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OFFICE OF CIVILIAN RADIOACTIVE WASTE MANAGEMENT
ANALYSIS/MODEL COVER SHEET
Complete Only Applicable Items

1. QA: QA

Page: 1 of: 45

2. ☒ Analysis Check all that apply

Type of Analysis
☒ Engineering
☐ Performance Assessment
☐ Scientific

Intended Use of Analysis
☐ Input to Calculation
☐ Input to another Analysis or Model
☒ Input to Technical Document
☒ Input to other Technical Products

Describe use:
Provide a basis for SDD Section 2 that provides input to the site recommendation.

3. ☐ Model Check all that apply

Type of Model
☐ Conceptual Model
☐ Abstraction Model
☐ Mathematical Model
☐ System Model
☐ Process Model

Intended Use of Model
☐ Input to Calculation
☐ Input to another Model or Analysis
☐ Input to Technical Document
☐ Input to other Technical Products

Describe use:

4. Title:
Overall Subsurface Ventilation System

5. Document Identifier (including Rev. No. and Change No., if applicable):
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OFFICE OF CIVILIAN RADIOACTIVE WASTE MANAGEMENT
ANALYSIS/MODEL REVISION RECORD
Complete Only Applicable Items

1. Page: 2 of: 45

2. Analysis or Model Title:

Overall Subsurface Ventilation System

3. Document Identifier (including Rev. No. and Change No., if applicable):

ANL-SVS-HV-000002 REV 00 ICN 1

4. Revision/Change No.	5. Description of Revision/Change
00	Issue Document
ICN 1	Added text to Section 4.1.1 to clarify ventilation requirement required to meet the 70 percent heat removal goal. No impact to the references or DIRS.

CONTENTS

FIGURES

TABLES

ACRONYMS

ALARA	as low as is reasonably achievable
CFR	Code of Federal Regulations
CRWMS	Civilian Radioactive Waste Management System
DOE	U.S. Department of Energy
EDA	Enhanced Design Alternative
ESF	Exploratory Study Facility
MGR	Monitored Geologic Repository
MTU	metric tons of uranium
NRC	U.S. Nuclear Regulatory Commission
PC	Performance Confirmation
SDD	System Description Document
SR	Site Recommendation
TBD	to be determined
TBM	tunnel boring machine
TBV	to be verified
VA	Viability Assessment
WP	Waste Package

1. PURPOSE

The purpose of this analysis is to provide a conceptual design for the Subsurface Ventilation System and address the construction, emplacement, monitoring, backfill, and closure ventilation phases. The design will be based on the recently established program requirements for transitioning to the Site Recommendation (SR) design as outlined by "Approach to Implementing the Site Recommendation Baseline" (Stroupe 2000) and the *Monitored Geologic Repository Project Description Document* (CRWMS M&O 1999d) (MGR).

This analysis will summarize the ventilation concepts that have developed from the incorporation of recent changes to the Technical Baseline and describe changes to the conceptual ventilation design that have resulted from the thermal management requirements. Ventilation concepts presented in the Viability Assessment Design (VA Design) that have not changed are identified and included.

The objective of this analysis is to provide a basis for the System Description Document (SDD) Section 2 that provides input to the SR Consideration Report.

The scope of the analysis includes the following tasks:

- Determine the number of primary shafts based on the emplacement airflow rate required to meet thermal goals
- Determine conceptual airflow networks for major repository phases including:
  - Construction
  - Emplacement
  - Monitoring
  - Closure
- In addition evaluate:
  - Radon mitigation concerns and options
  - Monitoring and control requirement changes needed to meet current guidelines
  - The impact on the ventilation system of a radiological release due to a potential subsurface fire involving a waste package.

2. QUALITY ASSURANCE

This analysis has been prepared in accordance with the Development Plan (CRWMS M&O 2000a) which was prepared in accordance with AP-2.13Q, *Technical Product Development Planning*. This analysis has been determined to be subject to the requirements of the *Quality Assurance Requirements and Description* (DOE 2000) document by Activity Evaluation (CRWMS M&O 1999a) which was completed under procedure QAP-2-0, *Conduct of Activities*. Per AP-2.16Q, *Activity Evaluation*, Activity Evaluations completed under QAP-2-0 will remain valid unless re-evaluation is required. Classification of MGR Subsurface Ventilation System is Conventional Quality per *Classification of the MGR Subsurface Ventilation System* (CRWMS M&O 1999b, p. 9). This document was prepared in accordance with AP-3.10Q, *Analyses and Models.*

3. COMPUTER SOFTWARE

The project standard suite of office computer software, which is not subject to AP-SI.1Q, *Software Management* verification was used in the report. These are commercial off-the-shelf software programs, and no specific qualification is needed. No routines or macros were utilized.

4. INPUTS

All technical product and sources of the input used in the development of this analysis are documented in this section. The to be verified (TBV) or to be determined (TBD) status is indicated in accordance with AP-3.15Q, *Managing Technical Product Inputs.*

4.1 DATA AND PARAMETERS

This section provides a list or tables of data and parameters, their sources, and their appropriateness for use as input in this analysis.

In order to provide reasonable assurance that a potential fire involving waste packages in the subsurface operations will not cause harm to workers or adversely affect public health and safety, the following document is referenced in Section 6.6.2 of this analysis: *Subsurface Fire Hazards Technical Report* (CRWMS M&O 1999f).

4.1.1 Emplacement Drift ANSYS Data

Emplacement drift airflow temperature data from the *ANSYS Thermal Calculations in Support of Waste Quantity, Mix and Throughput Study* (CRWMS M&O 1999g, Table 6-1) are in Table 1 (DTN:MO9911SPAWAQ01.000). The ANSYS calculations were used to analyze the effects of preclosure continuous ventilation in the emplacement drifts. As air passes over the waste packages it is heated as shown in Table 1, and expands. The calculation used a sensible heat-only method and did not consider the heat transfer associated with water vaporization and is therefore a conservative value. Used throughout the analysis.

Table 1. ANSYS Data at Ventilation Airflow Rate of 15 m^3/s

Initial Linear Heat Load (kW/m)	Peak Air Temperature (°C)	Time to Reach (Year)
1.2	53	10
1.4	58	10
1.6	63	10

Source: Derived from CRWMS M&O 1999g, Table 6-1 (DTN:MO9911SPAWAQ01.000)

For a line load of 1.45 kW/m (see Section 5.9) an exhaust air temperature of approximately 60°C is interpolated from the data above. The interpolation is included as Attachment III.

- At 1.6 kW/m and a 15 m^3/s airflow rate the emplacement drift outlet air temperature at 50 years is 48.77°C and drops thereafter (CRWMS M&O 1999g, Table III-8). There is no distinct calculation for the 1.45 kW/m line loading spacing (see Section 5.9), therefore, temperatures for the 1.6 kW/m line loading are used in this analysis are valid and provide an upper bound where used.

- At a line load of 1.4 kW/m and 15 m^3/s airflow rate 71 percent of the heat generated by waste packages was removed in 50 years (CRWMS M&O 1999g, Fig. II-8).
- At a line load of 1.6 kW/m and 15 m^3/s airflow rate 71 percent of the heat generated by waste packages was removed in 50 years (CRWMS M&O 1999g, Fig. III-12).

In this reference (CRWMS M&O 1999g) an emplacement drift receives continuous ventilation for 50 years in order to achieve the 71 percent heat removal. If an emplacement drift is ventilated for more or less than 50 years, the amount of heat removal will be different. The final design emplacement drift airflow may vary from the 15 m^3/s used in this analysis.

4.1.2 Waste Package Inventory

The "Approach to Implementing the Site Recommendation Design Baseline" (Stroupe 2000, Attachment 1, p. 1 of 3) is a management edict that directs the SR Design to accommodate the waste package inventories for 70,000 and 97,000 metric tons of uranium (MTU) (Section 5.10) in accordance with Input Transmittal RSO-SSR-99360.T (CRWMS M&O 2000b). The waste package (WP) inventory, which includes the WP quantities and the outer length of the waste package, for 70,000 MTU is outlined in Table 2 (CRWMS M&O 2000b, Item 2, pp. 3 and 5). The waste package inventory for 97,000 MTU is outlined in Table 3 (CRWMS M&O 2000b, Item 2 pp. 4 and 6). The waste package inventories are used to estimate the SR drift quantities. Used in Section 5.2 and in Attachment I.

Table 2. Waste Package Inventory for 70,000 MTU

WP Description	WP Outer Length (m)	Number of WPs
21 PWR AP (Pressurized Water Reactor, Absorber Plates)	5.06	4,299
21 PWR CR (Pressurized Water Reactor, Control Rods)	5.06	95
12 PWR AP Long	5.54	163
44 BWR AP (Boiling Water Reactor, Absorber Plates)	5.06	2,831
24 BWR AP	5.00	84
5 IPWF (immobilized plutonium waste form)	3.48	95
5 DHLW Short/1 DOE SNF Short (Defense High Level Waste/DOE Spent Nuclear Fuel)	3.48	1,052
5 DHLW Long/1 DOE SNF Long	5.11	1,406
2 MCO/2 DHLW Short (multi-canister overpacks/defense high level waste)	5.11	149
5 HLW Long/1 DSNF Short	5.11	126
HLW Long Only	5.11	584
Naval Short	5.32	200
Naval Long	5.96	100
Total		11,184

Source: CRWMS M&O 2000b, Item 2, pp. 3 and 5

Table 3. Waste Package Inventory for the 97,000 MTU

WP Description	WP Outer Length (m)	Number of WPs
21 PWR AP (Pressurized Water Reactor, Absorber Plates)	5.06	5,690
21 PWR CR (Pressurized Water Reactor, Control Rods)	5.06	106
12 PWR AP Long	5.54	293
44 BWR AP (Boiling Water Reactor, Absorber Plates)	5.06	3,732
24 BWR AP	5.00	98
5 IPWF (immobilized plutonium waste form)	3.48	127
5 DHLW Short/1 DOE SNF Short (Defense High Level Waste/DOE Spent Nuclear Fuel)	3.48	1,403
5 DHLW Long/1 DOE SNF Long	5.11	1,874
2 MCO/2 DHLW Short (multi-canister overpacks/defense high level waste)	5.11	199
5 HLW Long/1 DSNF Short	5.11	167
HLW Long Only	5.11	780
Naval Short	5.32	200
Naval Long	5.96	100
Total		14,769

Source: CRWMS M&O 2000b, Item 2 pp. 4 and 6

4.1.3 Radon Calculation Data

Subsurface Background Concentration Radiation Monitoring Calculations (CRWMS M&O 2000d, Section 2) describes a method to calculate concentrations of radon and its progeny in the Main and emplacement drifts when the radon flux is known. The calculation provides an empirical method to demonstrate the ventilation system will be capable of maintaining the radon levels to comply with applicable design provisions (see Section 4.2.16). Used in Section 6.4.2.

4.2 CRITERIA

The design criteria that apply to this analysis were developed based on requirements from the *Subsurface Ventilation System Description Document* (CRWMS M&O 2000c), *Subsurface Operations Monitoring and Control System Description Document* (CRWMS M&O 1998a), and *Subsurface Facility System Description Document* (CRWMS M&O 2000f). Specific System Description Document (SDD) criteria are cited for each of the criteria below.

4.2.1 The system shall minimize the dry bulb temperatures in the subsurface for areas requiring human access while limiting the maximum dry bulb temperature to 48°C (TBV-321). For subsurface areas requiring human access for a full shift (i.e., equal to or in excess of eight hours) without personnel heat stress protection, the system shall limit the maximum effective temperature to 25°C (CRWMS M&O 2000c, Section 1.2.1.3). Used in Section 6.1.

4.2.2 The system shall maintain underground air temperatures during repository remote access (remote equipment) modes to within the values specified in Table 4 (CRWMS M&O 2000c, Section 1.2.1.4). Used in Sections 5.7, 6.1, 6.1.4, 6.2.2 and 6.3.4.1.

Table 4: Remote Temperatures

Location	Operations	Maximum Temperature
Emplacement Drift	Remote Access*	50 degrees C Dry Bulb
Access Mains, Ramps, and Alcoves	Remote Access*	50 degrees C Dry Bulb
Performance Confirmation Drifts	Remote Access*	50 degrees C Dry Bulb
Exhaust Main	Remote Access*	50 degrees C Dry Bulb
Turnouts	Remote Access*	50 degrees C Dry Bulb

*Includes emplacement, retrieval, recovery, backfill, and abnormal modes of operation.

4.2.3 The system shall provide ventilation for the development and emplacement areas by two separate and independent systems (CRWMS M&O 2000c, Section 1.2.1.6). Used in Sections 6.1, 6.3.1 and 6.3.2.

4.2.4 The system shall be designed to remove at least 70 percent of the heat generated by the waste packages during preclosure (CRWMS M&O 2000c, Section 1.2.1.9). Used in Sections 6.1 and 6.1.1.

4.2.5 The system shall be designed to prevent reverse airflow in the emplacement drifts (i.e., from emplacement drifts to the turnouts) (CRWMS M&O 2000c, Section 1.2.2.2.4). Used in Sections 6.1 and 6.3.4.1.

4.2.6 The system shall be designed to ensure that occupational doses are as low as is reasonably achievable (ALARA) in accordance with the project ALARA program goals (TBD-406) and the applicable guidelines in "Information Relevant to Ensuring that Occupational Radiation Exposures at Nuclear Power Stations Will Be As Low As Is Reasonably Achievable" (Regulatory Guide 8.8) (CRWMS M&O 2000c, Section 1.2.2.2.5). Used in Sections 6.1, 6.4 and 6.4.2.

4.2.7 The system shall be capable of controlling average concentrations of radon daughters to levels that will not result in worker exposure exceeding the limits specified in 29 CFR 1910.1096 in potentially occupied areas (CRWMS M&O 2000c, Section 1.2.2.2.6). Used in Sections 6.4 and 6.4.2.

4.2.8 The system shall accommodate the MGR Operations Monitoring and Control System in providing system measurements and equipment status as listed in Tables 5 and Table 6, as a minimum. The type of monitoring capabilities (i.e., continuous versus intermittent) is dependent on the final system design and will be specified before system design is complete (CRWMS M&O 2000c, Section 1.2.4.1). Used in Section 6.5 and Figure 10.

Table 5. Monitoring Parameters

System Parameter	Location of Monitoring
Air Flow Rate (or Velocity)*	Main Intake, Exhaust, and Underground Working Areas
Air Pressure Differential*	Air Locks Ventilation Fans
Air Temperature*	Main Intake, Exhaust, and Underground Working Areas
Relative Humidity of Airflow*	Main Intake, Exhaust, and Underground Working Areas
Concentration of Airborne Particulates*	Main Intake, Exhaust, and Underground Working Areas
Concentration of CO*	Main Intake, Exhaust, and Underground Working Areas
*Anticipated ranges for normal operation, for anticipated operational occurrences, and accident conditions will be provided for these parameters as part of final design.	

Table 6. Equipment Status

Equipment	Parameter Indicated
Valves (Dampers)	Open/Close Position
Fans	RPM, Voltage, Current, On-Off
Emplacement Doors	Open/Close Position
Air locks	Open/Close Position

4.2.9 The system shall interface with the Subsurface Facility System to ensure that subsurface layout, arrangement, and opening sizes support ventilation (CRWMS M&O 2000c, Section 1.2.4.4). Used in Sections 6.2.2 and 6.2.4.

4.2.10 The system shall interface with the Emplacement Drift System to ensure ventilation capacity and availability to support temperature constraints (CRWMS M&O 2000c, Section 1.2.4.5). Used in Section 6.1.

4.2.11 The system interfaces with the Subsurface Excavation to accommodate ventilation needs for subsurface excavation operations (CRWMS M&O 2000c, Section 1.2.4.6). Used in Sections 6.2.2 and 6.2.4.

4.2.12 The system interfaces with the Backfill Emplacement System to accommodate ventilation needs for backfill operations (CRWMS M&O 2000c, Section 1.2.4.7). Used in Section 6.3.4.

4.2.13 The system interfaces with the Site Radiological Monitoring System to accommodate the installation of radiation monitors (CRWMS M&O 2000c, Section 1.2.4.9). Used in Section 6.5 and Figure 10.

4.2.14 The system shall have a maintainable service life up to 175 years (CRWMS M&O 2000c, Section 1.2.5.1). Used in Section 6.3.3.

4.2.15 The system shall include provisions for upgrades and refurbishments designed to increase the system's operational life to support a deferral of closure for up to 300 years (CRWMS M&O 2000c, Section 1.2.5.2). Used in Section 6.3.3.

4.2.16 The system shall comply with the applicable design provisions in Section 14.5 of "Radiation Protection in Uranium Mines" (ANSI N13.8-1973) to control concentrations of radon daughters in the potentially occupied areas of the repository (CRWMS M&O 2000c, Section 1.2.6.3). Used in Sections 4.1.3, 6.4 and 6.4.2.

4.2.17 For diagnostic purposes, the system shall provide real-time monitoring of the critical operating parameters: a) motor temperature and vibration, and b) rotating equipment bearing temperatures (CRWMS M&O 1998a, Section 1.2.1.26). Used in Section 6.5 and Figure 10.

4.2.18 The system shall provide monitoring for the following alarm status indicators, as a minimum, from the Subsurface Safety and Monitoring System: a) subsurface fire detection, b) subsurface radiological release, and c) subsurface air quality (CRWMS M&O 1998a, Section 1.2.2.2.3). Used in Section 6.5 and Figure 10.

4.2.19 The system shall provide the operator with the supervisory control of the following ventilation control functions: a) fan speed control, b) damper control (open/close), c) isolation door control (open/close), d) fan on/off and reversal (start/stop fans and direction), e) airflow restriction (actuator valves), and f) filter damper control (CRWMS M&O 1998a, Section 1.2.2.2.5). Used in Section 6.5 and Figure 10.

4.2.20 The Subsurface Facility SDD (CRWMS M&O 2000f, Section 1.2.18) states that three performance monitoring drifts, two postclosure simulated emplacement drifts, and one postclosure monitoring drift are to be provided. For the purposes of this analysis, these six drifts are labeled as the "Performance Confirmation (PC) drifts". Used in Sections 5.6, 6.2.2, 6.7 and Table 9.

4.2.21 The system shall space the emplacement drifts 81 m center to center (CRWMS M&O 2000f, Section 1.2.1.5). Used in Section 6.1.

4.3 CODES AND STANDARDS

The following codes and standards are referenced in this analysis.

29 CFR 1910

Code of Federal Regulations (CFR). Labor: Occupational Safety and Health Standards. Used in Section 4.2.7.

5. ASSUMPTIONS

This section contains the assumptions used in the analysis. All assumptions used for this conceptual design are considered accepted data, existing, or TBV, respectively where noted. No values derived from this analysis shall be used to support construction, fabrication, or procurement.

Assumptions in Sections 5.6 and 5.7 and are based on design parameters that may differ from the final SR design. For the purposes of this analysis, the air volumes are valid, applied consistent with good engineering practice and will not affect the outcome of the analysis at this conceptual level.

This document may be affected by technical product information that requires confirmation (TBV/TBD). Any changes to the document that may occur as a result of completing the confirmation activities will be reflected in subsequent revisions. The status of the input information quality may be confirmed by review of the Document Input Reference System database.

5.1 MGR design will provide means for controlling the spread of potential contamination and performing decontamination, consistent with applicable codes and standards, by selecting design features and decontamination operations that will comply with as-low-as-reasonably-achievable (ALARA) requirements and, to the extent practical, minimize effects on operations. MGR radiological, waste handling, and maintenance operations will be supported by equipment designed to decontaminate the handling equipment, waste containers, and personnel as near the source of contamination as practicable. Portable or mobile decontamination equipment will be provided where appropriate to support area clean up and for preliminary equipment decontamination for the purposes of safe handling to final decontamination. Major decontamination operations will be centralized where confinement and movement to the centralized facility is dictated by ALARA considerations. Decontamination equipment will be designed to collect, and confine the contamination byproducts in a way that can be safely transported or transferred for processing. (TBV-1008) (CRWMS M&O 1999d, CPA 013). Used in Section 6.4.

5.2 A Site Recommendation repository layout has not been baselined and it is assumed that drift quantities can be estimated using the WP inventory(see Section 4.1.2). Attachment I details how Tables 3 and 4 were used to determine the drift quantities shown below. For the purpose of this analysis, the following drift quantities are used in Sections 6.2.2 and 6.7 (see Attachment I):

70,000 MTU Inventory Emplacement Drift Quantity	54
97,000 MTU Inventory Emplacement Drift Quantity	71

Rationale and Justification: Since there is no SR repository layout available as a reference, repository drift quantities must be established in order to provide a basis for the ventilation system design. Utilizing the waste package stream to estimate the required number of drifts is a valid way to estimate the number of emplacement drifts. In Attachment I, emplacement drift quantities are estimated by determining the overall length of the WP stream, increasing for the 0.1m spacing between WPs, dividing by 1,200m, (double the 600m length of the emplacement drift split used in the ANSYS Calculations (CRWMS M&O 1999g, Section 3.6)), and adding a contingency. Per AP-3.15Q, Attachment 4, the waste package information is not considered TBV since it is management edict. A 15 percent contingency is added to this estimate since all emplacement drift splits are not 600m long.

5.3 For the purpose of this analysis, it is assumed there are five empty drifts available for use as cross-block drifts, emergency egress, or stand-by emplacement drifts. To be consistent with the VA Design, three drifts are designated for cross-block ventilation and two drifts are designated standby drifts in which to relocate waste packages if needed (DOE 1998, Section 4.2.1.2). Used in Sections 5.6, 6.1.3, 6.2.2, 6.7, and Table 9.

Rationale and Justification: A certain number of empty drifts must be included for ventilation use, emergency egress, or stand-by emplacement drifts. There were five of these drifts in the VA Design (DOE 1998, Section 4.2.1.2) and this number is used in this analysis for consistency.

5.4 For the purpose of this analysis, it is assumed an exhaust shaft, paired with an intake shaft, can provide an exhaust air volume capacity in the range of 800 to 850 m^3/s and 10 inches water gauge (wg) pressure. Used in Sections 6.2.4, 6.3.3, and 6.7.

Rationale and Justification: The thermal management requirements will require additional airflow and therefore, additional shafts to support the ventilation. Economically, the high airflow capacity shaft would reduce the required number of shafts to be excavated. The fan selected for use in *Design Feature 7: Continuous Preclosure Ventilation* (CRWMS M&O 1999e) (Design Feature 7) is one of the largest, commercially available fans (Joy 1982, Curve C-9804) and is considered in this analysis. The 10 m^3/s ventilation simulation output in the Design feature 7 report indicated the fans would operate at approximately 790 m^3/s at 10 inches wg. (CRWMS M&O 1999e, Appendix G, p. 20) (see Attachment II, p. II-1). This 790 m^3/s operating air volume is near the upper limit of the fan curve and does not allow for additional airflow to react to off-normal events. For this analysis, an option of two fans operating in parallel are considered to meet the 800 to 850 m^3/s volume required. Dual main fan installations (parallel operation) are a common practice in the mining industry. For fans operating in parallel, the airflows are added for any given fan pressure in order to obtain the characteristic curve (Hartman et al. 1997, p. 372). For the purposes of this analysis, Attachment II, p. II-2 includes the Design Feature 7 fan (Joy 1982, Curve C-9804) shown as a parallel installation to demonstrate the 800 m^3/s to 850 m^3/s operating range is viable. Two fans, each operating in the middle of their curve, would provide a better design condition and offer additional flexibility to the ventilation system. The system can be designed to a 10 inch wg operating pressure by reducing the friction losses in the system, or by enlarging the drift diameters to reduce the airflow velocity. This assumption is used to provide design estimates that may be used to compare costs in an external document and will not be used for fan selection or procurement. This assumption is not TBV per AP-3.15Q, Attachment 4, as it is in the realm of accepted engineering practices to apply fan laws to estimate operating parameters (Hartman et al. 1997, p. 546).

5.5 For the purposes of this analysis, the temperature of intake airflow at the emplacement drift inlet is assumed to be 25 °C (TBV-3690). Used in Section 6.2.2.

Rationale and Justification: The ANSYS Calculations utilized as input in Section 4.1.1 used an inlet air temperature of 25 °C in its report (CRWMS M&O 1999g, Section 3.6). For consistency the same inlet temperature of 25 °C is used in this analysis.

5.6 For the purposes of this analysis, the airflow in the Performance Confirmation (PC) drift (see Section 4.2.20) and cross-block drift (see Section 5.3) splits is assumed to be 20 m^3/s. Used in Sections 6.1.2, 6.1.3, and 6.2.2.

Rationale and Justification: In order to determine an overall repository air volume, airflow quantities must be assigned to the PC and cross-block drifts. The *Overall Development and Emplacement Ventilation Systems* report established these drifts are ventilated with a design airflow that varies from 3.57 m^3/s to 47 m^3/s (CRWMS M&O 1997a, Table 7.4.2, p. 42), depending upon repository requirements or off-normal events. The PC and cross-block drift effective areas are 19.63 m^2 (CRWMS M&O 1999h, Table 1) and the minimum rule of thumb air velocity in a main level drift is 1 m/s (Hartman et al. 1997, pp. 546, 547). This provides a volume of 19.63 m^3/s in the PC and cross- block drifts that is rounded to 20 m^3/s for the purpose of this analysis. This value is not labeled TBV per AP-3.15Q, as it is common engineering practice to estimate air volumes during the conceptual design stage and adjust the values as additional design information is obtained (Hartman et al. 1997, p. 546). A second mine ventilation design reference textbook, *Subsurface Ventilation and Environmental Engineering* (McPherson 1993), provides ventilation design information.

5.7 For the purposes of this analysis, an airflow of 47 m^3/s is assumed to be available for off-normal (blast) cooling in an emplacement drift. This capacity would provide airflow for a single blast cooling operation. Used in Section 6.1.4.

Rationale and Justification: The emplacement drift ventilation flow can be varied to allow limited-time for equipment access for evaluating and remediation work to deal with operational upsets. Since the emplacement drift air temperature peaks at 60 °C (see Attachment III), additional airflow will be required to lower the temperature below 50 °C (see Section 4.2.2) to allow equipment access. The off-normal access (blast cooling) design air volume of 47 m^3/s per split (CRWMS M&O 1997a, Table 7.4.2, p. 42) utilized in the VA Design is used in this analysis for consistency. The blast cooling volume must be included in the design to ensure the system components are capable of providing an air increase if needed. After 50 years of ventilation the emplacement drift outlet air temperature would be below 50 °C (see Section 4.1.1) and blast cooling is no longer needed. This blast cooling volume is not labeled TBV per AP-3.15Q, Attachment 4, as it is common engineering practice to estimate air volumes during the conceptual design stage and adjust the values as additional design information is obtained (Hartman et al. 1997, p. 546).

5.8 In order to estimate the conceptual ventilation system horsepower it is necessary to apply a fan operating efficiency to the overall repository air volume. For the purposes of this analysis it is assumed the main fans are operating at 75 percent efficiency. Used in Sections 6.2.4 and 6.7.

Rationale and Justification: Ventilation fans do not operate at 100 percent efficiency. A vane-axial fan will operate in the 70 percent to 85 percent efficiency range (Hartman et al. 1997, Table 9.3). For the purposes of this analysis, an efficiency of 75 percent has been selected and lies within the range specified by Hartman. This value is not labeled TBV per AP-3.15Q, Attachment 4, as it is common engineering practice to estimate fan parameters during the conceptual design stage and adjust the values as additional design information is obtained (Hartman et al. 1997, p. 546).

5.9 The average line load at the time of emplacement is 1.45 kW/m, and the maximum shall be 1.5 kW/m. (This assumes 0.1m spacing between the ends of the waste packages.) (Stroupe 2000, Attachment 1, p. 1 of 3). This is not labeled TBV per AP-3.15Q, Attachment 4, as it is management edict. Used in Section 4.1.1 and Attachment III.

5.10 The repository capacity is assumed to accommodate 70,000 MTU; and if authorized the SR Option for 97,000 MTU (Stroupe 2000, Attachment 1, p. 1 of 3). This is not labeled TBV per AP-3.15Q, as it is management edict. Used in Sections 4.1.2 and 6.7.

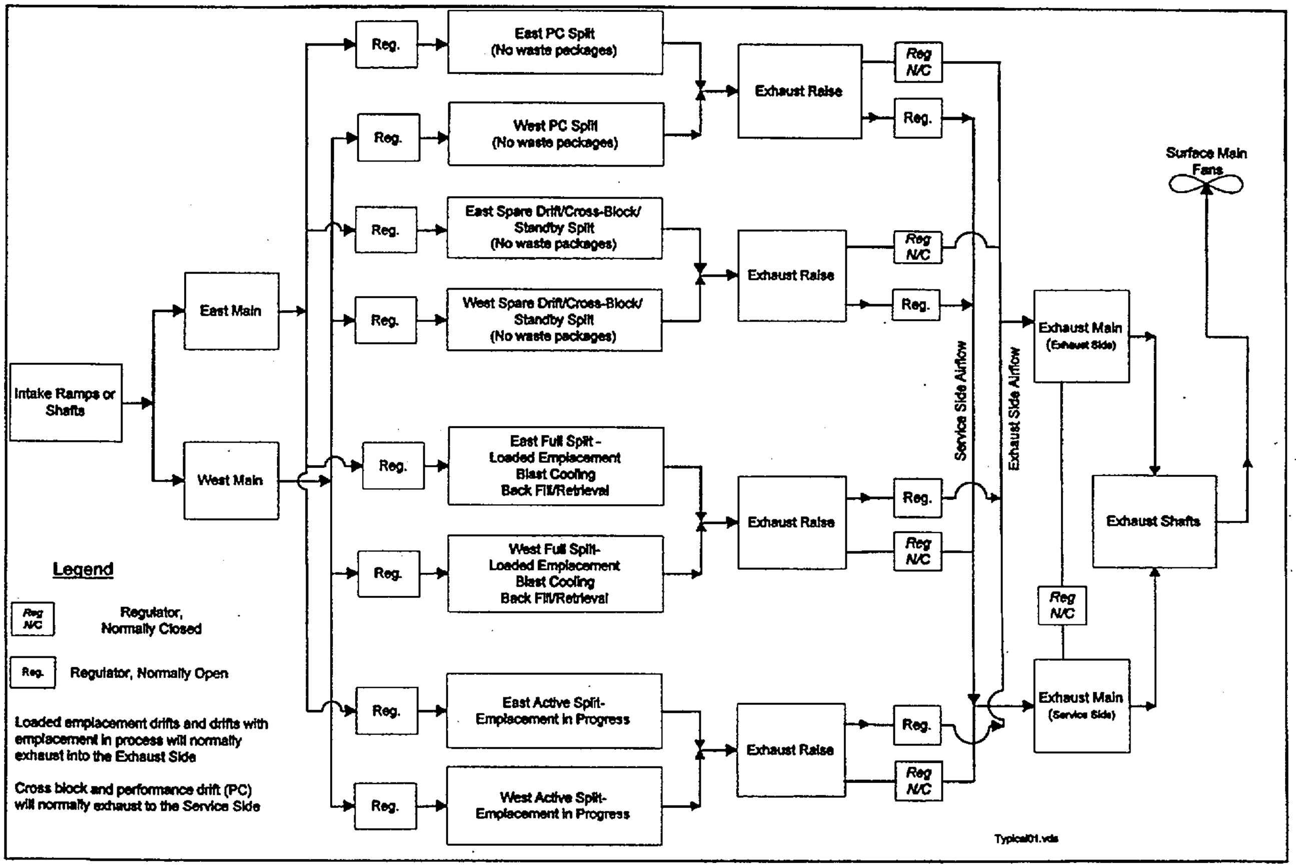
6. SUBSURFACE VENTILATION

6.1 EMPLACEMENT VENTILATION

The ventilation concepts developed for the VA Design (DOE 1998, Fig. 4-43 and p. 4-91) will not change in this conceptual design due to the increased drift spacing or higher emplacement air volumes. The VA Design emplacement drifts are spaced 28 meters center to center (DOE 1998, p. 4-45) and the SR emplacement drifts are spaced 81 meters center to center (see Section 4.2.21). This change in drift spacing effects only the distance the airflow moves, not the ventilation pattern. The thermal management design requires removal of at least 70 percent of the heat generated by the waste packages during preclosure (see Section 4.2.4). A preclosure period is not defined for this analysis, the ventilation system can be maintained for a period of 50 years, or up to 300 years if deemed necessary. The VA Design emplacement drift airflow was 0.1 m^3/s (CRWMS M&O 1997a, Table 7.4.2, p. 42) and the SR emplacement drift airflow is 15 m^3/s for this analysis. This difference results in significantly higher emplacement airflow in the SR Design than the VA Design and therefore, necessitates design changes to the overall ventilation system, but not the ventilation concepts. The basic ventilation concepts are described in this section and Sections 6.3.1 and 6.3.2.

Figure 1 shows the subsurface ventilation system as a process diagram detailing the interactions between major components of the system. The emplacement ventilation flow system is shown in Figure 1, the construction system, separated by isolation barriers (see Section 4.2.3), is not shown. In the basic ventilation concept, fresh air enters through an intake shaft, or one of the ramps, and is distributed to the East and/or West Main. The intake shafts are connected to the East and West Mains by a shaft access drift. From the mains, air enters emplacement, PC, or empty drifts and travels to centrally located exhaust raises. The exhaust raise effectively divides each respective drift in half, hereafter referred to as a "split". Each split receives a design air volume. Air entering the PC drift, cross-block drift, or empty emplacement drifts is directed to the Service Side of the Exhaust Main and air flowing through emplacement drifts containing waste packages is directed to the Exhaust Side of the Exhaust Main. The exhaust raises carry the airflow to an Exhaust Main, where it is then carried to the surface by the exhaust shafts. The Exhaust Main is connected to the exhaust shafts by shaft access drifts.

Fans located on the exhaust shafts provide the motivational force for the subsurface repository airflow. The fans are designed to have enough power to exhaust the maximum amount of air that will be required during the emplacement, monitoring, off normal, and closure phases. The airflow volume produced by the fans is variable such that as the thermal requirements of the repository change with time, the air volume can also be adjusted (see Section 4.2.10). Air distribution within the repository is controlled by regulators located at each emplacement drift, PC drift, cross-block drift, standby emplacement drift, and at the bottom of each exhaust raise. The surface fan installations, operating in an exhaust mode at each exhaust shaft, create a negative air pressure on the Exhaust Main level that is a higher negative air pressure than on the emplacement level, therefore, preventing recirculation from inside the emplacement drifts out to the main drifts (Section 4.2.5). If a major power outage were to result in all fans being off, the natural ventilation pressure would maintain a small airflow in the repository until backup power supplies can restore some limited fan capacity.



Loaded emplacement drifts and drifts with emplacement in process will normally exhaust into the Exhaust Side

Cross block and performance drift (PC) will normally exhaust to the Service Side

Figure 1. Conceptual Emplacement Flow Process Diagram

The natural ventilation pressure depends on the difference in elevation of the surface and the mine openings, and the difference in air temperature inside and outside the mine (Hartman et al. 1997, Section 8.1, p. 293). This is similar to airflow through a chimney where warm air rises and creates airflow from the inside to outside. A natural ventilation pressure is created by the elevation difference between the exhaust shafts located on the ridge of Yucca Mountain and the intake shafts located on the lower part of the mountain. Additionally, waste packages contained in the repository create a higher air temperature inside versus outside the facility.

Activities in the emplacement drifts vary as does the demand for airflow. During emplacement, airflow is required to provide an acceptable environment for equipment operation (see Section 4.2.2). After the waste has been emplaced, airflow is required to remove 70 percent of the heat generated by the waste packages during preclosure (see Section 4.2.4). The emplacement drift airflow can be adjusted for drip shield installation, backfill placement, or to react to off-normal events that may occur. This ability to regulate airflow demonstrates the ventilation system's capability to interface with the emplacement drift system (see Section 4.2.10) and satisfy meeting the temperature requirement for remote access (see Section 4.2.2). The installation of regulators at the entrances and/or exits of the emplacement drifts provide the method to meet these requirements. The ability to regulate the airflow volume at each emplacement drift and vary the total volume at the surface fans makes it possible to meet changing conditions.

Figure 2 shows the conceptual airflow pattern in an emplacement drift. Fresh air enters the emplacement drift through the East Main or West Main, travels through the emplacement drift where it is heated by the waste packages, and to a centrally located raise where it is carried to the Exhaust Side of the Exhaust Main. The Exhaust Main airflow then travels to a shaft connector drift where it is exhausted to the surface.

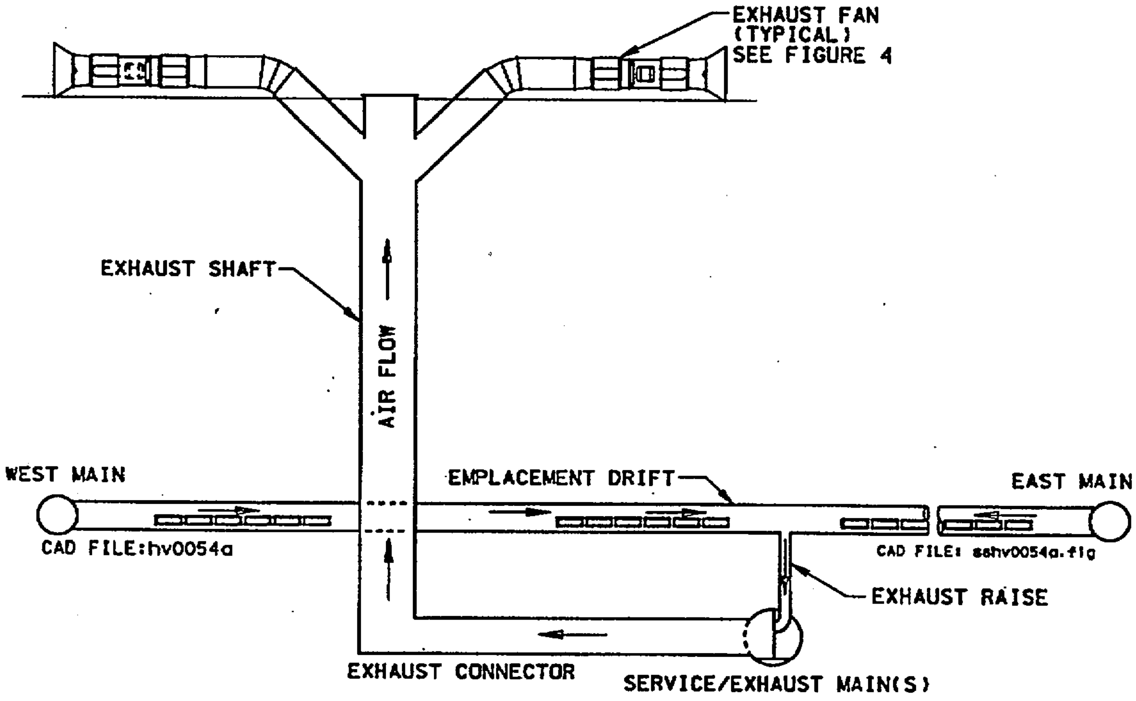


Figure 2. Emplacement Drift Conceptual Airflow Diagram

The emplacement drift ventilation system is described in detail in the *Emplacement Drift Air Control System* report (CRWMS M&O 1997d, Section 7.1, p. 14). In the VA Design, air control was provided by a single air door at the emplacement drift entry in combination with valves on the exhaust raise (CRWMS M&O 1997d, p. 44). As an option, the current design may use an air lock (dual doors) to provide the primary ventilation control at the emplacement drift entry. Air regulators would be contained at each airlock door and airflow would be regulated at the emplacement level rather than at the Exhaust Main level.

Due to the increased air volume and multiple intakes, it is envisioned the Exhaust Main will be a single drift with a center divider wall that will provide airflow isolation as discussed below. The potential emplacement drift exhaust air temperature of 60°C (see Attachment III) is a temperature barrier restricting personnel access (see Section 4.2.1). Due to the heat and possible contamination, personnel will not work in this air stream (see Sections 4.2.1 and 4.2.6). This air stream is contained in what is referred to as the Exhaust Side of the Exhaust Main.

The PC, empty spare emplacement, and cross-block drifts are the only air paths to provide airflow to what is referred to as the Service Side of the Exhaust Main where the instrumentation and personnel access is maintained. The PC, cross-block and empty emplacement drifts will not contain waste packages and therefore, will not be heated or exposed to the possibility of contamination. The air exiting these areas will be carried in an air stream (separate from the Emplacement Side air stream) that would be considered a normal work place (see Section 4.2.1). As an option, some or all of the cooler air contained in the Service Side can be redirected to the warmer airflow stream in the Exhaust Side to cool that air stream.

The cross-block drifts can function as emergency egress routes for personnel should the major routes be blocked.

6.1.1 Emplacement Drift Airflow

The ANSYS modeling concluded that for a ventilation flow rate of 15 m^3/s, at 1.4 kW/m and 1.6 kW/m load, 71 percent of the heat was removed after 50 years (see Section 4.1.1). With an upper and lower bound delineated, an emplacement drift air volume of 15 m^3/s per split is selected for use in this analysis since Section 4.2.4 (70 percent heat removal requirement) is met.

This emplacement drift air volume of 15 m^3/s used in this analysis compares to:

- The VA Design air volume of 0.1 m^3/s (CRWMS M&O 1997a, Table 7.4.2, p. 42)
- The EDA II air volume of 5 m^3/s (CRWMS M&O 1999c, p. 6-8)
- The Design Feature 7 air volume of 10 m^3/s (CRWMS M&O 1999e, p. iv).

As air passes over the waste packages it is heated and expands. The emplacement drift exhaust air volume is therefore, higher than the intake air volume due to thermal expansion. At 15 m^3/s airflow and a 1.45 kW/m load, the maximum outlet air temperature of 60°C (see Attachment III) is used to calculate the thermal expansion in Section 6.2.2. This air temperature compares to a VA Design air temperature of 141°C (CRWMS M&O 1997a, p. 34) at an emplacement airflow of 0.1 m^3/s per split.

6.1.2 Performance Confirmation Drift Airflow

The PC drift air volume is 20 m³/s per split (see Section 5.6). These drifts do not contain waste packages; therefore, no thermal expansion is applied to the PC volume. As shown in Figure 3, the PC drift airflow enters from the East main or West Main through a raise, or PC Main Drift, and passes through the PC drift to a centrally located exhaust raise, where is exhausted to the Service Side of the Exhaust Main. From there, the airflow travels to a shaft connector and is exhausted to the surface.

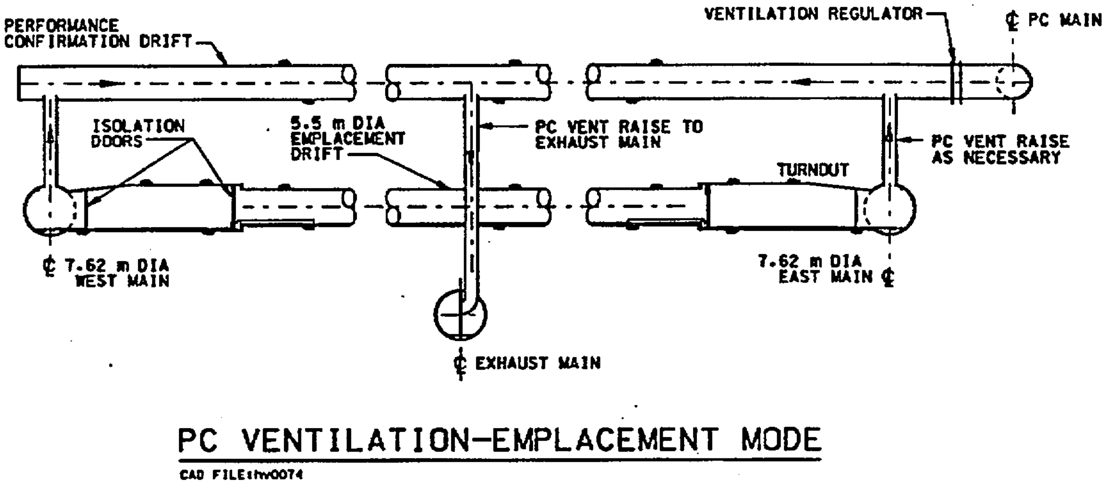


Figure 3. Performance Confirmation Drift Airflow Concept

6.1.3 Empty Drift Airflow

As noted in Section 5.3, in this analysis there are five empty drifts assumed. These empty drifts have an airflow pattern similar to the emplacement drift pattern shown in Figure 2. The three cross-block drifts are ventilated at 20 m³/s per split (see Section 5.6). These drifts do not contain waste packages; therefore, no thermal expansion is applied to the cross-block air volume.

The two standby emplacement drifts (see Section 5.3) are ventilated with the emplacement drift air volume of 15 m³/s per split as noted in Section 6.1.1. Because the empty emplacement drifts may contain waste packages, thermal expansion is applied for this analysis. Operationally, if an empty emplacement drift does not contain waste packages, it can be used as a cross-block drift for ventilation purposes. If waste packages are put in a standby drift, airflow is directed to the Exhaust Side of the Exhaust Main.

6.1.4 Retrieval/Removal Airflow

The emplacement drift airflow can be varied to allow limited-time equipment access for evaluating and remediation work to deal with operational upsets. Since the emplacement drift air temperature peaks at 60° (see Attachment III), additional airflow will be required to lower the temperature below 50°C in order to allow equipment access (see Section 4.2.2). During off normal access (blast cooling), additional airflow is made available in order to lower the air temperature to below 50° C as required for equipment access. A blast cooling design air volume of 47 m^3/s per split (see Section 5.7) is used in this analysis. The blast cooling volume must be included in the design to ensure the system components are capable of providing an air increase if needed. After ventilating an emplacement drift for 50 years, the outlet air temperature would be below 50°C (see Section 4.1.1) and blast cooling is no longer needed for retrieval.

6.2 70,000 MTU REPOSITORY AIR VOLUME REQUIREMENTS

The total repository design air volume is the sum of the emplacement, PC, blast cooling, cross-block and standby drift components. The repository volume is used to provide a basis for cost estimates external from this analysis and is not intended for construction or procurement use. The methodology used to determine the overall air volume is valid for repository layouts that may contain different quantities of emplacement, PC, or empty drifts.

6.2.1 Methodology

The repository air volume is the total of the individual components below:

- Calculate the thermal expansion factor
- Calculate the emplacement drift ventilation component (expanded)
- Calculate the PC drift and cross-block drift ventilation components
- Consider blast cooling requirements.

The total repository volume is then used to estimate the ventilation system details.

6.2.2 Calculations

The air volume of each repository component is determined by multiplying the number of drifts times the airflow split of the component, times two (two splits per drift), or

$$(\text{air volume}) \times (\text{drift quantity}) \times (2) = m^3/s \qquad \text{(Equation 1)}$$

Thermal Expansion Air Volume

As air passes across the waste packages, it is heated and expands. The emplacement drift exhaust air volume is therefore, higher than the intake air volume due to thermal expansion. Charles' Law applies to a constant pressure system and is used to calculate the thermal expansion of a gas. There is nothing to cause a pressure change in an emplacement drift, i.e. no elevation change or a fan pressurizing the drift. The pressure loss due to the resistance change is negligible compared to the natural barometric pressure therefore, applying Charles' Law is a valid engineering estimate.

Charles' Law states $v1/v2=T1/T2$ at a constant pressure, where temperatures are absolute ($T = t$ (°C) + 273.15) (Hartman et al. 1997, p. 22), or

$$v2 = (v1 \div T1) \times T2 \qquad \text{(Equation 2)}$$

where

$v1$ = initial volume (m^3)

$v2$ = final volume (m^3)
$T1$ = initial temperature (absolute)
$T2$ = final temperature (absolute)

At the 15 m^3/s emplacement airflow established in Section 6.1.1, an inlet temperature of 25°C (298 K) (see Section 5.5), an outlet temperature of 60°C (333 K) (see Section 4.1.1), and applying Equation 2 to calculate the expanded air volume gives:

$v2 = [(15\ m^3/s) \div (298)] \times 333$
$v2 = 16.8\ m^3/s$ (rounded to 17 m^3/s for this analysis)

This expanded air volume of 17 m^3/s per split is used as the exhaust component for drifts that contain waste packages. Though not all waste packages reach the maximum temperature at the same time, a conservative estimate is obtained by applying the expanded air volume to all drifts containing waste packages.

Emplacement Drift Air Volume

The 54 emplacement drifts (see Section 5.2) and two standby drifts (see section 5.3) contain waste packages therefore, the expanded air volume is used. Applying Equation 1:

$(17\ m^3/s) \times (54\ \text{drifts} + 2\ \text{standby emplacement drifts}) \times (2) = 1{,}904\ m^3/s$

PC and Cross-Block Drift Air Volume

The six PC drifts (see Section 4.2.20) and three cross-block drifts (see Section 5.3) air volumes are 20 m^3/s per split (see Section 5.6). Using Equation 1, the total air volumes for the components are as follows:

PC Drift total volume	$(20\ m^3/s) \times (6\ \text{PC drifts}) \times (2) = 240\ m^3/s$
Cross-block Drift total volume	$(20\ m^3/s) \times (3\ \text{cross-block drifts}) \times (2) = 120\ m^3/s$

Blast Cooling Air Volume

The blast cooling air volume of 47 m^3/s (see Section 6.1.4) is expanded since it will be heated to less than 50°C (see Section 4.2.2) to permit equipment access. At an inlet temperature of 25°C (298 K) (see Section 5.5) and an outlet temperature of 50°C (323 K), Charles' Law (Equation 2) is used to calculate the expanded volume:

$v2 = [(47\ m^3/s) \div (298)] \times 323$
$v2 = 51\ m^3/s$

Overall Repository Volume

The maximum air volume in the emplacement side of the repository is reached after all the waste packages have been emplaced. Table 7 shows the maximum air volume as the sum of components determined above, compared to the VA Design and Design Feature 7 air volumes.

Table 7. Volume Comparison Table

Component	VA Design [1]	Design Feature 7 [2]	Current Concept 70,000 MTU[3]
Number of Emplacement Drifts	105	105	54
Airflow per Emplacement Split	0.1 m^3/s	10 m^3/s	15 m^3/s (17 m^3/s exp.)
Number of Empty Drifts	5 (included above)	5 (included above)	5 (3 cross block/ 2emp)
Number of PC Drifts	5 (included above)	5 (included above)	6
Emplacement Drift Total Volume	In the total	In the total	1,904 m^3/s (expanded)
PC Drift Total Volume	In the total	In the total	240 m^3/s
Cross Block Drift Total Volume	In the total	In the total	120 m^3/s
Blast Cooling Total Volume	In the total	In the total	51 m^3/s
Total Repository Volume	360 m^3/s	3,563 m^3/s	2,315 m^3/s

Notes:
[1] VA Design numbers from DOE 1998, Section 4.2.1.2 and p. 4-91
[2] Feature 7 numbers from CRWMS M&O 1999e, Figure 1 and p. iv.
[3] Developed in this analysis

This total repository air volume represents the design ventilation load for the repository. The Subsurface Facility and Excavation Systems interface with this air volume, or components thereof, to ensure the repository is capable of supporting the ventilation needs (see Sections 4.2.9 and 4.2.11). During final design, when the mains fans are selected a contingency will be added to provide system flexibility and the fans will be sized accordingly (Hartman et al. 1997, p. 547).

6.2.3 Exhaust Main Ventilation

As discussed in Section 6.1, there are valves and regulators on the Exhaust Main horizon that allow the ventilation system to be adjusted. The ventilation system can react to off-normal conditions by utilizing the doors, valves, and regulators, or by adjusting fan volumes. As discussed in Section 6.1, the airflow in the Exhaust Main is isolated into two separate airflows. The Service Side contains the cooler airflow from the PC and cross-block drifts and is considered to be the normal working area. The Exhaust Side contains thermally hot exhaust airflow from the emplacement drifts. Shaft connector drifts provide the connection to the exhaust shafts.

6.2.4 Shaft Quantity and System Horsepower

The number of ventilation shafts must be estimated to provide an interface with the Subsurface Facility and Excavation Systems to ensure that the repository design is capable of supporting the ventilation needs (see Sections 4.2.9 and 4.2.11). This is the estimate required to support the ventilation requirements; the repository construction, excavation, and operational requirements are all combined to provide the final shaft configuration. Using two fans operating in parallel (see Figure 4), a repository volume of 2,315 m^3/s as estimated in Table 7, and an exhaust shaft volume range of 800 to 850 m^3/s (see Section 5.4), shows that about three shafts are required to support the ventilation needs as follows:

$$(2{,}315\ \text{m}^3/\text{s}) \div (800\ \text{m}^3/\text{s per shaft}) = 2.9\ \text{shafts}$$
$$(2{,}315\ \text{m}^3/\text{s}) \div (850\ \text{m}^3/\text{s per shaft}) = 2.7\ \text{shafts}$$

At 2,315 m^3/s as estimated in Table 7, 10 inches wg. (see Section 5.4), and 75 percent efficiency (see Section 5.8), this would require 10,307 brake horsepower as follows:

$P_a = HQ/6346$ hp (Hartman et al. 1997, p. 165) (Equation 3)
$P_a = [(10)(2{,}315\ m^3/s)(2119\ m^3/s \text{ per cfm})] \div 6346$
$P_a = 7{,}730$ hp
At 75 percent efficiency hp = 10,307 hp (7,686 kW)

where

P_a = air horsepower
H = total pressure (in wg)
Q = air quantity (cfm)
1 m^3/s = 2,119 cfm
1 hp = 0.7457 kW

A line load factor would be applied for the final design. Multiple shaft locations and cross-block drifts will provide the ability to adapt to off-normal access situations and redirect airflows as necessary. The two-fan installation provides additional flexibility to the system by allowing the airflow from one, or both fans to be adjusted to system conditions. Table 8 compares shaft quantities between designs.

Table 8. Shaft Comparison Between Designs

Component	VA Design [1]	Design Feature 7 (10 m^3/s) [2]	SR 70,000 MTU [3]
Number of Intake Shafts	0 and ramps	4 and ramps	3 (est.) and ramps
Number of Exhaust Shafts	1	6	3 (est.)
Exhaust Shaft Air Volume	360 m^3/s	594 m^3/s (avg. of Table 7)	850 m^3/s (max)

Sources: [1] DOE 1998, Section 4.2.1.3
[2] CRWMS M&O 1999e, Figure 10
[3] Developed in this analysis

A spare fan(s) would be kept available in storage for change out should the need arise. This method would be more cost effective than a three-fan surface installation. A fan, or components of, could be changed out in less than one week. If one of the fans were off for maintenance, the second fan could remain on and produce approximately 70 percent of the original air volume (McPherson 1993, Section 10.5.2, p. 349). With the multiple ventilation shafts, a single fan being down for maintenance, would not have a major impact on the overall repository air volume.

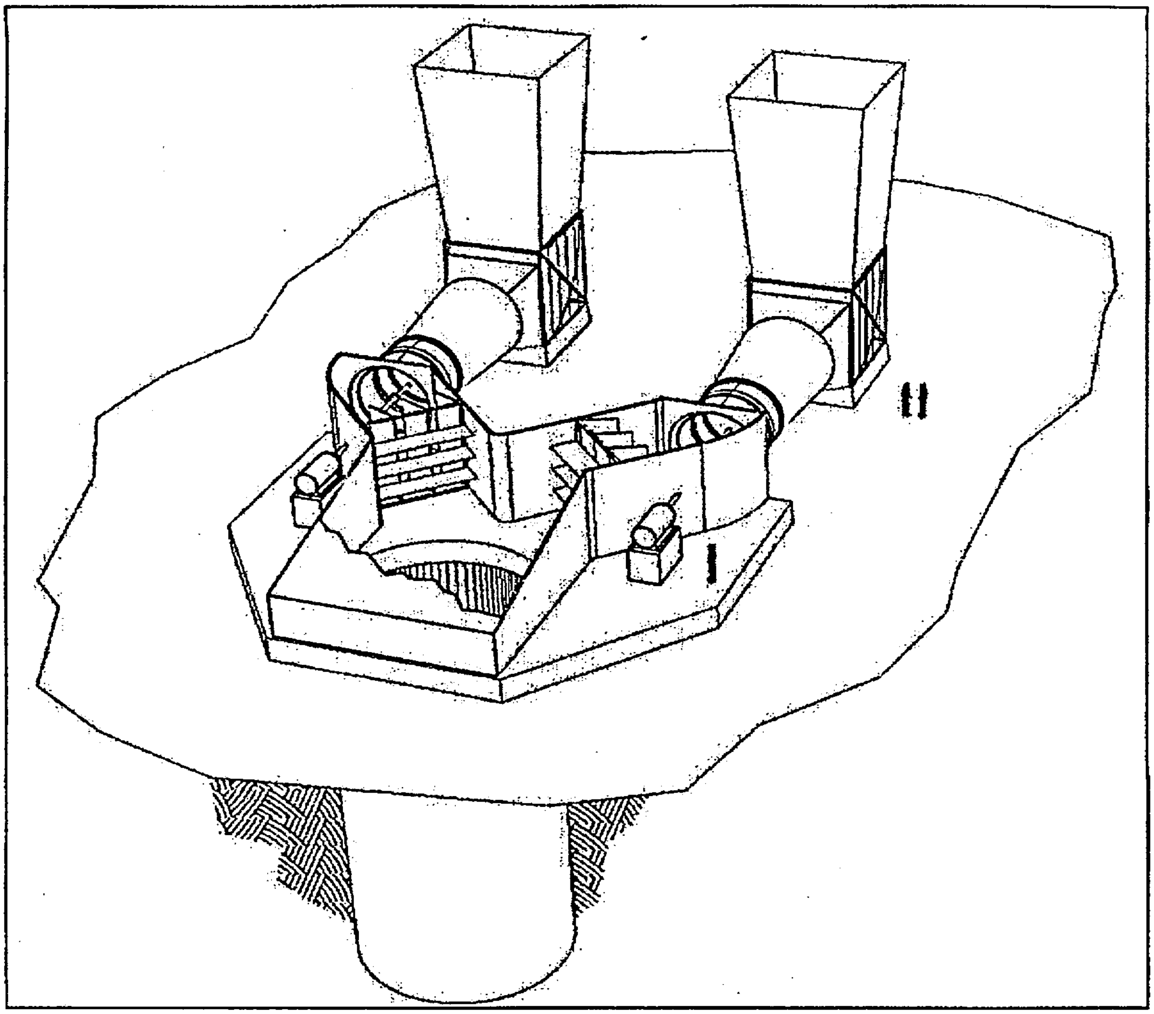


Figure 4. Conceptual Dual Fan Installation

6.3 VENTILATION FLOW NETWORK PHASES

At the conceptual level, the network phases are described in general concepts developed for the VA Design with changes due to the thermal management as noted.

6.3.1 Construction Ventilation Phase

During early repository construction the Exploratory Studies Facility (ESF) loop (North Ramp, East Main and South Ramp) provides a flow path for the ventilation air. The existing airflow pattern through ESF ventilation system will be used, i.e., fresh air intake through the North Ramp and exhaust out the South ramp. The ESF flow-though air volume will be capable of providing airflow for multiple work faces.

As discussed in Section 6.1, the development construction ventilation concepts developed for the VA Design are valid for SR since the increased drift spacing and increased emplacement drift airflow do not change these concepts. Therefore, the concepts documented in the *Ventilation Needs During Construction* (CRWMS M&O 1998b, Section 7.1) and *Overall Development and Emplacement Ventilation Systems* (CRWMS M&O 1997a, Section 7.6) reports are valid for this analysis.

The ventilation concept defined in the *Ventilation Needs During Construction* (CRWMS M&O 1998b, Section 3) was described as two parts. One part defined local ventilation and the other, global ventilation. Local ventilation provides ventilation from the Main Drift through to the working face. For example, the ventilation system between a tunnel boring machine (TBM) excavating an emplacement drift and the intersection of the emplacement drift and the main drift is a local system. The other ventilation system is termed "global ventilation," in which ventilation is provided in the Main Drifts. An example of the global ventilation system would be the system between the emplacement drift/main drift intersection and the surface. For purposes of this analysis, the working drift begins at the intersection of the main drift and the drift where excavation is taking place and contains the working face. The working face is where a mechanical excavator is extending the length of a drift that is a dead-end heading. Excavation methods can be either mechanical (TBM) or conventional (drill and blast). Each local ventilation system will interact with the global system to provide proper working face conditions. Figure 5 shows the basic conceptual interaction of the local and global ventilation concept using the ESF as a flow through system.

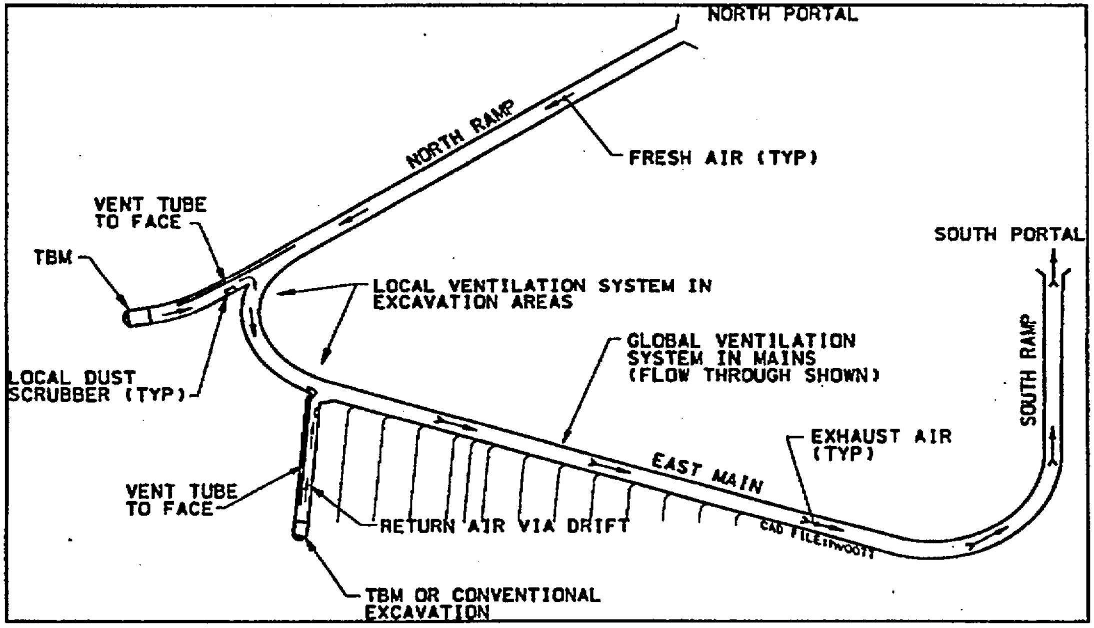


Figure 5. Examples of Global/Local Ventilation Concept

Local ventilation systems will intake fresh air from the ESF, will be used at the working face, be filtered as necessary and then be discharged back to the ESF south tunnel or ducted to the surface. It is envisioned that two main drifts would be excavated to the north, off the North ramp curve. The first main drift (North Ramp Access) will provide airflow to the first block of emplaced waste. The second main drift is required to allow the development effort to proceed after waste has been emplaced in the first block. This allows the two ventilation systems to be isolated by barriers (see Section 4.2.3) and provides a separate transportation route for waste package delivery from the surface.

Shaft excavations during the early construction phase would be ventilated by a local ventilation system that would intake fresh air from the surface. Similar to the VA Design, it is envisioned a development shaft would be installed in the southern part of the repository to provide airflow for the development effort as it progresses from north to south.

After an exhaust shaft has been completed, tunnels could be excavated from the shaft bottom in a method similar to Figure 6. In this figure, the surface air is the global ventilation system and the drift duct work is the local system. The ventilation system could be either ducted intake or ducted exhaust (CRWMS M&O 1998b, Section 7.1).

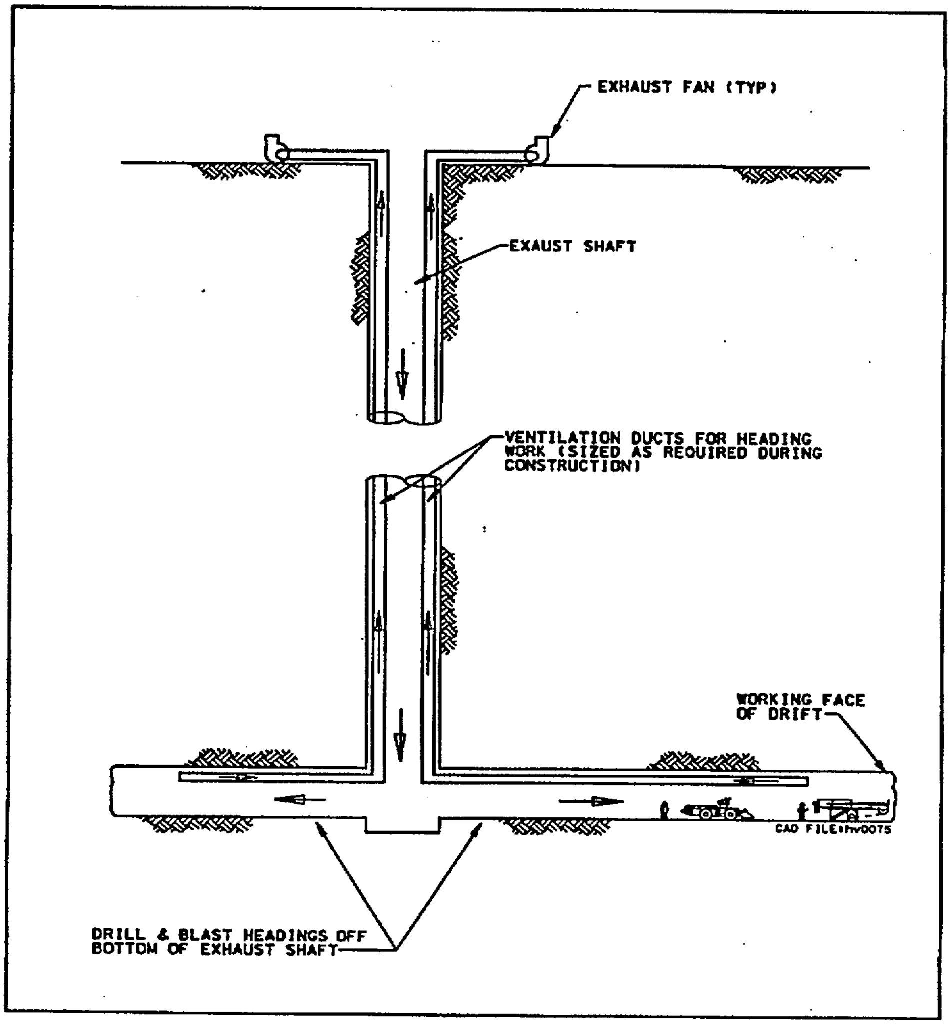


Figure 6. Conceptual Excavation Off of Shaft

6.3.2 Construction/Emplacement Phase

As detailed in Section 6.1, the increased drift spacing does not change the ventilation concept of the construction/development effort running concurrent with emplacement as presented in the *Overall Development and Emplacement Ventilation System* (CRWMS M&O 1997a, Section 7.8). In summary of this concept, the repository is developed in a series of "panels" isolated from the emplacement area by the isolation barriers that creates two independent ventilation systems (Section 4.2.3). Isolation barriers will exist at all emplacement/ development interfaces on both the emplacement and exhaust levels. When the development of a panel of emplacement drifts is complete, the isolation barriers are relocated and the panel is then released for emplacement. At that time, the next panel is developed. This sequence continues until all emplacement drifts in the repository are complete. As with the VA Design, the global construction/development ventilation air is supplied through a blowing system with the fan installed at the development intake shaft. The emplacement ventilation system operates in an exhaust mode (fans at the exhaust shafts). This system maintains a pressure differential across the isolation barrier separating the development and emplacement ventilation systems (see Section 4.2.3) and ensures any leakage between the two systems is from the development side toward the emplacement side.

The additional ventilation shafts required by the thermal management requirements would be brought on line according to emplacement requirements. The dual fan installations afford the ability to regulate air volumes by running one, or both of the fans as emplacement progresses. The highest total air quantity and power requirements are in the final stages of the construction/emplacement phase when the last emplacement panel is being developed and the rest of the repository is already in the emplacement mode. During this time it is likely all the emplacement fans and the development shaft fans will be operating.

6.3.3 Monitoring Phase

When all waste packages have been emplaced, the repository enters the monitoring phase. As determined in Table 7, a total air volume of 2,315 m^3/s is required, for a period of up to 175 years (see Section 4.2.14). In Design Feature 7, an emplacement airflow rate of 10 m^3/s determined that the required air volume was 3,563 m^3/s at 11,153 kW (14,951 brake horsepower) of power (CRWMS M&O 1999e, p. iv). The Design Feature 7, 10 m^3/s emplacement airflow design layout has six exhaust shafts, four intake shafts and two ramps (CRWMS M&O 1999e, Figure 10). The SR repository design concept requires a total air volume of 2,315 m^3/s at an assumed fan operating pressure of 10 inches water gauge (see Section 5.4). This SR conceptual air volume design lies within the emplacement air volume established by the Design Feature 7 report which verified a high air volume repository is viable.

Ventilation system components, including the fans, will be capable of regulating the airflows as necessary. Figure 7 shows the general airflow design of the repository. Main fans will require routine maintenance such as rebuild/refurbishing during the preclosure period and during any extended period of operation (see Sections 4.2.14 and 4.2.15).

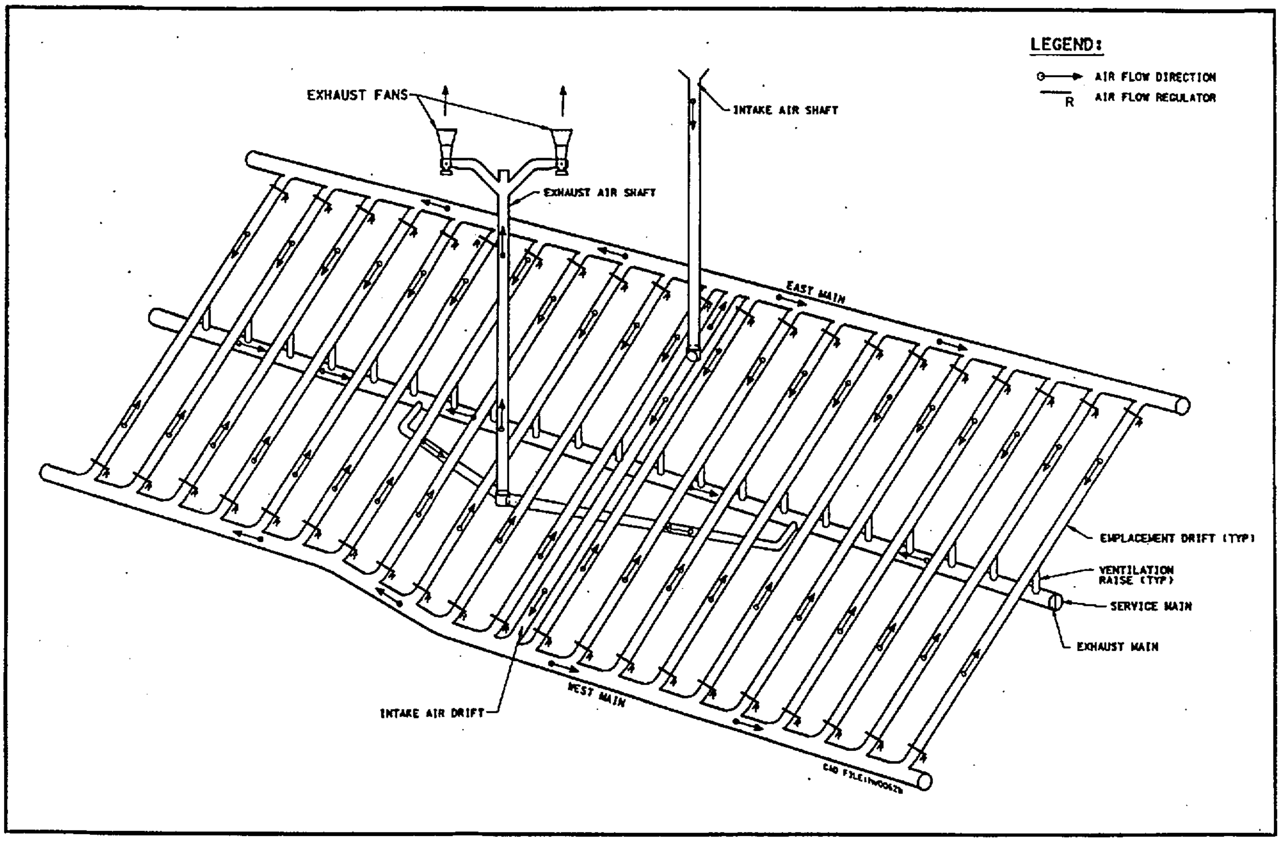


Figure 7. General Airflow Pattern

6.3.4 Closure Ventilation

At closure, the repository will be isolated by backfilling and sealing to ensure waste containment, discourage human intrusion, and prevent the repository openings from becoming preferential pathways for water. The current repository planning reflects the VA Design in that the closure and decommissioning phase will include closure and sealing of the subsurface facilities, including the shafts. Initially, the placing of backfill in the emplacement drifts was considered to occur within this closure period. However, the current strategy is to remove emplacement drift backfilling from the design basis without specifically excluding it from consideration in the future (Stroupe 2000, Attachment 1, p.1 of 3). The ventilation system interacts with the Backfill Emplacement System (see Section 4.2.12) to ensure backfill is placed in a manner to control contaminants and afford strategic withdrawal from the repository.

Closure ventilation will briefly address:

- Emplacement Drift backfill ventilation
- Main Drift backfill ventilation
- Shaft backfilling Ventilation

It is envisioned that the Main Drift backfill and Shaft backfill will, in part, be concurrent activities. The emplacement drift backfill (should this design consideration be exercised) would be conducted as a single activity.

6.3.4.1 Emplacement Drift Backfill Ventilation

At closure, which could occur 50 years from the start of emplacement, a maximum dry bulb temperature of 50°C (see Section 4.2.2) can exist in the emplacement drifts for equipment access. After 50 years of ventilation, an emplacement drift's outlet temperature for 15 m^3/s flow will have dropped to approximately 49°C (see Section 4.1.1), therefore no special airflow is required to lower the temperature.

Should backfill be needed in the emplacement drifts, it will cover the waste packages leaving the top of the emplacement drift open (see Figure 8). The ventilation system during emplacement backfill would be similar to the normal emplacement drift ventilation concept. The ventilation system would be capable of providing a reduced, controlled airflow both during and after backfill placement. The airflow during backfill placement will carry dust away from stowing equipment and personnel working in the main drifts. The contaminated air can be filtered with equipment as described in Section 6.4. After backfill placement a regulated flow can be maintained to ensure that the airflow direction does not reverse (see Section 4.2.5).

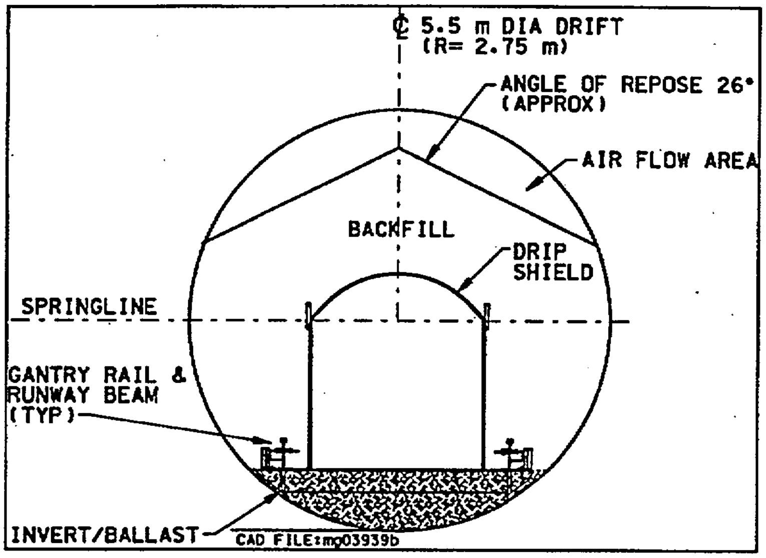


Figure 8. Extent of Conceptual Backfill in Emplacement Drift

6.3.4.2 Main Drift Backfilling Ventilation

Various construction activities required for closure and decommissioning need to be accomplished. Major activities include:

- Reconfiguration of isolation doors and airlocks
- Remove services (pipes for compressed air, water, etc.)
- Remove power cables and equipment
- Fill all applicable openings with crushed and sized tuff from the mined stockpile
- Install plug seals as applicable.

In general, the fill material will be placed in the mains and closure will be achieved in a manner to afford strategic withdrawal and to maximize the ability to utilize the vent shafts for air supply. Fresh air from the intake shaft is directed to the work area (backfilling), drawn across the face and exhausted through a cross-block drift. A suitably sized duct separates the fresh air work area from the polluted exhaust. As backfilling continues, the duct is repositioned and maintains the airflow return exhaust ahead of the operator. On completion of backfilling the section of mains utilized by the intake shaft, the shaft is abandoned (see Section 6.3.4.3).

The exhaust main (now devoid of any intake air) remains to be backfilled. Airflow can be established by installing rigid ducting (exhaust) down the shaft to the work area. On completion of the repository backfill, this shaft is also backfilled. The airflow volumes, types of dust collectors, fans, and ducts have not been determined, as these closure ventilation system components will be determined during final design.

6.3.4.3 Shaft Backfilling Ventilation

As an area of the repository reaches closure and backfilling is complete for that section, the shaft is no longer required. When demobilization, consisting of removal of the main fans and plenum, any services in the shaft is completed, backfilling of the shaft commences. The shaft backfilling system would be similar to other backfilling processes. Temporary ventilation can be supplied to the work area by flexible ducts and portable fans.

6.4 CONTAMINANTS

The subsurface ventilation system must be designed to prevent, control, remove, contain, or dilute contaminants such as radon and dust (which may include silica, crystalline, cristobalite, and quartz) (see Sections 4.2.6, 4.2.7, and 4.2.16).

Dust filtration units would be used during construction and development phases. If the emplacement exhaust air is contaminated, the airflow could be isolated and a mobile filtration unit would be used to treat the emplacement drift exhaust air (see Section 5.1). The concept for a mobile filtration unit described in the *Air Filtration System for Potential Radiological Releases Analysis* (CRWMS M&O 1997c, Section 7.4.3) is valid for off-normal events.

6.4.1 Dust

The SR dust control strategy will follow the concepts and guidelines established in the *Overall Development and Emplacement Ventilation System* Report (CRWMS M&O 1997a, Section 7.5). Repository changes brought on by the thermal management goals do not require changes to the comprehensive dust program established in the VA Design. Though additional shafts or connection drifts may be developed, the dust control process for individual activities is unchanged.

The recommended maximum design air velocity in a smooth lined drift is 8 m/s (McPherson 1993, Table 9.1, p. 295). At air velocities higher than 3 m/s settled dust may become re-entrained in the air stream (Hartman et al. 1997, p. 125). In the development side, where dust is typically generated, it is not expected the drift air velocity will exceed the 3 m/s velocity. In the emplacement side, where dust is not typically generated the 3 m/s velocity may be exceeded in portions of the main drifts. However, it is not expected that the design air velocity of 8 m/s would be exceeded.

6.4.2 Radon

The *Subsurface Ventilation System Description Document* (CRWMS M&O 2000c) has been revised to address radon concerns (see Sections 4.2.7 and 4.2.16).

Radon gas is liberated in proportion to the exposed area of rock (McPherson 1993, Section 13.4.1, p. 470) and can be controlled to acceptable limits by dilution (Hartman et al. 1997, Section 3.5, p. 55; and McPherson 1993, Section 13.6.1, p. 478). The emanation of radon-222 from repository surfaces depends on many factors including the radon emanating power, rock density, porosity and fracture density, moisture content, and the radium-226 content. Keeping the airway residence times to a minimum is made possible by designing airway paths to be as short as possible. Since radon gas is liberated in relation to the exposed rock area, the shortest airflow path will contain the minimum rock surface area and the air traversing this shortest path will contain the lowest possible radon concentration. Radon exposure can be controlled using blowing systems in development headings, filtering the air to remove the dust that attracts radon daughters, and lining the rock surface (McPherson 1993, pp. 478 and 485).

The Exploratory Studies Facility is currently collecting data to determine the radon emission (flux) rate. The *Subsurface Background Concentration Radiation Monitoring Calculations* (CRWMS M&O 2000d) (see Section 4.1.3) describes a method to calculate the concentrations of radon and its progeny in the Main and emplacement drifts when the radon flux is known. Using empirical formulas is a valid method for estimating radon gas emissions (Hartman et al. 1997, p. 547). Once the radon emission rates and a repository layout have been determined, the airflow volumes can be checked using the calculation method to ensure dilution is within acceptable limits.

A development heading can also be designed to control the theoretical length that will maintain radon exposures within applicable design provisions (see Section 4.2.16). The various excavation equipment, such at a 5.5 m TBM, or 7.62 m TBM, will each have their own ventilation system components. The design airflow, radon flux rate, and drift diameter (surface area) are combined to calculate the longest length of a dead-end heading that will keep radon levels within the requirements of Sections 4.2.6, 4.2.7, and 4.2.16. For example, a 5.5 m diameter tunnel would have a different length than a 7.62 m diameter tunnel due to a differences in air volumes, drift diameters and subsequent surface area of the exposed rock.

The following radon control alternatives are not noted above:

- In the mining industry, uranium mines often use a positive versus negative pressure ventilation system. This method maintains a higher than atmospheric pressure on drift walls which tends to keep the radon from migrating outward through the fissures. A repository ventilated with a positive pressure system, or combination positive/negative system is a possibility. The basic ventilation concepts presented in this analysis would not change, only the location of the fans. The fans would be moved from the exhaust shafts and mounted on the intake shafts to provide a positive pressure system during the monitoring phase. Note the development system is already designed as a positive pressure system.

- Lining the rock surface with sprayed coatings and film membranes may help control the radon emission rate (McPherson 1993, p. 485). It has been suggested that the repository main drifts be lined with concrete. The addition of cement has been suggested to reduce the radon flux further (McPherson 1993, p. 483), though no calculation has been made to verify this.

- Uranium mines frequently exceed the standard design intake drift velocity limits accepted for economics and dust control (McPherson 1993, p. 478). Though not expected to be necessary, the final repository design may utilize higher than normal intake drift velocities to ensure proper dilution.

6.5 MONITORING

As noted in Section 6.1, the increased drift spacing and emplacement airflow changes of the thermal management strategy have not changed the ventilation monitoring philosophy established in the VA Design, however, the required number of components will be reduced due to the lesser number of emplacement drifts. The "cooler" repository is also expected to increase the operating life of the monitoring units.

The Subsurface Ventilation Monitoring System is a component of the Repository Operations Monitoring and Control System. The ventilation-related monitoring requirements include pressure, humidity, temperature, flow rate, carbon monoxide, door status, fan status, and louver status for assorted locations including main intake, main exhaust drifts, and the working areas (Sections 4.2.8, 4.2.17, 4.2.18, and 4.2.19). Select monitoring of radioactive and non-radioactive particulates is also required (see Section 4.2.13). The ventilation related monitoring components supply data into the Subsurface Monitoring and Control System. Some monitoring points relay data such as temperatures, humidity, status and airflow rates, while some monitoring points, such as emplacement drift louvers, isolation doors and main fans, include some supervisory control functions.

Figures 9 and 10 are derived from the monitoring requirements and show the conceptual locations and monitoring parameters of ventilation system components. The Subsurface Monitoring and Control System includes other required components, such as transportation, equipment, utilities, personnel, etc., that are not detailed in these figures.

Should the repository be kept open for an extended period, the time of monitoring these operations will increase accordingly.

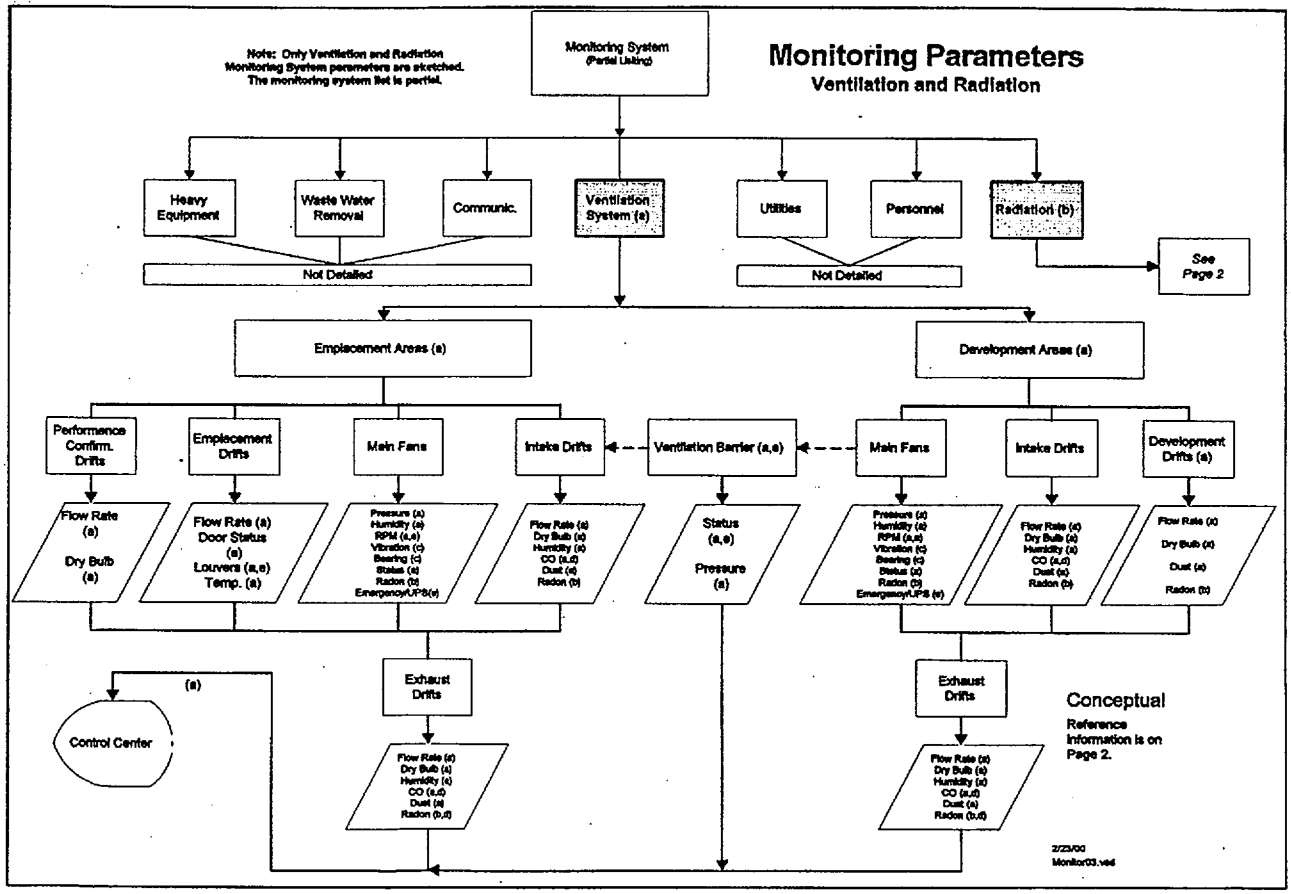
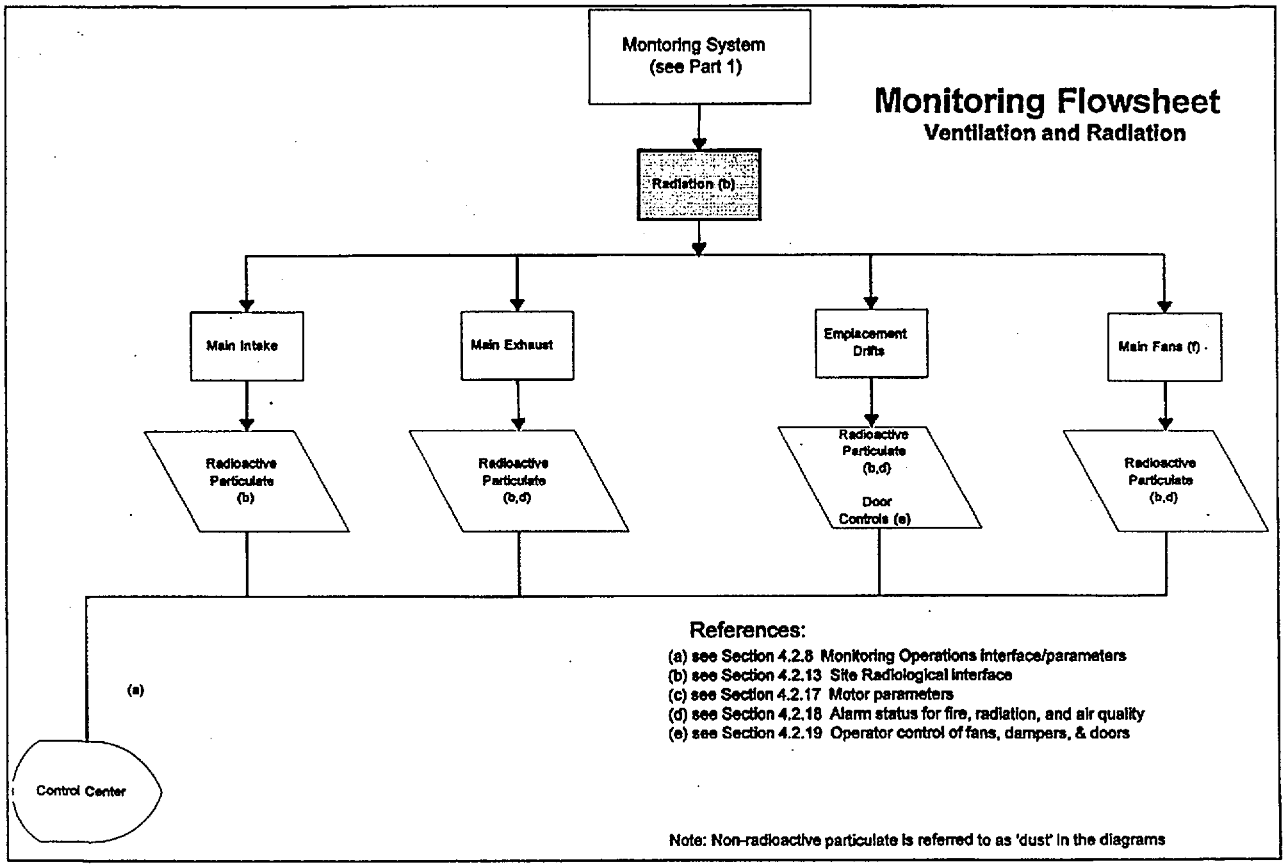


Figure 9. Conceptual Monitoring Flowsheet, Part 1



Monitoring Flowsheet

Ventilation and Radiation

References:

(a) see Section 4.2.8 Monitoring Operations interface/parameters
(b) see Section 4.2.13 Site Radiological interface
(c) see Section 4.2.17 Motor parameters
(d) see Section 4.2.18 Alarm status for fire, radiation, and air quality
(e) see Section 4.2.19 Operator control of fans, dampers, & doors

Note: Non-radioactive particulate is referred to as 'dust' in the diagrams

Figure 10. Conceptual Monitoring Flowsheet, Part 2

6.6 RADIOLOGICAL ANALYSIS OF SUBSURFACE FIRES

In order to provide reasonable assurance that a potential fire involving waste packages in the subsurface operations will not cause harm to workers or adversely affect public health and safety, a conceptual radiological analysis is included. It should be recognized any potential contaminant released in this scenario could be distributed by the ventilation system.

Ventilation system components provide the ability to regulate or control the airflow for off normal events, including a fire condition. The emplacement drift air doors, in a closed position, provide a physical separation between the waste packages and the main tunnels.

6.6.1 Waste Package Response to Fires

The state of waste packages during an operations incident can be categorized in terms of the magnitude of the mechanical and thermal loads that could be received by a waste package. Such factors include the mechanical loading generated by the impact velocity and the object that is struck and, in the event of a fire, the thermal loading generated by flame temperature and duration of the fire. This analysis is concerned only with a potential thermal state that could result in damage to the waste package and release of radioactive material. The response, similar to that of the spent nuclear fuel shipping container, depends on many factors as described in the modal study of the U.S. Nuclear Regulatory Commission (Fischer et al. 1987, Section 2.4). According to the NRC modal study, three mechanisms are necessary for establishing a release path from the spent fuel to the environment: (1) diffusion from cracked fuel pellets, (2) a leak from a breach of the fuel rod cladding, and (3) a leak through deteriorated package seals (Fischer et al. 1987, Figure 8-2). Before radioactive material is released into the waste package cavity, the fuel cladding must be breached during an accident as a result of high impact or high temperature.

The NRC *Standard Review Plan for Dry Cask Storage: Final Report* (NRC 1997, p. 4-1, IV.) and *Waste Package Design Basis Events* (CRWMS M&O, 1997b, p. 55) indicates that the peak cladding temperatures should remain below 570°C for short term accident conditions, such as fires. This peak cladding temperature therefore may be used as the threshold for characterizing thermal load response states for a waste package under fire events. This temperature can be related to three accident parameters: fire duration, fire location, and flame temperature. Fire duration is the duration of the fire during the incident and is dependent on the amount of burnable materials. Flame temperature, which usually ranges from 1,030 to 1,590K (Yuan et al. 1995, Section E.2, p. E-8), is dependent on the burning materials and the amount of oxygen present in the flame. Fire location is the relative distance from the fire to the waste package and has been found to be an important factor in determining the thermal load. For example, the heat load received by a waste package can decrease by a factor of 4 for a fire located 6m from the package (Yuan et al. 1995, Section E.2, p. E-8), compared with the heat load of an engulfing fire.

6.6.2 Potential For a Subsurface Fire

The potential for a subsurface hazardous incident during the development and emplacement phase of the subsurface repository is discussed in detail in the *Subsurface Fire Hazards Technical Report* (CRWMS M&O 1999f, Section 7.9). The report concluded that the potential for a toxic, biological and radiological incident due to a fire is not considered significant. The reasons are:

- Most materials selected for construction are essentially inert.
- Burning electrical cables can initiate a fire incident. However, the risk of combustion occurring is low, due to the expected use of special high temperature and fire-rated cables and by separating power cables from any non fire-rated instrument cables.
- Radioactive materials are not present during construction of the development phase of the subsurface repository. During the repository emplacement phase, radioactive materials, although present, are contained in the sealed waste packages.

In addition to the above, the locations of burnable materials and their limited volumes would also confine the magnitude of a potential fire and the heat flux that could be received by a waste package.

Based on the information provided above, it is judged that a fire incident with the magnitude that could result in waste package cladding peak temperature reaching 570°C in the subsurface repository is not considered significant.

6.7 97,000 MTU REPOSITORY AIR VOLUME REQUIREMENTS

The 97,000 MTU inventory case (see Section 5.10) is estimated to contain 71 emplacement drifts (see Section 5.2), six PC drifts for post-closure testing (see Section 4.2.20), and five empty drifts (see Section 5.3). The 71 emplacement drifts (see Section 5.2) and two standby drifts (see section 5.3) contain waste packages therefore, the expanded air volume is used. Applying Equation 1:

$$(17\ m^3/s) \times (71\ \text{drifts} + 2\ \text{standby emplacement drifts}) \times (2) = 2{,}482\ m^3/s$$

Using the airflows and method established in Section 6.2.2 for other repository components, the 97,000 MTU repository air volume is shown in Table 9.

Table 9. 97,000 MTU Inventory Case Air Volume

Component	97,000 MTU Case
Number of Emplacement Drifts [1]	71
Airflow per Emplacement Split [2]	15 m^3/s (17 m^3/s expanded)
Number of Empty Drifts [3]	5
Number of PC Drifts [4]	6
Emplacement Drift Total Airflow Volume (17 m^3/s)	2,482 m^3/s (expanded) (as above)
PC Drift Total Airflow Volume [5] (20 m^3/s ea.)	240 m^3/s
Cross Block Drift Total Airflow Volume [5] (20 m^3/s ea.)	120 m^3/s
Blast Cooling Total Airflow Volume [5]	51 m^3/s
Total Repository Air Volume	2,893 m^3/s

Sources: [1] Attachment I
[2] Section 6.1.1
[3] Section 5.3
[4] Section 4.2.20
[5] Section 6.2.2

For a repository air volume of 2,893 m^3/s, four exhaust shafts operating in the 800 to 850 m^3/s volume (see Section 5.4), would be needed to meet the ventilation requirements as follows:

$$(2{,}893\ m^3/s)\div(800\ m^3/s \text{ per shaft}) = 3.6 \text{ shafts}$$
$$(2{,}893\ m^3/s)\div(850\ m^3/s \text{ per shaft}) = 3.4 \text{ shafts}$$

Using Equation 3 at 2,893 m^3/s, 10 inches wg. (see Section 5.4) and 75 percent fan efficiency (see Section 5.8) would require 12,880 brake horsepower as follows:

$$((10")(2{,}893)(2{,}119))\div((6{,}346)(75\%)) = 12{,}880 \text{ hp } (9{,}605 \text{ kW})$$

7. CONCLUSIONS

This document may be affected by technical product information that requires confirmation (TBV/TBD). The existing TBV/TBD values are considered accurate for the application. Any changes to the document that may occur, as a result of completing the confirmation activities will be reflected in subsequent revisions.

The changes to the emplacement drift spacing and emplacement drift airflow do not change the development and construction ventilation concepts that were developed for the VA Design. These concepts are still valid for the SR.

The ventilation system can support an emplacement drift airflow rate of 15 m^3/s necessary to meet the thermal requirements for Site Recommendation. The repository ventilation can be maintained for a period of 50 years, or up to 300 years if necessary. The increased ventilation rate to 15 m^3/s per emplacement split does not require a new ventilation concept. The SR changes to emplacement drift spacing and emplacement drift airflow volumes do not change the overall repository ventilation patterns, however; an increased number of ventilation shafts are required to support the repository design.

It is necessary to have a detailed SR layout in order to determine the number of ventilation shafts accurately. However, based on the assumptions made in this analysis at the 15 m^3/s flow rate the 70,000 MTU Repository design would require one development, three intake, and three exhaust shafts to support ventilation requirements. If a decision is made to expand the repository to the 97,000 MTU, one development, four intake, and four exhaust shafts would be required to support the ventilation requirements. The shaft estimates represent only the ventilation requirements. The final repository layout will also include construction, development and operations requirements.

The ventilation monitoring concepts developed for the VA Design are still valid for SR. The cooler repository temperatures are expected to increase the life of the monitoring components.

Based on current information, radon levels can be maintained to within applicable design provisions by dilution with air, controlling the length of development headings, and administrative procedures.

The ventilation system described will be capable of supporting Closure operations.

The potential for a toxic, biological and radiological incident due to a fire involving a waste package is not considered significant.

The Ventilation SDD Criteria contained in Section 4.2 can be met at the conceptual design level contained within this analysis.

Table 10 provides a summary of the Ventilation SDD Criteria used in this analysis and the section(s) in which each criterion is discussed.

Table 10. Ventilation SDD Criteria Summary

Criterion	Criteria Summary	Section(s) the SDD is Discussed
4.2.1	For human access the maximum dry bulb temp is 48°C.	6.1
4.2.2	Maximum temperature 50°C for equipment.	6.1, 6.1.4, 6.2.2, 6.3.4.1
4.2.3	Separate ventilation systems for emplacement and development.	6.1, 6.3.1, 6.3.2
4.2.4	70 percent removal of preclosure heat.	6.1, 6.1.1
4.2.5	Prevention of reverse airflow in emplacement drift.	6.1, 6.3.4.1
4.2.6	Occupational radiation exposure ALARA.	6.1, 6.4, 6.4.2
4.2.7	Radon daughter exposure.	6.4, 6.4.2
4.2.8	Monitoring requirements.	6.5, Figure 10
4.2.9	Subsurface Facility System interfaces.	6.2.2, 6.2.4
4.2.10	Emplacement Drift System interfaces.	6.1
4.2.11	Subsurface Excavation interfaces.	6.2.2, 6.2.4
4.2.12	Backfill Emplacement System interfaces.	6.3.4
4.2.13	Radiological Monitoring System interfaces.	6.5, Figure 10
4.2.14	System service life up to 175 years.	6.3.3
4.2.15	Support closure deferral for 300 years.	6.3.3
4.2.16	Radon provisions per ANSI N13.8-1973, Uranium Mines	4.1.3, 6.4, 6.4.2

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ATTACHMENTS

ATTACHMENT I - DRIFT QUANTITY ESTIMATE

ATTACHMENT II- FAN CURVES

ATTACHMENT III – 1.45 kW/m INTERPOLATION

Attachment I
Drift Quantity Estimate

	A	B	C	D	E	F	G	H	I	J
1	70,000 MTU Case [4]						97,000 MTU Case [4]			
2	Waste Package	Length (m)	Quantity	Total Length			Waste Package	Length (m)	Quantity	Total Length
3				(LxQ)						(LxQ)
4	5 IPWF	3.48	95	331			5 IPWF	3.48	127	442
5	5 DHLW Short	3.48	1,052	3,661			5 DHLW Short	3.48	1,403	4,882
6	5 DHLW Long	5.11	1,406	7,185			5 DHLW Long	5.11	1,874	9,576
7	2 MCO/2	5.11	149	761			2 MCO/2	5.11	199	1,017
8	5 HLW Long/1 DSNF	5.11	126	644			5 HLW Long/1 DSNF	5.11	167	853
9	5 HLW Long Only	5.11	584	2,984			5 HLW Long Only	5.11	780	3,986
10	Naval Short	5.32	200	1,064			Naval Short	5.32	200	1,064
11	Naval Long	5.96	100	596			Naval Long	5.96	100	596
12	21 PWR AP	5.06	4,299	21,753			21 PWR AP	5.06	5,690	28,791
13	21 PWR CR	5.06	95	481			21 PWR CR	5.06	106	536
14	12 PWR AP Long	5.54	163	903			12 PWR AP Long	5.54	293	1,623
15	44 BWR AP	5.06	2,831	14,325			44 BWR AP	5.06	3,732	18,884
16	24 BWR AP	5	84	420			24 BWR AP	5	98	490
17										
18	*Total Packages*		11,184	55,107			*Total Packages*		14,769	72,742
19										
20	Length added by the 0.1 m spacing (C18*0.1m)			1,118			Length added by 0.1 m spacing (I18*0.1m)			1,477
21										
22	Total length required for emplacement (D18+D20)			56,226			Total length required for emplacement (J18+J20)			74,218
23										
24		**Truncated Case Drift Quantity [2]**						**Truncated Case Drift Quantity [2]**		
25		(Total length)/1200m [1]		47				(Total length)/1200m [1]		62
26		With 15% contingency [3]		54				With 15% contingency [3]		71
27										

28 Notes:

29 1) The ANSYS emplacement drift design length is 600m (CRWMS M&O 1999g, Sect. 3.6). This number is doubled since there
30 are two sides to each emplacement drift.

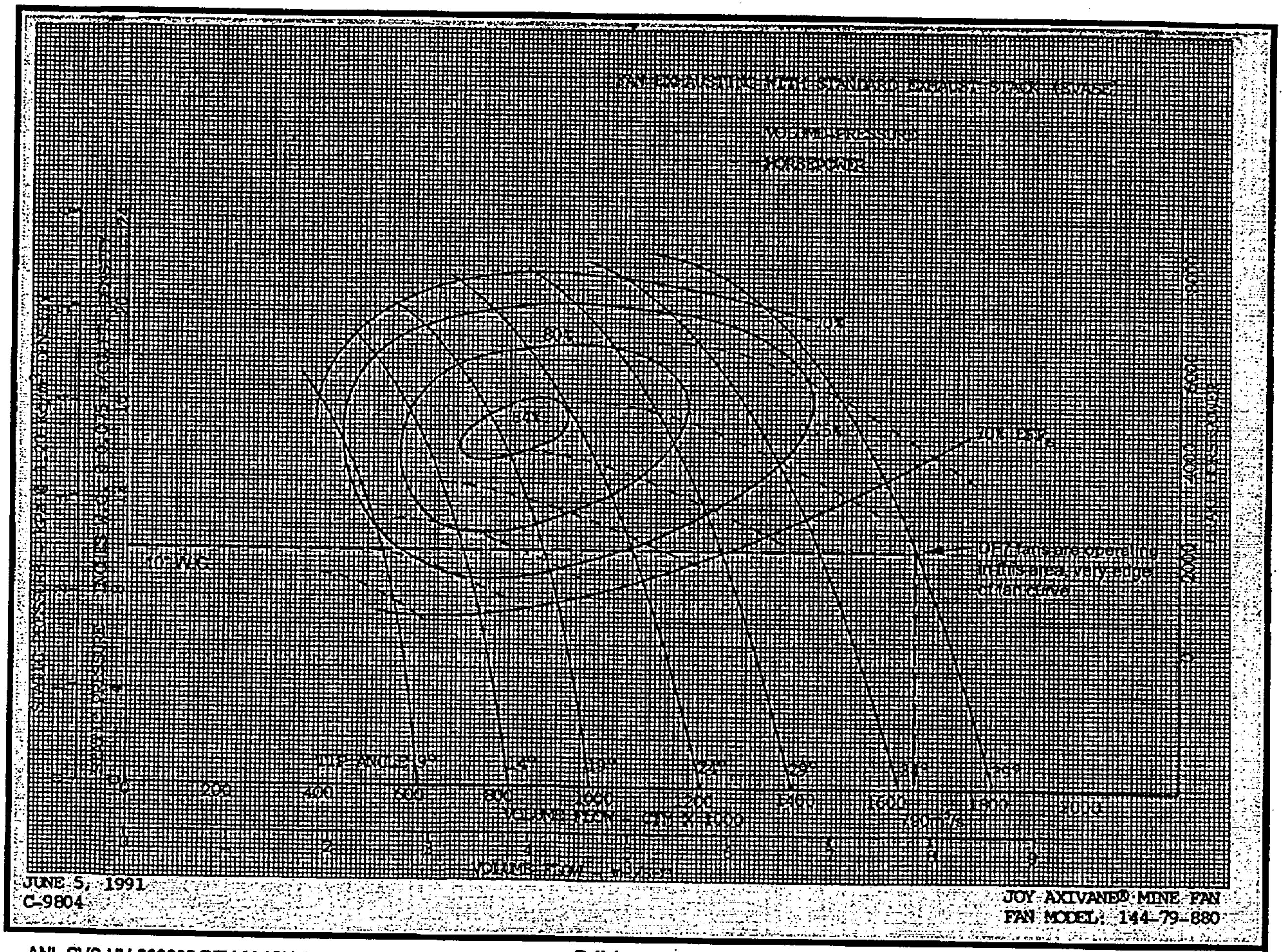
31 2) The total length of emplacement (D23 and J23) is divided by 1200 m to estimate the total number of emplacement drifts.

32 3) All emplacement drifts are not 600m in length, some are shorter based on the repository footprint. Therefore, 15% is added to the estimate.

33 4) CRWMS M&O 2000b, Item 2, pp. 3 through 6, as documented in Section 4.1.2.

34 5) Calculations have been spot checked by hand to ensure accuracy.

Attachment II
Fan Curves



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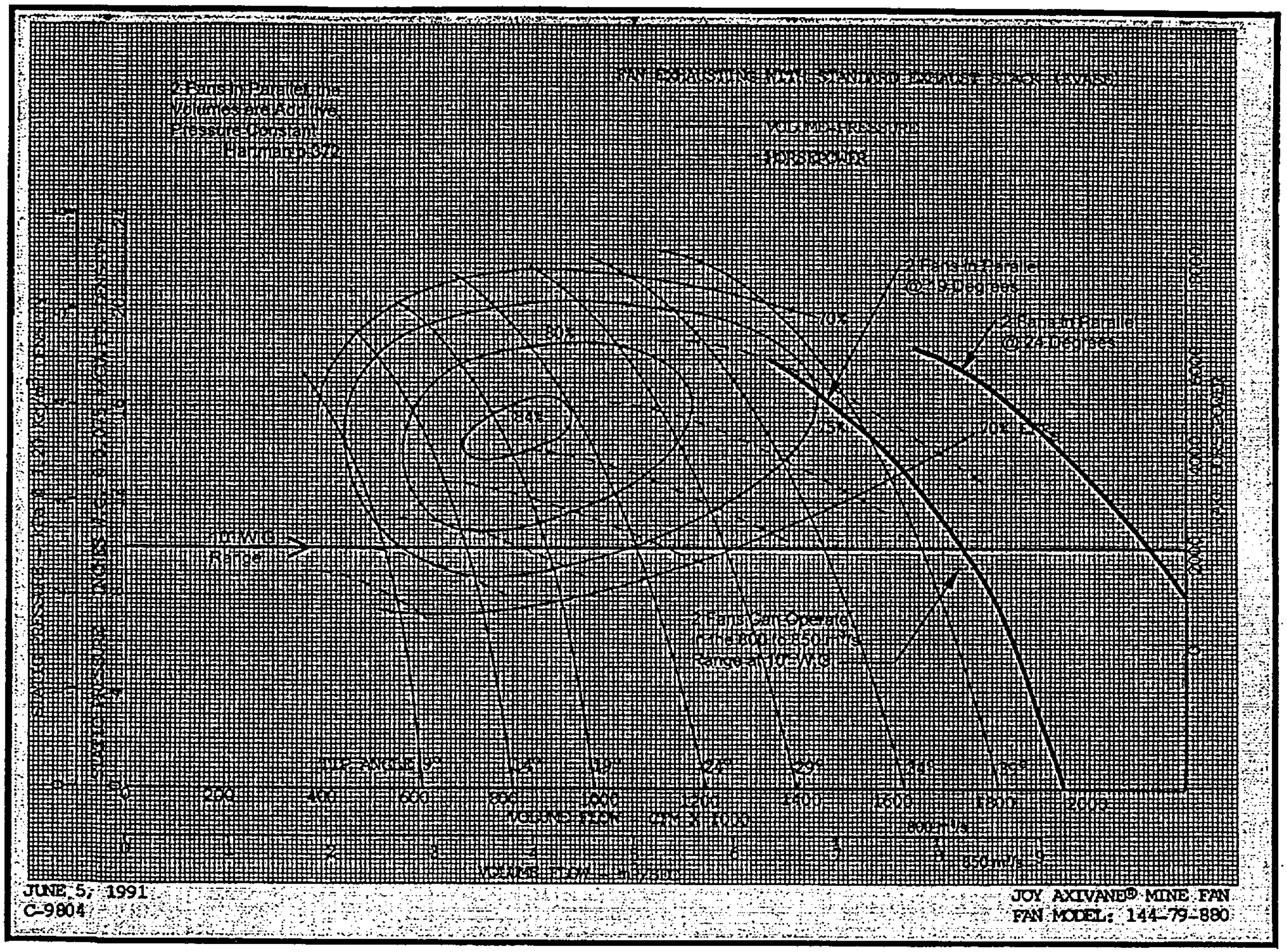
JOY AXIVANE® MINE FAN
FAN MODEL: 144-79-880

2 Fans in Parallel the
Volumes are Additive,
Pressure Constant
Hartman p.372
FAN EXHAUSTING WITH STANDARD EXHAUST STACK (EVASE)
VOLUME-PRESSURE
HORSEPOWER
2 Fans in Parallel
@ 19 Degrees
2 Fans in Parallel
@ 24 Degrees
70%
80%
84%
75%
70%
10" W.G.
Range
2 Fans Can Operate
in the 800 to 850 m³/s
Range at 10" W.G.
TIP ANGLE 9°
14°
19°
24°
29°
34°
39°
0
200
400
600
800
1000
1200
1400
1600
1800
2000
VOLUME FLOW CFM X 1000
800 m³/s
0
1
2
3
4
5
6
7
8
850 m³/s
9
VOLUME FLOW – m³/sec
STATIC PRESSURE
0
2000
4000
6000
8000
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JOY AXIVANE® MINE FAN
FAN MODEL: 144-79-880

Attachment III
1.45 kW/m Interpolation

1.45 kW/m Interpolation

The overall heat output of the WPs is approximately 1.45 kW/m (see Section 5.9) and the intake air to the emplacement drifts will expand because it will be heated as it passes the WPs. The anticipated exhaust air temperature can be interpolated from Figure III-1. This figure represents temperature profiles of the exhaust air at various overall WP heat output values (see Table 1, Section 4.1.1) for an emplacement drift ventilation rate of 15 m^3/s along a 600 meter long emplacement drift (CRWMS M&O 1999g, Sect 3.6).

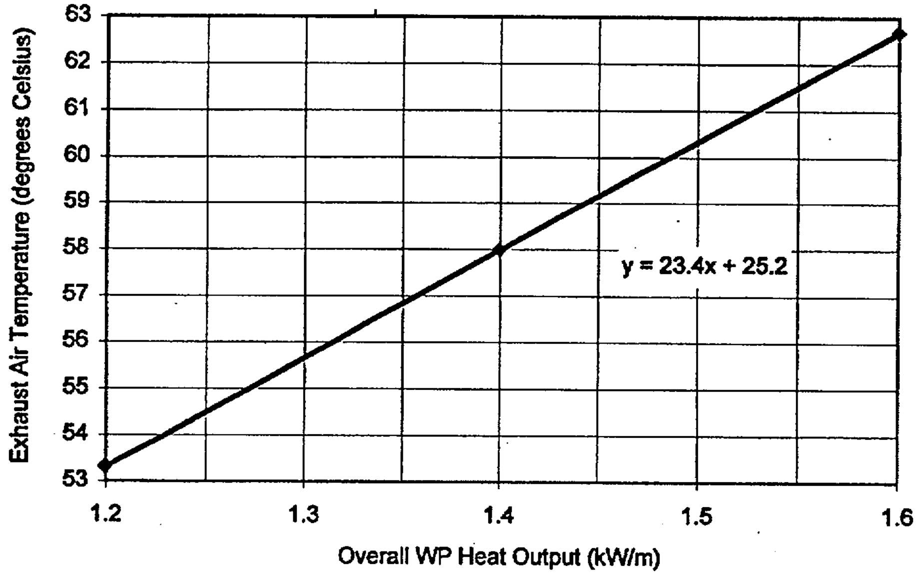

Figure III-1. Overall Heat Output versus Exhaust Air Temperature

Based on the trend line, the approximate exhaust air temperature from the emplacement drift at a overall WP heat output of 1.45 kW/m and a ventilation airflow rate in the emplacement drift of 15 m^3/s is 59.1 degrees Celsius, as calculated below.

$$y = 23.4x + 25.2$$

Where: y = temperature (degrees Celsius) and
χ = overall WP heat output (kW/m).

And: χ = 1.45 kW/m,

$$y = ((23.4)(1.45)) + 25.2$$
$$y = 59.13 \text{ degrees Celsius}$$

For the purposes of this analysis, the 59.13 degrees Celsius temperature is rounded to 60 degrees Celsius.