8 kV feeders intended for the subsurface facility emplacement service are used as follows:

- Two feeders for general subsurface facility power distribution (North Portal feeds)
- Twelve 13.8 kV feeders for ventilation exhaust fans and accessories (surface power distribution feeders).

The subsurface power for emplacement operations is derived from two feeds coming from the 13.8 kV switchgear buses A and B and going through the North Portal. The power cables for these two feeds are routed along the North Ramp and access mains, to 12 underground electrical stations located in alcoves excavated along the North Ramp and the different access mains. Subsurface emplacement electrical feeders are routed by using cable trays or conduits supported along the ramps and access main walls and into the electrical equipment alcoves. Electrical equipment in the alcoves includes several 13.8 kV to 480 V AC load centers to supply subsurface electrical equipment (TEV, emplacement access door motors, rectifiers, heaters, and lighting). The 480 V power is further stepped down to 208/120 V to supply other smaller loads, including lighting, receptacles, controls, and instrumentation (Section 1.4.1.1).

The approximate location of the underground electrical stations are shown in Figure 1.4.1-6. Figure 1.3.3-20 illustrates a typical alcove-based electrical station. Excavation of these alcoves and equipment installation will be phased with repository development. The electrical distribution single line diagram to support emplacement operations for Panels 1 through 4 is illustrated in Figure 1.4.1-2 (sheet 5 of 6).

In addition to the underground electrical distribution through the North Portal, North Ramp, and access mains described above, twelve 13.8 kV overhead power distribution feeders are installed on the surface of Yucca Mountain to power the subsurface ventilation and ancillary equipment located at the exhaust shaft pads to support emplacement and postemplacement operations. This exhaust shaft pad equipment includes ventilation fan motors, hoists, pumps, lighting, communications, and instrumentation and controls equipment. Power for the ventilation fans is stepped down to 4.16 kV, and power for ancillary equipment is stepped down to lower voltages as needed.

The subsurface ventilation fans located at the exhaust shaft pads will be provided with connections for diesel-powered backup generators for handling off-normal power outages.

Electrical support systems for the repository are described in Section 1.4.1.4.

Electrical Distribution to Development Areas—The 13.8 kV feeders intended for the subsurface facility development service are used as follows:

- Six 13.8 kV feeders for ventilation intake fans and accessories (surface power distribution feeders available during repository development)

- Two feeders for operation of tunnel boring machines and other construction equipment during initial excavation (South Portal feeders are provided initially, and changed to North Construction Portal feeders after completion of development of Panel 2).

Six 13.8 kV overhead power distribution feeders are installed on the surface of Yucca Mountain to power the subsurface ventilation and ancillary equipment located at the intake shaft pads during repository development. The equipment at the intake shaft pads includes ventilation fans and ancillary construction equipment during development, and a hoist for shaft inspections and personnel rescue during repository operations. Power for the ventilation fans is stepped down to 4.16 kV, and power for ancillary equipment is stepped down to lower voltages as needed.

Two 13.8 kV feeders from the 13.8 kV Switchgear Facility Building provide power to temporary construction switchgear located near the South Portal (BSC 2008a). Power from these switchgear is distributed to support subsurface facility development loads including tunnel boring machines and other construction support equipment. A similar power distribution will later be available at the North Construction Portal, after repository development activity transitions from the South Portal to the northern portion of the repository area.

The service hoists located at the intake shaft pads will be provided with connections for diesel-powered backup generators for handling off-normal power outages.

1.3.3.1.9 Subsurface Equipment Communications and Controls

The architecture for the repository communications network is described in Section 1.4.2.4 and shown in Figure 1.4.2-5.

The backbone telecommunication system supporting the subsurface facility consists of a network subsystem and a transport subsystem. The network subsystem interconnects all users of the communication system irrespective of their location. The transport subsystem carries all information over the same physical fiber-optic backbone transport subsystem. The transport subsystem includes wired, wireless, and synchronous optical network (or "SONET") components. The fiber-optic cabling loops the entire subsurface facility and connects all physical communication devices (i.e., PLCs, instrumentation, monitors, and alarms). The wireless component is the transceiver that converts information from wired to wireless to enable two-way communications with mobile equipment.

The optical communications backbone will run throughout the access main via a dual fiber-optic ring. Optical nodes will be located in electrical equipment alcoves, spaced approximately every 1,750 ft. These nodes will interface with radio frequency equipment that will also be colocated in the electrical equipment alcoves.

All subsurface communications services are provisioned (configured), monitored, and managed through a network management system located in the central communications room in the Central Control Center, which also provides information in support of maintenance operations. The subsurface facility communications system functional block diagram is shown in Figure 1.3.3-21.

1.3.3.2 Excavation

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

The primary horizontal nonemplacement excavations are the turnouts, and the access mains and exhaust mains. Additionally, there are the portals and ramps, an observation drift, and support excavations. The main vertical nonemplacement excavations are the shafts and raises. Mechanical excavation is the primary excavation method using tunnel boring machines for long horizontal drives and raise boring for applicable vertical development. The turnouts, performance confirmation observation drift and alcoves, and other auxiliary horizontal openings are excavated by drill-and-blast or with roadheader excavators. Large-diameter shafts and raises are excavated by drill-and-blast methods.

Subsurface Construction Methods (BSC 2007c) contains a comprehensive description of repository excavation and construction methods.

The Performance Confirmation Plan (Section 4.2.2.1) has identified geologic mapping of major nonemplacement excavations as a planned activity. Geologic mapping of the nonemplacement openings will be integrated into the overall development of the excavations so that project implementation and personnel safety are not impacted.

Excavation of the emplacement drifts is discussed in Section 1.3.4, including a discussion of tunnel boring machines.

1.3.3.3 Ground Support System

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

1.3.3.3.1 System Description

Ground supports for nonemplacement openings are classified as non-ITS and not important to waste isolation (ITWI). No credit is taken for ground support in the evaluation of the potential event sequences that involve nonemplacement openings. The main potential event sequence of concern is a rockfall occurring while the TEV carrying a waste package travels in the subsurface areas. No credit is taken for the ground support to mitigate the consequences of rockfall (Section 1.7). Information provided below is generally based on *Ground Control for Non-Emplacement Drifts for LA* (BSC 2007d) and in *Shaft Liner Design* (BSC 2008b).

The ground support designs for nonemplacement openings are summarized as follows:

- **Access Mains, Exhaust Mains, Shaft Access Drifts, Observation Drift, Observation Alcove, ECRB Cross-Drift Widening, and Tunnel Boring Machine Launch Chambers**—Fully grouted rock bolts with heavy-gauge welded wire fabric. The rock bolts have a nominal length of 3 m, are spaced in a square-grid pattern at 1.25-m centers, and the fabric is sized W4 × W4 with 100-mm center-to-center wire spacing.

- **Access Main/Turnout at Turnout Intersections, North Ramp, and Starter Tunnels**—Fully grouted rock bolts with steel fiber-reinforced shotcrete, and lattice girders as necessary for roof span control. The rock bolts at the intersections have a nominal length of 5 m, are spaced in a square-grid pattern at 1.25-m centers, and have a shotcrete application that is 0.10-m thick. The rock bolts for the North Ramp and starter tunnels have a nominal length of 3 m at the same grid spacing.

- **Exhaust Mains/Emplacement Drift at Emplacement Drift Intersections**—Fully-grouted rock bolts with steel fiber-reinforced shotcrete and lattice girders as necessary for roof span control. Application of shotcrete at these intersections is limited to the exhaust main walls. The rock bolts have a nominal length of 5 m, are spaced in a square-grid pattern at 1.25-m centers, and the shotcrete application (limited to the exhaust main) is 0.10-m thick.

- **South and North Construction Ramps**—Fully grouted rock bolts with steel fiber-reinforced shotcrete, and lattice girders as necessary for roof span control. The rock bolts have a nominal length of 3 m, are spaced in a square-grid pattern at 1.25-m centers, and the shotcrete application is 0.10-m thick. The shotcrete in these ramps is applied on an as-needed basis, depending on the rock mass condition and construction considerations.

- **Turnouts**—Stainless steel friction-type rock bolts with stainless steel heavy-gauge welded wire fabric. The rock bolts have a nominal length of 3 m, are spaced in a square-grid pattern at 1.25-m centers, and the fabric is W4 × W4 with 75-mm center-to-center wire spacing.

- **Shafts**—The main shaft bore for the large-diameter (8-m) shafts is lined with a nominal 0.3-m (12-in.) thick cast-in-place concrete liner without reinforcement. The cast-in-place concrete liner for the small-diameter (5-m) shafts has a nominal thickness of 0.25 m (10 in.), also without reinforcement (BSC 2008b, Section 7). The liner is applied after the in situ stress relaxation associated with the excavation has been allowed to occur to 100%, so that the concrete liner is installed as a stress-free structure. The shaft stations (base) where they intercept with the shaft access drifts are reinforced with fully grouted rock bolts with a nominal length of 3 m and installed in a square-grid pattern at 1.25-m centers. A nominal 0.10-m-thick, fiber-reinforced shotcrete liner is also applied at the shaft access drift intersections.

The nonemplacement drift ground support design applies both empirical and analytical methods. The empirical methods are used primarily for assessing the needs and selection of ground support for nonemplacement drifts. However, due to the complexity of ground support design for a radioactive waste repository and given the thermal-mechanical interactions with the rock, the repository ground support design focuses mainly on analytical methods by using computer programs to evaluate the stability of unsupported and supported openings. Applicable thermal and seismic loads are considered in the design in addition to the in situ loading conditions. The initial ground support installed immediately after the tunnel boring machine excavation for personnel protection purposes is not included in the analysis of performance of ground support for the preclosure period. In the event anomalies are encountered during non-emplacement excavation, a process will be employed as described in Section 1.3.4.3 to address such anomalies.

The following criteria are applicable to the design of the nonemplacement ground support SSCs:

- Ground supports must ensure availability of the subsurface facility nonemplacement openings throughout a preclosure period of 100 years.
- Ground supports must be accessible for repairs and maintainable throughout the preclosure period.
- The vertical separation between crossing drifts is a minimum of 10 m (33 ft) from the crown of the lower opening to the invert of the upper opening when drifts cross at different elevations.
- The minimum centerline-to-centerline spacing for nonemplacement drifts running parallel is three drift diameters, based on the diameter of the largest drift.

Underground excavation causes disturbance to the stress field within the rock mass. Provided that the strength of the rock mass surrounding an excavation is sufficient, a new state of equilibrium is attained after stress redistribution takes place. The ratio between the magnitude of the initial stress existing in situ prior to excavation to the new stress resulting from the excavation-induced stress redistribution is referred to as a stress concentration factor. The value of the stress concentration factor depends on the geometry of the excavation and the ratio between the horizontal and vertical stresses. For square or rectangular openings, the stress concentration factor reaches highest values at corners. For a circular tunnel, the limiting case occurs when the horizontal stress is equal to zero, and the vertical stress is the only acting stress. Redistribution of this vertical stress causes the tangential stress at the tunnel sidewall to reach levels three times higher than the vertical stress (Obert and Duvall 1967, Chapter 16).

The effect of the rock mass quality variability within the lithophysal and nonlithophysal units at the repository level is accounted for by considering different rock mass categories. The results from both rock mass rating and rock mass quality approaches were considered. The rock mass properties for the lithophysal and nonlithophysal rock mass, respectively, are determined by rock mass characterization based on laboratory and in situ testing. Rock mass mechanical properties, instead of intact rock and joint properties, were assigned to 3DEC V. 2.01 using a continuum modeling approach. For conservatism, the computer simulations for nonemplacement openings are mainly carried out for category 1 rock, the poorest quality rock mass, both in lithophysal and nonlithophysal units. Stability analysis for the category 5 rock, the strongest quality rock mass, is also included for the access and exhaust mains. A Mohr-Coulomb, elastic–plastic constitutive model is used for simulations.

In this analysis, the analytical methods used in ground support design have been supplemented with empirical observations of rock response and performance of different ground support methods used for excavations done during site characterization. The best available experience of drift stability for the repository host rock can be obtained from observations of stability conditions at the ESF tunnel and the ECRB Cross-Drift.

Empirical methods are usually applicable to designing tunnels in mining and civil engineering. The empirical approach relies on rock mass classification systems. Generally, these systems allow rock properties and geologic conditions shown in samples taken from boreholes, scanline, full-peripheral mapping, detailed test surveys, and certain outcrops at the planned site, to be compared with similar information compiled and categorized from existing underground facilities. Based on this comparison, support requirements or needs can be estimated.

Two common classification systems were recommended in the *Drift Design Methodology and Preliminary Application for the Yucca Mountain Site Characterization Project* (Hardy and Bauer 1991, p. 6-6) and in the *Support of Underground Excavations in Hard Rock* (Hoek et al. 2000, p. 44). These two classification systems are the rock mass rating value (Bieniawski 1989), and the Q value (Barton et al. 1974). Both methods incorporate geological, geometric, and design engineering parameters in arriving at their quantitative value for the rock mass quality. The latter system was used in designing the ESF and the successful performance of that facility has led to adoption of this system for analysis of ground supports for the repository nonemplacement openings (BSC 2007d, Sections 4.3 and 6).

Rock Mass Rating System—This method, otherwise known as the Geomechanics Classification, uses the following six parameters to classify a rock mass (Bieniawski 1989, p. 52):

- Uniaxial compressive strength of rock material
- Rock quality designation
- Spacing of discontinuities (e.g., joints, fractures)
- Condition of discontinuities (e.g., joints, fractures)
- Groundwater conditions
- Orientation of discontinuities (e.g., joints, fractures).

These parameters not only are measurable in the field by direct observation of exposed rock but can also be obtained from borings. Joints are the major factor in this classification system; four of the six parameters (rock quality designation, joint spacing, joint conditions, and orientation of joints) are related to joint characteristics. Increments of rock mass rating corresponding to each parameter are summed to determine a rock mass rating value.

The rock mass rating values for various rock units at the repository host horizon are generally available from data collected in the ESF tunnels and the ECRB Cross-Drift. In case these rock mass rating values are not available, empirical correlation can be used to estimate rock mass rating values based on known deformation modulus of rock mass.

Once the rock mass rating values are determined, the rock mass quality for each rock unit considered can be judged based on the guidelines provided by *Engineering Rock Mass Classifications* (Bieniawski 1989, Tables 4.1 and 4.2). Recommendations for the excavation scheme and rock support needs can also be made by following the guidelines presented in *Engineering Rock Mass Classifications* (Bieniawski 1989, Table 4.4).

Rock Mass Quality Q System—This method, also known as the Norwegian Geotechnical Institute Rock Mass Classification System (Barton et al. 1974, p. 187), is commonly used in the design of rock support for tunnels and large underground chambers. The six parameters in the Norwegian Geotechnical Institute system include (BSC 2007d, Section 4.3.1.2):

- Rock quality designator
- Number of joint sets
- Joint roughness
- Joint alteration
- Joint water condition
- Stress condition.

These parameters are used to calculate the rock mass quality Q with an empirical equation. Similar to the rock mass rating values, Q indices for various rock units at the repository host horizon are available from the ESF tunnels and the ECRB Cross-Drift characterization data. In case the Q indices are not available, empirical correlations can be used to estimate Q indices based on given rock mass modulus.

The Q index is used with the equivalent dimension, defined as the largest of span, diameter, and height divided by the excavation support ratio. The excavation support ratio is roughly analogous to the inverse of the factor of safety used in engineering design. The excavation support ratio reflects the degree of safety and ground support required for an excavation as determined by the purpose, presence of machinery, personnel, and other factors, to meet safety requirements. In essence, reducing the excavation support ratio value can increase the safety factor of an opening. The excavation support ratio values for various underground openings can be estimated from *Rock Mechanics* (Barton et al. 1974, Table 7). For example, the excavation support ratio for the access and exhaust mains and the turnouts, classified as “access tunnels,” is taken to be 1.3; the intersections are assigned a value of 1.0. The Norwegian Geotechnical Institute rock mass classification system provides guidance on bolt spacing, bolt length, and shotcrete thickness, based on the rock mass quality index (Q) and the opening dimensions.

Engineering analyses for drift stability, ground support design, and drift interaction at the repository host horizon are based on the site-specific thermal-mechanical rock properties reported in *Subsurface Geotechnical Parameters Report* (BSC 2007e, Section 6). Tables 1.3.3-2 and 1.3.3-3 summarize the rock mass mechanical properties developed for both lithophysal and nonlithophysal rocks, and are used for engineering design analyses (BSC 2007d, Section 6.1). Determination of the mechanical properties uses the porosity (caused primarily by the abundance of lithophysae) as surrogate for the lithophysal rock mass while the Geological Strength Index concept from the rock mass classification theories is used for the nonlithophysal rock, as indicated in the two tables. Table 1.3.3-3 shows the approximated mechanical properties for the rock mass, based on the rock mass classification theories.

A minimum separation of three diameters of the largest of the two openings (centerline-to-centerline) is required for drifts parallel to each other. The stress concentration or disturbance at the openings is negligible in areas more than two diameters from the center of the opening (Obert and Duvall 1967, p. 497, Figure 16.2.2). The excavation-related stress around the tunnel diminishes rapidly as the distance from the tunnel wall into the rock mass increases. The commonly known closed-form solution for a circular tunnel (Jaeger and Cook 1979) shows that in hard rocks, such as those encountered at Yucca Mountain, the impact of a single tunnel is negligible.

For overlying openings, a minimum vertical separation of 10 m (33 ft) from the crown of the lower opening to the invert of the upper opening is required to minimize the interaction of the two openings on each other. For the ground support design for nonemplacement drifts, stability of pillars between a shaft access drift and two underlying exhaust mains was investigated by numerical analysis using the 3DEC model. A horizontal separation of 23 m between two parallel exhaust mains (which is about three times the diameter of the opening) and a vertical separation of 10 m between the shaft access drift and the underlying exhaust mains were used in the modeling configuration. Results from the numerical analysis show that the excavation of an overlying 7.62-m diameter shaft access drift and two underlying 7.62-m-diameter exhaust mains have minimal or insignificant effect on the stability of the 10-m-thick interburden pillar, even when subjected to a combination of in situ, thermal, and seismic loads.

1.3.3.3.1.1 Ground Support for Portals

Analyses of the North Portal and the starter tunnel indicate that these openings are stable for the considered mechanical properties of the rock mass even if no ground support is used. Both excavations are supported in accordance with standard mining practice to enhance safety.

The ground support at the North Portal consists of fully grouted rock bolts with fiber-reinforced shotcrete installed around the portal frontal and lateral faces. The rock bolts on the lateral faces have a nominal length of 3 m and are installed in a square grid pattern at 1.5-m centers, while the bolts in the frontal face have a nominal length of 5 m and are spaced in the same manner as the 3-m bolts.

Similar ground support design is used for the South Portal and for the North Construction Portal with localized variations due to varying topographic relief and ground conditions.

1.3.3.3.1.2 Ground Support for Ramps

Due to the functions that the ramps provide as access ways for personnel and, in the case of the North Ramp, for waste package transportation, fully grouted rock bolts are supplemented with a lining of shotcrete to enhance the ground support function in the three ramps.

Ground support stability analyses for the ramps and other nonemplacement openings considered the following effects: excavation effects, such as the state of the stress change due to excavation; thermal effects, such as those due to heat output from the waste packages; and seismic effects, such as those from potential earthquake events. These effects are evaluated, and stress-controlled modes of failure are examined for representative rock mass categories of 1 and 5. Representative values for lithophysal and nonlithophysal rock are based on two empirical rock mass classification systems, the rock mass rating system and the rock mass quality Q system. The focus is on the category 1 rock because this rock mass is generally weaker than other categories of rock mass. The typical ground support design details for the ramps are shown in Figure 1.3.3-22.

1.3.3.3.1.3 Ground Support at Drift Intersections

Ground support design at intersections between the access mains and turnouts or between exhaust mains and emplacement drifts, or between ramps and the starter tunnel, consists of fully grouted rock bolts with fiber-reinforced shotcrete and lattice girders as necessary, depending on rock mass quality and roof span.

The numerical analysis for ground support was conducted using both discontinuum and continuum three-dimensional codes. The geometry of a typical intersection of an access main and a turnout as represented in the discontinuum model (3DEC) is shown in Figure 1.3.3-23. The figure shows only the tunnels; the model's representation of the surrounding rock is hidden for clarity. The typical ground support design details for intersections are shown in Figure 1.3.3-24.

1.3.3.3.1.4 Ground Support for Access Mains, Exhaust Mains, and Turnouts

Figures 1.3.3-25 and 1.3.3-26 illustrate the ground support design in (1) the access and exhaust mains, and (2) the turnouts, respectively. Fully grouted rock bolts with W4 × W4 welded wire mesh with wires welded on a 100-mm by 100-mm grid are designed to be used for ground support in most of the nonemplacement openings, including access mains, exhaust mains, observation drift, tunnel boring machine launch chambers, and the North Portal starter tunnel. Fully grouted rock bolts with W4 × W4 welded wire mesh with wires welded on a 75-mm by 75-mm grid are designed to be used in turnouts.

1.3.3.3.1.5 Ground Support for Shafts

Typically, shaft analyses include calculations of shaft deformations resulting from the in situ lithostatic stresses present at a particular shaft depth. These deformations depend on rock properties and shaft diameter as well as the type of the shaft liner and other ground support measures used to maintain stability of the shaft excavation. Initially, a baseline case is analyzed by evaluating the performance of shaft excavation without ground support. The permanent shaft support is then introduced, considering that entire strata deformation due to excavation has already occurred. This case is used as a benchmark of shaft performance to which the performance of the shaft with the shaft liner installed is compared. This consideration is justified because common experience with excavations developed in hard rock at shallow-to-moderate depths shows very small deformations of rock strata and overall rock strata stabilizing at a short distance away from the advancing shaft bottom.

This analysis is performed utilizing a set of geotechnical data characterizing the behavior of distinct stratigraphic units in terms of five rock mass categories, where category 1 refers to the lowest (poorest) rock mass quality while the best rock quality is represented by category 5. The bounding variability of strata properties is captured by considering an extreme range of rock properties characterizing rock mass quality 1 and 5.

It is noted that no credit is taken for an initial ground support. Installation of the initial ground support is dictated by the construction method used in excavating the shaft.

The FLAC3D V. 2.1 was used in the analyses. FLAC3D is a three-dimensional explicit finite-difference program for solving complex problems in geotechnical, civil, and mining engineering. FLAC3D simulates the behavior of three-dimensional structures built of soil, rock, or other materials that undergo plastic flow when a limiting yield condition is reached. Problems involving thermal-mechanical coupled effects can be solved readily with this method. The explicit, Lagrangian calculation scheme and the mixed discretization zoning technique used in the FLAC3D simulation ensure that plastic collapse and flow are modeled very accurately.

Analysis of Unlined Shaft—The baseline case was analyzed using the closed-form and numerical solution. Calculations of shaft closure for shaft segments located in the different units were performed using a closed form solution, as discussed in *Rock Mechanics and Rock Engineering* (Carranza-Torres 2003). The shaft deformation was calculated as a function of depth and applied confining pressure. The product of these calculations is a ground reaction curve, which in its basic form illustrates the magnitude of deformation as a function of radial stress and shaft internal pressure. To complement the analytical solution, numerical solutions were obtained for identical conditions. The modeling methodology applied is based on selection of thickness and elevation representative for the weaker strata, such that potentially the most unfavorable effects of in situ stresses on shaft stability can be evaluated.

The analysis was performed to evaluate the shaft deformation occurring at various stages of excavation. The purpose for this analysis was to establish the distance above the shaft bottom at which the entire deformation has taken place, such that the shaft liner installed at this distance does not incur a load due to in situ stress readjustments. This standoff distance varies depending on the depth (magnitude of stresses) and properties of rock constituting the given geological unit. Of interest in design and development of construction specifications is the standoff distance required such that the final liner be placed behind the face after the maximum wall closure has occurred.

The estimation of the distance between the shaft bottom and the liner, with the liner installed after 100% of the deformation due to excavation has taken place was accomplished by using the profiles of radial deformation obtained from the FLAC3D models.

Geometry of the Shaft Intersections—Two typical types of shaft–shaft access drift intersections were analyzed. Figure 1.3.3-27 shows these two generalized arrangements, referred to as "T-shape" intersections and "L-shape" intersections.

The initial "L" intersection arrangement was refined further to provide more details in the shaft station area. Figure 1.3.3-28 shows this more refined version including the shaft sump, a short connecting tunnel and the adjacent tunnel, in the ventilation scheme represented by the main ventilation drift. Figure 1.3.3-28 also displays the geometry of the FLAC3D numerical model resulting from the subsequent refinements of the initial shaft sketches.

Modeling of Lined Shaft—The selected cast-in-place 0.3-m- and 0.25-m-thick plain concrete shaft liners were evaluated for performance in terms of stresses and deformations of the liner for different loading conditions when they occur during the period of operation, and also for load conditions characteristic of the shaft location. The location of the shaft can have a substantial impact on its performance. A generic shaft was used in the models, based on a typical stratigraphic column for the repository overburden at Yucca Mountain, and load conditions for different shaft locations are considered in the analyses. The impact of temperatures over the preclosure period of 100 years after waste emplacement is included in the analyses.

The liner is designed to sustain two types of loads: (1) seismic loads, and (2) thermal loads, including an additional ground pressure due to inelastic rock-mass deformation caused by the thermal and seismic loads.

The ground supports for nonemplacement openings are classified as non-ITS and as such, the applicable design criterion for design basis ground motion (DBGM) would have been as prescribed by the *International Building Code 2000* (ICC 2003), in conformance with repository design criteria. However, considering that ground supports in some of the nonemplacement openings (i.e., inaccessible openings) are designed for a service life of 100 years without planned maintenance, a more stringent seismic criteria has been selected for the repository ground support SSCs. The application of the more stringent DBGMs as described below ensures more reliable operability of the openings over the preclosure period. The DBGM-2 (design basis ground motion with a mean annual probability of exceedance of 5×10^{-4} or a 2,000-year return period seismic event) was used as the seismic design basis. In addition, seismic events with a mean annual probability of exceedance of 10^{-4} (i.e., seismic events with a 10,000-year return period) were also specified as the "beyond DBGM," and used for assessment of design sensitivity to the more intense ground motions. The dynamic load is imposed by means of applying a full three-dimensional seismic wave ground motion at the model base. Stress boundary conditions, equivalent to the specified velocity histories, were applied at the bottom boundary of the model. The nonreflecting, quiet boundary condition was applied on the top model boundary. The free-field boundary condition was used on all vertical model boundaries.

The analysis of thermal effects was carried out using temperature fields after 100 years of heating. This process allowed for an assessment of stress–temperature dependence over time, and considering an infinite extent of the repository in the layout. The transient temperature field generated by the emplaced waste in the repository rock strata and within the rock mass surrounding the repository at Yucca Mountain will cause deformation and stress changes in the rock mass. These changes in turn cause deformation and stress changes in the shaft liners. Determination of the deformation and stress changes along the shaft bore, and especially at shaft station levels, requires that a three-dimensional, thermal-mechanical numerical model be used. The thermal-mechanical analyses were carried out using the FLAC3D computer code with mountain-scale thermal input from the FLUENT model. In the analyses, the deformation and stresses of the rock mass along the axes of the shafts were extracted from the modeling results at several time intervals. The time interval equal to 100 years after waste emplacement was used to assess the temperature-related impact on shaft liner performance.

The mechanical properties of the concrete liner used in the analysis are summarized in Table 1.3.3-4. The concrete liner is installed after 100% of stress relaxation resulting from opening deformation after excavation is allowed to take place. In effect, the liner has been considered to take load due to thermal and seismic effects only and is initially installed as a stress-free structure.

Final effort was directed at assessing the worst-case scenario by examining a combined effect of all major stresses generated due to in situ stress, excavation-related, thermal, and seismic loads.

Shaft Excavations and Ground Support Analysis Results—The following findings, derived from the analyses of the shaft ground support designs, are summarized below:

1. In situ stresses are the primary loads considered applicable during shaft excavation. Under a bounding range of in situ stresses, the analysis shows that an unlined shaft and its station intersection remain stable under varying ground conditions along the shaft alignment.

2. The shaft liner is installed to insure the long-term shaft stability during repository operations, when thermal loads and potential seismic events become the primary loads for shafts and shaft stations. The stresses resulting from combined thermal and seismic loads may result in liner fracturing. However, such fracturing is inconsequential to the structural support function of the liner (radial direction). The overall shaft and shaft station performance analyzed under thermal and seismic loads is considered acceptable.

1.3.3.3.1.6 Ground Support for Miscellaneous Openings

The details for ground supports for the observation drift and alcove, and for the tunnel boring machine launch chambers, as described in Section 1.3.3.3.1, are shown in Figures 1.3.3-29 and 1.3.3-30, respectively.

1.3.3.3.2 Operational Processes

The stability of the underground nonemplacement openings is necessary throughout the preclosure period to support personnel safety, waste emplacement operations, and subsequent performance confirmation activities and potential waste retrieval. Stability of the openings throughout the preclosure period is ensured through monitoring, maintenance, and inspection of the openings and their ground support.

The underground nonemplacement openings are classified into accessible (ramps, access mains, turnout intersections, intake shafts, and intake shaft access drifts, observation drift and alcove), and nonaccessible (turnouts beyond the bulkhead, exhaust mains, exhaust shaft access drifts, and exhaust shafts). Monitoring and inspecting both of these types of openings for ground support failure and drift degradation are key elements of a ground support maintenance plan. Information gathered from such inspections provides the basis upon which maintenance decisions are made. The methods of ground support monitoring and inspecting are mainly determined by the accessibility of the opening for safe personnel entry. Observations by technical experts and instrumentation are utilized in accessible areas, whereas observations in inaccessible areas, characterized by high temperatures and high radiation levels, require using remotely operated vehicles. In all inspection and maintenance operations, personnel safety and as low as is reasonably achievable considerations are implemented.

Inaccessible Nonemplacement Openings—These openings will be inspected and monitored using remotely operated vehicles for visual observations by video cameras and material sampling devices. In addition, remote sensing techniques may be employed to monitor ground conditions and detect rockfalls. Any necessary maintenance needs triggered by installation flaws, material defects, off-normal operational conditions, or unfavorable inspection results will be evaluated and potential steps involved in maintenance actions evaluated.

Exhaust shafts are inaccessible under normal operating conditions, so a specialized device equipped with cameras and laser measuring systems will be utilized. Such a device can be lowered or lifted with a tether, or deployed along a track mounted on the liner. No significant degradation is expected of either the cast-in-place concrete liner for the exhaust shafts or the shotcrete layers at the opening intersections. The rock bolts in the exhaust mains are encapsulated by grout in their boreholes, protecting the bolts from corrosion. Hence the inspections in inaccessible openings will focus on detecting corrosion of carbon steel components and loss or failure of rock bolts, and in identifying concrete and shotcrete defects such as application flaws, cracks (both microscopic and macroscopic), delaminations, spalls, void development, and chemical alteration. The severity of these defects will determine the need and extent of repairs.

Inspection of the turnouts beyond the bulkheads will be done by the remotely operated vehicles used to inspect the emplacement drifts. A favorable aspect of the turnout inspections is that the remotely operated vehicles can look at the rock visible through the stainless steel wire mesh while such an observation is not possible in the emplacement drifts because of the stainless steel sheet liner.

Accessible Nonemplacement Openings—These openings will be visually inspected by qualified personnel on a regular basis. A geotechnical instrumentation program designed to provide field measurements for drift closures, ground support loads, and potential overstressed zones will supplement the observations. Inspection, monitoring, and maintenance in accessible nonemplacement openings will be performed in a similar and conventional way as it is done in underground mines and in the tunneling industry.

If the visual inspections by remotely operated inspection equipment indicate that the replacement or repair of ground support components is warranted in an exhaust main or exhaust shaft, the exhaust ventilation in the damaged area is temporarily terminated and rerouted. Repairs can be made in the damaged area without interrupting ventilation throughout the rest of the repository. If repairs are needed at a specific location in these openings, efforts are made to make any necessary repairs with remotely operated equipment. In the event that maintenance by remotely operated equipment is not feasible and the damaged location is accessible only through an emplacement drift, drifts can be cooled (Section 1.3.5.2.2), radiological protection measures taken, and applicable waste packages relocated to another emplacement drift to allow human entry for repairs. This operation will also require installation of temporary isolation barriers. One important ground support maintenance aspect will be corrosion testing of steel components at different times during the preclosure period to ensure that the materials will function without failure due to corrosion throughout their 100-year service life. In addition to corrosion testing, a limited number of in situ pull-out tests will be performed to determine the anchorage capacity and bolt behavior, especially in the lithophysal rock. In conjunction with pull-out tests, overcoring the installed rock bolt and splitting the overcore will provide information on interaction of the friction-type rock bolts with lithophysal cavities, and whether localized areas along the bolt show initiation of stress corrosion cracking.

1.3.3.3.3 Design Codes and Standards

For steel ground support components in nonemplacement excavations, carbon steel, including high-strength low-alloy steel, is used. Steel components that are manufactured based on the following standard specifications included in the American Society for Testing and Materials (or "ASTM") standards are expected to perform satisfactorily in the nonemplacement drift environment:

- 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 242/A 242M-03a, *Standard Specification for High-Strength Low-Alloy Structural Steel*
- ASTM A 276-06, *Standard Specification for Stainless Steel Bars and Shapes*
- ASTM A 588/A 588M-03, *Standard Specification for High-Strength Low-Alloy Structural Steel with 50 ksi (345 MPa) Minimum Yield Point to 4-in. (100-mm) Thick*
- ASTM F 432-95, *Standard Specification for Roof and Rock Bolts and Accessories*.

For cementitious materials to be used for grouted rock bolts, shotcrete, or concrete, a low-pH mix is used. For material properties and use of shotcrete, the following standard specifications apply.

- ACI 506R-90, *Guide to Shotcrete*
- ACI 506.2-95, *Specification for Shotcrete*
- ACI 223-98, *Standard Practice for the Use of Shrinkage-Compensating Concrete*.

The installation, inspection, and testing of ground support components will be in accordance with conventional industry experience since these ground support components will be monitored and maintained during normal operations. ACI 506R-90, *Guide to Shotcrete*, provides the general guidance for testing, monitoring, and installation of shotcrete. ASTM D 4435-04, *Standard Test Method for Rock Bolt Anchor Pull Test*, will be used as a guide for testing rock bolts.

1.3.3.4 Invert System

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

1.3.3.4.1 System Description

The invert structures for nonemplacement openings have been classified as non-ITS and non-ITWI (Tables 1.9-1 and 1.9-8). These structures do not prevent or mitigate event sequences that result in radioactive releases resulting in radiological doses (Section 1.7).

The design of the invert structures and railway for the nonemplacement areas of the subsurface facility is primarily based on satisfying the requirements of the waste package transportation and emplacement equipment. Those requirements, applicable design criteria, design loads, design load combinations, and other design considerations are described in Section 1.3.2. By satisfying the heavier design loads for a loaded TEV, the invert structure and rail designs are thus adequate for other facility transportation requirements. Other facility transportation equipment have only been generally identified but no specific designs have been developed. The spacing between crane rails provides sufficient width to accommodate rubber-tired equipment if rail-based equipment is not selected for other uses.

Design calculations have been developed for the invert and rail designs for the initial subsurface waste package transportation route from the North Portal to the emplacement drifts, for Panels 1 and 2. This route follows the alignment of the existing ESF tunnels (North Ramp and main drift) in its entire length from the North Portal to the southernmost turnout in Panel 2. These existing excavations are equipped with precast concrete invert sections and 3-ft narrow-gauge rail. The repository invert structure design requires a wider, and therefore thicker, invert structure foundation; therefore, the new invert structures will be built over the old structures. This design eliminates the need to do unnecessary demolition and disturbance of the underground environment. The invert structure and rail designs for the new access mains (i.e., access main cross-drift to Panel 4 and access mains for Panels 3 and 4) will be similar in configuration except that the space occupied by the existing concrete inverts and existing rail in the existing ESF tunnels cross section will be replaced with new concrete.

Figures 1.3.3-31 through 1.3.3-33 illustrate the invert structure and rail designs representative of the waste package transportation route from the North Portal to the turnout approach to the emplacement drifts.

Figures 1.3.3-34 through 1.3.3-38 illustrate the invert structure and rail designs from the "point of switch" for the turnout at the access main, into the turnout past the tunnel boring machine launch chamber, into the curved section of the turnout, and into the straightaway approach to the emplacement drift.

The elevation view in Figure 1.3.3-31 shows the existing precast concrete structure and rail that will be covered with an 18-in. reinforced concrete slab on top of which the crane rail supports are mounted and held in place with 1-ft anchor bolts. The crane rails are installed at 11-ft centers. The hollow section of drift below the existing precast concrete invert sections will be filled with grout with a minimum strength of 5,000 psi.

Figure 1.3.3-32 shows the crane rail arrangement and installation details, with additional detail provided in Figure 1.3.3-33. The rail fixation system is with a forged steel rail clamp. The structural bearing slab is reinforced concrete with a minimum strength of 5,000 psi. The anchor bolts are 1-in. diameter by 12-in.-long expansion anchors. Rail will have a minimum joint stagger of 4 ft.

Figure 1.3.3-34 shows the plan view and elevation for the invert structure and rail section going from the access main into the turnout to the entrance to the emplacement drift. The sections shown in the balance of the turnout invert figures are located in this plan view. The section locations selected in this plan view represent typical potential variations in turnout invert structure cross section and design configurations. The plan and elevation views also show the location where the invert structure transitions from concrete to steel and ballast, beyond the tunnel boring machine launch chamber.

Section B in Figure 1.3.3-35 illustrates the configuration of the invert structure and rail at the beginning of the turnout excavation, beyond the rail switch for the turnout. The invert structure concrete thickness within the turnout excavation is 10 in. minimum. The overall thickness of the concrete invert section in the access main is primarily a function of the necessary height to achieve enough cross section width for the 11-ft centerline-to-centerline crane rail and TEV equipment envelope within the confines of the circular drift. In this section of the turnout there is no limitation on width, so the concrete invert is limited to a sufficient thickness to satisfy the design structural requirements.

Section D in Figure 1.3.3-36 illustrates the configuration of the invert structure at the tunnel boring machine launch chamber. At this location the top of concrete slopes up at a 1.75% grade, resulting in a thicker section of concrete of varying thickness (22 in. at the location of Section D). At the end of the tunnel boring machine launch chamber, the invert structure is made of steel and supported on the rock floor in notches cut into the drift wall as illustrated in Section E of Figure 1.3.3-37. Ballast is placed between the steel and the drift floor. The turnout excavation is circular from this point on towards the emplacement drift, and of the same diameter as the emplacement drift. As the turnout approaches the emplacement drift, the turnout invert structure progressively achieves the same thickness as that for the emplacement drift invert structure (52 in.). Detail 1 in Figure 1.3.3-37 illustrates the configuration of the longitudinal and transverse steel beams in the area of the turnout curve. Figure 1.3.3-38 provides fabrication and assembly details for the steel components of the invert structure in the turnouts. The turnout invert steel structure is not anchored to the rock but rests on the rock and is braced against the drift wall on the sides as illustrated in Section F of Figure 1.3.3-38.

The criteria below are applicable to the design of the invert structures for nonemplacement openings. Information regarding TEV operations over a crane rail track is provided in Section 1.3.3.5.1:

- Invert structures for the North Ramp and the access mains used for waste package transportation have been designed with grades not to exceed 2.5% (Figures 1.3.3-10 and 1.3.3-11).

- Invert structure alignments for turnouts conform to the requirements for a minimum radius of curvature of 200 ft.

- The subsurface facility nonemplacement area invert structures used for waste transportation are designed to allow safe transportation at the equipment design speeds.

Design of the subsurface rail system focuses on track and TEV features that enhance rail safety and performance. A goal of the design is to reduce operational limitations necessary to operate the subsurface rail system.

Design of the subsurface rail system includes a third rail used to power the TEV and drip shield emplacement gantry. The third rail design will support subsurface and surface repository operations and will be based on applicable codes and standards and accepted industry practices for development of an electrified third rail system. Power is transferred from the third rail through spring-loaded collectors that are mounted on the sides of the TEV. The TEV design features two collectors per side which allows the TEV to travel in either direction. Power for the drip shield gantry is provided using a similar collector configuration (BSC 2008c, Section 3.3.14; BSC 2007f, Section 4.5.1).

1.3.3.4.2 Operational Processes

The rails and switches will be maintained in accordance with a maintenance program that includes monitoring, routine and preventive maintenance, and inspections to ensure performance within design specifications.

1.3.3.4.3 Design Codes and Standards

The codes and standards applicable for cementitious components of the invert structures are as listed in Section 1.3.2.

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 rated at 171 lb/yd. The horizontal and vertical curves specified in the design are within the standard recommendations of the American Railway Engineering and Maintenance Association *Manual for Railway Engineering* (AREMA 2002; BSC 2007g, Sections 3 and 6; BSC 2007h, Sections 3 and 6). The design of the concrete section is in conformance with ACI 360R-06, *Design of Slabs-On-Ground*, and the design of the structural steel conforms to *Manual of Steel Construction, Allowable Stress Design* (AISC 1997).

1.3.3.5 Waste Package Transportation 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), (4), (5), (6), (9); Section 2.1.1.7.3.2: AC 1(1), (4); Section 2.1.1.7.3.3(II): AC 1(1), (3), AC 2(2), (6), AC 3(1), (2), AC 9(2)]

The primary function of the waste package transportation system is to safely transport waste packages from the CRCFs and the IHF to the repository subsurface for emplacement. This section discusses this function and the design of the TEV which is the primary equipment in the waste package transportation system.

1.3.3.5.1 System Description

The TEV operates over a crane rail track with a centerline-to-centerline spacing of 132 in. (11 ft). The 171 lb/yd American Crane Manufacturers Association crane rail is used on the surface and within the loadout areas of the surface nuclear facilities, within the Heavy Equipment Maintenance Facility, in the North Ramp, and in the access mains, turnouts, and emplacement drifts. The crane rail system is designed for the loads imposed by the fully loaded TEV. More information regarding the rail system is presented in Section 1.3.3.4.

The wheels and wheel block assemblies for the TEV are designed with the capability to negotiate the 200-ft radius used for design of the turnouts (ASME NOG-1-2004, Table 5452.3-1; CMAA 70-2000, Section 3.12). Each wheel has an independent drive system consisting of a high ratio gearbox and drive motor. Each wheel will be mounted directly onto the splined output shaft of its main linear drive gearbox. Each drive motor features an integral absolute encoder. This encoder will generate a unique output for each resolvable drive motor shaft position so that each shaft position is fully determined. By using absolute position of each drive motor shaft, the onboard PLC and Central Control Center know the location and speed of the TEV at any given moment. This information is used by the PLC to adjust the power supplied to each drive motor to compensate for travel around a curve. The rotary encoders and speed detection devices provide confirmation of the TEV's speed and position (BSC 2008c, Sections 3.3.4 and 3.3.5). The North Ramp and other access mains, in which the TEV operates, have curvatures with a minimum 1,000-ft radius (BSC 2007i, Section 6.2.1). The turnouts have curvatures with a minimum 200-ft radius. Areas on the surface, in which the TEV operates, have curvatures with a minimum 200-ft radius (Figure 1.2.1-2).

To facilitate the capability of the TEV to travel around a curve, one side of the TEV is equipped with double flanged wheels that are designed in accordance with ASME NOG-1-2004, Figure and Table 5452.4-1. The wheels on the opposite side of the TEV are left plain. This wheel configuration allows the TEV plain wheels to shift laterally on the rail, as needed, while the flanged wheels guide the TEV around a curve. A geometric assessment performed for this wheel configuration indicates that, in the center of the 200-ft curve, the flanges of the double flanged wheels have sufficient clearance to minimize the potential for wheel climb. As a result, the TEV wheels do not come off the rail. The use of double-flanged wheels on one side only does not interfere with movement of the TEV in either direction around a curve (BSC 2008c, Sections 3.2.1.34 and 3.4.9).

The TEV is designed to negotiate a rail grade of 2.5%; the North Ramp grade is 2.15% descending from the North Portal. The TEV is designed with pivoted wheel block assemblies that allow grade changes while maintaining equal wheel loading. This design configuration will allow the TEV to negotiate vertical curves and track undulations and will ensure grip of the wheels to improve acceleration and braking capability of the drive system (BSC 2008c, Sections 3.2.1.34 and 3.3.5). However, ASME NOG-1-2004 does not address design of a crane that is capable of traveling up or down a grade. To ensure that the TEV is capable of safely operating on a grade such as the North Ramp, the TEV was evaluated for operations both up and down grade and for a curve that is on a grade. Design calculations performed to determine horsepower requirements for operations on a grade used the *SME Mining Engineering Handbook* (Cummins and Given 1973) as a design guide. The calculations performed to determine TEV horsepower and braking requirements and operating capabilities indicate that the TEV can operate on the North Ramp and other anticipated repository grades in a manner that meets safety and operational requirements (BSC 2008c, Sections 2.4.4 and 3.1.1.1).

The following sections describe the design features of the major TEV SSCs.

1.3.3.5.1.1 Transport and Emplacement Vehicle Description

The TEV is a rail-based, shielded unit used to move waste packages. Pertinent features of the TEV are depicted in Figures 1.3.3-39 and 1.3.3-40. The TEV is designed to prevent an uncontrolled movement that may lead to a breach of a waste package. Due to these design requirements, several design features and functions of the TEV are classified as ITS and are described in the following discussion. Table 1.3.3-5 presents the preclosure nuclear safety design bases for the TEV and design criteria considerations associated with each design basis. There are no design features or functions of the TEV classified as ITWI.

The TEV is designed to carry the waste packages and associated emplacement pallets to be placed in the repository. The functions of the waste package transportation system are designed to support the emplacement throughput shown in Table 1.2.1-1. Because the TEV travels from the surface nuclear facilities into the subsurface as it transports waste packages, design of TEV SSCs must address both operating environments. Design considerations such as wind loads, wind-borne hazards, and surface temperatures are addressed during the design process along with rockfall and other design issues that are more specifically related to the subsurface (BSC 2008c, Section 3.2). Design, environmental and operational requirements, and implementation descriptions for the TEV are presented in Table 1.3.3-6.

The TEV is a crane-rail-based transport assembly that runs on standard crane rails and is self-propelled. Power for the TEV is an electrified (480 V AC) third rail that is supported through the repository electrical supply system. The TEV is equipped with dual-power pickup mechanisms to ensure a reliable and continuous source of power. The TEV also carries a battery backup power system that provides a limited supply of electrical power. In the event of loss of primary power, this backup system provides enough power for the TEV to maintain communication with the Central Control Center until directions are provided. The battery power supply will not support TEV movements. If a loss of power occurs, all TEV systems, except the communications network, cease function and lock in place. Upon the restoration of power, the TEV remains locked in place until operator actions initiate further movement.

For the emplacement pallet lifting operation, the TEV design utilizes two lifting features that are attached to each side of the shielded-enclosure lift-frame assembly. The shielded-enclosure assembly is raised and lowered by four vertical-lifting mechanisms. These mechanisms provide the vertical lifting force required to lift the waste package and pallet assembly. The lifting features engage and hoist the pallet along each side and are designed to accept any variation of waste package and pallet lengths. The TEV lifts the emplacement pallet with waste package at a nominal hoisting speed of 3 ft/min. When the travel lift height has been reached, four transportation shot bolts are engaged to carry the load of the shielded enclosure during transportation. The transportation shot bolts are mounted in the chassis of the TEV and are electrically activated. The transportation shot bolts are driven into holes in the sides of the lifting features. Once the transportation shot bolts are engaged, the screw jacks can be lowered, which removes the load of the shielded enclosure and waste package from the screw jack components during travel. The transportation shot bolts minimize the potential for a waste package drop and reduce vibrations being transmitted from the rails during movement of the TEV (ASME NOG-1-2004, Table 5331.1-1).

The TEV frame includes a combination of welded and bolted connections. The frame structure accommodates the initial assembly of the TEV and allows for maintenance and the replacement of components and operating systems to the extent practical. Different steel grades may be used in various components of the TEV. However, based on industry standards, carbon steel is an accepted material for uses such as the TEV structural frame components (BSC 2007j, Sections 3.2.7, 6.4 and 6.6).

In order to accommodate the high-radiation environment of the emplacement drifts, actions of the TEV are implemented by an onboard PLC while being monitored and controlled by operators in the Central Control Center. This approach minimizes the potential for personnel radiation exposures.

TEV movements are performed by the onboard PLC but are initiated by commands from the operators in the Central Control Center. Five major TEV movements require control: (1) the backward and forward movements of the TEV on the crane rails, (2) up and down motion of its shielded enclosure and lifting features, (3) raising and lowering of the rear shield door, (4) extending and retracting the shielded enclosure base plate, and (5) opening and closing the shielded enclosure front doors. The vertical motions of the shielded enclosure lifting features do not require a precise level of control to successfully engage and lift or set and disengage the emplacement pallet, on which rests the waste package. The shielded enclosure lifting features do not touch the waste package itself but rather engage the emplacement pallet. This design feature minimizes the risk of damage to the waste package during handling operations. The TEV design is such that it is physically limited from lifting the waste package beyond its maximum design drop height. This design safety measure is intended to prevent breaching of the waste package during transport.

Although most components of the TEV are based on commercially available equipment, integration of these components in the configuration required to perform emplacement and retrieval functions represents a first-of-a-kind application of existing technology. Codes and standards have been evaluated and design requirements and testing specifications are being developed to ensure the functions performed by the TEV meet the ITS reliability, safety, and performance objectives (BSC 2008d, Section 1; BSC 2008e, Sections 4, 8 and 9). The activities necessary to implement the component development process including testing requirements are discussed in Section 1.3.2.7.

Transport and Emplacement Vehicle Braking Processes—The TEV braking processes are designed to prevent a runaway condition. The primary method for slowing and stopping the TEV is through an electric motor braking process. The use of high-torque motors with integral disc brakes and high-ratio gearboxes mechanically limit the maximum speed the TEV can attain. These same operating parameters serve to slow or stop the TEV when power is decreased or cut off. The integral disc brake for each drive motor minimizes the potential of a TEV runaway. The integral disc brakes are released electrically and applied mechanically and operate on the fail safe principle that when the electrical supply is interrupted for any reason, the brake is applied automatically. The TEV is also equipped with rail brakes that are applied automatically upon loss of power. To the extent practical, the TEV drive and braking components are based on proven and commercially available technology, primarily nuclear and heavy industrial crane applications. The data and information from these applications and the design recommendations of ASME NOG-1-2004 provide an established basis to support development of a TEV design that meets or exceeds specified performance and reliability requirements. TEV components are based on proven technology and industry applications. Nonetheless, TEV components will be evaluated and refined as the TEV design progresses to ensure drive system and braking performance and reliability (BSC 2008c, Sections 2.1, 3.3.2, 3.3.3, and 3.3.4).

The preclosure safety analysis performed for the TEV evaluates the drive and braking process design and potentially related hazards and event sequences to assess potential impacts and identify system reliability rates. The safety analysis establishes expected reliability rates for the braking process using nuclear and industrial accident report data and fault-tree analyses. To limit the potential for a runaway, the reliability goal for the TEV is established such that a potential breach of the waste package due to a runaway event will have a probability of occurrence of less than or equal to 2.0×10^{-9} per transport (Sections 1.6, 1.7, and 1.9) (BSC 2008c, Section 3.1.1). With this level of reliability, event sequences involving a TEV runaway are beyond Category 2 (Section 1.7).

The safety analysis performed for the TEV indicates that the braking process reliability goal can be met using a nuclear or industrial crane drive system and brake configuration that includes high-torque drive motors and gearboxes supported by a drive motor integral electromechanical disc brake system. The fault-tree analysis process used to determine reliability goals is discussed in Section 1.7.

As recommended by ASME NOG-1-2004 for a crane load of 50 to 99 tons, the operating speed of the TEV will not exceed 150 ft/min (1.7 mph). This ASME NOG-1-2004 operating recommendation, referred to as a design rated load speed addresses travel speeds only on the basis of crane load, it does not consider gross vehicle weight. Drive motors and gearboxes are sized and selected to achieve but not exceed the recommended TEV operating speed, even during descent of the North Ramp which has a grade of 2.15% (Section 1.3.3.1.1). The motors selected for the main drive have a variable rotational speed capability and are coupled with high-ratio gearboxes, and 36-in.-diameter wheels. The mechanical components of this drive system configuration limit the operating speed that can be achieved by the TEV to the design rated load speed of 150 ft/min (1.7 mph) recommended by ASME NOG-1-2004. Additionally, the ratios of the gearboxes are sufficiently high, that if power to the drive motors is decreased or shut off, the rotational drag of the drive system provides braking action to slow or stop the TEV (BSC 2008c, Sections 3.1.1 and 3.2.1.1). The potential for wheel and track slippage that might cause a loss of traction has also been considered but is not judged to be a design concern.

The drive system braking process is a primary mechanism for slowing and stopping the TEV. However, the PLC onboard the TEV constantly monitors the speed of the TEV. If the speed of the TEV exceeds the established level according to the operation in progress, such as during emplacement, the PLC decreases power to the motors. If power to the drive motors is decreased, the rotational drag of the gearboxes slows the TEV. If power is shut off, the rotational drag of the gearboxes stops the TEV completely and the drive motor integral disc brakes are automatically applied (BSC 2008c, Sections 2.5.4, 3.1.1 and 3.2.1.3).

In addition to the integral disc brakes, the TEV also features rail brakes that are automatically applied upon a loss of power. The rail brakes, commercially referred to as “thruster” brakes, exert a vertical force equal to the weight of the vehicle to the top of the rail preventing further vehicle movement. The rail brakes will be electrically driven out of rail contact and spring-driven into rail contact, a configuration that ensures automatic application during electrical power loss. They also function as parking brakes during an electrical power outage to either the brakes or the vehicle and during a pause in vehicle movement, including slopes in either direction of travel (BSC 2008c, Section 3.3.3).

Although not directly a part of the TEV braking process, a significant activity will be a vehicle system verification and inspection at the North Portal Access Control Point before every descent into the subsurface. The system verification and inspection will include a check of the drive system, brakes, and operating systems while the TEV is stationary. Since the TEV will be maintained on a routine basis, the vehicle system verification and inspection will provide a confirmation of system functions and ensure that no system faults are present.

Collision and Speed Control—Event sequence analyses have been performed to evaluate potential collisions during waste package transport and emplacement between the TEV and other mobile equipment, emplacement access doors, and fixed structures (Sections 1.6 and 1.7). The analyses indicate the severity of a collision involving the waste package is essentially controlled by the speed of the TEV at the time of the collision. If a collision did occur, it would typically be at the low speeds involved in waste package transport operations. Since the operating speed for the TEV is 150 ft/min (1.7 mph), the impact velocity for a waste package involved in a collision does not exceed the design basis impact velocity for the TEV of approximately 2 mph (BSC 2007k, Section 3.1.2). Also, the collision would impact the TEV structure rather than the waste package. Therefore, the energy of the impact would be primarily absorbed by the structure of the TEV. Analyses have shown that a low-speed collision of the TEV while carrying a waste package does not cause a breach of the waste package (BSC 2007k, Section 7.3). Such an event does not initiate a Category 1 or Category 2 event sequence (Sections 1.6 and 1.7).

To ensure control of the speed of the TEV during waste package transport, the TEV includes design features that provide a margin of safety such as the high gear ratios of the drive motor gearboxes and a speed monitoring system. The speed monitoring system uses encoding sensors that are linked to the onboard PLC. The PLC receives constant signals from the speed monitoring encoders mounted on the wheel drive shafts. If an indication is received that the speed of the TEV exceeds the established limit for the operation being performed, the PLC provides notification to the operators in the Central Control Center and implements an operational sequence to decrease power to the motors. Since the onboard speed sensors and PLC continually monitor the travel speed of the TEV, the system ensures speed control reliability and provides an independent means of ensuring that the operating speed of 150 ft/min (1.7 mph) for the TEV is not exceeded (BSC 2008c, Section 3.1.1).

The speed monitoring and control system will work in conjunction with TEV instrumentation that includes rear and forward range sensing devices and a collision avoidance system. These SSCs will detect rocks and objects and stop the TEV before an impact occurs. A sweeper device will also be attached to the front of the TEV to move aside small rocks or objects (BSC 2008c, Sections 3.2.1.3, 3.2.1.28 and 3.2.1.38).

Tipover and Derailment—The structural configuration of the TEV limits the height of the bottom of the waste package pallet during transport to 14 in. above the top of the rail. This distance bounds the height from which a waste package may drop during a tipover event sequence. Although the probability of a tipover cannot be precluded, analyses indicate that a tipover is a beyond Category 2 event sequence (Sections 1.6 and 1.7) (BSC 2008c, Section 3.4.10).

In the unlikely event of a derailment, the bottom faces of the TEV chassis and the bottom face of the base plate are at the same level; both are only 2 in. above the top of the rail. This design configuration ensures that even if the TEV wheels come off the rails, the maximum drop of the TEV is limited to 2 in. plus the depth of the wheel flanges, nominally 1 in. If such an event occurs, design features at the bottom faces of the chassis and the bottom face of the base plate will sit directly on the rails and will support the TEV (Sections 1.6 and 1.7) (BSC 2008c, Figures 15 and 45 and Section 3.4.9).

Seismic Restraints—To meet the nuclear safety design bases requirement to protect against derailment in the loadout area and ensure that TEV performance during a seismic event is in accordance with ASME NOG-1-2004 (Section 4457) requirements for a Type 1 crane, seismic restraints are included in the design of the underside of the TEV chassis (Figure 1.3.3-41). These restraints consist of "L" shaped fabrications of sufficient size and capacity to limit the vertical lift of the TEV off the rails during a seismic event. The fabrications are located at the front and the back of the TEV, positioned on the outer side of both rails, and placed so that the leg of the "L" shape projects under the railhead on each side (Figure 1.3.3-41) (BSC 2008c, Figure 45, and Sections 3.1.2 and 3.4.9).

Shielded Enclosure and Rockfall—The shielded enclosure design for the TEV includes a combination of materials to provide for structural integrity and gamma and neutron radiation protection. Evaluations of the shielded enclosure have identified materials and a material layering design that meet requirements for personnel radiation protection and provide structural strength to protect the waste package from potential rockfall. The materials identified for the TEV shielded enclosure include Stainless Steel Type 316 and depleted uranium for structural strength and gamma shielding and borated polyethylene for neutron shielding. The shielding materials are encased between a thin inner and outer layer of the stainless steel to provide a smooth surface for ease of decontamination (BSC 2007l, Section 6.1.5). Radiation dose protection provided by the shielded enclosure is presented in Section 1.3.3.5.1.5.

Analyses have been performed to evaluate the potential rockfall that might impact the shielded enclosure of the TEV. These analyses have identified potentially credible rockfalls that might impact the TEV as a result of the most severe seismic event considered for the preclosure period. Using the rockfall data, a structural analysis has determined that a credible rockfall from the crown of the nonemplacement drifts that impacts the shielded enclosure of the TEV would not cause damage in a manner sufficient to jeopardize the structural integrity of the TEV or the waste package. However, since the waste package is designed to withstand a direct impact from such a rockfall without breaching, the shielded enclosure of the TEV is not credited with protecting the waste package (BSC 2008c, Section 3.2.2.11).

Shielded Enclosure and Thermal Performance—The final design of the TEV shielded enclosure will incorporate the results of thermal studies that have been performed to evaluate the ability of the materials and configuration of the shielded enclosure to accommodate and dissipate the anticipated heat loads associated with waste package transport. The thermal analysis for the shielded enclosure is based on a TAD waste package with a bounding heat load of near 22 kW. The shielded enclosure design for the TEV includes a combination of materials to provide for structural integrity and gamma and neutron radiation protection. The composite layer of the shielded enclosure that has the lowest thermal conductivity is the neutron shielding layer with an effective thermal conductivity of 6.5 W/m-K for the NS-4-FR neutron shield structure. This is a ten-fold increase in the thermal conductivity of NS-4-FR alone, but may be achieved in final design using a metallic grid structure for thermal shunts in the neutron shield material. The value (6.5 W/m-K) is reasonable when compared to the effective thermal conductivity (7.89 W/m-K) of the neutron shield structure in the NAC-UMS shipping cask (NAC 2002, Sections 1.2.1.2.1, 3.3.2, 3.4.1.1.1, and Table 3.2-1). The thermal studies for the TEV shielded enclosure used steady-state conditions, direct solar heating, no convective cooling, and a bounding ambient temperature of 50°C, thus showing thermal compliance for an indefinite period should the TEV become immobilized during the waste package transport process (BSC 2007m, Section 6.4).

Thermal conditions have been calculated for TAD and 5-DHLW/DOE SNF waste packages in the TEV (BSC 2007m, Section 7). The peak cladding temperatures for 18 and 25 kW TAD waste packages in the TEV were shown to be 356°C and 437°C, respectively (BSC 2007m, Table 35). Linear extrapolation shows the peak cladding temperature is 400°C for a 21.8 kW TAD waste package. These temperatures are valid for both normal and off-normal events, and considering the conservative assumptions used, it is concluded that cladding temperatures for TAD waste packages in the TEV will not exceed the 400°C/570°C normal/off-normal cladding temperature limits (BSC 2008f, Sections 11.2.2.4 and 11.2.2.18).

The peak high-level radioactive waste (HLW) vitrified glass and DOE SNF cladding temperatures for a 7.1 kW 5-DHLW/DOE SNF waste package in the TEV were shown to be 288°C and 339°C, respectively (BSC 2007m, Attachments IV and V). The maximum thermal power for a HLW canister is 720 watts (BSC 2008g, Table 24), so the maximum thermal power for a HLW and DOE SNF waste package is less than 6 kW (BSC 2008h, Section 6.2.1.6). These peak temperatures for both normal and off-normal events are below their corresponding limits of 400°C for HLW vitrified glass and 350°C for DOE SNF cladding (BSC 2008f, Section 11.2.2.18).

1.3.3.5.1.2 Subsurface Rail and Invert System

Information regarding the subsurface rail and invert designs as they relate to waste package transportation is presented in Section 1.3.3.4. Commercial quality installation for the rail and invert system is sufficient to minimize derailment potential. The subsurface rail and invert system is classified as non-ITS (Table 1.9-1).

1.3.3.5.1.3 Mechanical Handling Sequences and Operations

The TEV waste package transportation mechanical handling sequences and operations are shown in Figure 1.3.3-42. This figure identifies operations that are not specifically included in waste package transportation and emplacement but support implementation of the process.

During the waste package transportation and emplacement processes, it is possible that TEV operations could be affected by an event or condition that results in an off-normal operating situation. Off-normal operations are defined as an occurrence or condition outside the bounds of routine operations but within the range of analyzed conditions for the SSC. The requirements for worker health and safety, as low as is reasonably achievable, and radiation releases are not reduced during off-normal events. Handling off-normal events will require procedures and controls that are developed for a situation on the basis of the assessment performed to identify specific conditions and determine an appropriate operational strategy. During off-normal operations in the subsurface, ventilation may need to be modified and will be addressed in off-normal response planning (BSC 2008i, Section I1.4).

To the extent that it is deemed necessary and practical, equipment and facilities are designed to prevent or mitigate unsafe conditions resulting from power failures and equipment malfunctions. System operators will be trained to recognize and to respond to indications of unexpected or off-normal conditions. Procedures will be written to address potential off-normal situations and implementing strategies for recovery. These procedures may include the use of temporary backup or repair equipment as necessary to mitigate or eliminate unsafe conditions. Preliminary evaluations of potential events and recovery actions are described in *Strategies for Recovery After an Off-Normal Event to the Waste Package Transport and Emplacement Vehicle* (BSC 2007n).

1.3.3.5.1.4 Fire Protection

Fire protection is integrated into the design of the TEV and related support systems. The TEV is designed so that a credible fire does not exceed the thermal limits that the waste package is designed to withstand. To support this design approach, a fire hazards analysis identified and evaluated available design considerations to ensure that the design of the waste package transportation equipment incorporates appropriate fire protection measures, including:

- The TEV is primarily constructed of noncombustible materials. Borated polyethylene neutron shielding that may be combustible is encased in steel.

- Power and instrumentation cables are required to be fire resistant, and electrical distribution equipment is to be installed in National Electrical Manufacturers Association–rated enclosures, isolating them as potential sources of ignition.

- Electrical enclosures aboard the TEV are protected by redundant automatic fire detection and suppression systems.

A fire protection system on the TEV provides fire protection by monitoring, detecting, annunciating, and suppressing fires that occur in the TEV systems. The mobile fire protection system is an integral part of the repository fire protection system. The fire detection and suppression system aboard the TEV contains activation alarms that are transmitted wirelessly to the synchronous optical network, which transmits these fire alarm signals to the main fire alarm panel in the Fire, Rescue, and Medical Facility and the Central Control Center. Additional information regarding fire protection for the repository is presented in Section 1.4.3.

1.3.3.5.1.5 Radiation Shielding

The TEV does not remain inside an emplacement drift for extended periods. Radiation-shielded cabinets protect the radiation-sensitive electrical and electronic components. The TEV radiation shielding system is designed to withstand the design basis radiation environment around the TAD waste package loaded with 21-PWR SNF assemblies, which is the waste package with the highest potential dose rates (Section 1.10.3). Therefore, the shielded enclosure resistance to radiation is expected to last the life of the TEV. A description of the shielding source term used for waste package transportation is presented in Section 1.10.3.

The TEV shielded enclosure consists of shielding material to meet the dose rate criterion of 100 mrem/hr at a distance of 30 cm from the surface of the shielded enclosure (BSC 2007l, Sections 1 and 7.3; BSC 2007o, Section 4.10.1.3). More information regarding the material used for the TEV shielded enclosure is presented in Section 1.3.3.5.1.1. More detailed information regarding shielding is presented in Section 1.10.3.

1.3.3.5.2 Operational Processes

The waste package transportation process and related operational considerations are discussed in this section. Waste package transportation functions will be performed in accordance with procedures implemented to address normal operations and off-normal events.

A procedural safety control (PSC-10) will be implemented to address the amount of time that a waste form spends in each process area or in a given process operation, including total residence time in a facility. This information will be compared against the average exposure times used in the preclosure safety analysis. Additionally, component failures per demand and component failures per time period will be compared against the preclosure safety analysis. Significant deviations will be analyzed for risk significance (Table 1.9-10, PSC-10).

Waste package transportation system operations are supported by a maintenance program that includes monitoring, routine and preventive maintenance, and inspections to ensure performance within design specifications. Development of the TEV maintenance plan and implementation of TEV maintenance procedures and 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. Routine maintenance activities for the waste package transportation equipment will be performed in the Heavy Equipment Maintenance Facility.

In addition to the maintenance program, waste package transportation system operations are also supported by a safeguards and security program. More information regarding the safeguards and security program is included in GI Section 3.

1.3.3.5.2.1 Operational Overview

Operations for waste package transportation start with the preparation of the TEV at the Heavy Equipment Maintenance Facility and conclude with delivery of the waste package and emplacement pallet assembly to a predetermined location within an emplacement drift. Throughout the waste package movement and emplacement process, only the emplacement pallet is contacted during normal operations; no contact is made with the waste package.

The following steps describe the operational processes that are involved in moving a waste package from the surface nuclear facilities to the subsurface for emplacement.

1. Once the TEV has been inspected and determined to be operable for loading, transporting, and emplacing, it will be released from the Heavy Equipment Maintenance Facility. The TEV moves from the Heavy Equipment Maintenance Facility to the loadout room of a surface nuclear facility. A third-rail configuration is used to provide power for the TEV throughout the surface and subsurface facilities. As the TEV enters the loadout room, the hard-wired, mechanically-operated switch mounted on the TEV interfaces with the stationary, actuating device mounted to the rails inside the loadout room (Figure 1.2.4-93). Activating the switch allows the operator in the Central Control Center to unlock and open the shielded enclosure doors for waste package loading.

2. The TEV shielded enclosure front doors are opened, the rear shield door is raised, and the shielded enclosure base plate is extended.

3. The shielded enclosure is lowered to accept the emplacement pallet using remote handling equipment. The emplacement pallet carrying the waste package is moved into the TEV shielded enclosure (Figure 1.2.4-137).

4. The shielded enclosure with the emplacement pallet and waste package is raised and the shielded enclosure base plate is retracted under the TEV and secured. The TEV rear shielded door is lowered, the shielded enclosure front doors are closed and locked, and the TEV is readied to exit the facility.

5. The surface nuclear facility shield door is opened to permit movement of the TEV to the vestibule. As the TEV leaves the loadout room, the hard-wired, mechanically-operated switch mounted on the TEV again interfaces with the stationary, actuating bracket mounted to the rails. This action prevents the PLC from unlocking or opening the shielded enclosure doors. The surface nuclear facility shield door is closed after the TEV passes and the vestibule door is opened and closed as the TEV exits. The loaded TEV moves away from the loadout area at the surface nuclear facility.

6. The TEV moves through surface rail switches to ensure that it is correctly oriented for entry into the emplacement drift.

7. The TEV stops at the North Portal Access Control Point where a system verification and inspection is performed from the Central Control Center. The inspection includes a test of the TEV brake system and a check of the TEV instrumentation and operating control system. Other activities such as material accounting and radiological controls are also performed at the North Portal Access Control Point (Section 1.3.1.2.1).

8. The North Portal Access Control Point is located at the North Portal area. The facility will provide the means to control entry into and exit from the subsurface repository and will restrict subsurface activities during waste package emplacement operations. No other fixed access control facilities will be established to support subsurface emplacement operations. Access controls that may be needed in specific areas will be planned, implemented, managed and removed in accordance with applicable procedures (Sections 1.10.2.4 and 5.11.3.2) (BSC 2008i, Section H2.1).

9. Under control by the operators in the Central Control Center, the onboard PLC implements equipment actions and the TEV moves with the waste package into the subsurface facility. A combination of onboard instrumentation such as cameras and encoders will be used with predetermined, operational checkpoints to monitor and confirm the location of the TEV as it travels through the subsurface facility. This locating information will be processed by the PLC and relayed to the operators in the Central Control Center (BSC 2008c, Section 3.3.15).

10. The TEV stops in the access main near the turnout for the predetermined emplacement drift. Calibration of the onboard positional control devices will be checked at this point to confirm the datum point for waste package placement.

11. The rail switch is positioned to the turnout side and the emplacement access doors at the entrance to the turnout are remotely opened. More information regarding operation of the emplacement access doors is provided in Section 1.3.5.2.

12. The TEV moves into the turnout. As the TEV enters the turnout, the hard-wired, mechanically-operated switch mounted on the TEV interfaces with a stationary, actuating bracket mounted to the rails inside the turnout. As in the loadout room, activating the switch allows the onboard PLC to unlock and open the shielded enclosure doors during the emplacement process. The TEV proceeds to the entrance of the emplacement drift.

13. The emplacement access doors are closed after the TEV passes.

14. The TEV enters the emplacement drift and proceeds to the designated emplacement location. The TEV stops as it nears the identified location, the rail brakes are set, and the shielded enclosure front doors are unlocked and fully opened.

15. 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. The TEV design incorporates tolerances to accommodate slight misalignment of the emplacement pallet and waste package that may occur during normal emplacement operations. The lifting features on the TEV are beveled at the ends so that slight misalignments can be accommodated. If the alignment of the emplacement pallet is out of tolerance, an off-normal recovery process will be implemented as described in the *Strategies for Recovery After an Off-Normal Event to the Waste Package Transport and Emplacement Vehicle* (BSC 2007n).

16. The operations in the waste package emplacement sequence are monitored and controlled by the operators in the Central Control Center. These operations are described in Section 1.3.4.8.2.

17. After waste package emplacement is completed, the TEV backs away from the emplaced waste package, the shielded enclosure is raised, the shielded enclosure base plate is retracted, the rear shield door is lowered, and the shielded enclosure front doors are closed and locked. The TEV returns through the emplacement drift into the turnout.

18. The emplacement access doors are opened and the TEV exits the turnout. As the TEV leaves, the hard-wired, mechanically operated switch mounted on the TEV interfaces with the stationary, actuating bracket mounted to the rails inside the turnout. Activating the switch prevents the PLC from unlocking and opening the shielded enclosure doors. The emplacement access doors are closed as the TEV passes and moves into the access main.

19. In the access main, the rail switch is positioned to the access main side.

20. The TEV proceeds through the access main for the return trip to the surface.

21. At the North Portal Access Control Point, a confirmatory contamination survey is performed on the outside of the TEV prior to release of the TEV onto the surface.

1.3.3.5.2.2 Operating Condition Monitoring

Monitoring and annunciation functions for the TEV during waste package transportation are provided by a system of instruments, visual equipment, and alarms. This system provides capabilities for remote monitoring of mobile equipment operating parameters. The focus of the system is on conditions and parameters related to TEV operations on the surface and in the subsurface facilities. In addition to routine operations monitoring, the system provides the capability to detect, communicate, and respond to potentially off-normal conditions.

The TEV video monitoring system provides operators at the Central Control Center with real-time visual information about the operating environment and vehicle performance during the waste package transportation process on the surface and in the subsurface facility. The system installed on the TEV includes 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 waste package transport, emplacement, and retrieval processes) 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):

- TEV location
- Graphic representation of equipment and operations
- Video images of the operations to aid operators in control processes

- Status indications and operator messages concerning waste package transport, emplacement and retrieval operations
- Audible and visual alarms indicating off-normal operation
- Data collection, trending, and reporting of waste package transport, emplacement and retrieval operations parameters.

1.3.3.5.2.3 Operational Control

TEV operations in areas with potentially high radiation dose rates, such as the emplacement drifts and the waste package loadout area of a surface nuclear facility, mandate remote control capabilities as these environments are not amenable to human access. Control functions for the TEV are performed from the Central Control Center through an integrated system of monitoring and control instrumentation and equipment (BSC 2008c, Section 3.3.15). The architecture for the digital control and management information system is described in Section 1.4.2.

The TEV is designed with a control system that includes control and oversight provided by operators in the Central Control Center and equipment actions implemented through an onboard PLC. Although TEV equipment functions are executed by the onboard PLC, the operators in the Central Control Center initiate operational activities and use monitoring and instrumentation capabilities to maintain control of the TEV throughout the waste package transportation and emplacement process. Redundancy of PLC components is used to ensure high reliability and availability (BSC 2008c, Sections 3.3.14 and 3.3.15).

For waste package transportation operations, the PLC on board the TEV implements operational sequences to perform equipment functions and provides continuous information to the human–machine interface console in the Central Control Center through the repository communication system and the digital control and management information system. The communication interface between the TEV and the repository communications system (Section 1.4.2) is through an onboard transceiver that is linked to the PLC. The antenna configuration for the transceiver will be integrated in the TEV design. The TEV is designed to cease operations if power is lost (Table 1.3.3-6) (BSC 2008c, Sections 3.3.14 and 3.3.15; BSC 2007p, Sections 2.2.2 and 2.4).

Operating parameter information is input to the PLC by various sensors that are mounted on the TEV operating components. Information provided by the sensors is used by the PLC to execute operational sequences and determine equipment operating status. The PLC provides sensor data, equipment status, and component performance information through the communications system to the operators in the Central Control Center. Diagnostics are performed by the PLC and monitored by the Central Control Center to detect failures of inputs as well as equipment operating conditions. The PLC and system of sensors provide operators in the Central Control Center with the capability to evaluate any monitored parameter or condition on the TEV (BSC 2008c, Section 3.3.15).

TEV equipment functions implemented by the PLC are based on preprogrammed operational sequences provided in the PLC for the various TEV operations. An operational sequence may be short and straightforward or may consist of a series of sequences. The operators in the Central Control Center initiate operational sequences performed by the TEV by selecting the appropriate sequence and providing a command to the PLC to execute the equipment functions needed to implement the operational sequence. The PLC verifies that prerequisites for performing the operational sequence are met then executes the functional steps associated with that sequence. A prerequisite is a condition that must be met before the TEV equipment can be operated or a sequence step can be performed. When responding to operator commands to execute a selected operational sequence, the PLC confirms that prerequisites have been met to ensure that operations can be initiated properly and performed in the appropriate order. Prerequisites to perform a step in an operational sequence ensure that the previous step has been successfully completed, or that other prerequisites for performing the step have been completed or satisfied, or both. After a functional step has been completed, the PLC confirms completion to the Central Control Center. If a step is not completed properly, the PLC either stops and aborts the sequence or, depending on operational processes and programming, executes a step identified as a default in the event of improper completion of a functional step. In either case, a message is provided to the operators in the Central Control Center. Additionally, the operators have the capability to stop an operational sequence at any time. At routine completion of an operational sequence, the PLC identifies completion to the Central Control Center and awaits a command to initiate the next sequence (BSC 2008c, Section 3.3.15).

The preprogrammed operational sequences implemented by the PLC allow the operators in the Central Control Center to control the functions involved in the operation of the TEV. These functions include vehicle locomotion and braking, opening and closing of the front shield doors, raising and lowering of the rear shield door, extension and retraction of the base plate, lifting and lowering of the shielded enclosure, and control of temperatures in the electronic component and control enclosure. Monitoring for these functions is continuously performed, as well as radiation monitoring, position monitoring and equipment status monitoring (BSC 2008c, Section 3.3.15).

The PLC is used only to implement equipment operational sequences; it does not perform ITS functions and it is not relied upon to prevent or mitigate an event sequence. Implementation of the ITS function to prevent inadvertent opening of the doors is accomplished by means of a mechanically operated switch mounted on the TEV that interfaces with a stationary, actuating device mounted to the rails in the loadout rooms of the surface nuclear facilities and within the subsurface emplacement drifts (Figure 1.2.4-93) (BSC 2008c, Figure 39). The stationary actuating device activates the switch on the TEV as it enters the loadout rooms or emplacement drifts which allows control system components responsible for operating the locks of the shielded enclosure front doors to function. Activation of the mechanical switch on the TEV also permits the onboard PLC to unlock the doors and implement the TEV functions needed to perform the prescribed operational sequence. When operations in the surface nuclear facilities loadout rooms or the emplacement drifts are completed, the TEV leaves these areas. As the TEV exits the loadout rooms or emplacement drifts, the stationary actuating bracket again operates the mechanical switch on the TEV. This action disables unlocking of the front shield door locks and raising of the rear shield door and ensures the shielded enclosure doors cannot be inadvertently opened (BSC 2008c, Section 3.3.15).

The preliminary design solution for the mechanical switch mounted on the TEV is a lever-operated rotary switch of a radiation hardened type, mounted in an enclosure within the central legs of the structural chassis with the actuating lever protruding below the bottom face of the support leg. This position would deny operation of the switch to any other device but the dedicated, stationary actuator brackets mounted to the rails in the loadout areas and emplacement drifts (Figure 1.2.4-93) (BSC 2008c, Section 3.3.15). To minimize potential interference with the safety switch and waste package transport and emplacement operations, TEV instrumentation includes rear and forward range sensing devices and a collision avoidance system that will help detect rocks and objects and stop the TEV before an impact occurs. Additionally, a sweeper device will be attached to the front of the TEV to move aside small rocks or objects (BSC 2008c, Sections 2.5.3, 3.2.1.28 and 3.2.1.38).

Design requirements for the TEV control system are driven by the need to satisfy the nuclear safety design bases, comply with applicable codes and standards, and meet operational performance expectations. A description of design requirements for the TEV, including those related to the control system, is provided in the *Waste Package Transport and Emplacement Vehicle Gap Analysis Study* (BSC 2008d, Sections 4, 7, and 8).

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 process of refining requirements and design concepts for the TEV control system will be addressed through the component development process described in Section 1.3.2.7. Design requirements for the TEV are presented in Tables 1.3.3-5 and 1.3.3-6.

1.3.3.5.2.4 Transportation Routes and Operational Interfaces

Waste package transportation routes into the subsurface repository are through the North Portal and North Ramp into the emplacement areas. The waste emplacement sequence allows for waste transportation and emplacement operations to occur concurrently with construction of adjacent areas of the repository. A description of this process is provided in Section 1.3.1.2.7.

The waste package transportation routes result in operational interfaces described in this section. System operational interfaces include:

- **Heavy Equipment Maintenance Facility**—Equipment inspections, tests, and maintenance are performed before the TEV begins waste package transportation and emplacement operations.
- **Surface Nuclear Facilities**—Waste packages and emplacement pallets are loaded into the shielded TEV at the loadout room of the CRCFs or the IHF.
- **Subsurface Facility**—The emplacement and retrieval system moves waste packages and emplacement pallets from the loadout area of the CRCFs or the IHF, to the subsurface facility for waste emplacement.

1.3.3.5.3 Safety Category Classification

The waste package transportation and emplacement system design complies with the classification requirements of the preclosure safety analysis. Due to requirements that the TEV design prevent a breach of a waste package, features and functions of the TEV are classified as ITS (Table 1.9-1) and are addressed in the following discussion.

The nuclear safety design bases requirements identified in the preclosure safety analysis (Section 1.9), and design features and functions that will be implemented to address them, include (Section 1.3.2.3):

1. The probability of runaway of a TEV that can result in a potential breach of a waste package shall be less than or equal to 2.0×10^{-9} per transport (Section 1.9; Table 1.3.3-5, HE.SS.01). The TEV design for preventing a potential runaway event sequence includes the use of drive motors with integral disc brakes, high-ratio gearboxes, rail brakes, and drive components to mechanically limit the speed of the TEV to 1.7 mph.

2. The mean probability of inadvertent TEV door opening shall be less than or equal to 1.0×10^{-7} per transport (Section 1.9; Table 1.3.3-5, HE.SS.02). The TEV design for preventing potential radiation exposure to personnel is by limiting the possibility for inadvertent opening of the TEV doors through the use of a mechanical switch and hardwired circuitry for the front door locks and rear shield door.

3. The mean frequency of derailment of the TEV at the loadout station due to the spectrum of seismic events shall be less than or equal to 1.0×10^{-4} per year (Section 1.9). This nuclear safety design bases requirement is applicable during waste package loading in the IHF and CRCF surface nuclear facilities (Table 1.3.3-5, HE.IH.01 and HE.CR.01). Seismic restraints are included in the design of the underside of the TEV chassis to limit the vertical lift of the TEV off the rails during a seismic event.

4. The mean frequency of tipover of the TEV due to the spectrum of seismic events shall be less than or equal to 2.0×10^{-6} per year (Section 1.9) while the TEV is operating in repository surface and subsurface areas (Table 1.3.3-5, HE.IH.02, HE.CR.02, and HE.SS.03). The TEV design for preventing a potential tipover event sequence is through the use of an as-wide-as-practicable rail spacing and a low center of gravity.

5. The mean frequency of ejection of a waste package from the TEV due to the spectrum of seismic events shall be less than or equal to 2.0×10^{-4} per year (Section 1.9) while the TEV is operating in repository surface and subsurface areas (Table 1.3.3-5, HE.IH.03, HE.CR.03, and HE.SS.04). The shielded enclosure, front and rear shield doors, hinges, locking features, and interlocks are designed to ensure that structures remain intact during or after a DBGM-2 seismic event. The front shield door locks are designed to remain locked and in place during a collision or derailment (including tipover) without resulting in a Category 1 or Category 2 event sequence.

1.3.3.5.4 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 (PSC-10) has been identified for the waste package transportation system (Table 1.9-10), and is related to the amount of time that a waste form will spend in each process or operation area. Implementation of PSC-10 is discussed in Section 1.3.3.5.2.

1.3.3.5.5 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 quantitative assessment of event sequences, including the evaluation of component reliability and the effects of operator action, is developed in Section 1.7. Any SSC or procedural safety control appearing in an event sequence with a prevention or mitigation safety function is described in the applicable design section of the SAR.

Section 1.9 describes the methodology for safety classification of SSCs and features of the repository. The tables in Section 1.9 present the safety classification of the SSCs and features, including those items that are non-ITS or non-ITWI. These tables also list the preclosure and postclosure nuclear safety design bases for each structure, system, or major component.

To demonstrate the relationship between the nuclear safety design bases and the design criteria for the repository SSCs and features, the nuclear safety design bases are repeated in the appropriate SAR sections for each individual SSC or feature that performs a safety function. The design criteria are specific descriptions of the SSCs or features (e.g., configuration, layout, size, efficiency, materials, dimensions, and codes and standards) that are utilized to implement the assigned safety functions. Table 1.3.3-5 presents the nuclear safety design bases and design criteria for the TEV.

1.3.3.5.6 Design Methodologies

Design methodologies for the waste package transportation and emplacement system utilize proven and established nuclear crane and industrial crane rail-based technologies. As these technologies have been used in industrial and nuclear applications, information is available that includes usage and reliability data, lessons learned, and demonstrated operability in similar or analogous situations. The effects of seismic events are considered in the design of the TEV.

Refinement of design requirements to meet reliability goals for the TEV will continue through component development. This process is discussed in Section 1.3.2.7 and supports a progressive component development approach. The high-level functions identified for the TEV continue to be allocated to more specific functions as requirements are systematically refined and derived. Although components for the TEV are based on existing technology, integration of these components in the configuration required for waste package transportation and emplacement represents first-of-a-kind application that must be addressed through component development and testing (Table 1.3.3-7). The primary objectives of component development activities will be to demonstrate the reliability of the TEV performance for normal and off-normal operating conditions.

Implementation of integrating design and testing activities will be addressed in the performance specification for the TEV.

Performance of the shielded enclosure of the TEV generally provides radiation protection for the equipment operating systems. However, further analysis of potential exposures during loading, transport and emplacement operations may warrant supplemental shielding of components or selection of radiation hardened components, as applicable (BSC 2007l, Section 7.3; BSC 2008c, Section 3.2.1.40).

Performance of the shielded enclosure will be demonstrated through calculations, modeling and finite-element analysis. Extended acceptance testing will establish data for the predictable life of components in a harsh environment and will identify how performance of SSC safety functions is affected.

The approach implemented for extended factory acceptance testing is to test key TEV equipment systems in an environment that simulates actual operating conditions as closely as possible. Extended factory acceptance testing at full-scale will be performed in three phases: accelerated, extended, and sustained testing. Implementation of these test phases will demonstrate that the performance and reliability of TEV SSCs meet specified requirements. Testing will be performed in accordance with the codes and standards identified in *Waste Package Transport and Emplacement Vehicle Gap Analysis Study* (BSC 2008d; BSC 2008e, Section 9).

1.3.3.5.7 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 determined based on the range of anticipated operating conditions, including high temperatures, radiation effects, and fire protection requirements. Material properties identified are appropriate to ensure high material reliability and durability to support SSC functions over the designed operating life. Evaluation results for properties of materials exposed to a high-radiation environment indicate that cumulative radiation in emplacement drifts or surface nuclear facilities is not expected to have any measurable effect on the properties of either concrete or steel structures.

1.3.3.5.8 Design Codes and Standards

Demonstration of assurance that a component of an ITS SSC will perform as required will be achieved by following an established code or standard that prescribes how the component is to be designed, fabricated, and tested. However, due to the specialized nature of the TEV, consensus codes and standards may not be fully applicable. In order to satisfy project performance requirements, studies and evaluations have been performed to identify specific design areas of the TEV that perform ITS functions, identify codes and standards used to ensure these functions are performed as required, and determine where performance acceptance cannot readily be achieved through the use of commercially available equipment and consensus codes and standards. Since TEV components are based on existing technology, design studies performed to evaluate applicable codes and standards have found that ITS functions and requirements can be met using codes, standards and supplemental requirements developed specifically for industrial and nuclear crane applications. However, the studies identified some component development needs associated with satisfying several design bases, as identified in Table 1.3.3-7 (BSC 2008j, Section 1; BSC 2008e, Sections 3, 8, and 9).

Section 1.3.2.7 discusses the process for identifying supplemental requirements to augment codes and standards and describes the activities necessary to advance the design of subsurface SSCs to demonstrate their satisfactory performance of ITS functions.

Applicable requirements from the following mechanical, civil, structural, and architectural codes and standards are identified for use in the design of the waste package transportation and emplacement system (BSC 2008c, Section 7.3):

- ANSI/ANS-HPSSC-6.8.1-1981, *Location and Design Criteria for Area Radiation Monitoring Systems for Light Water Nuclear Reactors*
- ASME NOG-1-2004, *Rules for Construction of Overhead and Gantry Cranes (Top Running Bridge, Multiple Girder)*
- CMAA 70-2000, *Specifications for Top Running Bridge and Gantry Type Multiple Girder Electric Overhead Traveling Cranes*.

1.3.3.5.9 Design Load Combinations

Codes and standards are the basis for equipment design loads (ASME NOG-1-2004, Section 4130). Waste package and transportation and emplacement equipment design loads are defined in commercial, industry, and nuclear codes and standards and will also be derived from project-specific performance requirements. Calculation of TEV design loads will involve consideration of various load combinations that include seismic loads. The dead load of the TEV consists of the base vehicle substructure, wheels and wheel block assemblies, movable shielded enclosure base plate and back shielding door, drive motors, lifting system, shielded cabinets, rollers, and controls. Also included in the dead load are the TEV waste package shielded enclosure and enclosure doors, which constitute a major portion of the total gross load. Live loads for the TEV include the waste package and emplacement pallet assembly, wind loads, and seismically induced loads.

The methodology for computing seismic loads for the TEV equipment is based on the equivalent static load method described in NUREG-0800 (NRC 1989). To obtain an equivalent static load in the horizontal and vertical directions, a factor of 1.5 is applied to the respective peak ground acceleration of the applicable response spectra, using appropriate damping values for the structure or the component (BSC 2007o, Section 4.2.11.4.7). The project has determined that the equivalent static load methodology with an applied factor of safety for various load combinations is an appropriate evaluation approach for verifying TEV stability against sliding and overturning. Based on the frequency of operation and the probability of a seismic event occurring during waste package transport, a seismically induced event sequence resulting in a derailment and subsequent tipover and ultimate breach of the waste package has been categorized as beyond Category 2 (Sections 1.6 and 1.7) (BSC 2008c, Sections 3.1.2 and 3.1.3; BSC 2007o, Sections 4.2.11.4.7 and 6.1.10.1). Wind and tornado loads will be calculated during detail design and will ensure that the TEV functions in the design basis wind speed, which is an extreme straight wind of 90 mph. Additional outside or ambient environment criteria that will be considered for the TEV design include: rain, snow, lightning, temperature and humidity (BSC 2007o, Sections 4.3.1.5 and 6.1). Service factors will be applied to the load combinations per the appropriate code (ASME NOG-1-2004, Section 5000).

Design parameters used in developing design loads for the TEV are based on the functions the equipment must perform. Parameters used in developing design loads for the TEV include (BSC 2007j, Sections 6.1, 6.2, 6.3, and 6.4):

- Dimensions of the enclosure must account for clearances as well as allowance for the bottom shielding and its actuation system. A single waste package and its corresponding emplacement pallet, regardless of type, must fit within the shielded enclosure.
- Load distribution and overall length of the TEV. This configuration includes a determination of the distance between substructure frame components.
- Overall width.
- Maximum vertical dimension (top of shielded enclosure).

Equipment design loads for the TEV are based on codes and standards and address structural and mechanical component loads (ASME NOG-1-2004, Section 4130). Although design load calculations include each aspect of equipment design from component material densities to equipment assemblage, the emphasis for calculation development is on the finalized equipment configuration. Design load calculations for the TEV include determinations of weight distribution, configuration of chassis components, and the configuration of the wheels and wheel block assemblies (BSC 2007j, Section 6.4.3).

1.3.3.6 Conformance of Design to Criteria and Bases

[NUREG-1804, Section 2.1.1.7.3.1: AC 1(1), (2), (3), (4), (5), (6), (9)]

The subsurface facility SSCs in the nonemplacement areas that have an ITS classification are limited to the TEV. Table 1.3.3-5 presents the preclosure nuclear safety design bases for the TEV and design criteria associated with each design basis. Table 1.3.3-6 presents design, operational and environmental requirements, and implementation descriptions for functions that are not classified as ITS but support the capabilities of the TEV ITS components and functions.

Table 1.3.3-8 includes postclosure nuclear safety design bases and associated derived requirements that apply to subsurface facility nonemplacement SSCs. This table includes summarized information on conformance of the SSC designs to the design criteria and design considerations related to the postclosure derived internal constraints and on implementation controls to ensure conformance with the postclosure nuclear safety design bases.

1.3.3.7 General References

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Table 1.3.3-1. Characteristics for Repository Ventilation Shafts

Shaft Designation	Excavated Diameter (ft)	Finished Diameter (ft)	Length (ft)
Exhaust Shaft #1	16.0	14.36	1,167
Exhaust Shaft #2	26.0	24.0	958
Exhaust Shaft #3 North	26.0	24.0	1,404
Exhaust Shaft #3 South	16.0	14.36	915
ECRB Cross-Drift Exhaust Shaft	26.0	24.0	1,306
Exhaust Shaft #4	26.0	24.0	1,329
Intake Shaft #2	26.0	24.0	814
Intake Shaft #3	26.0	24.0	1,148
Intake Shaft #4	26.0	24.0	1,240

Source: BSC 2007q, Table 4; BSC 2008b, Section 7.

Table 1.3.3-2. Rock Mass Mechanical Properties for Lithophysal Rock

Parameter	Lithophysal Rock (Tptpul and Tptpll)				
Rock Mass Lithophysal Porosity Category	**1**	**2**	**3**	**4**	**5**
Lithophysal Porosity (%)	> 30	25 to 30	15 to 25	10 to 15	< 10
Poisson's Ratio	0.22	0.22	0.22	0.22	0.22
Modulus of Elasticity (GPa)	1.90	6.40	10.80	15.30	19.70
Bulk Modulus (GPa)	1.13	3.81	6.43	9.11	11.73
Shear Modulus (GPa)	0.78	2.62	4.43	6.27	8.07
Unconfined Compressive Strength (MPa)	10	15	20	25	30
Cohesion (MPa)	2.60	3.90	5.21	6.51	7.81
Friction Angle (°)	35	35	35	35	35
Tensile Strength (MPa)	1.0	1.5	2.0	2.5	3.0

NOTE: Unconfined compressive strength is the load per unit area under which a cylindric specimen of material will fail in a simple compressive test without lateral support.
Tptpll = Topopah Spring Tuff lower lithophysal rock unit; Tptpul = Topopah Spring Tuff upper lithophysal rock unit.

Table 1.3.3-3. Rock Mass Mechanical Properties for Nonlithophysal Rock

Parameter	Nonlithophysal Rock (Tptpmn)				
Rock Mass Quality Category	**1**	**2**	**3**	**4**	**5**
Geologic Strength Index (GSI)	51	59	62	68	72
Poisson's Ratio	0.19	0.19	0.19	0.19	0.19
Modulus of Elasticity (GPa)	10.59	16.79	19.95	28.18	35.48
Bulk Modulus (GPa)	5.69	9.03	10.73	15.15	19.08
Shear Modulus (GPa)	4.45	7.05	8.38	11.84	14.91
Global Compressive Strength (MPa)	26.90	32.02	34.28	39.57	43.90
Cohesion (MPa)	7.36	8.33	8.75	9.73	10.52
Friction Angle (°)	32.64	35.02	35.91	37.65	38.79
Tensile Strength (MPa)	0.27	0.50	0.63	0.99	1.33

NOTE: Global compressive strength is a parameter characterizing the overall behavior of the rock mass under compressive load.
Tptpmn = Topopah Spring Tuff middle nonlithophysal rock unit.

Source: BSC 2007d, Table 6-2.

Table 1.3.3-4. Mechanical Properties of Concrete Liner for Repository Shafts

Parameter	Value	Remark
Thickness (m)—Large-diameter shafts Thickness (m)—Small-diameter shafts	0.3 0.25	Converted from a 12-in. thickness (12.0 in. × 0.0254 m/in. = 0.3 m) Converted from a 10-in. thickness (10.0 in. × 0.0254 m/in. = 0.25 m)
Density (kg/m^3)	2,324	Converted from a typical unit weight for concrete $145\ lb/ft^3 \times 0.454\ kg/lb \times 35.315\ ft^3/m^3 = 2{,}324\ kg/m^3$
Young's Modulus (GPa)	29	Based on a mean value in Section 1.7 of ACI 506R-05
Poisson's Ratio	0.25	For concrete
Compressive Strength (MPa)	40.0	Converted from a typical concrete strength of 6,000 psi/(145 psi/MPa) = 40 MPa (approximately)
Tensile Strength (MPa)	4.0	10% of Uniaxial Compressive Strength or 0.1 × 40.0 MPa = 4.0 MPa
Thermal Expansion Coefficient (1/°C)	9.9×10^{-6}	For concrete
Allowable Stress (MPa)	26.0	Applied reduction factor (0.65 × 40 MPa = 26 MPa), based on ACI 318-02/318R-02, Section 9.3.2.2

Source: BSC 2008b, Table 6-6 and Section 7.

Table 1.3.3-5. Preclosure Nuclear Safety Design Bases and their Relationship to Design Criteria for the Transport and Emplacement Vehicle

System or Facility (System Code)	Subsystem or Function (as Applicable)	Component	Nuclear Safety Design Bases		Design Criteria
			Safety Function	Controlling Parameters and Values	
Emplacement and Retrieval/Drip Shield Installation System (HE)	Emplacement and Retrieval and Drip Shield Installation	Transport and Emplacement Vehicle (TEV)	Protect against derailment of a TEV during loading of a waste package	HE.IH.01. The mean frequency of derailment of the TEV at the loadout station due to the spectrum of seismic events shall be less than or equal to 1×10^{-4} per year.	The TEV is required to be designed in accordance with the requirements of ASME NOG-1-2004 for Type I cranes. The TEV and rails at the loadout station are required to be designed to prevent the TEV from derailing during a DBGM-2 seismic event.
			Protect against a tipover of the TEV	HE.IH.02. The mean frequency of tipover of the TEV due to the spectrum of seismic events shall be less than or equal to 2×10^{-6} per year.	The TEV is required to be designed in accordance with the requirements of ASME NOG-1-2004 for Type I cranes. The TEV is required to be designed with a low center of gravity with the rails widely spaced (11 ft from centerline to centerline) to prevent the TEV from tipover during a DBGM-2 seismic event.
			Protect against ejection of the waste package from the shielded enclosure of the TEV	HE.IH.03. The mean frequency of ejection of a waste package from the TEV due to the spectrum of seismic events shall be less than or equal to 2×10^{-4} per year.	The TEV's shielded enclosure, shield doors, and shield door locks are required to be designed to prevent the waste package from being ejected.
			Protect against derailment of a TEV during loading of a waste package	HE.CR.01. The mean frequency of derailment of the TEV at the loadout station due to the spectrum of seismic events shall be less than or equal to 1×10^{-4} per year.	The TEV is required to be designed in accordance with the requirements of ASME NOG-1-2004 for Type I cranes. The TEV and rails at the loadout station are required to be designed to prevent the TEV from derailing during a DBGM-2 seismic event.
			Protect against a tipover of the TEV	HE.CR.02. The mean frequency of tipover of the TEV due the spectrum of seismic events shall be less than or equal to 2×10^{-6} per year.	The TEV is required to be designed in accordance with the requirements of ASME NOG-1-2004 for Type I cranes. The TEV shall be designed with a low center of gravity with the rails widely spaced (11 ft from centerline to centerline) to prevent the TEV from tipover during a seismic event.

Table 1.3.3-5. Preclosure Nuclear Safety Design Bases and their Relationship to Design Criteria for the Transport and Emplacement Vehicle (Continued)

System or Facility (System Code)	Subsystem or Function (as Applicable)	Component	Nuclear Safety Design Bases		Design Criteria
			Safety Function	Controlling Parameters and Values	
Emplacement and Retrieval/Drip Shield Installation System (HE) (Continued)	Emplacement and Retrieval and Drip Shield Installation System (Continued)	Transport and Emplacement Vehicle (TEV) (Continued)	Protect against ejection of the waste package from the shielded enclosure of the TEV	HE.CR.03. The mean frequency of ejection of a waste package from the TEV due to the spectrum of seismic events shall be less than or equal to 2×10^{-4} per year.	The TEV's shielded enclosure, shield doors, and shield door locks shall be designed to prevent the waste package from being ejected.
			Protect against TEV runaway	HE.SS.01. The probability of runaway of a TEV that can result in a potential breach of a waste package shall be less than or equal to 2×10^{-9} per transport.	The TEV is required to be designed in accordance with the requirements of ASME NOG-1-2004 for Type I cranes. The TEV is required to be designed such that the drive mechanism and brakes limit the probability of runaway of the TEV.
			Protect against direct exposure of personnel	HE.SS.02. The mean probability of inadvertent TEV door opening shall be less than or equal to 1×10^{-7} per transport.	The TEV is required to be designed to have an interlock to prevent the front shield doors from opening when the TEV is between a surface handling facility and the emplacement drift turnouts.
			Protect against a tipover of the TEV	HE.SS.03. The mean frequency of tipover of the TEV due to the spectrum of seismic events shall be less than or equal to 2×10^{-6} per year.	The TEV is required to be designed in accordance with the requirements of ASME NOG-1-2004 for Type I cranes. The TEV is required to be designed with a low center of gravity with the rails widely spaced to prevent the TEV from tipover during a seismic event.
Emplacement and Retrieval/Drip Shield Installation System (HE) (Continued)	Emplacement and Retrieval and Drip Shield Installation System (Continued)	Transport and Emplacement Vehicle (TEV) (Continued)	Protect against ejection of the waste package from the shielded enclosure of the TEV	HE.SS.04. The mean frequency of ejection of a waste package from the TEV due to the spectrum of seismic events shall be less than or equal to 2×10^{-4} per year.	The TEV's shielded enclosure, shield doors, and shield door locks are required to be designed to prevent the waste package from being ejected.

NOTE: "Protect against" in this table means either "reduce the probability of" or "reduce the frequency of." For casks, canisters, and associated handling equipment that were previously designed, the component design will be evaluated to confirm that the controlling parameters and values are met. Seismic control values shown represent the integration of the probability distribution of SSC failure (i.e., the loss of safety function) with the seismic hazard curve. The numbers appearing in parentheses in the third column are component numbers.

Facility Codes: CR: Canister Receipt and Closure Facility; IH: Initial Handling Facility; SS: Subsurface Facility. System Codes: HE: Emplacement and Retrieval/Drip Shield Installation.

Table 1.3.3-6. Design Requirements and Implementation Descriptions for the Transport and Emplacement Vehicles

Structure, System, or Subsystem	Component or Function	Performance Parameter	Design Requirements	Design Implementation Descriptions
Design, Environmental and Operational Requirements				
Waste Package Transportation/ Emplacement System: Transport and Emplacement Vehicle (TEV)	TEV—Position and range sensors	Prevent collisions	Collision Prevention—The system shall prevent collision with equipment and other objects such as emplacement access doors, surface nuclear facility shield doors, another TEV or large rocks.	The TEV meets this requirement through the use of forward and reverse range sensing devices, forward and reverse range switches, front shield door locks, and drive motor integral disc brakes. To prevent collision, the forward and reverse range sensing devices detect objects within the path of the TEV. Upon detecting an object, a signal is sent through the forward or reverse range switches to the drive motors and the integral disc brakes. The forward and reverse range switches are effective whenever the front shield doors are closed. However, the forward and reverse range sensing switches are bypassed when the front shield doors are open (i.e. surface nuclear facility loadout rooms or emplacement drifts for loading or unloading a waste package). These sensors and switches detect the presence of an object such as another piece of equipment, another TEV, or a closed emplacement access door that may be in the path of the TEV and stop the TEV before a collision can occur (BSC 2008c, Section 3.2.1.28).
	TEV—Power distribution system	Eliminate movement of a TEV during a seismic event	Power Removed During Seismic Event—Power to the TEV shall be removed after a seismic event.	In the electrical power system, ITS seismic motion switches are provided to sense motion. If this motion is sensed, the switches disconnect the electrical power to the TEV third rail. Removal of power results in automatic setting of the TEV brakes and cessation of other TEV operations (BSC 2008c, Section 3.2.2.10).
	TEV—Drive and control system	Maintain control of equipment in weather	Extreme Wind—While on the surface the TEV shall be designed to function in an extreme straight wind (90 mph).	Although this requirement is non-ITS, it credits components that are ITS. Drive motors, motor brakes and gearboxes will be sized and selected for an operating speed of 150 feet per minute (1.7 mph) during a 90-mph head wind. Stopping capability of the TEV will be sized to account for a 90-mph tail wind. The TEV low profile will reduce vehicle instability in a 90-mph cross wind (BSC 2008c, Section 3.2.1.2).
	TEV—Position sensors	Prevent collisions	Collision—The TEV shall not collide with a waste package and cause a waste package breach.	Analyses show that in the unlikely event that a TEV collides with a waste package, the waste package does not breach (BSC 2007k, Section 7.3). The configuration of the TEV drive system limits the potential impact speed of a collision by limiting the speed that the TEV can achieve. Encoders on the drive shafts indicate TEV speed and location, which is used by the operators in the Central Control Center and the PLC programmed sequences to reduce the TEV speed as necessary (BSC 2008c, Sections 3.2.1.1 and 3.2.1.3).

Table 1.3.3-6. Design Requirements and Implementation Descriptions for the Transport and Emplacement Vehicles (Continued)

Structure, System, or Subsystem	Component or Function	Performance Parameter	Design Requirements	Design Implementation Descriptions
Waste Package Transportation/ Emplacement System: Transport and Emplacement Vehicle (TEV) (Continued)	TEV—Waste package shielding	ALARA considerations	Credible Fires/Explosions—The TEV shall be designed so that the severity of credible fires/explosions shall not breach a waste package, without taking credit for fire suppression systems.	The TEV shielded enclosure is constructed with nonflammable material; the credible fire/explosion does not contact the waste package (BSC 2008c, Section 3.2.1.4).
	TEV—Waste package shielding	ALARA considerations	Shielding Integrity Due to Seismic—The TEV shielded enclosure shall be designed to maintain shielding integrity for loading conditions associated with a DBGM-2 seismic event.	The shielded enclosure is constructed as a composite of materials that limit radiation exposure from the waste package. The shielded enclosure is designed to withstand a DBGM-2 seismic event. Additionally, the front shield door locks and rear shield door are designed and constructed to restrain the front shield doors and base plate during a DBGM-2 seismic event (BSC 2008c, Sections 3.2.1.5. 3.2.1.6, and 3.2.1.7).
	TEV—Shield door actuators	Limit damage to waste package	Movement of Front Shield Doors—Movement of the front shield doors shall not breach the waste package or cause it to fall.	Although this requirement is non-ITS, it credits components that are ITS. The TEV front shield door actuators are sized to open and close the front shield door, but not breach a waste package (BSC 2008c, Section 3.2.1.6).
	TEV—Shield door locks	Limit damage to waste package	Front Shield Door Locks—The front shield door locks shall withstand a collision or derailment (including tipover) without resulting in a Category 1 or Category 2 event sequence.	Although this requirement is non-ITS, it credits components that are ITS. The TEV front shield door locks are designed to retain the waste package during a collision or derailment (BSC 2008c, Section 3.2.1.7).

Table 1.3.3-6. Design Requirements and Implementation Descriptions for the Transport and Emplacement Vehicles (Continued)

Structure, System, or Subsystem	Component or Function	Performance Parameter	Design Requirements	Design Implementation Descriptions
Waste Package Transportation/ Emplacement System: Transport and Emplacement Vehicle (TEV) (Continued)	TEV—Control system	Limit damage to waste package	Power Loss—During power and communications loss, the TEV shall be design to stop, retain the load, and remain in a locked mode. Upon restoration of power, the TEV shall remain in the locked mode until operator action is taken.	Certain TEV features are designed to fail in an “as is” condition upon loss of power which involves the TEV stopping, retaining its load without releasing or dropping the load, and entering a locked mode to ensure the safe handling of waste packages. However, the functions of other features will continue such as the brakes which will automatically set upon loss of power and the control and communication systems which are powered by a backup, onboard battery. If a loss of power occurs during TEV loading or unloading with the shielded enclosure doors open, such an event would only take place in the surface nuclear facility loadout room or in the emplacement drift; both are controlled limited access areas. Upon restoration of power, the equipment remains in a locked mode until operator action is taken from the Central Control Center (BSC 2008c, Sections 3.2.1.8 and 3.4.1). Instrumentation and control systems for the TEV are designed to provide proper indication during the loss of power and prevent movement until restoration of power and operator action from the Central Control Center (BSC 2008c, Section 3.2.1.8).
	TEV—Waste package lift system	Limit damage to waste package	Waste Package Drop—The TEV shall not drop a waste package, regardless of the cause, including equipment failures, human error, or some combination of the two.	Since the waste package is considered a critical load, the TEV uses single failure-proof principles. The TEV will have six lifting mechanisms (four normal and two off-normal operations), which are capable of lifting the shielded enclosure (containing the waste package and emplacement pallet). Additionally, the TEV is designed with four transportation shot bolts to carry the shielded enclosure during transportation (BSC 2008c, Section 3.2.1.9).
	TEV—Waste package lift system	Limit damage to waste package	Maximum Lift Height—The TEV shall not lift waste packages (while resting on the emplacement pallet) above 6.5 ft from the pallet bottom to the unyielding flat surface.	The maximum lifting height for the TEV is 20 in. (BSC 2008c, Section 3.2.1.10).

Table 1.3.3-6. Design Requirements and Implementation Descriptions for the Transport and Emplacement Vehicles (Continued)

Structure, System, or Subsystem	Component or Function	Performance Parameter	Design Requirements	Design Implementation Descriptions
Waste Package Transportation/ Emplacement System: Transport and Emplacement Vehicle (TEV) (Continued)	TEV—Shielded enclosure	ALARA considerations	Shielded Enclosure Fall—If the shielded enclosure were to fall and impact the waste package, it would not cause the waste package to breach.	The shielded enclosure is fabricated in a “U” shape and straddles a waste package. If a drop of the shielded enclosure should occur, the clearances around the waste package prevent the shielded enclosure from contacting the waste package surface and prevent a waste package breach (BSC 2008c, Section 3.2.1.11).
	TEV—Control system, mechanical interlocks	Limit occurrence of collisions	Spurious Movements—The TEV shall be designed to minimize uncontrolled movements resulting from power loss or spurious signals.	The PLC senses the loss of power, alerts the operator, and enters a locked mode (suspends execution of any operational sequence steps). Upon power restoration, the PLC senses the restoration, alerts the operator, and waits for the operator to send a command or order the execution of a programmed sequence. Operator actions would be determined after evaluating TEV status and position and evaluating other repository conditions, in accordance with operating processes (BSC 2008c, Sections 3.2.1.8 and 3.4.1). In the event of a spurious signal, the TEV is designed to minimize uncontrolled movements (BSC 2008c, Section 3.2.1.12).
	TEV—Shielded enclosure	ALARA considerations	Rockfall—The TEV shall maintain shielding, and protect the waste package in the event of a rockfall.	The potential for a credible rockfall event within the emplacement drifts is minimal during preclosure because of the nature of the rock at the repository horizon. The TEV is designed to withstand a fall of failed ground support materials, as well as a set of rockfalls that exceeds the maximum total mass of 2.5 tons at a velocity of 7.668 m/s. However, since the waste package is designed to withstand such a rockfall, the TEV shielding is not credited for protecting the waste package (BSC 2008c, Sections 3.2.1.26 and 3.2.2.11.2).

NOTE: ALARA = as low as is reasonably achievable.

Source: BSC 2008c, Sections 3.2 and 3.4.

Table 1.3.3-7. Component Development Activities for Transport and Emplacement Vehicle

Nuclear Safety Design Basis Requirement	Applicable SSCs	ITS Design Development Needs[a]			
		Required Analysis	Required Drawings	Required Modeling	Required Testing
The probability of runaway of a TEV that can result in a potential breach of a waste package shall be less than or equal to 2.0×10^{-9} per transport (Section 1.9; Table 1.3.3-5, HE.SS.01).	Drive Motors, Gearboxes, Driveshafts, Wheels	Reliability Analyses	Detail Design Assembly Drawings	None Indicated in the Gap Analysis	None Indicated in the Gap Analysis
The mean probability of inadvertent TEV door opening shall be less than or equal to 1.0×10^{-7} per transport (Section 1.9; Table 1.3.3-5, HE.SS.02).	Rear Shield Door Actuators, Front Shield Door Locks, Circuitry for Hardwired Interlock, Interlock Switch	Reliability Analyses	Detail Design Assembly and Wiring Drawings, P&IDs and Logic Drawings	None Indicated in the Gap Analysis	None Indicated in the Gap Analysis
The mean frequency of derailment of the TEV at the loadout station due to the spectrum of seismic events shall be less than or equal to 1.0×10^{-4} per year (Section 1.9). This nuclear safety design bases requirement is applicable during waste package loading in the IHF and CRCF surface nuclear facilities (Table 1.3.3-5, HE.IH.01 and HE.CR.01).	Seismic Restraints	Reliability Analyses	Detail Design Assembly Drawings	None indicated in the Gap Analysis	None indicated in the Gap Analysis
The mean frequency of tipover of the TEV due to the spectrum of seismic events shall be less than or equal to 2.0×10^{-6} per year (Section 1.9) while the TEV is operating in repository surface and subsurface areas (Table 1.3.3-5, HE.IH.02, HE.CR.02, and HE.SS.03).	Center of Gravity/Stability	Reliability Analyses Tipover Calculation	Detail Design Assembly Drawings	None indicated in the Gap Analysis	None indicated in the Gap Analysis
The mean frequency of ejection of a waste package from the TEV due to the spectrum of seismic events shall be less than or equal to 2.0×10^{-4} per year (Section 1.9) while the TEV is operating in repository surface and subsurface areas (Table 1.3.3-5, HE.IH.03, HE.CR.03, and HE.SS.04).	Front Shield Door Locks, Front Shield Doors, Front Shield Door Hinges	Reliability Analyses Door Impact Calculation	Detail Design Assembly Drawings	None indicated in the Gap Analysis	None indicated in the Gap Analysis

NOTE: [a]This table identifies design development activities required for TEV ITS components. It does not address activities for the design of all TEV SSCs.

Source: Section 1.9; Table 1.3.3-5.

Table 1.3.3-8. Summary of Conformance of Subsurface Facility Design to Postclosure Control Parameters—Nonemplacement 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	01-09 Excavation Methods	The repository ramps, access mains, exhaust mains, and emplacement drifts shall be constructed by tunnel boring machines. The starter tunnel to support each unique tunnel boring machine advance shall be excavated by drill and blast or mechanical excavation methods.	No	The design of the underground openings includes excavation of the ramps, access mains, and exhaust mains with a 25-ft diameter tunnel boring machine, with the exceptions of the exhaust main for Panel 1, the access main cross-drift to Panel 4 and the emplacement drifts that will be excavated with an 18-ft diameter tunnel boring machine. Procurement specification for the excavation services will include these requirements. These excavation methods are described in Sections 1.3.3.2 and 1.3.4.3 and a conceptual drawing is illustrated in Figure 1.3.4-6.	NA

Table 1.3.3-8. Summary of Conformance of Subsurface Facility Design to Postclosure Control Parameters—Nonemplacement 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	01-12 Nonemplacement Opening Gradient	The repository nonemplacement opening shall provide a repository grade so overall water drainage and accumulation is away from emplacement areas.	No	The access mains (Panels 3 and 4) and exhaust mains (Panels 1, 3, and 4) in the northern half of the repository are designed to have a sloping grade to the north, towards the lowest collection point at the exhaust shaft 3N as illustrated in Figures 1.3.3-10 and 1.3.3-11. These figures also show that in the southern half of the repository the access mains (Panels 1 and 2) and exhaust main (Panel 2) also are designed to have a sloping grade to the north. The design of the turnouts, as described in Section 1.3.3.1.4, includes an upward slope from the access main to the emplacement drift to prevent water from the access mains from reaching or flowing towards the emplacement drifts. The inverts of the emplacement drifts are designed to be at a higher elevation than the exhaust main inverts.	NA

Table 1.3.3-8. Summary of Conformance of Subsurface Facility Design to Postclosure Control Parameters—Nonemplacement 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	01-19 Flood Protection	The portal and shaft collar locations shall be situated such that they can be protected from water inflow as a result of the probable maximum flood.	No	The repository portals and shaft collars will be designed so that they are above the flood elevation resulting from the probable maximum flood, as described in Sections 1.3.3.1.1 and 1.1.4.3.2). In addition, the areas adjacent to the portal and shaft openings will be graded so that storm runoff drains away from the openings.	NA
Waste Package	03-20 Materials Contacting the Waste Package	After fabrication final cleaning, the waste package shall be prepared for shipment. Materials or objects contacting the waste package outer surfaces during transportation, loading, and emplacement will be evaluated to ensure that any physical degradation and contamination are within allowable limits.	No	The fabrication specification for the waste package shall contain requirements to establish acceptable surface conditions of the waste packages.	The waste package handling procedures will establish the requirements for acceptable surface conditions of the waste packages. The waste package emplacement procedures will identify the acceptable handling equipment that is allowed to contact the surface of the waste package and require inspections during the handling process.

Table 1.3.3-8. Summary of Conformance of Subsurface Facility Design to Postclosure Control Parameters—Nonemplacement 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			
Waste Package	03-21 Waste Package Handling	The waste package shall be handled in a controlled manner during fabrication, handling, transport, storage, emplacement, installation, operation, and closure activities to minimize damage; surface contamination; and exposure to adverse substances.	Yes	NA (Background information: Criteria and design considerations for safe handling of the waste package from the surface facilities to the emplacement areas underground are described in Section 1.3.3.5. The waste package, when being transported in the TEV, rests on its pallet, and the surfaces of the waste package do not contact any other surfaces other than the pallet supports. Speed of travel of the TEV is designed and controlled to a slow rate and the pallet is restrained inside the shielded compartment so that its load is prevented from moving and incurring surface damage.)	The waste package emplacement procedures will include handling requirements to limit activities that could physically degrade, contaminate and limit exposure of adverse substances to the surface of the waste package. Inspection procedures will be developed to identify damage, surface contamination or exposure to adverse substances at the time of waste package emplacement. The TEV will have adequate means to inspect visible waste package surfaces. The operational and monitoring controls applicable to the TEV when handling the waste package on its pallet from the surface facilities to the underground turnouts are described in Section 1.3.3.5.2.3. Travel and movements of the TEV are controlled, and documented by remote operators from the CCCF.

Table 1.3.3-8. Summary of Conformance of Subsurface Facility Design to Postclosure Control Parameters—Nonemplacement 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**			
Waste Package	03-22 Waste Package Handling and Emplacement	Waste package handling and emplacement activities shall be monitored through equipment with resolution capable of detecting waste package damage. An operator and an independent checker shall perform the operations. Records demonstrating compliance shall be maintained.	No	NA (Background Information: In order to minimize damage, the pallet carrying the waste package is restrained inside the shielded compartment of the TEV and there is no movement or handling of the waste package inside the TEV when in transit. Handling of the pallet holding the waste package during emplacement is limited to lowering of the loaded pallet on to the emplacement drift invert structure.)	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. Procedures will be used to control the inspection by an operator and independent checker of the handling of the loaded pallet during emplacement. This inspection will be conducted remotely from the CCCF, using high-resolution cameras and by monitoring and verification of operational steps. The TEV operational steps are described in Sections 1.3.3.5.2.1 and 1.3.4.8.2.2.

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

Source: BSC 2008k, Table 1.

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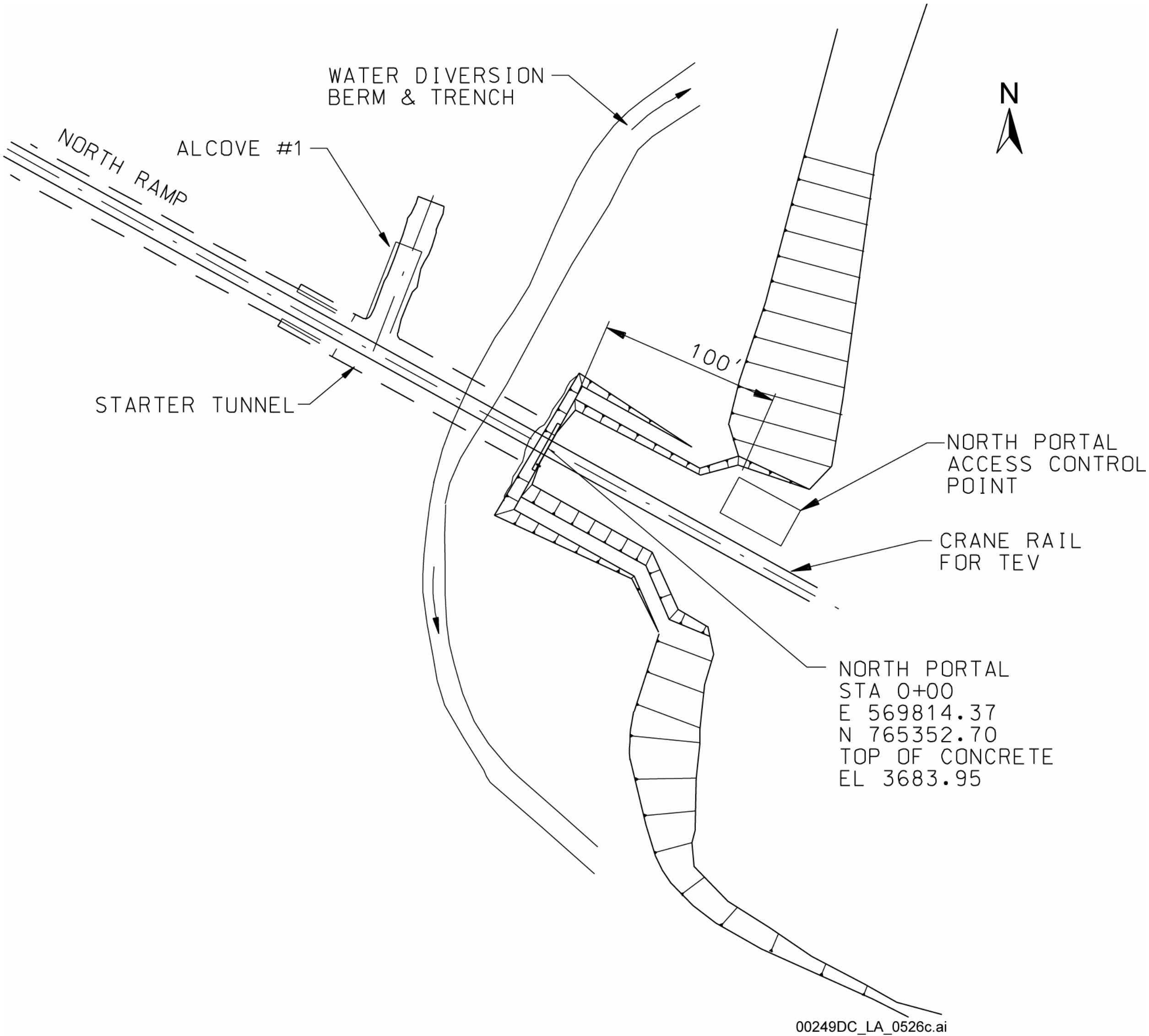


Figure 1.3.3-1. North Portal Plan View

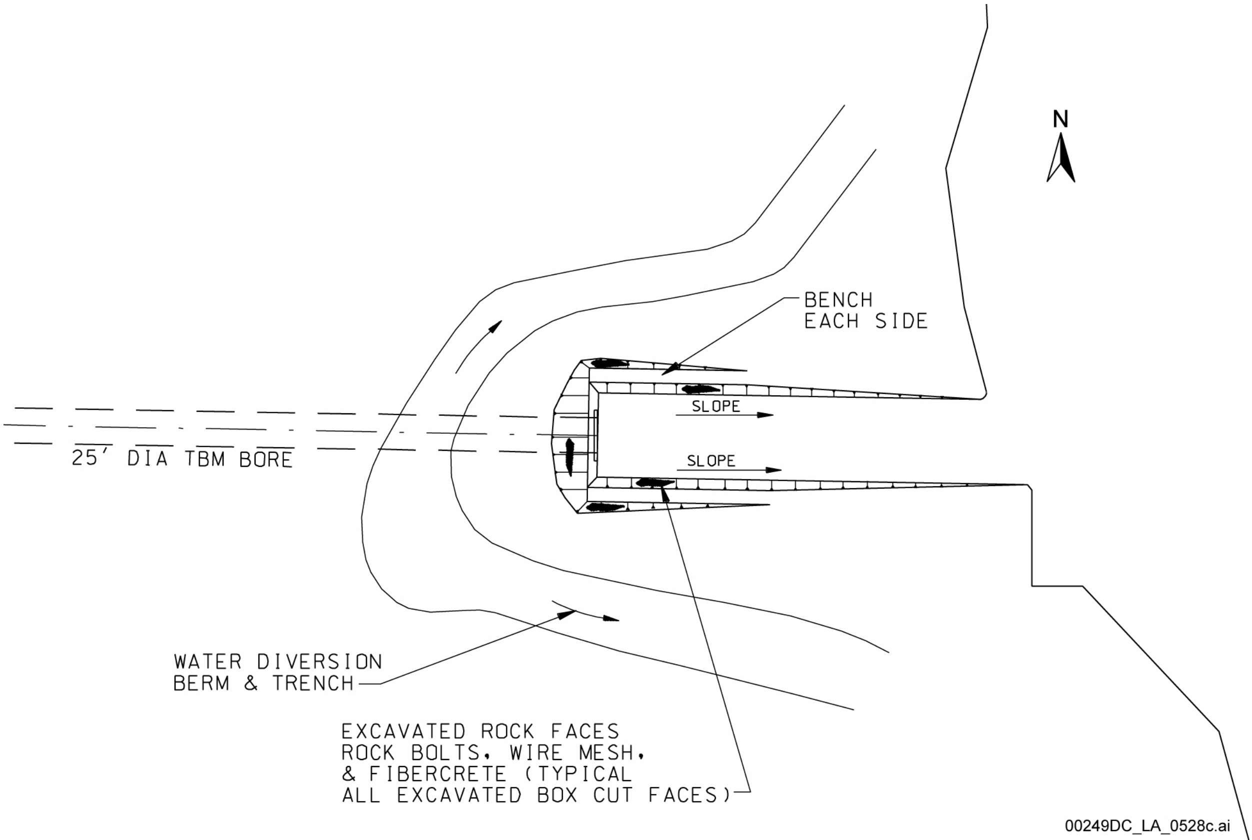


Figure 1.3.3-2. South Portal Plan View

NOTE: TBM = tunnel boring machine.

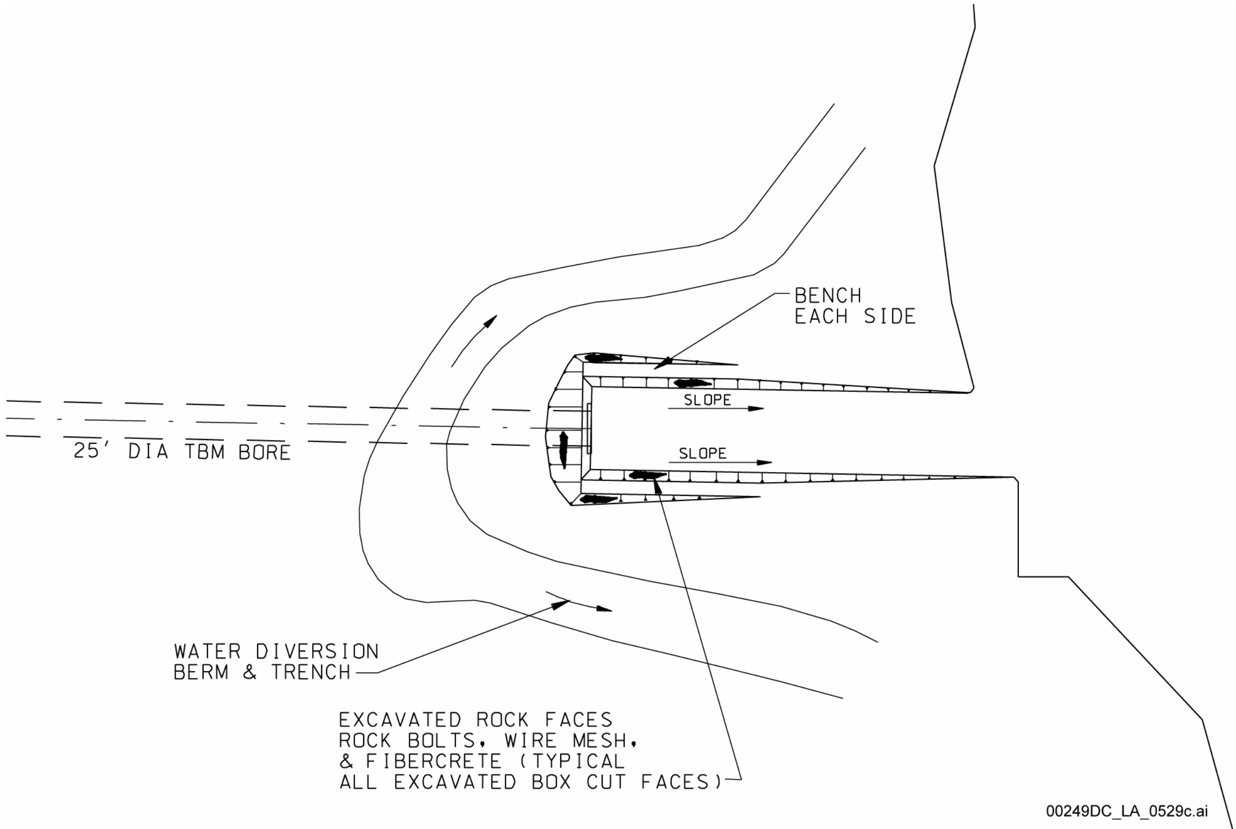


Figure 1.3.3-3. North Construction Portal Plan View (Typical)

NOTE: TBM = tunnel boring machine.

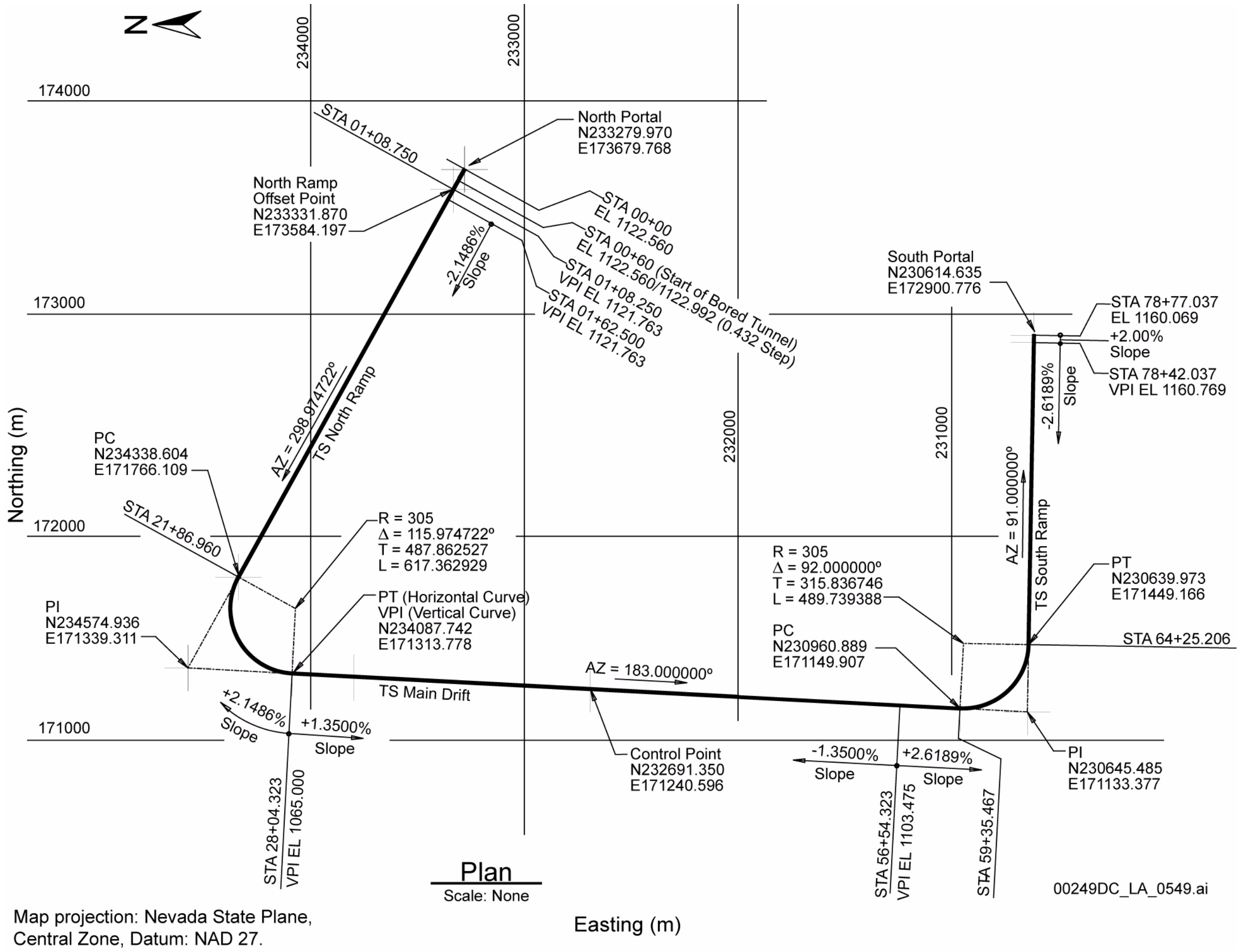


Figure 1.3.3-4. Exploratory Studies Facility Showing North and South Ramp Grades

NOTE: AZ = azimuth; P = point of curvature; PI = point of intersect; PT = point of tangent; TS = tube section; VPI = vertical point interface.

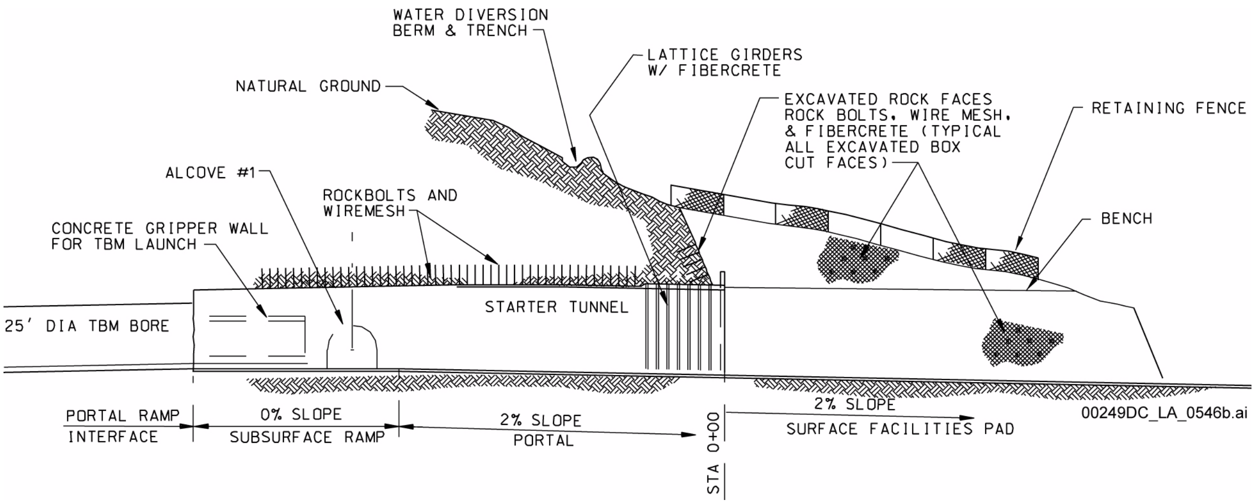


Figure 1.3.3-5. North Portal Long Section with Construction Features

NOTE: TBM = tunnel boring machine.

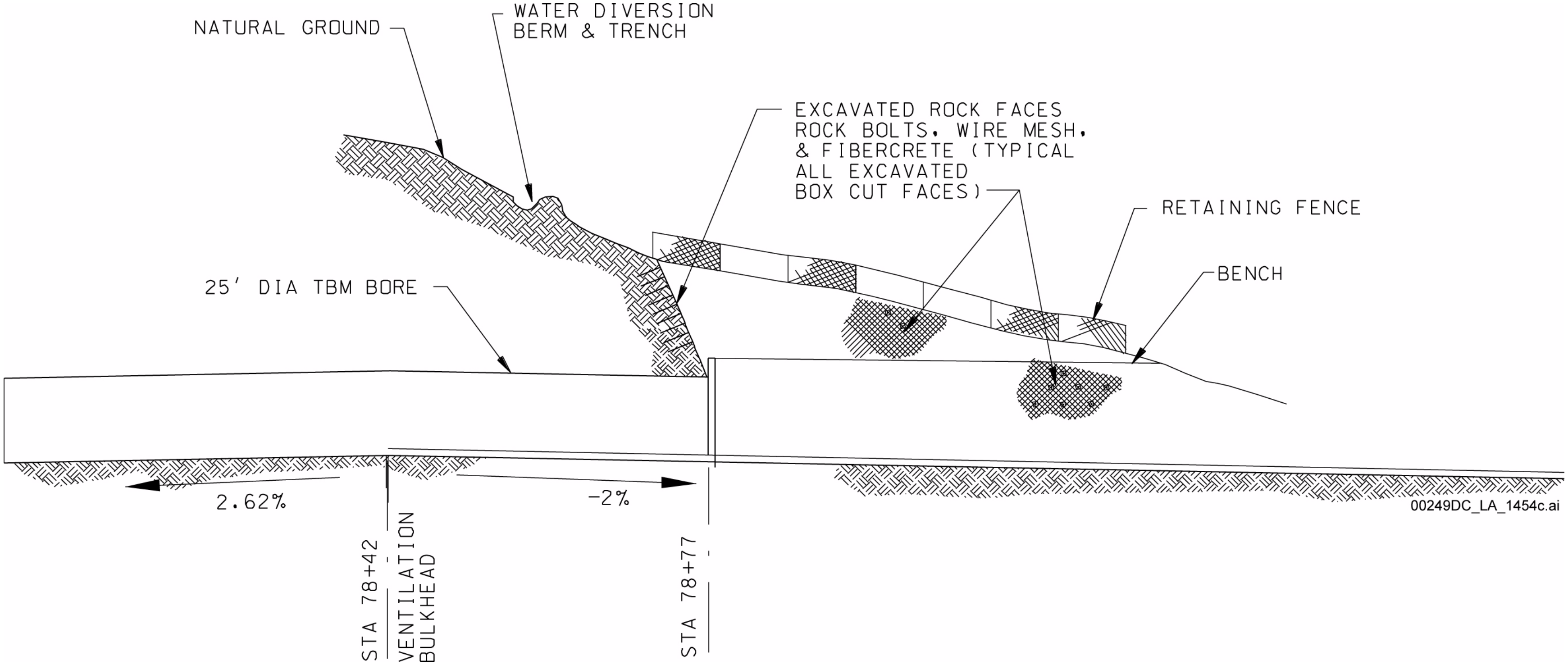


Figure 1.3.3-6. South Portal Long Section with Construction Features

NOTE: TBM = tunnel boring machine.

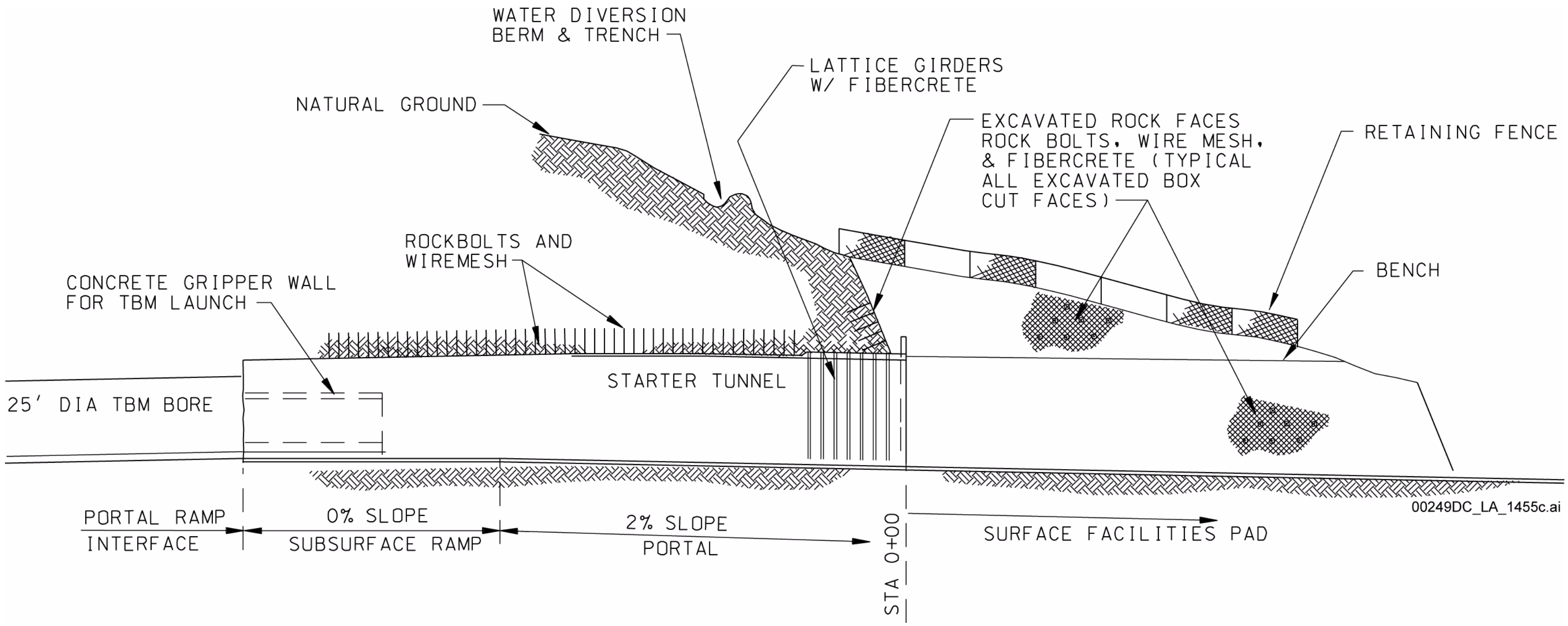


Figure 1.3.3-7. North Construction Portal Long Section with Construction Features

NOTE: TBM = tunnel boring machine.

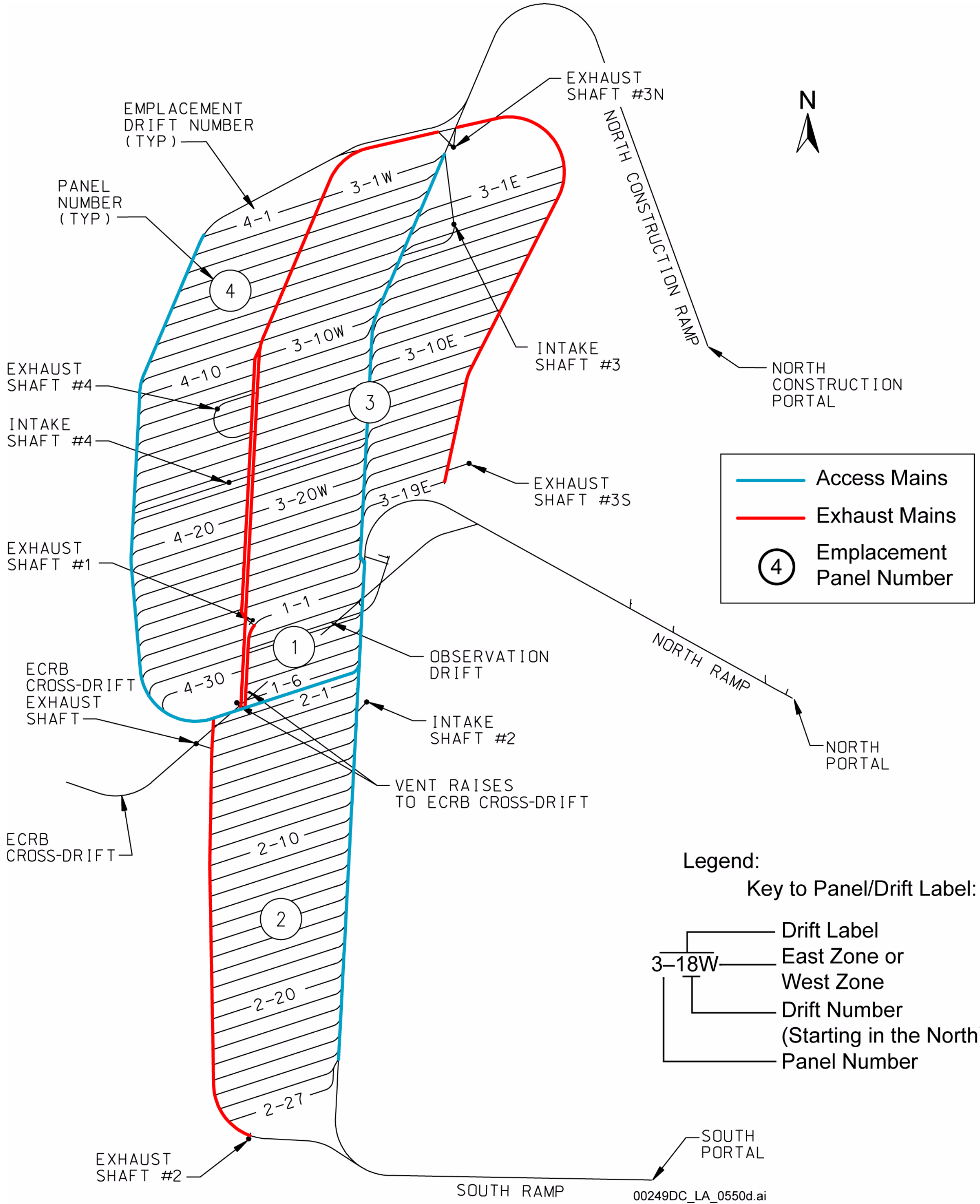
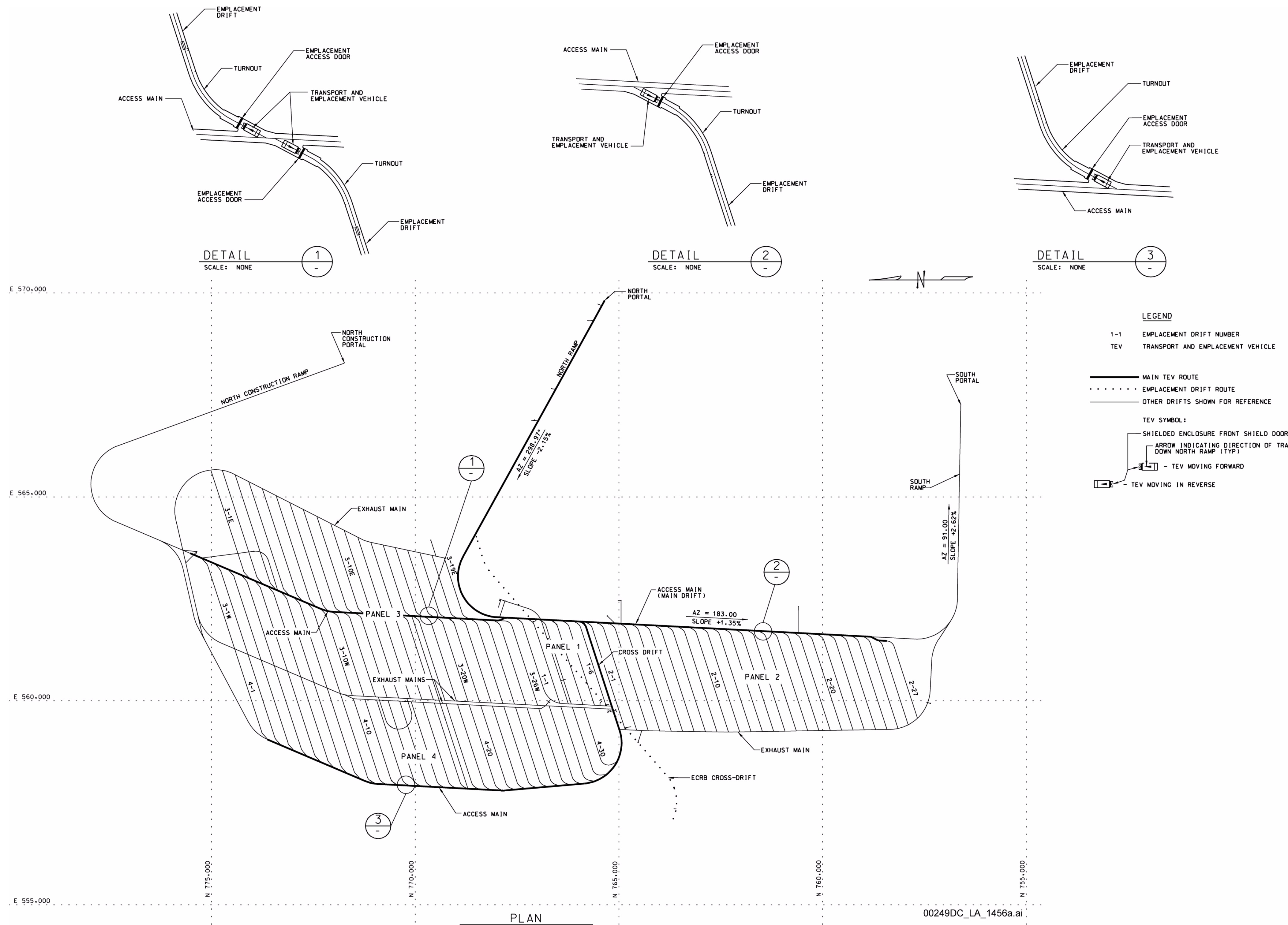


Figure 1.3.3-8. Access Main Alignments



NOTE: Coordinates are in meters.

Figure 1.3.3-9. Waste Package Transportation Routes and Typical Turnouts

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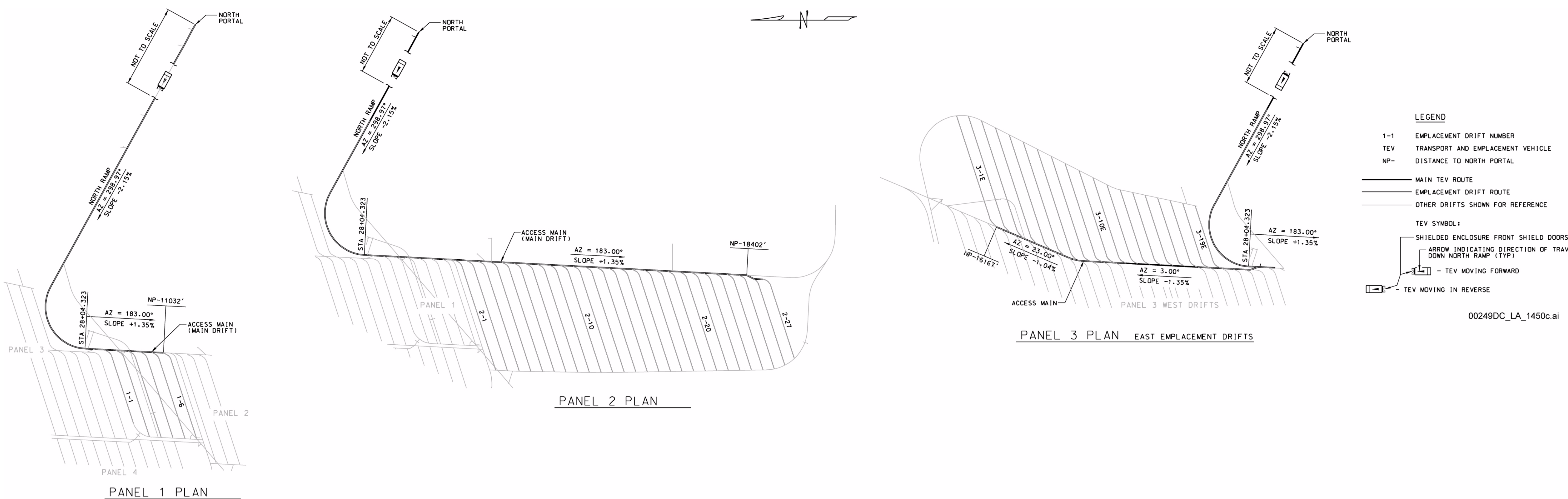

Figure 1.3.3-10. Waste Package Transportation Routes to Panels 1, 2, and 3–East

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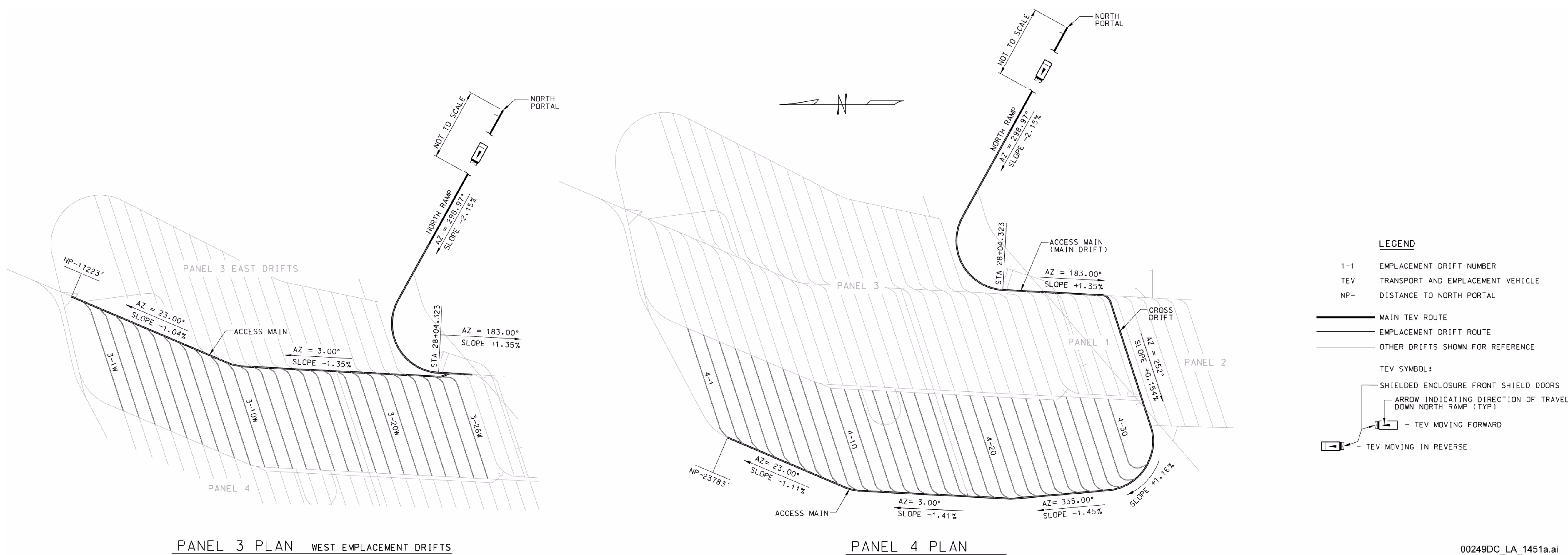

Figure 1.3.3-11. Waste Package Transportation Routes to Panels 3–West and 4

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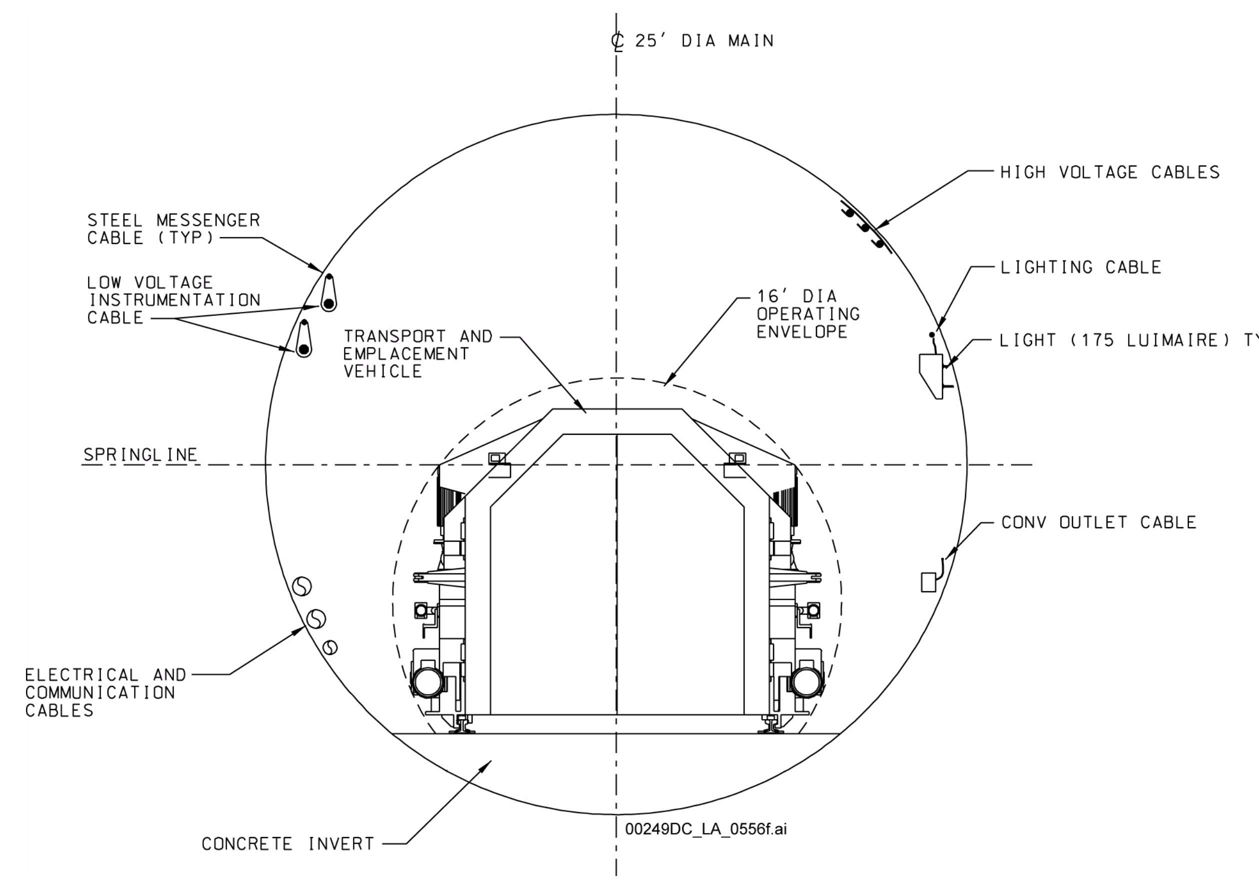

Figure 1.3.3-12. Typical Access Main Finished Cross Section

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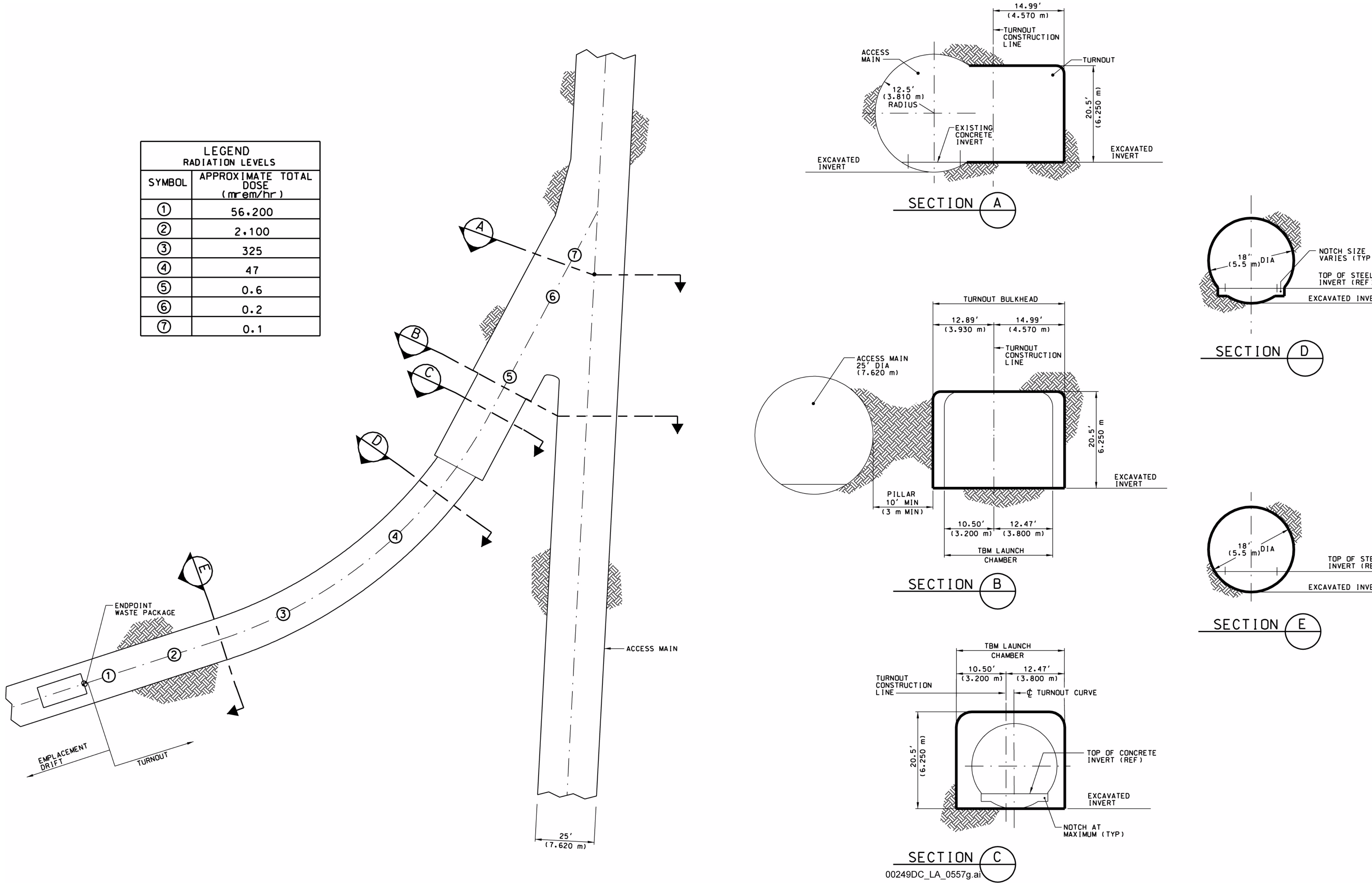

Figure 1.3.3-13. Representative Turnout Plan View and Sections

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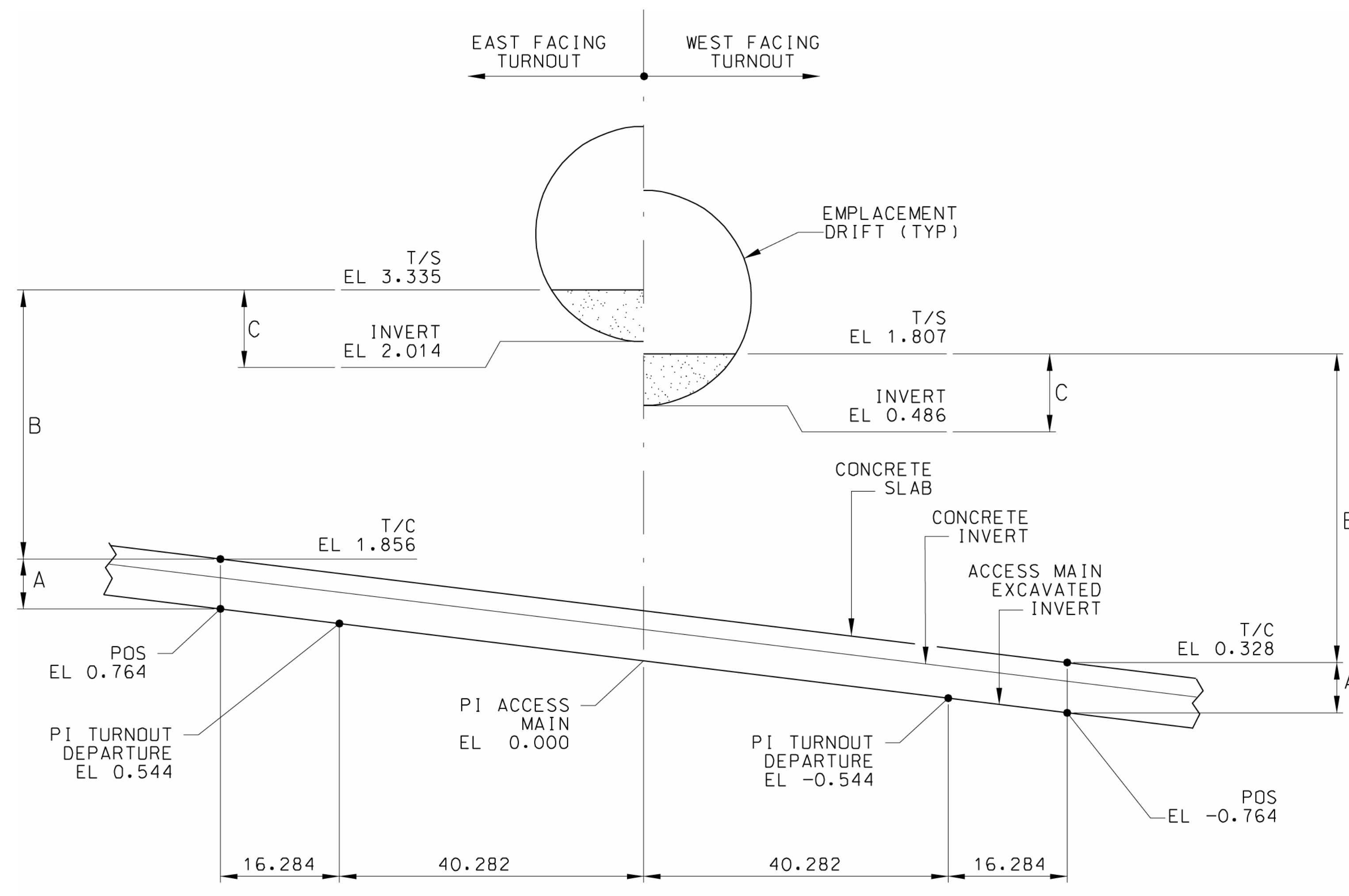

NOTE: Units shown are in meters. PI = point of intersection; POS = point of switch; T/C = top of concrete; T/S = top of steel.

Figure 1.3.3-14. Emplacement Drift, Turnout, and Access Main Elevation Interfaces

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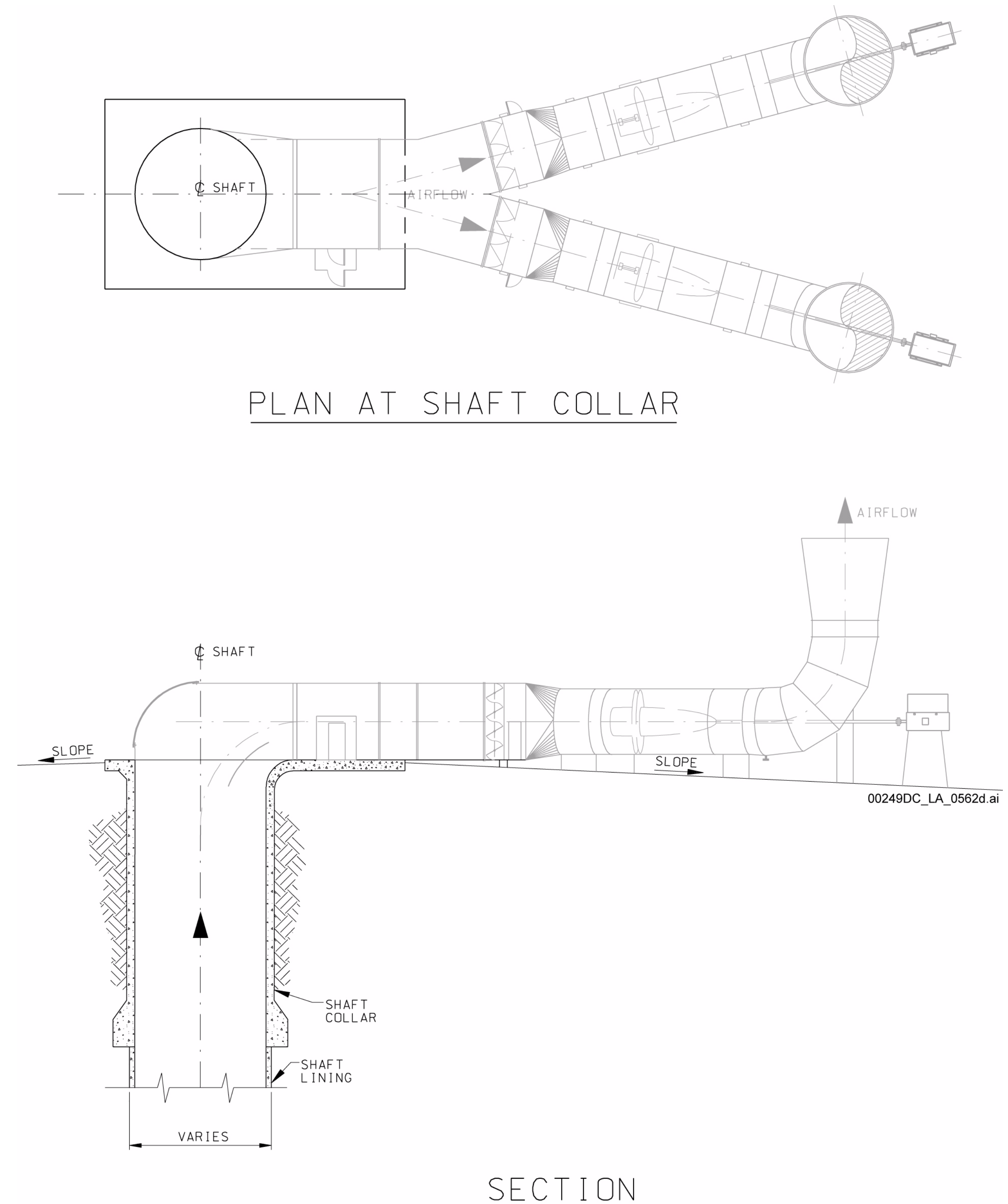

Figure 1.3.3-15. Typical Shaft Collar

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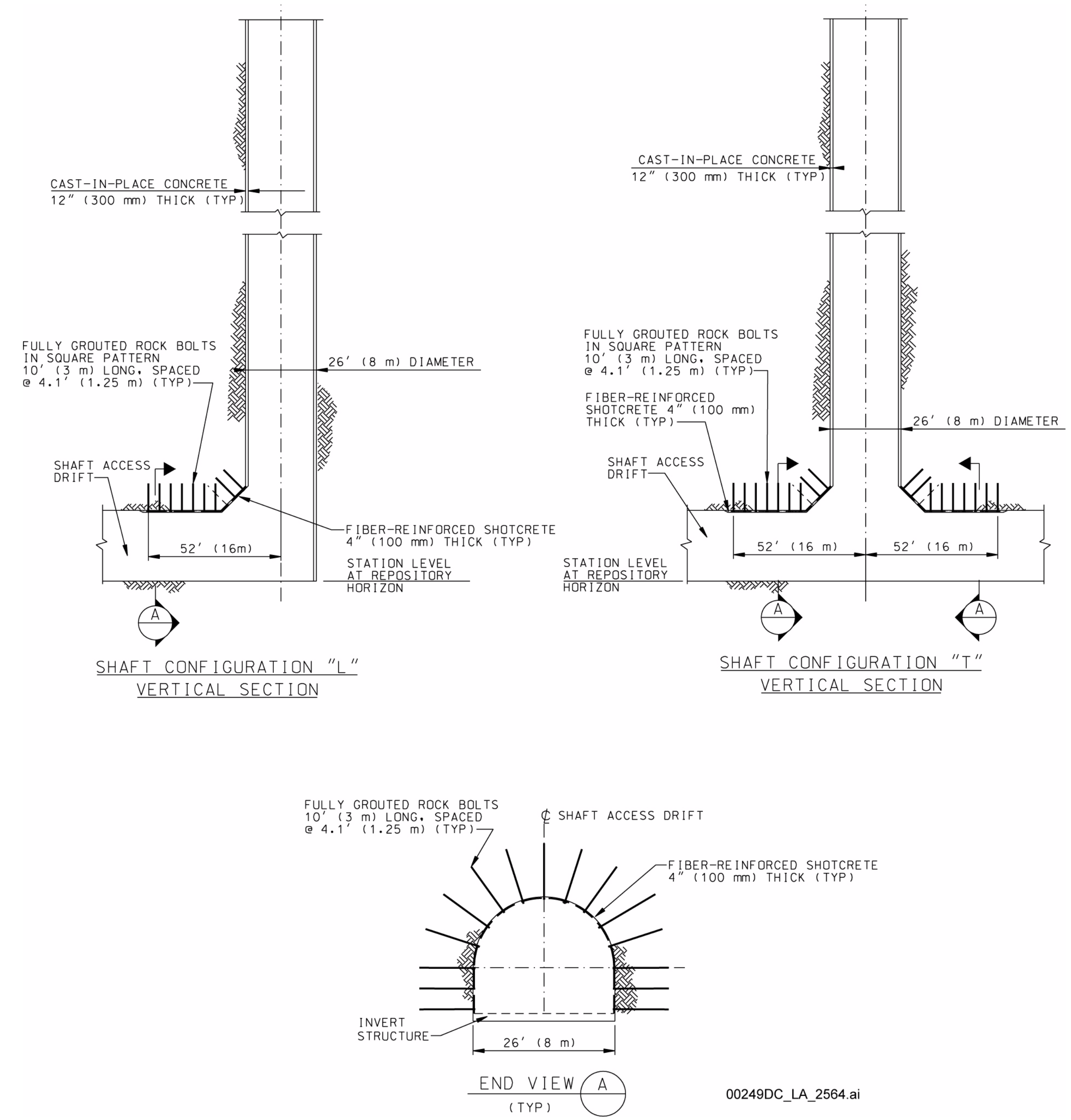

NOTE: DIA = diameter.

Figure 1.3.3-16. Typical Details for Shaft Stations

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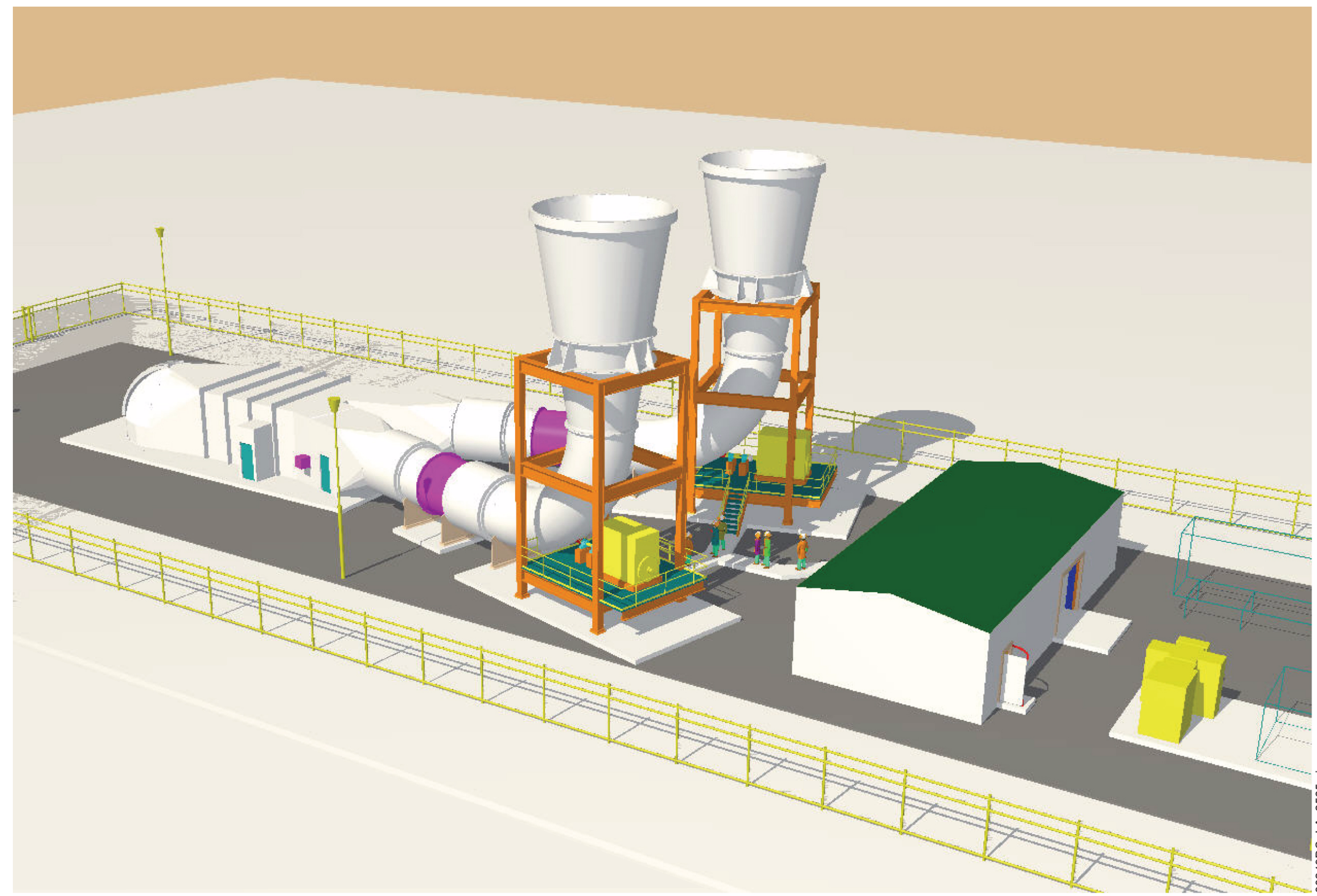

Figure 1.3.3-17. Typical Facilities and Equipment for an Exhaust Shaft Surface Pad

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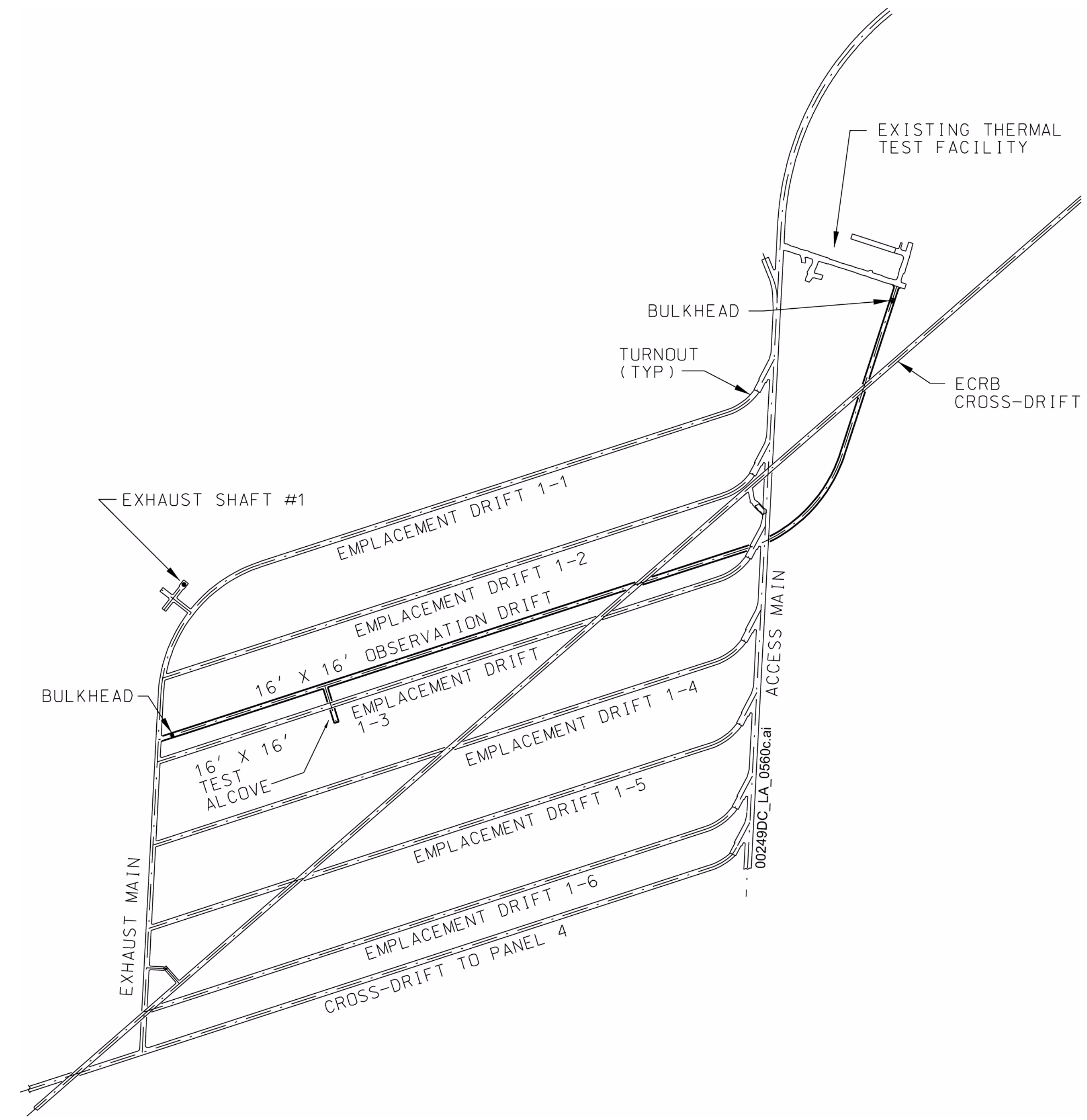

Figure 1.3.3-18. Observation Drift and Test Alcove Plan View

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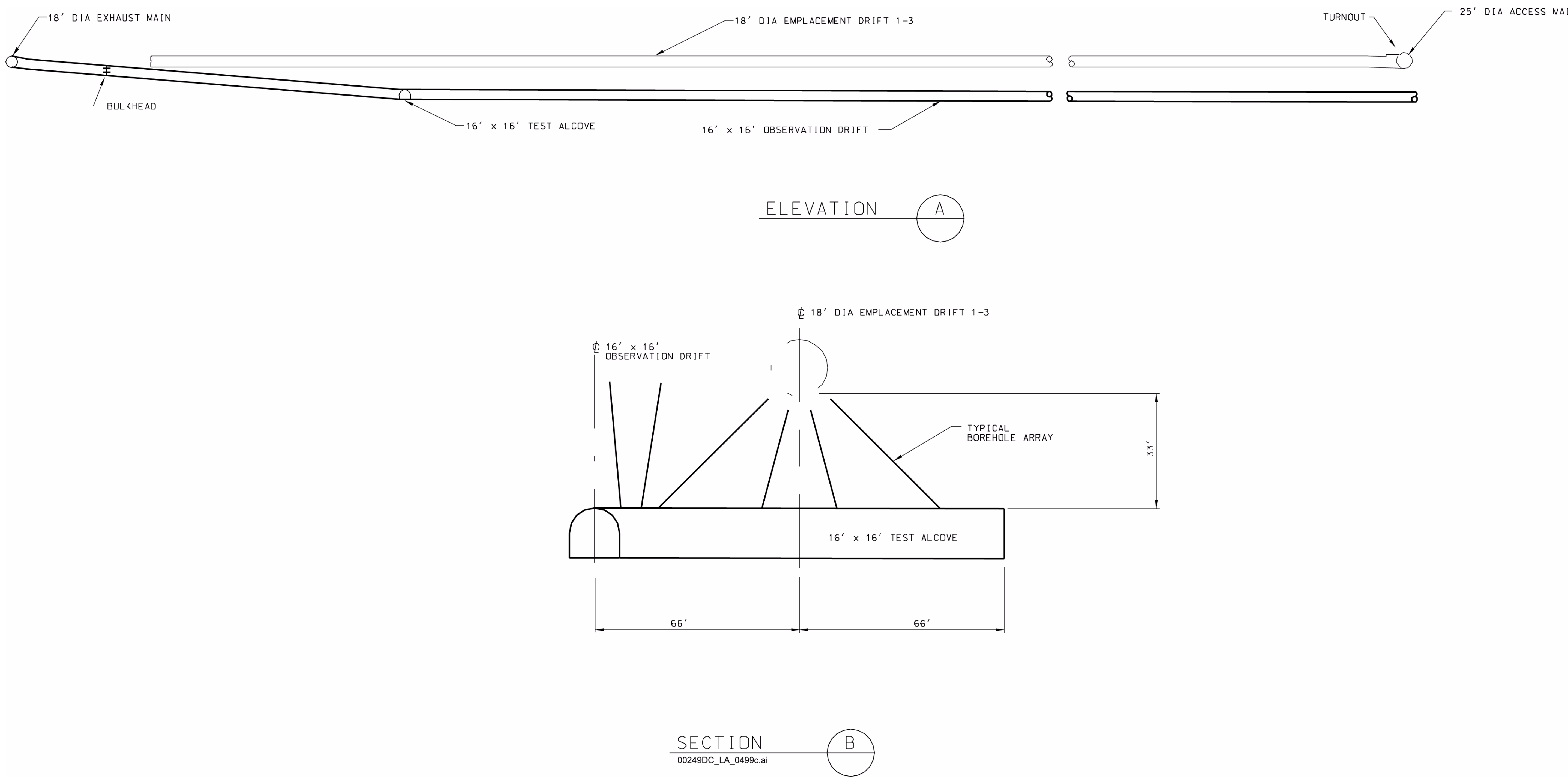

Figure 1.3.3-19. Profile of Observation Drift and Typical Arrangement of Monitoring Boreholes from Observation Alcove

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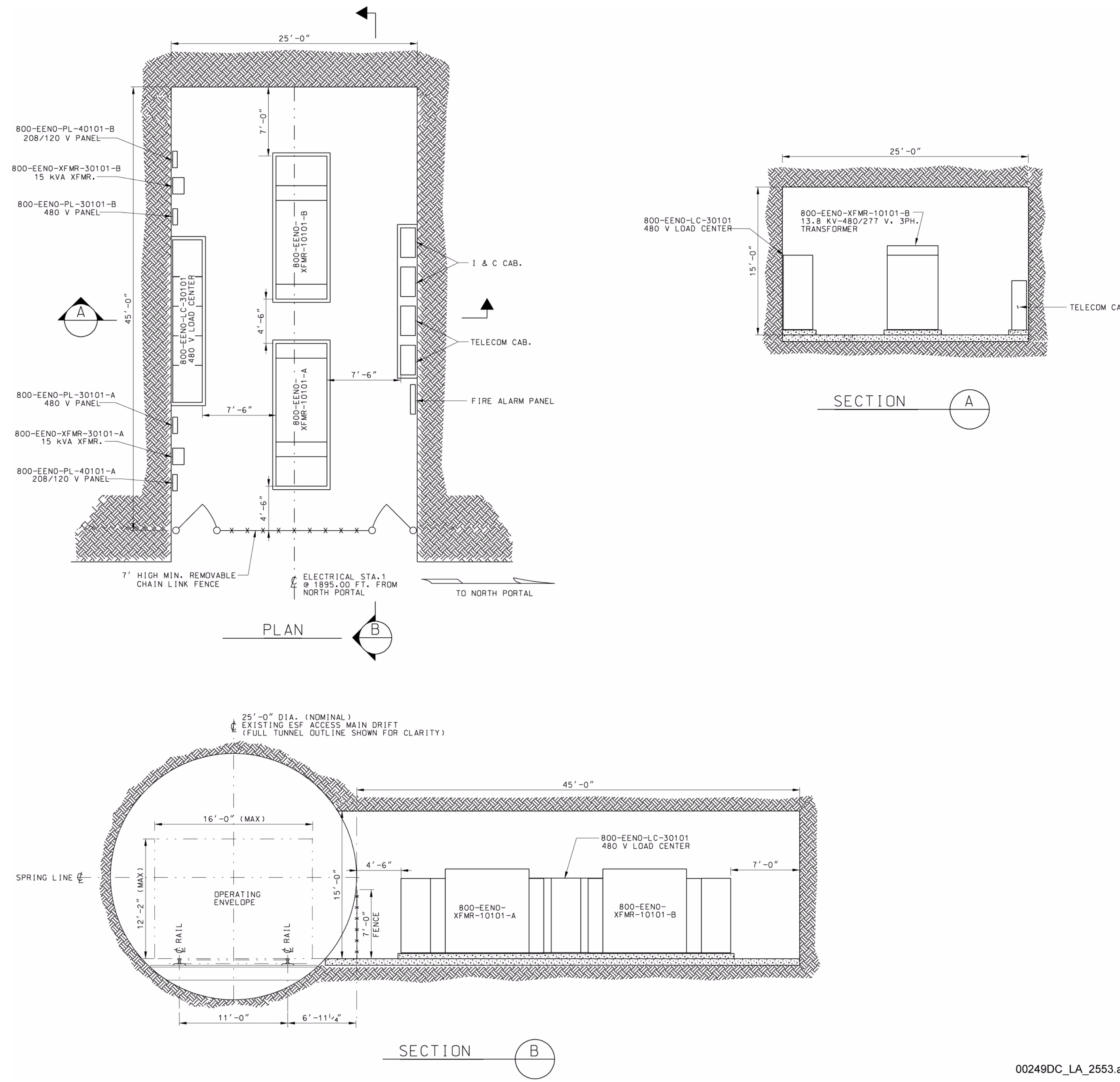

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Figure 1.3.3-20. Subsurface Facility Alcove-Based Electrical Station—Typical General Arrangement and Equipment Layout

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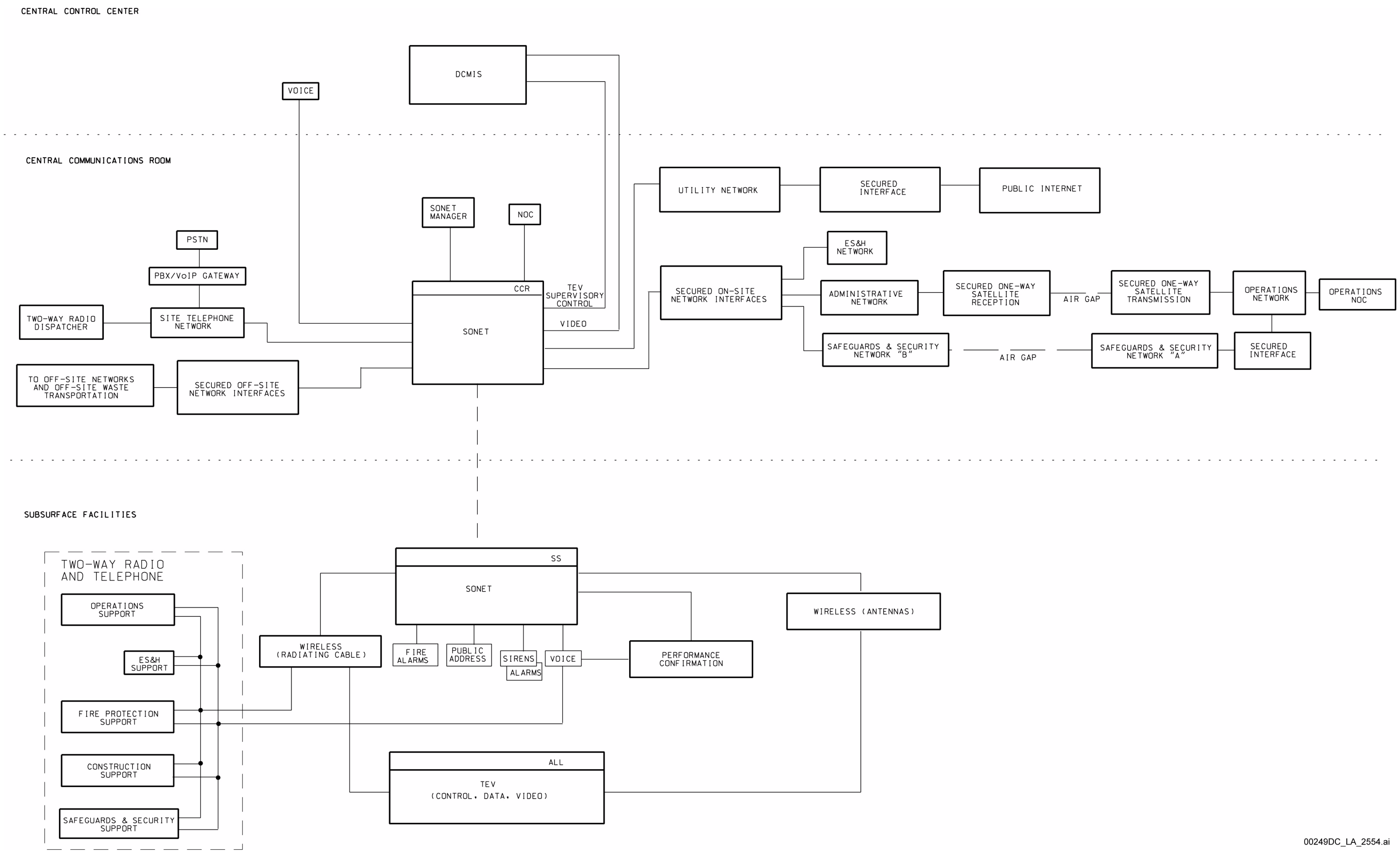

NOTE: CCR = central communications room; DCMIS = digital control and management information system; ES&H = Environmental Safety and Health; NOC = network operations center; PBX = private branch exchange; PSTN = public switched telephone network; SONET = synchronous optical network; VoIP = voice over internet protocol.

Figure 1.3.3-21. Subsurface Facility Communications System Functional Block Diagram

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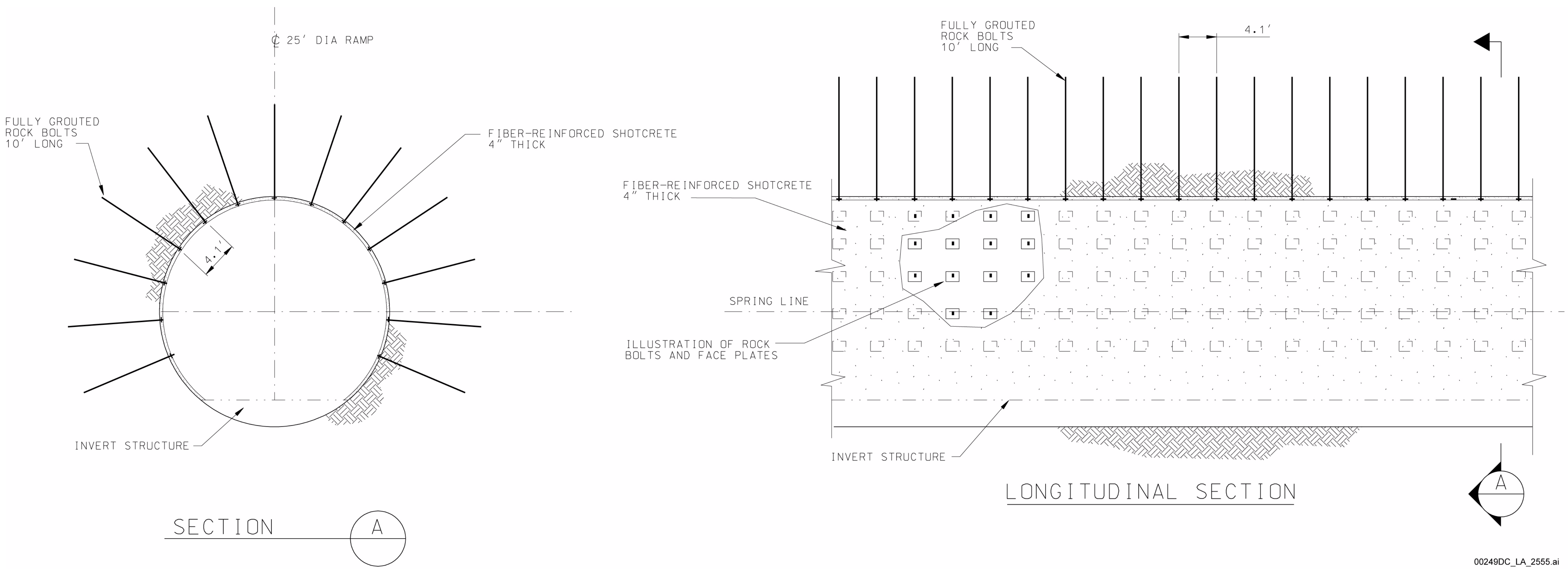

Figure 1.3.3-22. Typical Ground Support for Ramps

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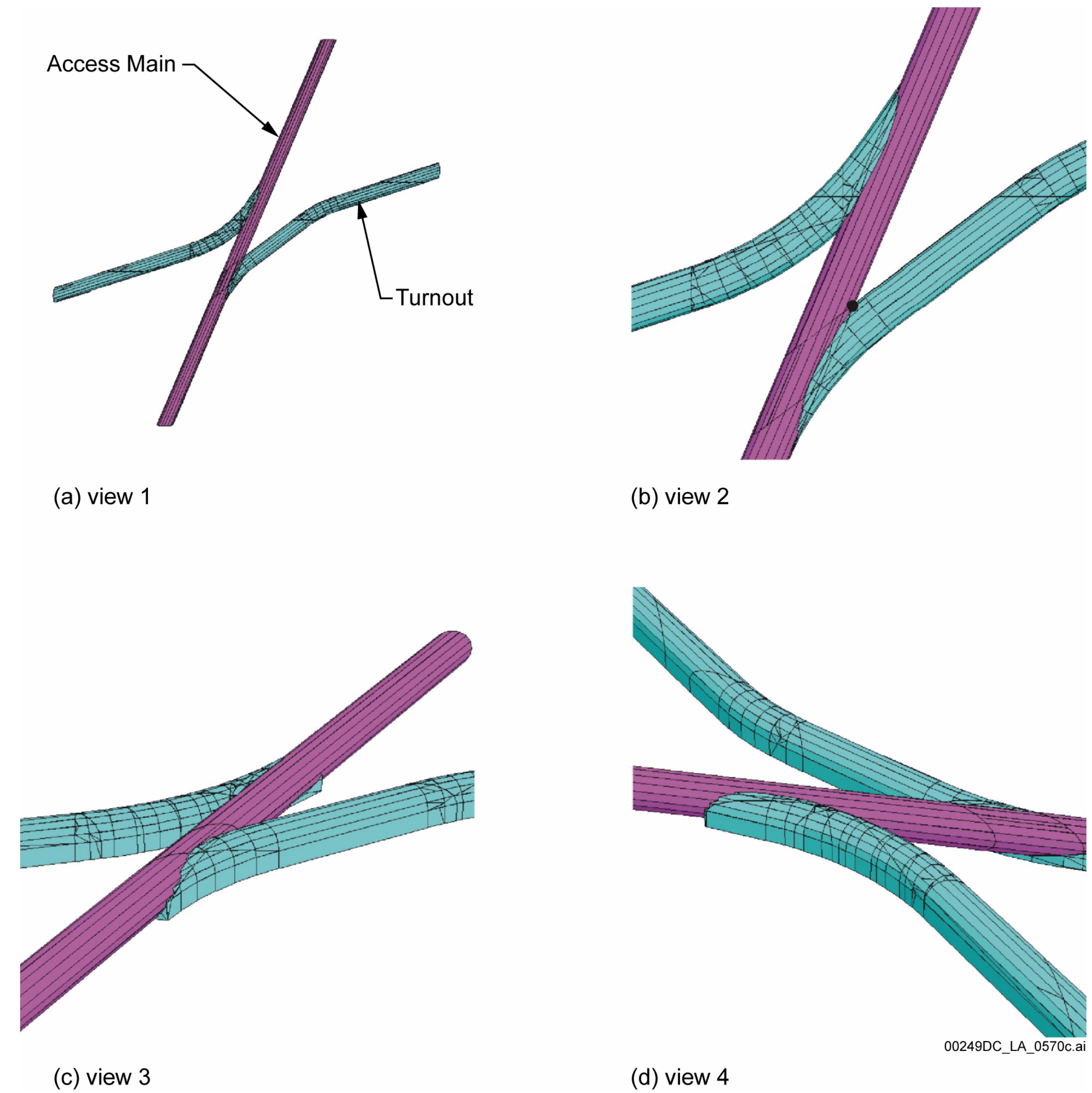

Figure 1.3.3-23. 3DEC Model Configuration of the Intersection of an Access Main and a Turnout

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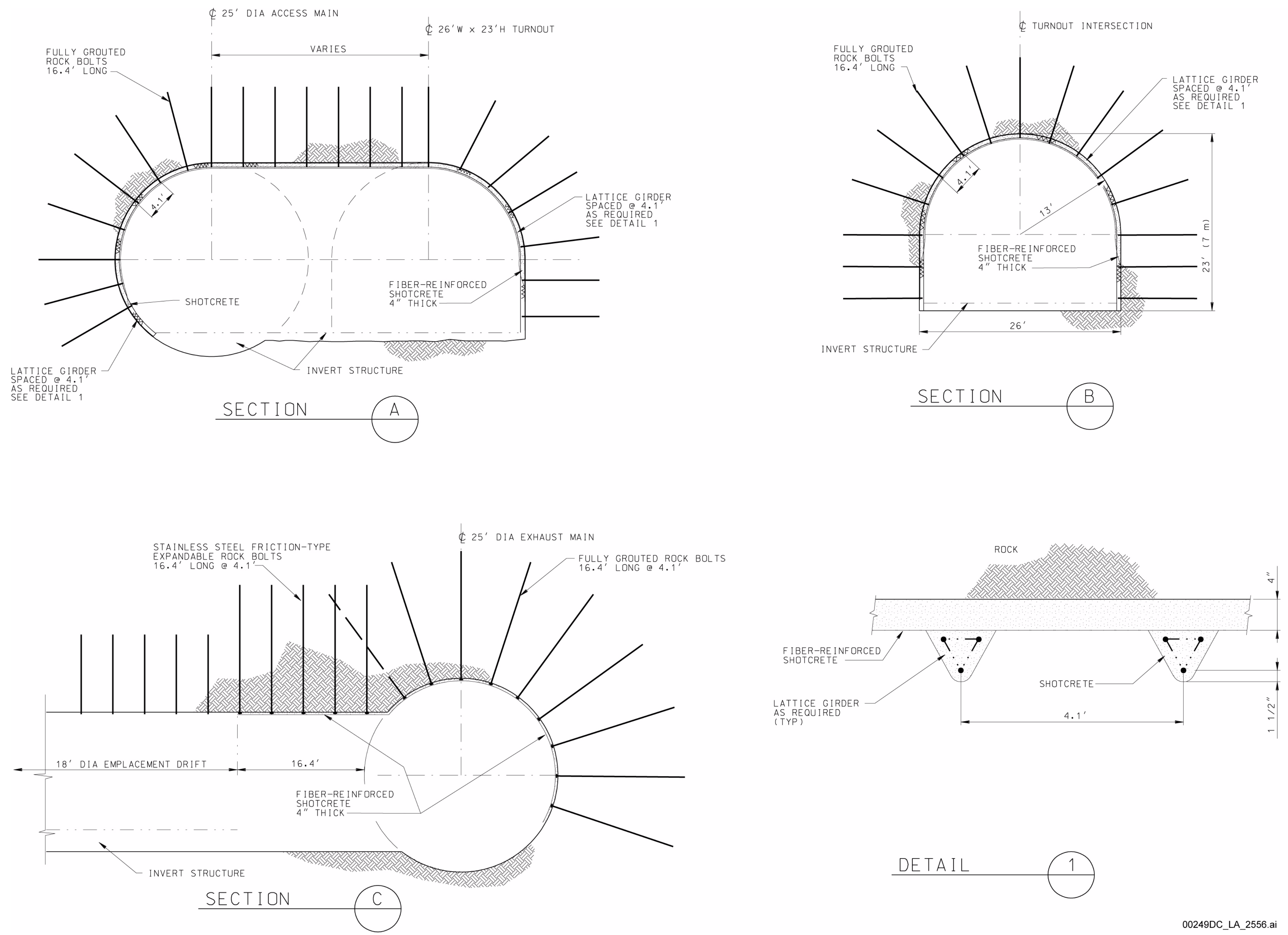

Figure 1.3.3-24. Typical Ground Support for Intersections

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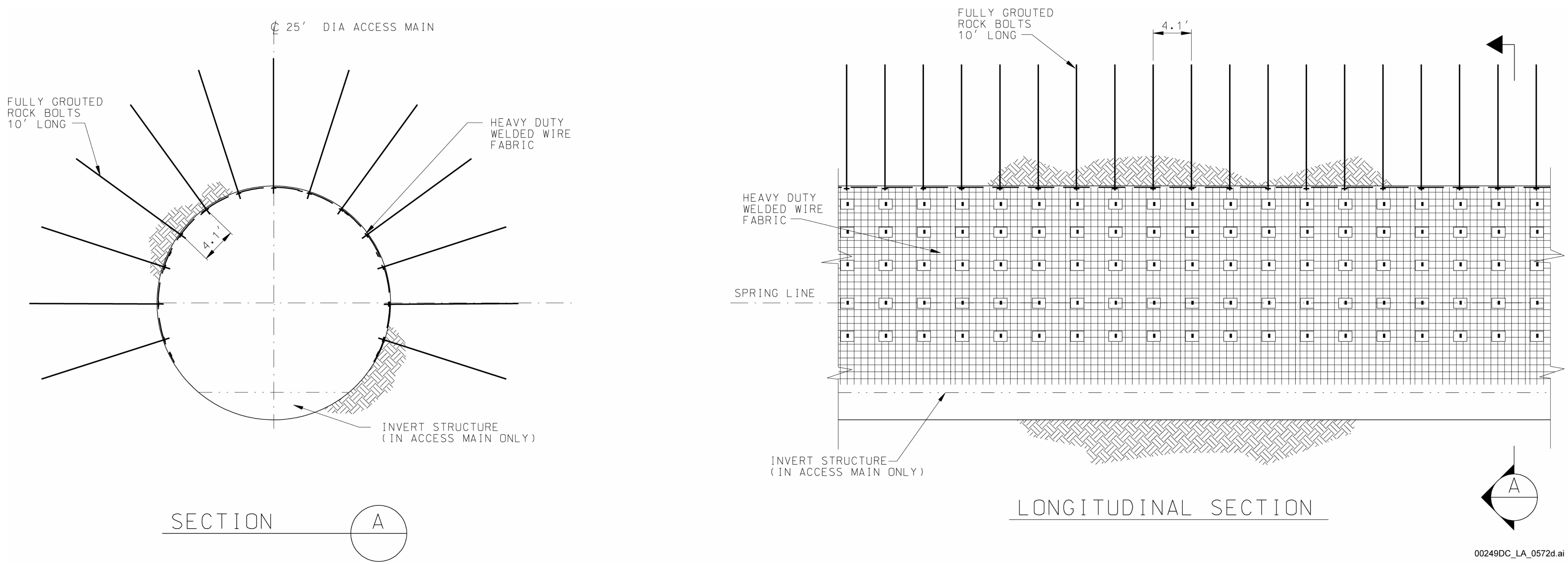

Figure 1.3.3-25. Ground Support System in Access or Exhaust Mains

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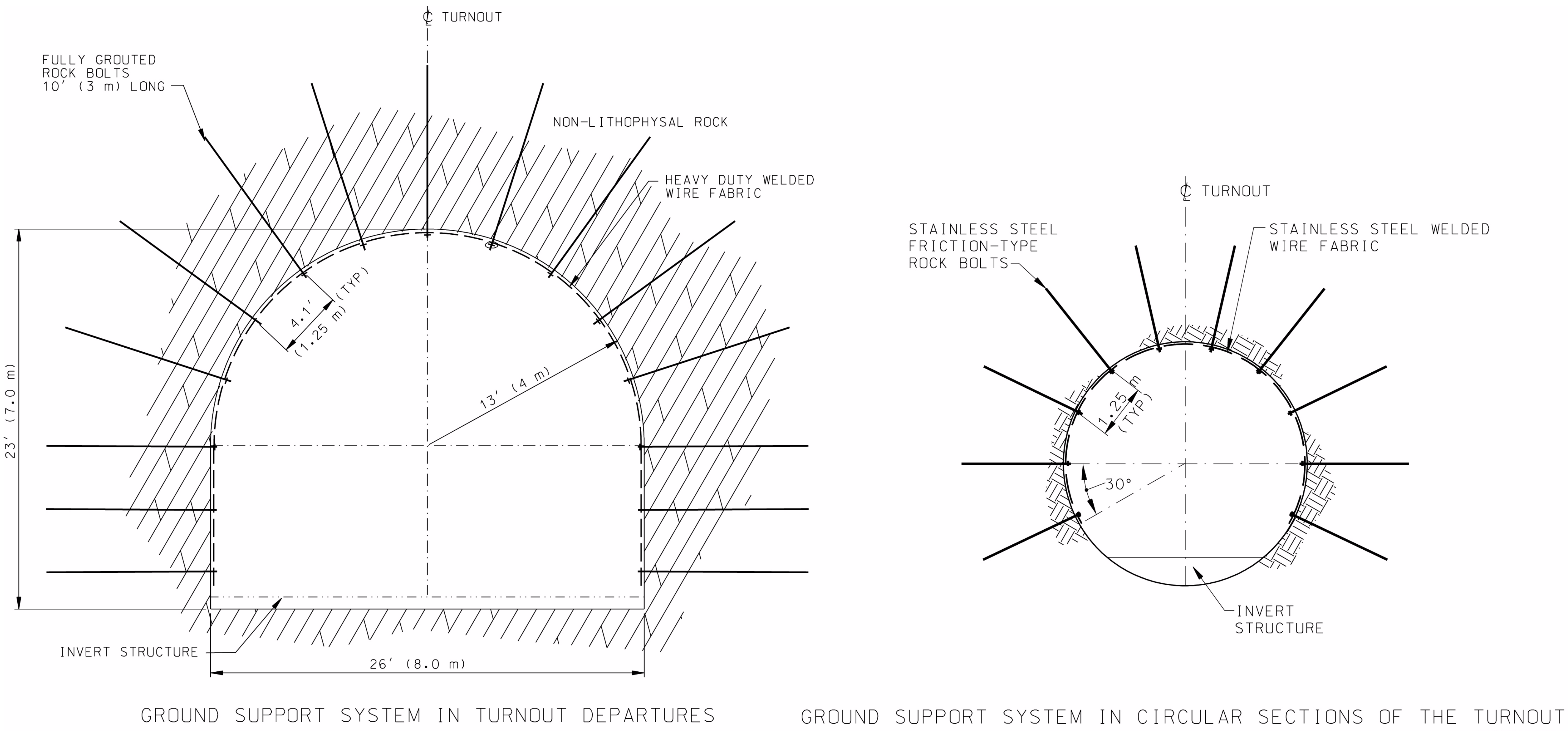

Figure 1.3.3-26. Ground Support System in Turnouts

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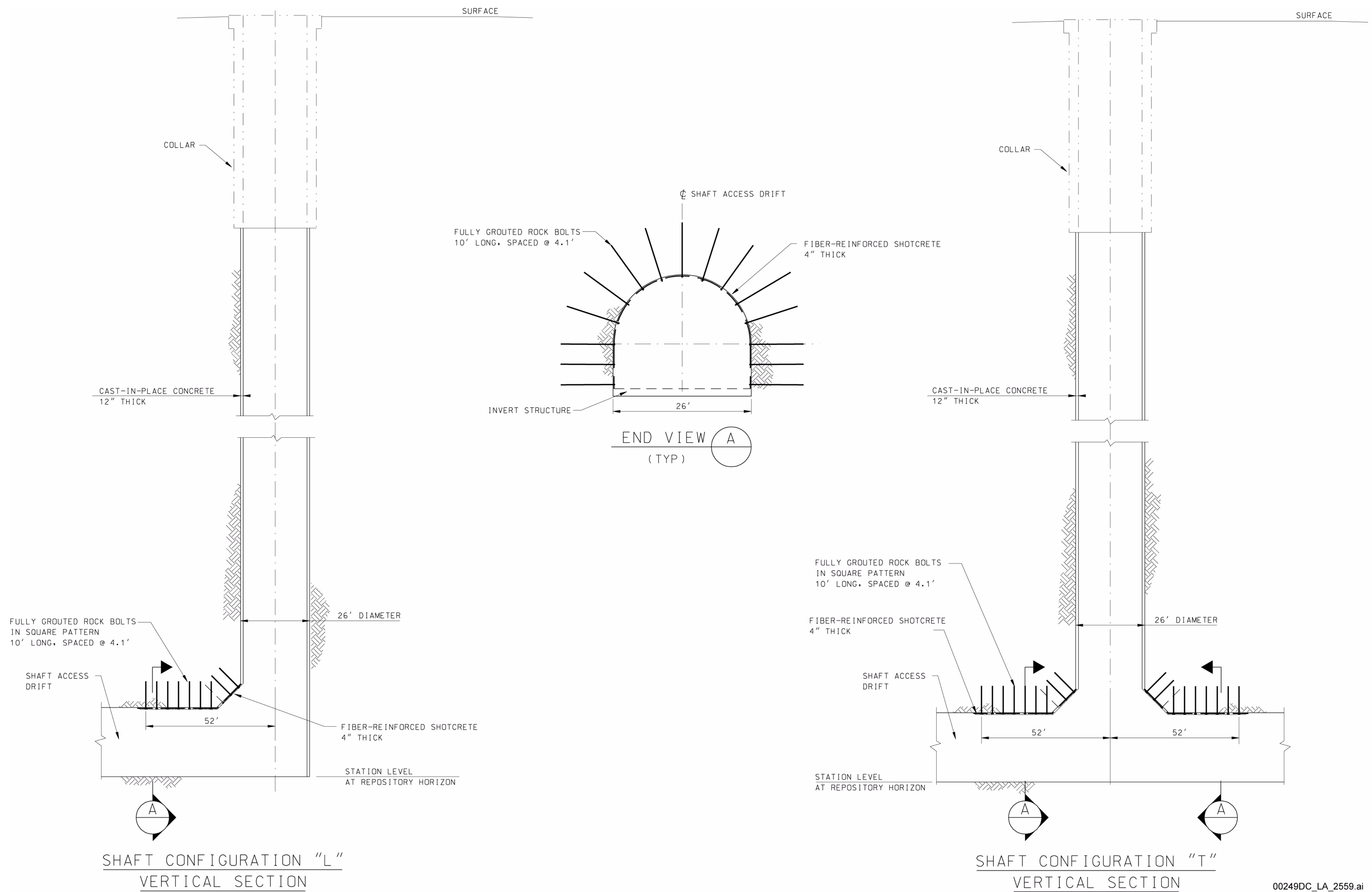

Figure 1.3.3-27. Typical Ground Support for Ventilation Shafts

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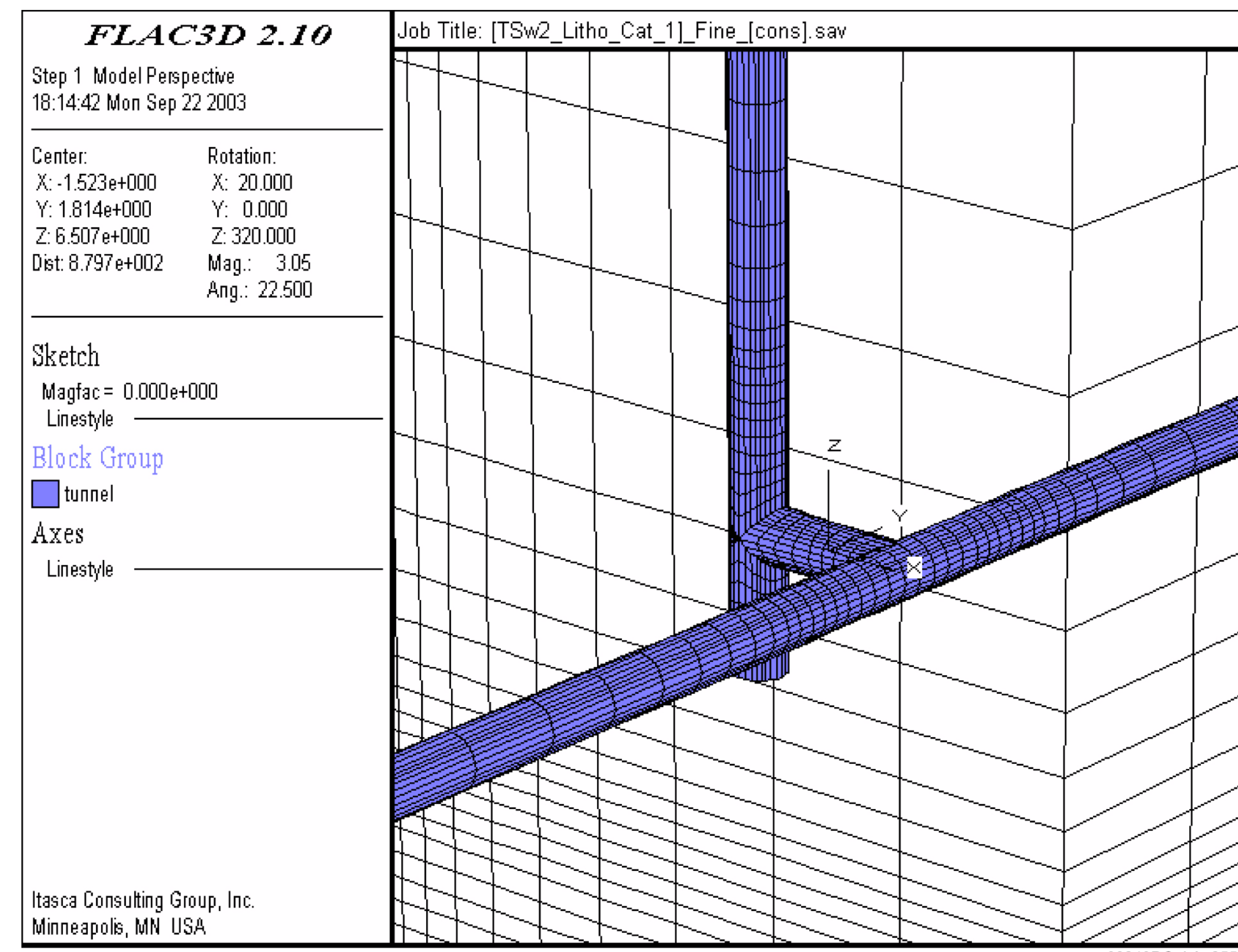

Figure 1.3.3-28. Detailed View of the FLAC3D Model for the “L” Intersection

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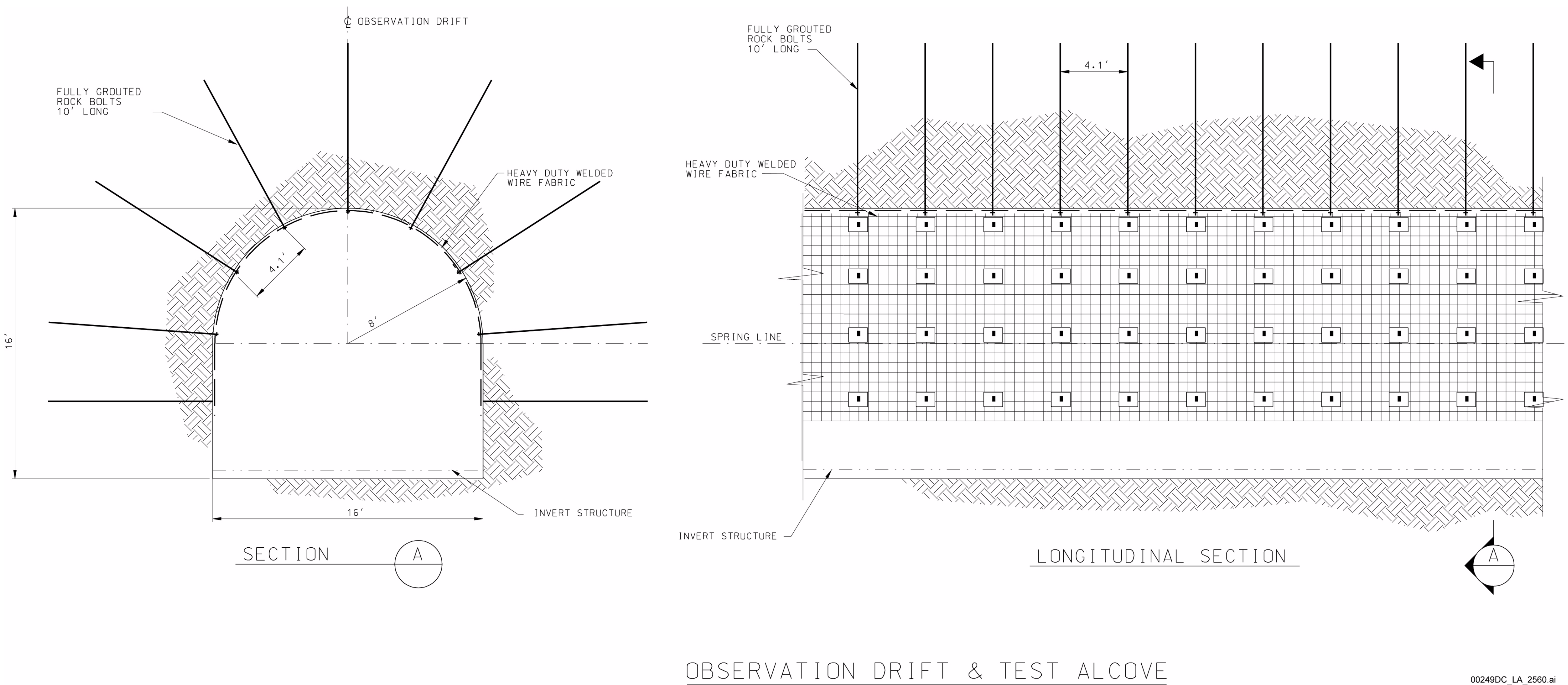

Figure 1.3.3-29. Typical Ground Support for Observation Drift and Observation Alcove

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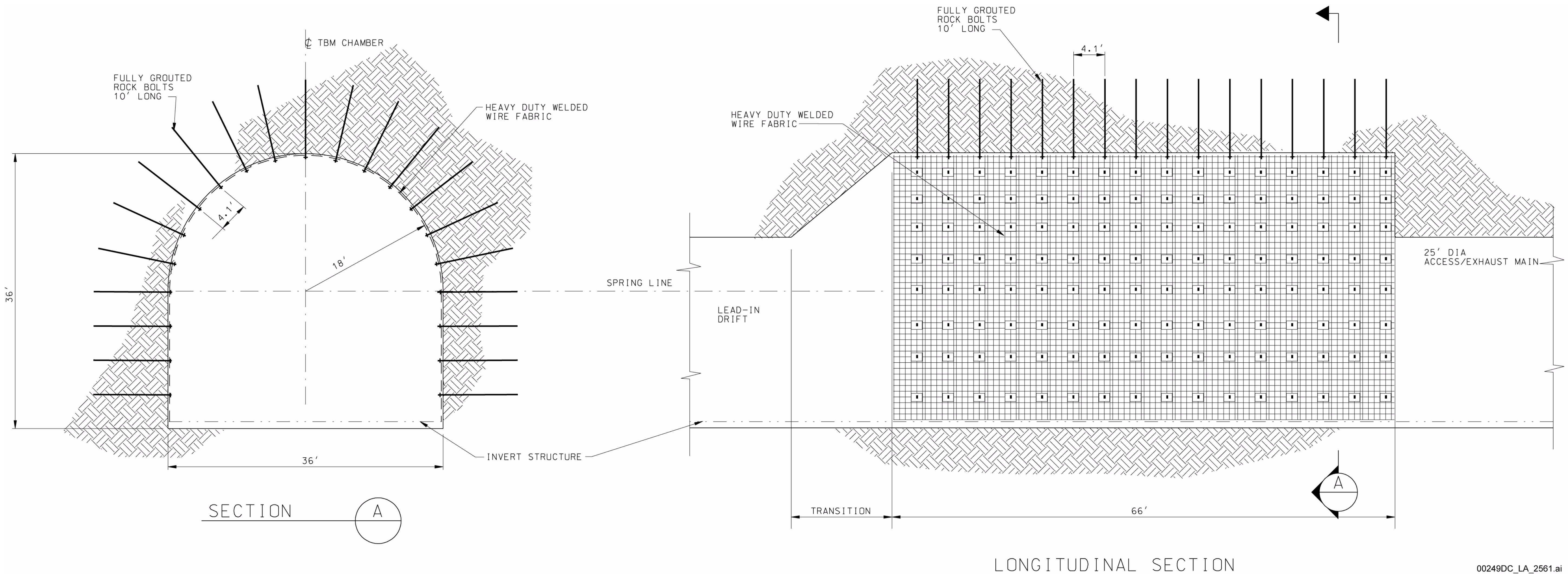

Figure 1.3.3-30. Typical Ground Support for Tunnel Boring Machine Launch Chambers

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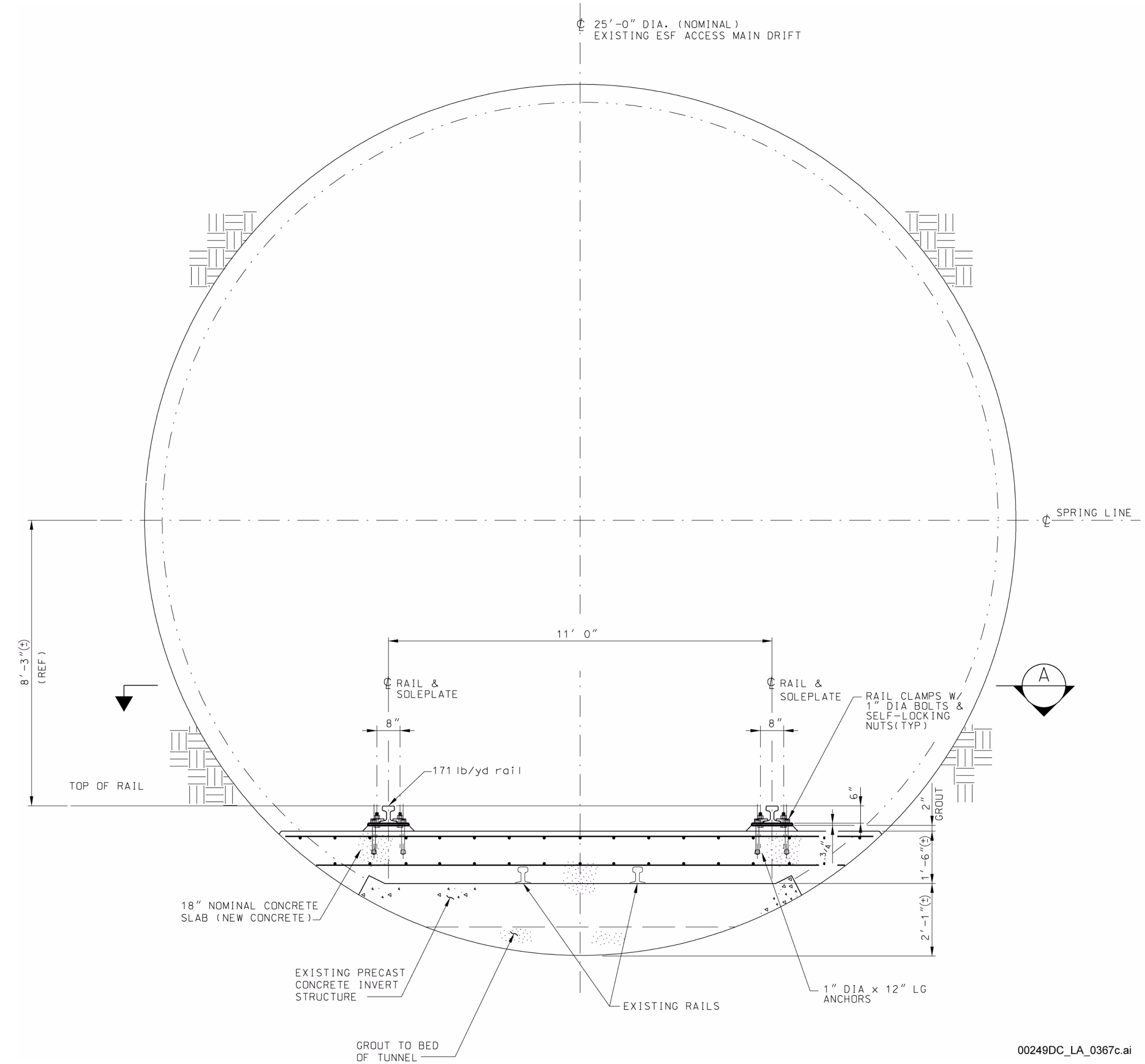

Figure 1.3.3-31. Access Main Invert and Rail Elevation

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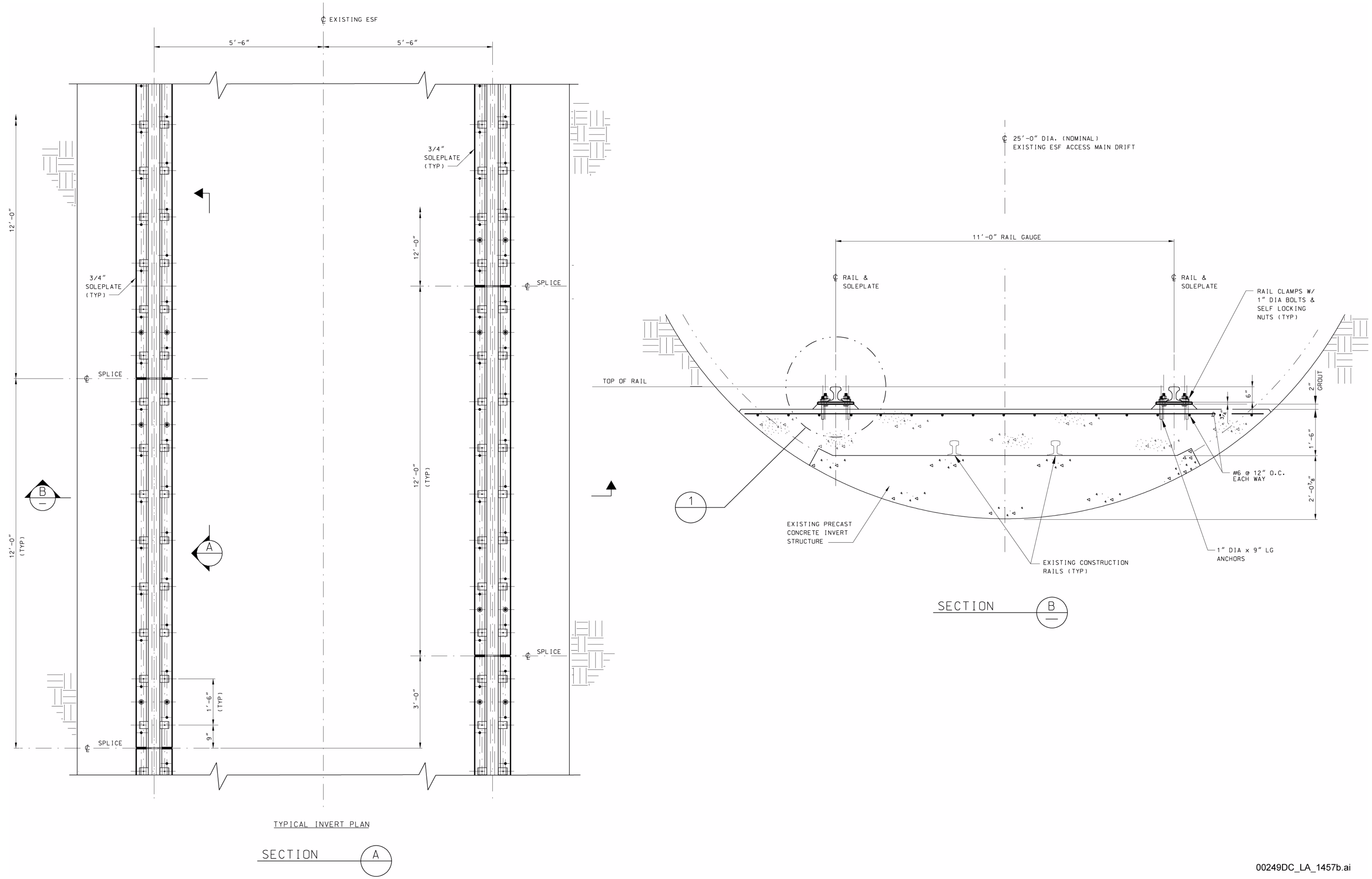

Figure 1.3.3-32. Access Main Invert and Rail Sections

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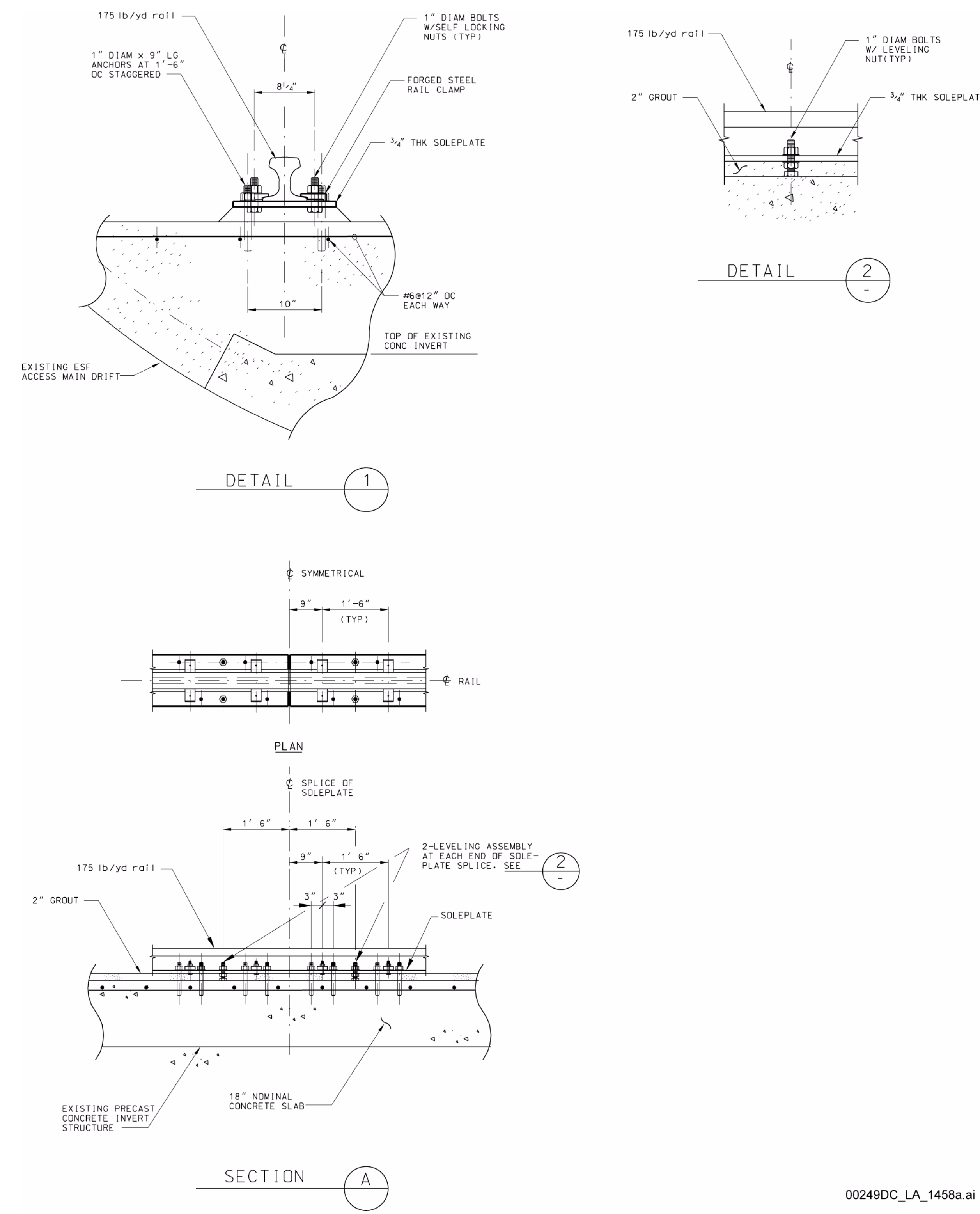

Figure 1.3.3-33. Access Main Invert and Rail Sections and Details

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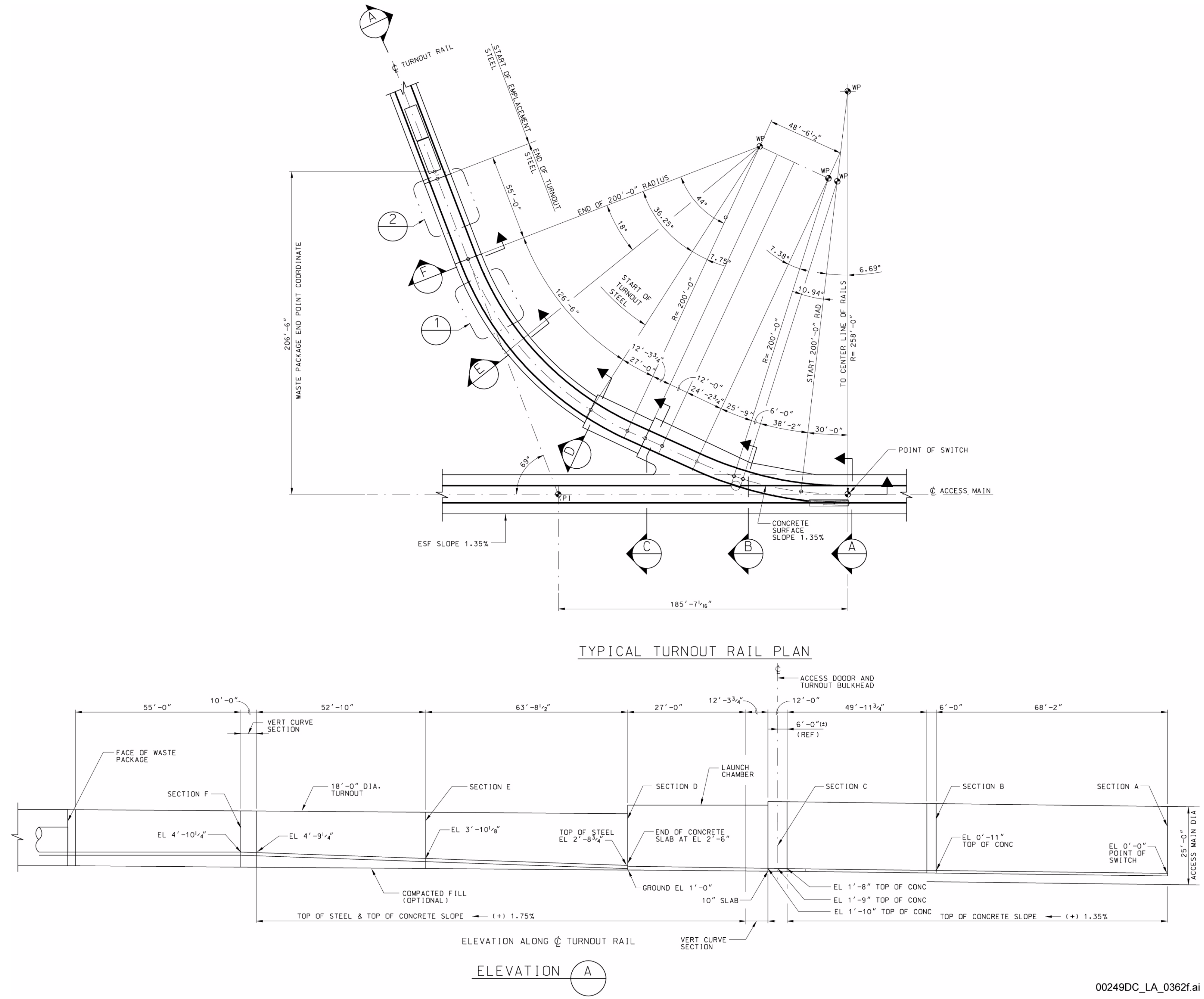

NOTE: 69° angle shown in this figure defines the emplacement drift alignment relative to the alignment of the access main, for a typical turnout configuration in Panels 1 and 2, and it is not the emplacement drift azimuth.

Figure 1.3.3-34. Cross Section Locations for Invert Structure and Rail Designs for Turnouts

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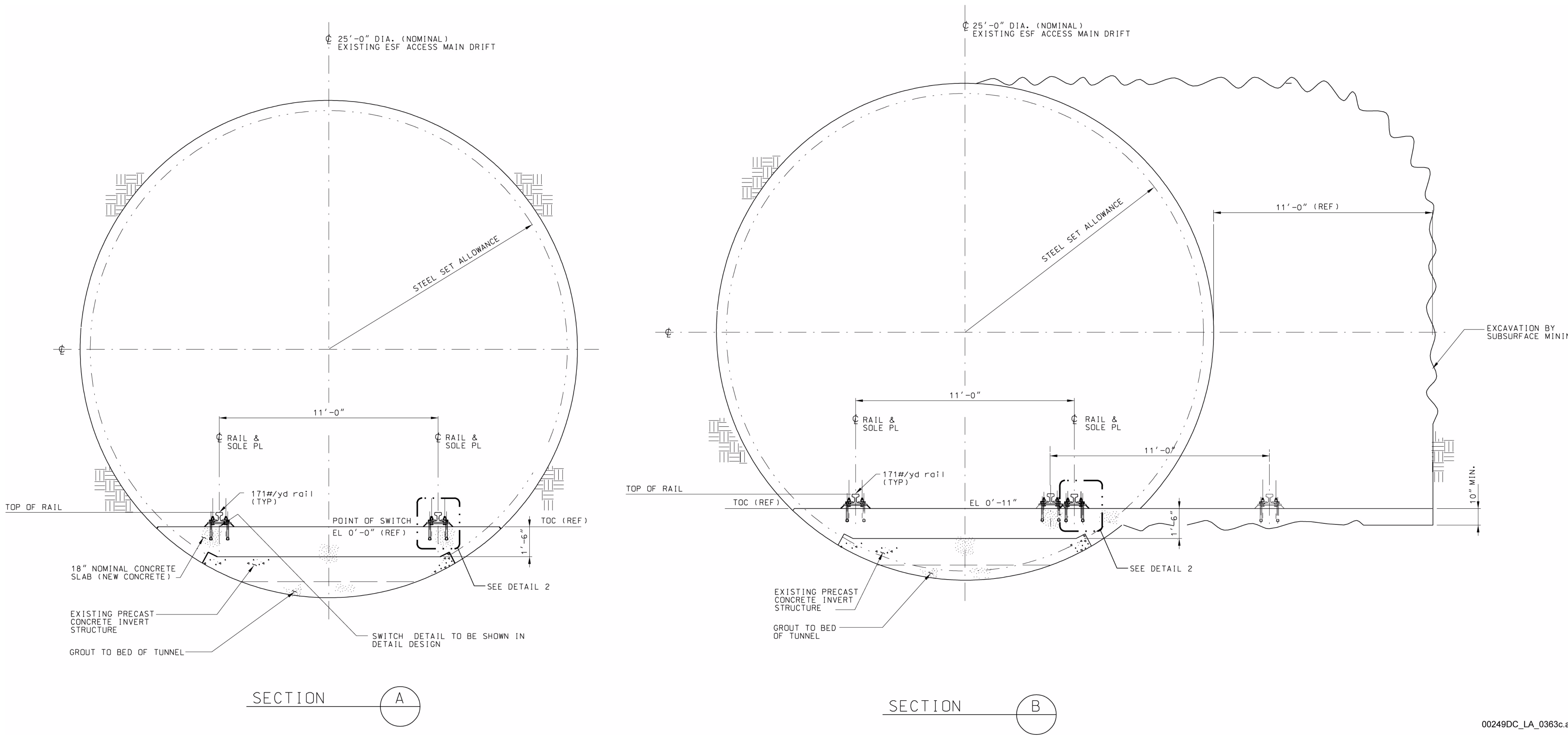

Figure 1.3.3-35. Invert Structure and Rail Designs for Access Main and Access Main-Turnout in Area of Rail Switch

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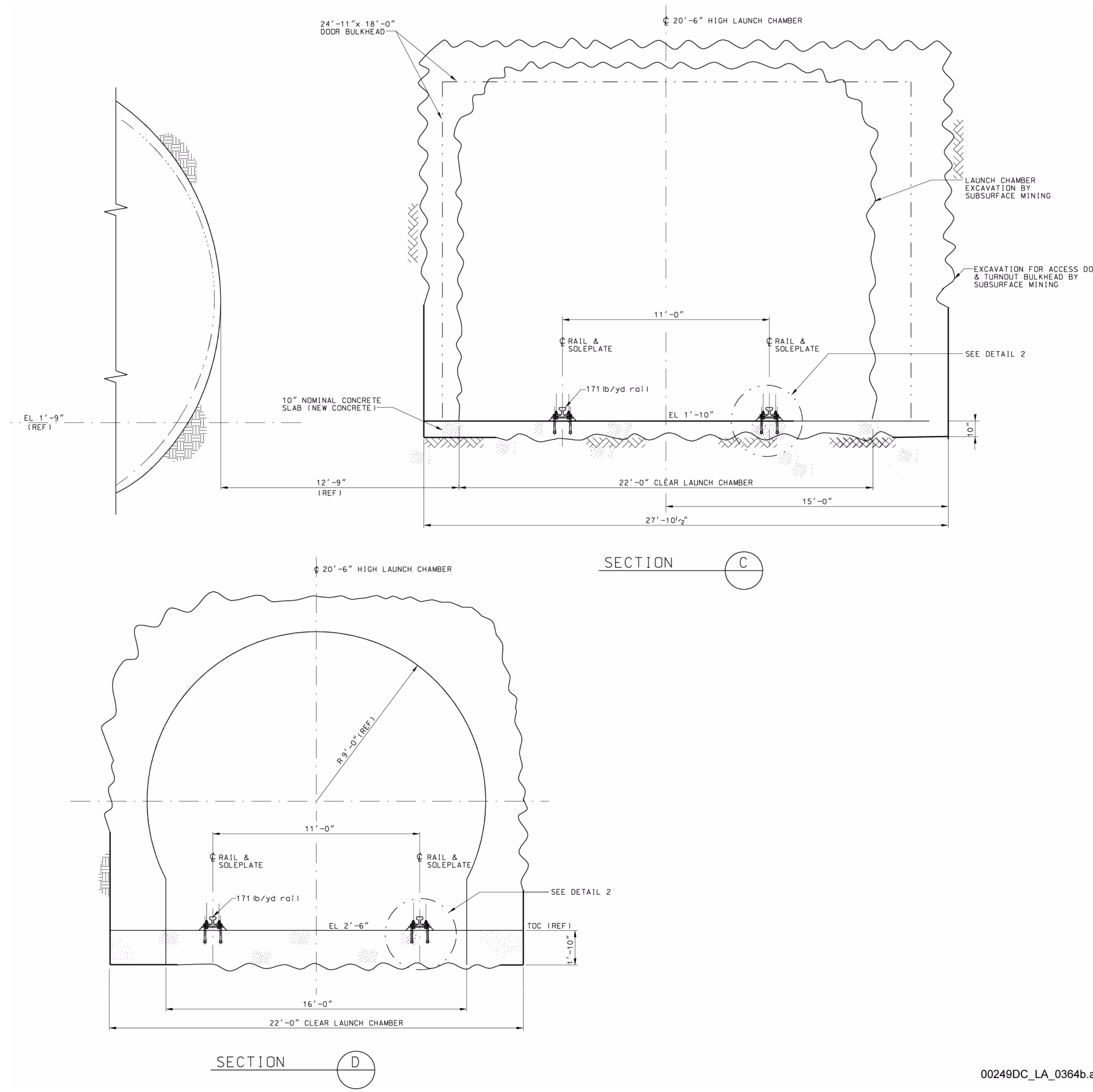

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Figure 1.3.3-36. Invert Structure and Rail Designs for Areas of Turnout Bulkhead and Tunnel Boring Machine Launch Chamber

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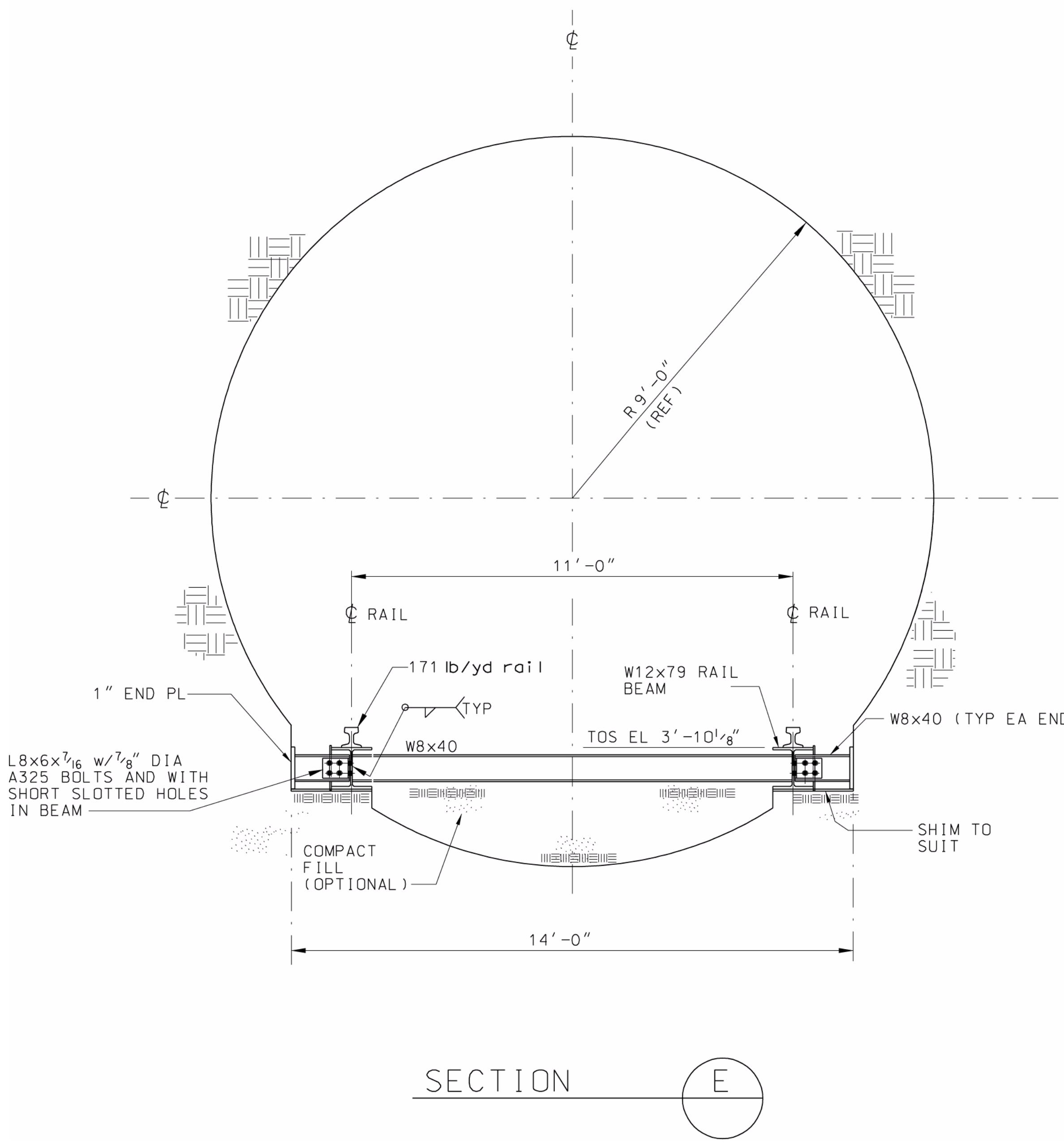

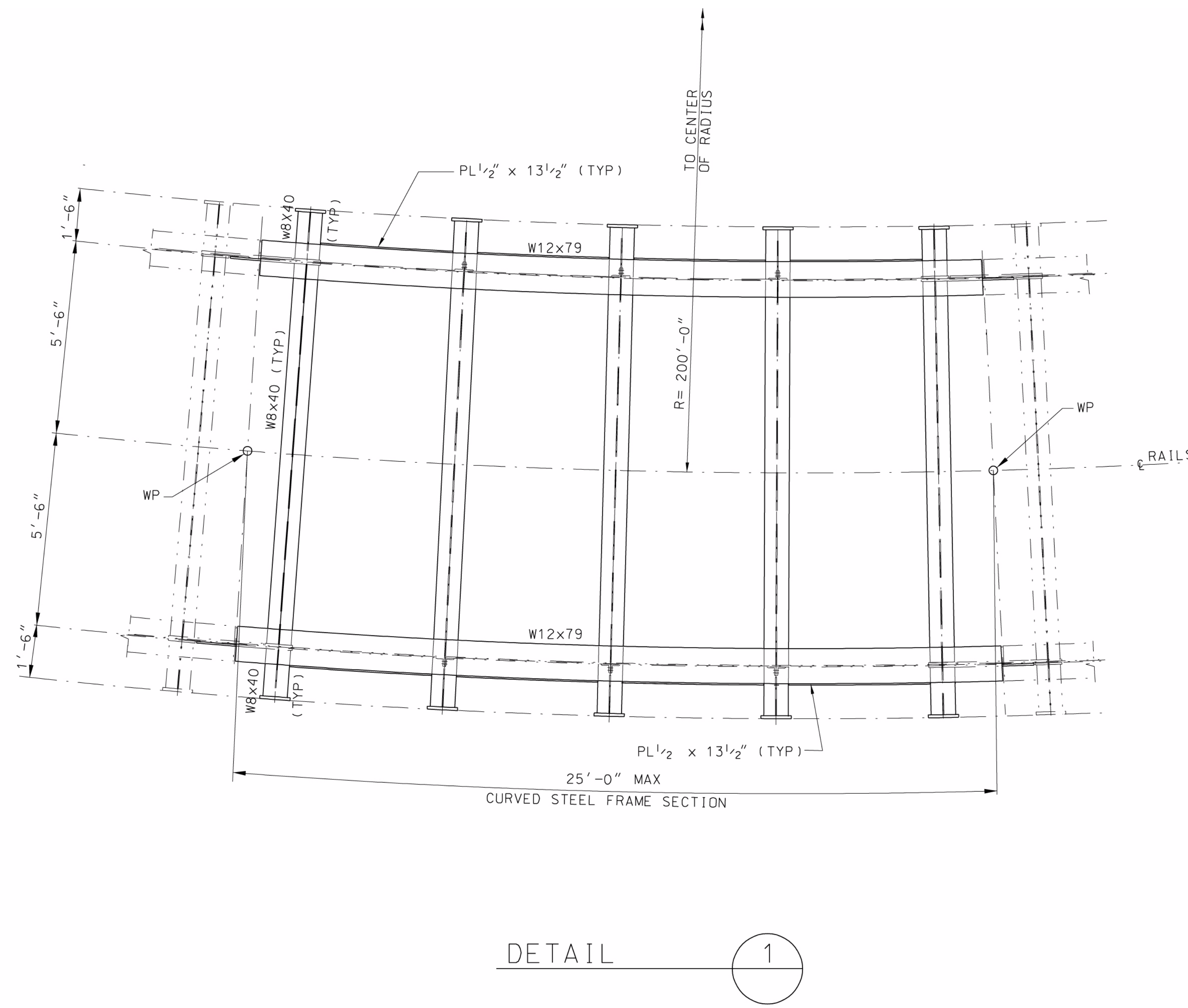

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NOTE: WP = Work Point.

Figure 1.3.3-37. Invert Structure and Rail Designs in Curved Section of Turnout

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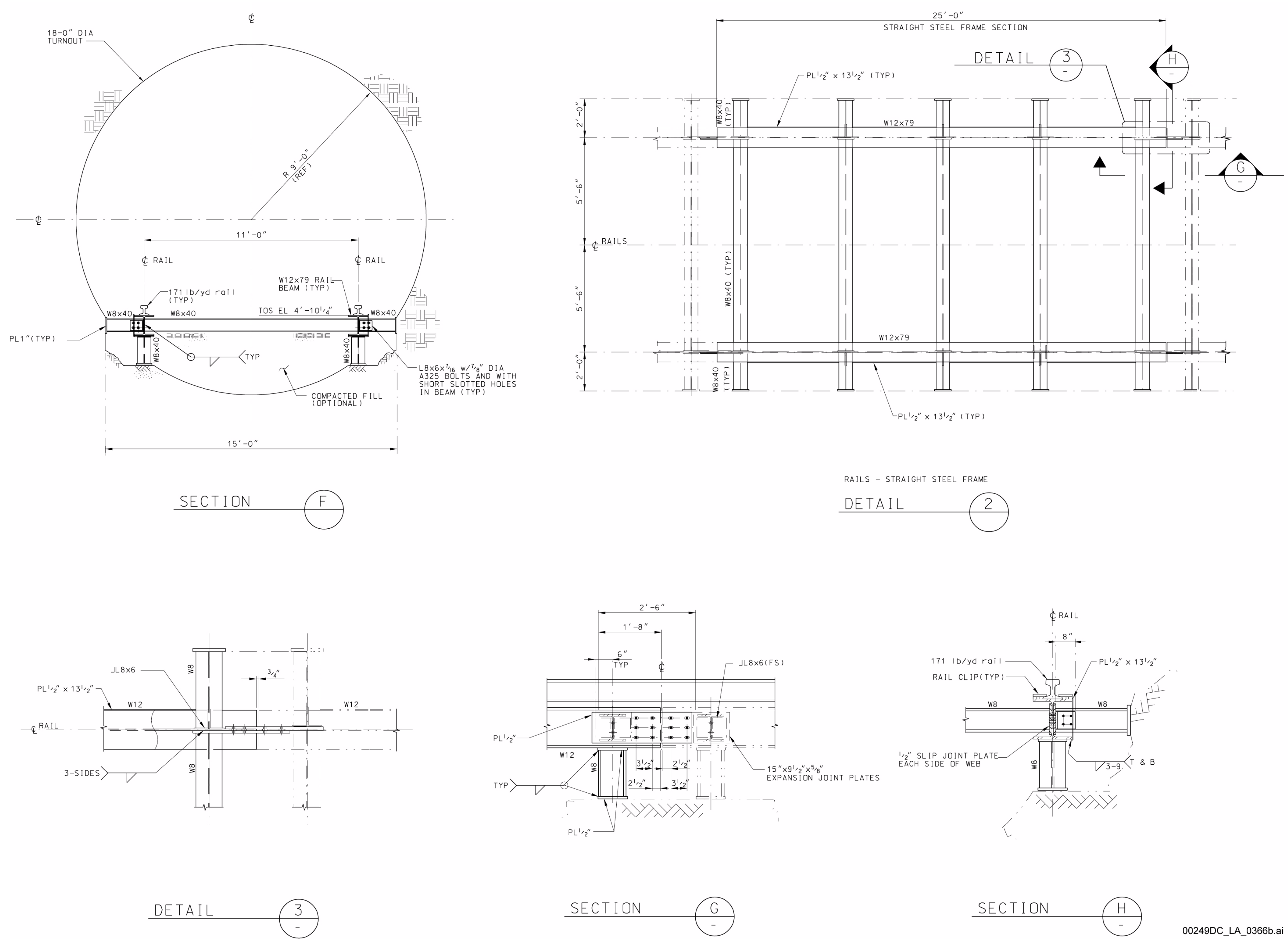

Figure 1.3.3-38. Invert Structure and Rail Designs and Details in Straight Section in Approach of Turnout to Emplacement Drift

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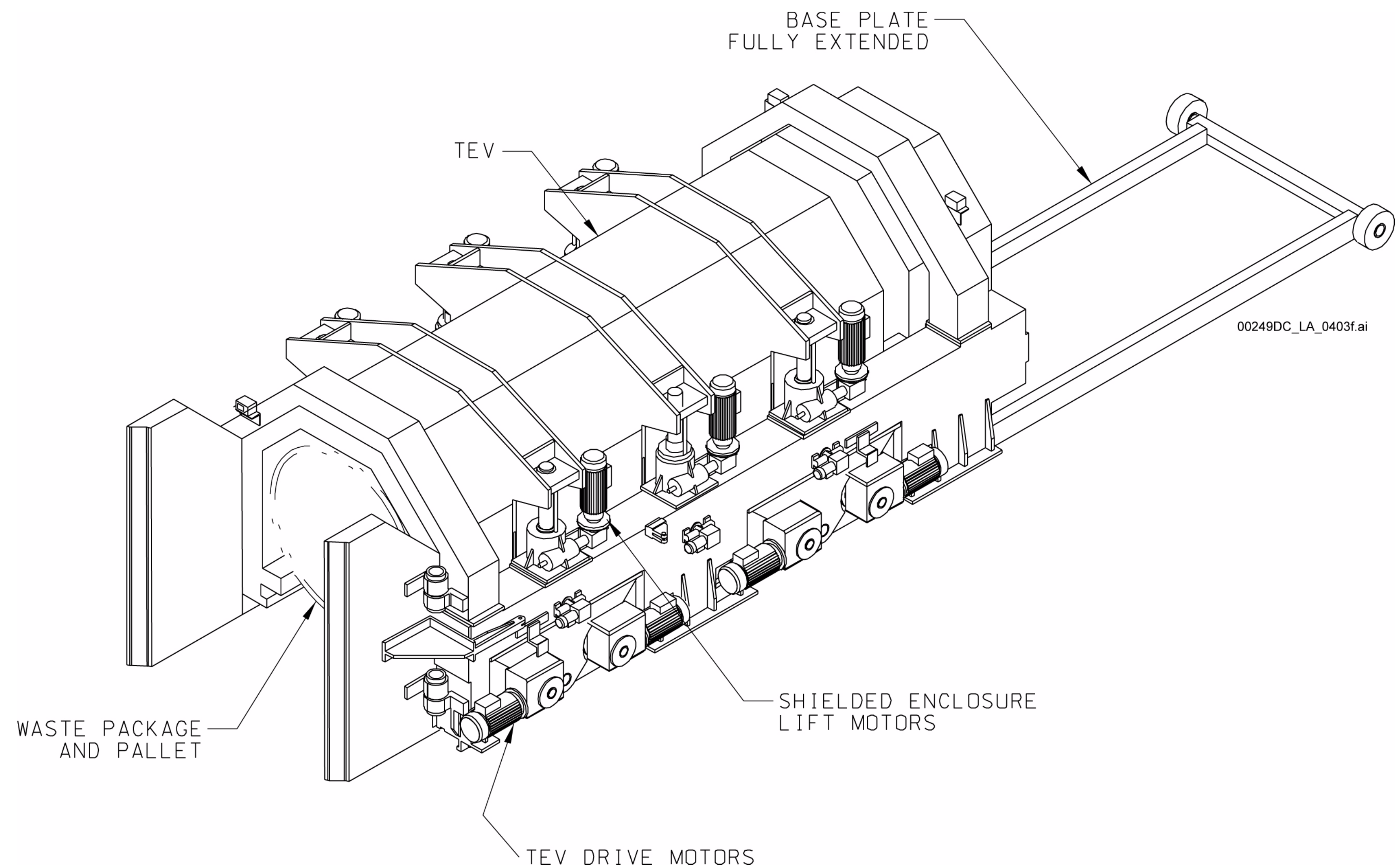

NOTE: Third rail is not shown.

Figure 1.3.3-39. Transport and Emplacement Vehicle Configuration

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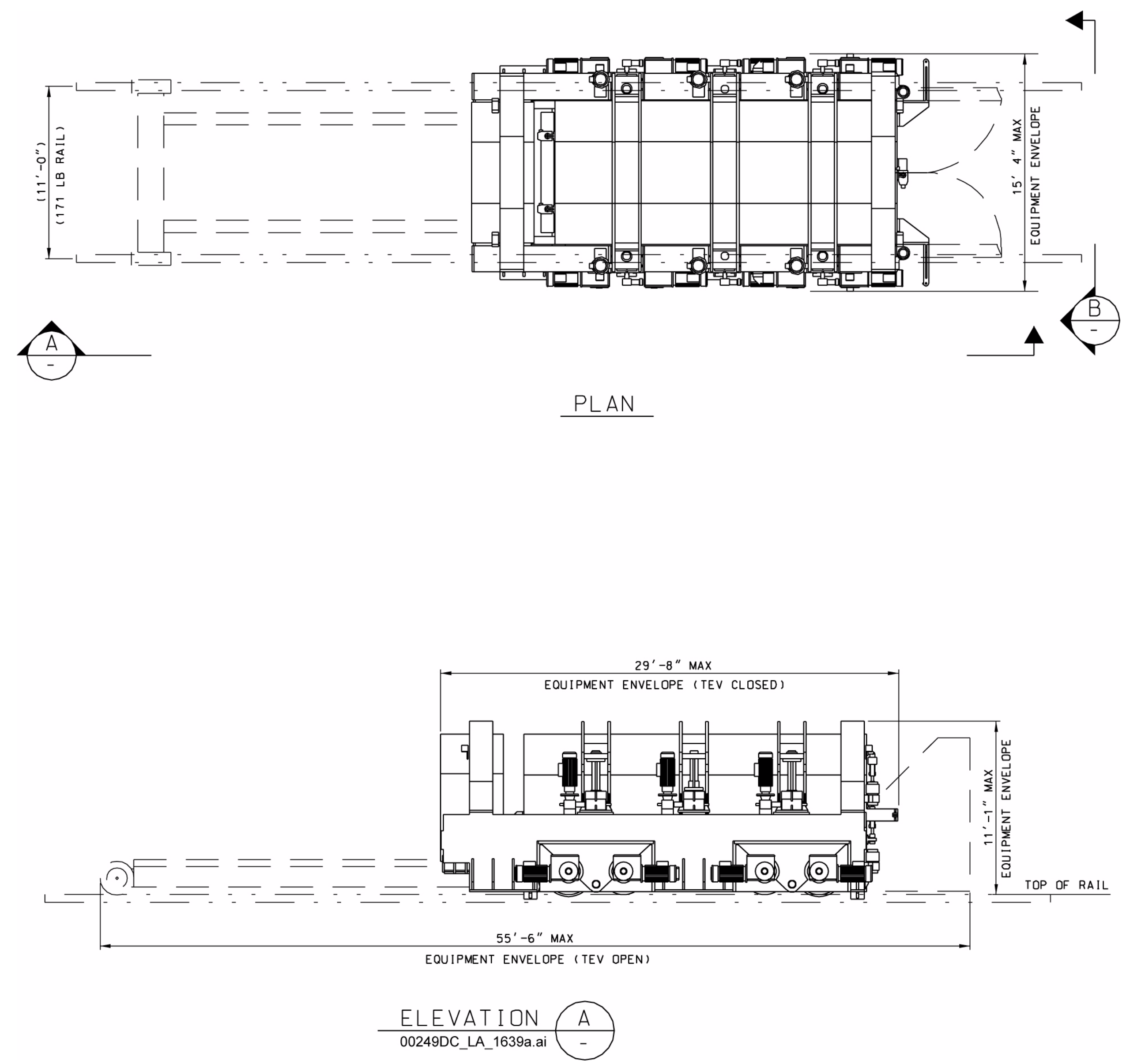

NOTE: The above Plan view "B" of the TEV illustrating the waste package and pallet in the raised position is depicted in Figure 1.3.4-20.

Figure 1.3.3-40. Transport and Emplacement Vehicle Plan and Elevation Views

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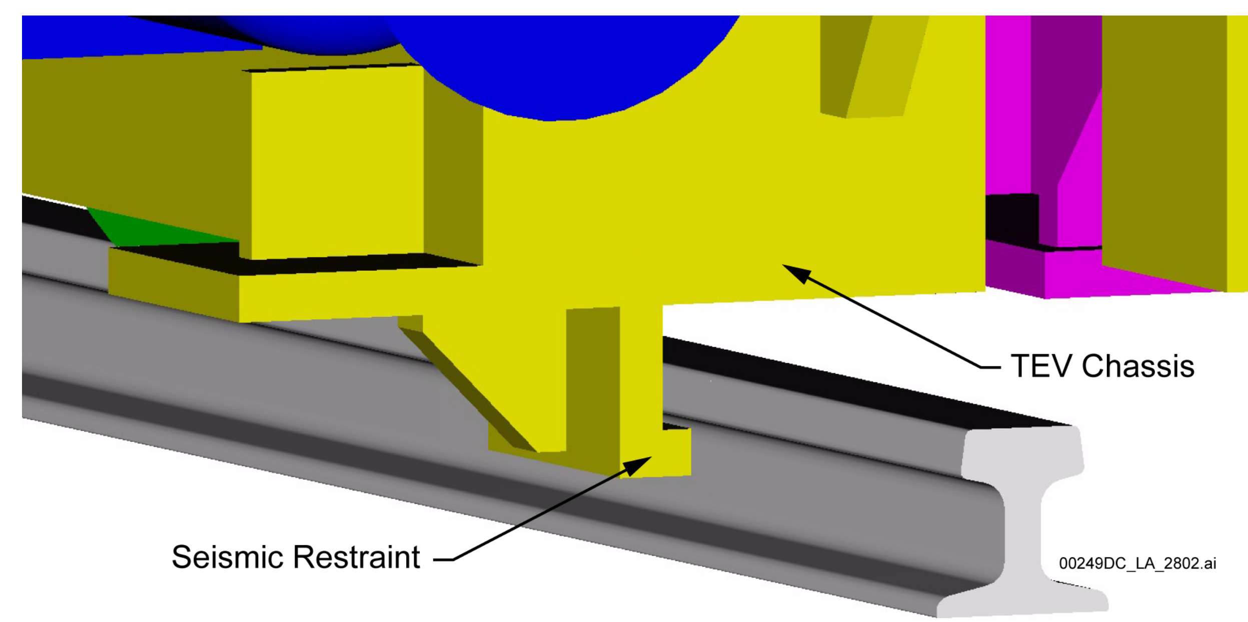

Figure 1.3.3-41. Transport and Emplacement Vehicle Seismic Restraints

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NOTE: Numbers in the blocks are step numbers indicating the mechanical handling flow path sequence shown by the arrows. The function is described in the block below the step number.

Figure 1.3.3-42. Waste Package Transportation Mechanical Handling Sequences and Operations

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