

ANALYSIS/MODEL COVER SHEET

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4. Title:

Shaft Siting and Configuration for Flexible Operating Mode

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

ANL-SFS-MG-000006 REV 00

6. Total Attachments:

4 Attachments

7. Attachment Numbers - No. of Pages in Each:

Attachment I-2, Attachment II-6, Attachment III-6, Attachment IV-2

	Printed Name	Signature	Date
8. Originator	James Sheridan	<i>James Sheridan</i>	8/2/01
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12. Remarks:

**OFFICE OF CIVILIAN RADIOACTIVE WASTE MANAGEMENT
ANALYSIS/MODEL REVISION RECORD**

1. Page 2 of 48

2. Analysis or Model Title:

Shaft Siting and Configuration for Flexible Operating Mode

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

ANL-SFS-MG-000006 REV 00

4. Revision/Change
No.

5. Description of Revision/Change

00

Initial Issue

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ACRONYMS AND ABBREVIATIONS

BCP	Baseline Change Proposal
BSC	Bechtel SAIC Company
CRWMS	Civilian Radiation Waste Management System
DIRS	Document Input Reference System
DOE	U. S. Department of Energy
DTN	Data Tracking Number
ESF	Exploratory Studies Facility
FEIS	Final Environmental Impact Statement
GFM	Geologic Framework Model
LA	License Application
SCM	Software Configuration Management
SDD	System Description Document
SR	Site Recommendation
TBM	Tunnel Bore Machine
TWP	Technical Work Plan
V-Mole	Vertical Mole

1. PURPOSE

The purpose of this document as stated in the *Technical Work Plan for Subsurface Design Section FY 01 Work Activities* (CRWMS M&O 2001a, pg. 14) is to review and evaluate the most current concepts for shaft siting and configuration. The locations of the shaft sites will be evaluated in reference to the overall subsurface ventilation layout shown in Figure 1.

The scope will include discussions on pad size requirements, shaft construction components such as collars, shaft stations, sumps, ground support and linings, head frames, fan ducting and facility equipping. In addition to these, shaft excavation methodologies and integration with the overall subsurface construction schedule will be described.

The Technical Work Plan (TWP), (CRWMS M&O 2001a), for this document has been prepared in accordance with AP-2.21Q, *Quality Determinations and Planning for Scientific, Engineering and Regulatory Compliance Activities*.

This document will be prepared in accordance with AP-3.10Q, *Analysis and Models*.

This document contributes to Site Recommendation (SR).

The intended use of this document is to provide an analysis for shaft siting and configuration criteria for subsequent construction. This document identifies preliminary design concepts that should not be used for procurement, fabrication, or construction.

2. QUALITY ASSURANCE

This document has been evaluated in accordance with AP-2.21Q, *Quality Determinations and Planning for Scientific, Engineering and Regulatory Compliance Activities*. It has been determined to be subject to the document requirements of the *Quality Assurance Requirements and Description* (DOE 2000).

This analysis is subject to a level 3 change control as stated in AP-3.10Q, *Analysis and Models*; Section 5.2b, Criteria #4. A Baseline Change Proposal (BCP) was initiated in accordance with AP-3.4Q, *Level 3 Change Control* and a newly designated BCP number has been assigned.

This document will be prepared in accordance with AP-3.10Q, *Analysis and Models*.

The TWP (CRWMS M&O 2001a) for this document has been prepared in accordance with AP-2.21Q, *Quality Determinations and Planning for Scientific, Engineering and Regulatory Compliance Activities*.

The reference citations to be used in this document will be listed in the Document Input Reference System (DIRS) database, in accordance with AP-3.15Q, *Managing Technical Products Inputs*.

The method used to control the electronic management of data as required by AP-SV.1Q, *Control of the Electronic Management of Data*, will be accomplished in accordance with the controls specified in the TWP (CRWMS M&O 2001a).

Inputs and their sources and their qualification status will be identified and documented according to AP-3.15Q, *Managing Technical Product Inputs*. All other technical information produced by CRWMS participants, which will be used as input, will be obtained from controlled source documents and will be referenced using the appropriate document identifier or record system accession number.

3. COMPUTER SOFTWARE AND MODEL USAGE

The computer software used for word processing was Microsoft® Word 97 SR-2. The operating system used was Windows 95, Version 4.0. It is a standard commercial off the shelf office computing software package capable of word processing. The software was obtained from Software Configuration Management (SCM) and was appropriate for the application and was used only within the range of validation in accordance with AP-SI.1Q, *Software Management*. This software is exempt from control per AP-SI.1Q, *Software Management* as stated in Sections 2.1.1 and 2.1.5.

Figures produced in this document have not been qualified. The software was obtained from Configuration Management (CM) and was appropriate for the application and was used only within the range of validation in accordance with AP-SI.1Q, *Software Management*. This software is exempt from control per AP-SI.1Q, *Software Management* as stated in Sections 2.1.1 and 2.1.5. The figures have been drawn using various CAD software programs and are used solely for the visual display of equipment drawings.

All tables contained in this document created were done using Microsoft® Word. The table shown in Attachment IV was created in Microsoft® Excel.

A commercially available software program, VULCAN v3.4, was used to support this analysis. VULCAN v3.4 is a geology and mine engineering computer design system developed by Maptek. VULCAN v3.4 is installed on a Silicon Graphics Octane workstation running the IRIX 6.5 operating system (CRWMS M&O CPU#116980).

VULCAN v3.4, STN: 10044-3.4-00, has been verified and validated (CRWMS M&O 2001b) according to the AP-SI.1Q procedure, *Software Management*. VULCAN v3.4 was used to calculate the centroid of the repository footprint and the Type I Fault traces both at the surface and the repository level for primary and lower blocks.

VULCAN v3.4 software was obtained from Software Configuration Management (SCM), was appropriate for the application used in this analysis and was used within the range of validation in accordance with AP-SI.1Q, *Software Management*.

The topography of Yucca Mountain has been documented in *Determination of Available Repository Siting Volume for Site Recommendation* (CRWMS M&O 2000e). The geologic model, Vulcan Geologic Framework Model (GFM) 3.1 Representation (DTN: MO0003MWDVUL03.002), includes a topographic surface.

4. INPUTS

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

4.1 DATA AND PARAMETERS

All technical product input and sources of the input used in the development of this technical report are documented in the following subsections. The qualification status of the input is indicated in accordance with AP-3.15Q, *Managing Technical Product Inputs*.

4.1.1 Overall Subsurface Layout

The overall subsurface layout was taken from *Low Temperature Subsurface Layout and Ventilation Concepts* (BSC 2001). This layout is shown in Figure 1, Figure 2, Figure 3 and Attachment I. These figures have been modified to better suit the needs of this document. The modification consists of omitting the labels for the emplacement drifts, ramp names and other drift name identifiers. The layout itself remains unaltered.

4.1.2 Shaft Excavation Volumes

The excavated shaft volumes were taken from *Low Temperature Subsurface Layout and Ventilation Concepts* (BSC 2001). The tables were modified to include the excavated swelled volumes of the shafts. This information is used in Tables 9, 10 and 11.

4.1.3 Surface Topography

The surface topography used in Figure 2, Attachments I, Attachment II and Attachment III came from the *Determination of Available Repository Siting Volume for the Site Recommendation* (CRWMS M&O 2000e). The geologic model, Vulcan Geologic Framework Model (GFM) 3.1 Representation (DTN: MO0003MWDVUL03.002) includes a topographic surface.

The contour interval selected for the overall layout in Attachment I is 20 meters. This interval yields sufficient representation of the surface topography of Yucca Mountain in the vicinity of the ventilation shafts without obscuring shaft location information.

The topography used in Attachment II and Attachment III is from the same source but has been enlarged to show detail contour information. The contour interval for the individual shaft sites used in these two attachments is 5 meters.

4.1.4 Flood Plain

The outline of the flood plain shown in the Figure 2 map came from the *Yucca Mountain Site Characterization Project Site Atlas 1997*, (DOE 1997). This map reference is for visual purposes only.

4.1.5 Type I Faults

The Type I Faults shown in Figure 3 came from VULCAN version 3.4. This source has been modified so as to include only the Type I Fault traces at the surface and at the repository level for both the primary block and the lower block for visibility purposes only. The two faults that are identified as Type I Faults at the repository are the Solitario Canyon Fault and the Bow Ridge Fault.

4.2 CRITERIA

4.2.1 System Interfacing Criteria

4.2.1.1 Subsurface Ventilation System

The system layout shall accommodate the Subsurface Ventilation System design criteria as stated in the *Subsurface Facility System Description Document* (CRWMS M&O 2000b, Section 1.2.4.1).

4.2.1.2 Surface Openings Relative to Flood Areas

The system shall locate the entrance of all surface openings to the subsurface facility outside of the probable maximum flood areas as stated in the *Subsurface Facility System Description Document* (CRWMS M&O 2000b, Section 1.2.2.1.3).

4.2.1.3 Minimum Geologic Standoffs to Repository Openings

The system shall accommodate the minimum standoffs from the closest edge of the repository openings as stated in the *Subsurface Facility System Description Document* (CRWMS M&O 2000b, Section 1.2.2.1.4) and shown in Table 1. Repository openings that are placed within these standoff distances shall be approved per site impact analysis.

Table 1. Repository Opening Standoffs

Geologic Areas	Standoff Distances
Top of Groundwater Table	160 meters from the closest edge of the emplacement drifts. (This value will need to be verified.)
Main Trace of Type I Fault Zone	60 Meters from the closest edge of the repository openings. (This value will need to be verified.)

Source: CRWMS M&O 2000b, Section 1.2.2.1.4

4.2.1.4 Escapeways

The system shall have two or more separate, properly maintained escapeways to the surface from the lowest levels, which are so positioned that damage to one shall not lessen the effectiveness of the others. A method of refuge shall be provided while a

second opening to the surface is being developed as stated in the *Subsurface Facility System Description Document* (CRWMS M&O 2000b, Section 1.2.2.2.1).

4.2.1.5 Groundwater and Radionuclide Migration

Excavation methods shall be selected that limit (relative to alternative methods that are considered) the potential for creating a preferential pathway for groundwater to contact the waste package or radionuclide migration to the accessible environment as stated in *Subsurface Excavation System Description Document* (CRWMS M&O 1999a, Section 1.2.3.1).

4.2.1.6 Separation Between Intake and Exhaust Shafts

The system shall locate main intake airways a minimum of 100 m away from surface air exhaust airways as stated in the *Subsurface Ventilation System Description Document* (CRWMS M&O 2000c, Section 1.2.2.2.1). This distance value of 100 m will need to be verified.

4.2.1.7 Water Loss to the Subsurface

The system shall be designed to minimize the use of water and to limit the loss of water to the subsurface environment in cubic meters/meter as stated in the *Subsurface Excavation System Description Document* (CRWMS M&O 1999a, Section 1.2.3.3). The amount of water usage has not been specified.

4.3 CODES AND STANDARDS

None used.

5 ASSUMPTIONS

5.1 OPERATIONAL

5.1.1 Shaft Site Facility Item Areas

It is assumed that the various shaft facilities will occupy specific areas during construction, excavation and/or operation. (Used in Sections 6.1.11.1, 6.1.11.2 and 6.1.11.3).

Rationale

There are several facilities needed for shaft construction. These facilities are commonly used in the mining industry for shaft sinking. The facilities vary in size of the footprint area that they would occupy. The footprint areas of the actual facilities may require further analysis not conducted within the scope of this document.

Table 5 lists those items that could be shared between different shaft sites so as to reduce the need for duplicity of items. The dimensions of the facilities listed are based on observational experience and represent an average magnitude of scale for actual items to be constructed.

Table 6 lists those facilities that would be used for shaft construction at each site. The dimensions of the facilities listed are based on observational experience and represent an average magnitude of scale for actual items to be constructed.

5.1.2 Excavated Shaft Rock Swelled Volume

It is assumed that the excavated shaft rock will increase in volume by 33-1/3 %. This increased volume is referred to as the "swell volume". (Used in Section 6.1.13).

Rationale

The in-place volume of rock will increase, or swell, upon excavation due to presence of voids. The swell factor obtained from the *FEIS Update To Engineering File - Subsurface Repository* (page 6-6) is based on Exploratory Studies Facility (ESF) site experience. Similar rock types are expected to be encountered when shaft sinking therefore a similar order of magnitude of swell is expected. This volume increase can be obtained by the following calculation:

$$\text{Swell Volume} = \text{In-Place Volume} \div 0.75.$$

This formula was used to compute the swell volume of rock in Table 9, Table 10 and Table 11.

5.1.3 Excavated Shaft Rock Storage and Transfer

It is assumed that some excavated shaft rock may be temporarily stored at each respective site and is limited to 2 weeks of shaft production. The excavated shaft rock will be transferred to a more permanent centralized waste rock storage stockpile. (Used in Section 6.1.13).

Rationale

If the entire amount of excavated shaft rock produced at each shaft site were stored on its individual site, a substantial amount of room would be required to accommodate its storage. Though some rock may be used for various shaft site construction purposes, a limit of 2 weeks production of shaft rock would be imposed so as to not exceed the pad size and restrict construction mobility. The remainder of the excavated shaft rock would be hauled to a more permanent centralized storage area. The quantity of rock excavated during a two week period, assuming drill and blast techniques, is calculated as follows:

Shaft Area = πr^2 where $\pi = 3.14$ and $r = \text{shaft radius} = 4 \text{ meters}$

Shaft drill depth per day advance = 3.2 meters

Volume of in place rock excavated in one day = $3.14 * (4)^2 * 3.2 = 160.8 \text{ meters}^3$

Volume of in place rock excavated in a 2 week period = $160.8 \text{ meters}^3 * 14 = 2,250 \text{ meters}^3$

Two week volume of swell rock = $2,250 \text{ meters}^3 \div 0.75 = 3,000 \text{ meters}^3$

5.1.4 Shaft Construction Scheduling

It is assumed that the scheduling of the shaft construction will be sequenced so as to satisfy the demand for ventilation in the subsurface facility. The construction method selected should utilize excavation techniques commonly used by the mining industry that would meet this schedule. (Used in Section 6.1.14).

Rationale

Demand for ventilation is the primary driving force for when shafts are scheduled for construction. Subsurface excavations will be done in panels containing sets of shafts. Individual shaft construction can begin prior to when the panels they are contained in are being developed. Untried shaft excavation methods could cause unnecessary delays due to the uncertainties associated with using techniques and technologies not yet proven. The scheduling of shaft work should minimize lead-time for contractor selection, mobilization, setup and development, and final excavation.

6. ANALYSIS

6.1 GENERAL SHAFT SITING AND CONFIGURATION DISCUSSION

General shaft siting and configuration consists of many factors that support ventilation for the subsurface facility. Included in these factors are the examination of surface topography for access and constructability. Site locations should take into account the proximity to water drainages, flood zones and standoff distances to geologic features. Shaft sites must be large enough to accommodate the equipment and supplies necessary for excavation and subsequent operation. Shaft siting should also minimize the amount of disturbance due to construction to the extent possible. All shafts are currently assumed to be vertical. These aspects are discussed in the following sections.

The overall subsurface ventilation layout will be analyzed for shaft siting. This layout is flexible so as to include layouts for smaller configurations. The overall subsurface ventilation layout occupies all of the primary block emplacement area the lower block emplacement area (BSC 2001). Refer to Figure 1 for the overall subsurface ventilation shaft site locations.

This analysis utilized the screening criteria listed in the Screening Criteria for Grading of Data attachment in AP-3.15Q, *Managing Technical Product Inputs*. Using this information, this analysis is classified as Level 3 importance. The reason is that this analysis does not provide estimates of any of the Factors or Potentially Disruptive Events listed in the Screening Criteria for Grading of Data attachment in AP-3.15Q.

As mentioned in Section 2, this analysis is subject to a level 3 change control as stated in AP-3.10Q, *Analysis and Models*; Section 5.2b, Criteria #4 which states "Directly supports Site Recommendation or LA". Since shaft siting has an integral role in the repository ventilation, this analysis is appropriate in its respective degree of evaluation of importance.

All shafts in this layout will be evaluated by comparing their specific aspects against the criteria and assumptions deemed necessary for shaft siting. This matrix is shown in Tables 7 and 8.

This analysis considered the following criteria and assumptions pertinent to shaft siting and configuration:

- Repository ventilation.
- Location relative to flood plains and water drainages.
- Minimum geologic standoffs.
- Secondary escapeways.
- Groundwater and radionuclide migration.

- Separation between Intake and Exhaust Shafts.
- Water loss to the subsurface environment.
- Navigable road access to individual sites.
- Topographic consideration to shaft location.
- Pad preparation work.
- Excavated Rock Swell Volume
- Shaft site facility items and their area of occupancy.
- Utility distribution prior to construction.
- Excavated shaft rock to be transferred.
- Construction scheduling.
- Adequate pad size with which to construct, excavate and operate.

6.1.1 Overall Subsurface Ventilation Layout

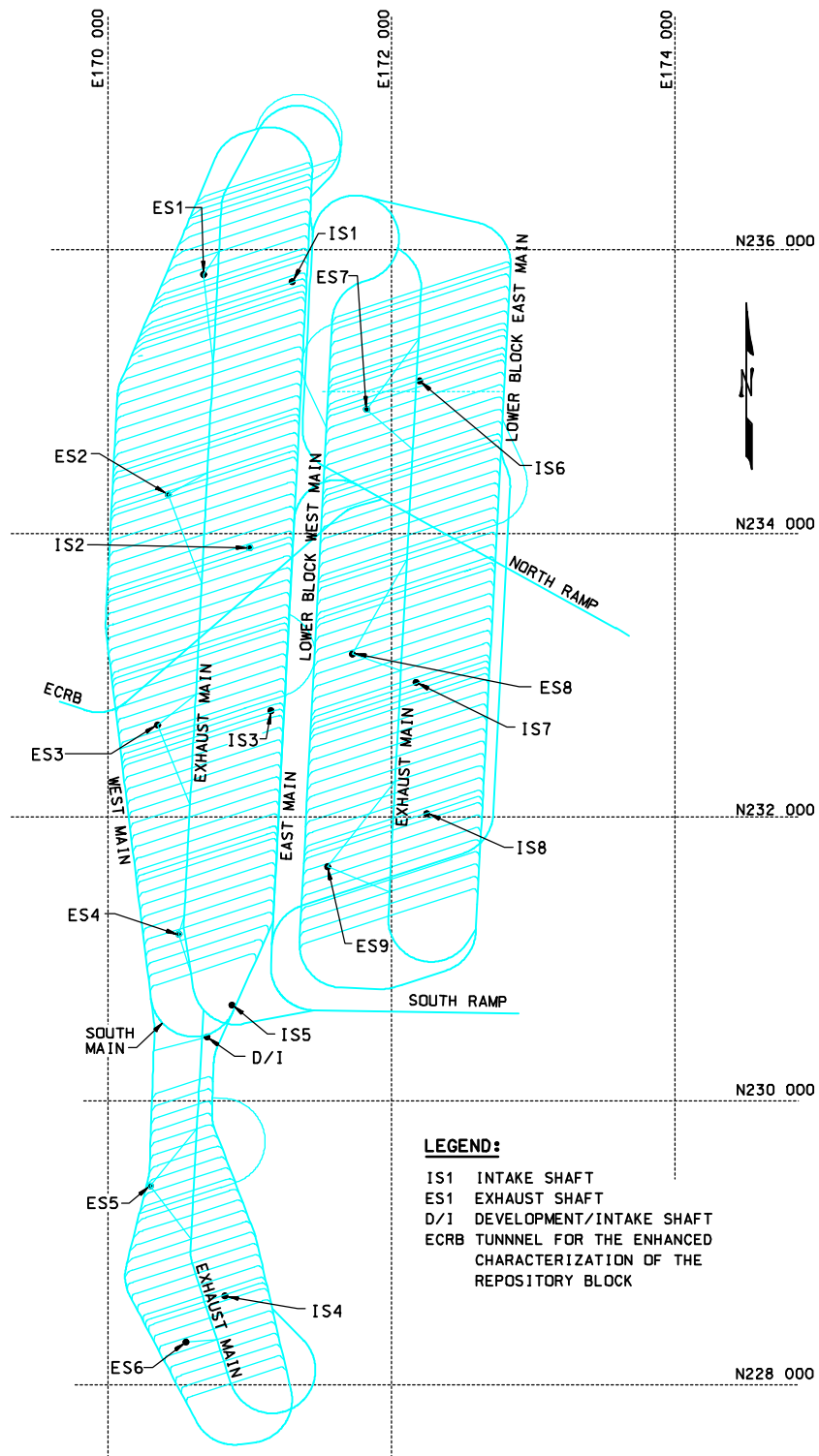
Seven intake shafts are required to supply the necessary ventilation flow rates to the Subsurface Facility in the overall subsurface ventilation layout (Criterion 4.2.1.1), in addition to the North and South Ramps. The shafts represented in this layout satisfy the ventilation criterion. The locations of the intake shafts are listed in Table 2.

Table 2. Intake Shaft Locations for the Overall Subsurface Ventilation Layout

Intake Shaft Number	Northing (m)	Easting (m)	Collar Elevations (m)
IS1	235,775	171,300	1,435
IS2	233,900	171,000	1,390
IS3	232,750	171,150	1,365
IS4	228,625	170,825	1,435
IS5	230,675	170,875	1,390
IS6 (L)	235,075	172,200	1,335
IS7 (L)	232,950	172,175	1,260
IS8 (L) Contingency	232,025	172,250	1,250

NOTE: (L) indicates lower block.

Source: BSC 2001



NOTES:

1. DIMENSIONS, COORDINATES, AND ELEVATIONS ARE SHOWN IN METERS.
2. NORTHING AND EASTING VALUES ARE NEVADA STATE PLANE COORDINATE SYSTEM, NAD 27.

PLAN

CAD FILE: ssmg0495b.fig

SCALE: NONE

Repository layout modified from source: BSC 2001

Figure 1. Overall Subsurface Ventilation Layout

Nine exhaust shafts are required to exhaust emplacement side air from the Subsurface Facility in the overall subsurface ventilation layout. The locations of the exhaust shafts are listed in Table 3.

Table 3. Exhaust Shaft Locations for the Overall Subsurface Ventilation Layout

Exhaust Shaft Number	Northing (m)	Easting (m)	Collar Elevation (m)
ES1	235,825	170,675	1,465
ES2	234,275	170,425	1,475
ES3	232,650	170,350	1,485
ES4	231,175	170,500	1,435
ES5	229,400	170,300	1,470
ES6	228,300	170,550	1,405
ES7 (L)	234,875	171,825	1,360
ES8 (L)	233,150	171,725	1,340
ES9 (L)	231,650	171,550	1,360

NOTE: (L) indicates lower block.

Source: BSC 2001

The Development / Intake Shaft, located near the South Main, provides intake airflow for the construction and development operations in the Subsurface Facility, and will be converted to an intake shaft for emplacement operations. The location of this shaft is listed in Table 4.

Table 4. Development / Intake Shaft Location for the Overall Subsurface Ventilation Layout

Development / Intake	Northing (m)	Easting (m)	Collar Elevation (m)
D / I	230,450	170,700	1,380

Source: BSC 2001

6.1.2 Flood Zones

The shafts have been located such that the shaft collars are situated outside the probable maximum flood plain zone (Criterion 4.2.1.2). Refer to the map in Figure 2. The outline of the flood plain represented in this figure came from the *Yucca Mountain Site Characterization Project Site Atlas 1997* (DOE 1997). From visual inspection of Figure 2 all shaft collars lie outside the probable maximum flood plain zone.

The flood plain outline shown in the atlas is in English units. To convert from English to metric, a factor of 1/3.28 was applied in order to be in the proper metric units for representation in the surface topography.

The flood plain outline is based on a 500-year flood, and is sufficient to meet the 300-year period of operation of the repository. A concern is to not provide a preferential pathway for surface water to enter the subsurface in the event of a flood. The shafts represented in this layout satisfy this criterion.

Previous flood plain mapping at Yucca Mountain was done in 1986 (Bullard 1986) and in 1992 (Blanton 1992). These two analyses produced maps of the Midway Valley in the vicinity of the North Portal Pad. These analyses should be reviewed and updated to reflect existing and planned surface modifications. Additional flood plain evaluation may be needed to include the entire repository footprint.

6.1.3 Minimum Geologic Standoffs

The shafts have been located such that they meet the required standoff distance of 60 meters from Type I Faults (Criterion 4.2.1.3). The shafts represented in this layout satisfy this criterion. A concern is to excavate the shafts without inducing adverse ground movement in the shaft. Locating and excavating the shafts away from Type I Faults can avert this possible adverse ground condition and at the same time mitigate a preferential pathway for surface water to enter the subsurface. Refer to Figure 3 to view the Type I Fault traces for the repository. These faults include the Bow Ridge Fault and the Solitario Canyon Fault. A 60 meter offset line was generated in this figure to show by visual inspection that all shafts meet this standoff criterion.

It should be noted that the elevation of the fault traces at the repository level for the primary block is approximately 1044 meters and the elevation of the fault traces at the repository level for the lower block is approximately 977 meters. These elevations were produced by Vulcan 3.4.

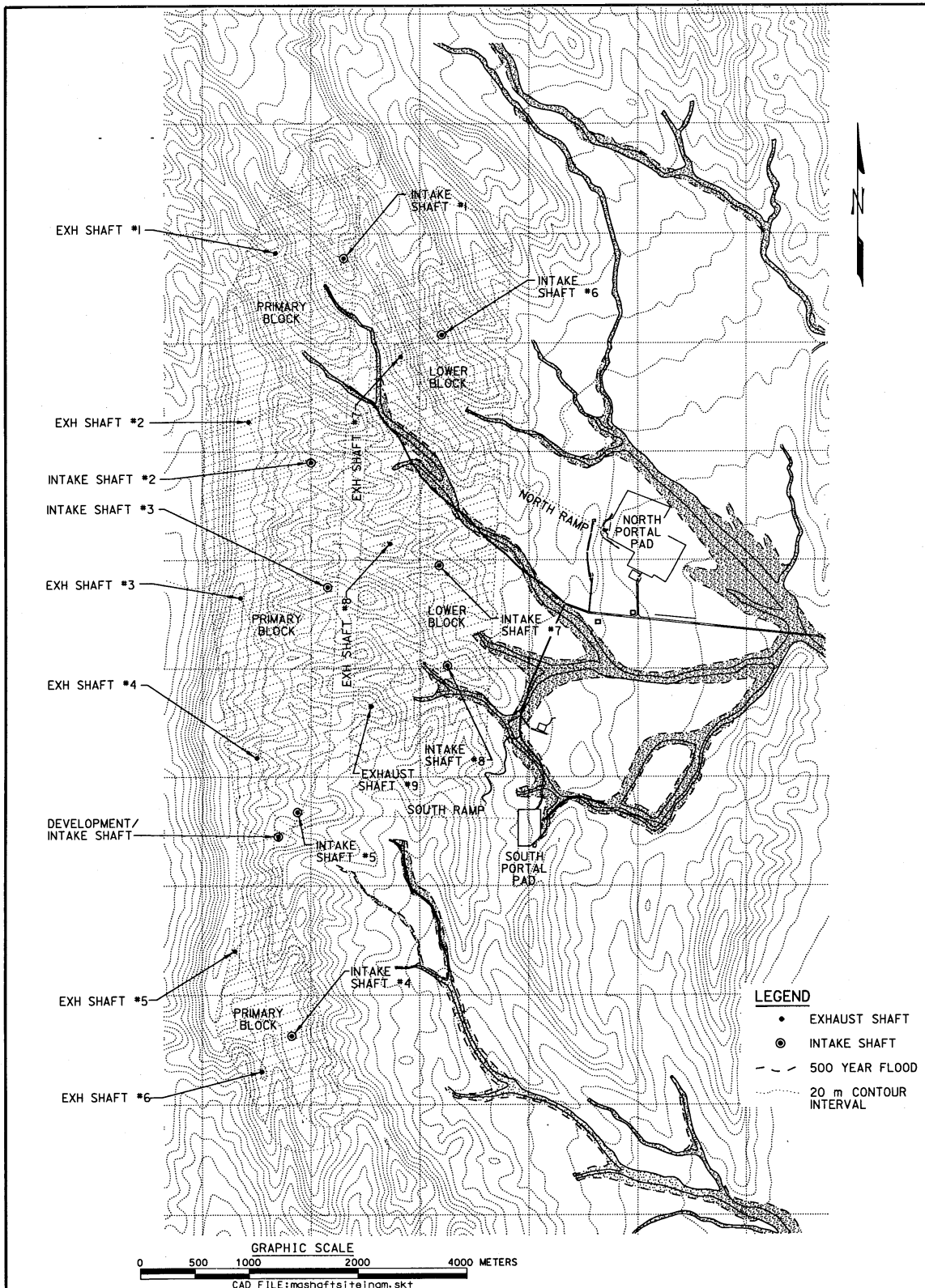
6.1.4 Secondary Escapeways

Upon completion of the excavation and construction of the shafts, a hoisting device will be installed to provide a means of shaft inspection. It is recommended that this hoisting system serve as a secondary escape at the intake shafts (Criterion 4.2.1.4) as well. The ability to evacuate via the intake shafts provides the necessary means to satisfy the need for a secondary escapeway. The shafts represented in this layout (see Figure 1) will satisfy the criterion.

During shaft excavation work each shaft will have a separate uniquely identified hoisting system to evacuate shaft construction personnel.

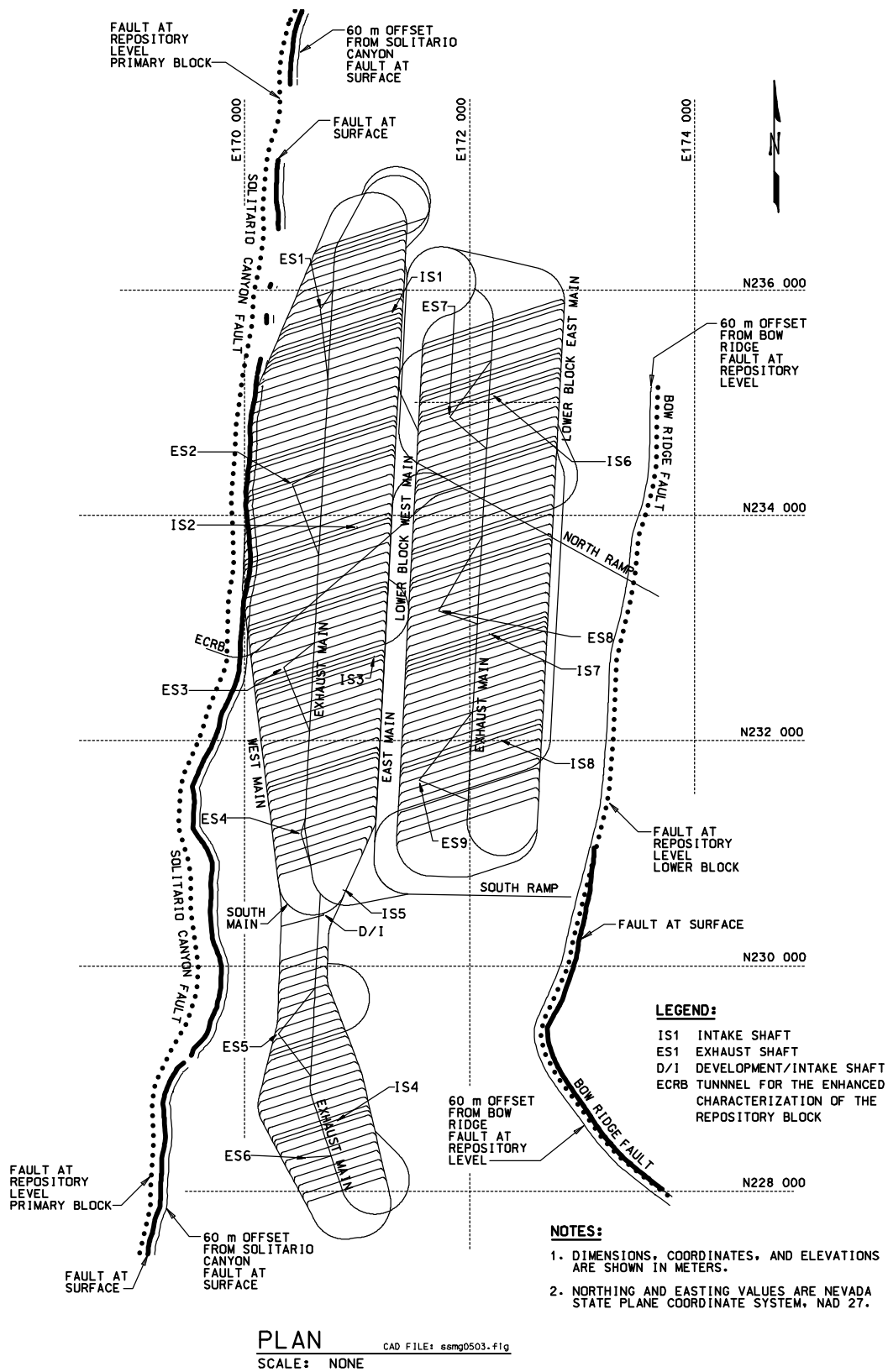
6.1.5 Groundwater and Radionuclide Migration

The shaft sinking method selected for excavation and construction should mitigate the creation of a preferential pathway for ground water to follow (Criterion 4.2.1.5). A concern is that the ground water could come in contact with the waste packages and provide a channel for radionuclide migration into the accessible environment. While a variety of shaft sinking methods are available there is little difference between them regarding the creation of a preferential water pathway. Shafts will be designed to include a lining and collar such as to deter preferential water channeling. The shafts represented in this layout (see Figure 1) will satisfy this criterion.



Repository layout modified from source: BSC 2001
 Flood plain taken from DOE 1997
 Topography taken from Vulcan 3.1

Figure 2. Shaft Location Relative to Flood Plain and Topography



Repository layout modified from source: BSC 2001
 Type I fault traces from Source: Vulcan 3.4

Figure 3. Shaft Locations Relative to Type I Fault Traces

6.1.6 Separation Between Intake and Exhaust Shafts

The minimum allowable distance from the intake shaft to the exhaust shaft is 100 meters (Criterion 4.2.1.6). This is to ensure that the subsurface ventilation main intake airways are located so as to minimize the potential for recirculation of subsurface air containing exhaust air to re-enter the repository via the intake shafts. The shafts represented in this layout satisfy this criterion. Refer to Figure 1. Refer also to Attachment IV for trigonometric calculation of distances between intake shafts and exhaust shafts.

Justification for the 100 meters separation distance criterion as documented in the Subsurface Ventilation SDD (CRWMS M&O 2000c). The 100 meters is appropriate from a radiological standpoint. For all other non-radiological gas emissions, the issue of 100 meters separation distance is site specific. Topics such as topography, elevation, wind speed and plume dispersion studies should be done to define the basis for separation distance.

6.1.7 Water Loss to the Subsurface Environment

The shaft sinking method selected for excavation and construction should minimize the amount of water used and the loss of water to the subsurface environment (Criterion 4.2.1.7). It is recognized that the application of water may be necessary for assisting in dust minimization and also as a cooling agent for the excavating equipment. Water used in shaft sinking will be pumped to the surface for proper retention located near the shaft collar. The shafts represented in this layout will satisfy this criterion.

6.1.8 Road Access to Shaft Sites

Before shaft construction can begin, access to the site is necessary. The construction of roads allows for heavy equipment used in shaft construction to better navigate the topography and reach the shaft site safely. Roads should be located so as to minimize the environmental impact to the area. Location of access roads should incorporate the following factors:

- Slope or grade of the finished road.
- Proper drainage control, including ditches and culverts.
- Berms for traffic safety where necessary.
- Widths or turnouts to accommodate two-way traffic.

A team of engineers from the Subsurface Facility Design Group visited the shaft sites in February 2001 (Sheridan 2001). An existing road provided access to the ridge crest of Yucca Mountain. From here, most shaft sites could be reasonably accessed by several existing intermediate roads. Road construction to the shaft sites would require varying degrees of improvement to handle the heavy construction trafficking necessary for shaft excavation work.

6.1.9 Surface Topography

Yucca Mountain is composed of irregularly shaped volcanic rock uplifts, generally trending north and south. Deep valleys, steep slopes and abrupt drop-offs characterize the topography. The uplifts are generally flat on top with some degree of tilting. Elevation changes and variations in topography are considerable within this area.

The shafts have been located such that they can be constructed with minimal concern for unfavorable topography. The shafts have been located on ground approaching level, such as broad saddles and flat uplifts. Individual shaft sites are shown in Attachment II and Attachment III to illustrate this consideration. Shaft sites located on the side of a slope can present difficult problems for shaft construction with regard to access, cut and fill, pad preparation and shaft excavation. The closer to level the shaft site area, the less difficult are the shaft construction tasks. It is recognized that a certain amount of cut and fill earthwork will be needed to accommodate construction of the shaft pads. Figure 2 shows the shaft sites relative to the topography. The topography used in this figure has been documented in *Determination of Available Repository Siting Volume for Site Recommendation* (CRWMS M&O 2000e). The surface contours can be cited back to the Data Tracking Number: MO0003MWDVUL03.002.

6.1.10 Pad Preparation Work

Most shaft pads will require a degree of site preparation prior to shaft construction and excavation. This may include topsoil removal and site leveling. Site location groundwork preparation should be minimized in order to reduce the difficulty of reclaiming the disturbed area. Pre-construction of the shaft pad site is necessary in order to have a level working area with which to operate shaft construction equipment and to provide room for material assembly.

6.1.11 Shaft Site Facilities Area of Occupancy

6.1.11.1 Shared Shaft Facilities

Several shaft facilities may be shared by other concurrent shaft site construction activities. This has the advantage of not only saving construction space at individual sites, but also minimizes the total number of support facilities for construction (Assumption 5.1.1).

Table 5 lists the shared construction facilities and recommended surface area they would occupy. The exact location of the shared facilities site has not been determined, but it is suggested to be located where access from the individual shaft sites is advantageous. These facilities may not be grouped together on a single location but may be grouped by the service they would provide.

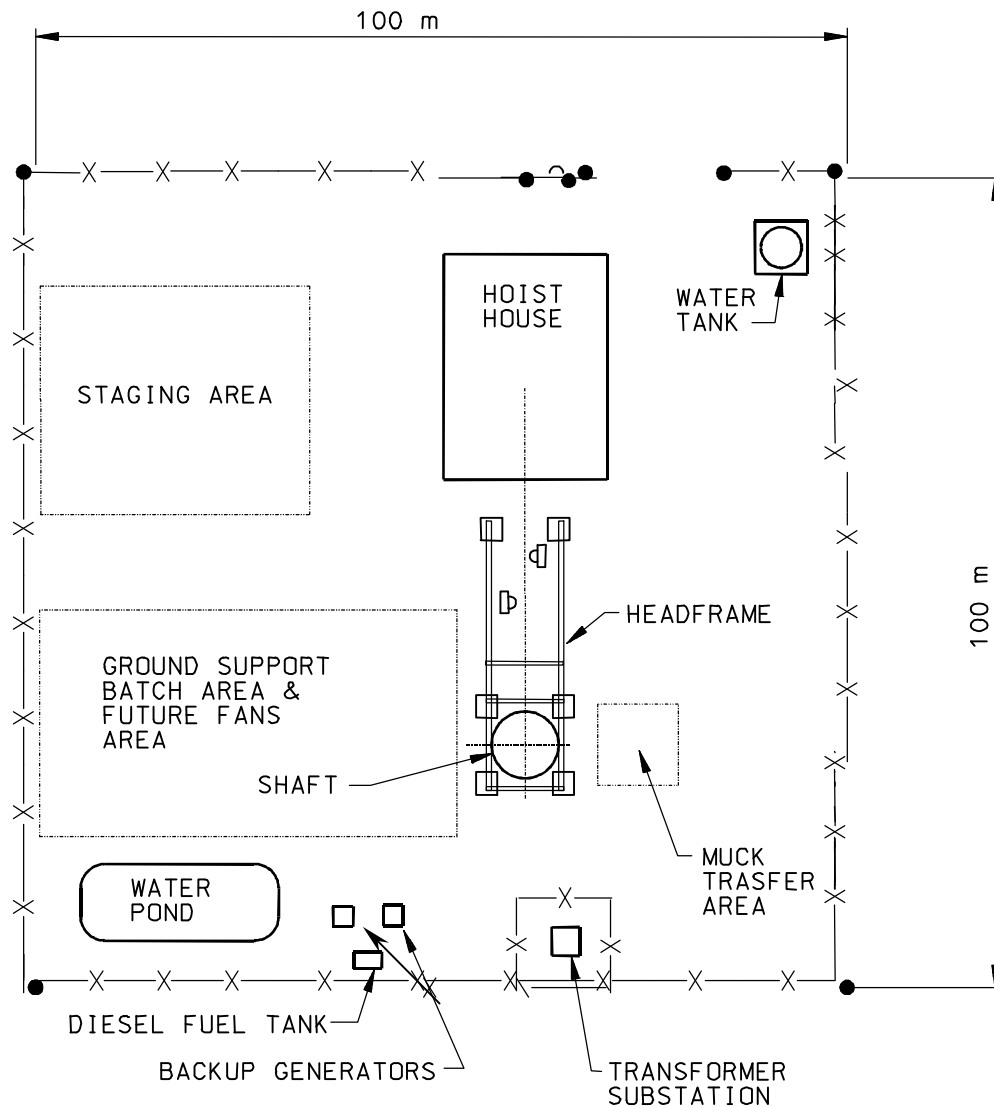
Table 5. Shared Shaft Construction Facilities

Facility	Recommended Footprint Surface Area	Total Area (m ²)
Miners Dry (change room)	4m x 15m	60
Office Trailer	4m x 15m	60
Water Tank (23,000 gal)	6.5m x 6.5m	42.25
Diesel Generators	2.5m x 2.5m	6.25
Mechanics Shop	5m x 7m	35
Electrical Shop	5m x 7m	35
Warehouse	5m x 18m	90
Material Laydown Area	50m x 40m	2,000
TOTAL		2,328.5

The footprint of a typical shaft pad size for construction is based on this analysis and was determined to be approximately 10,000 square meters. This could represent a pad size of 100 meters by 100 meters. The shaft sites need not necessarily be square. This size was derived by estimating the surface areas that the facility items and buildings will occupy and providing extra room with which to operate equipment. Specific arrangement of the pad facilities may require a more detailed analysis. Table 6 lists the typical site construction facility items and approximate surface area they would occupy (Assumption 5.1.1). Figure 4 shows the items listed in Table 6 in a proposed typical layout for construction purposes.

Table 6. Shaft Site Construction Facility Items

Facility Item	Recommended Footprint Surface Area	Total Area (m ²)
Hoist, Headframe, Galloway Winches (for construction)	60m x 22m	1,320
Supervisor/Engineer Trailer	5m x 3m	15
Shaft Top Lander Shack	5m x 3m	15
Transformer Substation	3.5m x 3.5m	12.25
Diesel Generators	2 @ 2.5m x 2.5m	12.5
Diesel Fuel Storage Tank	3.5m x 2.5m	8.75
Water Tank (23,000 gal)	6.5m x 6.5m	42.25
Waste Muck Storage (varies with site)	10m x 10m	100
Ground Support and Concrete Batching	45m x 35m	1,575
Water Retention Pond	6m x 6m	36
TOTAL		3,136.75



NOTES:

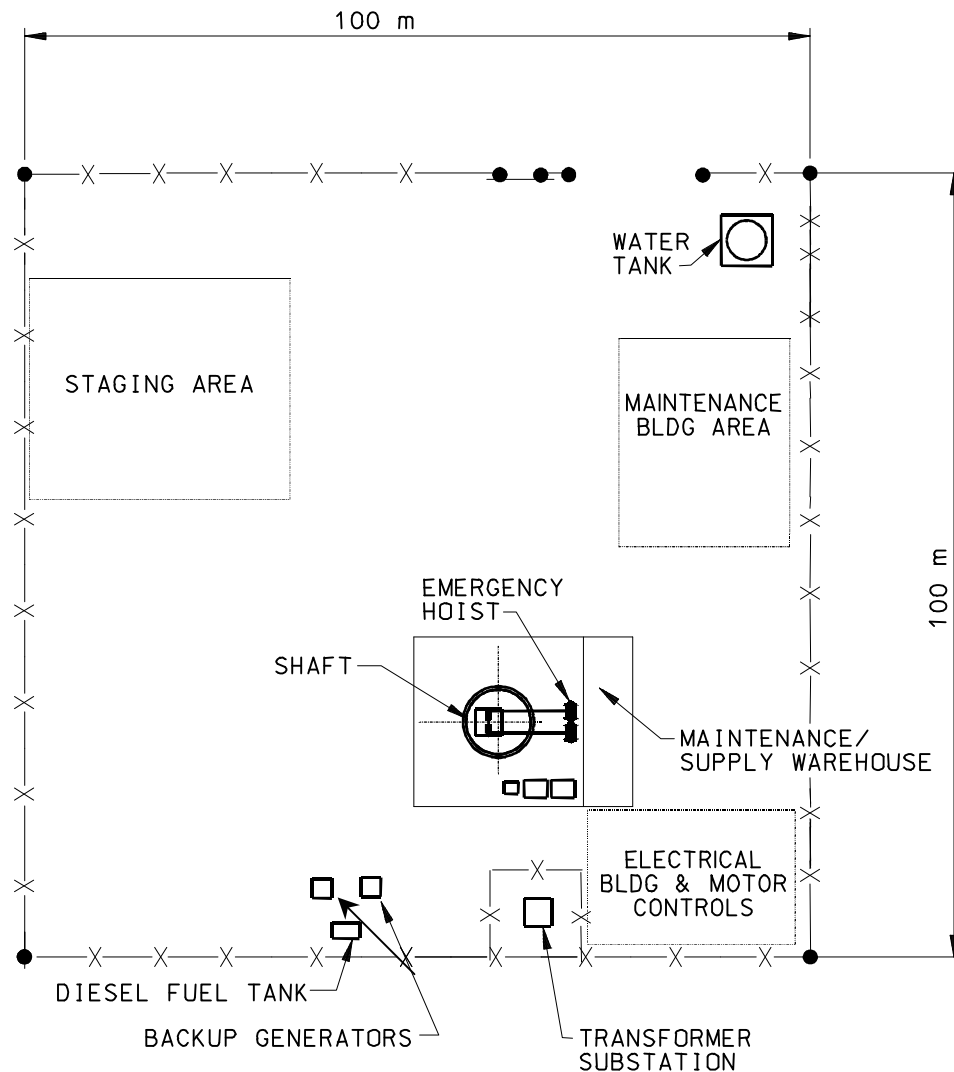
CAD FILE: ssmg0492a.fig

1. THIS FIGURE REPRESENTS A TYPICAL DIMENSIONAL LAYOUT.
2. ALL LAYOUTS WILL HAVE APPROXIMATELY 10,000 SQUARE METERS.

Figure 4. Shaft Site Surface Facilities Arrangement During Construction

6.1.11.3 Typical Shaft Site Items During Operation

When shaft excavation is completed, the shaft will be in operation as either an intake shaft or an exhaust shaft. Intake shaft sites in operation would have a layout similar to that shown in Figure 5. Exhaust shaft sites in operation would have a layout similar to that shown in Figure 6. Both intake and exhaust sites will be contained in the 100 meter by 100 meter pad area.

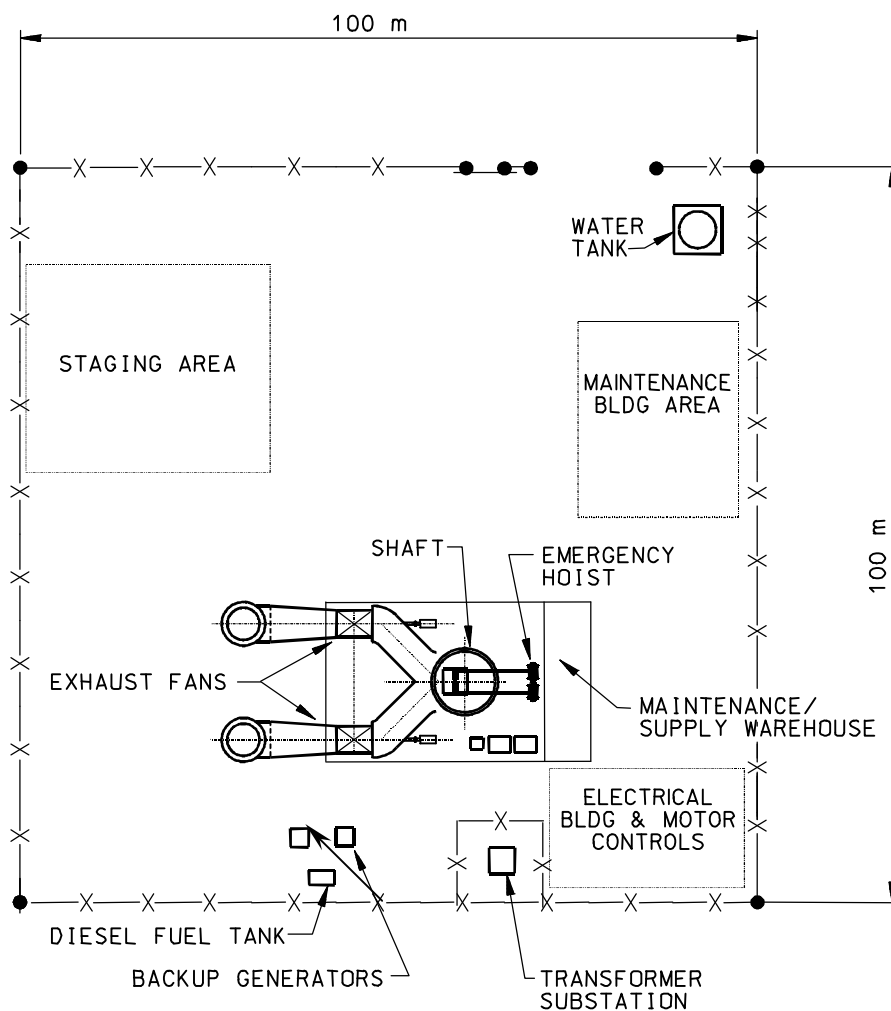


NOTES:

CAD FILE: ssmg0492c.fig

1. THIS FIGURE REPRESENTS A TYPICAL DIMENSIONAL LAYOUT.
2. ALL LAYOUTS WILL HAVE APPROXIMATELY 10,000 SQUARE METERS.

Figure 5. Intake Shaft Site Surface Facilities Arrangement During Operation



NOTES:

CAD FILE: ssmg0492b.fig

1. THIS FIGURE REPRESENTS A TYPICAL DIMENSIONAL LAYOUT.
2. ALL LAYOUTS WILL HAVE APPROXIMATELY 10,000 SQUARE METERS.

Figure 6. Exhaust Shaft Site Facilities Arrangement During Operation

6.1.12 Utility Distribution

Utilities needed for construction such as communications and electrical power distribution should be in place prior to shaft construction and excavation. A reason for this is that pre-installation of utilities can help to reduce delays in construction work. Installation of a centralized utility system serving many shaft sites can also help to assist in minimizing or duplicating unnecessary utilities. In-place power would provide such services as lighting and equipment operation. In-place communications would provide immediate contact for things such as medical response and expeditious personnel and materials delivery.

6.1.13 Excavated Shaft Rock Storage and Transfer

During shaft excavation, large volumes of excavated rock will be produced. The amount produced will occupy a significant area if wholly stored at the individual site. This would greatly increase the size of the construction pad for the shafts. In order to keep the shaft pad size to a minimum, this excavated material should be transferred to a designated storage area. A portion of excavated rock generated by shaft excavation may be temporarily stored at each shaft site until it can be transferred to a more permanent storage location. The amount stored would be limited to two weeks of shaft excavation waste (see calculation of quantity in Section 5.1.3). Some waste rock may be used for construction purposes such as pad leveling or roadwork. The balance of the waste rock produced will be transferred to a designated centralized waste rock stockpile (Assumption 5.1.2 and 5.1.3). By doing this, the storage area for the excavated rock at the shaft sites would be minimized and long-standing piles of waste rock could not pose environmental problems at the shaft site.

The excavated volumes of rock for both intake shafts and exhaust shafts of the overall subsurface ventilation layout are listed in Table 9 and Table 10 respectively. The excavated volume of rock from the Development / Intake shaft is listed in Table 11.

6.1.14 Shaft Construction Scheduling

The overall excavation of the subsurface facility is divided into construction panels. Each panel will have specific subsurface excavation work that needs to be completed in the time allowed. Shaft excavation will be scheduled for completion to support each panel's scheduled construction (Assumption 5.1.4).

In shaft sinking, conventional drill and blast has the advantage that shaft work can be conducted prior to or concurrently with subsurface activities making them available for use earlier in the construction schedule. Pre-existing subsurface openings are not required for this excavation method. This is a significant advantage in the initial panel construction period, when the need for subsurface ventilation air may be a limiting factor to progress.

Raise boring, although not capable of attaining the final proposed shaft diameters, may be used in conjunction with drill and blast. Where underground access exists, the initial pilot hole and ream hole can be bored and conventional drill and blast can then be used to slash out the shaft to the final diameter of 8 meters (CRWMS M&O 2000a, pg. IV-34).

Although the Vertical Mole (V-Mole) advance rates are faster than either drill and blast or raise boring during actual construction, the major scheduling constraint that influences V-Mole excavation is the need to have pre-existing underground access. This requirement could substantially delay the construction of mechanically excavated V-Mole shaft(s).

It is recommended that geotechnical boreholes be drilled for each shaft site prior to construction regardless of the shaft excavation method selected, to confirm the geologic and hydrologic rock mass properties. Scheduling the drilling of boreholes should take place after shaft site road access construction but prior to any pad preparation work. The geotechnical borehole should be drilled along or near the shaft center and be directionally surveyed to ensure accuracy of the borehole placement with depth.

In summation, of the three methods of shaft excavation described, only the V-Mole and the drill and blast techniques are viable stand-alone options for excavating the 8-meter diameter shafts designed for the repository. Should the shaft diameter change to a smaller diameter of 6 meters or less, raise boring should be reconsidered.

6.2 SHAFT LOCATION EVALUATION MATRIX

The criteria and assumptions used in the subsections of 6.1, General Shaft Siting and Configuration Discussion, were compiled into an evaluation matrix and each shaft evaluated. Refer to Tables 7 and 8 for this evaluation.

Interpretations of the numbers represented in the cells of the matrix are identified below.

- 1** Indicates that the shaft being evaluated meets the criterion/assumption.
- 2** Indicates that the shaft being evaluated does not meet the criterion/assumption.
- 3** Indicates that the shaft being evaluated will comply with the criterion/assumption at the time of construction / excavation.

Further explanations of the designations represented in the matrix tables are identified below.

IS1 for example represents "Intake Shaft 1".

ES1 for example represents "Exhaust Shaft 1".

D / I represents "Development / Intake Shaft".

Table 7. Intake Shaft Site Location Evaluation Matrix

Criteria Number and Description	IS1	IS2	IS3	IS4	IS5	IS6	IS7	IS8	D / I
4.2.1.1 Subsurface Ventilation System	1	1	1	1	1	1	1	1	1
4.2.1.2 Surface Openings Relative to Flood Areas	1	1	1	1	1	1	1	1	1
4.2.1.3 Minimum Geologic Standoffs	1	1	1	1	1	1	1	1	1
4.2.1.4 Escapeways	1	1	1	1	1	1	1	1	1
4.2.1.5 Groundwater and Radionuclide Migration	3	3	3	3	3	3	3	3	3
4.2.1.6 Separation Between Intake and Exhaust Shaft	1	1	1	1	1	1	1	1	1
4.2.1.7 Water Loss to the Subsurface	3	3	3	3	3	3	3	3	3
Consideration or Assumption Number And Description	IS1	IS2	IS3	IS4	IS5	IS6	IS7	IS8	D / I
Access Roads	3	3	3	3	3	3	3	3	3
Topographic Consideration	3	3	3	3	3	3	3	3	3
Pad Preparation Work	3	3	3	3	3	3	3	3	3
5.1.1 Shaft Site Facility Items	3	3	3	3	3	3	3	3	3
5.1.2 Excavated shaft Rock Swell Volume	3	3	3	3	3	3	3	3	3
5.1.3 Excavated Shaft Rock Storage and Transfer	3	3	3	3	3	3	3	3	3
5.1.4 Shaft Construction Scheduling	3	3	3	3	3	3	3	3	3
Pad Size	3	3	3	3	3	3	3	3	3
Utility Distribution	3	3	3	3	3	3	3	3	3

Table 8. Exhaust Shaft Site Location Evaluation Matrix

Criteria Number and Description	ES1	ES2	ES3	ES4	ES5	ES6	ES7	ES8	ES9
4.2.1.1 Subsurface Ventilation System	1	1	1	1	1	1	1	1	1
4.2.1.2 Surface Openings Relative to Flood Areas	1	1	1	1	1	1	1	1	1
4.2.1.3 Minimum Geologic Standoffs	1	1	1	1	1	1	1	1	1
4.2.1.4 Escapeways	1	1	1	1	1	1	1	1	1
4.2.1.5 Groundwater and Radionuclide Migration	3	3	3	3	3	3	3	3	3
4.2.1.6 Separation Between Intake and Exhaust Shaft	1	1	1	1	1	1	1	1	1
4.2.1.7 Water Loss to the Subsurface	3	3	3	3	3	3	3	3	3
Consideration or Assumption Number And Description	ES1	ES2	ES3	ES4	ES5	ES6	ES7	ES8	ES9
Access Roads	3	3	3	3	3	3	3	3	3
Topographic Consideration	3	3	3	3	3	3	3	3	3
Pad Preparation Work	3	3	3	3	3	3	3	3	3
5.1.1 Shaft Site Facility Items	3	3	3	3	3	3	3	3	3
5.1.2 Excavated shaft Rock Swell Volume	3	3	3	3	3	3	3	3	3
5.1.3 Excavated Shaft Rock Storage and Transfer	3	3	3	3	3	3	3	3	3
5.1.4 Shaft Construction Scheduling	3	3	3	3	3	3	3	3	3
Pad Size	3	3	3	3	3	3	3	3	3
Utility Distribution	3	3	3	3	3	3	3	3	3

6.3 SHAFT CONSTRUCTION COMPONENTS

6.3.1 Shaft Diameters, Lengths and Volumes

All the ventilation shafts will be excavated to a diameter of 8 meters (CRWMS M&O 2000a, pg. IV-34), based on the largest shaft size necessary to support the subsurface ventilation system and to standardize the equipment size required for shaft excavation. The length, in-place volume and swell volumes of intake and exhaust shafts for the overall subsurface ventilation layout are shown in Table 9 and Table 10 respectively.

Table 9. Intake Shaft Depths and Volumes for the Overall Subsurface Ventilation Layout

Shaft Number	Shaft Depth (m)	Shaft Sump (m)	Total Shaft Depth (m)	Total Volume In-place (m ³)	Total Volume Swelled (m ³)
I1	386.4	5.0	391.4	19,675.7	26,234.3
I2	321.9	5.0	326.9	16,433.3	21,911.1
I3	275.4	5.0	280.4	14,095.7	18,794.3
I4	289.2	5.0	294.2	14,789.4	19,719.2
I5	283.4	5.0	288.4	14,497.9	19,330.5
I6 (L)	334.7	5.0	339.7	17,076.7	22,768.9
I7 (L)	275.9	5.0	280.9	14,120.8	18,827.7
I8 (L) ^a	272.9	5.0	277.9	13,970.8	18,627.7
Totals	2,439.8	40	2,479.8	124,660.3	166,213.7

NOTE: All shafts are 8 meters in diameter.

^a Denotes contingency shaft

Source: Refer to Input 4.1.2 and Assumption 5.1.2

Modified from source: BSC 2001

Table 10. Exhaust Shafts Depths and Volumes for the Overall Subsurface Ventilation Layout

Shaft Number	Shaft Depth (m)	Shaft Sump (m)	Total Shaft Depth (m)	Total Volume In-place (m ³)	Total Volume Swelled (m ³)
E1	404.8	5.0	409.8	20,600.6	27,467.5
E2	391.7	5.0	396.7	19,942.1	26,589.5
E3	371.6	5.0	376.6	18,931.7	25,242.3
E4	315.5	5.0	320.5	16,111.5	21,482.0
E5	340.5	5.0	345.5	17,368.3	23,157.7
E6	261.4	5.0	266.4	13,391.9	17,855.9
E7 (L)	345.0	5.0	350.0	17,594.5	23,459.3
E8 (L)	337.5	5.0	342.5	17,217.5	22,956.7
E9 (L)	370.9	5.0	375.9	18,898.7	25,198.3
Totals	3,138.9	45	3,183.9	160,056.8	213,409.2

NOTE: All shafts are 8 meters in diameter.

Source: Refer to Input 4.1.2 and Assumption 5.1.2

Modified from source: BSC 2001

The length, in-place volume and swell volume of the Development / Intake shaft is shown in Table 11.

Table 11. Development / Intake Shaft Depth and Volumes for the Overall Subsurface Ventilation Layout

Shaft Number	Shaft Depth (m)	Shaft Sump (m)	Total Shaft Depth (m)	Total Volume In-place (m ³)	Total Volume Swelled (m ³)
D / I	282.7	5.0	287.7	14,462.7	19,283.6

NOTE: All shafts are 8 meters in diameter.

Source: Refer to Input 4.1.2 and Assumption 5.1.2

Modified from source: BSC 2001

6.3.2 Shaft Collars

The shaft collar is the upper part of the shaft constructed of concrete and extending from the surface to the first footing. The shaft collar must be anchored in competent rock since it will provide the foundation with which to support the headframe and equipment used for shaft excavation. The shaft collar also is the first line of defense for keeping surface water from entering the shaft. Grading around the shaft collar should be in the direction away from the shaft collar.

Shaft construction begins by the excavating and forming of the shaft collar. The shaft collar provides the necessary stability and alignment for the length of the shaft to be excavated. When the shaft collar is completed, the headframe, sheave deck, and hoisting facilities for the excavation can be erected.

The construction of the shaft collar depends upon the following parameters:

- Shaft depth.
- Cross-section or diameter of the shaft.
- Collar thickness required.
- Shaft function (i.e., ventilation, muck hoisting, personnel and materials hoisting).
- Overburden rock properties.
- Hydrologic conditions and resulting water and ground pressures.
- Excavation method to be used.
- Additional loading from the headframe and from the foundations of nearby structures.

Standard excavation construction methods can be used to construct the collar to its full depth. Rock is excavated in combination of jackhammers, mechanical excavators, or explosives. The excavated rock or muck, is removed by backhoes and front-end loaders, and where beyond their reach, by bucket and mobile crane.

Shaft collar construction will vary depending on the excavation method, the design and requirements of the headframe structure. In conventional drill and blast construction, the headframe must be designed to allow for high-speed hoisting of muck. This constraint necessitates a more substantial shaft collar than for a V-Mole operation. The hoisting system for the V-Mole operation is designed only for personnel and material hoisting.

6.3.3 Shaft Stations

The shaft station is the opening that provides access at the bottom of the shaft to the underground access tunnel. Standard methods of conventional drill and blast or mechanical excavation can be used to excavate the shaft station.

When conventional drill and blast excavation construction is used, the shaft station can be partially or fully constructed from within the confines of the shaft as the shaft progresses from the upper to lower station limits. Initial excavation to form the station takes place when the shaft floor penetrates several meters below the crown of station.

When mechanical excavation construction is used, the shaft station is excavated when establishing the subsurface access to the shaft bottom. The shaft station design needs to be more elaborate for demobilizing the V-Mole or for setting up the raise bore drill, including muck removal, than for conventional drill and blast shaft excavation.

6.3.4 Shaft Sumps

At the bottom of the shafts are extended excavations called shaft sumps. These sumps are designed to extend 5 meters deeper than the floor of the shaft station. The purpose of the shaft sump is to provide collection and containment of water entering the subsurface via the shaft itself. Any water that is collected can then be pumped to the surface into an appropriate retention facility. Shaft sumps are generally equipped with backup pumps in the event that excessive water collects in the sump or the primary pump becomes inoperable.

6.3.5 Ground Support and Linings

It is common mining practice to line the excavated shaft with concrete. In North America, it is the mining industry standard for circular shafts because of the ease and relative economy of placement with techniques commonly used by contractors and the relative ease with which items can be embedded or anchored as the concrete forms are set. Cast-in-place concrete, without reinforcement, has been used as a traditional lining method in many shafts. The installation of the concrete liner lags somewhat behind the excavation face of the shaft. The structural role of a shaft liner is passive. It has little effect on the ground stresses in the surrounding rock. Shaft liners serve five primary functions. These are listed below.

- Prevents the wall rock of the shaft from unraveling or sloughing.
- Ensures safe travel of men and materials.
- Provides an anchor for shaft steel and utility hangers.
- Provides a smooth wall for more efficient ventilation characteristics.
- Protects the wall rock from the effects of weathering.

The design of cast-in-place shaft lining is independent of the method of shaft construction. It is the timing of the shaft lining placement and the method of placement that may affect the shaft construction excavation cycles and/or schedules. A number of methods of placing a concrete liner are available. These options include forming the concrete lining from the shaft collar, concurrent with shaft excavation, or a continuous slip forming of the concrete lining from the shaft bottom upon completion of the shaft excavation.

6.3.6 Headframes

Headframes are surface structures mounted over the top of the shafts and are used for hoisting of personnel, materials, and the hoisting of muck during excavation which provide the means to support the shaft sinking equipment. Headframes are built of steel, concrete or a combination of steel and concrete. Steel headframes typically increase in cost exponentially to the height, where as concrete headframes increase in costs nearly linearly to the height (de la Vergne 2000, Chapter 16, pg. 199) when the height is less than approximately 160 feet.

Concrete headframes can weigh up to a factor of ten times more than that of a steel headframe of equal design parameters. Due to this, steel headframes may be favored in construction over a concrete headframe in a seismically active area.

Table 12 shows the relative advantages of steel and concrete headframes.

6.3.7 Fan Ducting

Conceptually, a dual fan installation atop of the ventilation shaft would provide flexibility to the system by allowing the airflow from one, or both fans to be adjusted to system conditions as stated in *Overall Subsurface Ventilation System* (CRWMS M&O 2000d). The fans and necessary ducting would be mounted similarly as depicted in Figure 7.

Table 12. Relative Advantages of Steel and Concrete Headframes

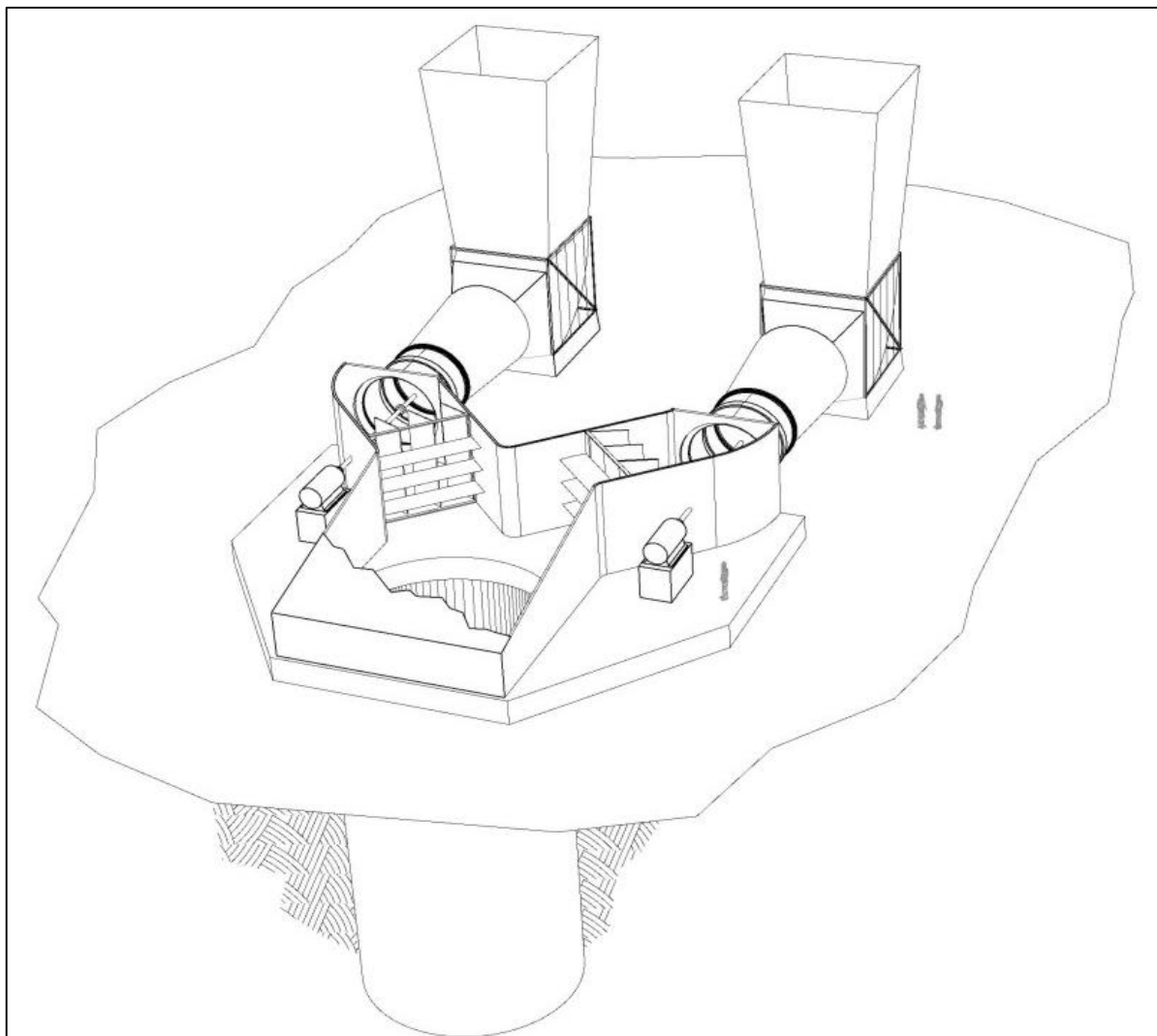
Advantages of Steel Headframe

- Usually less expensive than a concrete headframe.
- Considerably lighter, requires less foundation.
- Simpler to design.
- Can be designed to withstand seismic loads.
- Construction can be interrupted by work schedules without detrimental effects.
- Quality control of steel fabrication is done at the steel mill site under "shop conditions".
- Easier to re-plumb for verticality if foundation shifts.
- May have salvage value at end of its use.

Advantages of Concrete Headframe

- Less maintenance and less susceptible to corrosion.
- Provides shaft enclosure upon completion.
- Less susceptible to vibration.
- Less susceptible to sway in high winds.
- Can be designed to withstand seismic loads.
- Less susceptible to accidental crash damage.
- Quality control of concrete is performed in "field conditions".
- Once concrete pouring begins, interruptions can be detrimental.
- May take up less surface area for construction.

Source: de la Vergne 2000



Source: CRWMS M&O 2000d

Figure 7. Conceptual Dual Fan Installation

6.4 SHAFT EXCAVATION METHODOLOGIES

There are essentially three methods of shaft excavation used in the mining industry. These methods are raise boring, vertical mole and drill and blast. Each of these methods is briefly described in the following sections. These methods were chosen since they have the capability of

excavating large diameter shafts. However, only the V-Mole and the drill and blast techniques are viable stand-alone options for excavating the 8-meter diameter shafts designed for the repository. Raise boring, although not capable of attaining the final proposed shaft diameters, may be used in conjunction with drill and blast. Where underground access exists, the initial pilot hole and ream hole can be bored and conventional drill and blast can then be used to slash out the shaft to the final diameter of 8 meters (CRWMS M&O 2000a, pg. IV-34).

6.4.1 Raise Boring

Raise boring has been used to drill shafts ranging in moderate inclinations from horizontal to vertical, with the majority of applications involving large-diameter holes steeper than 45°. Shaft excavation using raise-boring techniques requires that underground access be completed prior to drilling. The shaft station should be sufficiently large enough in order to attach the reamer cutting head. The sequence begins by first drilling a pilot hole to intercept the shaft station. The pilot hole drill bit is removed and a large diameter reamer cutting head is installed in its place. The cutting head is then pulled upward to the surface using rotation and thrust. Drill cuttings from the reaming operation fall to the bottom of the shaft station, where the reaming cutter head was installed, and are removed by underground mucking techniques.

Larger diameter holes require the use of multiple stage (sequentially larger) reaming by installing a slightly larger diameter cutting head in successive passes until the desired diameter is reached. Shafts using raise-boring techniques are commonly unlined since raise drilling is typically used in relatively competent formations as found in *Shaft Construction Methodologies* (CRWMS M&O 1999b).

Raise boring if used, would deploy techniques that would satisfy Criterion 4.2.1.4, Criterion 4.2.1.5, Criterion 4.2.1.6 and Criterion 4.2.1.7.

The raise boring method of shaft excavation has been discussed and evaluated in a previous study for its application to deep geologic repositories (Golder Associates 1989) and in *Repository Shafts and Ramps Facility Concepts* (CRWMS M&O 1993, pp. 5-80 to 5-83). The *SME Mining Engineering Handbook* (Hartman, H.L., ed. 1992, Section 22.1.4.4) also provides detailed descriptions of this shaft construction method.

6.4.2 Vertical Mole

Vertical Mole or V-Mole shaft excavation is based on the utilization of a pre-drilled central borehole for the removal of muck and for vertical alignment. Operationally, it is similar to a horizontally mounted tunnel bore machine (TBM). Excavation of the central borehole by raise drilling methods requires prior excavation to an underground access. The sequence begins by drilling a pilot hole followed by excavating the central borehole by raise drilling. The V-Mole then begins at the top of the shaft and reams down the central borehole to the bottom to obtain the full shaft diameter. The drill cuttings fall down through the pre-drilled raise bore hole and are removed by underground mucking techniques.

The use of the V-Mole requires that the ground conditions are stable enough to allow the shaft wall support to follow behind the cutting face as it is installed from a working deck at the top of the machine. The ground also must be competent enough to withstand the pressure of the gripper pads. The shaft lining can be placed from work platforms located above the gripper assembly of

the V-Mole, which provides a continuous excavation lining cycle, or the shaft lining could be deferred until after the shaft excavation is complete as found in *Shaft Construction Methodologies* (CRWMS M&O 1999b). Figure 8 shows an elevation view of a typical V-Mole with hoisting.

Although the Vertical Mole (V-Mole) advance rates are faster than either drill and blast or raise boring during actual construction, the major constraint that influences V-Mole excavation is the need to have pre-existing underground access. This requirement could substantially delay the construction of mechanically excavated V-Mole shaft(s).

V-Mole if used, would deploy techniques that would satisfy Criterion 4.2.1.4, Criterion 4.2.1.5, Criterion 4.2.1.6 and Criterion 4.2.1.7.

The V-Mole method of shaft excavation has been discussed and evaluated in previous studies for its application to deep geologic repositories (Gonano et al. 1982, Section 4.3.5; Golder Associates 1989; and (CRWMS M&O 1993, pp. 5-87 to 5-90). The *SME Mining Engineering Handbook* (Hartman, H.L., ed. 1992, Section 22.1.4.3) also provides detailed descriptions of this shaft construction method.

6.4.3 Drill and Blast

Shaft construction using conventional drill and blast techniques is a blind construction method, where the broken rock, also referred to as muck, and any water encountered is removed upward through the shaft itself. Blind refers to the absence of a bored hole from surface to an underground access that provides direction and verticality guidance for the construction equipment. These conventional construction methods consist of simultaneous face advancing and permanent lining in competent rock without temporary support, or with temporary support in weak, unstable rock. This method of shaft construction consists of repeating cycles of face advancement. These cycles are:

- 1) Drilling and Blasting
- 2) Muck Removal
- 3) Ground Support and Lining Installation

In the case of the repository subsurface facility, this method can be operated as an independent activity with little interface required to other activities or personnel in the subsurface facility as found in *Shaft Construction Methodologies* (CRWMS M&O 1999b). In shaft sinking, conventional drill and blast has the advantage that shaft work can be conducted prior to or concurrently with subsurface activities making them available for use earlier in the construction schedule. Pre-existing subsurface openings are not required for this excavation method. This is a significant advantage in the initial panel construction period, when the need for subsurface ventilation air may be a limiting factor to progress.

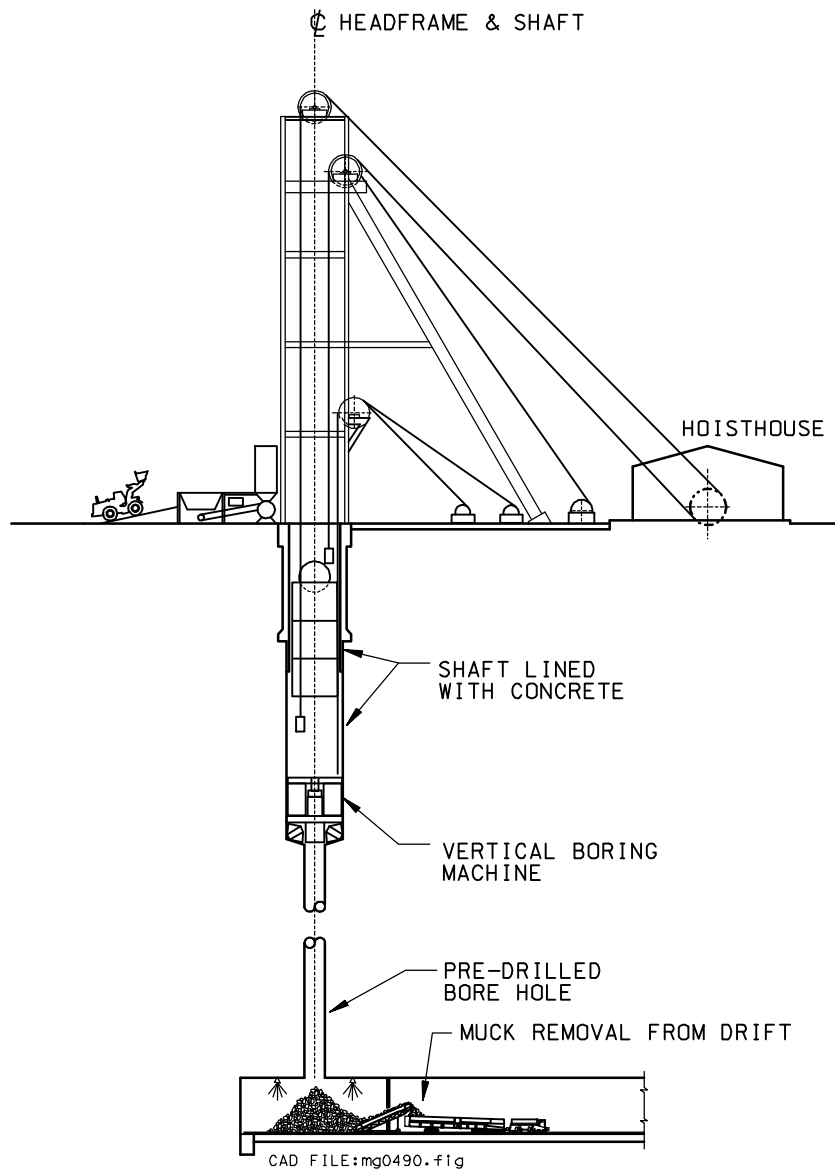


Figure 8. Section View of Vertical Mole

Using controlled blasting techniques can minimize blast damage. Rock damage can be limited to less than 3 feet. A tolerance of 3 feet (approx. 1 meter) is recommended. Rock fracture damage should be checked by refractive techniques (Van Eeckhout 1987).

Drill and blast if used, would deploy techniques that would satisfy Criterion 4.2.1.4, Criterion 4.2.1.5, Criterion 4.2.1.6 and Criterion 4.2.1.7.

Conventional drill and blast method of shaft excavation has been discussed and evaluated in previous studies for its application to deep geologic repositories (Gonano et al. 1982; Bertram 1984; and Golder Associates 1989). The *SME Mining Engineering Handbook* (Hartman, H.L., ed. 1992, Section 17.4.2.2) also provides detailed descriptions of this shaft construction method.

7. CONCLUSIONS

The objectives stated in the purpose have been discussed and analyzed. The criteria and the assumptions used were incorporated into a matrix table in order to make an assessed evaluation. The results from the matrix indicate that the shaft sites either meet current criteria or will meet the criteria prior to or during shaft construction work. There are no conditions at this time that do not or will not meet a stated criteria or assumptions. This evaluation satisfies the purpose and scope of the document.

The criteria excerpted from the SDD's have been appropriately addressed and are discussed as follows:

Criterion 4.2.1.1, Subsurface Ventilation, is satisfied since the overall layout of shaft locations and diameter of the shafts, meet the necessary ventilation requirements.

Criterion 4.2.1.2, Surface Openings Relative to Flood Areas, is satisfied since all shafts locations are located well outside of the maximum probable flood plains.

Criterion 4.2.1.3, Minimum Geologic Standoffs to Repository Openings, is satisfied by visual inspection of Figure 3 since all shafts are at a minimum of 60 meters away from Type I Faults. The distance value will need to be verified.

Criterion 4.2.1.4, Secondary Escapeways, is satisfied since the intake shafts will have hoisting capability for evacuation of personnel.

Criterion 4.2.1.5, Groundwater and Radionuclide Migration, will be satisfied since the shafts will be located 60 meters away from Type I Faults. Appropriately sized shaft collars will be constructed. Grading away from the shaft collar will be performed. The use of water will be limited. These construction designs will assist in limiting a preferential pathway for water.

Criterion 4.2.1.6, Separation Between Intake and Exhaust Shafts, is satisfied since the overall layout has located the intake shafts a minimum of 100 meters from the exhaust shafts. The nearest distance between two shafts is 425 meters. The distance value of 100 m will need to be verified.

Criterion 4.2.1.7, Water Loss to the Subsurface, is satisfied since shaft excavation methods will minimize the use of water and that which is used will be pumped to the surface and retained. The amount of water usage has not been specified.

It is suggested that shaft sites be examined on an individual basis. Due to the irregularity of the topography, not all sites will be constructed in the same way. It is recognized that preliminary selection of the shaft location and the pad size may be altered in order to facilitate shaft construction.

The scheduling of excavation may have an impact to the type of shaft excavation method selected. For example, methods employing raise bore and V-Mole techniques will require that subsurface access work to the shafts be completed prior to using these methods. This may also

include a means for removing the excavated shaft waste as well. Drill and blast techniques, on the other hand, are not dependent upon pre-existing subsurface work and the excavated waste rock can be brought up the shaft to the surface for storage.

It is recognized that a more detailed analysis should be made to further study the individual shaft sites with emphasis on earthwork. The objectives of the earthwork should focus on specific cut and fill quantities to accommodate the room necessary for shaft construction work.

It is also recognized that a detailed analysis should be made to establish the network of access roads to the individual shaft sites. The focus should be on maximizing the road system while minimizing the cut and fill work.

Detailed analyses should also be made with respect to the type of headframe selected for construction. Both steel and concrete headframes offer advantages and disadvantages related to cost, ease of construction, intended use and maintenance.

7.1 DESIGN REQUIREMENTS

7.1.1 Escapeways

Upon completion of shaft construction, a hoisting system could be installed to provide for secondary escape for the intake shafts. This design attribute will satisfy Criterion 4.2.1.4.

7.1.2 Shaft Pad Size

The shaft facility items and the equipment used in shaft construction and excavation will be contained within the 10,000 square meter pad area. The post-construction operation of shafts as either an intake or exhaust shaft will also need to be contained within this same size area.

7.1.3 Excavated Shaft Rock Transfer

With the exception of temporary storage (equal to 2 weeks worth of shaft excavation of approx. 3,000 m³) at the shaft sites and use in shaft pad work or roads, the remaining volume of excavated rock should be transferred from the shaft site to a designated area for more permanent storage.

7.1.4 Shaft Construction Size

All the ventilation shafts, regardless of case layout scenario or excavation method selected, will be excavated to a diameter of 8 meters (CRWMS M&O 2000a, pg. IV-34), based on the largest shaft size necessary to support the subsurface ventilation system.

7.1.5 Individual Shaft Ventilation During Construction

Shaft excavations during the construction phase would be ventilated by a local ventilation system that would intake fresh air from the surface.

7.1.6 Topsoil Salvaging

In Section 6.1.10, it is briefly mentioned that topsoil removal may be done as part of the work needed for pad preparation. Salvaging topsoil provides the means with which to assist in reclaiming the shaft site and is appropriate in order to have the shaft construction foundation established on competent ground.

7.2 CONSTRUCTION SCHEDULING

7.2.1 Access Roads

Access roads to the shaft sites will need to be completed prior to shaft construction. The construction of access roads is necessary for the heavy equipment used in shaft construction to better navigate the topography and reach the shaft site safely.

7.2.2 Utilities Distribution

Utilities such as electrical distribution and communications should be in place prior to shaft construction in order to facilitate expeditious construction and efficient use of materials.

7.2.3 Shaft Pad Preparation

The shaft pad area should be prepared prior to shaft construction. This work may involve some topsoil stripping, road access and site leveling by cut and fill. Construction of the shaft pad site is necessary in order to have a level working area with which to operate shaft construction equipment and to provide room for material assembly.

7.2.4 Shaft Construction

Of the three methods of shaft excavation described, only the V-Mole and the drill and blast techniques are viable stand-alone options for excavating the 8-meter diameter shafts designed for the repository. Should the shaft diameter change to a smaller diameter of 6 meters or less, raise boring should be reconsidered.

Drill and blast techniques can be executed without pre-existing subsurface access in place, therefore providing an advantage in shaft scheduling. Both V-Mole and raise boring techniques require a substantial amount of pre-existing subsurface work be in place, thus deferring scheduling of shaft construction.

7.2.5 Geotechnical Boreholes

Geotechnical boreholes should be drilled for each shaft site prior to construction regardless of the excavation method selected, to confirm the geologic and hydrologic rock mass properties. The geotechnical borehole should be drilled along or near the shaft center and be directionally surveyed to ensure accuracy of the borehole placement with depth.

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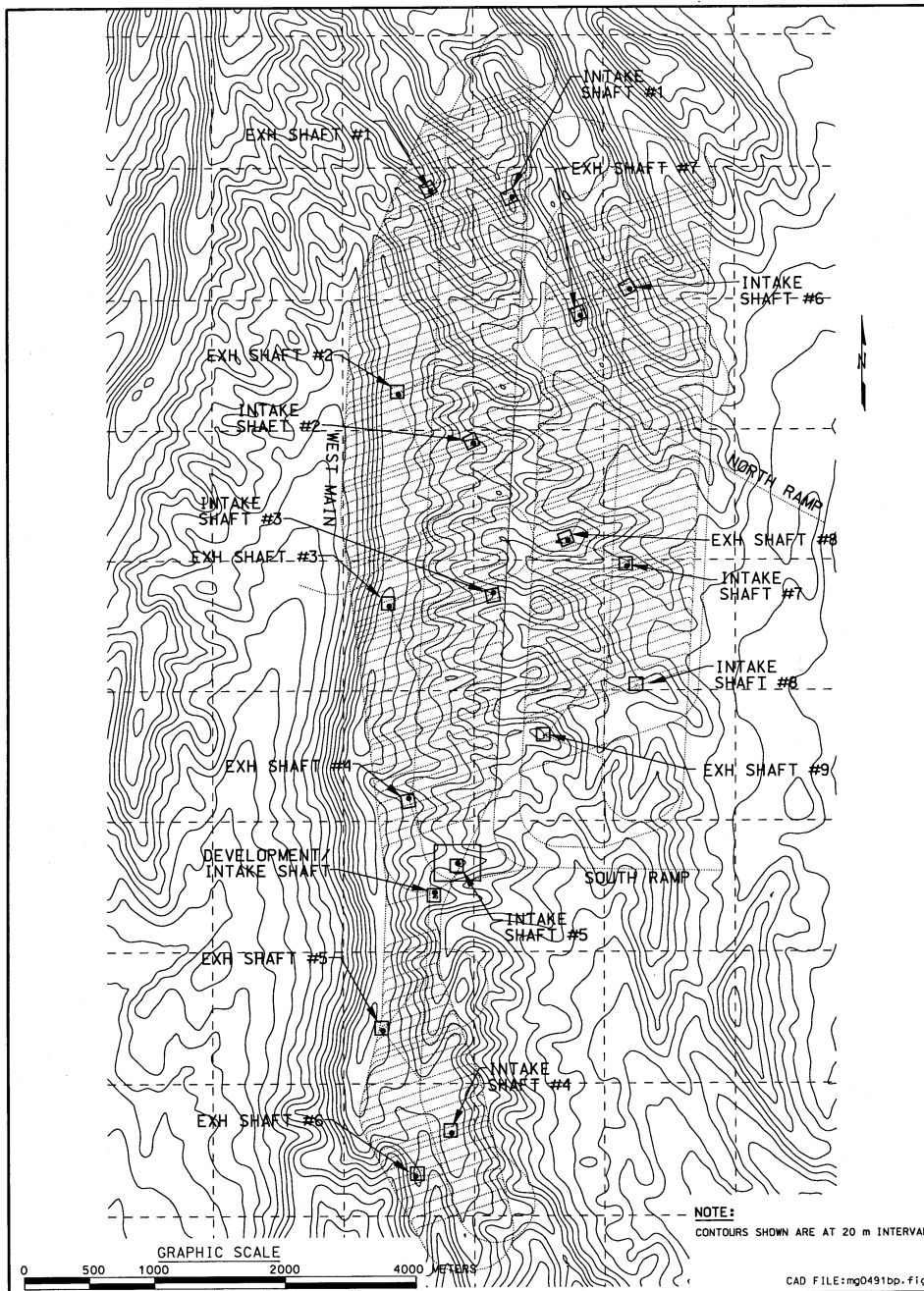
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ATTACHMENT I
OVERALL SHAFT SITES LAYOUT ORIENTATION

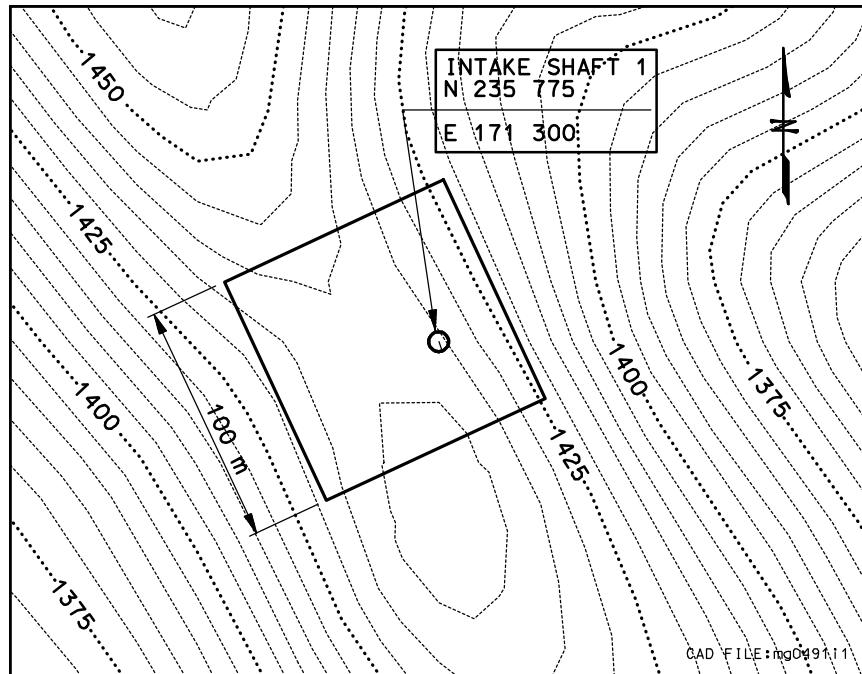


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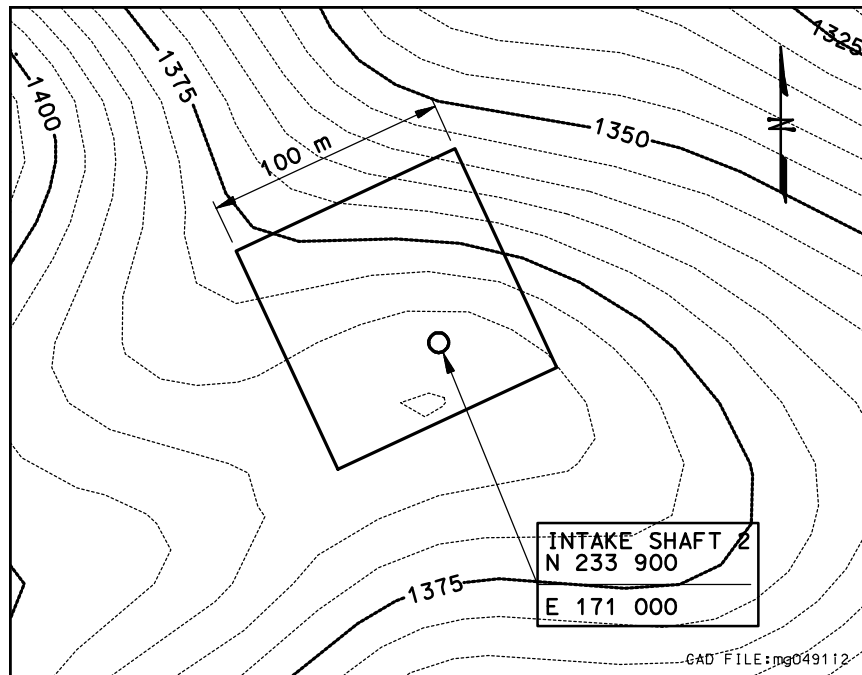
Topography modified from source VULCAN 3.1
Repository modified from source: BSC 2001

Overall Shaft Sites Layout

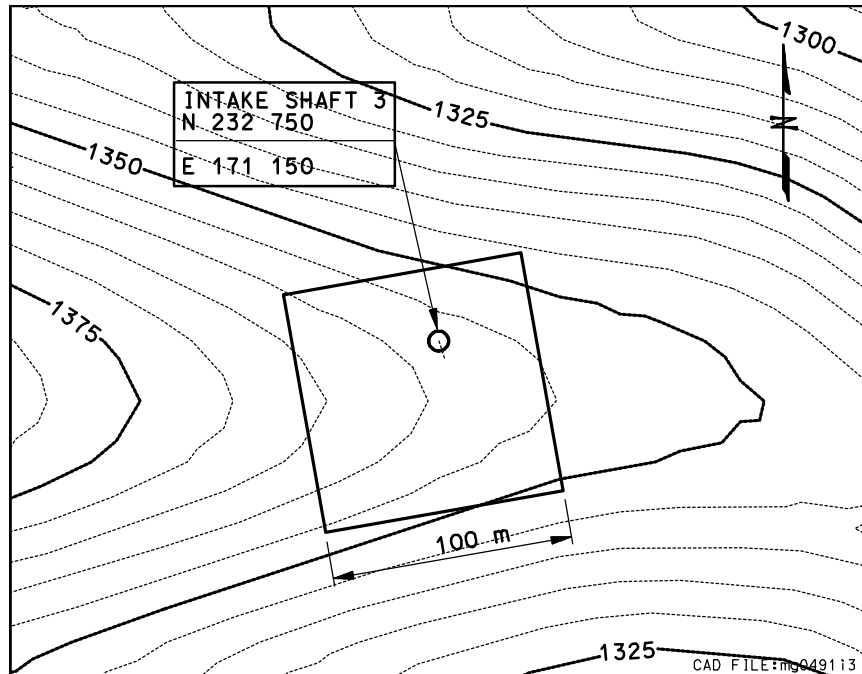
ATTACHMENT II
INTAKE SHAFTS SITE LAYOUTS ORIENTATION



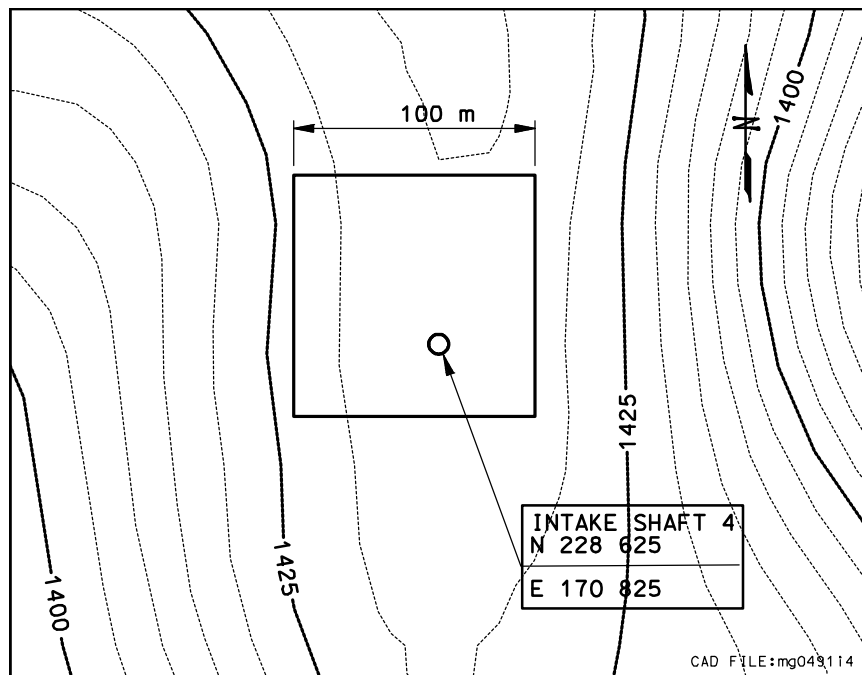
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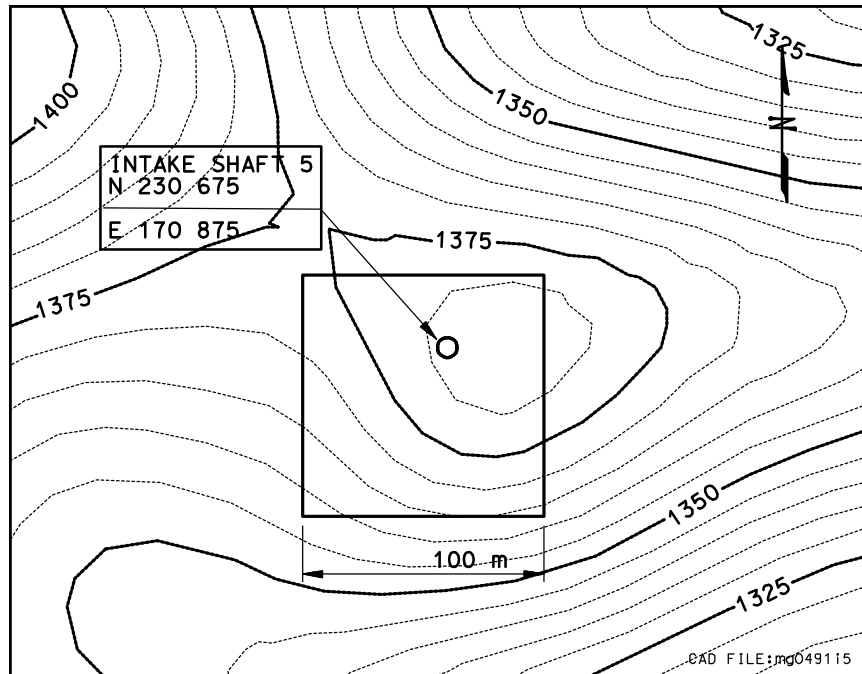
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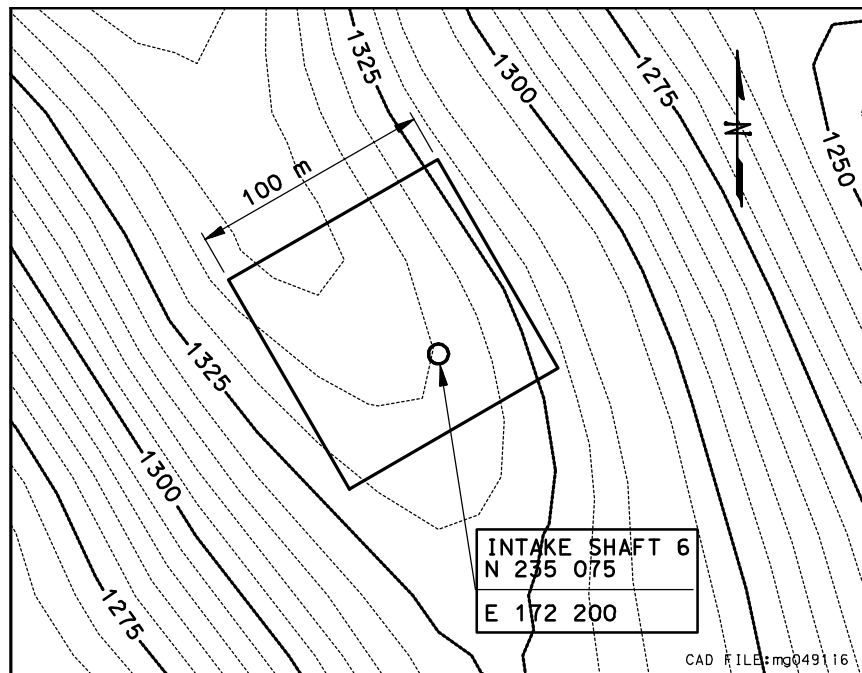
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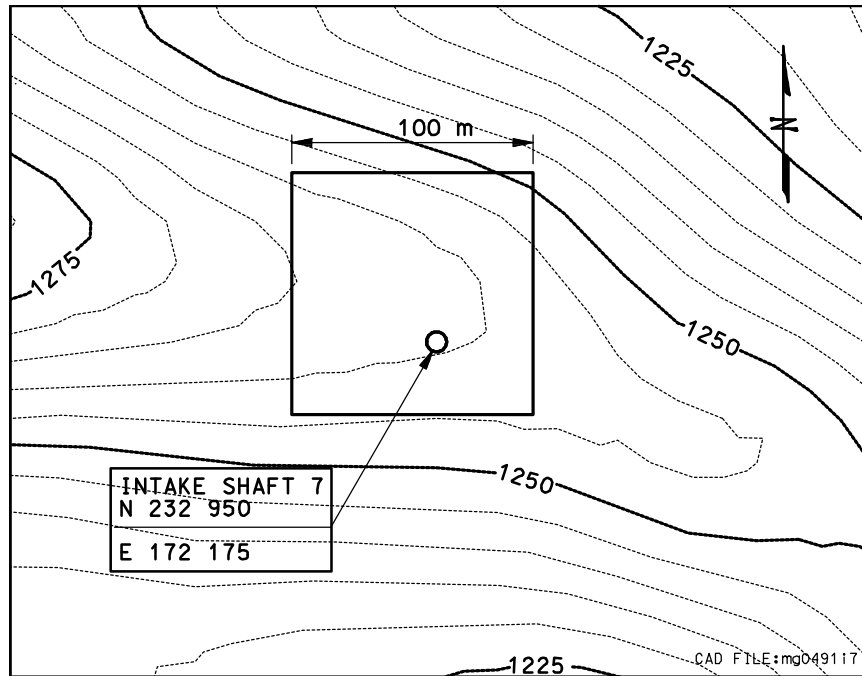
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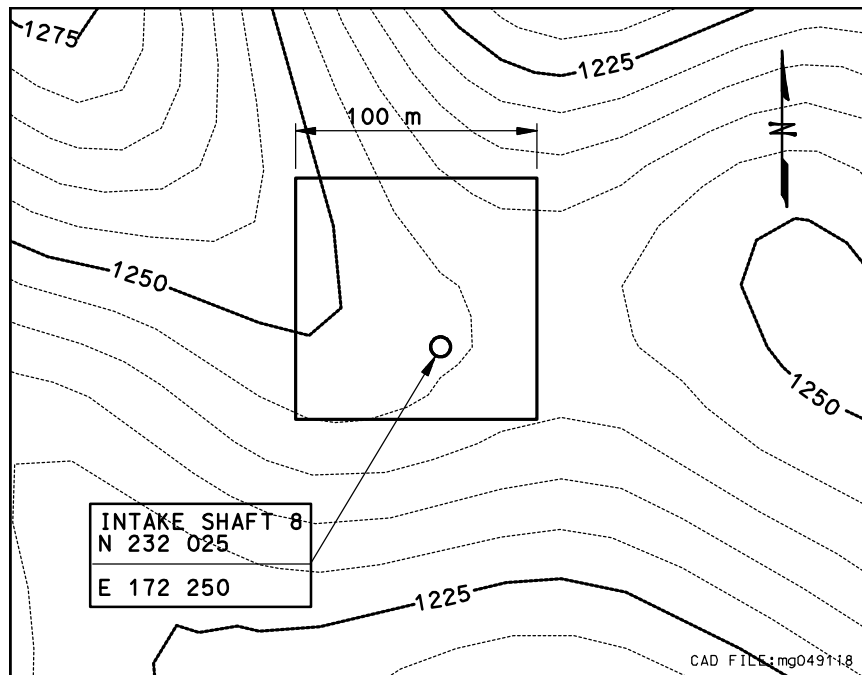
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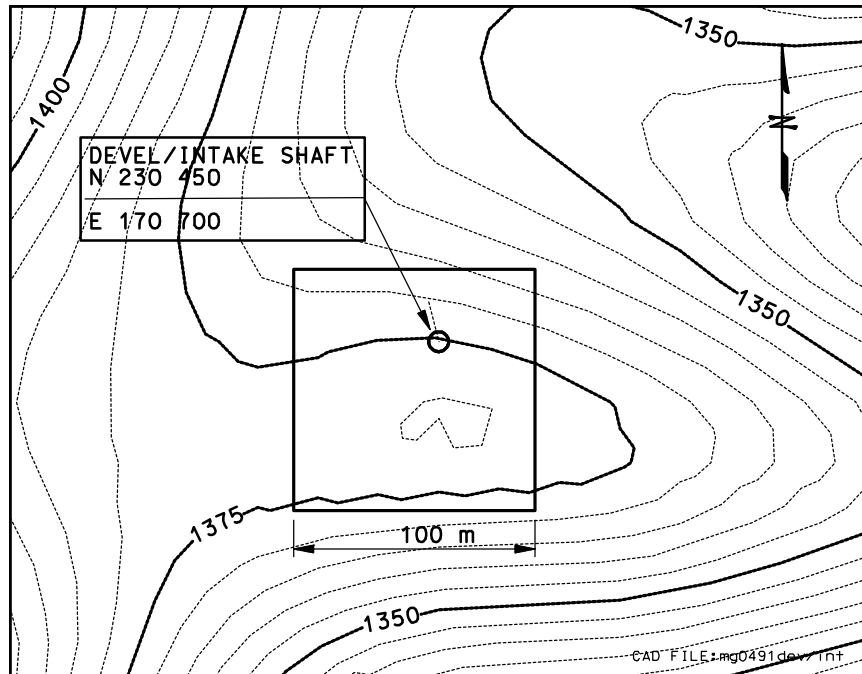
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Intake Shaft No. 7 Layout

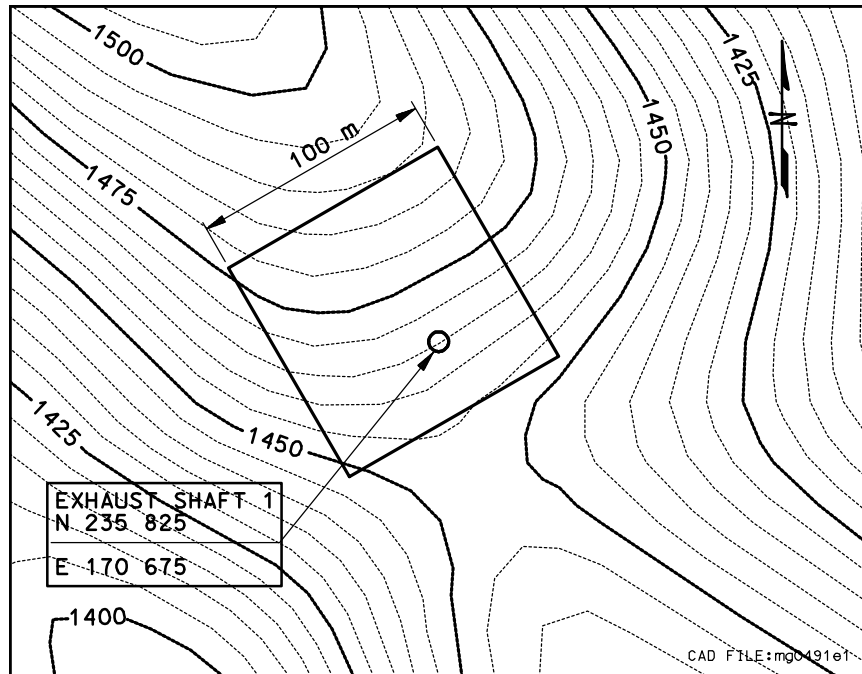


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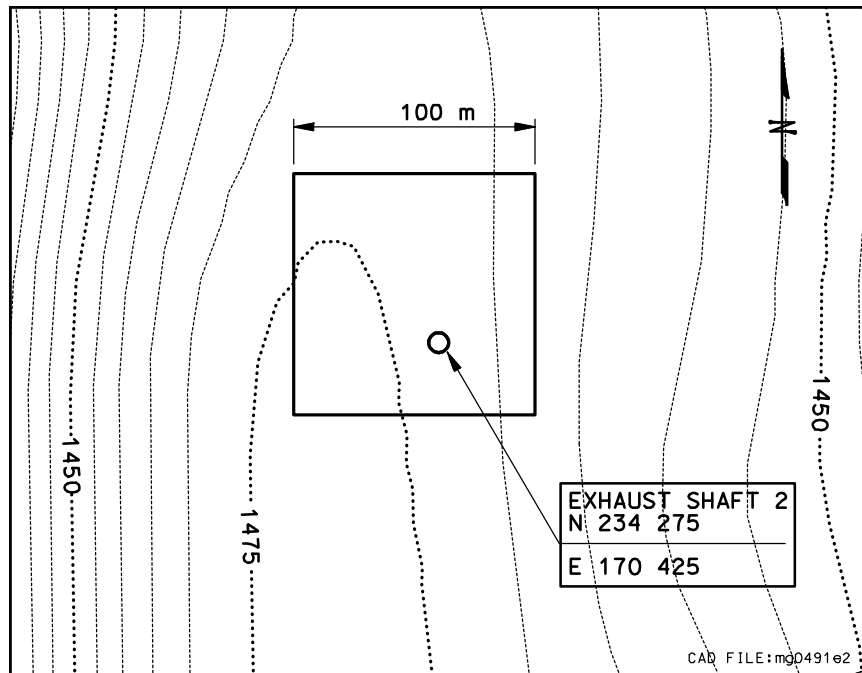


Development / Intake Shaft Layout

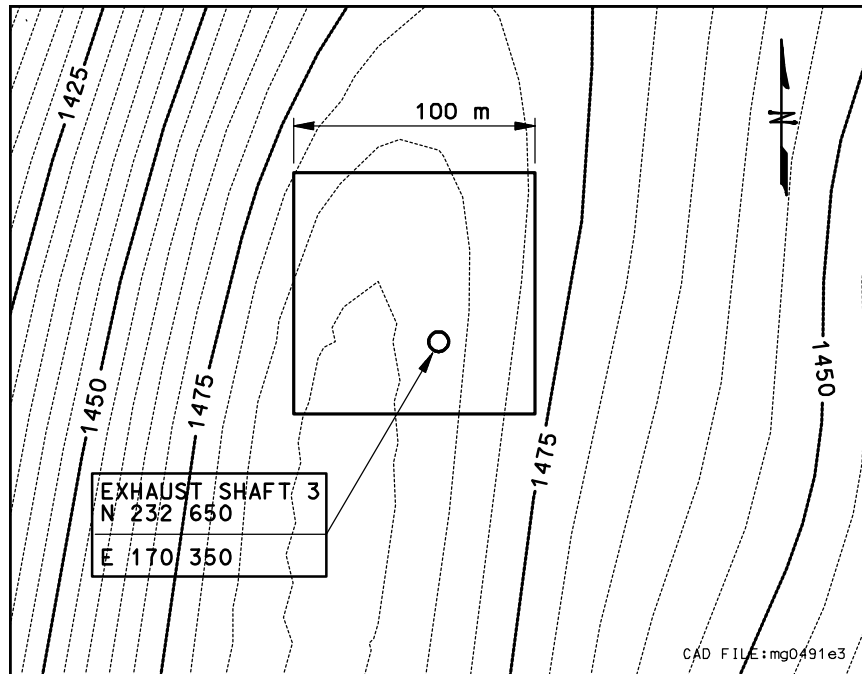
ATTACHMENT III
EXHAUST SHAFTS SITE LAYOUTS ORIENTATION



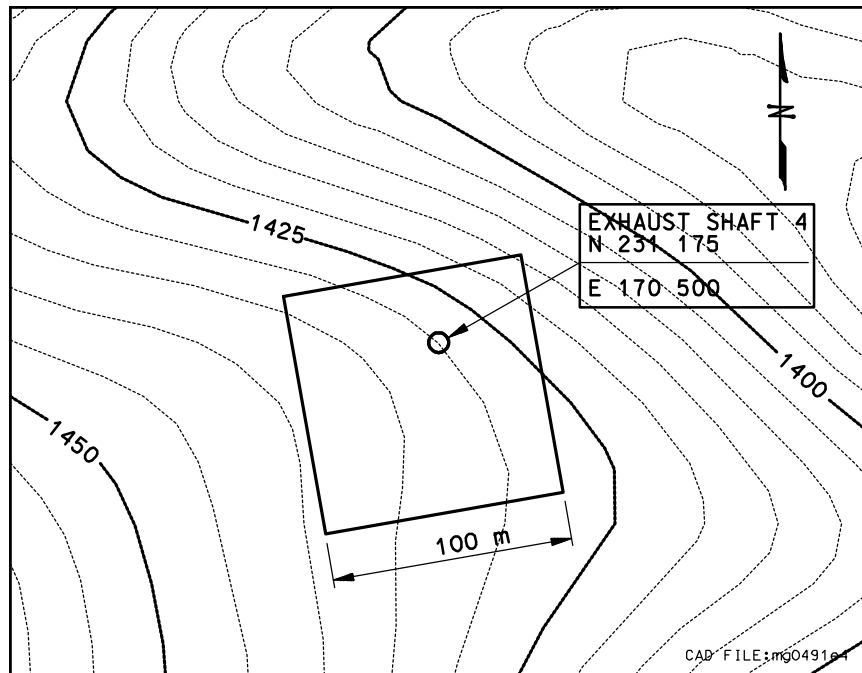
Exhaust Shaft No. 1 Layout



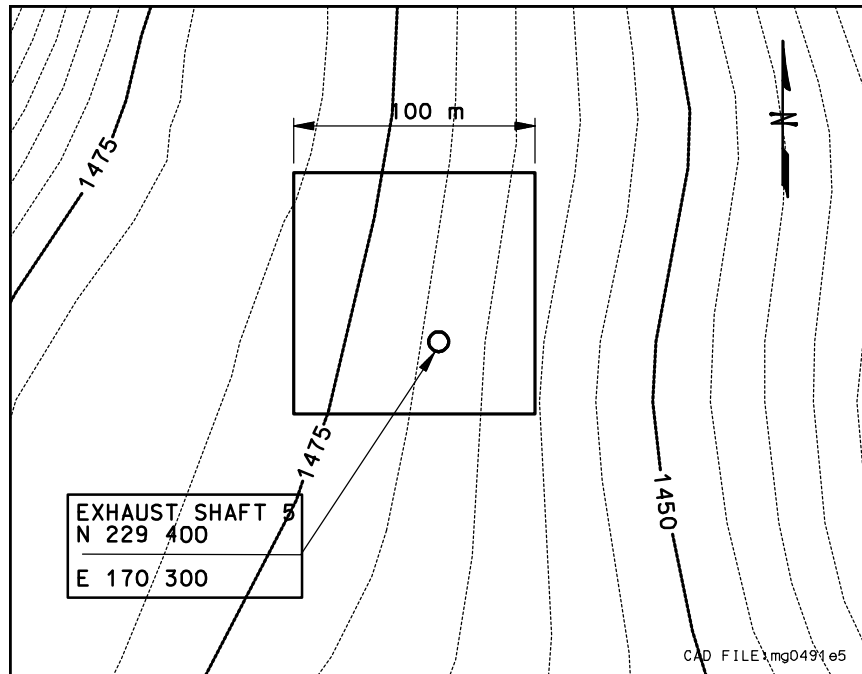
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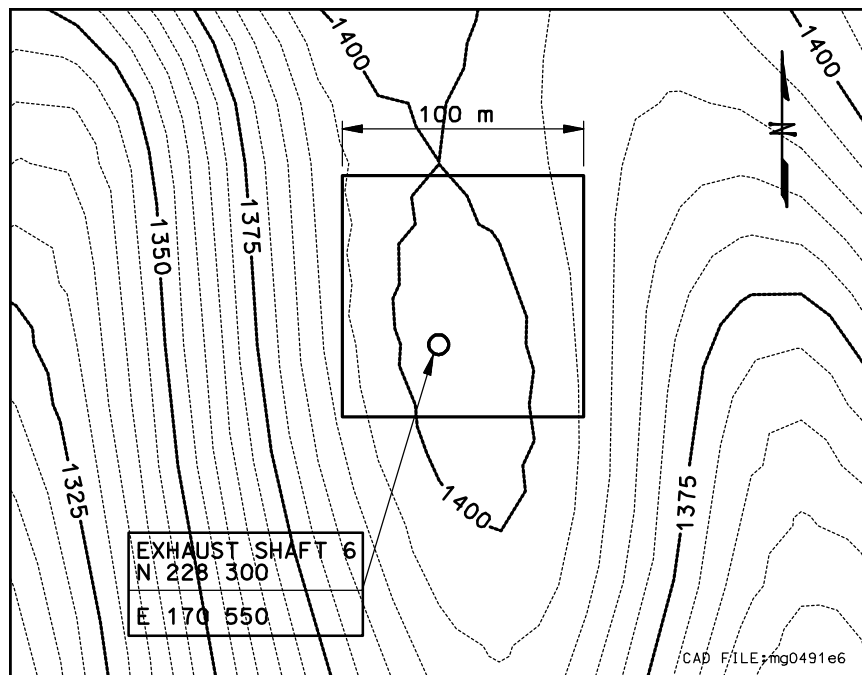
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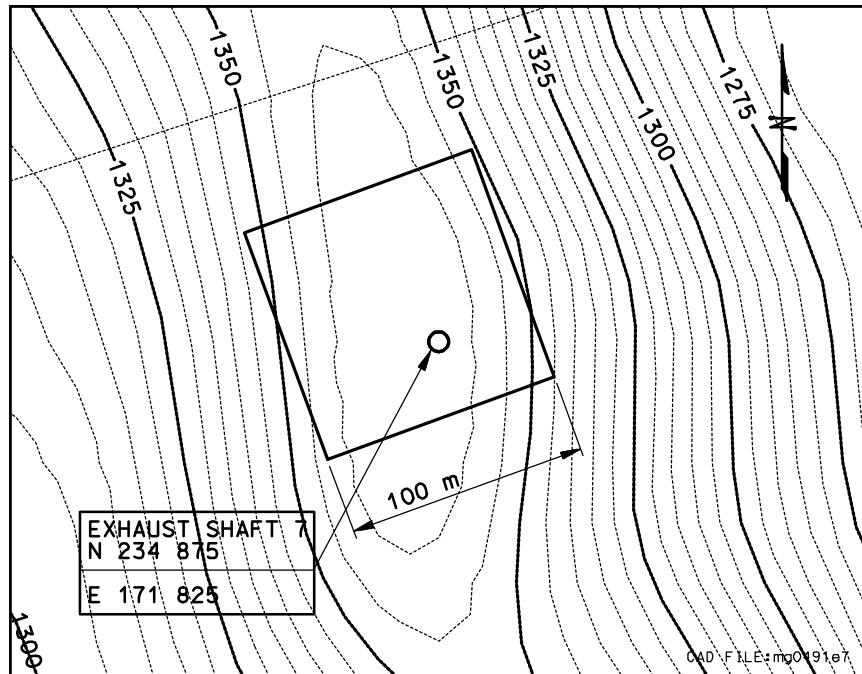
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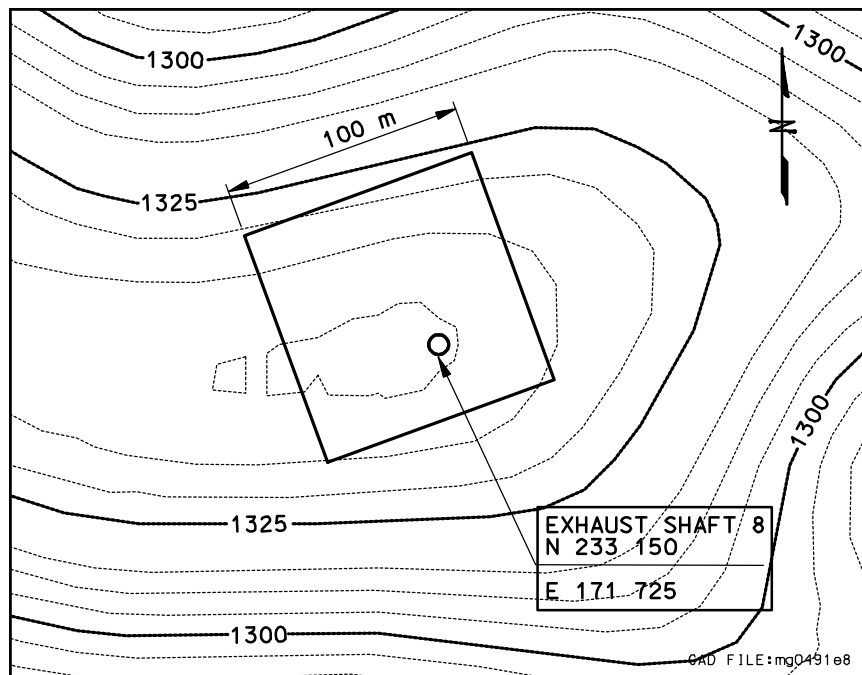
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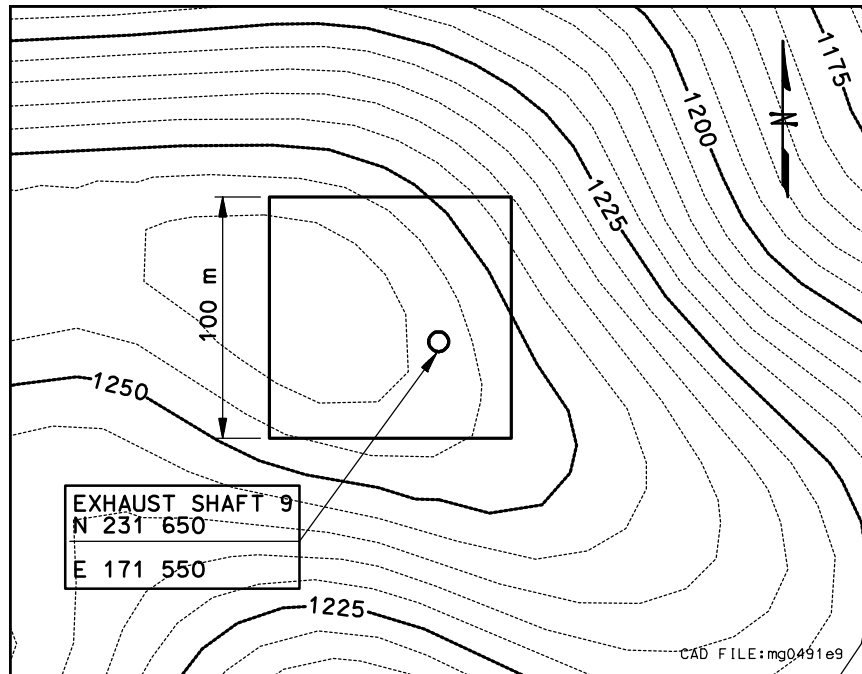
Exhaust Shaft No. 6 Layout



Exhaust Shaft No. 7 Layout



Exhaust Shaft No. 8 Layout



Exhaust Shaft No. 9 Layout

ATTACHMENT IV
CALCULATION OF DISTANCE BETWEEN INTAKE AND EXHAUST SHAFTS
BY TRIGONOMETRIC METHOD

Calculation: Separation Distance = ((Difference in Northing)² + (Difference in Easting)²)^{.5}

NOTE: Distances calculated are in meters.

Intake Shaft No. 1	Northing 235,775	Easting 171,300	Exhaust Shaft No. 1	Northing 235,825	Easting 170,675
Separation Distance = 627					
Intake Shaft No. 2	Northing 233,900	Easting 171,000	Exhaust Shaft No. 2	Northing 234,275	Easting 170,425
Separation Distance = 686					
Intake Shaft No. 3	Northing 232,750	Easting 171,150	Exhaust Shaft No. 3	Northing 232,650	Easting 170,350
Separation Distance = 806					
Intake Shaft No. 5	Northing 230,675	Easting 170,875	Exhaust Shaft No. 4	Northing 231,175	Easting 170,500
Separation Distance = 625					
D / I Shaft	Northing 230,450	Easting 170,700	Exhaust Shaft No. 4	Northing 231,175	Easting 170,500
Separation Distance = 752					
Intake Shaft No. 4	Northing 228,625	Easting 170,825	Exhaust Shaft No. 5	Northing 229,400	Easting 170,300
Separation Distance = 936					
Intake Shaft No. 4	Northing 228,625	Easting 170,825	Exhaust Shaft No. 6	Northing 228,300	Easting 170,550
Separation Distance = 426					
Intake Shaft No. 6	Northing 235,075	Easting 172,200	Exhaust Shaft No. 7	Northing 234,875	Easting 171,825
Separation Distance = 425					
Intake Shaft No. 7	Northing 232,950	Easting 172,175	Exhaust Shaft No. 8	Northing 233,150	Easting 171,725
Separation Distance = 492					
Intake Shaft No. 8	Northing 232,025	Easting 172,250	Exhaust Shaft No. 9	Northing 231,650	Easting 171,550
Separation Distance = 794					

Shaft Northings and Eastings taken from Tables 9, 10 and 11 (Source: BSC 2001)