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BSC

Design Calculation or Analysis Cover Sheet

Complete only applicable items.

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2. Page 1 of 71

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7. Document Status Designation

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8. Notes/Comments

This analysis incorporates information from and supersedes previously issued calculation No: 800-P~~O~~aC-MGR0-00200-000-00B. BCG, 1/24/08

This report supports License Application and is not intended for construction, procurement, or fabrication.

The revision bars are not used due to extensive revisions.

This document has color figures

Attachments	Total Number of Pages
None	

RECORD OF REVISIONS

9. No.	10. Reason For Revision	11. Total # of Pgs.	12. Last Pg. #	13. Originator (Print/Sign/Date)	14. Checker (Print/Sign/Date)	15. EGS (Print/Sign/Date)	16. Approved/Accepted (Print/Sign/Date)
A	Issued to support LA. The DI was changed to reflect the Subsurface Ventilation reorganization into Subsurface Engineering. Revisions reflect reference updates, LA terminology consistency, and procedural related changes.	78	78	Bharat Gandhi 9/26/07	Jeff Steinhoff 9/26/07	Hang Yang 9/26/07	Robert Saunders 9/26/07
B	LA Committed. Revised to incorporate CR 11410, changes in references and other numerous editorial changes.	80	80	Bharat Gandhi 12/14/07	Jeff Steinhoff 12/14/07	Hang Yang 12/14/07	Robert Saunders 12/14/07
C	LA Committed. Revised to incorporate change in air temperatures due to higher Thermal Loads, changes in references and other numerous editorial changes. Ventilation system airflows and motor horsepower removed and are now part of Network Model for LA calculation.	71	71	Bharat Gandhi BCGandhi 1/24/2008	Jeff Steinhoff 1/24/2008	Hang Yang Hang Yang 01-24-2008	Robert Boutin Robert Boutin 1/24/08

DISCLAIMER

The analysis contained in this document is developed by Bechtel SAIC Company, LLC (BSC) and is intended solely for the use of BSC in its work for the Yucca Mountain Project (YMP).

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ACRONYMS AND ABBREVIATIONS

Acronyms

ACGIH	American Conference of Governmental Industrial Hygienists
ALARA	as low as reasonably achievable
AMR	Analysis Model Report
BOD	Basis of Design
BSC	Bechtel SAIC Company, LLC
DIRS	Document Input Reference System
DOE	U.S. Department of Energy
ESF	Exploratory Studies Facility
FHA	Fire Hazards Analysis
HEPA	High efficiency particulate air (filter)
ITS	Important to Safety
ITWI	Important to Waste Isolation
LA	License Application
MGR	monitored geologic repository
MSHA	Mine Safety and Health Administration
NVP	natural ventilation pressure
PC	Performance Confirmation
PDC	Project Design Criteria
TBM	tunnel boring machine
TAD	Transport Aging and Disposal
TEV	Transport and Emplacement Vehicle
TLV	threshold limit value
WP	waste package

Abbreviations

°C	Degrees Celsius
cfm	Cubic feet per minute
CO	Carbon monoxide
°F	Degrees Fahrenheit

ft (ft^2)	Feet (square feet)
fpm	Feet per minute
Hp	Horsepower
in. wg.	Inches of water gauge
kW/m	Kilowatt per meter
m (m^2)	Meter (square meter)
m/s	Meter per second
m^3/s	Cubic meter per second
Mrem	Millirem
Rh	Relative humidity
T	Degrees Kelvin, absolute
td	Dry bulb (temperature)
tw	Wet bulb (temperature)

1. PURPOSE

The purpose of the *Subsurface Construction and Emplacement Ventilation* analysis is to summarize and identify current design information provided in other Subsurface Ventilation System design products that provide the design to comply with Basis of Design (BOD), Project Design Criteria (PDC), and other industry standards. These design documents provide technical information necessary to support License Application (LA). The scope of this analysis is to provide adequate descriptions and design information for the structures, systems, components, and equipment.

The subsurface ventilation system meets applicable subsurface ventilation design requirements and supports the waste isolation strategy. The design of the subsurface ventilation system will be consistent with applicable criteria, codes and standards normally used in the underground mining industry.

This revision incorporates information from and supersedes the previously issued *Subsurface Construction and Emplacement Ventilation* calculation No: 800-POC-MGR0-00200-000-00B.

2. REFERENCES

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2.3 DESIGN CONSTRAINTS

None.

2.4 OUTPUTS

This document summarizes the the Subsurface Ventilation System and is performed to support information in the License Application (LA).

3. ASSUMPTIONS

This section contains assumptions used in this calculation and the rationale for use.

3.1 ASSUMPTIONS THAT REQUIRE VERIFICATION

None.

3.2 ASSUMPTIONS NOT REQUIRING VERIFICATION

None.

4. METHODOLOGY

The conceptual design information provided in various Subsurface Ventilation System design products are reviewed and pertinent information to support LA are summarized in this document.

4.1 QUALITY ASSURANCE

The calculation was prepared in accordance with the procedure EG-PRO-3DP-G04B-00037, *Calculations and Analyses* (Reference 2.1.1). The *Basis of Design for the TAD Canister-Based Repository Design Concept* (Reference 2.2.2, Section 22.1.2) has classified the subsurface ventilation system consisting of the emplacement ventilation subsystem and development ventilation subsystem as non-ITS, non-ITWI, and non-safety category (non-SC). Therefore, the approved version of this calculation is designated QA: N/A.

In three cases, Information Exchange Drawings were used to determine data values and other information. *IED Emplacement Drift Configuration and Environment* (Reference 2.2.33) was used to determine the air temperature at the end of 600 m long emplacement drifts; and to verify the emplacement drift airflow requirement. *IED Performance Confirmation* (Reference 2.2.34) was used to describe the Performance Confirmation Plan. Specific references to Data Tracking Numbers (DTNs) contained on the IED are made when the data is used in the calculation.

4.2 USE OF SOFTWARE

This report is prepared with the project standard software that is not subject to verification under IT-PRO-0011, *Software Management* (Reference 2.1.2). This calculation was prepared on central processing unit #501644. No routines or macros were utilized and computations using standard mathematical functions are documented in the body and are reproducible in a manual check without recourse to the originator.

Conversions

The following standard conversions are used:

$\pi = 3.14$
1 meter (m) = 3.28 feet (ft)
1 square meter (m^2) = 10.76 square feet (ft^2)
1 meter per second (m/s) = 197 feet per minute (fpm)
1 cubic meter per second (m^3/s) = 2,119 cubic feet per minute (cfm)
$^\circ F = (1.8 \times {}^\circ C) + 32$
$T = ({}^\circ C) + 273.15$ temperature Kelvin (absolute)

In this report, the term ‘volume’ is used to refer to the ‘volume flow rate of air’ and is stated in terms of cubic feet per minute (cfm). Air volumes are considered as ‘actual’ and not standardized to sea level. The final design and specification of fans would consider the appropriate density adjustments for elevation and temperature. The design airflow volumes are rationalized to the nearest 1,000 cfm. Temperatures are rationalized to the nearest 1/10th of a degree. The excavated drift dimensions are nominal designs.

4.3 ANALYSIS METHODOLOGY

This document presents the current the Subsurface Ventilation System design for LA. The document summarizes information from project documents, expanding the information to provide interfaces to other groups, and serve as a basis for detailed design during the post LA period.

This Subsurface Ventilation System design criteria and requirements reside in the *Basis of Design for the TAD Canister-Based Repository Design Concept* (Reference 2.2.2), the *Project Design Criteria Document* (Reference 2.2.24). *IED Performance Confirmation* (Reference 2.2.34) defines activities that interface with the Subsurface Ventilation System.

Mine Ventilation and Air Conditioning (Reference 2.2.37) and *Subsurface Ventilation and Environmental Engineering* (Reference 2.2.40) are industry recognized textbooks for subsurface ventilation design used to support this calculation. *The Handbook for Dust Control in Mining* (Reference 2.2.39) is a NIOSH publication that provides industry recognized dust control design principles.

The subsurface ventilation system design is based on the repository layout defined in the *Underground Layout Configuration for LA* (Reference 2.2.29, Figure 11) as illustrated in Figure 1. With respect to the layout configuration, this document supports terminology changes to rename Exhaust Raise #1 and Exhaust Raise #2 to Exhaust Shaft #4 and Exhaust Shaft #5, respectively.

The initial construction sequencing and airflow allocations described in the *Underground Layout Configuration for LA* (Reference 2.2.29) are supplemented by the *Subsurface Construction Strategy* report (Reference 2.2.11). The information describes development concepts based on the construction sequence, as it exists at this phase in the design. The development ventilation system will include contractor input and can be designed for any combination of excavation sequences and equipment and is not limited to the descriptions herein.

The *Post Closure Modeling and Analyses Design Parameters* (Reference 2.2.51, Table 1, Item 06-06) provides the derived constraint of 15 $m^3/s \pm 2$ m^3/s preclosure emplacement drift ventilation rate.

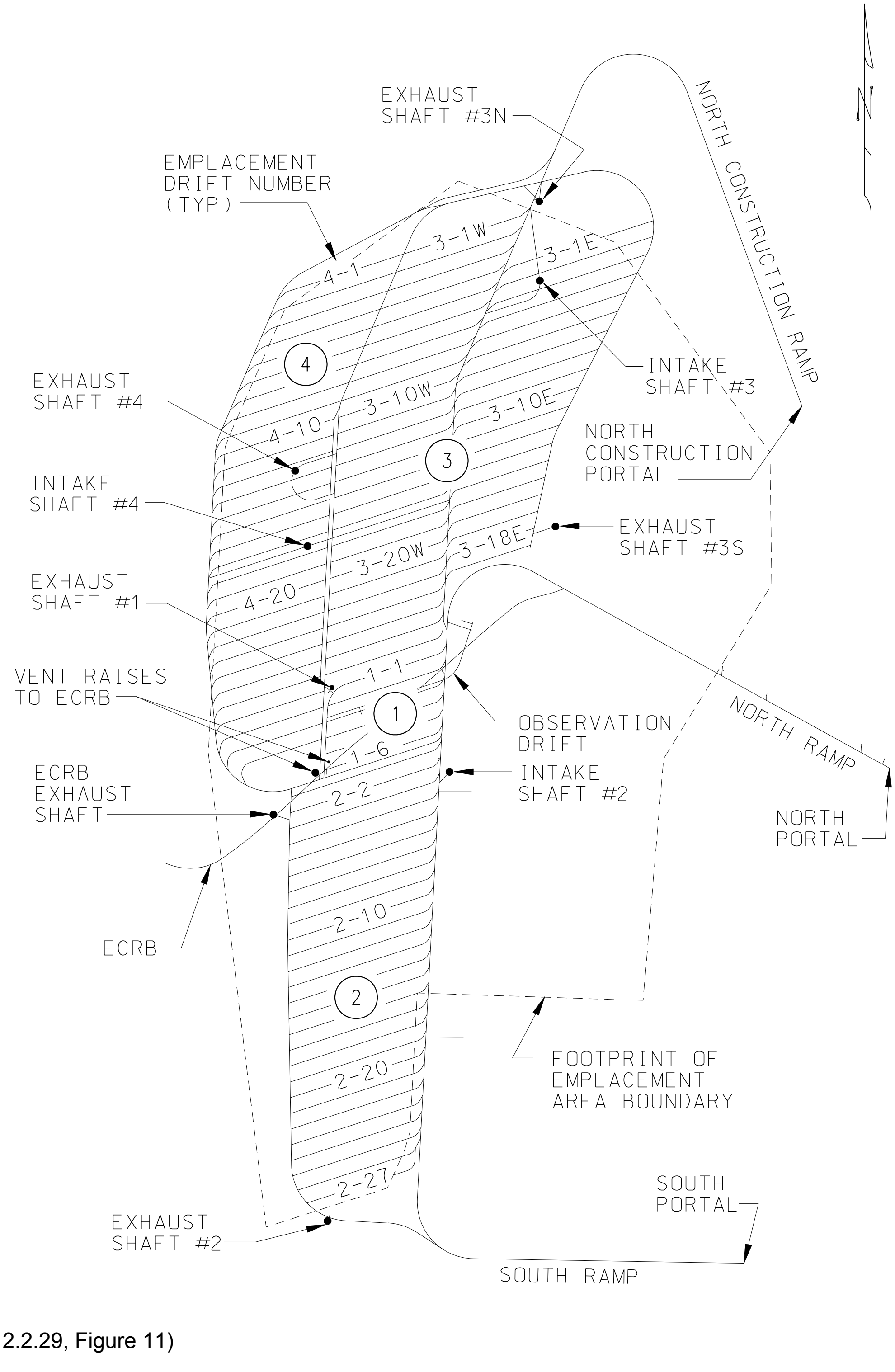
On October 25, 2005 DOE directed the project to accept canisterized fuel at the Yucca Mountain repository. The report considers that the impact to the subsurface repository design is to load all available emplacement drifts rather than keeping contingency drifts available. Drift quantity usage determines the emplacement ventilation system air volume. Emplacing waste over a larger number of emplacement drifts will provide a lower overall heat load and, therefore, existing documents and designs are bounding and valid for use here.

The emplacement drift quantities by panel numbers are listed in Table 1.

Table 1. Repository Drift Quantities

Location	**Emplacement Drift Quantity**
Panel 1	6
Panel 2	27
Panel 3 East	19
Panel 3 West	26
Panel 4	30
Total	108

(Adapted from Reference 2.2.29, Table 3)



(Reference 2.2.29, Figure 11)

Figure 1. Repository Layout Configuration for LA with Shafts and Portals

The subsurface ventilation design is based on a non-gassy (methane) mine classification. The ESF operation was established as non-gassy and the classification will remain for the repository. With the volcanic rock formations the potential for methane emission is remote and not considered an issue (Reference 2.2.30, Section 11).

The Subsurface Ventilation System design consists of two operationally independent and separate systems: the development ventilation system and the emplacement ventilation system. Isolation barriers separate the two ventilation systems. The systems use fans to circulate the ambient surface air throughout the subsurface development and waste package disposal areas and remove the exhaust air. This provides fresh air for a safe work environment and supports thermal management goals by ventilating and cooling emplacement drifts. The development ventilation system supports the excavation of subsurface openings and construction activities such as installing emplacement drift inverts, turnout bulkheads, isolation barriers, and the like. The emplacement ventilation system supports waste emplacement and ensuing forced ventilation and closure periods.

Although the system is located underground, some of the infrastructure may be housed or located on the surface. The ventilation system is designed with the flexibility to handle both normal and off-normal situations in the development and operational phases of the repository.

This report is presented in the following order:

- Subsurface ventilation system overview
- Components common to both the development and emplacement ventilation systems
- Development ventilation system
- Emplacement ventilation system
- Natural ventilation pressure
- Fire protection and emergency preparedness
- Closure and sealing
- Hazards analysis
- Output uncertainty

4.3.1 Ventilation System Structures and Components

The *Subsurface Emplacement Ventilation System Design Analysis* (Reference 2.2.14) provides information pertaining to the design, operation, and maintenance of the turnout bulkheads, emplacement access doors, and airflow regulators. The *Subsurface Emplacement Access Door and Bulkhead Arrangement for LA* (References 2.2.26 and 2.2.27) and *Subsurface Emplacement Access Door Airflow Regulator and Control Arrangement for LA* (Reference 2.2.25) provide the general arrangement information for the turnout bulkhead. The emplacement access door dimensions are based on the equipment envelope defined in the *Emplacement and Retrieval Transport and Emplacement Vehicle Mechanical Equipment Envelope* drawing (Reference 2.2.48).

The *Shaft Collars and Fan layout General Arrangement Analysis* (Reference 2.2.19) provides main fan general arrangement concepts.

The *Panel 1 Construction and Emplacement Ventilation Sequence* (Reference 2.2.45) information is obtained from *Underground Layout Configuration for LA* (Reference 2.2.29), *Panel 1 Ventilation Interface and Airflow General Arrangement* (Ref 2.2.16), *Subsurface Construction Strategy* (Reference 2.2.11) and *Isolation Bulkhead and Airlock Calculation* (Reference 2.2.44).

Subsurface emplacement ventilation composite airflow diagram, monitoring, and instrumentation (Reference 2.2.18) information is obtained from *Subsurface Ventilation Airflow Arrangement for LA Full Emplacement* (Reference 2.2.15) and *Subsurface Emplacement Ventilation System Design Analysis* (Reference 2.2.14).

4.3.2 Thermal Line Loads and Airflow

The *Post Closure Modeling and Analyses Design Parameters* (Reference 2.2.51, Table 1, Item 06-06) provides the derived constraint of 15 $m^3/s \pm 2$ m^3/s preclosure emplacement drift ventilation rate. The application of this airflow rate is shown in Table 2.

Table 2. Emplacement Drift Design Airflow Volumes

Air Volume (m^3/s) [a]	**Air Volume (cfm) b**	**Air Volume (cfm) (rationalized)**
13m³/s	27,547	28,000
15 m³/s	31,785	32,000
17 m³/s	36,023	36,000

NOTES: [a] See discussion in first paragraph of Section 4.3.2

[b] Volume (m³/s) x 2,119 (Conversions)

The subsurface ventilation system design incorporates meteorological information collected at the site (Reference 2.2.36). The USGS measuring Station 28+93 is located in the ESF Main Drift, near the center of Panel 1 and representative of the emplacement drift inlet conditions as listed in Reference 2.2.47, Input Tab Spread Sheet.

Table 3. Emplacement Drift Inlet Air Properties

Parameter	**Average Annual at ESF Station 28+93**
Dry Bulb Temperature (td)	73.0ºF (22.82ºC)

(Adapted from Reference 2.2.47, Input Tab Spread Sheet)

In subsurface openings the surrounding rock will transfer heat to and from the air and tend to moderate the air temperature to approximate the natural rock temperature. As a result, the air temperatures at the emplacement drift entrance will not have the extreme seasonal temperature swings seen in the ambient surface air.

4.3.3 Ventilation Network Model and Fan Capacities

In the *Ventilation Network Model for License Application* a commercially available program, VnetPC 2003, Version 1.0.0.1 program (software brand name hereafter referred to as VnetPC) was used to model the repository airflow with all drifts loaded (Reference 2.2.28, Section 4) with 2.0 kW/meter line load. The model is done using the LA layout (Reference 2.2.29, Figure 11) and calculating cross-sectional areas, perimeters, and shock losses for the repository openings. The network model considers all 108 emplacement drifts and the Observation Drift ventilated and provides a nominal emplacement ventilation system design volume. The VnetPC program solves a mathematical representation of the repository ventilation network.

The intake and exhaust airflow volumes are listed in Reference 2.2.28, Table 19 and the fan operating duties are listed in Reference 2.2.28, Table 18. Network model leakage at the isolation barriers and fans totaled 88,000 cfm, and the Observation Drift airflow volume was 46,000 cfm (Reference 2.2.28, Section 6.4). The blast cooling air volume for an emplacement drift is 100,000cfm (47.2 m^3/s) (Reference 2.2.25).

4.3.4 Air Velocity Guidelines

The air velocity guidelines listed in Table 4 are followed in the design of the subsurface facility. These are mining industry rule of thumb guidelines used to help control power costs and ensure personnel comfort. The guidelines are adequate for use to provide a check/balance indicator to the designer and, if the values are exceeded, it does not imply the design is unstable.

Table 4. Air Velocity Guidelines

Repository Opening	Area Described in Text	Velocity	
		Metric	**Imperial**[1]
Mains and Ramps	Muck Haulage Routes*	6 m/s* (max)	1,182 (1,200) fpm
Shaft Access Drifts, Access Main, Exhaust Main	Smooth lined airways* Personnel Access	8 m/s* (max)	1,576 (1,600) fpm
Intake and Exhaust Shafts, Raises	Ventilation Shafts*	20 m/s* (max)	3,940 (4,000) fpm
All Openings	Minimum velocity for human access	0.5 m/s	98 (100) fpm

*(Adapted from Reference 2.2.40 Table 9.1)

NOTE [1] Rationalized to the nearest 100 fpm

The 0.5 m/s (100 fpm) minimum air velocity used for construction activities to help control dust and equipment heat removal, exceeds the minimum regulatory standard of 30 fpm. For excavation requirements, the 0.5 m/s (100 fpm) velocity is increased to 0.76 m/s (150 fpm) (used in Section 6.3.1) and is consistent with historical ventilation design work for the ESF construction (Reference 2.2.31, Page 19).

4.3.5 Radiological Contamination Methodology

The *Potential Loss of Subsurface Isolation Barrier and Consequence Analysis* (Reference 2.2.23) demonstrates that potential contamination from an unlikely emplacement drift airflow reversal is not a safety concern.

4.3.6 Off-Normal Response Methodology

The *Thermal Calculation for Off-Normal Scenarios* (Reference 2.2.17, Section 6.3.2) examined a ventilation shutdown with no credit for natural ventilation, and a partial emplacement drift blockage.

The *Scoping Analysis on Sensitivity and Uncertainty of Emplacement Drift Stability* examined ventilation shutdown scenarios to determine the impacts on the ground support (Reference 2.2.8, Section 6.4.3). The report examined one-day, one-week, and one-month ventilation shutdowns at various times during preclosure. The Scoping Analysis considered a zero airflow scenario and didn't consider the natural ventilation influence.

5. LIST OF ATTACHMENTS

None.

6. BODY OF SUBSURFACE VENTILATION SYSTEM ANALYSES

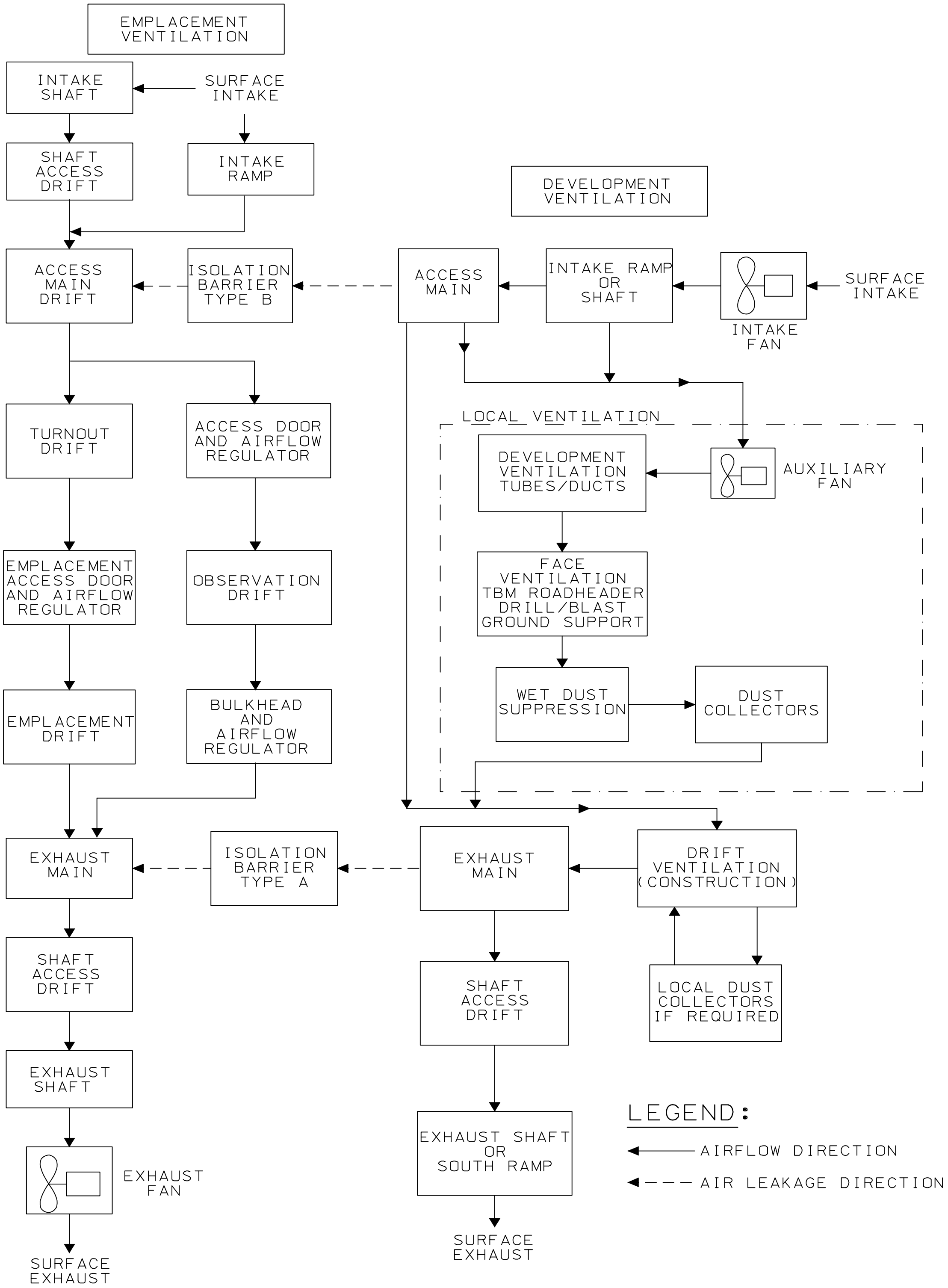
In a typical industrial ventilation system, such as an office, building, or factory, the ventilation system is designed for the end use. During facility construction, the ventilation is often based on ambient conditions. In buildings and industrial facilities the diameter of ventilation supply and return ductwork is used to help regulate the airflow. In contrast, the subsurface repository tunnels are equivalent to the ductwork and the diameters are based on their end use and do not change diameter in order to regulate airflow. With the access mains at 25 ft diameter and emplacement drifts 18 ft diameter, the airflow must be regulated to provide the proper emplacement airflow distribution. The repository airflow distribution is controlled using a bulkhead and regulator located in each emplacement drift turnout.

The repository Subsurface Ventilation System consists of two operationally independent and separate subsystems: the development ventilation subsystem and the emplacement ventilation subsystem. Each subsystem has independent airflow networks and fan systems that operate concurrently to provide air control. Isolation barriers physically separate the development and emplacement subsystems as shown in Figure 2. The ventilation flow is illustrated in Figure 7.

The development ventilation subsystem is a supply system and the emplacement ventilation subsystem is an exhaust system. This arrangement provides a higher relative air pressure on the development side than the emplacement side to prevent air infiltration from the emplacement side to the development side of the repository. This combination will ensure that in the event that one system shuts down, a pressure differential between the two systems will be maintained and any unlikely radioactive release is contained to the emplacement side. Hereafter the development and emplacement ventilation subsystems will be referred to as “systems” rather than “subsystems”.

The subsurface openings used by the ventilation system include the ramps, access and exhaust mains, turnouts, emplacement drifts, shafts, raises, and shaft access drifts. Subsurface Ventilation System components include ventilation fans, turnout bulkheads, isolation barriers, development ductwork, regulators, and instrumentation for control and management of the system. Although the system is located underground, some of the systems structures and components are located on the surface.

Fans circulate ambient surface air throughout the subsurface development and the subsurface waste package handling areas to provide fresh air for a safe work environment and to support thermal management goals by removing heat from emplacement drifts. The Subsurface Ventilation System will remove potential contaminants, such as silica, radon, smoke, and diesel particulates, to meet the air quality requirements. The ventilation system also removes moisture from the host rock by evaporation. Volumetric flow rates for the subsurface ventilation design are based on airflow considerations required by subsurface personnel, equipment operations, thermal performance management, and air quality control.



(Adapted from Reference 2.2.16)

Figure 2. Typical Development and Emplacement Ventilation Flow Diagram

The Subsurface Ventilation System operates throughout the development, preclosure, and closure periods to maintain a normal range of temperatures in the repository. The repository includes habitable areas, areas suitable for equipment use, and areas considered not normally accessed; and, therefore, there is no single set of normal temperatures that characterizes the entire operation. The ranges of temperatures expected in the subsurface are summarized in Table 5.

Table 5. Normal Range of Air Temperatures in the Repository

Subsurface Facility Areas	**Air Temperature Range, °C**	**Comment**
Access mains, and turnouts (habitable) [a]	14 – 32	N/A
Fully loaded emplacement drifts (uninhabitable) [b]	23 – 100	In-drift air temperatures vary per these parameters: location in drift (low values near drift entrance); emplacement drift length; and years of ventilation. NOTE: (a) 23°C is the emplacement drift inlet design temperature; (b) in-drift air temperatures are maintained below 50°C when emplacement equipment is operating.
Exhaust mains, shaft access drifts, and shafts (uninhabitable)[b]	42 - 100	Temperatures in these areas vary with extent of emplacement in a given area or panel, and years of ventilation.
Exhaust fans [c]	39 – 97	These temperatures reflect a 3-degree cooling per 1000-ft vertical ascent.

Source: [a] Reference 2.2.36, Trh07_02HydroData.xls

[b] Reference 2.2.50, Table 9

[c] Reference 2.2.40, Page 248

6.1 SUBSURFACE VENTILATION SYSTEM QA CLASSIFICATION

The Subsurface Emplacement Ventilation system is classified as “not important to waste isolation”, “not important to safety”, and the Safety Category is “Non-SC” (Section 4.1). Based on the QA classification, the subsurface emplacement ventilation system is not required to perform radiological release prevention or mitigation functions and thereby not subject to standby/backup and emergency power requirements. However, system components may need to be available to support emergency management, but they have not been detailed at this time.

There are no credible Category 1 or Category 2 event sequences identified that would result in a radiological release for subsurface facility operations. A waste package (WP) breach and leakage of radioactive material from a waste package are not credible events during preclosure.

Prior to transportation to the subsurface facility, waste package surfaces are surveyed for contamination and are decontaminated to below predetermined levels (Reference 2.2.35, Section 6.2). Releases of activated air and dust to the environment are considered part of normal subsurface operations (Reference 2.2.21, Sections 7.2 and 7.4).

The following subsections summarize information that demonstrates why the Subsurface Ventilation System is not relied on to prevent or mitigate thermal or radiological functions.

6.1.1 Periods of No Ventilation

Though the subsurface ventilation system is operated at a specified design volume to support thermal goals, analyses demonstrate that thermal goals are not exceeded from system shutdowns that may occur due to power loss, fan failure or replacement, or airflow blockage due to drift collapse. The following information demonstrates that the thermal limits are not exceeded if forced ventilation is lost for a one-month period.

The *Scoping Analysis on Sensitivity and Uncertainty of Emplacement Drift Stability* (Reference 2.2.8) examined the impact to ground support for various ventilation shut-off scenarios during the preclosure period. Thermal calculations were conducted for 1 day, 1 week, and 1-month ventilation shut-off cases, at various times during preclosure. Though there was a rapid increase in temperatures, the wall temperature did not exceed boiling (above 96ºC) for the 1-day and 1-week no-ventilation scenarios. The wall temperature did exceed boiling for the 1-month ventilation shut down period for a brief time, but only near the end of an 800 m long drift and localized near the drift crown. In all no-ventilation cases, the rapid increase in temperature diminished rapidly after ventilation was resumed. (Reference 2.2.8, Section 6.4.3). The Scoping Analysis considered a complete no-ventilation scenario (zero airflow) providing the worst-case condition, however, it didn't consider the natural ventilation influence that would keep airflow moving (see Section 6.5). As long as the repository airways remain open, the natural ventilation pressure would maintain airflow through the system and a true "no-flow" condition would not exist.

The *Thermal Calculation for Off-Normal Scenarios* (Reference 2.2.17) determined how long the ventilation system could be shut down before thermal design requirements were violated. The calculation parameters included a complete ventilation shutdown, a shutdown with natural ventilation in effect, and a partial blockage drift collapse. It was determined the cladding temperature was the driving thermal parameter. The calculation concluded forced ventilation could be lost to any particular emplacement drift for a period of approximately 0.4 years (4.8 months) before cladding temperature limits were reached for an 800 m long drift. For a ventilation shutdown accounting for natural ventilation, the calculation determined an airflow rate of as little as 5 m^3/s (8,500 cfm) is sufficient to ensure the fuel cladding design criterion is met for an 800 m long drift (Reference 2.2.17, Section 6.4.3). This information further demonstrates the subsurface ventilation system can be off for approximately 1 month without causing the thermal parameters to be violated.

The emplacement ventilation system utilizes six exhaust shafts with each shaft having two fans. A localized power outage would result in a loss of forced ventilation in the subsurface. The power supply to the ventilation fans is from two different normal electric power sources with a provision to supply power from a standby diesel generator (Reference 2.2.49). If a single fan were off due to maintenance or failure, there would be limited impact to the ventilation system as described in Section 6.2.1.4. There is sufficient time to restore the system, or portions of the system, to normal conditions before thermal limits are exceeded. It is reasonable to expect that forced ventilation can be restored in less than one month.

6.1.2 Drift Blockage

The *Thermal Calculation for Off-Normal Scenarios* (Reference 2.2.17) examined partial emplacement drift blockage and concluded the ventilation system is capable of maintaining the design airflow volume (32,000 cfm) for an emplacement drift that is 94% obstructed by rockfall (Reference 2.2.17, Section 6.4.2). Numerical modeling of the preclosure stability of emplacement drifts under in situ, thermal and seismic loading indicate that unsupported emplacement drifts are stable with only minor collapse possible. The worst-case rockfall scenario postulated for an unsupported emplacement drift created a 1.5% obstruction (Reference 2.2.17, Section 6.4.2), well below the 94% obstruction that would impact the airflow volume. Again, the modeling was for unsupported emplacement drifts, and emplacement drift ground support consisting of rockbolts and stainless steel surface sheeting is specified in the emplacement drift design. Therefore, during the preclosure period a significant collapse that prevents airflow is highly improbable. Only minor emplacement drift rock falls are expected from thermal and seismic loading (Reference 2.2.8, Section 7.1).

The subsurface repository configuration contains multiple fan installations, numerous intakes and exhausts airway paths, and interconnected access and exhaust mains as shown in Figure 7. If a section of access tunnel were to collapse, airflow can be rerouted through other main drifts and shaft airflow volumes can be adjusted to maintain the overall airflow.

6.1.3 Emplacement Drift Airflow Reversal and Access Main Radiation Dose

The system is designed to maintain emplacement drift airflow from the access main toward the exhaust main. The potential for an unlikely airflow reversal in a partially loaded emplacement drift was identified under extreme inlet air temperature conditions. The *Potential Loss of Subsurface Isolation Barrier and Consequence Analysis* (Reference 2.2.23) concluded that the resulting radiological dose in the turnout drift from an unlikely airflow reversal was determined to be negligible compared to the 100-mrem/year limits. The direct external dose rate for emplacement workers would not change due to the airflow reversal (Reference 2.2.23, Section 7).

6.2 COMPONENTS COMMON TO THE DEVELOPMENT AND EMPLACEMENT VENTILATION SYSTEMS

The following subsections describe components that are common to both the development and emplacement ventilation systems. The detailed design phase of the system components and structures has not started. As the design advances, the materials will be selected based on applicable standards and requirements. All primary components of the subsurface ventilation system are standard commercial grade components consistent with system Non-Q classification.

The subsurface ventilation system is designed to operate throughout the subsurface development and waste emplacement periods and during the post emplacement monitoring and repository closure operations, a period of up to 100 years. The subsurface ventilation system operates for a minimum period of 50 years after final waste emplacement to achieve the repository thermal conditions for initiation of the postclosure phase.

The subsurface development ventilation system interfaces with the repository subsurface facility electrical, safety and health, fire protection, and monitoring systems to provide adequate airflow for personnel underground. The system design considers dust, diesel particulates, and other potential airborne contaminants, heat control, and radon. The subsurface emplacement ventilation system interfaces with the electrical, monitoring and control systems, performance confirmation, safeguards and security, fire protection, and environmental safety and health systems, as shown in the subsurface emplacement ventilation and instrumentation diagram (Reference 2.2.18). Specific subsurface ventilation system interfaces and interface functions are summarized as follows:

- Compile and relay ventilation component information to Central Control Center
- Report fan and controls status to Central Control Center
- Data storage for ventilation monitoring equipment
- Video and voice communications

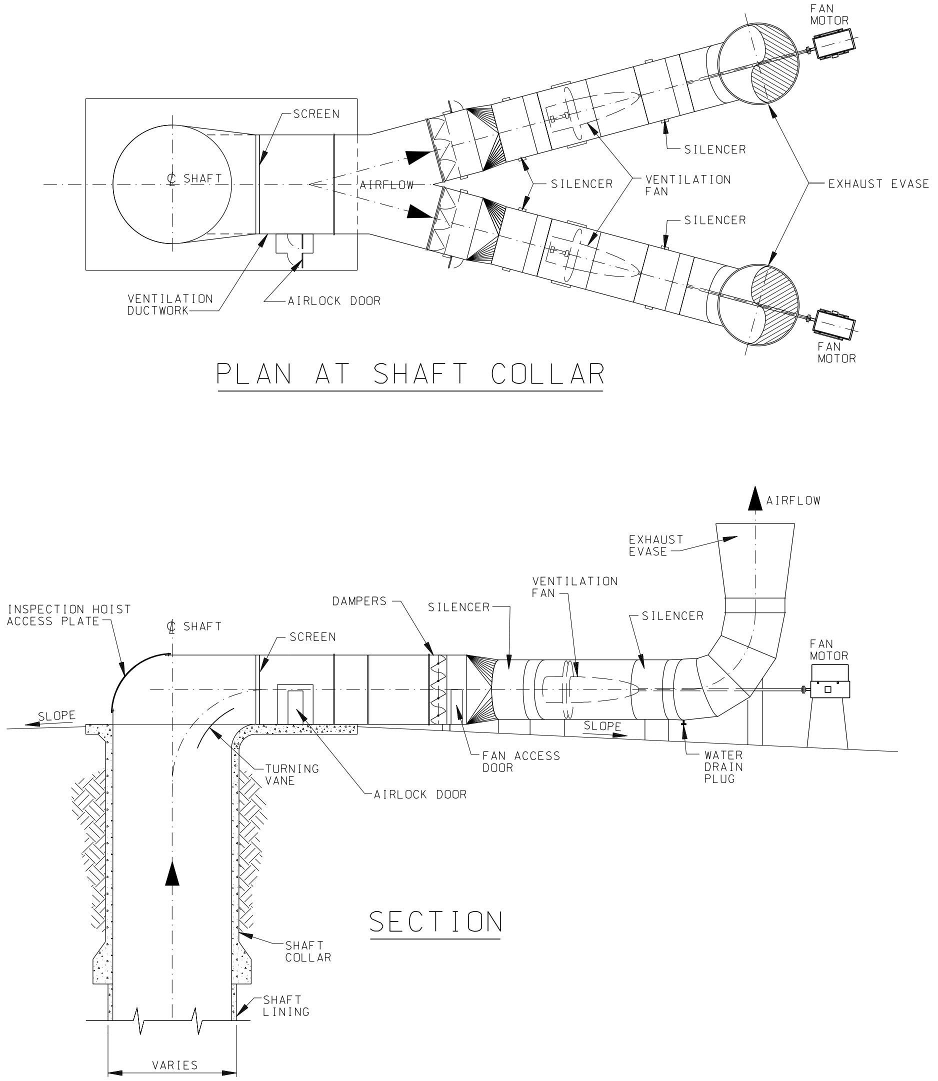
6.2.1 Main Fans

The main fans provide the means to produce and control the repository airflow for both the development and emplacement systems. The information in this section describes main fans as they apply to the emplacement ventilation (exhaust) mode, though similar concepts apply to the development ventilation (supply) mode. The design considers axial flow fans, though mixed flow axial fans are not precluded. The fan operating pressures and airflows are provided in *Subsurface Ventilation Network Model for LA* (Reference 2.2.28, Table 18). Note: booster or auxiliary fans are the smaller fans used to ventilate development areas, niches, or alcoves.

Shaft collar locations are selected on topography and an attempt to provide a repository airflow balance with consideration for the velocity guidelines listed in Table 4. The physical distance between shafts and portals prevents direct recirculation of intake and exhaust air. Normal releases of activated air and dust from the exhaust shafts are not a concern (see Section 6.4.13). The calculated worker dose from potential releases from the North Portal surface facilities was less than 2 mrem/yr, and any potential recirculation into the North Ramp would be diluted further. There are no safety and health issues related to using the North Portal as an intake source.

The exhaust main fans are located at the shaft collars with two fans capable of parallel operation as shown in Figure 3. Parallel fan installations are commonly used within the mining industry. Dual fans provide operational flexibility in that operating one or both fans, the airflow volume can be adjusted as emplacement progresses. When one of the dual fans is down for maintenance, the second fan maintains a reduced airflow in the effected area (see Section 6.2.1.4). Once the repository is fully emplaced, both exhaust fans on the large 26 ft. diameter shafts will operate in parallel, while the small 16 ft. diameter shafts would operate a single exhaust fan, with the second exhaust fan being a standby unit. Multiple and single fan operation characteristics are described in Reference 2.2.19, Section 6.4.

The design considers long-term operating efficiency by using a single ventilation sweep off the shaft and arranging the ductwork to provide smooth airflow patterns. The ventilation structures offset from the shaft collar ensure they do not interfere with other appurtenances and do not add significantly to the shaft collar load. The ductwork would be designed to support monitoring required by radiological, performance, or environmental groups. The shaft collar ductwork is constructed of steel and designed within applicable structural requirements. A louver at each fan provides for isolation of one fan while the other fan is in operation. The louver may also be used to vary the air volume, if required, during emplacement operations.



(Reference 2.2.19, Figure 6)

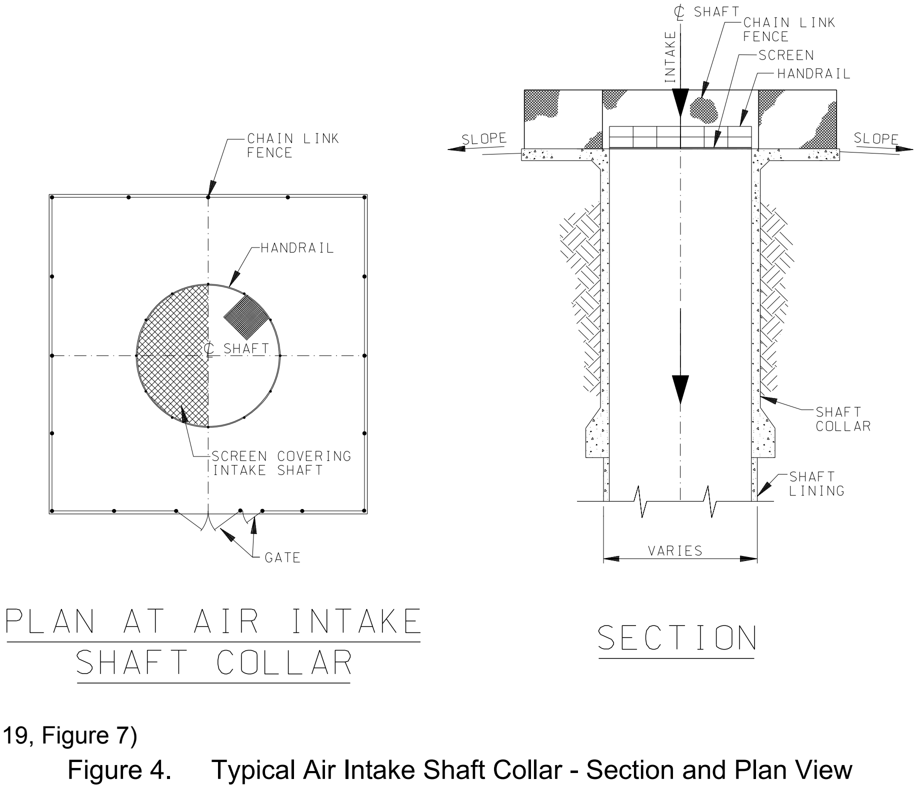
Figure 3. Typical Exhaust Fan Installation - Section and Plan View

The shaft collar design accommodates both development and emplacement use. The emplacement fan installation (exhaust mode) is illustrated in Figure 3. The development ventilation systems will include contractor input and a possible development fan installation. The contractor can use the fans in supply or exhaust mode during development, as desired. The shaft collar appurtenances (hoist, cage, etc.) are shown for illustration purposes and may be revised as shaft access requirements are defined further. A vertical fan discharge arrangement is illustrated in Figure 3. However, the installation can also be designed as a horizontal discharge depending on project preferences. The vertical discharge fan arrangement would result in a visible condensation related plume during the winter months. The vertical discharge design supports stack velocity calculations that may be used for dispersion modeling.

The exhaust shaft fans would be 10 ft diameter, based on volume and pressure requirements using commercially available axial vane fans (Reference 2.2.38). The diameter could be larger or smaller depending on designs from different suppliers. The variable pitch, axial flow fans driven by variable speed motors provide the flexibility to supply air to a varying number of emplacement drifts as operations advance over time. All main fans should be purchased from the same manufacturer and be identical in make and model in order to reduce design and maintenance requirements. As a minimum, the two fans at each shaft installation would be identical in make and model. Fan bearings and electronic components are industrial grade and have acceptable availability.

The emplacement ventilation fans located at the shaft collars exhaust the heated repository air; however, the projected operating temperatures (Table 5) do not require special equipment. A mix of emplacement drift outlet air temperatures, combined with natural cooling as the air rises and (not the maximum value at the emplacement drifts) would determine the exhaust shaft temperature. The determination of the fan inlet air temperature is not within the scope of this document for the current level of design detail.

Figure 4 shows a typical air intake shaft collar arrangement. The shaft collar is provided with handrail, screen covering and chain link fence for personnel safety to prevent a fall.



(Reference 2.2.19, Figure 7)

Figure 4. Typical Air Intake Shaft Collar - Section and Plan View

6.2.1.1 Design Requirements for Main Fan Installations

The main fan structures are classified as non-SC and will be designed to an International Building Code Seismic Group II design basis. The main fan structures, including ductwork, structural steel, concrete pads, foundations, and anchors, will be designed in accordance with this criterion to ensure that there will be no failure of the components due to a seismic event. The fans may trip off due to vibration, but could be restarted after determining the cause and subsequent equipment inspection and repairs, if necessary.

Shafts are located away from surface fault contacts, outside the zone of the maximum possible flood, and the shaft collar will slope away from the structure to prevent water inflow (Reference 2.2.19, Figure 6 and Figure 7). The fan ductwork design will consider applicable extreme wind, tornado, and volcanic ash fall design requirements. Components requiring maintenance will be located to facilitate personnel access where possible. The fan motors present an electrical energy hazard that will be designed within appropriate codes and standards. The main fan units are manufactured with steel housings and cast alloy blade assemblies that consider the impeller and blade rotational energy in the housing design.

6.2.1.2 Main Fan Operating Characteristics

The fans are designed to have enough power and capacity to exhaust the maximum amount of air that will be required during the emplacement, preclosure, off normal, and closure phases. The airflow volume at each exhaust shaft can be modified by (1) variable frequency drive motors, (2) operating one or two fans, or (3) by blade angle adjustments in the fan. The repository configuration includes multiple exhaust shafts and interconnected access and exhaust mains that will enable airflow to be redirected during off-normal events (Reference 2.2.19, Section 6.4).

By regulation, fans on the construction side must be reversible. As a result, booster and auxiliary ventilation systems will be designed with reversible features (see Section 6.3.1). It is possible to electrically reverse the airflow direction on the main construction fans. However, this would only occur with operations management approval and after personnel were evacuated from the subsurface or to a rescue chamber. The pressure differential across the isolation barriers must be maintained during this type of reversal. However, details describing how to maintain the pressure differential across barriers have not been developed at this time.

The main fan installation and repository designs consider long-term energy efficient operations. The *Ventilation Airflow Shaft Sizing and Energy Use* calculation considered construction costs, energy costs, design airflow, depth, and duration of operation to determine the most economical shaft diameters for the subsurface ventilation system (Reference 2.2.9, Sections 1 and 4). The report concluded that the 26-foot diameter shaft was the most economical choice for an airflow range from 650,000 cfm to 1,250,000 cfm with a depth ranging from 940 to 1,450 ft (Reference 2.2.9, Section 7). A shaft diameter of between 14 and 16 ft was determined as the economical choice (Reference 2.2.9, Section 7). The nominal fan horsepower requirements are provided in the *Subsurface Ventilation Network Model for LA* (Reference 2.2.28, Table 18). A 15% volume contingency is applied to the calculated nominal fan horsepower (Reference 2.2.28, Section 7.2.3) to account for potential variations in the repository operation, off-normal events, and other design changes.

A 900 Hp motor size (min) would be suitable for normal and off-normal airflow requirements for all ventilation fans. For design and interface purposes each fan motor would be 900 Hp, where two fans would be operating in parallel on the larger diameter shafts (1800 Hp total) and one fan operating (900 Hp total) on the smaller diameter shafts. A standard motor size and type would reduce warehousing and spares requirements.

6.2.1.3 Main Fan Monitoring and Maintenance

The main fan monitoring parameters include differential pressure, rotational speed, vibration, bearing temperature, and power status to allow potential operational problems to be identified and mitigated prior to a fan malfunction (Reference 2.2.19, Table 2). A main fan would shut down in a predictable fashion if sensors indicate a problem. Each main fan would incorporate recent technology for operating, remote start/stop, or speed adjustment features. The air stream entering the main fan would be monitored for flow rate, humidity, dry bulb temperature, carbon monoxide (CO), and dust for performance confirmation and permitting requirements (Reference 2.2.18). The system would accommodate any airborne radiological or environmental monitoring required at the exhaust fans.

There are typically monthly, semi-annual, and annual maintenance requirements for the main fans. The main fan motor, fan bearing lubrication fittings, starter, and assorted sensors are located outside the exhaust air stream and can be serviced without entering the ductwork. Dampers located at each fan inlet are intended for isolation during maintenance operations and not for airflow regulation. In order to service components that may be located inside the shaft collar ductwork, the fan would be shut down, isolated from the adjacent unit, and locked out. Spare component monitoring sensors would be warehoused on site.

Fan and motor maintenance requirements will follow manufacturer's recommendations that have not been defined at this time. As reviewed in Section 6.4.13, release of activated air and dusts to the environment are considered part of normal subsurface operations. These contaminants might settle out on the shaft collar ductwork and main fan components. Though the radiological contamination releases are within the regulated limits (Section 6.4.13), maintenance activities would consider potential contamination for both personnel access and disposal of materials.

With a program of maintenance, repair, and replacement, the ventilation fans would be available for the 100-year preclosure period, with the potential for up to 300 years of operation, if necessary. The ventilation system design has not evolved enough to determine the operational readiness, but from a conceptual operating strategy, and historical industry applications, typical maintenance activities would provide an inherent availability that exceeds 0.9825.

6.2.1.4 Main Fan Failure Mode

With multiple ventilation shafts having two fans, a single fan that is not operating because it is being maintained or because it has failed would not have a major impact on the repository air volume. The two fans are physically separated as shown in Figure 3 and a mechanical failure of one fan would not cause a failure of the adjoining fan. The air volume handled by the smaller diameter shafts do not require two fans operating and the second fan would be a back up. Though quantities have not been specified, a spare fan(s) and motor(s) would be warehoused locally for change out. Based on historical industry use, a fan or components could be changed out in less than one week (References 2.2.42).

As a characteristic of parallel fan installations, if one fan fails or is off-line for maintenance, the second fan could remain operational and produce approximately 70% of the original air volume (Reference 2.2.40, Page 349). Multiple and single fan operation are described in Reference 2.2.19, Section 6.4.

The ventilation system must respond to emergency and off-normal events. The access and exhaust mains between the panels are interconnected so the air can flow between panels, if necessary. The power supply to the ventilation fans is from two different normal electric power sources with a provision to supply power from a standby diesel generator (Reference 2.2.49). If a single fan were off due to maintenance or failure, there would be limited impact to the ventilation system.

6.2.2 Isolation Barriers

The ventilation system uses isolation barriers to separate areas of low potential nuclear contamination from zones having a high potential for nuclear contamination. The isolation barriers also prevent inadvertent access to high radiation areas by personnel. An isolation barrier consists of two bulkheads, airlocks, and related operating and monitoring components (Reference 2.2.10). Isolation barrier monitoring functions include door status and pressure differential. Performance confirmation, security, fire protection, emergency egress, monitoring, and off-normal access requirements have not been fully developed at this time, so this information is presented as conceptual. The following types of isolation barriers (Reference 2.2.44, Section 6.2) may be used in the repository:

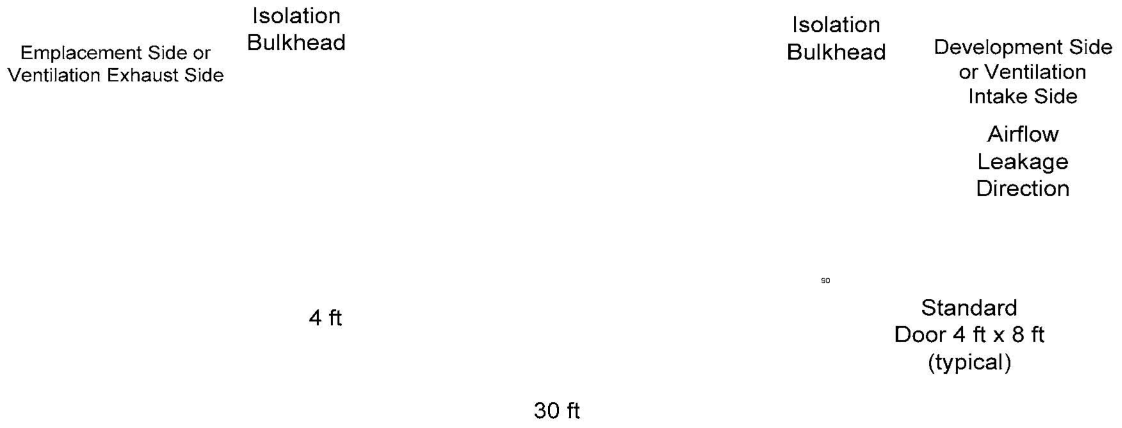
- Type A–Temporary isolation barrier that separates the main emplacement exhaust drift from the development areas. The barriers consist of two bulkheads; each has a locked access door to prevent unauthorized entry into the waste packages located at the exhaust side of the emplacement drifts. Type A isolation barriers are removable and transferable as the emplacement area expands. Type A barriers do not allow personnel emergency egress

- Type B–Temporary isolation barriers that separate the access main emplacement intake drift from the development areas. The barriers consist of two bulkheads; each has an access door to allow personnel emergency egress. Type B isolation barriers are removable and transferable as the emplacement area expands.

- Type C–Permanent isolation barriers that separate the repository ventilation exhaust from the intake system during the preclosure period. The barriers consist of two bulkheads; each has a locked access door to prevent unauthorized entry into the waste packages located in the emplacement drifts. Type C isolation barriers are permanent and do not allow personnel emergency egress.

The fire hazards analysis will determine the fire rating of the barriers (Reference 2.2.24, Section 4.9.3.9).

The bulkhead shape will vary with the opening dimensions. Isolation barrier components would be of a common design to reduce inventory, installation, maintenance, and repair costs. A typical isolation barrier with an access door/air lock installation is illustrated in Figure 5.



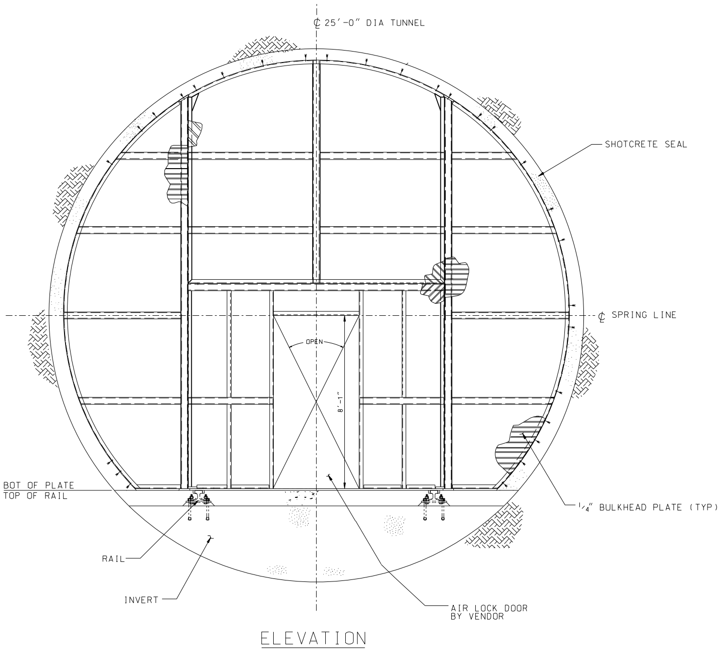
(Adapted from Reference 2.2.44, Figure 1)

Figure 5. Typical Isolation Barrier Arrangement

A typical isolation barrier consists of two bulkheads to ensure uninterrupted operation if one bulkhead is damaged. The cross section of a typical isolation barrier is shown in Figure 6. The two bulkheads are spaced a sufficient distance apart to form a chamber between them. The chamber length depends on the location and will be determined during final design. Access doors in the Type B isolation barriers would be self-closing and alarmed when opened. The Type A isolation barrier does not permit access. Therefore, the doors shown in Figure 5 could be replaced with bolt on plates that would prevent access and make the typical barrier shown in the figure a Type A barrier. Perimeter Intrusion Detection and Assessment System (PIDAS) control will be developed for the barrier arrangement in the future.

During the development phase, Type A and B isolation barriers are maintained between the development ventilation system and the emplacement ventilation system. The Type A and B isolation barriers are considered temporary and are installed/moved as the development effort progresses as discussed in Section 6.2.2.1. Figure 16 and Figure 17 illustrate the progression of the isolation barriers as Panel 1 is developed.

The third type of isolation barrier (Type C) is permanent and is installed in the access mains. The Type C barriers prevent the short-circuiting of intake airflow to the exhaust system; and, ensure access to high radiation and high temperature areas is restricted as shown in Figure 7. The Type C isolation barrier remains in place during the forced ventilation period. Performance confirmation will require access for remote equipment, so an access door is considered in the design, and secured to prevent personnel access under normal conditions. Figure 7 illustrates the Type C isolation barrier locations for the fully emplaced repository (all development complete).

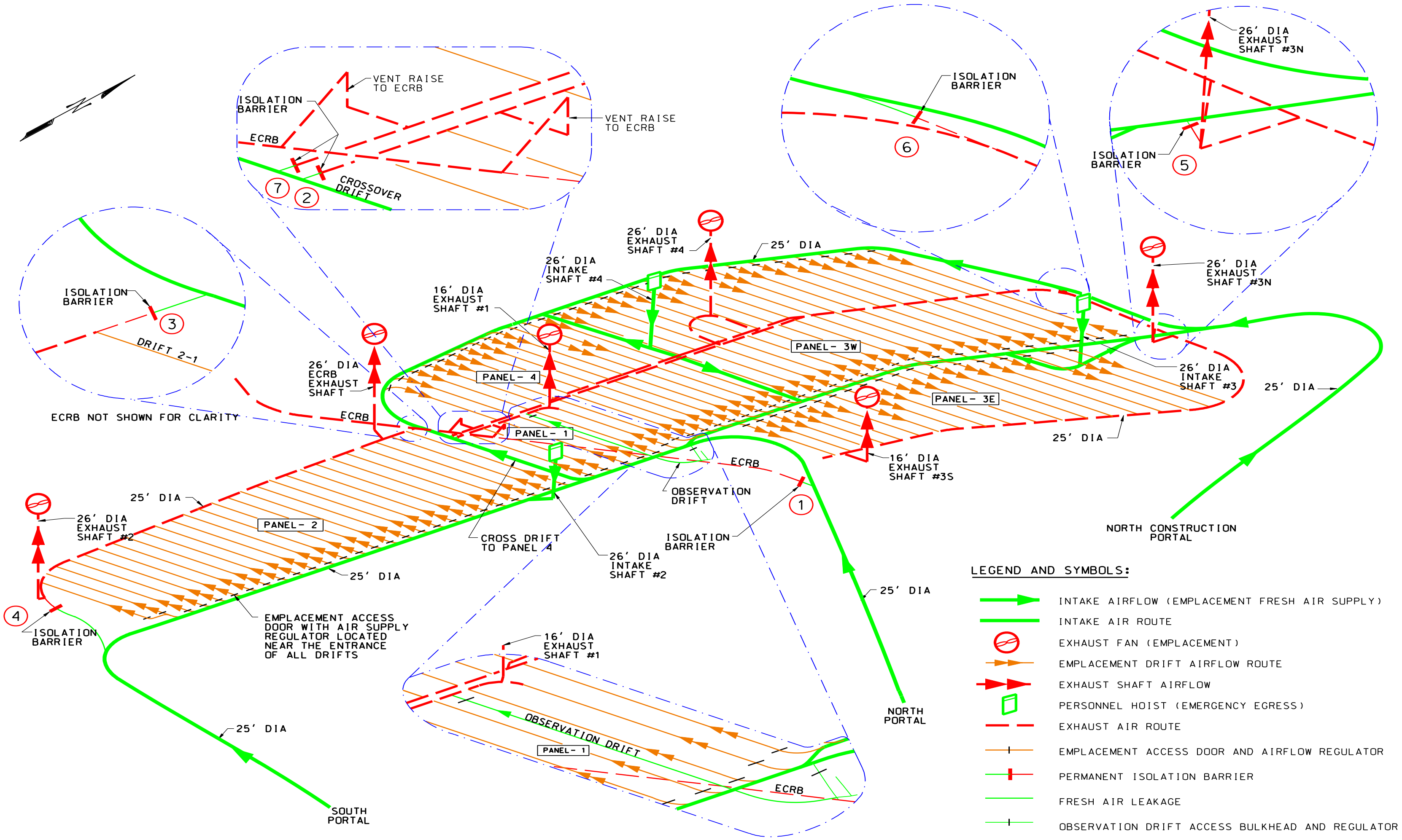


(Adapted from Reference 2.2.44, Figure 2)

Figure 6. Typical Isolation Bulkhead – Cross Section

The air pressure on the development side (supply system) would be higher than the air pressure on the emplacement side (exhaust system) forcing in any leakage to flow toward the emplacement side. A pressure differential of approximately 0.1 in. wg is maintained across an isolation barrier during normal operations. If the development ventilation system is off, the emplacement fans (exhaust mode) maintain the pressure differential. If the emplacement system is off, the development system (supply mode) maintains the pressure differential. If both systems are off, the natural ventilation pressure (Section 6.5) maintains airflow out the emplacement exhaust shafts.

The bulkhead structural design considers the ventilation system operating and fan stall pressures to establish steel construction of the isolation barriers. The isolation barrier design would be similar to the turnout bulkhead described in Section 6.4.2.1, fabricated from steel, and constructed in a modular fashion to facilitate construction and installation. Specified tolerances for the modular pieces would allow for field fitting at each location. The design will include ready-made penetrations and cutouts for fitting the structural frame and panels around the invert the rail, and to accommodate utilities as needed. Sealant is used around the periphery of the bulkhead to minimize leakage at the drift wall. Specialized equipment would reduce risk to construction personnel and ensure stability when installing bulkhead sections.



(Adapted from Reference 2.2.44, Figure 4)

Figure 7. Repository Airflow Arrangements with Permanent Isolation Barriers

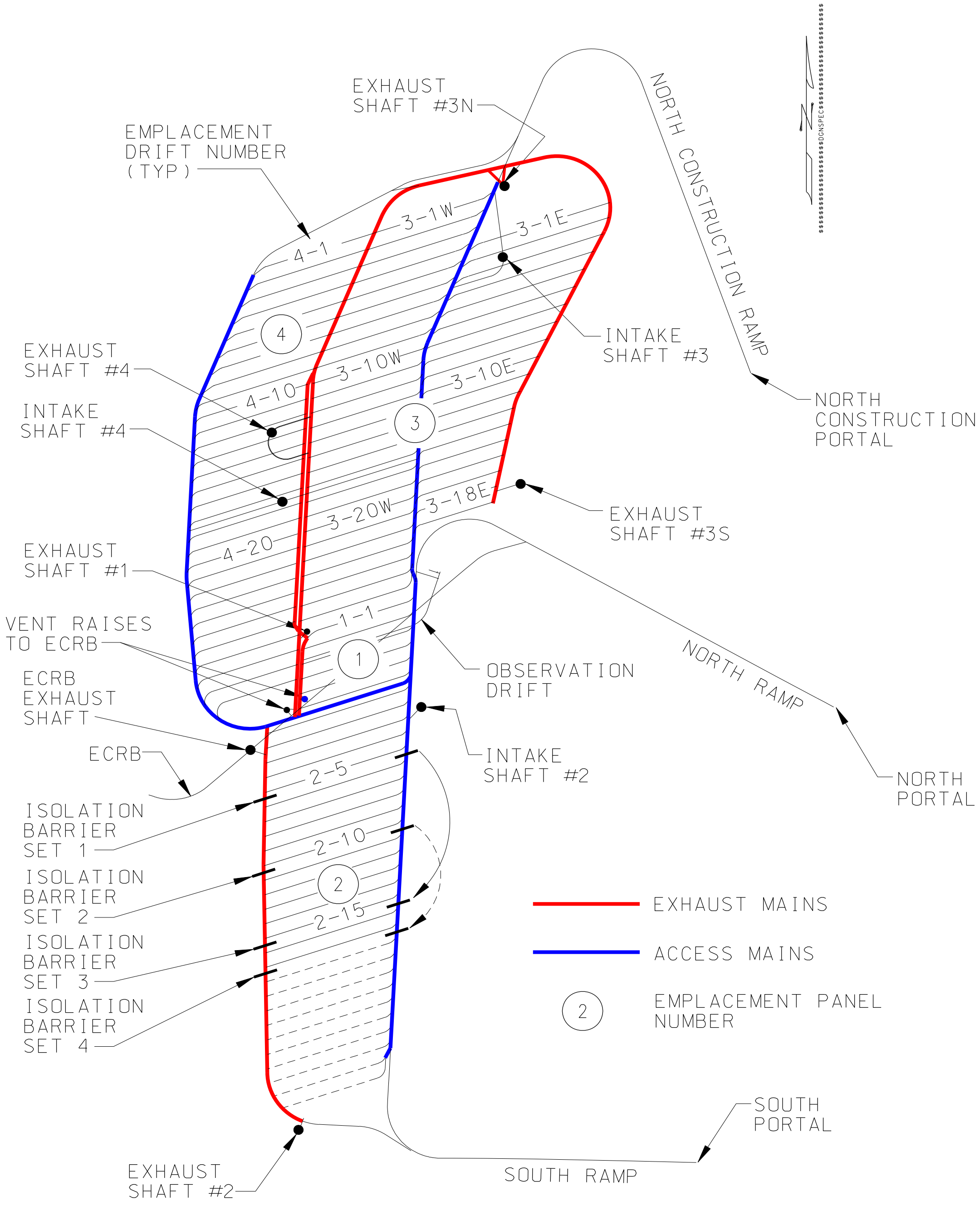
The failure of an isolation barrier due to rockfall, equipment collision, or other impact does not initiate an event sequence because the subsurface ventilation system is not relied upon to prevent or mitigate event sequences. In addition, the isolation barriers are located in the main drifts and are physically separated from the waste packages in the emplacement drifts so that no isolation barrier failure can directly impact a waste package. If one bulkhead of an isolation barrier were to be damaged, the second bulkhead would maintain the integrity while repairs were made to the damaged structure.

6.2.2.1 Isolation Barrier Relocation

In a typical panel, the isolation barriers are relocated in sets that consist of a Type A barrier in the exhaust main and a Type B barrier in the access main, located on opposite sides of the emplacement panel. Figure 8 uses Panel 2 to illustrate the steps involved in the relocation of isolation barriers to maintain separation of the development and emplacement sides at all times. The sequence is preliminary because a detailed construction schedule has not been developed. However, the scheme shows the steps involved which could be used when more details are available.

Figure 8 shows a time where the first five emplacement drifts in Panel 2 have been commissioned for emplacement and the isolation barrier installations are complete. Completion of development activities for the first five emplacement panels would include construction of the access main invert structure, including rail installation, and installation of electrical equipment through and beyond the location of the first set of isolation barriers. This allows construction of the structures south of the isolation barriers to continue on the development side without impacting the emplacement side. The first set of isolation barriers located south of emplacement drift 2-5, designated in as Set 1, separates the emplacement in the first five drifts from the development activities in the rest of the panel. Emplacement drift excavation activities continue beyond this set of barriers. Installation of a second set of isolation barriers, Set 2, is initiated at a location south of emplacement drift 2-10. This set of isolation barriers is left open or partly completed to allow construction equipment and personnel traffic across the barriers. Similar to the case of the first five drifts, completion of the second set of emplacement drifts includes completion of the access main invert structure, and installation of rail and utilities beyond the location of the isolation barrier. This allows Set 2 of barriers to be closed, sealed, and made ready for commissioning of emplacement drifts 2-6 through 2-10. At this point in time, Set 1 of isolation barriers are no longer needed and can be removed and relocated to the intended location for Set 3 of barriers. Removal of the isolation barriers takes place inside an emplacement area being commissioned; however, this activity is limited to dismantlement and does not include demolition or dust generating activities.

The bulkheads for the isolation barriers are constructed by bolting modules together to a structural frame that is attached to the access main or exhaust main rock walls. The structural frame may be left in place or it can be removed and reused, depending on details of final design and fabrication for these structures. The design and fabrication of the bulkheads will include features that will allow disassembly and removal of components with minimal disruption to their surroundings. This is necessary because the disassembly will take place in the commissioned emplacement area. The activity will take place at an adequate distance away from waste package emplacement so that appropriate radiological protection controls can be used and so that the interaction between emplacement operations and bulkhead removal will be minimal. Removal of the disassembled barrier components can be through Set 2 of the isolation barriers and into the development side; or, through the emplacement side (North Portal) if it is practical to do so. The goal in removal of the barrier is to avoid impacting the emplacement operation or the integrity of the completed emplacement drifts.



(Adapted from Reference 2.2.29, Figure 11)

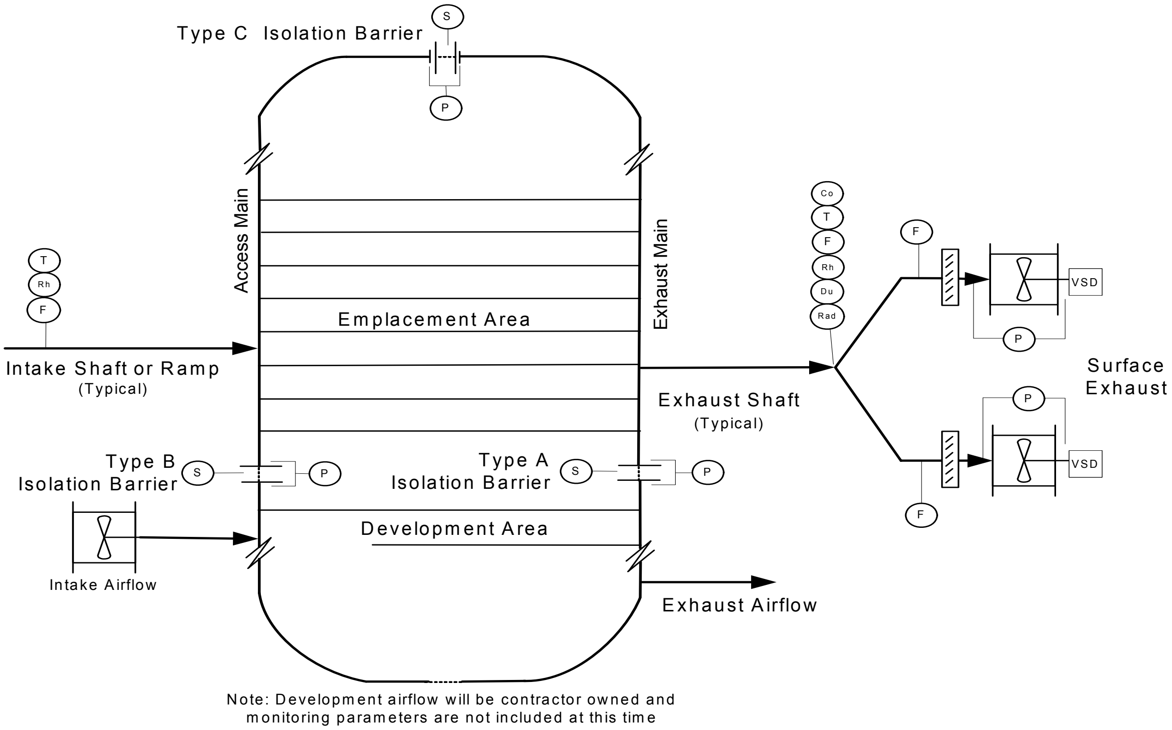
Figure 8. Isolation Barrier Relocation Sequence

After Set 2 of isolation barriers are sealed and the second set of emplacement drifts is commissioned for emplacement, construction activities would continue beyond the Set 2 of barriers south of emplacement drift 2-10. Components from Set 1 of isolation barriers that are removed from the locations south of emplacement drift 2-5 can then be reconditioned and reinstalled at Set 3 barrier locations.

After the third set of emplacement drifts (drifts 2-11 to 2-15) is commissioned for emplacement, Set 2 of isolation barriers is similarly removed, reconditioned, and relocated to the end of the emplacement panel south of emplacement drift 2-17. The process described above limits the work activities in the emplacement side of the isolation barriers to a controlled removal of panels from the structural bulkhead frame and hauling them out of the area via rail cars in the access main side; or, via rail car, rubber tire or track equipment in the exhaust main side.

6.2.3 Subsurface Ventilation Monitoring

The subsurface ventilation system monitoring parameters include airflow distribution, air temperatures, dust, humidity, air door status, fan status, and other related parameters at select locations (Reference 2.2.18). The ventilation system monitoring capabilities (continuous or intermittent) are dependent upon the final design but would combine centralized and local monitoring to provide redundancy and diversity as needed. The subsurface ventilation monitoring information would be transmitted to the Central Control Center. The subsurface ventilation system interfaces with the Digital Control and Management Information, Radiological, and Environmental/ Meteorological Monitoring Systems (Section 6.2) but does not specify their equipment designs or locations. A simplified emplacement monitoring design is illustrated in Figure 9. A typical turnout bulkhead instrumentation diagram is discussed in Section 6.4.2 and shown in Figure 10.

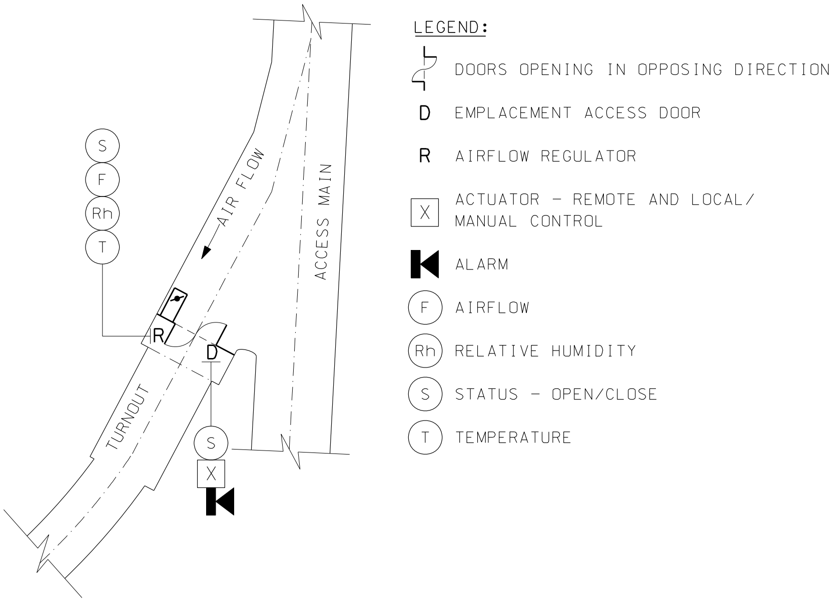


(Source: None – Illustrates Concept)

Figure 9. Simplified Emplacement Monitoring Illustration

Monitoring instrument locations have not been detailed at this time. The detailed design would define specific monitoring equipment types and locations. Monitoring will be continuous through the forced ventilation period and can be extended with a maintenance and replacement program. There are no monitors located in the exhaust main because personnel access is not allowed or is restricted.

Commercially available off-the-shelf, industrial quality instruments can meet the monitoring requirements for temperature, humidity, airflow, carbon monoxide (CO), non-radioactive particulate, and radon.



(Adapted from Reference 2.2.14, Figure 11)

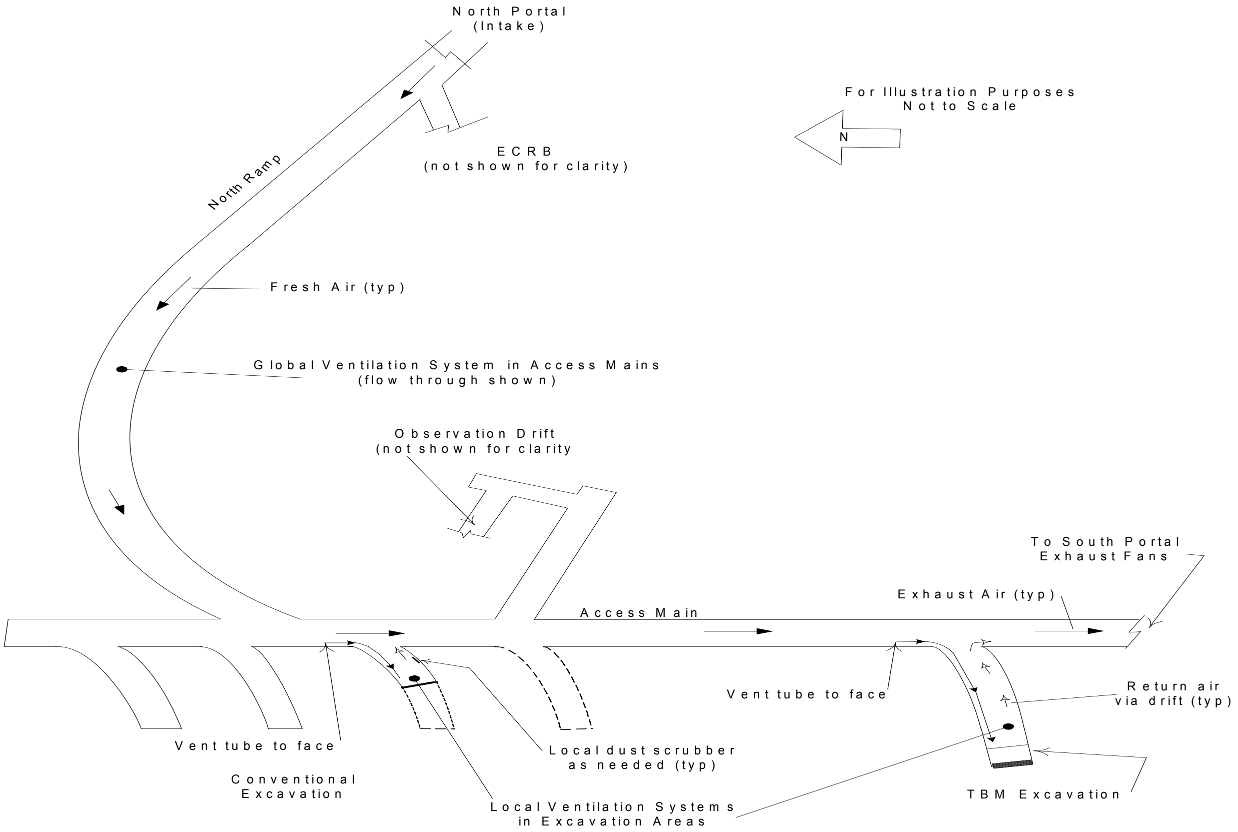
Figure 10. Typical Turnout Bulkhead Instrumentation

6.3 DEVELOPMENT VENTILATION SYSTEM

The Development Ventilation System supports the tunnel excavations and ensuing construction work by circulating ambient surface air throughout the subsurface development areas and removing the exhaust air. This provides fresh air for a safe work environment, and removes or dilutes potential contaminants such as radon, dust and fumes. The airflow regulates the temperature in the underground development areas. The development ventilation components include main fans, booster fans, ventilation ductwork, dust control, isolation barriers, ventilation instrumentation, controls, and monitoring equipment. The development ventilation system and the installations are considered temporary. The development ventilation system will evolve as the excavation progresses and panels are turned over for waste emplacement.

Preliminary design information, dust control, radon, and other hazards are examined within subsections that describe concepts as they pertain to the current construction methodology. Ventilation systems described herein are common to the mining and tunneling industries and the final construction specifications, installations and details would be coordinated with contractors. The development ventilation system can be designed to support any combination of excavation sequences and equipment uses. Though there are ventilation concepts defined, air volumes, and horsepower determined, development ventilation will include contractor input and may differ from the information herein. The repository openings provide airflow pathways as they are excavated and connected. For purposes of this report, the working drift begins at the intersection of an access main and includes the working face, where excavation is extending the length of a drift in a dead-end heading.

The development ventilation system consists of two parts common to the mining and tunneling industries; one part is defined as global ventilation and the other part is local ventilation. The global ventilation part keeps air flowing through the repository and out to the surface. It must be capable of maintaining the air quality and quantity for use by multiple local systems. Local ventilation systems acquire fresh air from the global system, circulate it in the work area, and exhaust it back to the global system. The local system may also duct air to the surface. An example of a global system is the existing ESF airflow entering the North Ramp and exhausting out the South Ramp. An example of an existing local system is the ECRB vent line that draws fresh air off the North Ramp airflow. Figure 11 illustrates this global/local ventilation concept at the start of construction where the ESF loop is the global airflow system; and, local airflow systems draw off the ESF airflow for use in a conventional excavation operation and in a tunnel boring machine (TBM) excavation operation. The initial ESF flow-though air volume will be designed to support multiple work faces.

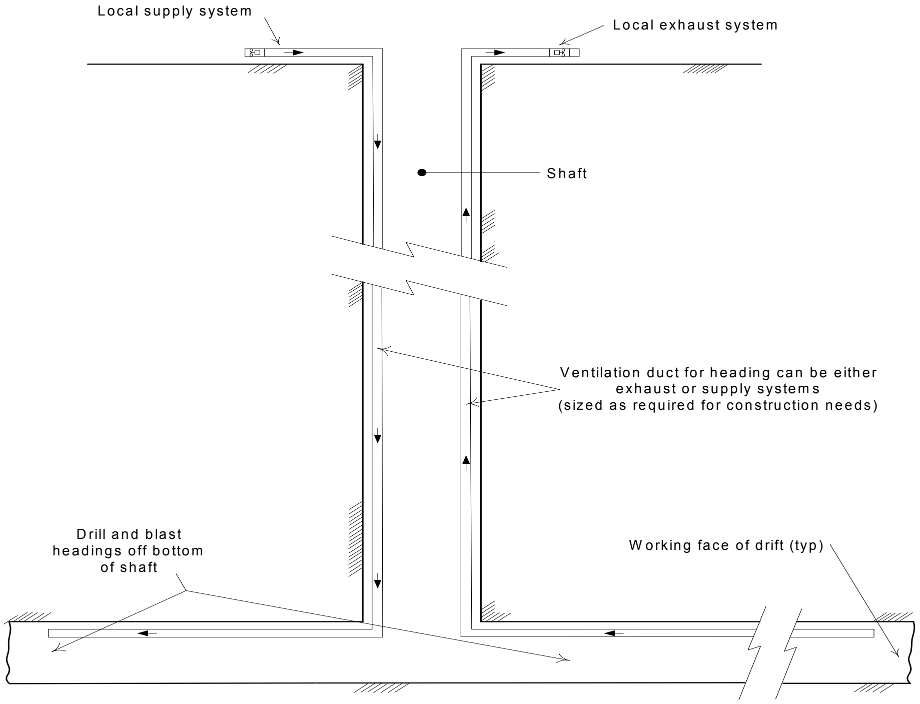


(Source: None - Illustrates Text)

Figure 11. Examples of Global/Local Ventilation Concept

Conventional shaft excavations (Figure 12) are ventilated by a local ventilation system that would intake fresh air from the surface (see Section 6.3.1.3). After a shaft excavation is complete, tunnels could then be excavated from the shaft bottom in a method similar to with the local ventilation system being either ducted intake or ducted exhaust. As tunnels are developed and flow through connections are established, the shafts are then configured as global ventilation systems in either an exhaust or an intake mode as required by the construction sequence.

In order to minimize dust re-entrainment, the North Construction Ramp and South Ramp are used as exhaust airflow routes in conjunction with their use as development muck-haul routes. Once the development effort is complete, the North Construction Ramp and South Ramp are utilized for emplacement intake air.



(Source: None – Illustrates Text)

Figure 12. Conceptual Excavation Off of a Shaft

Mining and tunneling equipment are designed for severe industrial use under hot and humid conditions and there are no unique repository design constraints. The development ventilation system components are commercially available and standard tunneling ventilation practices and equipment are adequate. Maintenance requirements will be developed once a final design has been approved. In general, ducts will be kept clear of obstructions, fans will be maintained per manufacturer's recommendations, and airflow volumes and quality will be monitored to ensure system performance.

6.3.1 Local Ventilation System for Construction

This section provides local ventilation system details used for drift excavation and construction using TBM. This information is preliminary. A detailed design of the development ventilation system is not within the scope of this document. The final design would incorporate input from contractors, consideration for safety, personnel access, equipment requirements, and duct leakage factors. Rules governing underground diesel particulate requirements are being revised, becoming more stringent, and factors for diesel ventilation are not addressed at this time.

Minimum Air Volumes for Excavation

Using $\pi \times r^2$ and an airflow velocity of 0.76 m/s (150 fpm) (Section 4.3.3), the minimum excavation air volumes needed at the working face are calculated as follows:

Minimum air volume for a 25 ft. diameter tunnel (excavation):

$= (25 \text{ ft} \times 0.5)^2 \times \pi \times 150 \text{ fpm} = 73{,}631$ cfm, rationalized to 74,000 cfm

Minimum air volume for an 18 ft. diameter tunnel (excavation):

$= (18 \text{ ft} \times 0.5)^2 \times \pi \times 150 \text{ fpm} = 38{,}170$ cfm, rationalized to 38,000 cfm

Minimum air volume for a 26 ft. diameter shaft (excavation):

$= (26 \text{ ft} \times 0.5)^2 \times \pi \times 150 \text{ fpm} = 79{,}639$ cfm, rationalized to 80,000 cfm

For construction activities in an emplacement drift, the air volume is as follows:

Minimum air volume for an 18 ft. diameter tunnel (construction work 100 fpm, Table 4),

$= (18 \text{ ft} \times 0.5)^2 \times \pi \times 100 \text{ fpm} = 25{,}447$ cfm, rationalized to 25,000 cfm

Minimum air volume for a possible crew size of 20 employees working a tunnel

= 20 employees × 200 cfm per employee = 4,000 cfm

These working face volumes are sufficient to prevent stratification of respirable dust and provide cooling for personnel and equipment. Turnouts, though physically larger than the emplacement drift, are relatively short excavations adjacent to the access mains and would receive adequate ventilation from the planned TBM ventilation system operating with minimal resistance.

Reversible airflow volumes are calculated for local development ventilation systems using the 30-ft/min velocities. Following the method above, the minimum airflow volumes required for a reversed condition are:

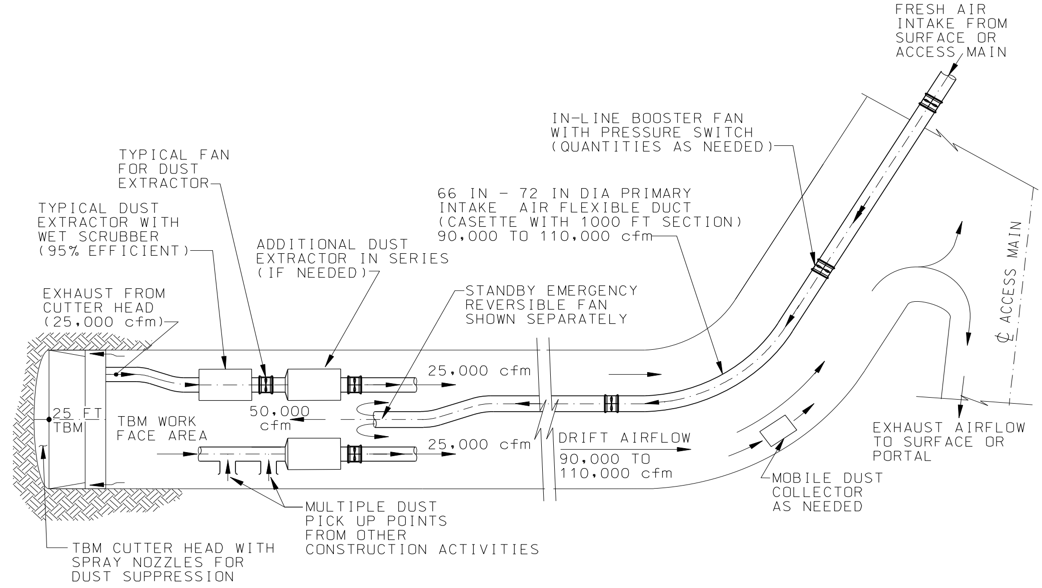
- A 25 ft diameter tunnel requires 14,726 cfm, rationalized to 15,000 cfm
- An 18 ft diameter tunnel requires 7,634 cfm, rationalized to 8,000 cfm.

6.3.1.1 25 Foot Diameter Drift Ventilation System

The access mains and ramps will be excavated by a 25-foot diameter TBM (Reference 2.2.46). The TBM ventilation can be supplied by either a blowing system or an exhausting system. Either system can use rigid ventilation duct or collapsible ventilation bag, where rigid duct is typically made of either fiberglass or steel. The Mine Safety and Health Administration (MSHA) certify commercially available ventilation bags and fiberglass ducts as flame resistant. Analysis of potential variations to the TBM ventilation system design and components is not within the scope of this document.

Rigid ventilation duct made of steel or fiberglass is used in the mining industry, however applications for TBM excavations are infrequent. Though rigid duct installations can be automated to some extent, in order to maintain rapid TBM advance rates, the machine cannot be constantly shut down to advance the ventilation duct. The logistics of supplying rigid ventilation duct in 20 to 30 foot lengths for an advancing tunnel(s) adds to the supply handling requirements. Ventilation bag is also more economical on a cost per basis and as explained below, does not place a burden on the supply system.

The ESF was constructed with a suction ventilation system using 20' sections of steel duct with fans placed in series along the length of duct. The numerous duct joints leaked and re-circulate contaminated air, even though the joints were sealed and maintained. As the intake air was drawn through the main drift it, was contaminated by transient and re-circulated dust as it moved toward the working face. The ESF construction experience concerning dust, airflow, leakage, and recirculation, showed that the ventilation system needed to be redesigned for safety and health reasons (Reference 2.2.32, Section 8.5). A blowing system commonly used in the TBM industry is shown in Figure 13.



(Adapted from Reference 2.2.46, Figure 9)

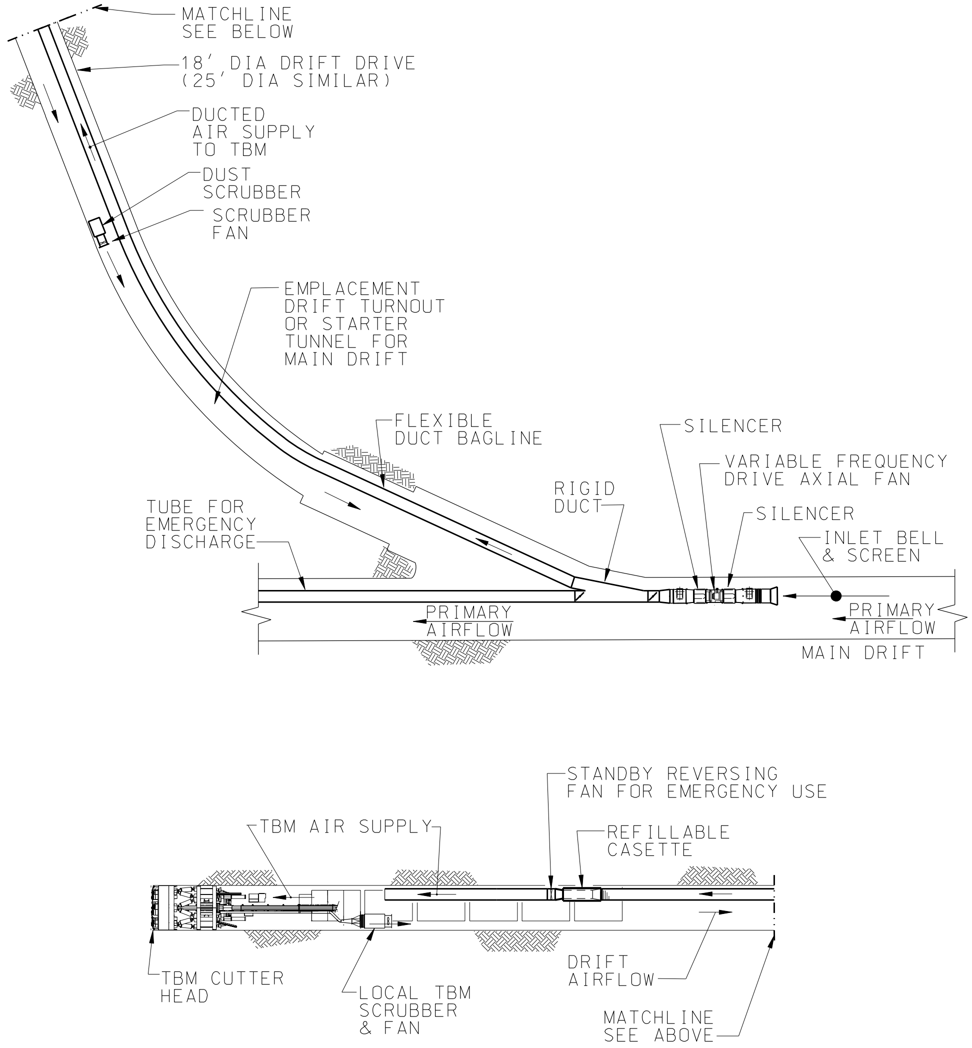
Figure 13. Recommended Supply Air Arrangement for 25 ft TBM

The blowing system consists of variable speed fans operating in series, ventilation bag, and duct cassettes. The fans blow fresh air through the ducts. This means that leakage from the duct consists of fresh air that flows from the duct into the excavation. Cassettes can hold as much as 1,000 continuous feet of ducting which drastically reduces the number of joints. The combination of the drastically reduced number of joints that reduces leakage and the fact that leakage consists of fresh air makes the system superior to the system used during ESF excavation. Approximately, 60,000 cfm to 75,000 cfm air quantity is used to flush out potential contaminants and provide cooling for employees. The radon level at the working face would also be lower than with an exhaust system since the air contained in the duct is not exposed to the drift walls until it reaches the working face. A high-pressure water spray nozzles directing water to the area between the cutter head and the face trap the dust as it is generated and further reduces contamination.

Figure 14 illustrates a TBM ventilation system that utilizes ventilation bag and variable speed fans. The variable speed fans provide for airflow volume adjustments as the tunnel advances and positive pressure in the duct that prevents the ventilation bag from collapsing. For long excavation lengths, variable speed drive fans are incrementally installed as the TBM advances. They may also be stacked in series at the duct inlet. As illustrated in Figure 15., a ventilation duct cassette is typically installed toward the end of the TBM's trailing gear. The ventilation duct cassette plays out flexible ducting as the TBM advances. Empty duct cassettes are easily changed out with another cassette pre-loaded with 1,000 ft of bag. This arrangement creates a very efficient and economic TBM ventilation system that can be several miles in length.

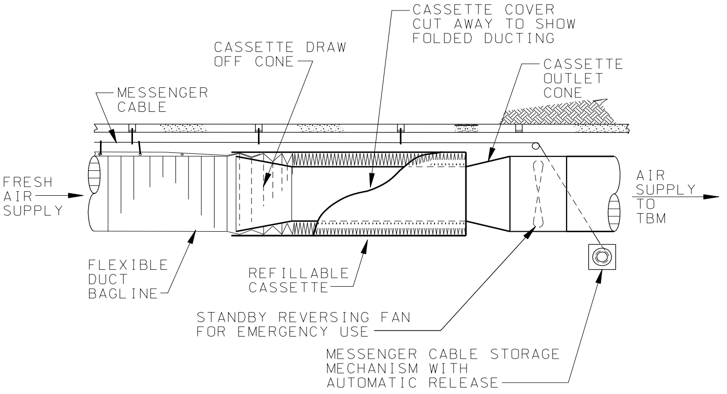
Regulations require that mechanical ventilation systems on the development side be reversible and applies to either a blowing system or an exhaust system. In order to meet the airflow reversibility requirement for the TBM blowing system, a fan can be installed near the ventilation duct discharge in the TBM trailing gear as shown in Figure 15. A fan designated for a reversed airflow condition would be sized to provide the minimum reverse air volumes calculated in Section 6.3.1. The fan could either free wheel at the ventilation tube outlet, or can be installed in a 'y' connected to the TBM ventilation system. For off-normal conditions, the supply fans are shut down and the reversal fan is activated.

Two TBMs may be used to excavate emplacement drifts using a leapfrog process where one TBM will be excavating while the second TBM is being moved or readied in the adjacent emplacement drift. When excavation of the 1st drift is complete, the crew will then move to the next drift where the TBM has been readied for use.



(Adapted from Reference 2.2.45, Figure 4)

Figure 14. TBM Ventilation Air From Access Main - Emplacement Drift Excavation



(Adapted from Reference 2.2.46, Figure 11)

Figure 15. TBM Operation - Standby Reversible Fan

Although fire hazards and smoke dispersion are considered the highest priority, the probability of them happening may be low and a design basis frequency has not been developed at this time. Dust is a hazard that will be an ongoing concern during the excavation phase and the design must include substantial mitigation for dust control. The final design of local ventilation systems will include consideration for safety, noise, dust, fire events, equipment requirements, contractor input, and duct leakage factors. Water use restrictions imposed during the ESF construction have been lifted and water will be available for dust suppression use at the TBM cutting head and muck transfer points. Similar to ESF construction practices, localized dust scrubbers may be installed in the drift behind a TBM to filter the air before it is returned to the global ventilation circuit.

6.3.1.2 18 Foot Diameter Drift Ventilation Systems

The 18-foot diameter emplacement drifts are excavated by TBM using a ventilation system design similar to the system described in Section 6.3.1.1. For additional information see Reference 2.2.46.

6.3.1.3 Shaft Construction

Conventional drill and blast shaft excavations utilize local ventilation systems that can be either a ducted blowing or a ducted exhaust system. A blowing system provides better air circulation on the shaft bottom and the duct outlet can be located away from the working bottom to avoid blast damage. With a blowing system, a vertically suspended duct cassette and ventilation bag can be attached to the shaft-sinking platform and discharged automatically as the equipment is lowered. The shaft ventilation system design will consider contractor input. The shaft ventilation system would be also capable of reversible airflow.

6.3.1.4 Other Ventilation Support Systems

The emplacement drift turnouts and TBM assembly chambers can be ventilated with equipment that will be used for the corresponding TBM excavations. Once a turnout excavation has advanced enough to require forced ventilation, the emplacement drift TBM ventilation system components are installed and used to ventilate the excavation. The fans would be operating at minimal pressure due to the short duct length and the system would support the increased volume required by the larger drift. When the turnout excavation is complete, the ventilation system components would support TBM assembly, emplacement drift excavation, and TBM removal.

Industry standard ventilation systems with fans and duct sized for the 150 fpm design velocity (Section 4.3.3) will be used for excavation of the PC observation drift, shaft connectors, niches, and alcoves. These ventilation systems would also be designed for reversible airflow.

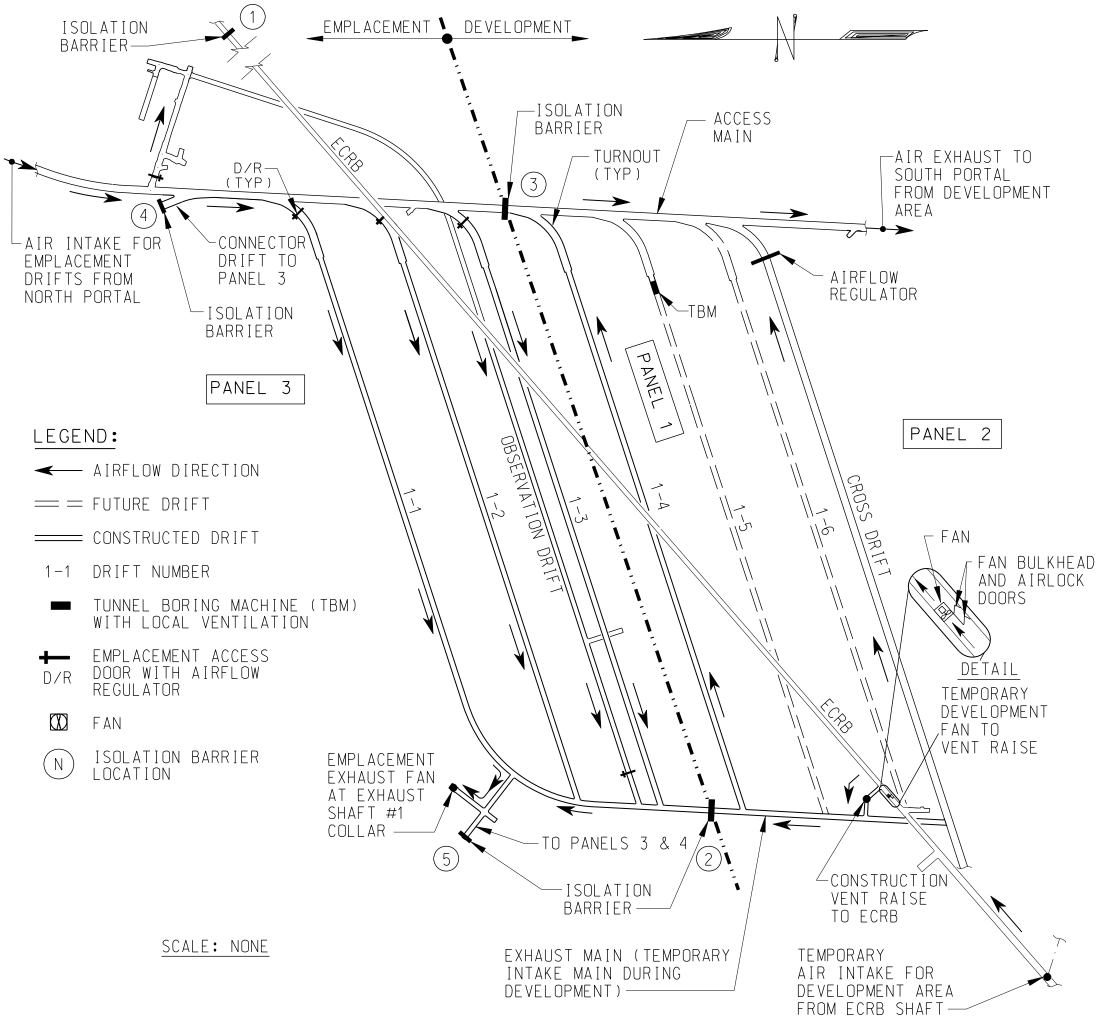
6.3.2 Overview of Panel 1 Development Ventilation System Concepts

The initial development sequence includes excavation of Panel 3 Connector Drift, the observation drift, Panel 1 exhaust main, and Panel 1 turnouts, followed by TBM excavation of Panel 1 emplacement drifts and exhaust raise (Reference 2.2.11, Sections 7.13 and 7.14). The existing ESF ventilation system will be upgraded to provide the global airflow for the initial

Panel 1 development effort. Figure 11 illustrates the ESF ventilation system that would support the initial Panel 1 development.

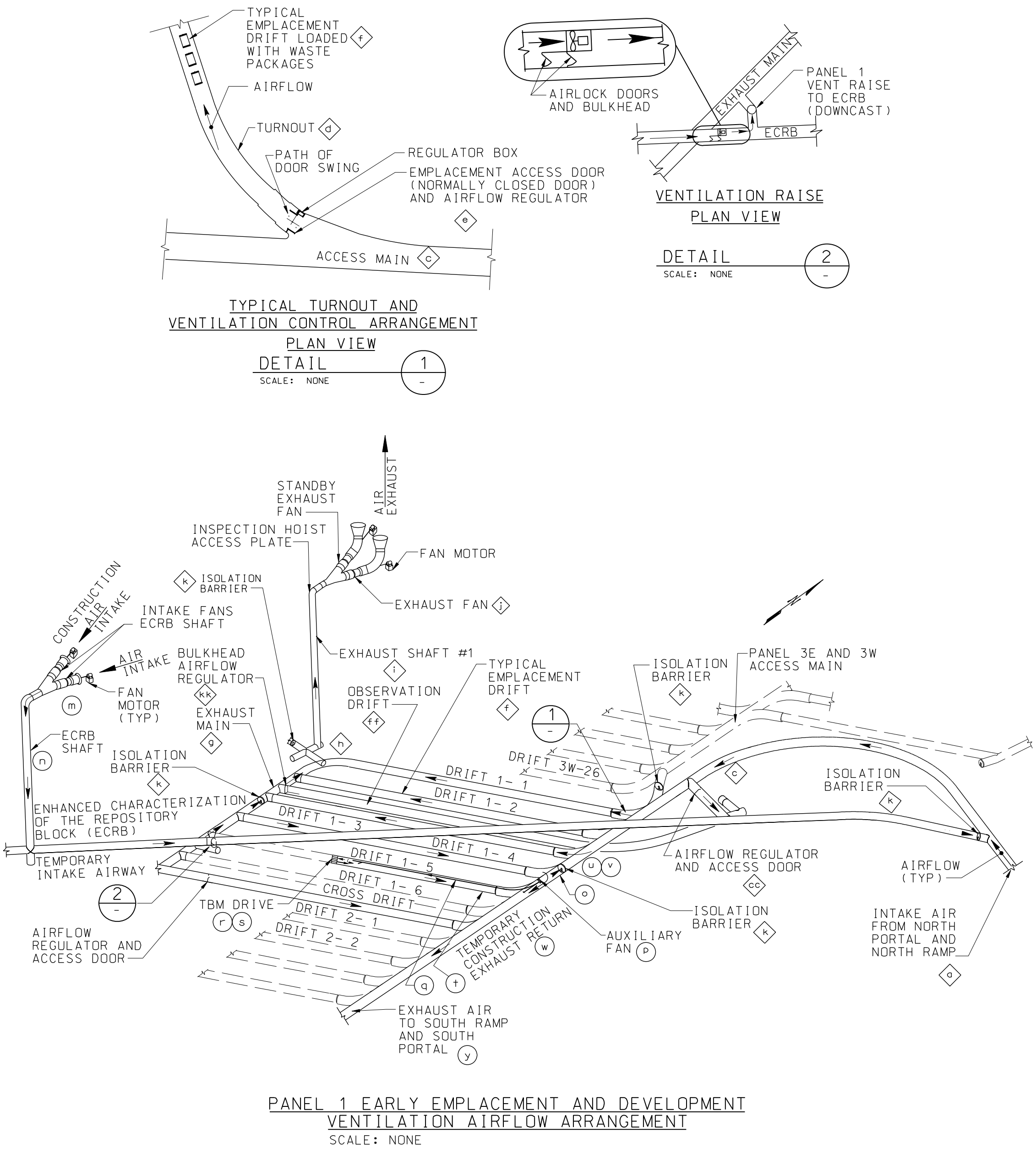
Panel 1 consists of six 18 ft diameter emplacement drifts. The Observation Drift used for instrumentation and performance confirmation purposes is located under and offset from emplacement drift #2 and excavated at 5 m × 5 m (16 ft × 16 ft). The Panel 1 emplacement drift excavation sequence is from north to south, with the first three drifts accepting the initial waste emplacement (Reference 2.2.45). The fourth emplacement drift is excavated as part of the initial construction sequence. Isolation barriers are constructed to separate the first three emplacement drifts from the remaining Panel 1 development activities. After the isolation barriers are in place, flow-through ventilation from the North Portal to the South Portal is not possible and the ECRB Shaft supplies the development air.

Development and emplacement of Panel 1 require isolation of various areas. The progression of Panel 1 development through the fully emplaced panel is illustrated in Figure 16 and Figure 17.



(Adapted from Reference 2.2.45, Figure 5)

Figure 16. Early Emplacement - Panel 1 Development



(Adapted from Reference 2.2.45, Figure 10)

Figure 17. Isometric View of Early Emplacement - Panel 1 Development

6.3.3 Dust Control

The process of excavating tunnels and transporting the broken rock will create dust whether the method is mechanical or drill and blast. Engineered systems are necessary for effective dust control during repository excavation and construction activities. These engineered dust control techniques consider airflow volumes, water, and collection/ filtration, or combinations of the three. A comprehensive and effective dust control program will be required to ensure worker exposures are within acceptable levels.

6.3.3.1 Threshold Limit Values

In accordance with ACGIH 2006 (Reference 2.2.1, Page 50), the Threshold Limit Values (TLV) to which workers can be exposed for a conventional 8 to 10-hour workday and a 40-hour workweek without experiencing adverse health effects is established at 0.025 mg/m^3 respirable fractions for crystalline silica (including quartz and cristobalite or any combination of the two).

While the TLV represents the upper limit for personnel exposure, a lower level referred to as the "Action Level (AL)" is used as the set point for real-time, direct reading instruments that measure dust concentration. For the future construction work at YMP, the "Action Level" exposure limit is calculated at 0.085mg/m^3 (Reference 2.2.46, Section 6.1.3.1). If the direct reading instrument's set point level is exceeded, administrative, protective, and investigative steps are taken to reduce the dust level.

6.3.3.2 Dust Control Methods

The *Handbook for Dust Control in Mining* (Reference 2.2.39) describes industry methods used for dust control practices in mines and tunnels. The engineered dust control system designs vary, but usually involve dilution ventilation, water, and/or dust collectors as described below. Dust control systems can be designed as an integral part of tunnel excavation equipment to reduce exposure to dust generated during excavation. The choice of the type of Tunnel excavation equipment will include contractor input. Details about equipment have only been broadly defined in this document and in Reference 2.2.46.

The following information summarizes design methods available to mitigate dust generated by excavation equipment, but does not present the design details of the equipment. The use of multiple methods may be required to effectively control dust. Engineered dust controls must be applied before the use of respirators is relied on as the method for reducing exposure.

Dilution Ventilation

For dilution ventilation an increased airflow volume is used to reduce the contaminant concentration level. By regulation the minimum linear velocity is 30 fpm in a tunnel. The design volumes presented in Section 6.3.1 utilize a 150 fpm drift velocity to provide dilution ventilation based on lessons learned during ESF construction (Reference 2.2.31, Page 19). Increasing the airflow volume does have design limitations due to equipment considerations, fan and duct system capacities, drift dimensions, and air velocity levels that will re-entrain dust.

Dust can also be captured at/near the source and discharged at some distance from the workers. However, this method will impact workers located downstream from the original activity.

Water

The majority of dust particles created during breakage stay attached to the surface of the broken material rather than being released to the air (Reference 2.2.39, Page 7). Wetting broken material uniformly will also help reduce dust generated during secondary handling processes, such as conveyor belt transport, or muck haul car dumping. As little as 1% of moisture on dry rock significantly reduces dust, however, to ensure uniform application the moisture content may be as high as 5% (Reference 2.2.39, Page103). Water sprays are typically used to wet the broken material and capture airborne particles. The over application of water for dust control may create operational problems and material handling issues, so various issues must be addressed during the design of systems that use water.

Spray nozzles are used to capture a portion of airborne dust particles and their effectiveness is determined by a well-engineered design. Full cone, flat cone, hollow cone, and atomizing spray nozzles are used for dust control and wetting broken rock. Use of high-pressure water sprays will help control dust and will reduce water consumption at the same time. High-pressure water sprays can create large volumes of entrained air and the ventilation system must be designed accordingly. The final water spray system design may use a combination of nozzles and water pressures to obtain the best results.

Wetting agents, additives, or foam can improve the effectiveness of water-based systems. However, their impact on long-term waste isolation would need to be developed and their use approved.

Dust Collectors

Dust collectors can provide respirable dust filtration efficiencies of 90% - 95% (Reference 2.2.39, Page 12). Dust collectors can be either a wet-type or a dry-filter type. The air discharged from a dust collector is reused if it is of acceptable quality. Due to the nature of silica dust, multiple stages of dust filtration may be required to get better than 95% filtration efficiency. Dust collectors are typically an integral part of a TBM or roadheader design and will extract and filter dust-laden air from the cutter head area. Dust collectors require maintenance and can become high maintenance items requiring servicing each shift under extreme conditions. Similar to historical use during the ESF construction, supplemental dust scrubbers may be utilized in the return air stream (Reference Figure 13 and Figure 14).

Other Factors

Housekeeping issues, and the education and training of personnel also influence dust control efforts. Dust that has settled in primary airways and travel routes should be removed on a regular basis. Personnel should be trained to recognize and respond to dust related issues, including awareness for maintenance of dust control and ventilation equipment.

6.3.3.3 Tunnel Boring and Roadheader Dust Control

TBM dust is commonly suppressed with water sprays at the cutting head, a scrubber mounted on the trailing gear, and by water sprays at conveyor discharge points. The TBM cutting head design creates a contained area suited for dust capture and extraction. As discussed in Section 6.3.1.1, a typical TBM ventilation system discharges the primary air supply near the back of the trailing gear and smaller localized fans and dust scrubbers overlap to remove airborne contamination and heat. TBM dust scrubbers can be either a wet scrubber or dry (bag) design and draw contaminated air directly from the cutting head area (exhaust system). The TBM and roadheader performance specifications will include requirements for water sprays, dust scrubbers, cabs, and booster fans to handle local airflow requirements.

Roadheader excavations will typically be at drift turnouts where use of TBM is not feasible. Water sprays provide cooling to the picks on the cutting head and act as a dust suppressant. The roadheader cutting head can be designed to incorporate high-pressure water sprays engineered to help control dust at the pick impact point. A localized dust scrubber system captures and filters the dust laden from the cutting area. Enclosed operator cabs are commonly used to reduce dust exposure and assist with noise abatement. As an option, remote control of a roadheader allows the operator to step back and out of high dust concentrations.

6.3.3.4 Conventional Drill and Blast Excavation Dust Control

Conventional drill and blast excavations would use industry-accepted practices to reduce dust and fume exposure. These include items such as wet drilling, using foggers, and wetting down muck piles to control fumes and dust created by blasting. The blasting fumes and dust are allowed to settle and dilute before workers return to the heading.

6.3.3.5 Muck Rail Car System for Dust Control

For future excavation, covered muck rail car system could be used for muck haulage to surface in place of conveyor belts that were used during ESF construction. Based on ESF construction experience, the empty belt impacting the return idlers was a large source of transient dust. Other potential sources of airborne dust are dumping stations and transfer points. A covered conveyor belt system from a TBM will dump cuttings into a waiting solid bottom muck car that will be then covered to minimize dust release into the atmosphere. These muck cars will haul muck to the portals and empty muck cars could be washed before returning back to the subsurface excavation area.

6.3.3.6 Other Dust and Particulate Control

Personnel must be trained on dust control procedures, recognizing dust hazards, housekeeping, and the proper use and maintenance of dust control equipment.

Diesel engines that are used in the subsurface would add contaminates to the airflow. Diesel equipment would operate within airflow requirements and would incorporate the appropriate diesel particulate filters and catalytic converters to reduce harmful emissions. Diesel particulate emissions requirements have recently become more stringent.

6.3.4 Noise Control of Ventilation Equipment

Ventilation equipment, such as fans, that exceed noise level limits will be equipped with silencers. The existing ventilation equipment at the ESF is equipped with fan silencers. Fans should not be installed near phones and other communication devices.

6.3.5 Radon

Radon is emanated from the wall rock at rate referred to as the flux rate. There are many factors that impact radon concentration, one of which is the area of exposed rock. The greater the surface area of exposed rock, the more radon is emitted, i.e., tunnel diameter and length are factors. Once the radon is in the air stream, it will typically remain there until the air is discharged to the surface. Mechanical ventilation (dilution) and other protective techniques (respirator or tunnel lining) can control the exposure to radon.

During the construction and operation of the MGR, subsurface workers are exposed to airborne radon. The ventilation system is designed to control, within acceptable limits, the concentration of radon and its decay products. Per existing procedures the Environmental Safety and Health group monitors radon levels using portable instruments to control personnel radon exposures.

In the *Subsurface Radon Flux Calculation* (Reference 2.2.6), the radon flux rate is determined using the historical radon and airflow data collected at the ESF. The report concluded that flux rates had an inverse relationship with respect to barometric pressure changes. For a drop in the barometric pressure during a data period, a corresponding increase in the flux rate was recorded. Therefore, a negative pressure ventilation system would tend to increase the flux rate. The emplacement ventilation system operates as a negative pressure system and a higher radon flux rate is projected. However, personnel access on the emplacement side would be limited and therefore, the potential for exposure is reduced. Conversely, the development ventilation system operates under a positive pressure system and the radon flux rate may be suppressed.

The *Subsurface Radon Exposure Calculation* (Reference 2.2.12) applied the radon flux rate calculated in the *Subsurface Radon Flux Calculation* (Reference 2.2.6) to the ventilation model and predicted average radon concentrations and working levels during the emplacement period. The radon information from the calculation is listed in . Note: the exhaust main is considered not occupied. During development and construction the predicted average radon concentrations would be lower than shown in since the development system operates under positive pressure (Reference 2.2.6). Respiratory protection can be used if needed.

Table 6. Average Radon Levels During Emplacement

Description	Concentration (pCi/L)	Working Levels (WL)
Access Main	5.8	0.012
Emplacement Drift	47	0.050
Exhaust Main	72	0.10
Applicable Limits	30	0.33

(Adapted from: Reference 2.2.12, Table 5)

Additional work is required to determine the radon exposure levels during the development phase.

6.3.6 Heat Stress During Development

The Subsurface Ventilation System design is based on ambient surface air temperatures so there will be seasonal and diurnal temperature fluctuations underground. In subsurface openings the surrounding rock will transfer heat to and from the air and tend to moderate the air temperature to approximate the natural rock temperature. As a result, the air temperatures in the emplacement area will not have the extreme seasonal temperature swings seen in the ambient surface air. The mining industry utilizes an "effective temperature" measurement as a guide to control temperatures in the subsurface environment. The effective temperature is based on combined effects of wind velocity, wet bulb and dry bulb temperatures. The "effective temperature" is similar to the "wind chill" at the cold end of the spectrum.

The applicable ACGIH Heat Stress and Heat Strain Guidelines (Reference 2.2.1, Page 182) will be addressed during the detailed design phase. Historical average air temperature and humidity in the repository horizon are 73.1°F_{td} (Reference 2.2.47, Input Tab Spread Sheet). Based on historical ESF meteorological records and experience during the ESF construction, mechanical refrigeration will not be necessary for normal repository construction. The design of development ventilation systems will include considerations for equipment heat loads added to the ambient air. Equipment heat loads have not been developed at this time and preliminary design airflow volumes in Section 6.3.1 are subject to change. If development work areas exceed ACGIH heat stress limits, supplemental cooling would be required. Portable refrigeration units that are common to the mining industry could be used for localized cooling. The large diameter TBMs driving the access mains may incorporate an integral cooling unit in the trailing gear that will cool the work area near the TBM face.

During the winter months, the temperature fluctuation at night could create transitory freezing problems at the intake shafts and ramps. The problem is not considered excessive to the point where heating the intake air would be required. Personnel working in the primary intake airways should be encouraged to wear proper protective clothing. Water lines in the intake airways should be insulated to prevent freezing.

6.3.7 Development Monitoring and Control Systems

Development and construction monitoring parameters include airflow rates, air temperature, relative humidity, airborne particulates, radon, and carbon monoxide (CO). Industrial quality instruments are available off-the-shelf and are compatible with the monitoring and control system. Development monitoring instrument locations have not been defined at this time.

6.4 EMPLACEMENT VENTILATION SYSTEM

Emplacement ventilation will start when the construction of a block of emplacement drifts is completed and turned over for commissioning and waste emplacement. The Subsurface Ventilation System operates throughout the preclosure and closure periods to provide fresh air for a safe work environment and to maintain waste package and emplacement drift wall temperatures below the design limits. Although the system is located underground, some of the infrastructure is located on the surface.

The primary emplacement ventilation components include the exhaust fans, the turnout bulkhead, isolation barriers, ventilation instrumentation, controls, and monitoring equipment. The various repository openings provide the airflow pathways. The exhaust fans provide the mechanical ventilation, the turnout bulkheads control the airflow distribution and restrict access into emplacement drifts, and the isolation barriers separate the development and emplacement ventilation systems and the intake and exhaust systems (Section 6.2.2). Dual fan installations, variable frequency drives, and adjustable regulators provide the means to vary emplacement drift airflow rates for thermal requirements, remote access, drip shield installation, backfilling, or off-normal events (Sections 6.2.1 and 6.6). The turnout bulkhead contains the emplacement access doors, regulator, and associated hardware and monitoring instrumentation (Section 6.4.2). The emplacement access doors are sized to accommodate the TEV (Section 4.3.1) and provide the means to restrict access to the high radiation areas. The airflow regulators provide the means to control the emplacement drift airflow volume (Section 6.4.2.5). The 32,000 cfm emplacement drift inlet airflow rate and 50 year forced ventilation period have demonstrated the thermal requirements are satisfied (Section 4.3.2).

In the emplacement ventilation system ambient intake air enters the North Construction Ramp, North Ramp, South Ramp, and Intake Shafts 2, 3, and 4 (Figure 7), and is distributed to the access mains. Access drifts connect the shafts to the access mains. Fresh air from the access drifts enters the emplacement drift, or the observation drift via automated regulators that control the airflow distribution. As air passes over the waste packages it is heated and expands, and the emplacement drift exhaust volume is therefore higher than the intake volume (Section 6.4.4). The airflow then travels to the exhaust main where it is exhausted to the surface through Exhaust Shafts 1, 2, 3N, 3S, 4 and the ECRB Exhaust Shaft (Figure 7). The exhaust mains are considered humanly inaccessible due to high radiation and elevated air temperatures. None of the emplacement drift exhaust airflow will be in contact with humans until it is on the surface where the ambient air dilutes it further.

Air will tend to follow the path of least resistance. In an unregulated system most of the airflow would course through the drifts closest to the intake and exhaust sources, and the drifts furthest from the intake and exhaust sources would receive little airflow. The emplacement ventilation airflow is controlled through the regulators located in the turnout bulkheads. The regulators closest to the intake and exhaust sources would be closed more and the regulators farther from the intake and exhaust sources would be open more, if not fully open. The position and status of the airflow regulator, airflow volume, and emplacement access door status are monitored (Reference 2.2.14). Refer to Section 6.4.2 for additional information concerning the emplacement drift ventilation structures and components.

The operational design life of the emplacement ventilation system of 100 years includes the emplacement, forced ventilation, and closure phases. With a program of maintenance, repair, and replacement, the components would be available for up to 300 years of operation if necessary.

6.4.1 Observation Drift Ventilation

The emplacement ventilation system supports the observation drift airflow volume of 46,000 cfm necessary for personnel and equipment. The air flowing in the Panel 1 Access Main would flow-through the observation drift to the exhaust main and is then exhausted to the surface via Exhaust Shaft #1. Ventilation is controlled through the use of bulkheads and regulators at each end of the observation drift. The regulators would be similar to the emplacement drift installations. The alcove located off of the observation drift would have a ducted ventilation system. Depending on PC access frequency or equipment needs, the system could provide continuous airflow in the observation drift or only when personnel are present (Reference 2.2.14, Section 6.6).

Personnel access through the observation drift and into Panel 1 exhaust main is restricted due to radiation and elevated air temperatures. Provisions for performance confirmation remote access equipment may be provided in the exhaust main bulkhead (Reference 2.2.14, Section 6.6).

6.4.2 Emplacement Drift Ventilation Components

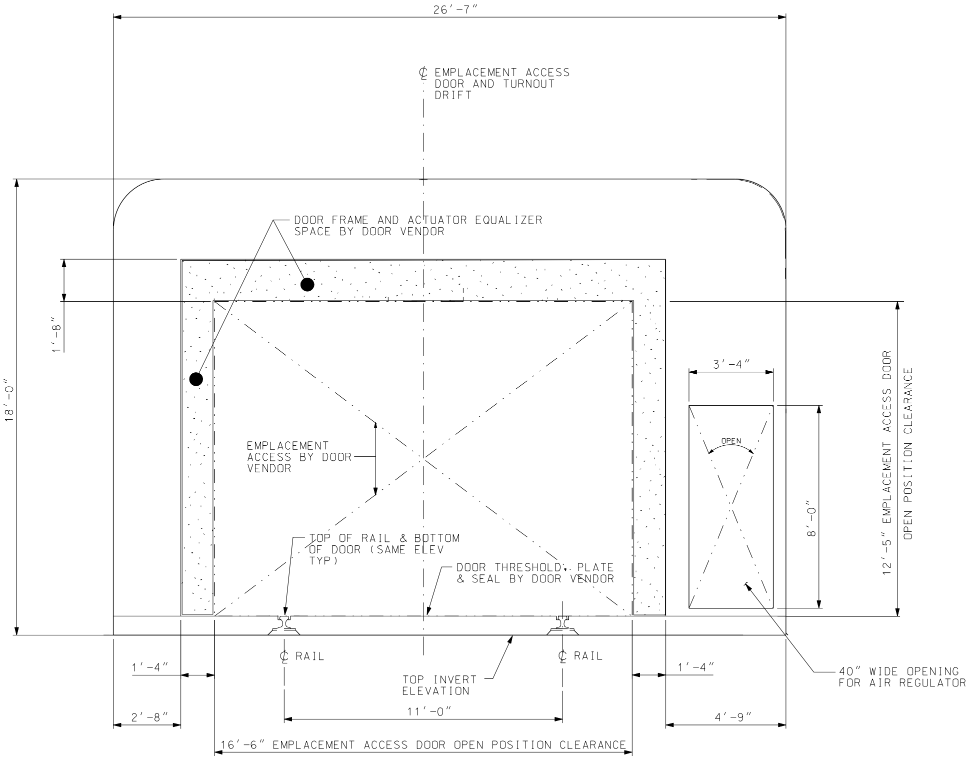
The primary component of the emplacement ventilation system is the turnout bulkhead. The turnout bulkhead consists of a bulkhead, emplacement access doors, regulator, and all related hardware and monitoring instrumentation (see Figure 22 and Figure 23). The design and configuration of the turnout bulkheads, regulators, and monitoring information found in the *Subsurface Emplacement Ventilation System Design Calculation* (Reference 2.2.14) are summarized in this section. Though the repository application is unique, the regulators, sensors, interlocks, and actuators are commercially available components and used throughout industry.

The emplacement access doors provide the means to restrict access to the high radiation areas, and the regulators provide the means to control the emplacement drift airflow volume. The integrity of the ventilation system and the goal to deliver the desired airflow through each emplacement drift supports the MGR thermal and safety objectives. The emplacement access door and regulator function with one another providing the monitoring, instrumentation, alarms, and safety interlocks. With a nominal 100-year design life for structures and components, routine maintenance and refurbishing will be required during the preclosure period and during any extended period of operation.

6.4.2.1 Turnout Bulkhead

The repository layout includes 108 emplacement drifts, each having a turnout bulkhead. There are 108 potential turnout bulkhead installations (Table 1) that occupy the cross-sectional area of the turnout (Figure 18). The turnout bulkhead is located at the turnout and access main intersection, as close to the access main as possible and away from the radiation shine from waste packages (Reference 2.2.48). This location provides the maximum distance between the bulkhead and the last WP emplaced in an emplacement drift and contributes to reducing the radiation exposure.

The emplacement and retrieval equipment envelope of 16 ft in width and 12 ft in height provides the minimum access door opening dimensions (Reference 2.2.48). With equipment tolerances, potential variations in rail alignment, and the location in the turnout curve, the door opening must be larger than the equipment envelope to ensure that no contact is made between the equipment and the door. An emplacement access door size of 16.5 ft wide and 12 ft 5 in high allows for clearance. A collision between an emplacement door and TEV would not initiate a design basis event. The current design places the airflow regulator in the lower right hand position as shown in .



(Adapted from Reference 2.2.14, Figure 7)

Figure 18. Bulkhead Size - Emplacement Access Door & Airflow Regulator

The airflow regulator controls the airflow into each emplacement drift for thermal management requirements. The primary objective of the bulkhead construction is to minimize air leakage into the emplacement drift. The bulkhead design would consider modular construction where prefabricated sections would be used rather than constructing each bulkhead from scratch. The modular pieces would have adequate tolerances and excess to allow for field fitting in each turnout drift. Due to the potential size and mass of prefabricated sections and the quantity of bulkheads in the repository, specialized equipment would be used to install the turnout bulkhead. The specialized equipment would reduce risk to construction personnel and ensure stability when installing bulkhead sections. The equipment would also be used for isolation barrier installation and removal, and installation of the emplacement access doors.

Sealant is used around the periphery of the bulkhead to ensure airtight mating surfaces with the turnout walls. The conceptual design does not provide specific detail for sealing the door joints, but the detailed design would specify an industrial sealant that would stand up to the intended use and conditions. The final design of door components would consider any potential impact to the long-term isolation of waste. Where practical, the turnout bulkhead components would be interchangeable with isolation barrier components (Section 6.2.2).

6.4.2.2 Emplacement Access Door

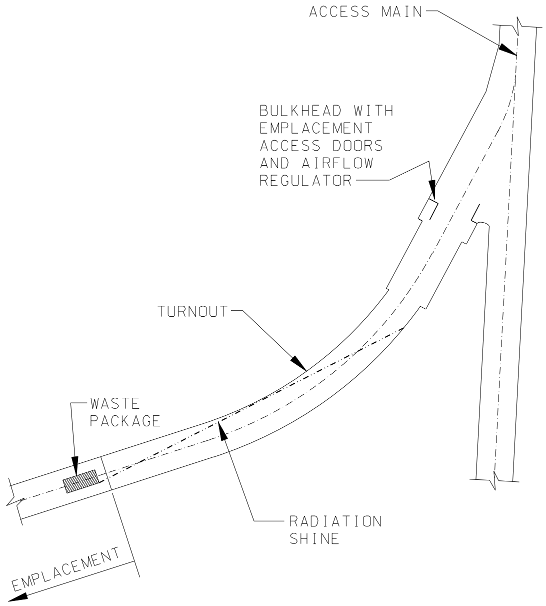
Figure 19 and Figure 20 illustrate the turnout bulkhead and emplacement access door configuration. The emplacement access door is used to restrict access to the high radiation areas.

The door operations would link to the Central Control Center with instrumentation including remote open/close functions, door position indicators, alarms, interlocks, and local overrides with safety protection (Figure 22). The door would not operate without Central Control Center input to prevent inadvertent access to the high radiation areas. The door instrumentation interfaces with the Digital Control and Management Information System to provide real-time status and supervisory control (Section 6.4.2.4).

Major controls and instrumentations would be located on the access main side of the door to limit maintenance personnel exposure and prevent inadvertent access to the emplacement drift.

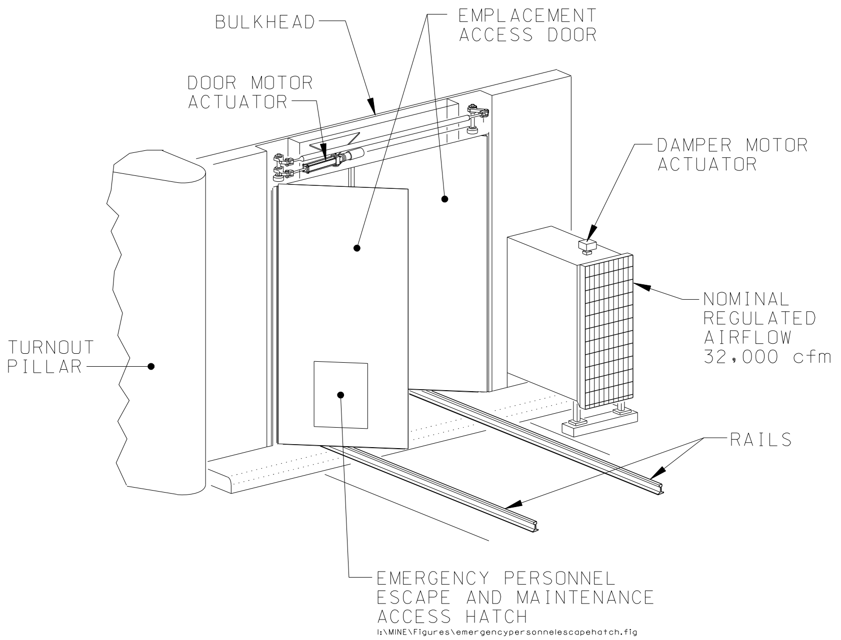
The door is of a counter-opening type and normally closed except during TEV access to the emplacement drift. With a counter-opening design, the force placed on the door by the ventilation system will aid in opening one door while oppose opening of the other door. This result is a net force equal to zero and, thereby, reduces the overall horsepower necessary to operate the door. This type of counter-opening door technology is used in the mining industry.

In the event of a power failure, the emplacement access doors would remain in the position at time of power loss, normally closed. The door maintaining a closed position would have no impact on the ventilation system, as the closed position is the “normal” state and maintains the desired airflow pattern. If the doors were to fail during the open/close mode, they could be closed manually once equipment has cleared the door.



(Adapted from Reference 2.2.14, Figure 2)

Figure 19. Turnout Bulkhead Layout and Radiation Line of Sight

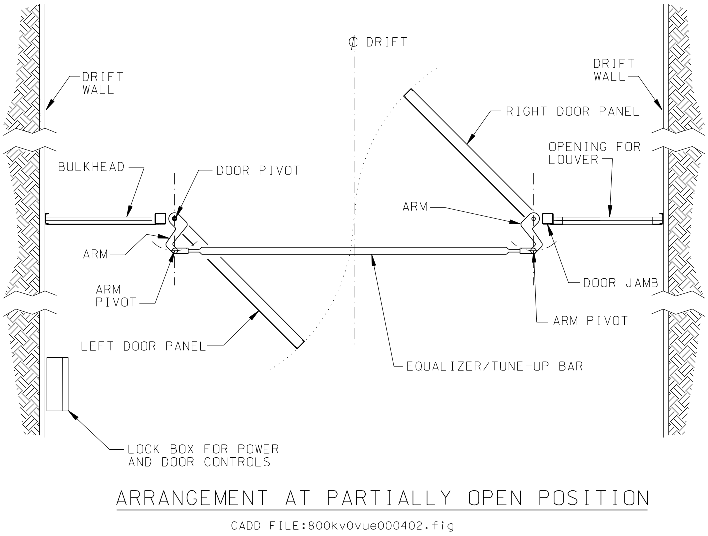


(Adapted from Reference 2.2.14, Figure 6)

Figure 20. Isometric View of Turnout Bulkhead

6.4.2.3 Emplacement Access Door Operations, Maintenance, Inspection and Repair

As discussed in Section 6.4.2, the emplacement access doors are of a counter opening design in which one door opens inward and one door opens outward. Figure 21 shows a plan view of the counter-opening door in a partially open position. This system relies on a single actuator and linkage bar to open both doors, thereby reducing the maintenance cost when compared to dual actuators. The linkage would contain an adjustment mechanism to provide fine-tuning of the door sealing (Figure 21).



(Adapted from Reference 2.2.14, Figure 8)

Figure 21. Counter Opening Emplacement Access Door Arrangement

A door actuator provides the force necessary to open the doors and could be electrical, mechanical, hydraulic-electric or other method and has not been designed at this time. The actuator would also contain a manual drive mechanism to allow closure of a partially open door. Final design constraints will consider the space available for the actuator mechanism, power availability, cost, maintenance, and any other factors that may influence operations. The gasket material on the door will be made of a high radiation dose rating (> 1000 rad) and located on the intake side of the door, so it should last the life of the preclosure period.

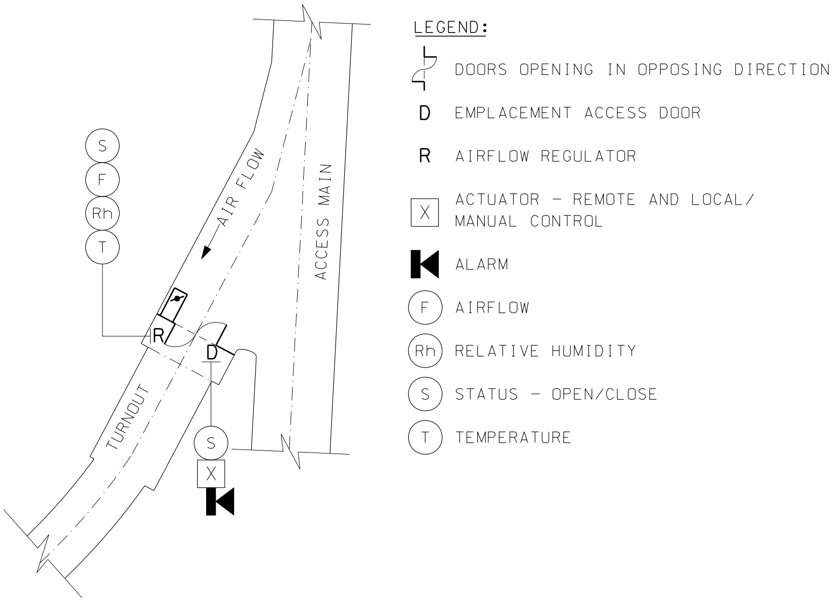
The radiological dose rate does not influence the basic design of the turnout bulkhead, but would require consideration for maintenance. The emplacement access door would require periodic maintenance and the maintenance employees must be prevented from inadvertently entering the high radiation area of the turnout (Reference 2.2.14). If the doors were open for maintenance, a portable shield may be used to provide radiation protection. Alternatively, a secondary alarmed, physical barrier could be used to prevent access to the high radiation area.

The bulkhead and frame would be designed to require minimal maintenance. Doors would be robust enough to not require replacement during the forced ventilation and closure period. Specialized equipment would be used when handling doors during installation and maintenance. The actuators are needed only to operate a few hundred times at each turnout for the approximately 120 waste packages placed per drift, occasional PC access, and drip shield installation. There is no planned maintenance on the door actuator. It can be tested to see if it is operational. If it is found to be inoperable, the actuator can be replaced prior to emplacement access. The failure rate of the actuators is expected to be low because of the low frequency of use and the simplicity and robustness of their design (Reference 2.2.14, Section 6.9).

The emplacement access door and regulator components will require regular maintenance and inspection, though a schedule has not been specified at this time. Components would be modular and designed for easy replacement. As the equipment ages, an enhanced inspection program may be useful to identify and prevent potential problems. All seals, bearings, and electronics would be industrial grade and an inherent availability of 0.9825 is possible with a good maintenance and inspection program.

6.4.2.4 Emplacement Access Door Monitoring and Instrumentation

Emplacement access door monitoring parameters include pressure differential, open/close status, and an alarm connected to the open/close operation. The door would not operate without central control center input to prevent inadvertent access to the high radiation areas. The turnout bulkhead monitoring and instrumentation concept is illustrated in . Though an emergency escape hatch hasn’t been designed, it would open from the inside only. It would be secured but not monitored.



(Adapted from Reference 2.2.14, Figure 9)

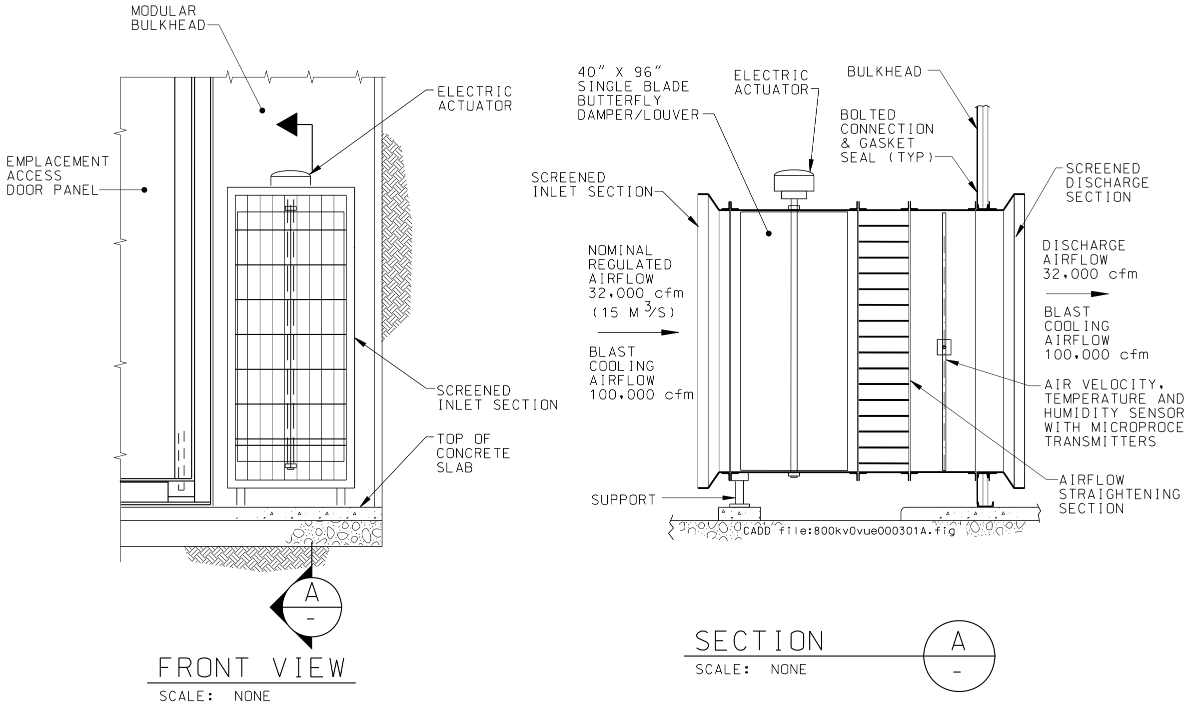
Figure 22. Emplacement Drift Turnout Bulkhead Instrumentation

6.4.2.5 Airflow Regulators

The design utilizes an electric actuated airflow regulator, in conjunction with a microprocessor based airflow sensor, to provide the desired emplacement drift airflow, thereby controlling the removal of thermal energy in order to satisfy the MGR thermal objectives. Fans located on the exhaust shafts create a differential pressure drop across a regulator that ensures the air moves from the access main toward the exhaust main.

Figure 23 illustrates an airflow regulator installation in the turnout bulkhead. The illustration shows a single rectangular regulator (Reference 2.2.14, Section 6.10). The airflow regulator would be sized to deliver a nominal airflow of 32,000 cfm with the ability to adjust the airflow for off-normal events or thermal strategy adjustments, and would be able to close completely to prevent an airflow reversal (Reference 2.2.14, Section 6.10.2). Regulator airflow would be calibrated to include any airflow leakage in the turnout bulkhead structure. Screened inlets and outlets ensure personnel cannot gain access to a loaded emplacement drift via an airflow regulator, nor get exposed to pinch points in the regulator mechanism.

The components would be located on the access main side of the turnout bulkhead to prevent unnecessary exposures for routine maintenance, calibration, inspection, and repair. Regulators manufactured for industrial settings are a common application and the repository environment does not introduce any conditions unlike those for other industrial applications. The regulator is a bolt-on, modular item that could be changed out in its entirety. The reliability of the regulator would be important to the design and include a robust industrial model of common design, with minimal moving parts. The final turnout bulkhead design would impact the regulator dimensions, location, and quantity.



(Adapted from Reference 2.2.14, Figure 11)

Figure 23. Typical Emplacement Drift Airflow Regulator Installation

Regulator instrumentation would include air velocity, temperature, and humidity. The instrumentation would be linked to the Central Control Center and interface with the Digital Control and Management Information System to provide real-time monitoring, adjustment, and recording of the ventilation conditions for each emplacement drift. The Central Control Center will have the capability to adjust the regulator airflow and provide for manual overrides. Use of digital instrumentation provides the capability to diagnose instrument errors through redundant measurements and known flow characteristics of the regulators. The airflow sensors will be maintained as recommended by the manufacturer (Reference 2.2.14, Section 6.10.1).

With an emplacement airflow volume range of 32,000 cfm ± 4,000 cfm, the automation process can be programmed to avoid excessive regulator adjustments. The regulators would be interlocked with the emplacement access door position such that when an access door is opened, the regulator would not try to adjust for the temporary decrease in airflow (Reference 2.2.14, Section 6.10). Though the system could be fully automated, the intent is not to have the main fans and louvers interlocked and operating in a continual search/balance mode.

After a panel has been fully emplaced and the individual emplacement drift airflow distribution volumes are stabilized, it may be possible to set the regulators in a static position that wouldn't require continual adjustments. It is unlikely the regulators could be set to a fixed position since the system must be able to respond to off-normal events, thermal changes based on performance confirmation, remote inspections, and the like.

In the event of a power loss, the regulators would remain fixed in their current position at time of power loss (an open position), allowing airflow. Because an emplacement drift is continually ventilated, the regulators are open and, therefore, would never fail in a closed state. In the unlikely event a regulator was to fail in a closed position, the regulator can be changed within the one-month operational guideline (Section 6.1.1).

6.4.3 Emplacement Drift Intake Airflow Volume

The nominal design volume of 32,000 cfm per emplacement drift satisfies thermal requirements for an emplacement drift up to 800 m long, at an initial line load of 2.0 kW/m (Section 4.3.2). Though an automated operating range hasn't been developed, the design range is 32,000 cfm ± 4,000 cfm per emplacement drift based on thermal calculations (Table 2). The emplacement ventilation system components would have the flexibility to provide airflow in the 28,000 and 36,000 cfm range. Since the emplacement drift lengths and the installed thermal line load will vary, the airflow volume may be different from drift to drift to support the thermal performance goals.

6.4.4 Emplacement Drift Outlet Air Volume

As the air moves through a loaded emplacement drift it is heated by waste packages and, therefore, expands. There is nothing to cause a pressure change in the emplacement drift (no elevation change, no fan pressurizing the drift) and the pressure loss due to resistance is negligible compared to the barometric pressure. Therefore, Charles' Law equation provides an estimate of the thermally expanded air volume. Charles' Law states $v_1/v_2=T_1/T_2$ at a constant pressure, where temperatures are absolute (Reference 2.2.37, Page 22).

As calculated in *Subsurface Ventilation Network Model for LA* (Reference 2.2.28, Section 6.1.5), the 32,000 cfm air quantity entering a 800 meter emplacement drift expands to 40,000 cfm at the drift exit based on 2.0 kW/m line load.

6.4.5 Emplacement Drift Airflow Velocity

The air velocity in a loaded emplacement drift will vary due to (1) the WP diameters and (2) the thermal expansion, as the air is heated. The emplacement drift effective area with and without largest diameter waste packages is approximately 159.93 ft^2 and 206.57 ft^2 respectively (Reference 2.2.28, Section 6.2.3). The emplacement drift air velocity will range between 150 fpm and 250 fpm as illustrated in Table 7.

Table 7. Emplacement Drift Air Velocities

Description	**Available Flow Area ft²**	**Velocity at 32,000 cfm fpm [b]**	**Velocity at 40,000 cfm fpm [b]**
Drift with waste package	159.93[a]	180	250
Drift without waste package	206.57[a]	155	194

Source: [a] Reference 2.2.28, Section 6.2.3, [b] cfm/area

For the blast cooling volume of 100,000 cfm, the drift airflow velocity is approximately 625 fpm that is acceptable during emergency cooling.

6.4.5.1 Emplacement Ventilation Monitoring

The ventilation system is monitored to provide operational information, safety considerations, and establish a baseline to confirm thermal management goals. The main intake, exhaust, and underground monitoring parameters include airflow velocity, barometric pressure, air temperature, humidity, airborne particulates, CO, and radon. The emplacement drift regulator monitoring provides operational information, supports performance confirmation, and enables the system components to be adjusted if repository requirements change. Airflow, temperature, relative humidity and effluent monitors at the exhaust shaft collars provide ventilation system performance information. The ventilation system would also interface to support radiation, radon, and CO monitoring at the exhaust shafts. Figure 9 and Figure 22 illustrate the basic monitoring information.

6.4.6 Emplacement Ventilation Network Modeling

The *Ventilation Network Model for License Application* (Reference 2.2.28) provides detail of the numerical model used to evaluate the subsurface ventilation network. Repository drift dimensions, lengths, cross section areas, perimeters, resistances, elevations, and airflow volumes support the ventilation network model. Model outputs include airflow distribution, pressure drops, resistances, and other related design information. The *Ventilation Network Model For License Application* provides the fan operating duties and repository airflow volumes (Reference 2.2.28, Table 18 and Table 19). This airflow distribution provides a representative basis for design use and should not be construed as the only possible or final airflow distribution.

Because of the large quantity of air required for the subsurface facility and the distances air must travel from intake to exhaust, the emplacement ventilation system is complex. The design has been simplified where possible and components are interchangeable where possible. Smooth-lined airways and moderate airflow velocities will reduce the overall system resistance, thereby reducing the power costs, a primary concern for the long period of forced ventilation.

6.4.7 Ventilation of Drifts During Active Waste Emplacement

There are no special ventilation requirements when waste packages are being loaded in an emplacement drift. Short-term interruptions due to opening and closing of emplacement access doors do not create thermal management problems (Section 6.4.8). Waste packages are loaded from the exhaust end of the drift toward the intake side, so the emplacement gantry would operate in intake air conditions. An emplacement drift's air volume could be minimal at the start of emplacement and gradually increase as waste packages are loaded in an emplacement drift.

6.4.8 Thermal Management

The purpose of ventilation is to remove sufficient heat during preclosure so that thermal goals can be attained. The subsurface ventilation system provides the ability to modify airflow rates to meet ventilation/cooling demands during normal and off-normal operations, and provide operational flexibility as repository conditions change with time. For additional information for 600 meter and 800 meter long emplacement drifts, refer to *Preclosure Emplacement Drift Temperature Calculation for the 2.0 kW/m Thermal Load* (Reference 2.2.50) calculation. It provides waste package surface, drift wall and ventilation air temperatures.

One Performance Confirmation drift is provided to support Performance Confirmation activities (Reference 2.2.34). The ventilation system provides 46,000 cfm airflow necessary to support the Performance Confirmation drift (Reference 4.3.3) activities.

6.4.9 Ventilation System Design Airflow

By using the North Construction Ramp and South Ramp as intakes during emplacement, the intake airflow velocities are lower, thereby reducing the fan operating pressure and overall power costs.

As noted in Section 4.3.3, the Ventilation Network Model used 108 emplacement drifts to calculate the system design volume. The intake and exhaust airflow volumes are listed in Reference 2.2.28, Table 19 and the fan operating duties are listed in Reference 2.2.28, Table 18.

6.4.10 Radiation Monitoring Interface

The Subsurface Ventilation System interfaces with the Radiological Monitoring System but does not dictate their equipment types or locations. Fixed area radiation and airborne monitoring instrumentation have not been defined at this time.

6.4.11 Panel 1 Emplacement Ventilation Details

The process and operational interfaces of concurrent development and emplacement ventilation systems can be best described by analyzing the ventilation design aspects of a single emplacement panel. Panel 1 has been chosen for this demonstration as it is the initial panel to be used for emplacement and because other design aspects, such as the utilization of existing underground facilities and an aggressive development schedule, bring out facets of the design that make Panel 1 a unique challenge.

The Panel 1 emplacement ventilation concept is illustrated in Figure 16. The air flows in from the North Ramp, is distributed/regulated to the emplacement drifts, flows through the exhaust main, and is exhausted to the surface through Exhaust Shaft #1. In addition, airflow is supplied to the Observation Drift that is located under and offset from the third emplacement drift. The isolation barrier locations required to isolate Panel 1 emplacement from development of the other panels are also shown. Exhaust Shaft #1 is the only exhaust source for Panel 1 and would contain two exhaust fans; one fan would be operational and one fan would be on standby. A dual fan installation will provide standby ventilation capabilities and support any additional airflow for performance testing, as needed.

In Panel 1, the Observation Drift is for the Performance Confirmation testing areas and will have variable or limited airflow volumes at different times (Section 6.4.8). The emplacement ventilation system would have the ability to respond to Performance Confirmation requirements.

6.4.12 Retrieval and Off-Normal Ventilation

The repository must retain the ability to retrieve selected waste packages from the emplacement drifts for 50 years after the completion of waste emplacement. Retrieval is the permanent removal of waste packages from the subsurface and recovery is temporarily removing waste packages from an emplacement drift(s) for inspection or other reason. The removal of waste packages in either scenario is reverse of normal emplacement and would be ventilated in the same manner as during WP emplacement, with approximately 32,000 cfm airflow. To remove a single WP, all WPs between the access main and the selected WP in the same drift must be removed in order to provide access to the selected WP. By removing WPs, the heat load and temperature profile along the emplacement drift will decrease (Reference 2.2.3, Section 6.2.1).

The *Drift Degradation Analysis* (Reference 2.2.13) indicated that in nonlithophysal tuff, preclosure design basis seismic events resulted in minor drift damage due to rockfalls. In the lithophysal tuff, there were no significant preclosure rockfalls in rock mass categories 1 through 5 due to rock heating or preclosure ground motion. A relatively minor amount of rockfall is predicted for a category 1 rock mass. (Reference 2.2.13, Executive Summary) The *Emplacement Drift Retrieval Ventilation Analysis* (Reference 2.2.3) examined various retrieval options, though a rockfall that would impact the ventilation is not expected to occur during pre-closure.

The ventilation system design supports temporary blast cooling (the rapid cooling of the emplacement drift) with a potential airflow of 100,000 cfm (47.2 m^3/s) in an emplacement drift (Reference 2.2.25). Blast cooling is considered necessary for mitigation of an off-normal event and would involve a managerial operations decision, not an automated response. The additional airflow would be for a limited time and would be used to reduce the wall rock temperature. The regulator would be opened fully to accommodate increased airflow and would be supplemented by partially opening the air door, if necessary (within security and ALARA concerns). The increased airflow can be provided by either increasing the main fan volume or by reducing the volume in nearby emplacement drifts. As discussed in Section 6.1.1, a reduced or no airflow condition can exist for 1 month without violating thermal design criteria. Reducing and not stopping the airflow in an adjacent emplacement drift for an off-normal event ensures airflow is maintained in the proper direction.

6.4.13 Radiological Releases

Normal subsurface facility operations involve the transport and placement of waste packages that are closed and sealed. No Category 1 or Category 2 event sequences resulting in radiological releases have been identified for subsurface facility operations. Releases of activated air and dust to the environment are potential events considered part of normal subsurface operations.

The *Radiological Releases Due to Air and Silica Dust Activation in Emplacement Drifts* (Reference 2.2.5, Section 6.2) corroborated that HEPA (high efficiency particulate air) filters were not needed for the removal of activated air and dust. There are three mechanisms that could generate potential airborne releases of radioactive materials during normal operations of the subsurface facility:

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

Prior to transportation to the subsurface facility the surface of each waste package is surveyed for contamination and decontaminated to below predetermined levels (Reference 2.2.35, Section 6.2). Residual contamination on the surface of a waste package may be resuspended in the emplacement drift, entrained in the ventilation airflow, and released to the environment through the shafts. The maximum waste package contamination levels ensure that any resuspended waste package contamination releases are within the regulated limits. Similarly, neutron flux activated air and dust in the emplacement drifts and host rock can be released to the environment through the shafts. The calculations of airborne releases during normal subsurface facility operations are calculated in Reference 2.2.5.

Any potential subsurface radiological releases were due to activation of the air and dust and their offsite dose contributions were insignificant. Results for activated products in air and activated products in silica dust, as calculated for the exhaust shaft emissions for normal operation airflow rates, are presented in Table (Reference 2.2.5, Section 6). The table includes the regulatory limits for those activated products. The calculation for activated products in dust is conservative because it is based on the potentially maximum dust emission rate of 250 tons/year, a limit that includes the emissions from the repository development areas that are not subject to neutron activation (Reference 2.2.5, Section 5.3.3). Combination of the calculated concentrations for activated products in silica dust represents approximately 0.01% of the regulatory limit (Table 8); therefore, there is no need to use engineered controls such as HEPA filters in the subsurface facility to conform to emission limits (Reference 2.2.5, Section 6.2).

HEPA filters would not remove the radioactive gases (activated products in air); however, the radioactive gas concentrations for the repository exhaust air emissions listed in Table 8 are a very small percentage (less than 1% and 6.6% for N-16 and Ar-41, respectively) of the regulatory limits (Reference 2.2.5, Section 6.1).

Table 8. Activated Product Releases During Normal Operation

Activation Product	10 CFR 20 Effluent Release Limit (μCi/ml)	Activated Product Release from Exhaust Shaft (μCi/ml)	Ratio (product activity/ 10 CFR 20 limit)
Activated Products in Air			
N-16	1E-09	5.5599E-12	5.5599E-03
Ar-41	1E-08	6.6401E-10	6.6401E-02
Activated Products in Silica Dust			
N-16	1E-09	3.1283E-17	3.13E-08
Na-24	7E-09	8.9156E-14	1.27E-05
Al-28	1E-09	8.1819E-14	8.18E-05
Si-31	4E-08	1.2658E-14	3.16E-07
K-42	7E-09	1.9272E-14	2.75E-06
Fe-55	3E-09	1.9816E-15	6.61E-07
Total Activated Products			
Total	6.90E-08	6.69775E-10	9.71E-03

Source: Reference 2.2.5, Table 6-1.

Though a WP leak has been identified as not credible during preclosure, the *Subsurface Contamination Control* calculation (Reference 2.2.43) evaluated the magnitude of potential radiological releases from a defective WP and its detectability. The results indicated the maximum dose to offsite and on site individuals would be a very small fraction of the ALARA dose requirements. The report indicated sampling the exhaust air for WP leaks would be complicated by a potential release of WP surface contamination and the existence of radon and its progeny (Reference 2.2.43, Sections 7.1 and 7.2).

Portable filtration units would provide contamination control during decontamination, after an event has occurred, and is not an automated system. Details for use of a portable filtration unit have not been developed at this time. The units could be designed and applied such that potential airborne radiological releases could be contained during a clean-up effort.

The *Potential Loss of Subsurface Isolation Barrier and Consequence Analysis* (Reference 2.2.23) demonstrated that an unlikely emplacement drift airflow reversal and corresponding radiological dose is not a safety concern. The intent of the calculation was to determine a potential dose rate for a partially loaded emplacement drift. The analysis is based on the outlet air temperature at a point in time when forced ventilation is lost and it does not consider subsequent heating of the unmoving air mass by the waste packages (Reference 2.2.23, Assumption Section 3.2.1). For the given conditions (summer intake temperatures and no subsequent heating), the potential for an airflow reversal exists if an emplacement drift contains less than 120 m of emplaced waste. The radiological dose from the airflow reversal is negligible (Reference 2.2.23, Section 7).

6.5 NATURAL VENTILATION PRESSURE

This section summarizes the natural ventilation concept and supporting calculation’s outputs. Though not required to support LA, after 50 years of forced ventilation (Reference 2.2.4), a period of natural ventilation could be used as an alternative to remove additional heat from the repository and bolster the postclosure performance.

The waste packages add a significant heat load to the ventilation system. This added heat would cause the air in the exhaust system to be less dense than the air in the intake system, creating a natural imbalance in the ventilation system. The imbalance imparts a driving force on the air that induces and maintains airflow similar to the effect of a common chimney. This effect is referred to as the natural ventilation pressure (NVP). The fact that the NVP will exist is not in question; however, the exact magnitude of the NVP and resulting airflow is difficult to predict. Since the WP thermal energy reduces over time, the corresponding NVP will reduce according to the waste package decay heat. The NVP also varies due to the ambient natural diurnal cycles and seasonal temperature changes.

During the preclosure period the NVP provides a benefit by reducing the main fan operating pressure and provides a direct reduction in power consumption. This information will be developed further during detailed design. The NVP will maintain airflow even if the exhaust fans are off due to a power outage or out of service for repair.

Various methods can be used to estimate the NVP including some that require accurate psychometric parameters that are not developed at this time. One method used to estimate the NVP is a density calculation based on the difference in the specific weight of air between the intake and exhaust airways, along with the shaft depth. The *Natural Ventilation Pressure Calculation* used emplacement drift air inlet temperatures and outlet air temperatures, along with shaft depth to estimate the NVP using the density calculation method (Reference 2.2.4, Section 6.1.6). Three different inlet conditions and a range of outlet temperatures were used to estimate NVPs. For additional information, see Reference 2.2.4 and Reference 2.2.7. It is important to note this is a point in time airflow volume; the NVP declines as the WP decay heat declines.

6.6 FIRE PROTECTION AND EMERGENCY PREPAREDNESS

The subsurface repository fire hazards analysis establishes requirements for the subsurface repository to minimize fire and explosion hazards and provides a proper level of personnel safety and property protection for emplacement operations. The Fire Detection and Alarm Systems will interface with the Subsurface Ventilation System for supervisory control and emergency management operations. The level of detail for the ventilation system support and interfaces in emergencies has not been developed at this time. The various repository systems will interface with each other as design details are developed (Section 6.2).

Subsurface personnel carry self-rescuers and the current practice of storing self-contained self-rescuers at strategic locations would continue. An alarm system(s) would warn subsurface personnel of potential emergencies.

A future, separate Fire Hazard Analysis (FHA) will address development and construction hazards. The following Fire Protection System and Subsurface Ventilation System interfaces require further evaluation.

- Development area fire hazards analysis work.
- Incorporate smoke and combustion byproduct flow and concentration into the ventilation system design. Evaluate the ventilation system requirements for assisting in smoke removal.
- Evaluate emergency egress routes and evacuation plans, including shafts.
- Determine locations of emergency refuge stations.

6.7 CLOSURE AND SEALING

Drip shields would be installed prior to closure of the repository. If the temperature in the emplacement drift where equipment is operating does not fall within the acceptable range, then additional airflow will be provided. If select emplacement drifts did require additional airflow in order to operate the drip shield gantry, the ventilation system could accommodate the airflow increase. Once the drip shields have been placed, the repository would be prepared for backfilling.

The *Closure and Sealing Design Calculation* (Reference 2.2.22, Section 6) identified the repository closure strategy and approach. The closure and sealing process would involve removal of all previously installed items that could potentially interact with waste packages over time. These items could include concrete, air doors, electrical cables, rail, etc. The backfilling of ramps and shafts is required. The backfilling effort requires interface with the Subsurface Ventilation System to regulate and adjust airflows, as needed. Conceptually, the ventilation system has the flexibility to support backfilling operations. Ducted ventilation systems and dust filters would be utilized to ventilate dead end work faces being backfilled and in ramps or shafts. The system would be designed for worker safety and would minimize dust loading on the waste packages. The main fan volumes would be reduced, as required areas are backfilled. Once the backfilling operation for a shaft begins and the fans are no longer needed, the fans would be decommissioned and salvaged.

6.8 HAZARDS ANALYSIS SUMMARY

The ventilation system is subject to external event hazards and internal event hazards. The hazards that apply to the ventilation system must be recognized and the system must be designed and built to allow for safe operation and maintenance, accordingly. External events include items such as an aircraft crash, military induced, extreme wind, rainstorms, range fires, flooding, lightning, power loss, tornado, or volcanism-ash fall. Internal events include items such as collision/crushing, flooding, explosion, and radiation, electrical, fissile, and thermal.

An operating requirement of the subsurface ventilation system directs evacuation of the construction and emplacement sides of the subsurface whenever ventilation on the emplacement or construction side is inoperable. This measure is a precautionary response to ensure that worker doses remain as low as reasonably achievable. It also mitigates a potential loss of confinement due to emplacement-side ventilation malfunction or other breach of a confinement barrier leading to the release of activated material from the emplacement side of the repository to the development side.

If an airplane were to hit an intake shaft or portal directly, associated flames and gasses would be drawn into the subsurface. In case of a catastrophic ground fall, personnel may be trapped in a dead-end tunnel. For major incidents such as airplane hit or ground fall, the airflow intakes and exhausts (Refer Section 6.8.1) may need to be reconfigured to support thermal management requirements. As discussed in Section 6.4.8, the fans can be off for a one-month period without greatly impacting the thermal management.

For incidents such as a range fire or ash fall, where the intake air quality may be impacted, the surface environmental conditions would be monitored and, if needed, a management decision would determine the need to evacuate personnel and shut down the ventilation system or select system components thereof.

6.8.1 Main Fan Hazards

The main fans are located on the shaft collars for both the development and emplacement ventilation systems. The shafts are physically separated by large distances and placed at various locations on Yucca Mountain. The installations are located away from surface fault contacts, above the flood plains, and the shaft collars slope away to prevent water inflow. No combustible vegetation or materials are kept within the immediate area of the shaft collars. The installations are designed within applicable seismic, wind, tornado, and other criteria. Main fans are monitored and the system would shut down in a predictable fashion if the sensors indicate a problem. The subsurface repository is designed with multiple shafts and the main tunnels are interconnected to provide alternate airflow options in case any single main fan is off.

The loss of the entire ventilation system due to a power outage, lightning storm, or similar incident would be considered short term and would not impact the thermal management. The ventilation system must be able to respond to off-normal and emergency conditions; therefore the emergency diesel power system hook-up arrangement is provided to supply power to the main exhaust fans. Personnel would be evacuated from the subsurface during a power outage.

It is not expected that an external event, such as an aircraft crash, industrial accident, fissile, or military induced accident, would impact more than one fan installation. If a single installation were to be damaged beyond use, the other installations would still be capable of providing ventilation in the repository. The system would need to be reconfigured for the duration of the repair/recovery period. If the incident resulted in the collapse of the shaft structure, a more extensive reconfiguration may be required.

Multiple shafts may not available for emplacement ventilation during the early stages of Panel 1 emplacement. Prior to emplacement starting in Panel 1, the ECRB Shaft could be excavated to provide airflow for subsequent Panel 1 development. If the ventilation capacity at Exhaust Shaft #1 is off for an extended period, the airflow could than be rerouted out the ECRB Shaft during the recovery stage. This would require stopping the development effort, reconfiguration of select isolation barriers, and reversal of the fan(s) in the ECRB Shaft.

The main fan power supplies are considered high-energy sources and would be protected accordingly. Commercially available fan housings (both main and auxiliary) are designed to control any catastrophic blade failure. With a blade failure the airflow will stop. In main fans, vibration sensors would shut the fan off automatically. In auxiliary fans the motors may continue to run and, if multiple fans were in use, the system would operate at a reduced volume. Surface fan structures would have lightning protection systems installed.

6.8.2 Other Structure Hazards

The subsurface components, such as auxiliary fans, emplacement doors, and isolation barriers, would be subjected to seismic events. Auxiliary fans would be suspended with a hanger designed for its intended use and to ensure the fan would not drop. The hanger would be flexible and the fans would not be damaged by seismic motion. Doors and barriers would be designed in accordance with the applicable regulations and the expected thermal and the radiation loads. The bulkhead/rock interface may receive damage due to seismic motion and may require resealing of the interface contact. Emplacement drift regulators are located in an accessible area and can be changed if necessary. Subsurface ventilation components would require operating and control power supplies that would be installed per electrical codes to provide appropriate electrical shock, grounding, and excessive voltage protection.

Emplacement doors will be designed with adequate clearance for the TEV. However, if a collision were to occur due to a door malfunction, the components would need to be replaced. The collision between an emplacement door and TEV would not initiate a design basis event. The emplacement door is used to restrict access and not act as a radiation barrier. However, the emplacement door may be inoperable until it is repaired and a method to restrict access to the high radiation area of the emplacement drift would be required during the repair.

Water will be provided to the development operations, but not the emplacement operations. The potential for localized flooding does exist in the development side, but not the emplacement side. In industry it is common to have shut-off valves in the pipes to limit flooding in the event of a pipe break. The development ventilation auxiliary fans are installed in the upper portions of the tunnels and are not subject to flooding. Similarly, the load centers that provide power to the fans are located in niches, above the invert level. The systems would continue to operate for a localized flooding event.

If power or ventilation is lost during development, personnel are evacuated, as necessary. Isolation barriers are subject to equipment related collision incidents and, therefore, designed with two bulkheads. If one side is damaged, the other would still be used and the barrier integrity is maintained. Components would be repaired or replaced, as required.

Explosives would be used during the development effort, and as such, there is the possibility of explosion related incidents, primarily blast concussion related. Though isolation barriers are installed between the development and emplacement systems, the construction sequencing provides enough distance (81 m between drifts) between any potential blasting and the barriers. Utilities passing through a blast area would also be protected or removed to prevent damage.

Battery charging would be done on the surface in ventilated areas. Standby batteries for underground components would be selected to minimize hydrogen off gassing and installations would be properly ventilated.

Monitoring equipment would be specified so interference from radios would not create hazards. Emissions to the atmosphere, such as radiological, radon and dust, are monitored for downstream dosage impacts and considered part of the operating permit process. There are no credible design basis events during pre-closure that result in a radiological discharge from the subsurface.

6.9 OUTPUT UNCERTAINTY

The results of the information contained in this report are suitable for its intended use and consistent with design criteria. The interface requirements are accurate and correct as of the date of issue. This information provides a representative basis for design use and should not be construed as the only possible airflow volume design and distribution. Uncertainties with the ventilation concepts exist due to the existing level of design detail available of the various systems and interfaces. As the design of the systems and interfaces develop further, the ventilation system design will be developed accordingly.

7. CONCLUSIONS

This analysis confirms that the *Subsurface Construction and Emplacement Ventilation* comply with Basis of Design (BOD), Project Design Criteria (PDC), and other industry standards referenced in Section 4.3. The subsurface ventilation system consists of the emplacement ventilation subsystem and development ventilation subsystem. The entire system is non-ITS, non-ITWI, and non-safety category (non-SC).