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1. PURPOSE

The purpose of this analysis is to provide recommendations for the preliminary design of the Subsurface Ventilation System. This analysis pertains to emplacement drift air control and the regulation of ventilation. The focus will be on the regulation of ventilation during different scenarios such as emplacement, retrieval, monitoring and backfilling operations. The purpose is to support engineering of the repository Ventilation System for viability assessment design.

The scope of the analysis for design of the emplacement drift ventilation system covers:

- Assessment of air pressure differentials, sealing requirements, and potential air leakage through the system.
- Provision for airflow in the emplacement drift for performance confirmation monitoring, and possible emplacement drift cooling and moisture removal, and approaches for providing and controlling the airflows.
- Development of the configuration and arrangement of the ventilation control system.
- Regulation of the airflow during off-normal events.
- Control the spread of radiation leakage from emplaced waste through the ventilation system.
- Control and monitoring systems.
- Materials of construction.

The analysis will not address the control of radiation through air control structures as this will be covered in other analyses.

2. QUALITY ASSURANCE

The items which are the subject of this design analysis have not been classified in accordance with QAP-2-3. However, air locks, isolation doors, and other ventilation barriers (permanent and temporary) have been placed on the *Q-List* (Ref. 5.1) by direct inclusion. Therefore, for purposes of this analysis, all emplacement doors and related structures will be considered *Quality Affecting and subject to the Quality Assurance and Requirements Description* (Ref. 5.2). This design analysis activity has been evaluated in accordance with QAP-2-0 and found to be quality affecting.

This analysis is preliminary and will not be used for construction, procurement, or fabrication. Unqualified data inputs which will need to be verified are marked TBV or TBD but formal TBV and TBD tracking system described in NLP-3-15, Rev. 3, To Be Verified (TBV) and To Be Determined (TBD) Monitoring System is not applicable to this analysis.

3. METHOD

The emplacement air control system will be evaluated on the basis of its function, performance (in regards to minimal leakage and regulated access), and structural integrity. The air control system

configuration and structural requirements will be determined by considering the construction materials and airflow volumes and pressures.

4. DESIGN INPUTS

4.1 Design Parameters

4.1.1 Elevation of Repository

The elevation of the repository is approximately 1100 m (TBV). (Ref. 5.3.)

4.1.2 Atmospheric Pressure

Atmospheric pressure is 12.92 psi at 3500 ft and 12.68 psi at 4000 ft. (Ref. 5.15)

4.1.3 Kinematic Viscosity of Air

Kinematic viscosity of air is 1.79×10^{-5} m²/sec at 50° C and 2.85×10^{-5} m²/sec at 150° C. (Ref. 5.21)

4.1.4 Dimensions of a Typical Waste Emplacement Drift

The typical waste emplacement drift will be 5.5 m diameter with a 0.2 m lining (TBV). (Ref. 5.3)

4.1.5 Dimensions of a Typical Ventilation Raise

The typical ventilation raise will be 2.0 m diameter with a 0.15 m lining (TBV). (Ref. 5.3)

4.1.6 Maximum Length of an Emplacement Drift

The maximum usable emplacement length of the longest emplacement drift is approximately 1184 m (TBV). (Ref. 5.3) Emplacement occurs from both ends with a ventilation raise in the middle and divides the drift into two emplacement drifts (See Figure 1). For this analysis a conservative drift length of 600 m will be used.

4.1.7 Emplacement Drift Layout

The current subsurface emplacement drift layout contains long parallel emplacement drifts, a single emplacement block, in-drift waste package emplacement, and a central exhaust main below the emplacement drifts as per Figure 1 and Attachment VI (TBV). (Ref. 5.3)

4.1.8 Air Leakage Through a CD60 Louver

Air leakage through a 4' by 4' square (1.49 m²) CD60 Louver at 5 in of water (1.24 kPa) is 64 CFM (.030 m³/sec) (TBV). (Ref. 5.12)

FIGURE 1
EMPLACEMENT DRIFT LAYOUT

4.1.9 Airflow Versus Temperature for a 600m Drift

A drift air temperature of 46° C will result from a flow of 10 m³/sec as per Figure 9.3-6 (TBV). A quantity of 100 m³/sec will cool the drift to 43° C in 5 weeks as per Figure 9.4-1 and a quantity of 30 m³/sec will cool the drift to 63° C in 5 weeks as per Figure 9.4-2 (TBV). (Ref. 5.10)

4.2 Design Criteria

Reference used: *Repository Design Requirements Document (RDRD)* - Ref. 5.4.

4.2.1 Robustness of Ventilation Barrier Design

The emplacement drift ventilation barriers shall be designed to continue functioning during normal operations and under postulated accident conditions. (RDRD; 3.7.5.B.2)

4.2.2 Control of Airborne Radioactive Material

The emplacement drift ventilation control structures shall be designed so that radioactive particulates and gases within the airflow will be contained to the extent practical by barriers and other engineered control systems. (RDRD; 3.2.2.3.A and 3.7.5.B.1)

4.2.3 High Radiation Area Access Control

Access to high and very high radiation areas shall be controlled. Emplacement drifts shall provide at each entrance or access point to a high radiation area a conspicuous visible or audible alarm signal so that the individual entering the high radiation area and the supervisor of the activity are made aware of the entry. Entryways are locked except during periods when access to the areas is required. (RDRD; 3.2.4.3.2.A and 3.2.4.3.2.B1)

4.3 Assumptions

References used: *Controlled Design Assumptions Document (CDA)* - Ref. 5.6, *Subsurface Ventilation and Environmental Engineering* - Ref. 5.5, and *Subsurface Ventilation Analysis-Construction Phase* - Ref. 5.16.

4.3.1 Not Used

4.3.2 Not Used

4.3.3 Material Restrictions

Organic materials are restricted for use as rock support and other post-closure permanent materials in all openings. Concrete and steel are allowable preclosure construction material in all openings. (Ref. 5.6, CDA, DCSS 027) [Used in Sec. 7.3.1]

4.3.4 No Human Entry in Emplacement Drifts Containing Waste Packages

No human entry is planned in emplacement drifts while waste packages are present. The waste emplacement/retrieval equipment may use robotics and/or remote control features to perform operations and monitoring within the emplacement drifts. Under off-normal conditions, human entry will be considered if protection to the workers can be provided. (Ref. 5.6, CDA Key 013) [Used in 7.2.2]

4.3.5 Waste Package Shielding

Personnel radiation protection from individual waste packages will be provided through the use of: (3) Shielding and seals at the entrances to emplacement drifts. (Ref. 5.6, CDA Key 031) [Used in Sec. 7.3]

4.3.6 Backfill in Emplacement Drifts

The repository design should not preclude the use of emplacement drift backfill at the end of the preclosure period. (Ref. 5.6, CDA Key 046) [Used in Sec. 7.1.1]

4.3.7 Performance Confirmation Requirements

10. ... These operations are to include, but are not to be limited to, capabilities for:

- d. Recovery of selected or malfunctioning waste packages shall be performed on a non-routine basis, as required.
- e. The design, excavation, and ground support of emplacement drifts shall permit installation of and access to test/monitoring instrumentation, and observation drift instrumentation, and provide access for remotely operated vehicles or mobile inspection platforms to obtain measurements.
- h. The air temperature, relative humidity, and gaseous radioactive emissions of all emplacement drifts shall be monitored through the drift ventilation.
- i. The ventilation monitoring system shall be capable of identifying the specific drifts that are sources of gaseous radioactive emissions, if any, within TBD hours of detection of such emission. (Ref 5.6, CDA Key 061) [Used throughout]

4.3.8 Emplacement Drift Ventilation

Emplacement drift ventilation will be maintained at a low, controlled volume for monitoring purposes. (Ref. 5.6, CDA Key 067) [Used in Sec 7.1.1 and 7.3]

4.3.9 Emplacement Drift, Shafts, Ramps Maintenance Plans

Emplacement drifts will be designed to be stable through the caretaker period, with the goal to minimize or eliminate planned maintenance to sustain the ability to retrieve, sample, or relocate waste packages. Shafts, ramps, and all other drifts will be stable, but may rely on periodic planned maintenance. (Ref. 5.6, CDA, DCSS 028) [Used in Sec. 7.1 and 7.3]

4.3.10 Air Monitoring Underground

Air in underground excavations, including shafts and ramps (and emplacement drifts), will

be monitored as required for health, safety, and performance confirmation. (Ref. 5.6, CDA, DCSS 038) [Used in Sec. 7.2.2 and 7.3]

4.3.11 Maximum Underground Air Temperature - Access Mains

Maximum allowable air temperature in access mains during:

Operations: 27°C effective (Ref. 5.6, CDA, DCSS 020) [Used in Sec. 7.1]

4.3.12 Maximum Underground Air Temperature - Exhaust Mains

Maximum allowable air temperature in exhaust mains during:

Operations: 50°C dry-bulb (Ref. 5.6, CDA, DCSS 029) [Used in Sec. 7.1.1]

4.3.13 Surface Humidity

Surface Air Humidity: Maximum: 71%
Minimum: 13% (Ref. 5.6, CDA, TDSS 021)

[Used in Sec. 7.2.1]

4.3.14 Limit on Temperature

To limit the thermal and thermomechanical response of the host rock and surrounding strata and groundwater system, the Engineered Barrier Segment (EBS) configuration and loading shall:

> Keep emplacement drift wall temperatures <200° C (TBV). (Ref. 5.6, CDA, EBD RD 3.7.G.2) [Used throughout]

4.3.15 "K" Factors for Ventilation Air Flow

			(x10 ⁻¹⁰ lb min ² /ft ⁴)
Shafts:	Ventilation Shaft	0.0030 kg/m ³	(20)
	Man-and-Material Shaft	0.0176 kg/m ³	(95)
Ramps/Mains:	Waste Ramp	0.0056 kg/m ³	(30)
	Tuff Ramp	0.0111 kg/m ³	(60)
	Exhaust Mains	0.0111 kg/m ³	(60)
	Service Mains	0.0130 kg/m ³	(70)
	TBM Launch Mains	0.0130 kg/m ³	(70)
	Waste Main	0.0111 kg/m ³	(60)
Emplacement Drifts:	with Waste Packages	0.0158 kg/m ³	(85)
	without Waste Packages	0.0130 kg/m ³	(70)

(TBV) (Ref. 5.6, CDA, DCSS 022) [Used in Attachment VI]

4.3.16 VNETPC Input Values

Equivalent resistance for net leakages are as follows:

Airlock Doors 1000 units
Emplacement Door Regulators (Range) 1 to 500 units

Gate Valve Regulators (Range)	0.21 to 99,000 units
Development/Emplacement Barrier (each)	1000 units
Total Fan Bulkhead (TBV) (Ref. 5.5) [Used in Attachment VI]	2000 units

4.3.17 Exhaust Main Air Tubes

The exhaust main air tubes which direct air from the ventilation raises to the emplacement shaft are 1.83 m (72 inches) (TBV) in diameter. Two tubes exhaust main tubes are assumed (Ref. 5.8). These tubes have an average ventilation capacity of 50 m³/sec each or 100 m³/sec together (TBV) (Attachment VI). The emplacement drifts nearer the fan will have a higher capacity because the negative pressure of the fan will be stronger. The metal pipes are smooth lined ("K" factor = 0.002 kg/m³) (TBV) (Ref. 5.5), installed in welded or flanged joints with negligible leakages. [Used throughout]

4.3.18 Equivalent Length

Equivalent length used to account for joints and minor misalignments is +10% of the total duct or drift length (TBV). (Ref. 5.16) [Used in Attachment VI]

4.4 Codes and Standards

4.4.1 Not Used

4.4.2 ASHRAE Design Guide, Section 6 (1993)

Secondary Confinement Area Ventilation

...in rooms surrounding primary confinement enclosures, a minimum of four and a maximum of eight air changes per hour (based on gross room volumes) are recommended.

4.4.3 American Institute of Steel Construction (AISC) (1989)

AISC MO16-89 AISC Manual of Steel Construction, Allowable Stress Design, Ninth Edition.

4.4.4 American Society for Testing and Materials (ASTM) (1996)

ASTM A36/A36M-96 Standard Specifications for Carbon Steel.

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Ventilation Simulation Program with Gas Distribution per QAP-19-1. CSCI 20.93.3003-AAu3.1. Las Vegas, NV

- 5.18 *Retrievability Strategy Report. B000000000-01717-5705-00061, Rev. 00. Las Vegas, Nevada.*
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- 5.22 *Repository Subsurface Ventilation Scoping Evaluation Report. BACD00000-01717-5705-00001, Rev. 00. Las Vegas, Nevada.*
- 5.23 *Ventilation Simulation Program with Gas Distribution User's Manual. VNETPC Version 3.1. Fourth Edition. February, 1991.*
- 5.24 *MGDS Subsurface Radiation Shielding Analysis. BCAE00000-01717-0200-00001, Rev. 00. Las Vegas, Nevada.*
- 5.25 *Radiation Control Manual. April, 1994. DOE/EH-0256T, Rev. 1. Washington, D.C.*
- 5.26 *Accident Analysis for a Nonmechanistic Waste Package Failure (Subsurface). BCA000000-01717-0200-00001, Rev. 00. Las Vegas, Nevada.*

6. USE OF COMPUTER SOFTWARE

VNETPC Version 3.1, Ventilation Simulation with Gas Distribution computer software and Lotus 1-2-3 for Windows, Release 5, spreadsheet are used in this analysis. Lotus 1-2-3 is a common off-the-shelf computer spreadsheet program. It is used to check the VNETPC output. VNETPC Software is used to simulate the computer model of the overall repository ventilation. The application of the software is only used within the validated range as describe in the Verification and Validation documentation of VNETPC Software. (Ref. 5.17)

Attachment VI is a copy of the output of the VNETPC Software and provides an explanation of how the output was developed and an interpretation of the output. Not all of the VNETPC output was used in this analysis. Only that portion of the output used in this analysis will be explained.

7. DESIGN ANALYSIS

This design analysis is based on the emplacement drift layout shown in Figure 1. Air flows from both the East and West Mains down each emplacement drift to the central raise. Air flows down the raise to the central exhaust main where it is drawn to a shaft and sent out of the repository. The repository configuration will change as different stages are completed and so ventilation requirements for the emplacement area will change. However, the overall flow pattern for each emplacement drift should not change.

This design analysis will develop and describe a preliminary design for the emplacement drift air control system. The analysis will examine air control requirements under the following conditions: no flow, low controlled flow, monitoring, waste emplacement, retrieval, recovery, backfill, and abnormal. The control system will be illustrated by the use of Process and Instrument Diagrams (P&ID's) and General Arrangement (GA) Figures.

7.1 Ventilation

The emplacement drift air control system will consist of an inlet structure and an outlet structure for the drift. Structures are required because air flow through parallel emplacement drifts (see Figure 1) would be impossible to control without physical regulators. The quantity of ventilation air in a drift is inversely proportional to the drift resistance, the higher the resistance the lower the quantity of air flowing (at a given head). The drift resistance is a function of the drift length, roughness of the walls and the number of bends in the drift. As shown in Attachment VI the repository is not symmetrical with respect to air flow and thus the pressure head varies with the emplacement drifts distance from the North Ramp and emplacement shaft. Drifts with lower resistance, higher pressure heads, or both will receive a disproportionate amount of the ventilation air (Ref. 5.15). Structures allow the appropriate quantity of ventilation air to flow through parallel emplacement drifts and prevent large fluctuations in flow. Inlet and outlet structures are required so that ventilation can still be controlled when one structure is open or undergoing repair. In addition the entire emplacement drift could be closed off in the event of a leaking waste package with inlet and outlet controls. Substantial structures will be needed to handle the pressures as expressed in Attachment VI. Specific structure requirements are shown in Table 1.

Table 1
Emplacement Drift Structure Requirements

Function	Reference	Inlet	Outlet
Open & Close (for access)	None	Yes	Some
Radiation Protection (airborne)	4.2.2	Yes	Yes
Radiation Protection (shielding)	4.3.5	Some	Some
Controlled Access	4.2.3	Yes	Yes
Ventilation Regulation	4.3.8	Yes	Yes

The requirement for opening and closing of emplacement drifts to allow access is derived from the fact that waste package will be stored in the drifts. These waste packages will need to enter the drift for placement and thus a structure will need to open and close to allow the placement to occur. As the outlet structure will be located in a raise, no waste packages will enter by this route and thus there is no requirement for waste package access with the current emplacement drift layout. However, there will be a requirement for access for maintenance (4.3.9).

Structures which will meet all these requirements are a door with a regulator for the inlet and a valve for the outlet. The valve for the outlet structure may either allow the <200° C (4.3.14) emplacement drift ventilation air to go directly to the exhaust main (Figure 2) or to discharge into tubes (Figure 3).

If air is discharged directly into the exhaust main local hot spots will be formed and create safety concerns for workers accessing the main. As the amount of <200° C (4.3.14) air discharged to the main air increases, the average air temperature will go up. Potentially, the exhaust main air temperature could increase to unacceptable levels for human access (4.3.11). Radioactive particles or gases from leaking waste packages would be discharged directly into the exhaust main. Management of the air flow in this case will thus create operational restrictions for the repository. This system constrains the overall ventilation system and limits its options.

If air is discharged into tubes the <200° C (4.3.14) emplacement drift ventilation air will be contained and thus minimize the impact of the air temperature in the exhaust main. The exhaust main would thus be fully accessible for maintenance and inspection activities. Radioactive particles or gases from leaking waste packages would also be contained in the tubes.

FIGURE 2
VENTILATION AIR INTO
EXHAUST MAIN

FIGURE 3
VENTILATION AIR INTO TUBES

The recommended arrangement at the outlet of the drift is therefore to discharge the emplacement drift air into tubes. The justification for the diameter and number of tubes will be determined by other analyses. For this analysis two tubes have been assumed as per Assumption 4.3.17.

7.1.1 Specific Ventilation Situations

In the following section and throughout the report the following definitions will apply:

- 1) An "emplacement drift" will consist of that portion of the emplacement drift between the entrance door and the ventilation raise. There are about 200 of these drifts in the repository (Attachment VI).
- 2) When figures for air flow are given they are understood to be the volume of air per time unit at 27° C (4.3.11). After ventilation air has passed through an emplacement drift with waste packages in it, the air will undergo expansion because of heat. This will be noted by the phrase "expanded" which will be near the value for the air which has undergone thermal expansion.

The "no ventilation" condition can be achieved by closing the emplacement drift doors and regulator plus shutting the valve at the drift outlet structure. This arrangement will minimize leakage around the door and valve and is thus called "no ventilation".

A low controlled ventilation (4.3.8) can be maintained by opening the inlet door regulator and the outlet valve slightly. Some air leakage around the door seal or through the rock mass is anticipated. The amount of air leakage is impossible to determine in advance because of the variability of rock joints and cracks. For this design analysis, minimal ventilation plus air leakage is calculated to be less than or equal to 0.1 m³/sec per drift. This ventilation rate will produce 0.3 m³/sec (expanded) at the raise which collects air from two emplacement drifts (Attachment I).

Drift monitoring may be accomplished by allowing 14 m³/sec to flow into the drift for 1 hour. See Section 7.2.2 for a more complete discussion of monitoring and an estimation of the appropriate flow rate to use for monitoring. The 14 m³/sec will expand to 15 m³/sec at the raise when thermal expansion effects are taken into account (Attachment I).

In active emplacement drifts the temperature must be kept to 50° C or less (4.3.12) to allow emplacement equipment to operate properly. The emplacement equipment will operate upstream in the ventilation system from the waste packages. Since the equipment will be in unheated air its temperature should be kept close to that of air in the access mains (about 27° C). The portion of the emplacement drift downstream from the equipment can exceed the 50° C temperature with no adverse effects on the emplacement equipment. If the total ventilation capacity of both tubes were used it would equate to about 100 m³/sec (expanded) (4.3.17). As the number of full emplacement drifts will vary over time, the capacity available for waste emplacement drift equipment cooling will also vary as shown in Table 2.

Table 2
Emplacement Drift Airflow Quantity (m³/sec)(expanded)

Maximum Ventilation	Continuous Vent for Drifts	Ventilation for Monitoring	Air Quantity Remaining	# Drifts which can be cooled with this volume+
100	0*	15	85	1 to 6
100	30**	15	55	1 to 4

Notes: * 1 emplacement drift filled.

** 200 (approximate) emplacement drifts filled (Attachment VI).

+ Assuming continuous cooling to keep drift temperatures at 50° C or less.

This table shows that as the number of emplacement drifts filled with waste packages increases the amount of air available for use in cooling drifts undergoing emplacement decreases. Note that the amount of air used for monitoring is not continuous and Table 2 shows the maximum amount of air needed.

During repository operations it is possible to use one tube exclusively for continuous ventilation and monitoring. The other tube could be used for ventilation associated with the emplacement of waste packages. This arrangement allows a certain flexibility in operations as a problem in one operation will not necessarily shut down the other. The repository will change configuration over time as more emplacement drifts are filled. The demands on the ventilation system will correspondingly increase as the drifts are filled and therefore the flexibility of the ventilation system will decrease as the repository is filled with waste packages. The following discussion on retrieval, backfill and recovery will reflect this loss of flexibility.

Retrieval of the waste packages in an entire emplacement drift may occur during the lifetime of the repository. Retrieval will begin by blast cooling the drift with air to lower the temperature to 50°C (4.3.12). A recommendation has been made to lower the air temperature from 200 °C to 50 °C within 30 days (Ref. 5.18). The capacity of one tube or about 50 m³/sec (expanded) is available for blast cooling (4.3.17). The other tube would collect the continuous ventilation air and any air used for monitoring. Only one drift could be retrieved at a time using this system.

Recovery of a specific waste package for performance confirmation (4.3.7) may occur during the lifetime of the repository. Waste package recovery ventilation requirements will be the same as retrieval requirements.

Backfill may be required for the emplacement drift (4.3.6). If backfilling does occur the drift temperature will have to be cooled to 50° C (4.3.12) by blast cooling. During backfill operations

air will be discharged through the man access port included with the outlet structure. The air thus discharged will go through a filter to remove dust generated by the backfill operation and be vented into the exhaust main. Only one drift could be backfilled at a time using this system.

The tubes limit the total capacity of the ventilation system. Because of this limitation neither backfill, recovery nor retrieval can happen at the same time as emplacement operations.

7.1.2 Abnormal Conditions

This design analysis will not attempt to list or analyze all abnormal conditions. It is anticipated that the emplacement air control system will be designed for seismic events. It is outside the scope of this analysis to determine the frequency of these events. The most likely abnormal events which the emplacement drift air control system may be called upon to handle (4.2.1) are:

- Rock fall in drift which damages a waste package or blocks drift access.
- Removal of a leaking waste package.
- Power failure which affects the ventilation system.
- Malfunction of drift inlet or outlet structures.

A rock fall in an emplacement drift can be handled by:

- a) Blast cooling to reduce the temperature to 50° C
- b) Removing waste packages to provide access for repair equipment.
- c) Removing/ repairing the rock fall.
- d) Replace waste packages removed in Step b.

A leaking waste package is a potentially more serious event. This event can be repaired as shown below:

- a) Cut-off all ventilation to the emplacement drift by closing the door regulator and the outlet valves.
- b) Connect a portable High Efficiency Particulate Air (HEPA) filter to the man access port on the outlet structure and vent the air into the exhaust main.
- c) Blast cool to reduce the temperature in the emplacement drift to 50° C.
- d) Remove the leaking waste package(s).
- e) Decontaminate the emplacement drift.
- f) Return the repaired waste package(s) to the emplacement drift.
- g) Remove the HEPA filter and return the drift to a low continuous ventilation state.

A power failure would be an unlikely event which would require that primary power and backup generators fail. However, a power failure would stop the exhaust fan for the emplacement side of the repository. When the fan is operating, there was always a pressure on the emplacement drift which directs the air flow from the perimeter mains to the exhaust main. Even with this fan being

stopped, natural ventilation will cause the ventilation air to always move towards the exhaust main (Ref. 5.22). Natural ventilation is caused by the elevation difference between the ramp portal and the emplacement shaft exit plus the buoyant effects of air heated in the emplacement drifts (Ref. 5.15).

Maintenance of the emplacement drift air control system may be required. Air flow in the emplacement drift in the event of a malfunction of the inlet can be controlled by the valves at the outlet. A malfunction of the emplacement drift outlet requires more extensive preparation for repairs. The inlet controls at the entrance door may be shut off to stop most of the air flow. The raise access port will then be opened and the negative pressure from the fans will cause air to flow from the exhaust main into the exhaust tubes. An inflatable plug (Figure 4) can be inserted up the raise to seal off the air flow to the exhaust tubes. The plug can be inserted by a jack or small scissors lift and inflated remotely to insure no personnel are exposed to the $<200^{\circ}\text{C}$ (4.3.14) ventilation air in the raise. After repairs are made the plug can be removed and the access port resealed. Access to the port can be made via a scissors lift or similar equipment. Simultaneous failure of both the inlet and outlet controls is such an unlikely event that it will not be discussed.

The entire exit structure for the raise and associated tubing could be replaced or decontaminated should they become contaminated with radioactive material. Under normal operations air from a raise will be directed by a valve to one of the two exhaust main tubes. Should a problem occur, one tube can be completely shut down and ventilation air from all drifts directed to the second tube. After the inflatable plug is inserted in the raise, the exit structure and tubing can be removed or decontaminated. The raise can be decontaminated in stages up to the level of the emplacement drift by advancing the plug up the raise.

7.2 Monitoring

Two of the most basic questions to answer when discussing monitoring are: What should be monitored? and How should monitoring take place?

Assumption 4.3.7 lists specific parameters to be monitored. The emplacement drift exhaust air temperature, relative humidity, and possible gaseous and particulate radioactive emissions are all to be monitored. Air quantity is another desirable characteristic to measure to ensure air flow in the drifts is kept to a low value, to help balance the ventilation system, and to allow determination of the amount of moisture removed.

Assumption 4.3.7 requires monitoring of emplacement drifts but does not specify that each drift be individually monitored. Instruments could monitor an aggregate of several drifts or the ventilation air from all drifts and still satisfy the assumption. The assumption does require that the monitoring system be capable of identifying the specific drift that is a source of gaseous radioactive emissions, but is not specific as to the length of time to accomplish the task. However, it is reasonable to assume that identification should be accomplished in an expeditious manner.

FIGURE 4
INFLATABLE PLUG
FOR RAISE

There is no specific requirement that only the ventilation system be used to monitor the emplacement drifts. A recent analysis (Ref. 5.13) recommended a remote inspection gantry be used in performance confirmation of waste packages. This option will be discussed in more detail below.

The eight specific ventilation situations mentioned in Sections 7.1.1 and 7.1.2 of this Design Analysis have different requirements for instrumentation and this will also be discussed below.

7.2.1 Instrumentation

This Section will discuss where instruments should be located and what type of instruments are required.

Detection instruments could be located in five general locations. These locations are:

- Top of the emplacement ventilation shaft.
- Bottom of the emplacement ventilation shaft.
- At the first emplacement drift (emplacement drift located closest to the shaft).
- Spaced at intervals along the exhaust main.
- At every emplacement drift raise.

These five general locations could be equipped with instruments which will detect radiation leaks from waste packages. If no action to contain the radiation leak were taken, the radiation would travel from the waste package, down the raise and into the tubes in the exhaust main. The radiation would then travel down the tubes where it would travel up the emplacement shaft to the surface and eventual discharge into the atmosphere. It is anticipated that the repository control system will take some action to contain the radiation leak. The actions which will be taken are the subject of other M&O analyses.

In order to give the control system as much time as possible to react to the leak, detector locations at the top and bottom of the shaft are eliminated from further consideration as a detector located at the first emplacement drift allows the control system a longer time to react. The installation cost of a monitoring system is similar in the first three locations mentioned above.

The velocity of the airstream carrying the radiation does not effect the decision to eliminate instruments located at the top and bottom of the shaft. An instrument located at the first emplacement drift gives more time for the control system to react then either the top or bottom of the shaft instrument locations. Detectors could be placed at the top and bottom of the shaft for redundancy reasons, but not as the primary detection location.

Final selection of detector locations will depend upon the determination of how long after a leak is detected is it necessary to determine the specific emplacement drift containing the leaking waste package. Placing a detector at each raise is the most conservative option as it provides, consistently,

the least travel time until detection. This option is tentatively picked until a specific determination is made of the time from detection until finding the leaking waste package is made. Assumption 4.3.7 indicated that this time is to be determined (TBD) and therefore all options must be considered.

The type of instruments to be chosen depends upon the expected range of environmental conditions to be monitored. The environmental conditions can change under different ventilation situations as shown below:

Table 3
Ventilation Situation Versus Type and Range of Instrumentation

Vent Situation	Humidity	Temperature	Expanded Flow m ³ /sec	
			From Raise	From 1 Tube
No Flow	----	----	0	0
Low Flow	0-71%	20-200° C	0-0.3	0.3-50
Monitoring Flow	“	“	15	15
Emplacement	“	“	10*-50	10-50
Retrieval	“	“	30*-50	30-50
Recovery	“	“	30-50	30-50
Backfill	“	“	30-50	30-50
Off-Normal	“	“	0-50	0-50

* 10 m³/sec (approximate) is set as the lower limit for maintaining temperature in an emplacement drift and 30 m³/sec is the lower limit to reduce temperature in an emplacement drift (Attachment II).

The following information is provided to justify the expected conditions listed in the table above and to show that the table bounds all reasonable conditions.

Assumption 4.3.13 indicates that surface air humidity will range from 13 to 71%. As the air will undergo thermal expansion in the emplacement drifts, its relative humidity will drop and thus 0% relative humidity is a reasonable minimum value to use (although 0% relative humidity is not expected). A review of humidity instrumentation reveals that many manufacturers provide instruments which range from 0 to 95% relative humidity. A single type of humidity instrument will thus cover the entire range specified in Table 3. The instrument is not location sensitive and could be placed in any position in the exhaust main with no degradation in capability. See Figures 5 and 6 for proposed locations of instrumentation.

LEGEND:

INSTRUMENT ABBREVIATIONS:

AAH	ANALYZER ALARM HIGH
AE	ANALYZER SENSOR
AI	ANALYZER INDICATOR
AIT	ANALYZER INDICATING TRANSMITTER
AR	ANALYZER RECORDER
RAH	RADIATION ALARM HIGH
RE	RADIATION SENSOR
RI	RADIATION INDICATOR
RIT	RADIATION INDICATING TRANSMITTER
RR	RADIATION RECORDER
TAH	TEMPERATURE ALARM HIGH
TE	TEMPERATURE SENSOR
TI	TEMPERATURE INDICATOR
TIT	TEMPERATURE INDICATING TRANSMITTER
TR	TEMPERATURE RECORDER
FAL	FLOW ALARM LOW
FE	FLOW SENSOR
FI	FLOW INDICATOR
FIT	FLOW INDICATING TRANSMITTER
FR	FLOW RECORDER

* INSTRUMENT ABBREVIATION

SHARED DISPLAY MONITORING OR CONTROL POINT ON THE INSTRUMENTATION DATA HIGHWAY AND AT THE SUBSURFACE OPERATION'S CONTROL CENTER LOCATED ON THE SURFACE.

FIELD MOUNTED INSTRUMENT

----- ELECTRIC SIGNAL

---o---o---o--- SYSTEM LINK (SOFTWARE)

INSTRUMENTATION SHOWN IS TYPICAL FOR EACH DUCT

FIGURE 5
 POSSIBLE ARRANGEMENT OF DRIFT INSTRUMENTATION NEAR 1st EMPLACEMENT RAISE

LEGEND:

AAH ANALYZER ALARM HIGH
 AE ANALYZER SENSOR
 AI ANALYZER INDICATOR
 AIT ANALYZER INDICATING TRANSMITTER
 AR ANALYZER RECORDER
 RAH RADIATION ALARM HIGH
 RE RADIATION SENSOR
 RI RADIATION INDICATOR
 RIT RADIATION INDICATING TRANSMITTER
 RR RADIATION RECORDER
 TAH TEMPERATURE ALARM HIGH
 TE TEMPERATURE SENSOR
 TI TEMPERATURE INDICATOR
 TIT TEMPERATURE INDICATING TRANSMITTER
 TR TEMPERATURE RECORDER
 FAL FLOW ALARM LOW
 FE FLOW SENSOR
 FI FLOW INDICATOR
 FIC FLOW INDICATING CONTROLLER
 FIT FLOW INDICATING TRANSMITTER
 FR FLOW RECORDER
 FS FLOW SWITCH
 FV FLOW VALVE

* INSTRUMENT ABBREVIATION

SHARED DISPLAY MONITORING OR CONTROL POINT ON THE INSTRUMENTATION DATA HIGHWAY AND AT THE SUBSURFACE OPERATION'S CONTROL CENTER LOCATED ON THE SURFACE.

FIELD MOUNTED INSTRUMENT

----- ELECTRIC SIGNAL

---o---o--- SYSTEM LINK (SOFTWARE)

INSTRUMENTATION SHOWN IS TYPICAL FOR EACH RAISE

FIGURE 6
 POSSIBLE ARRANGEMENT OF DRIFT INSTRUMENTATION AT EMPLACEMENT RAISE

Emplacement drift wall temperature (and hence air temperature) will be a maximum of 200° C (4.3.14), which sets the upper bound for expected operating conditions. The lower bound was set at 20° C as temperatures below this value should not have adverse affects on repository workers or equipment. A variety of temperature instrumentation with different scales can be chosen from numerous instrument manufacturers. A single temperature instrument can provide the range specified in Table 3. The instrument or instruments can be placed at any location in the exhaust main with no degradation in capability.

As discussed previously there are three possible locations for instrument placement, the following discussion will therefore be applicable to all options. The wide variations in flow to be measured mean that one instrument can not measure all values with a reasonable accuracy. There is an inverse relationship between measurement scale and accuracy- the wider the scale the less accurate a measurement can be obtained. Therefore, low flows of 0.3 m³/sec (expanded) require one type of quantity measurement and flows of 10-50 m³/sec (expanded) require another type of flow instrument.

The low flow quantity instrument for an emplacement drift could be located at the drift inlet or outlet. If located at the drift inlet, approximately 200 instruments would be needed. If located at the drift outlet only about 100 instruments would be needed (because 2 drifts connect to 1 raise where the instrument would be located). It is recommended the instrument be located in the raise as this halves the number of instruments required to measure flow and providing that all drifts need to be monitored. Locating the instrument in the raise would also allow an estimation of leakage around the emplacement drift doors. This leakage estimation would not be possible with a flow instrument located in the door.

Flow instruments for quantities of 10-50 m³/sec (expanded) could be located at the first emplacement drift or spaced at intervals along the tubes in the exhaust main. Since there will be two tubes, the emplacement drift air flow can be separated to allow greater control of air flow. For example, all low flow and monitoring ventilation air could go into one tube, while all air used for emplacement, backfill or retrieval could go into the other. This will allow separate measurements of relative humidity, temperature, flow, and gaseous radioactive emissions of both air streams. Low flow measurement would thus be an aggregate of all emplacement drifts. Total flow will be approximately 300 m³/sec (Attachment VI) compared to a maximum emplacement drift flow of 30 m³/sec (expanded) and therefore it is unnecessary to monitor each drift as their individual contribution is small.

Radiological instrumentation will be required for the repository during the preclosure period (4.3.7) in order to accomplish the following goals:

- Provide protection to workers by alerting them of potential hazardous radiation fields and of potential contamination release.
- Provide protection of the environment by limiting the spread of contamination beyond the

confines of the repository.

- Identification of the emplacement drift containing a leaking waste package.
- Maintain exposures to workers As Low As Reasonably Achievable (ALARA).

This design analysis will not attempt to provide a detailed analysis of the specific radiation detection instruments that will be required. These instruments will be discussed in another analysis. Rather, this analysis will develop a preliminary approach for locating radiation detection instruments in and about the emplacement drifts.

A combination of direct radiation detector and airborne radiation detector is proposed for the protection of personnel and for the determination of a potential leaking waste package. Direct radiation detection will likely be required in order to meet the first and fourth goals stated above. A combined radiation field consisting of both gamma and neutron components is expected at the entrance to each emplacement drift as a result of the waste packages in each drift (Ref. 5.24). The direct radiation field at the entrance to the emplacement drift turnoff is 0.8 mr/hr with the drift doors closed and 3.5 mr/hr with the doors open (Ref. 5.24). This is sufficiently close to the Radiation Area limit of 5.0 mr/hr (Ref. 5.25) to justify the need for a direct radiation monitor in order to provide for personnel protection. Since the majority of the field consists of gamma radiation (Ref. 5.24) the most likely type of detector to be used in this application will be a Geiger-Mueller type of instrument.

Fixed airborne radiation detectors will likely be required at the outlet of the emplacement drift in order to meet all four goals stated above. A leaking waste package may result in the release of radioactive particulates and gases (Ref. 5.26). These will be the source of alpha, beta, and gamma radiation with potential dose consequences from inhalation and from submersion in the case of radioactive gases. The off-line airborne radiation detectors will likely be used to detect radiation fields.

The closer the detector is to the leaking waste package the more likely is the probability of detection of radioactivity because of less dispersion in the air. For the layout under consideration (Figure 1) the emplacement drift raise is the closest point a detector could be located. Locating a detector in each raise would require about 100 instruments (one for each raise). If the detectors are located in the exhaust main tubes, two instruments would be required for each location (one per tube).

A group of instruments consisting of a radiation, flow, temperature and relative humidity detectors should be located in close proximity to each other to insure the maximum amount of information is derived from a set of readings. Instrument readings need to be taken together to insure correlation between the various instruments.

7.2.2 Monitoring of Drifts

Air in an emplacement drift will be $<200^{\circ}\text{C}$ (4.3.14) and low air flows of $0.1\text{ m}^3/\text{sec}$ may result in stratification of the air flow in the drift. The air flow will be laminar under these conditions as shown in Attachment III. Under stratification conditions, radioactive leakage from a waste package possibly would not travel far from the package and would thus pose a minimal risk to the environment. Instruments will continuously sample the low air flow to check for radiation leaks. Because of the low air flow conditions it may take a considerable time for the leak to register, if at all, on the instruments. It therefore seems prudent to periodically check the drifts to ensure that leaking waste packages are detected. These checks insure that a leak will not become a major problem because of inaction on the part of the repository staff.

A recent analysis (Ref. 5.13) indicated that waste packages would be tested (by a remote inspection gantry entering the drift) every ten years. It may be desirable to obtain this information more frequently. Assumption 4.3.7 does not mention how often testing is required. Assumption 4.3.10 says "Air... will be monitored as required for health, safety, and performance confirmation." but does not specify how often testing is required.

Drift monitoring schemes must address the overall requirement in Assumption 4.3.10 but exactly how to achieve this goal is not specified. A period of time of approximately one year is perhaps reasonable based on the number of emplacement drifts which contain waste packages (about 200 drifts). If one drift were checked per day this would equate to 200 days - which is approaching the number of working days in a year. A yearly cycle time would be appropriate as the nuclear industry conducts periodic tests at 6 month to 3 year intervals depending on the type of test conducted (Ref. 5.7).

There are two monitoring philosophies which can be used to test the emplacement drifts. The first uses the ventilation system to blow contamination to the detecting instrument. The second brings the instrument near the contamination for detection.

In the nuclear industry periodic sampling of buildings is conducted. Four air changes of the building volume are specified per hour (4.4.2) to ensure that ventilation air velocities are high enough to achieve adequate mixing of the air and that a good, representative sample of the air is collected. A similar policy could be instituted in emplacement drifts to ensure that air turbulence will disturb any air stratification in the drift. As per Attachment I, $15\text{ m}^3/\text{sec}$ of expanded air will be used to achieve the 4 changes per hour. The average air velocity in the drift will therefore be:

$$\begin{aligned} 15\text{ m}^3/\text{sec} / [(5.1\text{ m} \times 5.1\text{ m} \times \pi)/4] &= 0.73\text{ m/sec (144 ft/min)} \\ \text{Quantity/ Gross Area of Drift} &= \text{Velocity in Drift} \end{aligned}$$

A previous analysis (Ref. 5.16) indicated that the minimum air velocity to prevent stratification of the air was 0.508 m/sec (100 ft/min) and so layering of the air should not occur (see Attachment III).

Using the ventilation system to monitor for leaking waste packages may cause the contamination from the leak to become more widespread. During monitoring, emplacement drifts will be subjected to a 0.73 m/sec air velocity and this could cause radiation to be spread along the drift and possibly into other parts of the ventilation system. During low flow ventilation the air velocity will be slow:

$$0.1 \text{ m}^3/\text{sec} / [(5.1\text{m} \times 5.1\text{m} \times \pi)/4] = 0.0049 \text{ m/sec (average)}$$

(or 0.0073 m/sec after thermal effects have expanded the air)

and thus not be able to spread contamination far from its point of origin.

Another way to monitor the emplacement drifts is to use the remote inspection gantry to check for radiation leaks (4.3.4). A recent analysis (5.13) discusses the operating characteristics of such a gantry. The successful application of an inspection gantry to this type of radiation monitoring depends upon the specific operating parameters for the machine which are eventually developed. For example, the amount of insulation and internal cooling will determine the length of time per day a gantry can spend in the <200° C (4.3.14) environment in the emplacement drift. The amount of insulation and internal cooling will in turn determine the number of machines needed to check all active emplacement drifts. If one drift is checked per day then only one or two machines will be needed to maintain a yearly schedule of checking. More than one machine may be needed to insure that a gantry would always be available in the event of mechanical breakdowns or other inspection commitments on the machine.

The remote gantry could spread radiation because radioactive particles attach to its wheels but using the ventilation system to blow the radiation towards a monitor will cause radiation to be more widespread. Therefore, using a remote gantry to monitor radiation leaks is the preferred method. However, both drift inspection methods could be used.

7.3 Doors

As discussed in Section 7.1, the entrance to the emplacement drift from the perimeter main will be via a door. A typical emplacement drift ventilation door will open and close frequently while waste package emplacement is occurring. After emplacement the door will remain closed and will infrequently be opened. The exit from the emplacement drift raise to the exhaust main will be via an air ducting structure which will include valves and an access port. The following discussion will be mostly for the entrance door but will also apply to the exit structure. Desirable characteristics for doors include:

- Seal to prevent air leakage.
- Contain louvers/dampers to allow air flow (when needed).
- Provide some radiation protection.
- Control access to the emplacement drifts.
- Be instrumented to monitor air flow (exit only).
- Be resistant to different thermal loadings.
- Be designed for low maintenance.

Assumption 4.3.8 requires a low, controlled volume of air. One way to achieve this requirement is to have seals which prevent or restrict the amount of unwanted air leakage into the emplacement drift. For purposes of this analysis, continuous ventilation is calculated to be no more than 0.1 m³/sec (average) per drift (Attachment I). This quantity includes air due to leakage and air deliberately introduced by the louver/damper. Louvers/dampers are included in the door to allow air flow into the drift when needed.

Calculations for the door are shown in Attachment V. The proposed door is heavier/sturdier than necessary to provide for ventilation control and this is to insure that the door will provide some level of radiation protection (4.3.5). This report will not attempt to design a door to protect against radiation hazards. The proposed door is heavier than necessary to insure that it is on the conservative side of emplacement drift door design. Details of door radiation protection will be forthcoming in other analyses which will calculate the thickness of door required for radiation protection. However, door configurations proposed in this analysis will be consistent with the requirement to prevent radiation from escaping through gaps in the door or between the door and the door support frame (4.2.2).

Assumption 4.2.3 is specific as to requirements for control of access and a signal system for the doors. These requirements will not be reiterated.

There are no specific requirements to include instrumentation in the exit structure, this requirement can be derived from Assumptions 4.3.7 and 4.3.10. In order to insure that a continuous low flow less than or equal to 0.1 m³/sec is occurring, instrumentation for air flow is proposed (as already discussed in 7.2.1).

The emplacement drift walls will be <200°C (4.3.14) and the access mains will be a maximum of 27°C (4.3.11). As the door structure will be at the interface between these two temperature zones, differences in thermal loadings are anticipated.

A requirement for low door maintenance is inferred from Assumption 4.3.9. Low maintenance does not imply no maintenance and since the repository may operate from the start of emplacement operations through caretaker phase, maintenance will be required on many items (4.3.7 & 4.3.9). The most conservative philosophy regarding maintenance requires that it be possible for repairs to be made to any item in the repository.

This analysis will not discuss opening and closing mechanisms for the door. This discussion will be provided in another M&O analysis.

7.3.1 Material of Construction

The ventilation emplacement drift doors will be constructed of metal or concrete (4.3.3). Typical metals used on doors are aluminum and steel. Aluminum is usually used where its strength and light

weight outweigh its greater cost and is thus eliminated from further consideration.

A door made entirely of reinforced concrete might crack because of the different thermal expansion coefficients of the steel reinforcement and the concrete. The cracks could weaken this type of door structurally, but more importantly would be the probability of increased air leakage through the structure. A composite door with a steel exterior and a concrete filled interior would not suffer from these same concerns.

An all steel door will be composed of two plates which are joined together by steel spacers. The overall door thickness should be about 18 cm (Attachment V) to be structurally sound and provide an adequate distance to install the seal. A single leaf door would weigh approximately 5,000 kg (Attachment V) and a single leaf door would weigh half this amount per leaf. The interior of the door might be hollow or filled with an insulating material to decrease thermal effects. Another insulation possibility is to place a thermal barrier on the surface of the door inside the emplacement drift.

For purposes of this analysis a door made entirely of steel, with internal insulation is chosen. However, a steel/concrete composite door with exterior insulation would also be acceptable.

The emplacement drift exit structure will be constructed of steel. The structure may have to provide radiation protection (radiation protection will be covered in other analyses) and will need to withstand anticipated air pressures. Based on the information in Attachment V, the air pressure should be less than 34" water gauge (Attachment VI). Figure 3 shows a possible arrangement of this exit structure. The calculations presented in Attachment V show that the exit structure is heavier than required to provide ventilation control. This conservative design insures that when the radiation protection analysis is accomplished, the proposed exit door structure will still be acceptable.

Seals can be made from elastomer, plastic and metal materials. The high temperatures associated with the emplacement drifts preclude most of the elastomeric seals from being used. Elastomer materials also have less resistance to radiation than metal or plastic materials. Plastic materials (such as Teflon) and metal seals perform better at high temperatures. Metal seals can only be reused once to a few times because of their inelastic nature but they have a longer service life than plastic seals in 200°C temperature applications. Teflon seals are more appropriate to use where there are a limited number of sealing and resealing cycles as Teflon is inelastic but not as inelastic as metal seals. Teflon seals can be constructed with a spiral-wound metal structure to increase their elasticity (Ref. 5.14).

A seal made with a spiral-wound metal structure and covered by Teflon is recommended for the drift entrance door. Seals made of metal are acceptable for the outlet structure as it will not need to be opened and closed.

The door and frame will be placed at the interface between the short turn out drift and the beginning

of the emplacement drift (see Figure 1). The door and frame will be set in a bulkhead which will be made of concrete. Concrete is selected because it will form a seal against the rock and tend to fill cracks which might be in the rock. This should decrease leakage around the bulkhead.

7.3.2 Regulators

Regulators or louvers/dampers (called louvers hereafter) need to be able to control air flow and prevent radiation to escape from the emplacement drift.

The louver must control the flow of air during low flow conditions. Ideally the louver can be completely shut and not leak air. Thus the only air admitted to the drift would be through air leakage from the door seal or through the surrounding rock mass. A cover will be placed over the louver to completely cut-off air flow if air flows due to leakage are greater than 0.1 m³/sec to ensure that the louver does not leak unwanted air. As shown below in Table 4 the air flow is dependent not only on the size of the louver but also on the magnitude of the pressure which drives the air through the louver.

Table 4
Regulator Size in m² (ft²) Versus Different Pressures and Quantities

Driving Pressure kPa (in H ₂ O)	Quantity m ³ /sec (cfm)			
	0.1 (212)	1.0 (2119)	10.0 (21,189)	60.0 (127,132)
0.05 (0.201)	0.018 (0.189)	0.176 (1.891)	1.76 (18.91)	10.5 (113.4)
0.25 (1.00)	0.008 (0.085)	0.079 (0.848)	0.79 (8.48)	4.7 (50.9)
1.0 (4.02)	0.004 (0.042)	0.039 (0.423)	0.39 (4.23)	2.4 (25.36)

This table is derived using the formula for computing pressure losses through regulators found in Reference 5.11.

$$A = \frac{(40 \times Q)}{\sqrt{H}}$$

A= Area of Regulator (ft²)

Q= Quantity of Air (cfm/100,000)

H= Pressure Loss (in of water)

The closer the emplacement drift is to the fan the higher the pressure (Attachment VI). Since the air flow through the louver is low (0.1 m³/sec) during low flow conditions, the size of the louver can be small. Reference 5.12 indicates a 4' x 4' louver (1.49 m²) would have air leakage less than 0.03

m³/sec (4.1.8) at anticipated pressures in the emplacement drift.

A permanent installation of a 1.49 m² louver should be made. Provisions for installation of larger louvers in the door should be made (up to 5 m²). Modular louvers of 1 m² size could be inserted in the emplacement doors to provide air flows as needed. A provision should be made in the door to easily accept the insertion of these louvers. Blast cooling will be a relatively rare event so only a few sets of the larger louvers need be procured.

The 1.49 m² louver should be located in the door as opposed to being located in the door frame or off to one side of the emplacement drift entrance. Since the recommended size of the louver is small it more readily lends itself to being located in one location as opposed to being spread out along the frame. The air will stratify (Attachment III) in the drift and a central location of the louver will tend to ensure hot, stratified air is kept away from the door (air velocity will be highest near the door, as the air proceeds down the drift its velocity will slow to the average velocity in the drift of about 0.0073 m/s). The louver should be located near the bottom of the door in the center. This allows easy access for maintenance and eases insertion of additional louver sections should blast cooling be required.

The requirement to prevent escape of airborne radiation is partly satisfied by the pressure differential between the perimeter main and the emplacement drift. That is air always flows from the main to the drift. To prevent high energy radioactive particles from escaping, a baffle or plate will be installed on the drift side of the louver.

7.3.3 Emplacement Drift Entrance Door Arrangements and Seals

A maximum of 0.1 m³/sec air leakage is estimated through the emplacement drift doors. In order to achieve less than this value the gap between the door and frame must be minimized and a competent seal will need to be installed.

Table 5
Door Thermal Expansion

Material	Elongation in 4 m
Steel	0.90 cm*
Concrete	0.72 cm**

* 70°F to 400°F expansion = 2.7"/100ft (5.20)

** expansion = 5.5×10^{-6} in/in °F (5.19)

As shown in Table 5 above, expansion of materials will have a large effect on the door. If the gap between the door and its frame is large (to account for thermal effects), it may leak excessive

amounts of air. If the gap between the door and frame is small, the door may expand and stress the frame and become stuck. If door and frame are made of different materials they will expand different amounts. In addition the expansion of the frame could stress the surrounding rock mass.

Seals are generally an integral part of most doors. Small imperfections in the door and frame will cause gaps to form and thus allow air to flow through these gaps. In addition thermal expansion may cause existing gaps or imperfections to increase. A seal will assist in diminishing the flow of air through the door and frame. Pressure can be used to close the gap between the frame and door and to compress the seal to reduce air flow. However, this requires a constant axial pressure on the door. A portion of this axial pressure can come from ventilation air pressure. Gravity can also close the gap but would only affect the bottom of the door. If the door is hung correctly and is ridgedly constructed, it should not compress the seal due to gravity.

The thermal effects will be complicated if two swing doors as shown in Figure 7 are used as opposed to one large door as shown in Figure 8. The use of two doors increases the total length to be sealed as the seam between the doors must be sealed. If there is differential buckling, in which one door expands and twists away from the other, a gap could be created along the seam between the doors. Two doors will not require as great an area for their swing as one large door and this is an advantage in this regard.

A possible strategy to pursue to insure a minimal gap between the door and frame and to achieve a tight seal is to make the frame slightly larger than the door. As the door and frame expand due to the thermal load a tighter seal is achieved and thus air leakage between the perimeter main and the emplacement drift is greatly reduced. There are several problems with this strategy. Initially, until the door and frame expand, the seal may be poor. It may prove difficult to predict the temperature inside the emplacement drift and thus choose the correct initial gap between the door and frame. Finally, as the emplacement drift cools, the door seal should become poorer and air leakage increase. Manufacturing tolerances would be very tight on this type of door.

An expandable seal could be used to seal the gap between the door and frame. Elastomeric material would be ideal for this application but due to the high temperatures involved their service life would be short.

Another seal strategy to pursue is to make the door larger than the frame as shown in Figure 9. The seal would thus be formed when the door is closed against the frame. Use of a wide contact strip on the frame would insure an adequate seal as the door expands and contracts under different thermal loads. Radiation and thermal effects will be less in this seal than to ones directly exposed to these effects since the seal will be shielded by the frame.

If the door and frame are made wedged shaped, as shown in Figure 10, then the door and frame could expand and contract but not affect the seal. The door would not always close the same distance each time but it would achieve the same seal as the wedged shaped door would key into the

NOTE - DOOR OPENING AND
CLOSING MECHANISMS NOT
SHOWN FOR CLARITY

FACE OF DRIFT ELEVATION

FIGURE 7
EMPLACEMENT DRIFT
WITH TWO SWING DOORS

NOTE - DOOR OPENING AND
CLOSING MECHANISMS NOT
SHOWN FOR CLARITY

FACE OF DRIFT ELEVATION

FIGURE 8
EMPLACEMENT DRIFT
WITH ONE SWING DOOR

FIGURE 9
EMPLACEMENT DRIFT DOOR
WHICH CLOSSES AGAINST FRAME

FIGURE 10
EMPLACEMENT DRIFT DOOR
WEDGE SHAPED SEALING EDGES

wedged shaped frame. The emplacement drift side of the frame would be smaller than the perimeter main side. This will help to prevent the door from becoming stuck as it opens into the perimeter main. Manufacturing tolerances would be demanding to achieve similar wedge angles on both the door and frame.

Two doors in series could be used to decrease air leakage and reduce thermal effects. An inner door (closest to the waste packages) would provide thermal protection for the outer door. An outer door would prevent air leakage through the emplacement drift. The inner door could warp and not affect the air tightness of the system as the outer door would be shielded. Two doors in series would approximately double the costs as both would need to be substantial structures. This arrangement is not recommended for this reason.

If the door and frame are slightly tilted toward the emplacement drift then the force of gravity can be used to assist in achieving a good seal. A system of counter weights could assist in opening the door.

The emplacement drift doors should not be opened very often to allow access to the drift. Therefore, a high temperature sealant of some kind could be applied around the door to limit air leakage. The sealant would have to be replaced after each door opening but as the doors are infrequently opened after initial waste package placement, this is not an excessive operational problem.

Figures 7-10 imply that the door is located in the plain which separates the short turn out access drift from the emplacement drift. This is not necessarily a correct implication. The door and frame could be offset a short distance from this plain and towards the access main. This offset provides additional space for locating the louvers. If the door is in the plain separating the short turn out drift, space limitations require the louvers to be located in the door. If the door is offset, the frame surrounding the door becomes available for possible louver location. This analysis can not determine which door location is more advantageous.

Several different types of door have been discussed. This analysis will not determine which of these different types is superior to the others. However, one door scheme has been picked so that a door weight can be estimated and structural calculations performed. This analysis recommends one large door to enter the drift. The door will be constructed as shown in Figure 9. Figure 9 also shows latching mechanisms which keep pressure on the door to achieve a better seal and to prevent unauthorized access to the drift. The door, seal and louver should be tested for leakage as part of the turn over procedure prior to emplacement of waste packages. This test can be accomplished by closing the louver and opening the gate valve at the raise to provide a suction pressure on the door.

7.3.4 Emplacement Drift Outlet Structure

The emplacement drift outlet structure will be constructed of steel. Since the structure will be large (1.7 m diameter) and heavy (to withstand the anticipated air pressures) it will be fabricated in

sections. The seams between the sections can either be welded or sealed with a metal seal to prevent air leakage. Welded construction is preferred as it seals the seam completely which will prevent leakage and facilitate decontamination. There will be access ports for instruments and to admit workers and these port seams are recommended to be filled with a metal seal (see Figure 11). Appropriate signage will be made on the access door for entry into the radiation area in the raise (4.2.3)

Valves are recommended to be used to control air flow from the raise to the exhaust main tubes. A valve allows air from the raise to be completely shut off from the tubes if required or to be throttled to a low continuous flow. After initial waste package placement the valve can be closed, slowly, to its final position which allows $0.1 \text{ m}^3/\text{sec}$ to flow down the drift. Closing the valve slowly insures that the drift ventilation system can be monitored by operations personnel to prevent backflow of hot air towards the access mains. Gate valves are shown in Figure 11 and in other figures in this analysis but other type of valve could be chosen as well.

The thickness of the steel used in the outlet structure should be similar to the thickness used for the tubes in the exhaust main. Attachment V shows a tube thickness of 0.64 cm (0.25 in).

7.4 Drifts with no Waste Packages

Some drifts will not have waste packages and these drifts will receive the majority of the ventilation air (Attachment VI). Therefore, it is prudent to have a mechanism for controlling air flow through these drifts. Such a mechanism is shown in Figure 12. Figure 12 is basically an exit structure with a large louver at the bottom of the raise. As a minimum flow instrumentation, relative humidity and temperature detectors should be provided to ensure proper control of the flow. Radiation monitors could be provided in this louver, but their inclusion is the subject of another M&O analysis. The drift could be furnished with all items required for waste emplacement and with inlet and outlet structures in case the drift needed to be used rapidly to emplace waste from another drift. It is recommended that at least one of the drifts be furnished for immediate use.

The raise can be equipped with an access platform and door to allow inspection of the raise or to allow workers to use the raise as an escape route. Access to the platform could be via a removable ladder. The ladder could be stored on the side of the drift when not being used. Access from the platform to the drift could be via a ladder stored on the platform.

There should be a ladder inside the ventilation raise which will allow access between the emplacement drift and the exhaust main. This ladder will be equipped with all necessary safety equipment including intermediate platforms. A pole and lanyard system is suggested (versus a safety cage) as this will keep the ventilation raise relatively free of obstructions.

FIGURE 11
EMPLACEMENT DRIFT
OUTLET STRUCTURE

ELEVATION

PARTIAL PLAN

FIGURE 12
LOUVER FOR RAISE OUTLET W/O
WASTE PACKAGES IN EMPLACEMENT DRIFT

8. CONCLUSIONS

Recommendations pertaining to Section 7.1:

Inlet and outlet structures for the emplacement drift are needed. A door and louver combination is proposed for the drift entrance. An exit structure with air flow controlled by valves is proposed for the drift outlet.

Ventilation air from emplacement drifts should be discharged into tubes to ensure $<200^{\circ}\text{C}$ air does not restrict activities in the exhaust main. Radioactive particles or gas leaking from waste packages would also be contained in the tubes.

Two tubes are recommended to provide flexibility for the air control system. Total flow in the tubes will be about $100\text{ m}^3/\text{sec}$ (expanded) and this quantity will be sufficient for all ventilation situations discussed in this analysis.

A low continuous flow of $0.1\text{ m}^3/\text{sec}$ was proposed for each emplacement drift. Eight ventilation scenarios were discussed including off-normal conditions. The emplacement drifts can be maintained and continue to operate under all conditions covered in this analysis.

Recommendations pertaining to Section 7.2:

Two monitoring schemes were discussed. One used a detector mounted on a remote gantry to monitor for radioactive contamination. The other used the ventilation system to blow the radioactive contamination to a detector. Both schemes could be used but the remote gantry scheme limits the spread of contamination during its use.

The air parameters (relative humidity, temperature, and radioactivity) which are to be checked for are specified in the assumptions. Air quantity instrumentation is recommended for the exit from emplacement drifts to insure proper control of the entire emplacement side ventilation system and to allow evaluation of moisture removed from emplacement drifts.

Monitoring instruments located at each emplacement raise will meet all design assumptions. This is about 100 sets of instruments. Monitoring instruments could be placed at the top and bottom of the exhaust shaft but not as the primary detection location. The primary location should be nearer to the emplacement drifts to allow the maximum time for the control system to react. However, the length of time between radiation detection and finding which emplacement drift contains a leaking waste package has not been determined. A fewer number of instruments monitoring emplacement drift exhaust air from an aggregate of several drifts may be permissible depending on the time duration chosen.

A group of instruments consisting of a radiation detector, flow meter, relative humidity, and temperature indicators should be located in close proximity to each other to provide the maximum amount of information. Two types of flow instruments will need to be utilized because of the wide range of flows to be measured. The range of readings required from the temperature or relative humidity indicators can be provided by single instruments.

Recommendations pertaining to Section 7.3:

A single emplacement drift door similar to Figure 9 is recommended for the drift entrance. This type of door provides a better seal than entrances with two swing doors. The door should be equipped with a 1.49m² permanent louver and cut-outs for five 1m² louvers. Five louver inserts are recommended to provide a blast cooling capability for the emplacement drift. The permanent louver should be located near the bottom center of the door to allow maintenance access. Provisions should be made in the door for a closure plate which can slide over the permanent louver to cut off the flow of air through the louver.

The door should be constructed of a steel frame structure similar to the one shown in Attachment V. Insulation material should fill the hollow spaces of the door. An 18 cm thick door will weigh about 5,000 kg and could be supported by hinges. The seals for the door should be protected from heat and radiation by making the door larger than the frame (as shown in Figure 9). The seals should be Teflon covered, spiral-wound metal.

The emplacement drift outlet structure should be constructed as shown in Figure 11. Its construction material should be steel and metal seals should be used to prevent air leakage. Provisions for a man access port should be made in the structure. Two gate valves should be used in the structure to insure air flows are regulated. Gate valves are used in this analysis but other valves will also work in this application.

Recommendations pertaining to Section 7.4

A louver is recommended for all emplacement drifts which do not have waste packages. The raise for these drifts should be equipped with flow, relative humidity and temperature instrumentation. An access platform similar to the one shown in Figure 12 is recommended for inspection and to act as an escape route.

9. ATTACHMENTS

There are six (6) attachments to this document.

Attachment I:	Low Flow Calculation and Thermal Expansion Effects	(3 pages)
Attachment II:	Air Flow Versus Drift Temperature	(1 page)
Attachment III:	Reynolds Number Calculation	(2 pages)
Attachment IV:	Air Volume Calculation for 600m Drift	(1 page)
Attachment V:	Emplacement Drift Door and Outlet Calculation	(5 pages)
Attachment VI:	Computer Output for VNETPC Ventilation Program	(27 pages)

Attachment I
Low Flow Calculation and Thermal Expansion Effects

A low continuous flow in an emplacement drift accomplishes three things:

- Ensures proper direction of ventilation air flow.
- Removes moisture.
- Allow detection of waste package leaks.

As long as ventilation air is flowing down the drift, backflow of emplacement drift air can not occur. A low continuous flow towards the raise ensures backflow will not occur. The thermal expansion of the low flow air (and subsequent lowering of relative humidity) ensures that moisture will not build up in the emplacement drift. The low flow air will also carry radioactive gases and small particles to the radiation detector.

Flow detectors have been proposed for the raises to measure ventilation air quantity. The lower detection limit for this type of detector is 0.05 m/sec (10 SFPM - Standard Feet per Minute)(Ref. 5.9). A standard foot per minute is measured at 21.1° C and 1 atmosphere pressure (760 torr). The following table provides the appropriate pressure at the repository by interpolation between known pressures.

Table I-1
Barometric Pressure Difference Versus Altitude

Elevation (ft)	Elevation (m)	Pressure (psi)	Pressure (torr)**
3500*	1066.8	12.92	---
3608.9	1100+	12.87	665
4000*	1219.2	12.68	---

*Design Parameter 4.1.2

+Design Parameter 4.1.1

** Pressure (torr)= (Pressure (psi)/14.7) x 760

Adjusting for the maximum expected temperature in the drift (200 °C) (4.3.14) and the pressure at the repository (665 torr pressure) yields:

$$[760/665] \times [(273 + 200)/(273 + 21)] \times 10 = 18.4 \text{ FPM (0.093 m/sec)}$$

A velocity of 0.093 m/sec is equivalent to a quantity of 0.21 m³/sec $((1.7 \times 1.7 \times \pi/4) \times 0.093 = 0.21 \text{ m}^3/\text{sec})$ in the 1.7 m diameter raise (4.1.5). Remember that the quantity in the raise is the product of two drifts (one from the East Main and one From the West Main). The quantity of flow in each drift will therefore be about 0.1 m³/sec or 0.2 m³/sec at the raise.

The 0.1 m³/sec will expand due to thermal effects of the waste packages. The amount the air expands depends upon the residence time in the drift and temperature to which it is exposed as shown in Table I-2.

Table I-2
Air Expansion Versus Temperature

Temperature °C	Volume m ³ *	Expansion
27	1	----
50	1.077	108%
100	1.243	124%
150	1.410	141%
200	1.576	158%

$$\frac{P_1 V_1}{T_1} = \frac{P_2 V_2}{T_2} \quad (\text{Ref.5.5})$$

Since the pressure is constant, P₁ and P₂ are equal and this equation can be rearranged to:

$$V_2 = \frac{T_2 V_1}{T_1}$$

T= Temperature °K (0° C = 273.15° K)

P= Pressure

V= Volume (m³)

Since air velocity in the drift will be low, air residence time in the drift will be high and the air will expand fully. An average thermal expansion of 150% is proposed for the low continuous flow of air through an emplacement drift (i.e. 0.1 m³/sec flow).

The 0.1 m³/sec will expand to 0.15 m³/sec prior to entering the raise. Since two drifts combine at the raise they will produce a raise velocity of:

$$(0.15 + 0.15) / [(1.7 \times 1.7 \times \pi) / 4] = 0.13 \text{ m/sec}$$

Which is within the detection range (0.093 m/sec under the conditions stated above) of the flow instrument. With no thermal expansion the velocity is just barely sufficient to register on the instrument.

A quantity of 0.1 m³/sec flowing in a typical drift with a volume of 12,200 m³ (Attachment IV) will, theoretically, take $12200 / 0.1 = 122,000$ seconds or 33.9 hours to make one air change. As the air in the drift will stratify, the time to completely change the air in the drift will be more. With a quantity of 14 m³/sec a drift of 12,200 m³ volume will take $12200 / 14 = 871$ seconds or about 15 minutes to completely change the air.

The short residence time in the drift at a flow of 14 m³/sec will produce a thermal expansion than the 150% used for a flow of 0.1 m³/sec. An exact solution to this thermal expansion problem would require extensive calculations which are outside the scope of this analysis. An approximation of the thermal expansion can be made by using Figure 9.3-6 in Reference 5.10 (4.1.9). A 600 m drift will have an air temperature of 46° C at a flow of 10 m³/sec one year after emplacement. Using Table I-1, a temperature of 50° C will produce a thermal expansion of 8%. Since 46° C and 50° C plus 10 m³/sec and 14 m³/sec are similar numbers, an 8% thermal expansion is proposed.

The flow of 14 m³/sec will therefore expand to about 15 m³/sec after thermal effects are taken into account.

Attachment II
Air Flow Versus Drift Temperature

Reference 5.10 discusses the effect of different air flows on drift temperature. The drift temperature is a function of drift spacing, waste package spacing and waste package contents. The air temperature in the drift is affected by drift temperature, air velocity and moisture content.

Figure 9.3-6 (Ref. 5.10) shows a drift air temperature of 46° C for a 600m drift length and a 10 m³/sec airflow (4.1.9). An airflow of approximately 10 m³/sec is chosen as the minimum quantity required to keep the drift temperature below 50° C.

Figure 9.4-1 indicates a quantity of 100 m³/sec (expanded) will cool a 600m drift to 43° C in 5 weeks. Figure 9.4-2 indicates a quantity of 30 m³/sec (expanded) will cool a 600m drift to 63° C in 5 weeks (4.1.9). Using this information the following table was developed.

Table II-1
Airflow Versus Temperature Expected After 5 Weeks of Cooling

Quantity m ³ /sec	Temperature °K	Temperature °C
100	316	43
90	319	46
70	325	52
50	330	57
30	336	63

Table II-1 is based on a straight line interpolation between 100 m³/sec and 30 m³/sec and their associated temperatures. This table is based upon an initial rock temperature of 170° C and therefore is not a bounding case. However, the conclusions shown below and drawn from this table would still apply at 200° C (4.3.14).

The quantity available to cool the drift is 50 m³/sec (4.3.17) and the desired temperature is 50° C or less (4.3.12). Therefore, 1) precooling of the ventilation air prior to entering the drift is required or 2) an increase in quantity is needed to cool the drift to 50° C or less. The increased quantity could be achieved by using both tubes instead of just one.

Attachment III
Reynolds Number Calculation

Flow detectors have been proposed for the raises to measure the ventilation quantity. If the ventilation system is used to monitor the drifts for radiation leaks a quantity of 10 m³/sec is proposed. The Reynolds number is a measure of laminar or turbulent flow. The following tables determine laminar or turbulent flow under different flow and temperature conditions.

Table III-1
Reynolds Number Under Different Flow Conditions (50° C)

Flow m ³ /sec	Velocity*m/sec	N _{RE} ⁺
0.1	0.0049	1396
0.15(expanded)	0.0073	2080
10.0	0.489	139,460
15.0 (expanded)	0.734	209,190

* Velocity = (Flow/Area) = Q/20.43 Air velocity taken in the volume between adjacent waste packages where the air speed will be slowest.

+ N_{RE} = DV/v (Ref. 5.15)

D= Diameter of Emplacement Drift (5.5m - 0.2m - 0.2m = 5.1m) (4.1.4)

V= Velocity m/sec

v= Kinematic Viscosity (1.79 x 10⁻⁵ m²/sec @ 50° C) ((4.1.3)

Table III-2
Reynolds Number Under Different Flow Conditions (150° C)

Flow m ³ /sec	Velocity m/sec	N _{RE} ⁺
0.1	0.0049	877
0.15	0.0073	1306
10.0	0.489	87,590
15.0	0.734	131,386

+ ν = Kinematic Viscosity ($2.85 \times 10^{-5} \text{ m}^2/\text{sec}$ @ 150°C) (4.1.3) and using the same formula as above.

According to Reference 5.15, flows with a Reynolds number below 2000 are considered laminar while those with a Reynolds number above 4000 are considered turbulent.

Comparing Tables III-1 and III-2, flows at $0.15 \text{ m}^3/\text{sec}$, or less, will always be laminar at temperatures above 150°C and therefore it is unnecessary to calculate a Reynolds number for a 200°C condition. The Reynolds number for temperatures below 50°C are not important to this analysis.

Attachment IV
Air Volume Calculation for 600m Drift

Design Parameter 4.1.4 indicates that the average emplacement drift will be 5.5m in diameter and have a lining of 0.2m. This yields a drift diameter of 5.1m (5.5-0.2-0.2). A drift length of 600m is selected as representative of one of the longest drift lengths (4.1.6). The volume for the waste packages or waste package pedestals is not included to make the answer more conservative.

The air volume in this drift is calculated as follows:

<u>Item</u>	<u>Volume m³</u>
Volume of air in empty drift= $(5.1\text{m} \times 5.1\text{m} \times \pi)/4 \times 600\text{m}$ = $20.43 \text{ m}^3/\text{m} \times 600\text{m}$	12,256.9
Less Misc. Items (light, pipes, etc.)	<56.9>

Total	12,200

Four air changes per hour equal a flow of 48,800 m³/hour (4 x 12,200 m³) or 13.5 m³/sec [48,800 m³/(60 x 60)]. The 13.5 m³/sec is rounded up to 14 m³/sec to account for variations in drift diameter.

Attachment V
Emplacement Drift Door and Outlet Calculations

Emplacement Drift Door - General Arrangement

Elevation

End View

Section AA

Emplacement Drift Door - Structural Frame

Elevation

END VIEW

CHECKED DATE: _____

Emplacement Drift Door (Continued)

Dead Load (DL)

$$\frac{1}{2}" \text{ Plate (2ea): } 13.12' (14.76') (20.4 \text{ psf}) (2) = 7901 \text{ lb}$$

$$\begin{aligned} \text{C6x13: } & 2 @ 14.76' = 29.52' \\ & 7 @ [13.12' - \frac{(2.125' \cdot 2)}{12 \text{ in/ft}} = 0.35'] = 89.39' \\ & 2 @ 4.0' = 8.0' \\ & 3 @ (0.9' \cdot 3.28' - 0.35') = 7.81' \\ & 10 @ (3.28') = 32.8' \\ & 6 @ (1.5' \cdot 3.28' - 0.35') = 27.42' \end{aligned}$$

$$\text{Pieces} = 30$$

$$\frac{794.94 (3)}{3} = 2534$$

$$\text{Insulation: } [13.12' (14.76') - 5 (3.28')^2 - (1.22' \cdot 1.22' \cdot 10.76' \text{ in}^2)] 0.5' (7.5 \text{ psf}) =$$

$$[193.65 \text{ ft}^2 - 53.8 \text{ ft}^2 - 16.02 \text{ ft}^2] 3.75 \text{ psf} = 464$$

$$\text{Total DL} = 10899 \text{ lb}$$

Generally weight of covers is exceed by weight of cover plate over the openings, therefore the door weight is based on full coverage by the $\frac{1}{2}"$ plate on both sides.

Ventilation Pressure (P): (Ref. 5.9)

$$P = 1.0 \text{ KPa} = 0.14 \text{ PSI} = 20.88 \text{ psf}$$

This pressure loading will have no impact on the door structure.

Emplacement Drift Door (Continued)

Analysis of door structural section:

Disregard frame and use the two $\frac{1}{2}$ " plates carrying the DL. Analyze the plates as a cantilevered beam with a uniformly distributed load. (AISC, p. 2-302)

$$M_{max} = \frac{wL^2}{2} \quad w = \frac{10899 \text{ P}}{13.12 \text{ ft}} = 630.7 \text{ P/ft} \quad \text{Use } \underline{631 \text{ P/ft}}$$

$$L = 13.12 \text{ ft}$$
$$M_{max} = \frac{631 \text{ P/ft} (13.12 \text{ ft})^2}{2} = 71522 \text{ P-ft}$$

Allowable plate stress: Consider door as a beam with a compact section.

$$F_b = 0.66 F_y \quad (\text{AISC, F1-1, 4.4.3})$$

$$\text{Use } F_y = 36000 \text{ P/si} \quad (\text{ASTM A36 Steel, 4.4.4})$$

$$F_b = 23760 \text{ P/si}$$

$$\text{Required } S_r = \frac{71522 \text{ P-ft} (12 \text{ in/ft})}{23760 \text{ P/si}} = 36.12 \text{ in}^3$$

$$\text{Available } S_a = \frac{bd^2}{6} \quad (\text{AISC, p. 6-17})$$

$$b = 0.5 \text{ in } (\frac{1}{2} \text{ plate})$$

$$d = 24 \text{ in } (2 \text{ } 12 \text{ in hinge anchorages on one side of door})$$

$$S_a = \frac{0.5 \text{ in} (24 \text{ in})^2}{6} = 48 \text{ in}^3 > 36.12 \text{ in}^3$$

As a minimum use 2-12" hinges anchored to exterior $\frac{1}{2}$ " plate.

Ventilation Duct

Determine wall thickness for 72" duct with external pressure of 75" water gage (wg):

Wall Thickness, $t = D \left(\frac{6p}{E} \right)^{1/3}$ in inches
(Ref. 5.19, p. 21-36)

D = diameter of pipe in feet = $\frac{72"}{12"} = 6'$

E = modulus of elasticity in psi
= 29×10^6 psi

p = uniform external pressure in psf
= 75" wg (5.2 psf/in) = 390 psf

$$t = 6' \left(\frac{6 \times 390}{29 \times 10^6} \right)^{1/3} = 0.259"$$

If a wall thickness of 0.25" is used determine allowable p_a :

$$p_a = \frac{E \left(\frac{t}{D} \right)^3}{6} \quad \text{with above values}$$

$$D = 6' \text{ \& } t = 0.25"$$

$$p_a = \frac{29 \times 10^6 \left(\frac{0.25}{6} \right)^3}{6} = 349.63 \text{ psf} = 67.2" \text{ wg}$$

Determine wall thickness for 84" (7') duct with $p = 390 \text{ psf}$: $t = 0.302"$

Determine allowable p_a for $D = 7'$ & $t = 0.25"$:
 $p_a = 299.68 \text{ psf} = 57.6" \text{ wg}$

(Ref. 5.19) Standard Handbook for Civil Engineers,
Merritt, F., McGraw-Hill, 1968.

Attachment VI
Computer Output for VNETPC Ventilation Program

This attachment uses information from Design Parameter 4.1.7 and Assumptions 4.3.15, 4.3.16, 4.3.17 and 4.3.18 along with the VNETPC Program to calculate values for the ventilation air quantities and pressures. The VNETPC Program is a self-contained package of commercially available software generally used by the mining industry for mine ventilation modeling. When given the input data that describes the geometry of the mine layout (4.1.7 and the attached figure), airway resistances (4.3.15, 4.3.16 & 4.3.17) or dimensions (4.3.18), and the locations and characteristic curves of fans, the program will produce tabulated listings and graphical plots of the network undergoing analysis. Reference 5.23 provides greater detail of this program.

The attached computer output pages are detailed below

Pages VI-2 thru VI-5 are a tabulation of Lotus 1-2-3 input used for the program. These pages show the dimensions and airway resistance.

Pages VI-6 thru VI-15 are the VNETPC output for the repository at an early stage of construction. Page VI-15 is a simple drawing of the repository at this stage with some of the mains, drifts and shafts noted.

Pages VI-16 thru VI-26 are the VNETPC output for the repository at a late stage of emplacement. Page VI-25 shows the pressures in the repository in inches of water gauge. Note that branch 403-603 shows a pressure of 34" of water gauge. This same pressure was used in Attachment V. Page VI-24 shows the volume of air flowing through the repository. Branch 6-702 shows a volume of 676,000 cfm or 319 m³/sec. This value was rounded to 300 m³/sec in the analysis. In the context that the 300 m³/sec value was used in the analysis, it is a conservative number. Page VI-24 also shows the pressures in the emplacement drifts. These pressures range from a high of 4.8" of water gauge (1.2 kPa) in branch 203-303 to a low of 0.2" of water gauge (0.04 kPa) in branch 212-312. These values assisted in the construction of Table 4 in the analysis. Page VI-24 shows the amount of air flowing in the tubes in the exhaust main. When branches 512-595 and 612-695 are added together (91,200 cfm + 123,100 cfm = 214,300) or about 101 m³/sec. This justifies the Design Parameter 4.1.9.

Page VI-27 is a representation of the repository.

Maximum potential power demand during worse case scenario in repository operation and casetaker.

Line No.	BRANCH		RESISTANCE in PU VNETPC INPUT	REGULATOR RESISTANCE in PU (Field Installed)	RESISTANCE in PU From R	AIRWAY RESISTANCE R = KPL(3.2A^3) in min^2/R^6	FRICTION FACTOR K (x10^-10)	CROSS AREA A (Ft)	PERIMETER P (Ft)	ACTUAL LENGTH meter (m)	ACTUAL LENGTH L' (Ft)	EQUIV. LENGTH L=L'+10% (Ft)	NOTES FOR BRANCH DESCRIPTION	LINE NO.
1	1	2	0.0053		0.0053	0.0533	30	395.1000	72.2600	2187	7175	7893	North Ramp	1
2	2	101	0.0014		0.0014	0.0142	30	395.1000	72.2600	582	1911	2102	North Ramp Ext. (1)	2
3	101	102	0.0023		0.0023	0.0234	30	395.1000	72.2600	961	3152	3467	North Ramp Ext. (2)	3
4	102	103	0.0035		0.0035	0.0348	60	395.1000	72.2600	713	2338	2572	East Main Drift, empl drift 1 to 5 + drift connection	4
5	103	115	0.0017		0.0017	0.0170	60	395.1000	72.2600	348	1141	1256	East Main Drift, empl drift 6 to 25	5
6	115	135	0.0028		0.0028	0.0283	60	395.1000	72.2600	580	1902	2092	East Main Drift, empl drift 26 to 45	6
7	2	135	0.0017		0.0017	0.0166	30	395.1000	72.2600	681	2235	2458	North Ramp curve to East Main	7
8	135	155	0.0028		0.0028	0.0283	60	395.1000	72.2600	580	1902	2092	East Main Drift, empl drift 46 to 65	8
9	155	175	0.0028		0.0028	0.0283	60	395.1000	72.2600	580	1902	2092	East Main Drift, empl drift 66 to 85	9
10	175	195	0.0028		0.0028	0.0283	60	395.1000	72.2600	580	1902	2092	East Main Drift, empl drift 86 to 104	10
11	195	112	0.0024		0.0024	0.0240	60	395.1000	72.2600	493	1617	1778	East Main Drift, empl drift 105 to 120	11
12	112	198	0.0041		0.0041	0.0408	60	395.1000	72.2600	835	2740	3015	East Main Drift, south end	12
13	198	199	0.0024		0.0024	0.0239	60	395.1000	72.2600	490	1607	1767	East Main Drift curve to South Ramp	13
14	199	100	0.0087		0.0087	0.0865	70	389.1000	72.2600	1452	4763	5239	South Ramp	14
15	102	700	0.0009		0.0009	0.0088	30	395.1000	72.2600	362	1186	1305	North Main - East loop	15
16	700	200	0.0015		0.0015	0.0154	30	395.1000	72.2600	632	2075	2282	North Main - West loop	16
17	200	203	0.0007		0.0007	0.0073	60	395.1000	72.2600	150	492	541	West Main Drift, empl drift 1 to 5	17
18	203	215	0.0017		0.0017	0.0170	60	395.1000	72.2600	348	1141	1256	West Main Drift, empl drift 6 to 25	18
19	215	235	0.0028		0.0028	0.0280	60	395.1000	72.2600	573	1881	2069	West Main Drift, empl drift 26 to 45	19
20	235	255	0.0028		0.0028	0.0277	60	395.1000	72.2600	567	1862	2048	West Main Drift, empl drift 46 to 65	20
21	275	255	0.0028		0.0028	0.0279	60	395.1000	72.2600	572	1877	2065	West Main Drift, empl drift 66 to 85	21
22	295	275	0.0028		0.0028	0.0283	60	395.1000	72.2600	581	1906	2096	West Main Drift, empl drift 86 to 104	22
23	212	295	0.0026		0.0026	0.0260	60	395.1000	72.2600	533	1749	1924	West Main Drift, empl drift 105 to 120	23
24	298	212	0.0061		0.0061	0.0610	60	395.1000	72.2600	1250	4101	4512	West Main Drift, empl drift 120 to Dev. Shah	24
25	298	299	0.0010		0.0010	0.0098	60	395.1000	72.2600	200	656	722	West Main Drift, south end	25
26	299	799	0.0010		0.0010	0.0099	60	395.1000	72.2600	202	663	729	West Main Drift curve to South Ramp Ext/Exh Main	26
27	799	199	0.0043		0.0043	0.0431	60	395.1000	72.2600	884	2900	3190	South Ramp Ext	27
28	103	303	0.0156		0.0156	0.1555	85	219.8900	52.5700	533	1749	1924	Emplacement Drifts, empl drift 1 to 5	28
29	115	315	0.0156		0.0156	0.1555	85	219.8900	52.5700	533	1749	1924	Emplacement Drifts, empl drift 6 to 25	29
30	135	335	0.0164		0.0164	0.1639	85	219.8900	52.5700	562	1843	2028	Emplacement Drifts, empl drift 26 to 45	30
31	155	355	0.0178		0.0178	0.1779	85	219.8900	52.5700	610	2001	2201	Emplacement Drifts, empl drift 46 to 65	31
32	175	375	0.0183		0.0183	0.1826	85	219.8900	52.5700	626	2054	2259	Emplacement Drifts, empl drift 66 to 85	32
33	195	395	0.0183		0.0183	0.1836	85	219.8900	52.5700	629	2063	2270	Emplacement Drifts, empl drift 86 to 104	33
34	112	312	0.0167		0.0167	0.1671	85	219.8900	52.5700	573	1879	2067	Emplacement Drifts, empl drift 105 to 120	34
35	203	303	0.0156		0.0156	0.1555	85	219.8900	52.5700	533	1749	1924	Emplacement Drifts, empl drift 1 to 5	35
36	215	315	0.0156		0.0156	0.1555	85	219.8900	52.5700	533	1749	1924	Emplacement Drifts, empl drift 6 to 25	36
37	235	335	0.0164		0.0164	0.1639	85	219.8900	52.5700	562	1843	2028	Emplacement Drifts, empl drift 26 to 45	37
38	255	355	0.0178		0.0178	0.1779	85	219.8900	52.5700	610	2001	2201	Emplacement Drifts, empl drift 46 to 65	38
39	275	375	0.0183		0.0183	0.1826	85	219.8900	52.5700	626	2054	2259	Emplacement Drifts, empl drift 66 to 85	39
40	295	395	0.0183		0.0183	0.1835	85	219.8900	52.5700	629	2063	2270	Emplacement Drifts, empl drift 86 to 104	40

FILE # Repva0A, VNETPC INPUT, Viability Assessment Report

Maximum potential power demand during worst case scenario in repository construction or retrieval.

LINE NO.	BRANCH	From	To	RESISTANCE VNETPC INPUT	RESISTANCE REGULATOR IN PU	RESISTANCE IN PU From R	AIRWAY RESISTANCE KPL43 2A-73 in mil-2A-73	FRICTION FACTOR K (10 ⁻⁴ lb)	CROSS AREA A (ft ²)	PERMITTER P (ft)	ACTUAL LENGTH L (ft)	ACTUAL LENGTH L (ft)	RELEV. LENGTH L-L*10%	NOTES FOR BRANCH DESCRIPTION	LINE NO.
41		212	312	0.0167	0.0167	0.0167	0.1671	85	219.8900	52.5700	1879	573	2067	Emplacement Drifts, empl drift 105 to 120	41
42		303	403	0.0167	0.0167	0.0167	0.1668	20	24.4300	17.5200	10	33	36	Raises, empl drift 1 to 5	42
43		315	415	0.0167	0.0167	0.0167	0.1668	20	24.4300	17.5200	10	33	36	Raises, empl drift 6 to 25	43
44		335	435	0.0167	0.0167	0.0167	0.1668	20	24.4300	17.5200	10	33	36	Raises, empl drift 26 to 45	44
45		355	455	0.0167	0.0167	0.0167	0.1668	20	24.4300	17.5200	10	33	36	Raises, empl drift 46 to 65	45
46		375	475	0.0167	0.0167	0.0167	0.1668	20	24.4300	17.5200	10	33	36	Raises, empl drift 66 to 85	46
47		395	495	0.0167	0.0167	0.0167	0.1668	20	24.4300	17.5200	10	33	36	Raises, empl drift 86 to 104	47
48		412	512	0.0167	0.0167	0.0167	0.1668	20	24.4300	17.5200	10	33	36	Raises, empl drift 105 to 120	48
49		403	703	0.0050	0.0050	0.0050	0.0500	20	24.4300	17.5200	3	10	11	Raise Door to Exhaust Main, empl drift 1 to 5	49
50		415	715	0.0050	0.0050	0.0050	0.0500	20	24.4300	17.5200	3	10	11	Raise Door to Exhaust Main, empl drift 6 to 25	50
51		435	735	0.0050	0.0050	0.0050	0.0500	20	24.4300	17.5200	3	10	11	Raise Door to Exhaust Main, empl drift 26 to 45	51
52		455	755	0.0050	0.0050	0.0050	0.0500	20	24.4300	17.5200	3	10	11	Raise Door to Exhaust Main, empl drift 46 to 65	52
53		475	775	0.0050	0.0050	0.0050	0.0500	20	24.4300	17.5200	3	10	11	Raise Door to Exhaust Main, empl drift 66 to 85	53
54		495	795	0.0050	0.0050	0.0050	0.0500	20	24.4300	17.5200	3	10	11	Raise Door to Exhaust Main, empl drift 86 to 104	54
55		412	712	0.0050	0.0050	0.0050	0.0500	20	24.4300	17.5200	3	10	11	Raise Door to Exhaust Main, empl drift 105 to 120	55
56		403	503	0.0214	0.0214	0.0214	2.1412	11	4.2800	7.3300	3	10	11	Gate valve, raise to Duct 1, empl drift 1 to 5	56
57		403	603	0.0214	0.0214	0.0214	2.1412	11	4.2800	7.3300	3	10	11	Gate valve, raise to Duct 2, empl drift 1 to 5	57
58		415	515	0.0214	0.0214	0.0214	2.1412	11	4.2800	7.3300	3	10	11	Gate valve, raise to Duct 1, empl drift 6 to 25	58
59		415	615	0.0214	0.0214	0.0214	2.1412	11	4.2800	7.3300	3	10	11	Gate valve, raise to Duct 2, empl drift 6 to 25	59
60		435	535	0.0214	0.0214	0.0214	2.1412	11	4.2800	7.3300	3	10	11	Gate valve, raise to Duct 1, empl drift 26 to 45	60
61		435	635	0.0214	0.0214	0.0214	2.1412	11	4.2800	7.3300	3	10	11	Gate valve, raise to Duct 2, empl drift 26 to 45	61
62		455	555	0.0214	0.0214	0.0214	2.1412	11	4.2800	7.3300	3	10	11	Gate valve, raise to Duct 1, empl drift 46 to 65	62
63		455	655	0.0214	0.0214	0.0214	2.1412	11	4.2800	7.3300	3	10	11	Gate valve, raise to Duct 2, empl drift 46 to 65	63
64		475	575	0.0214	0.0214	0.0214	2.1412	11	4.2800	7.3300	3	10	11	Gate valve, raise to Duct 1, empl drift 66 to 85	64
65		475	675	0.0214	0.0214	0.0214	2.1412	11	4.2800	7.3300	3	10	11	Gate valve, raise to Duct 2, empl drift 66 to 85	65
66		495	595	0.0214	0.0214	0.0214	2.1412	11	4.2800	7.3300	3	10	11	Gate valve, raise to Duct 1, empl drift 86 to 104	66
67		495	695	0.0214	0.0214	0.0214	2.1412	11	4.2800	7.3300	3	10	11	Gate valve, raise to Duct 2, empl drift 86 to 104	67
68		412	512	0.0214	0.0214	0.0214	2.1412	11	4.2800	7.3300	3	10	11	Gate valve, raise to Duct 1, empl drift 105 to 120	68
69		412	612	0.0214	0.0214	0.0214	2.1412	11	4.2800	7.3300	3	10	11	Gate valve, raise to Duct 2, empl drift 105 to 120	69
70		512	612	0.0214	0.0214	0.0214	2.1412	11	4.2800	7.3300	3	10	11	Duct 1 from Emplacement Drift 105 to 120	70
71		512	595	0.3248	0.3248	0.3248	3.2484	11	28.2700	18.8500	580	184	184	Duct 1 from Emplacement Drift 66 to 104	71
72		512	575	0.3694	0.3694	0.3694	3.6943	11	28.2700	18.8500	576	2093	2093	Duct 1 from Emplacement Drift 65 to 85	72
73		512	555	0.3694	0.3694	0.3694	3.6943	11	28.2700	18.8500	576	1870	2057	Duct 1 from Emplacement Drift 46 to 65	73
74		512	535	0.3631	0.3631	0.3631	3.6306	11	28.2700	18.8500	574	1885	2073	Duct 1 from Emplacement Drift 26 to 45	74
75		512	515	0.3659	0.3659	0.3659	3.6586	11	28.2700	18.8500	574	1142	1256	Duct 1 from Emplacement Drift 6 to 25	75
76		503	501	0.2217	0.2217	0.2217	2.2168	11	28.2700	18.8500	470	1542	1696	Duct 1 from Emplacement Drift 1 to 5 + length to shaft	76
77		501	500	0.2994	0.2994	0.2994	2.9936	11	28.2700	18.8500	60	197	217	Centrifugal Fan 1	77
78		500	500	0.0003	0.0003	0.0003	0.0034	60	387.5008	78.7402	60	197	217	Drift connection 6x6 - Duct 1 discharge to Empl Shaft	78
79		500	600	0.0003	0.0003	0.0003	0.0034	60	387.5008	78.7402	60	197	217	Drift connection 6x6 - Duct 2 discharge to Empl Shaft	79
80		600	695	0.3248	0.3248	0.3248	3.2484	11	28.2700	18.8500	580	184	184	Duct 2 from Emplacement Drift 105 to 120	80
		695	675	0.3694	0.3694	0.3694	3.6943	11	28.2700	18.8500	580	2093	2093	Duct 2 from Emplacement Drift 66 to 104	80

FILE # Repva0A, VNETPC INPUT, Viability Assessment Report

Maximum potential power demand during worst case scenario in repository construction or retrieval.

Line No.	BRANCH	RESISTANCE in PU VNETPC INPUT	REGULATOR RESISTANCE in PU (field installed)	RESISTANCE in PU From R	AIRWAY RESISTANCE R = KPL(3.2A ²)	FUNCTION FACTOR K (10 ⁻⁴ to 10)	CROSS AREA A (ft ²)	PERIMETER P (ft)	ACTUAL LENGTH L' (ft)	ACTUAL LENGTH L (ft)	PNV LENGTH L-L' 10% (ft)	NOTES FOR BRANCH DESCRIPTION	LINE NO.
81	From 675 To 655	0.3669	0.3669	0.3669	3.6688	11	28.2700	18.8500	576	1890	2079	Duct 2 from Emplacement Drift 65 to 85	81
82	655	0.3631	0.3631	0.3631	3.6306	11	28.2700	18.8500	570	1870	2057	Duct 2 from Emplacement Drift 46 to 65	82
83	635	0.3659	0.3659	0.3659	3.6586	11	28.2700	18.8500	574	1885	2073	Duct 2 from Emplacement Drift 26 to 45	83
84	615	0.2217	0.2217	0.2217	2.2166	11	28.2700	18.8500	348	1142	1256	Duct 2 from Emplacement Drift 6 to 25	84
85	601	0.2739	0.2739	0.2739	2.7389	11	28.2700	18.8500	430	1411	1552	Duct 2 from Emplacement Drift 1 to 5 + length to shaft	85
86	601	0.2739	0.2739	0.2739	2.7389	11	28.2700	18.8500	60	197	217	Centrifugal Fan 2	86
87	600	0.0382	0.0382	0.0382	0.3822	60	387.5008	78.7402	30	98	108	Drift connection for duct 1 & 2 discharge to Shaft, 6x8	87
88	702	0.0002	0.0002	0.0002	0.0017	70	318.1400	72.2600	1322	4337	4771	Exhaust Main, South Ramp Ext to Empl Drift	88
89	712	0.0144	0.0144	0.0144	0.1441	70	318.1400	72.2600	510	1873	1841	Exhaust Main from Emplacement Drift 105 to 120	89
90	712	0.0056	0.0056	0.0056	0.0556	70	318.1400	72.2600	580	1803	2093	Exhaust Main from Emplacement Drift 86 to 104	90
91	775	0.0063	0.0063	0.0063	0.0632	70	318.1400	72.2600	576	1890	2076	Exhaust Main from Emplacement Drift 65 to 85	91
92	755	0.0062	0.0062	0.0062	0.0621	70	318.1400	72.2600	570	1870	2057	Exhaust Main from Emplacement Drift 46 to 65	92
93	735	0.0063	0.0063	0.0063	0.0626	70	318.1400	72.2600	574	1885	2073	Exhaust Main from Emplacement Drift 26 to 45	93
94	703	0.0038	0.0038	0.0038	0.0379	70	318.1400	72.2600	348	1142	1256	Exhaust Main from Emplacement Drift 6 to 25	94
95	703	0.0047	0.0047	0.0047	0.0469	70	318.1400	72.2600	430	1411	1552	Exhaust Main from Emplacement Drift 1 to 5	95
96	700	0.0015	0.0015	0.0015	0.0150	70	318.1400	72.2600	138	453	488	Exhaust Main Aftlock to North Main	96
97	701	0.0002	0.0002	0.0002	0.0018	70	527.4316	91.8635	58	190	209	Exhaust Main connection to Emplacement Shaft, 7x7	97
98	702	0.0012	0.0012	0.0012	0.0123	20	309.5700	62.8700	417	1368	1505	Emplacement Shaft (Collar Elev. 1455m)	98
99	6	0.0002	0.0002	0.0002	0.0016	11	309.5700	62.8700	100	328	361	Primary Emplacement Fan	99
100	7	0.0000	0.0000	0.0000	0.0000	0	0	0	0	0	0	Primary Emplacement Fan leakage leg 1	100
101	7	0.0000	0.0000	0.0000	0.0000	0	0	0	0	0	0	Primary Emplacement Fan leakage leg 2	101
102	7	0.0000	0.0000	0.0000	0.0000	0	0	0	0	0	0	Surface dummy, Empl Shaft to North Ramp Portal 1	102
103	8	0.0000	0.0000	0.0000	0.0000	0	0	0	0	0	0	Surface dummy, Empl Shaft to North Ramp Portal 2	103
104	1	0.0000	0.0000	0.0000	0.0000	0	0	0	0	0	0	Surface dummy, North Ramp Portal to South Ramp Po	104
105	3	0.0000	0.0000	0.0000	0.0000	0	0	0	0	0	0	Surface dummy, North Ramp Portal to Dev Shaft leg 1	105
106	4	0.0000	0.0000	0.0000	0.0000	0	0	0	0	0	0	Surface dummy, South Ramp Portal to Dev Shaft leg 2	106
107	4	0.0001	0.0001	0.0001	0.0011	11	309.5700	62.8700	70	230	253	Primary Development Fan	107
108	5	0.0000	0.0000	0.0000	0.0000	0	0	0	0	0	0	Primary Development Fan leakage leg 1	108
109	1001	0.0000	0.0000	0.0000	0.0000	0	0	0	0	0	0	Primary Development Fan leakage leg 1	109
110	4	0.0000	0.0000	0.0000	0.0000	0	0	0	0	0	0	Primary Development Fan leakage leg 1	110
111	5	0.0048	0.0048	0.0048	0.0478	95	309.5700	62.8700	342	1122	1234	Development Shaft (Collar elev. 1452m)	111
112	9	0.0002	0.0002	0.0002	0.0018	60	527.4316	91.8635	70	230	253	Development Shaft connection to West Main	112
113	334	0.0110	0.0110	0.0110	0.1097	60	219.8900	52.5700	633	1749	1924	Vent Drift + PC Bypass Regulator from East Main, 1	113
114	334	0.0110	0.0110	0.0110	0.1097	60	219.8900	52.5700	633	1749	1924	Vent Drift + PC Bypass Regulator from West Main, 1	114
115	334	0.0167	0.0167	0.0167	0.1668	20	24.4300	17.5200	10	33	36	Raise for Vent Drift + PC Bypass Regulator, 1	115
116	370	0.0128	0.0128	0.0128	0.1279	60	219.8900	52.5700	621	2037	2241	Vent Drift + PC Bypass Regulator from East Main, 2	116
117	370	0.0128	0.0128	0.0128	0.1279	60	219.8900	52.5700	621	2037	2241	Vent Drift + PC Bypass Regulator from West Main, 2	117
118	304	0.0123	0.0123	0.0123	0.1233	60	219.8900	52.5700	599	1985	2162	Vent Drift + PC Bypass Regulator from East Main, 3	118
119	304	0.0123	0.0123	0.0123	0.1233	60	219.8900	52.5700	599	1985	2162	Vent Drift + PC Bypass Regulator from West Main, 3	119
120	712	0.0167	0.0167	0.0167	0.1668	20	24.4300	17.5200	10	33	36	Raise for Vent Drift + PC Bypass Regulator, 3	120

CALCULATIONS

Ref. Line	Calculation	Net Area of Perm. Items	Net Area of Used	Perimeter Used
1				
2				
3				
4	North Ramp / North Main, 7.62m dia	30	395.10	72.26
5	East / West Main drifts, 7.62 m dia	60	395.10	72.26
6	Emplacement drifts, 5.1 m dia	70	219.89	52.57
7	Empl drifts (Loaded), 5.1 m dia	85	219.89	52.57
8	Smooth exhaust ducts, 72" ID, 84" OD	11	28.27	18.85
9	Exhaust main (raise bottom & duct blockage)	70	318.14	72.26
10	Raises, 1.7 m dia	20	24.43	17.52
11	Emplacement Shaft, 6.1 m dia	20	314.57	62.87
12	Development Shaft, 6.1 m dia	85	307.57	62.87
13	Regulator valves 28" dia housing	11	4.28	7.33
14	South Ramp Service Main	70	389.10	72.26
15				
16	Less estimated permanent obstruction in airways:			
17	a - main invert (34.34); b - conveyor (6); c - concrete lining above invert (58.44); d - duct 84" OD (38.48); g - guides in shaft (42.19); u - utilities & rails (2).			
18	when "u" has			
19	Water Supply	0.35		
20	Water Return	0.35		
21	Compressed Air	0.20		
22	Power & Hangers	0.60		
23	Rail	0.50		
24				
25				
26				
27	Note: Liner in ramps and mains are assumed 12 inches thick for concrete or 8 inches thick for steel			
28				
29				
30				
31	FILE # Repvda, VNETPC INPUT, Viability Assessment Report			
32				
33	RESISTANCE EQUIVALENT CALCULATION, (H = RQ ²)			
34				
35	Resistance Equiv. Per Fan Assembly			
36	@ 1.0" WG/110000 cfm			
37	(Pressure loss includes inlet & outlet silencers, cones, screen, & adapters)			
38	Pressure Loss, H = 1.0" WG			
39	Air Quantity, q = 110000 cfm, Q = 1.1			
40	Resistance, R = H/Q ²			
41	R = 1.0/(1.1) ² = 0.8264			
42	RPU = R/10			
43	= 0.0826			
44				
45				
46				

Resistance Equiv. for Net Leakage per Fan Span
 @ 6324 cfm per 10" WG
 Pressure Loss, H = 10" WG
 Air Quantity, q = 6324 cfm, Q = 0.06324
 Resistance, R = H/Q²
 R = 10/(0.06324)²
 RPU = R/10
 2500 in.min⁻¹

Resistance Equiv. for Fan Performance Adjuster
 @ 4082 cfm per 10" WG
 Pressure Loss, H = 10" WG
 Air Quantity, q = 4082 cfm, Q = 0.04082
 Resistance, R = H/Q²
 R = 10/(0.04082)² = 6001 in.min⁻¹
 RPU = R/10 for two branches = 600
 RPU for one branch = 300

VNETPC (Version 3.1)
17:05:03
05-15-1997

Output File Name: OUTPUT.TMP
Network File Name: REPVA0A2
Network Title: REPOSITORY VENTILATION
Mine Name: YUCCA MOUNTAIN PROJECT
Company: M&O/MK/RSJURANI
Comments: EARLY EMPLACEMENT/DEVELOPMENT PHASE

**** DATA SUPPLIED BY USER ****

Fan Data:

Fan Ref No.	From	To	Operating Pressure in.w.g.	No. Characteristic Pts.
1 13	4	5	10.000	10
2 18	6	7	5.000	10
3 2	501	500	5.000	10
4 2	601	600	5.000	10

Fan Characteristic Points:

Fan 1	Pressure in.w.g.	Airflow kcfm
	28.000	40.00
	24.000	120.00
	20.000	230.00
	18.600	290.00
	19.200	330.00
	20.000	380.00
	18.000	450.00
	14.000	540.00
	10.000	600.00
	4.000	660.00

Fan 2	Pressure in.w.g.	Airflow kcfm
	17.400	10.00
	16.400	40.00
	15.200	70.00
	14.000	110.00
	12.200	180.00
	11.200	220.00
	10.000	260.00
	7.600	300.00
	5.200	330.00
	1.500	400.00

Fan 3	Pressure in.w.g.	Airflow kcfm
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2.400	140.00
4.700	120.00
5.500	110.00
6.100	90.00
6.700	80.00
6.000	60.00
5.400	50.00
4.850	30.00
5.000	20.00
6.800	0.00

Fan 4	Pressure in.w.g.	Airflow kcfm
	2.400	140.00
	4.700	120.00
	5.500	110.00
	6.100	90.00
	6.700	80.00
	6.000	60.00
	5.400	50.00
	4.850	30.00
	5.000	20.00
	6.800	0.00

Branch Data:

Branch	From	To	Resistance P.U.	Airflow kcfm	Pressure Dp in.w.g.	Frict. Factor lb/min ² /ft ⁴ X10 ⁻¹⁰	Len ft	Equiv Len ft	Area ft ²	per ft
1	1	2	0.00530							
2	2	101	0.00140							
3	101	102	0.00230							
4	102	103	0.00350							
5	103	115	1000.00201							
6	115	135	0.00280							
7	2	135	1000.00201							
8	135	155	0.00280							
9	155	175	0.00280							
10	175	195	0.00280							
11	195	112	0.00240							
12	112	198	0.00390							
13	198	199	0.00240							
14	199	100	0.00870							
15	102	700	0.00090							
16	700	200	0.00150							
17	200	203	0.00070							
18	203	215	1000.00201							
19	215	235	0.00280							
20	235	255	0.00280							
21	275	255	0.00280							
22	295	275	0.00280							
23	212	295	0.00260							
24	298	212	0.00610							
25	298	299	0.00100							
26	299	799	0.00100							
27	799	199	5.00430							
28	103	303	0.01560							

29	115	315	0.01560
30	135	335	1.01640
31	203	303	0.01560
32	215	315	0.01560
33	235	335	1.01640
34	303	403	0.01670
35	315	415	0.01670
36	335	435	0.01670
37	403	703	0.00500
38	415	715	0.00500
39	435	735	0.00500
40	403	503	0.21410
41	403	603	0.21410
42	503	501	0.29940
43	501	500	0.03820
44	500	600	0.00030
45	603	601	0.27390
46	601	600	0.03820
47	600	702	0.00020
48	799	712	0.01390
49	712	795	0.00560
50	795	775	0.00630
51	775	755	0.00630
52	755	735	0.00620
53	735	715	0.00630
54	715	703	1000.00403
55	703	701	0.00470
56	700	701	1000.00098
57	701	702	0.00020
58	702	6	0.00120
59	6	7	0.00020
60	7	1002	1000.00000
61	1002	6	1000.00000
62	7	8	0.00001
63	8	1	0.00001
64	1	100	0.00001
65	100	3	0.00001
66	3	4	0.00001
67	4	5	0.00010
68	5	1001	1000.00000
69	1001	4	1000.00000
70	5	9	0.00480
71	9	298	0.00020
72	115	334	1.01100
73	235	334	1.01100
74	334	735	1.01670
75	155	370	5.01280
76	275	370	5.01280
77	370	775	1.01670
78	195	304	5.01230
79	212	304	5.01230
80	304	712	1.01670

***** OUTPUT DATA *****

Annual costs are based on electricity charges of 10.0 cents per kWh and fan efficiencies of 70.0%
Cost given for an NVP represents money saved by natural ventilation

Network File Name - REPVA0A2
Output File Name - OUTPUT.TMP

*** Fan Operating Points ***

Fan Ref No.	From	To	Pressure in.w.g.	Quantity kcfm	Air Power hp	Op.Cost \$/year	
1	13	4	5	12.750	558.74	1122.57	1047589
2	18	6	7	3.979	353.08	221.38	206595
3	2	501	500	5.701	103.27	92.77	86573
4	2	601	600	5.642	105.24	93.56	87311

Network File Name - REPVA0A2
Output File Name - OUTPUT.TMP

*** Branch Data ***

Branch	From	To	Press.Dp m.in.wg.	Airflow kcfm	Resist. P.U.	AP Loss hp	Op.Cost \$/year
1	1	2	609	339.25	0.00530	32.6	30381
2	2	101	163	341.93	0.00140	8.8	8196
3	101	102	268	341.93	0.00230	14.4	13475
4	102	103	100	169.47	0.00350	2.7	2492
5	103	115	-8140	-2.85	1000.00201	3.7	3415
6	115	135	434	393.76	0.00280	26.9	25130
7	2	135	-7173	-2.68	1000.00301	3.0	2825
8	135	155	551	443.86	0.00330	38.5	35964
9	155	175	620	470.62	0.00280	46.0	42907
10	175	195	620	470.62	0.00280	46.0	42907
11	195	112	606	502.69	0.00240	48.0	44797
12	112	198	985	502.69	0.00390	78.0	72813
13	198	199	606	502.69	0.00240	48.0	44797
14	199	100	2572	543.80	0.00370	220.4	205672
15	102	700	26	172.46	0.00130	0.7	659
16	700	200	43	170.81	0.00150	1.2	1080
17	200	203	20	170.81	0.00070	0.5	502
18	203	215	-10805	-3.29	1000.00201	5.6	5223
19	215	235	-138	-222.44	0.00280	4.8	4514
20	235	255	-203	-269.66	0.00280	8.6	8050
21	275	255	203	269.66	0.00130	8.6	8050
22	295	275	220	280.74	0.00280	9.7	9082
23	212	295	204	280.74	0.00260	9.0	8422
24	298	212	522	292.69	0.00610	24.1	22467
25	298	299	69	263.53	0.00100	2.9	2674
26	299	799	69	263.53	0.00100	2.9	2674
27	799	199	8454	41.10	5.00430	54.8	51097
28	103	303	463	172.33	0.01560	12.6	11733
29	115	315	-1924	-351.28	0.01560	106.5	99386
30	135	335	-2831	-52.78	1.01640	23.5	21972
31	203	303	472	174.09	0.01560	12.9	12083

32	215	315	749	219.15	0.01560	25.9	24138
33	235	335	416	20.24	1.01640	1.3	1238
34	303	403	2004	346.42	0.01670	109.4	102086
35	315	415	-291	-132.13	0.01670	6.1	5654
36	335	435	-17	-32.53	0.01670	0.1	81
37	403	703	95	137.91	0.00500	2.1	1927
38	415	715	-87	-132.13	0.00500	1.8	1690
39	435	735	-5	-32.53	0.00500	0.0	24
40	403	503	2283	103.27	0.21410	37.2	34669
41	403	603	2371	105.24	0.21410	39.3	36692
42	503	501	3192	103.27	0.29940	51.9	48472
43	501	500	407	103.27	0.03820	6.6	6181
44	500	600	3	103.27	0.00030	0.0	46
45	603	601	3033	105.24	0.27390	50.3	46936
46	601	600	423	105.24	0.03820	7.0	6546
47	600	702	8	208.50	0.00020	0.3	245
48	799	712	687	222.43	0.01390	24.1	22470
49	712	795	229	202.30	0.00560	7.3	6812
50	795	775	257	202.30	0.00630	8.2	7645
51	775	755	219	186.62	0.00630	6.4	6010
52	755	735	215	186.62	0.00620	6.3	5900
53	735	715	116	135.73	0.00630	2.5	2315
54	715	703	13006	3.61	1000.00403	7.4	6898
55	703	701	94	141.52	0.00470	2.1	1956
56	700	701	2730	1.65	1000.00098	0.7	663
57	701	702	4	143.17	0.00020	0.1	84
58	702	6	148	351.68	0.00120	8.2	7654
59	6	7	24	353.08	0.00020	1.3	1246
60	7	1002	1977	1.41	1000.00000	0.4	409
61	1002	6	1977	1.41	1000.00000	0.4	409
62	7	8	1	351.68	0.00001	0.1	52
63	8	1	1	351.68	0.00001	0.1	52
64	1	100	0	12.43	0.00001	0.0	0
65	100	3	3	556.22	0.00001	0.3	245
66	3	4	3	556.22	0.00001	0.3	245
67	4	5	31	558.74	0.00010	2.7	2547
68	5	1001	6359	2.52	1000.00000	2.5	2358
69	1001	4	6359	2.52	1000.00000	2.5	2358
70	5	9	1485	556.22	0.00480	130.2	121463
71	9	298	61	556.22	0.00020	5.3	4989
72	115	334	-2077	-45.33	1.01100	14.8	13845
73	235	334	735	26.98	1.01100	3.1	2916
74	334	735	-342	-18.35	1.01670	1.0	923
75	155	370	-3590	-26.76	5.01280	15.1	14129
76	275	370	615	11.08	5.01280	1.1	1002
77	370	775	-250	-15.68	1.01670	0.6	577
78	195	304	-5156	-32.07	5.01230	26.1	24318
79	212	304	715	11.95	5.01230	1.3	1256
80	304	712	-411	-20.12	1.01670	1.3	1216

Number of Iterations = 2

The following table gives the frictional pressure relative to 0 m.in.wg. at junction No. 1
The table may be used to find neutral points and the pressure difference available to produce flow

between any two junctions in the network.

** The value 99999 indicates an inaccessible junction **

Junction	Pressure	Junction	Pressure	Junction	Pressure	Junction	Pressure
1	0	2	-609	3	3	4	0
5	12719	6	-3947	7	8	8	7
9	11234	100	6	101	-772	102	-1040
103	-1140	112	4169	115	7000	135	6566
155	6015	175	5395	195	4775	198	3184
199	2578	200	-1109	203	-1129	212	10644
215	9676	235	9814	255	10017	275	10220
295	10440	298	11166	299	11097	303	-1603
304	9931	315	8924	334	9077	335	9397
370	9605	403	-3607	415	9215	435	9414
500	-3788	501	-9082	503	-5890	600	-3791
601	-9011	603	-5978	700	-1066	701	-3796
702	-3799	703	-3702	712	10341	715	9302
735	9419	755	9636	775	9855	795	10112
799	11028	1001	6360	1002	-1969		

***** NETWORK EXERCISE COMPLETE *****

Some information may be obliterated but may be deduced from pages 9-11.

Some information may be obliterated but may be deduced from pages 9-11.

Some information may be obliterated but may be deduced from pages 9-11.

VNETPC (Version 3.1)
16:07:53
05-15-1997

Output File Name: OUTPUT.TMP
Network File Name: REPVAOAI
Network Title: REPOSITORY VENTILATION
Mine Name: YUCCA MOUNTAIN PROJECT
Company: M&O/MK/RSJURANI
Comments: LATE EMPLACEMENT/CARETAKER OPER

**** DATA SUPPLIED BY USER ****

Fan Data:

Fan Ref No.	From	To	Operating Pressure in.w.g.	No. Characteristic Pts.
1 18	4	5	2.000	10
2 12	6	7	12.000	10
3 35	501	500	35.000	10
4 35	601	600	35.000	10

Fan Characteristic Points:

Fan 1	Pressure in.w.g.	Airflow kcfm
	17.400	10.00
	16.400	40.00
	15.200	70.00
	14.000	110.00
	12.200	180.00
	11.200	220.00
	10.000	260.00
	7.600	300.00
	5.200	330.00
	1.500	400.00

Fan 2	Pressure in.w.g.	Airflow kcfm
	28.000	60.00
	24.000	140.00
	20.000	240.00
	18.600	310.00
	20.000	370.00
	20.600	420.00
	18.800	500.00
	14.800	600.00
	8.200	700.00
	4.000	740.00

Fan 3	Pressure in.w.g.	Airflow kcfm
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44.840 0.00
49.070 26.73
51.610 53.45
50.760 80.18
47.380 106.90
44.840 120.27
42.300 133.63
36.380 160.35
25.380 187.00
13.540 213.80

Fan 4 Pressure Airflow
in.w.g. kcfm

44.840 0.00
49.070 26.73
51.610 53.45
50.760 80.18
47.380 106.90
44.840 120.27
42.300 133.63
36.380 160.35
25.380 187.00
13.540 213.80

Branch Data:

Branch	From	To	Resistance P.U.	Airflow kcfm	Pressure Dp m.in.wg.	Frict. Factor lb/min ² /ft ⁴ X10 ⁻¹⁰	Len ft	Equiv Len ft	Area ft ²	per ft
1	1	2	0.00530							
2	2	101	0.00140							
3	101	102	0.00230							
4	102	103	0.00350							
5	103	115	0.00170							
6	115	135	0.00280							
7	2	135	0.50170							
8	135	155	0.00280							
9	155	175	0.00280							
10	175	195	0.00280							
11	195	112	0.00240							
12	112	198	1000.00403							
13	198	199	0.00240							
14	199	100	0.00870							
15	102	700	0.00090							
16	700	200	0.00150							
17	200	203	0.00070							
18	203	215	0.00170							
19	215	235	0.00280							
20	235	255	0.00280							
21	275	255	0.00280							
22	295	275	0.00280							
23	212	295	0.00260							
24	298	212	1000.00598							
25	298	299	0.00100							
26	299	799	0.00100							
27	799	199	0.00430							
28	103	303	50.01560							

29	115	315	45.01560
30	135	335	40.01640
31	155	355	40.01780
32	175	375	35.01830
33	195	395	35.01830
34	112	312	0.01670
35	203	303	50.01560
36	215	315	45.01560
37	235	335	40.01640
38	255	355	40.01780
39	275	375	35.01830
40	295	395	35.01830
41	212	312	0.01670
42	303	403	0.01670
43	315	415	0.01670
44	335	435	0.01670
45	355	455	0.01670
46	375	475	0.01670
47	395	495	0.01670
48	312	412	0.01670
49	403	703	2000.00500
50	415	715	2000.00500
51	435	735	2000.00500
52	455	755	2000.00500
53	475	775	2000.00500
54	495	795	2000.00500
55	412	712	20.00500
56	403	503	100.21410
57	403	603	2000.21399
58	415	515	100.21410
59	415	615	2000.21399
60	435	535	90.21410
61	435	635	2000.21399
62	455	555	90.21410
63	455	655	1900.21399
64	475	575	85.21410
65	475	675	1850.21399
66	495	595	80.21410
67	495	695	1800.21399
68	412	512	0.21410
69	412	612	0.21410
70	512	595	0.32480
71	595	575	0.36940
72	575	555	0.36690
73	555	535	0.36310
74	535	515	0.36590
75	515	503	0.22170
76	503	501	0.29940
77	501	500	0.03820
78	500	600	0.00030
79	612	695	0.32480
80	695	675	0.36940
81	675	655	0.36690
82	655	635	0.36310
83	635	615	0.36590
84	615	603	0.22170
85	603	601	0.27390
86	601	600	0.03820
87	600	702	0.00020
88	799	712	1000.01398

89	712	795	0.00560
90	795	775	0.00630
91	775	755	0.00630
92	755	715	0.00620
93	735	715	0.00630
94	715	703	0.00380
95	703	701	0.00470
96	700	701	1000.00201
97	701	702	0.00020
98	702	6	0.00120
99	6	7	0.00020
100	7	1002	1000.00000
101	1002	6	1000.00000
102	7	8	0.00001
103	8	1	0.00001
104	1	100	0.00001
105	100	3	0.00001
106	3	4	0.00001
107	4	5	0.00010
108	5	1001	1000.00000
109	1001	4	1000.00000
110	5	9	0.00480
111	9	298	0.00020
112	115	334	1.01100
113	235	334	1.01100
114	334	735	0.01670
115	155	370	1.01280
116	275	370	1.01280
117	370	775	0.01670
118	195	304	0.01230
119	212	304	0.01230
120	304	712	0.01670

**** OUTPUT DATA ****

Annual costs are based on electricity charges of 10.0 cents per kWh and fan efficiencies of 70.0%
Cost given for an NVP represents money saved by natural ventilation

Network File Name - REPVAOA1
Output File Name - OUTPUT.TMP

*** Fan Operating Points ***

Fan Ref No.	From	To	Pressure in.w.g.	Quantity kcfm	Air Power hp	Op.Cost \$/year
1	18	4	5	2.758	376.19	152571
2	12	6	7	9.640	678.16	961344
3	35	501	500	34.865	164.02	840908
4	35	601	600	40.289	142.71	845471

Network File Name - REPVAOA1
Output File Name - OUTPUT.TMP

*** Branch Data ***

Branch	From	To	Press.Dp m.in.wg.	Airflow kcfm	Resist. P.U.	AP Loss hp	Op.Cost \$/year
1	1	2	2366	668.18	0.00530	249.1	232474
2	2	101	514	606.00	0.00140	49.1	45804
3	101	102	844	606.00	0.00230	80.6	75211
4	102	103	302	294.21	0.00150	14.0	13066
5	103	115	137	284.37	0.00170	6.1	5729
6	115	135	140	224.12	0.00280	4.9	4614
7	2	135	1939	62.18	0.50170	19.0	17730
8	135	155	216	277.89	0.00280	9.5	8827
9	155	175	151	232.82	0.00280	5.5	5170
10	175	195	143	226.57	0.00280	5.1	4764
11	195	112	28	109.15	0.00240	0.5	449
12	112	198	-6019	-2.45	1000.00403	.2.3	2172
13	198	199	0	-2.45	0.00240	0.0	0
14	199	100	1173	367.22	0.00870	67.9	63342
15	102	700	87	311.79	0.00090	4.3	3989
16	700	200	143	309.52	0.00150	7.0	6509
17	200	203	67	309.52	0.00070	3.3	3049
18	203	215	152	299.68	0.00170	7.2	6698
19	215	235	236	290.48	0.00280	10.8	10081
20	235	255	152	233.63	0.00280	5.6	5222
21	275	255	-143	-226.51	0.00280	5.1	4763
22	295	275	-95	-184.98	0.00280	2.8	2584
23	212	295	-84	-179.97	0.00260	2.4	2223
24	298	212	6926	2.63	1000.00598	2.9	2681
25	298	299	138	372.39	0.00100	8.1	7557
26	299	799	138	372.39	0.00100	8.1	7557
27	799	199	587	369.67	0.00430	34.2	31910
28	103	303	4837	9.83	50.01560	7.5	6995
29	115	315	3818	9.21	45.01560	5.5	5171
30	135	335	2829	8.41	40.01640	3.7	3498
31	155	355	2072	7.20	40.01780	2.3	2193
32	175	375	1367	6.25	35.01330	1.3	1256
33	195	395	865	4.97	35.01230	0.7	632
34	112	312	208	111.61	0.01670	3.7	3414
35	203	303	4842	9.84	50.01560	7.5	7006
36	215	315	3807	9.20	45.01560	5.5	5149
37	235	335	2723	8.25	40.01640	3.5	3304
38	255	355	2029	7.12	40.01780	2.3	2125
39	275	375	1332	6.17	35.01830	1.3	1208
40	295	395	878	5.01	35.01930	0.7	647
41	212	312	165	99.64	0.01670	2.6	2418
42	303	403	6	19.67	0.01670	0.0	17
43	315	415	5	18.41	0.01670	0.0	14
44	335	435	4	16.66	0.01670	0.0	10
45	355	455	3	14.32	0.01670	0.0	6
46	375	475	2	12.42	0.01670	0.0	4
47	395	495	1	9.98	0.01670	0.0	1
48	312	412	745	211.25	0.01670	24.8	23143
49	403	703	-540	-0.52	2000.00500	0.0	41
50	415	715	-171	-0.29	2000.00500	0.0	7

51	435	735	-174	-0.30	2000.00500	0.0	8
52	455	755	-79	-0.20	2000.00500	0.0	2
53	475	775	20	0.10	2000.00500	0.0	0
54	495	795	139	0.26	2000.00500	0.0	5
55	412	712	-188	-3.07	20.00500	0.1	85
56	403	503	25876	16.07	100.21410	65.5	61144
57	403	603	34033	4.12	2000.21399	22.1	20644
58	415	515	21905	14.78	100.21410	51.0	47624
59	415	615	30658	3.92	2000.21399	18.9	17650
60	435	535	16266	13.43	90.21410	34.4	32119
61	435	635	24871	3.53	2000.21399	13.8	12897
62	455	555	11602	11.34	90.21410	20.7	19348
63	455	655	19169	3.18	1900.21399	9.6	8953
64	475	575	7845	9.60	85.21410	11.9	11070
65	475	675	13715	2.72	1850.21399	5.9	5491
66	495	595	4599	7.57	80.21410	5.5	5121
67	495	695	8280	2.14	1800.21399	2.8	2611
68	412	512	1781	91.23	0.21410	25.6	23892
69	412	612	3244	123.10	0.21410	62.9	58721
70	512	595	2703	91.23	0.32480	38.9	36261
71	595	575	3605	98.80	0.36940	56.1	52376
72	575	555	4310	108.40	0.36690	73.6	68700
73	555	535	5205	119.74	0.36310	98.2	91646
74	535	515	6488	133.16	0.36590	136.1	127047
75	515	503	4852	147.95	0.22170	113.1	105560
76	503	501	8054	164.02	0.29940	208.2	194254
77	501	500	1027	164.02	0.03820	26.5	24770
78	500	600	8	164.02	0.00030	0.2	193
79	612	695	4921	123.10	0.32480	95.5	89078
80	695	675	5794	125.24	0.36940	114.3	106708
81	675	655	6007	127.96	0.36690	121.1	113035
82	655	635	6244	131.14	0.36310	129.0	120411
83	635	615	6635	134.67	0.36590	140.8	131392
84	615	603	4257	138.58	0.22170	93.0	86752
85	603	601	5578	142.71	0.27390	125.4	117055
86	601	600	777	142.71	0.03820	17.5	16305
87	600	702	18	306.72	0.00020	0.9	812
88	799	712	7371	2.72	1000.01398	3.2	2943
89	712	795	213	195.05	0.00560	6.5	6109
90	795	775	240	195.31	0.00630	7.4	6893
91	775	755	454	268.64	0.00630	19.2	17935
92	755	735	446	268.44	0.00620	18.9	17606
93	735	715	852	367.80	0.00630	49.4	46080
94	715	703	513	367.50	0.00380	29.7	27723
95	703	701	632	366.98	0.00470	36.5	34106
96	700	701	5151	2.27	1000.00201	1.8	1719
97	701	702	27	369.25	0.00020	1.6	1466
98	702	6	548	675.98	0.00120	58.4	54473
99	6	7	91	678.16	0.00020	9.7	9075
100	7	1002	4774	2.19	1000.00000	1.6	1534
101	1002	6	4774	2.19	1000.00000	1.6	1534
102	7	8	4	675.98	0.00001	0.4	398
103	8	1	4	675.98	0.00001	0.4	398
104	1	100	0	7.80	0.00001	0.0	0

105	100	3	1	375.02	0.00001	0.1	55
106	3	4	1	375.02	0.00001	0.1	55
107	4	5	14	376.19	0.00010	0.8	774
108	5	1001	1372	1.17	1000.00000	0.3	236
109	1001	4	1372	1.17	1000.00000	0.3	236
110	5	9	675	375.02	0.00480	39.9	17224
111	9	298	28	375.02	0.00020	1.7	1544
112	115	334	2634	51.05	1.01100	21.2	19773
113	235	334	2388	48.60	1.01100	18.3	17067
114	334	735	165	99.65	0.01670	2.6	2418
115	155	370	1452	37.87	1.01280	8.7	8087
116	275	370	1266	35.36	1.01280	7.1	6582
117	370	775	89	73.23	0.01670	1.0	958
118	195	304	155	112.45	0.01230	2.7	2563
119	212	304	84	82.96	0.01230	1.1	1025
120	304	712	637	195.40	0.01670	19.6	18304

Number of Iterations = 3

The following table gives the frictional pressure relative to 0 m.in.wg. at junction No. 1
The table may be used to find neutral points and the pressure difference available to produce flow
between any two junctions in the network.

** The value 99999 indicates an inaccessible junction **

Junction	Pressure	Junction	Pressure	Junction	Pressure	Junction	Pressure
1	0	2	-2366	3	4	4	3
5	2747	6	-9535	7	14	8	10
9	2072	100	5	101	-2880	102	-3724
103	-4026	112	-4841	115	-4163	135	-4303
155	-4519	175	-4670	195	-4813	198	1178
199	1178	200	-3954	203	-4021	212	-4883
215	-4173	235	-4409	255	-4561	275	-4704
295	-4799	298	2043	299	1905	303	-8863
304	-4968	312	-5049	315	-7981	334	-6797
335	-7132	355	-6591	370	-5971	375	-6037
395	-5678	403	-8869	412	-5794	415	-7986
435	-7136	455	-6594	475	-6039	495	-5679
500	-8961	501	-42799	533	-34745	512	-7575
515	-29891	535	-23402	555	-18196	575	-13884
595	-10278	600	-8969	601	-48480	603	-42902
612	-9038	615	-38644	635	-32007	655	-25763
675	-19754	695	-13959	700	-3811	701	-8961
702	-8987	703	-8329	712	-5606	715	-7815
735	-6962	755	-6515	775	-6059	795	-5818
799	1767	1001	1375	1002	-4760		

**** NETWORK EXERCISE COMPLETE ****

Some information may be obliterated but may be deduced from pages 20-22.

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SUBSURFACE REPOSITORY LAYOUT FOR VA DESIGN