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Radioactive Materials Management

Deep Geologic Repository Conceptual Design

Annex 4

Repository Layout and Excavation Methods

December 2002

NOTICE to the Reader

"This document has been prepared by CTECH Radioactive Materials Management, a joint venture of Canatom NPM Inc. and RWE Nukem Ltd. ("Consultant"), to update the conceptual design and cost estimate for a deep geologic repository (DGR) for long term disposal of used nuclear fuel. The scope is more fully described in the body of the document. The Consultant has used its professional judgment and exercised due care, pursuant to a purchase order dated October 2001. (the "Agreement") with Ontario Power Generation Inc. acting on behalf of the Canadian nuclear fuel owners ("the Client"), and has followed generally accepted methodology and procedures in updating the design and estimate. It is therefore the Consultant's professional opinion that the design and estimate represent a viable concept consistent with the intended level of accuracy appropriate to a conceptual design, and that, subject to the assumptions and qualifications set out in this document, there is a high probability that actual costs related to the implementation of the proposed design concept will fall within the specified error margin.

This document is meant to be read as a whole, and sections or parts thereof should not be read or relied upon out of context. In addition, the report contains assumptions, data, and information from a number of sources and, unless expressly stated otherwise in the document, the Consultant did not verify those items independently. Notwithstanding this qualification, the Consultant is satisfied that the updated conceptual design and cost estimate was carried out in accordance with generally accepted practices in a professional manner .

This document is written solely for the benefit of the Client, for the purpose stated in the Agreement, and the Consultant's liabilities are limited to those set out in the Agreement."

Summary

It is proposed that the emplacement of CANDU used nuclear fuel will be undertaken in a deep geologic repository (DGR) excavated in crystalline rock in the Canadian Shield. CTECH has been contracted by Ontario Power Generation (OPG) to review the existing repository design, update the layout and construction method, and prepare a cost estimate for construction of the underground repository.

This report discusses the design and construction of the underground repository. Access to and from the underground facility will be by vertical shaft, with four shafts being constructed in total. The current design concept includes a repository designed to accommodate 3.6 million used fuel bundles excavated at a depth of 1000 m below surface in a sparsely-fractured granite pluton. The repository consists of the waste emplacement area and underground accessways and infrastructure to safely conduct emplacement operations of used fuel in Used Fuel Containers (UFCs) and comprises a system of tunnels and emplacement rooms arranged in four distinct sections in an area of about 1.4 km by 1.4 km. The central access drifts and perimeter tunnels join at opposite ends of the repository where the shafts are located. The shafts comprise:

- Service/Production shaft for transportation of personnel, equipment and supplies
- Maintenance Facility Exhaust Raise
- Primary Exhaust Raise
- Waste Shaft for transportation of the used fuel

All the shafts, except the Primary Exhaust Raise, are located in relatively close proximity to one another in an area designated as the Service Shaft Complex. The Primary Exhaust Raise is located approximately 1.4 km from the Service Shaft Complex at the opposite end of the repository.

Excavation will be by drill and blast methods utilizing engineered blast designs to provide for very smooth wall blasting to minimize the excavation damage zone (EDZ). A comparison of drill and blast techniques and tunnel boring machines (TBMs) has resulted in the conclusion that drill and blast techniques will provide satisfactory EDZ characteristics and provide a more flexible tool than TBMs. Innovative TBMs are being developed, that provide greater flexibility with reduced turning radii compared to conventional TBMs, but these are still considered to be at the prototype stage and are not sufficiently proven in the field to be considered for the development of the DGR at this time.

Excavation will be carried out in phases. The first phase will be an exploration phase involving site selection and construction of an exploration shaft that will later serve as the Service/Production shaft for transport of personnel, equipment and supplies. A second shaft to serve as the Maintenance Facility Exhaust Raise is also constructed during this period, together with other underground facilities and infrastructure including a component test area.

The second phase of construction comprises pre-emplacement development where the main access drifts and perimeter of the repository is developed, the Primary Exhaust Raise and

Waste Shaft constructed and the first campaign of emplacement room excavation completed that consists of 39 rooms. The mining contractor will complete the balance of 65 emplacement rooms over three subsequent campaigns for a total of 104 rooms.

The emplacement room will be 315 m in length and accommodate 108 UFCs in each. The rooms will be 4.2 m high and 7.14 m wide and elliptical in shape. Accessways and other tunnels will be 4.2 m high by 7.0 m wide and rectangular in shape with an arched back.

Emplacement of UFCs and the schedule for campaign mining of the emplacement rooms has been carefully scheduled and planned to permit concurrent activity. Excavation and emplacement both retreat towards the Service Shaft complex with the general airflow being from the Service Raise Complex to the Primary Exhaust Raise. Airflows for emplacement and excavation operations are always maintained separate.

Cask and buffer block movement is planned always to be uni-directional in a clockwise direction. Such an arrangement, as opposed to an unrestricted flow of traffic, is a more safe arrangement and reduces excavation requirements for emplacement room access.

Ventilation requirements for the DGR have been estimated on a basis of the airflows required for a drill and blast method of excavation and air velocities to control the heating effect from the stored UFCs. During emplacement activities the estimated airflow requirement is 240 m^3/s, whereas only 140 m^3/s is required for emplacement activities only.

Although normal excavation strategy will provide for excavation and emplacement activities always to take place at opposite sides of the repository, blast vibration concerns are discussed and possible blast vibration levels estimated. The concern principally relates to potential damage to emplaced UFCs and associated clay-based sealing materials during blasting operations or the likely potential for such damage if professional blasting standards and engineered blasts are not followed. It was concluded that no problem should exist for normal blasting operations when engineered blast designs are used.

Contents

Tables

Appendices

1 Introduction

Within the framework of a project to update the design concept for emplacement of CANDU used nuclear fuel in a deep geologic repository (DGR) excavated in crystalline rock in the Canadian Shield, CTECH has been contracted by Ontario Power Generation (OPG) to review the existing repository design described in documentation prepared by the AECL and Baumgartner et al[1], update the layout and construction method, and prepare a cost estimate for construction of the underground repository.

The current design concept includes a repository designed to accommodate 3.6 million used fuel bundles excavated at a depth of 1000 m below surface, in a sparsely-fractured granite pluton. Access to and from the underground facility will be by shaft.

The updated DGR design concept and cost estimate will be used for a comparison of options for the long-term management of used nuclear fuel in Canada and to initiate a siting process for such a facility, if the government selects the DGR option as the approach to long-term management of used nuclear fuel in Canada.

Following a site selection process, once experimental data is confirmed and the design of the facility is finalized, excavation of an underground repository would commence.

The actual repository excavation process would continue over many years. The repository layout described here consists of four repository sections each containing two emplacement panels. Each panel consists of 13 emplacement rooms connected by a common access drift, with each of the rooms having a capacity of 108 Used Fuel Containers (UFC).

The completed DGR layout as illustrated in Figure 1a indicates the four repository sections to be located adjacent to each other in an overall rectangular shape. In reality, the four repository sections would likely not be laid-out in a regular pattern, but may be separated because of structural discontinuities in the rock mass or other geotechnical considerations. The four sections are bounded by a pillar created by dual access drifts where the sections share a common boundary. The pillars will reduce rock temperatures at the boundaries of the repository sections after UFC emplacement. As rock stability and degradation is a function of temperature, the pillars so created will reduce the temperature of the access drift from which emplacement has not yet taken place and provide a safer working environment that will be of particular value in the case of UFC retrieval. Controlled ventilation airflows will mitigate the temperature increase in the access drifts.

On a basis of operating 230 days per year, it will take approximately 7.5 years to fill each section (26 emplacement rooms) of the repository. On a basis of mining 365 days per year, excavating and preparing 26 rooms for emplacement will require approximately 2.5 years. As a result, a “campaign” mining regime, utilizing mine contractors, has been proposed to excavate and prepare the emplacement rooms on an “as needed” basis.
Excavation of the DGR will utilize mechanized drill and blast mining techniques, with the broken material transported back to a central rock dump located on the surface within the perimeter fence of the DGR. The arrangement of the underground excavations are such that:

[1] Engineering for a Disposal Facility Using the In-Room Emplacement Method, P. Baumgartner, D.M. Bilinsky, Y. Ates, R.S. Read, J.L. Crosthwaite, D.A. Dixon, AECL-11595-96-223, June 1996.

- The transport of all UFCs, and unit trains containing the clay-based sealing materials will be in a clockwise direction to the emplacement rooms. If in the event that campaign mining and used fuel emplacement coincides, the separation of emplacement and excavation activities will minimize the interaction of each activity's traffic flows. The common uni-directional aspect of both activities will provide for ease of traffic flow and will facilitate operation of the facility providing an inherently safer material flow compared to the omni-directional flow described in Reference Document 4[2].
- The ventilation of the repository will allow for the emplacement of UFCs whilst campaign excavation proceeds. In each instance, potential contaminants from both activities will be contained in separate ventilation circuits to provide a safe working environment. In this respect, the ventilation system maintains the concepts developed in Reference Document 4.

2 Design Parameters

2.1 SUMMARY OF DESIGN PARAMETERS

A summary of design parameters is provided in Table 1a and Table 1b.

2.2 EXCAVATION DIMENSIONS

As indicated in Table 1a, the perimeter drifts, emplacement room access drifts and the central access drifts are 7.0 m wide by 4.2 m in height. They are rectangular in shape, with the roof of the tunnels being slightly arched. These dimensions are based upon:

- The provision of adequate and safe clearances for the combined rail car and used fuel cask.
- The provision of adequate clearances for equipment and services used during excavation (compressed air, water, electrical, auxiliary ventilation).

The emplacement rooms are 7.14 m in width and 4.2 m in height. The individual emplacement rooms will be elliptical in shape consistent with the aspect ratio recommended by Baumgartner of 1.7 between the major and minor axes. With this aspect ratio in mind, the dimension of the emplacement room becomes a function of the height requirement to safely transport the used fuel cask within the emplacement room.

Shaft dimensions are also indicated in Table 1a.

[2] Engineering for a Disposal Facility Using the In-Room Emplacement Method, pg. 39, P. Baumgartner, D.M. Bilinsky, Y. Ates, R.S. Read, J.L. Crosthwaite, D.A. Dixon, AECL-11595-96-223, June 1996.

Table 1 a – Excavation Design Parameters

Item		Unit	Comment
Contractor Excavation Schedule			
Number of Days per Year	365	Days	
Shifts per Day	3	Shifts	
Hours per Shift	8	Hours	
Excavation Data			
Waste Shaft	6.15	m	Circular, internal diameter
Service/Production Shaft	7.3	m	Circular, internal diameter
Maintenance Facility Exhaust Raise	3.96	m	Circular, internal diameter
Primary Exhaust Shaft	3.66	m	Circular, internal diameter
Perimeter Access Drift Dimension	4.2 x 7.0	m	Rectangular, arched back
Central Access Drift Dimension	4.2 x 7.0	m	Rectangular, arched back
Panel Access Drift Dimension	4.2 x 7.0	m	Rectangular, arched back
Emplacement Room Dimension	4.2 x 7.14	m	Elliptical
UFC Transport Turning Radius	25	m	Centreline
Minimum Distance Emplacement Rooms to Perimeter Access Drift	45	m	Centreline to centreline
Minimum Distance Emplacement Rooms to Central Access Drift	45	m	Centreline to centreline
Distance between Emplacement Rooms	45	m	Centreline to centreline
Distance between Emplacement Room Ends	22.7	m	Centre to centre perimeter drifts
Total Width of Emplacement Area	1358	m	Centre to centre upper-most panel
Total Length of Emplacement Area	1343	m	access to lower-most panel access drift

Table 1b – UFC Emplacement Parameters

Item		Unit	Comment
UFC Emplacement Schedule			
Number of Days per Year	230	Days	46 Weeks at 5 days per week
Shifts per Day	2	Shifts	
Hours per Shift	8	Hours	Shift duration reduced by 1 hour to 7 hours to accommodate underground travel time
UFC Emplacement Data			
Number of Emplacement Rooms per Section	26	Room	As per CTECH Document[3]
Number of UFCs per Emplacement Room	108		
Average Number of UFCs per Day	1.6		
Emplacement Room Data			
Container and Buffer Material Length (pairs)	5.13	m	As per CTECH Document
Number or Pairs per Emplacement Room	54	m	
Length of Room for UFCs and Buffer Blocks	277.02	m	
Buffer Block Shielding at End of Room	1	m	
Concrete Bulkhead	12	m	
Room Access Turning Radius	25	m	
Total Room Length	**315.02**	**m**	

[3] Initial UFC Design Outline (Rev. C), January 2002

3 DGR Excavation Development

3.1 SITING PHASE PLAN

The Siting Phase would involve developing a siting process and site screening criteria, site screening and site evaluations, preparation of safety assessment and environmental impact documents, participation in public consultations and hearings, and the preparation of license applications.

Geological and other natural environment data would be gathered during site screening and evaluations to develop an understanding of the surface and underground physical, chemical and biological conditions in and around the potential sites to confirm their suitability for hosting a DGR. The site characterization activities would include analysing existing regional-scale data, performing reconnaissance surveys to gather additional data, borehole investigations, developing and applying criteria for accepting or rejecting locations and ranking them for further investigation. These site characterization activities would be coupled with extensive public and government consultation leading to the selection of a preferred site.

During the Siting Phase, preliminary conceptual repository facility designs would be prepared for each site being evaluated. Design work would be completed for the surface and underground facilities primarily to establish the access, utility and infrastructure requirements. These requirements would be considered during site screening to ensure that they could be met at potentially suitable site locations in the areas selected for detailed evaluation. Details of the environmental and repository monitoring programme would also be developed, and the plan to incorporate this programme into subsequent site evaluation activities would be prepared during site screening. Following the selection of a preferred site, a preliminary repository design specific for the site would be completed and approved prior entering into the environmental assessment process.

The implementing agency would be required to demonstrate, during the environmental assessment process, that there would be no adverse impact on the environment resulting from the construction, operation, decommissioning and closure of the repository, and during the post-closure period. Whilst there would inevitably be much focus on the radiological components of environmental impact, the more conventional environmental concerns would also be addressed. A comprehensive environmental survey to measure and record the current background conditions at the proposed site would be conducted.

The end point of the Siting Phase would be the receipt of a Construction License giving approval to begin construction of the repository facility on the preferred site.

3.2 CONSTRUCTION PHASE PLAN

The Construction Phase would involve constructing the infrastructure and surface facilities needed to dispose of nuclear fuel waste, the underground access ways and service areas, and a portion of the underground disposal rooms. However prior to the start of full-scale construction there would be a period of underground evaluation in the Underground Characterization Facility (UCF). Data gathered in the UCF would be used to confirm suitability of the site and to gather additional information for the detailed design of the repository. The Construction Phase would begin with the receipt of regulatory approval to start construction and would end when the first used fuel is received at the site.

3.2.1 Underground Evaluation

Underground investigations in the UCF will provide improved definition of the geotechnical parameters determined from surface investigations. As the underground evaluation proceeds, the design of the underground repository would evolve as the geologic structures and characteristics of the site become better defined. The purpose of the underground evaluation is:

- To gain direct access to the repository-level environment
- To verify and refine the surface-based evaluation interpretation of site conditions and behaviours
- To delineate in detail the acceptable areas for waste emplacement
- To perform geotechnical mapping, characterization and component testing for deriving engineering design values and constraints, and
- To develop final construction and operation designs for the repository and its component that may differ from the symmetrical layout indicated in Figure 1a due to the presence of faults or other geological features.

The underground evaluation will be accomplished in three phases. Figure 1e (i) demonstrates the initial phase to establish the infrastructure for test work to be undertaken to determine the characteristics of the rock mass. From a logistics perspective approximately 3700 m of drifting and raising will be required during this phase. Initially, mucking of excavated material into rail cars will be required, but as exploration development continues, proper provisions for rock handling must be in place and operational. During this phase of the construction, the following facilities will be established:

- Service/Production Shaft complete with loading and spill pocket
- Rock dump, grizzly and storage bin
- Concrete unloading drift
- Mine water sump
- Explosive and detonator magazines
- Main refuge station
- Mechanized drill and blast maintenance facility
- Component Test Area (CTA)

- Maintenance Facility Exhaust Raise
- Permanent fuel and lubricant storage area.

The function of the CTA is to carry out experiments to define vault design parameters. This area provides the opportunity for the DGR operators to plan and layout the remainder of the facility and conduct tests for the most effective UFC emplacement and retrieval methods. The CTA will be located so that the DGR shafts, access tunnels and disposal rooms will not interfere with the long-term tests and demonstrations.

In the initial phases all drifts around the exploration shaft will be initially driven 3.0 m x 3.0 m, then slashed to the required shape and dimension, dependent upon its function and experimental study being undertaken. In addition, the central access tunnels, perimeter tunnels and panel access tunnels that pass through and around the repository, will be driven at this time.

During the initial driving of the central access tunnels, perimeter tunnels, and panel access tunnels geotechnical studies will continue, to further define and characterize the design components of the underground facility. These geotechnical studies will include:

- Approximately 6000 m of 76 mm and 96 mm diameter horizontal and sub-horizontal exploratory diamond drilling in and around the projected repository horizon
- An additional 37,000 m of 76 mm and 96 mm diameter exploratory diamond drilling in and around the repository horizon with all holes being grouted upon completion
- Characterization of the geological environment by core and borehole logging and sampling, excavation mapping, borehole sampling and testing, excavation deformation measurements, and geophysical imaging
- Excavate the equivalent of approximately 2,000 m of exploration sized tunnels and begin rock mass behavioural testing in the CTA
- Conduct appropriate research and development as needed, and
- Produce the detailed engineering specifications and plans for the construction of the DGR facility.

After the completion of the characterization studies of the underground facility, in which the central access, perimeter and panel access tunnels are developed (Figure 1e(ii)) the following will have been completed:

- Approximately 2600 m of 4.2 m by 7 m rectangular perimeter tunnel
- Approximately 2600 m of 4.2 m by 7 m rectangular drift comprising the central access corridor
- Approximately 9300 m of 4.2 m by 7 m rectangular panel access tunnel complete with emplacement room entrances

- The Service Shaft Complex except for the Waste Shaft, Waste Shaft access and rail car parking

- Approximately 150 m extension of the right-hand central access drift (4.2 m by 7 m) to the Primary Exhaust Raise

- Figure 1b demonstrates the support infrastructure that will be in place in the Service Shaft Area, whilst Figure 1c provides details of the infrastructure associated with the Exhaust Shaft Complex.

A number of the activities outlined are sequential in nature (infrastructure, shaft sinking, initial drilling, tunnelling, and component testing), whereas others are parallel activities associated with the sequential activities (characterization and additional drilling during the excavation process). Approximately two years of component testing for deriving engineering design values and constraints will be required in order to develop final construction and operation designs of the repository and its components after excavation of the CTA and prior to completion of this project phase.

The exploration shafts are located such that they would fit in the plans for the subsequent phases of the implementation. The exploration tunnels and other underground facilities are also located and constructed such that they should be easily adapted to be used as the actual repository elements.

All excavation, drilling and construction activities during underground evaluation are based on 3 shifts/day, 360 days per annum. Component testing is assumed to occur over 1 shift/day, 230 days per annum.

3.2.2 Facility Construction

After the underground evaluation studies have been carried out and the final designs completed the construction of the full-scale repository facility can begin. The purpose of the construction is to build all the facilities necessary for the operation of the repository and its components. Provision is made in the design for concurrent excavation during the Operational Phase. The Construction Phase plan consists of the following activities:

- Upgrade the site infrastructure to perform large scale shaft sinking and tunnelling

- Construct the Used Fuel Packaging Plant (UFPP) and associated facilities

- Sink and equip the Waste Shaft to a depth of approximately 1,000 m and develop the empty and loaded rail car areas

- Excavate 39 disposal rooms (i.e. 1.5 panels), 4.2 m by 7.14 m in size, to give a total of 12,285 m of available room space for the Operation Phase

- Characterize the geotechnical environment by core and borehole logging and sampling, geological mapping, borehole sampling and testing, excavation deformation measurements, geophysical imaging and in-situ stress testing

- Carry out additional rock mass behavioural tests in the CTA. The tests will continue into the Operations Phase

- Prepare the access tunnels with services and ventilation ducting; pour concrete for floors, and install rails

- Prepare a minimum of four emplacement rooms with services, ventilation ducting and install rails

- Commission all the underground equipment and produce detailed operating procedures

- Conduct appropriate research, as needed, and development, and

- Prepare the detailed safety assessment for the operation of the DGR facility and apply for an operating licence.

A number of the activities outlined are sequential in nature (infrastructure, shaft sinking, initial drilling and tunnelling), whereas others are parallel activities associated with the sequential activities. Figure 1e(iii) shows the vault layout at the end of the Construction Phase.

3.3 OPERATION PHASE PLAN

The Operation Phase would involve receiving nuclear fuel waste transported to the DGR facility, sealing it in corrosion resistant UFCs, placing and sealing the UFCs in emplacement rooms, and constructing and preparing additional emplacement rooms. After the last UFC has been placed in the repository there would be a period of extended monitoring.

3.3.1 Emplacement of Disposal Containers

The purpose of the Operation Phase is to emplace and seal the UFCs in the repository. There are three major concurrent groups of operational activities occurring during the Operation Phase:

- Room Excavation, including drilling and blasting, muck removal and ground support installation

- Room preparation, including the installation of concrete floors, installation of rails and other support services (mechanical and electrical), and

- UFC emplacement involving installation of dense backfill and buffer blocks, placement of the light backfill material, emplacement of jacketed UFCs, installation of remaining dense backfill and buffer blocks and injection of dry granular bentonite and sand mixture infill.

After all the UFCs are emplaced in a room, the room bulkhead is constructed.

The three major activities are scheduled to take place concurrently, such that when UFCs are being emplaced in one panel, on one side of the central access tunnel, room preparation and room excavation takes place in another panel on the other side of the central access tunnel. It is envisaged that room preparation and excavation will be of shorter duration than emplacement and therefore there will be periods where ongoing construction is suspended with the construction being carried out on a campaign basis. Two separate ventilation systems are maintained: one for the radiological operations (UFC emplacement) and the other for non-radiological operations (i.e. room excavation and room preparation). A single upcast shaft will be utilised to accommodate extract from both systems.

Sufficient rooms are excavated and prepared during the Construction Phase such that at the start of the Operation Phase, the crews for these activities are at staggered locations and operate in a non-interfering mode. Specifically, the rooms in the lower panel of Section A and all the rooms in Section B will have been excavated and prepared. At the beginning of the Operation Phase, block placement and waste emplacement starts in the lower panel of Section B. When all rooms in the lower panel of Section B are filled, UFC emplacements will then take place in Section A. At an appropriate time during the filling of Section A, followed by the lower panel of Section D (see Figure 2a).

The principle of segregating the radiological operations from the non-radiological operations is maintained. The central access tunnels are twinned to reduce the potential for traffic accidents, particularly with radioactive materials and to provide a secondary route for worker and material transport. The emplacement operations retreat from the Upcast Shaft Complex towards the Service Shaft Complex. Thus the work progresses from potentially contaminated areas towards clean areas with a fresh air source, enhancing the environment for workers.

At the end of each cycle when the waste emplacement operations are completed in a room panel, each functional activity is moved to the next sequence of rooms in the opposite Section across from the central access tunnels. Figure 2a through to Figure 2d.

3.3.2 Extended Monitoring

The extended monitoring would involve monitoring and assessing the conditions in the vicinity of the DGR prior to decommissioning and closure of the repository. The extended monitoring programme makes use of the shafts and underground access tunnels while they are still available prior to repository sealing in the Decommissioning Phase. Extended monitoring activities would include environmental monitoring, monitoring UFC performance and monitoring rock mass behaviour. The monitoring data would be used to predict the long-term performance of the sealed repository.

A work force would be present at the facility to maintain full access, equipment, facilities, physical security, safety and monitoring systems, and to analyze and interpret data. Although much of the operations equipment would be “mothballed”, most of the ancillary service facilities would operate at reduced capacity to support site staff activities both above and below ground at the DGR.

Extended monitoring activities would end when regulatory approval is received to decommission the DGR facility.

3.4 DECOMMISSIONING PHASE PLAN

The purpose of the Decommissioning Phase is to:

- Decontaminate and remove all the related underground support works

- Backfill and seal the balance of the repository, that consists of all exploratory and instrumented boreholes drilled from underground, tunnels, service and upcast shaft complexes, CTA and shafts

- Decontaminate and dismantle the UFPP, sealing and compaction plant and associated facilities

- Dismantle all surface buildings and associated facilities

- Dismantle and remove the rock crushing plant, concrete batch plant, shaft headframes, fans and collar houses, and

- Dismantle and remove all surface infrastructure including roads, drainage and services.

The Decommissioning Phase plan consists of the following activities:

- Remove instruments from all underground boreholes and seal each borehole

- Backfill the upcast complex, installing sealing bulkheads at strategic locations

- Ream the waste and upcast shafts to remove the concrete linings and any wall rock degradation, re-equip each shaft with services and stagings, and backfill the shafts including the installation of shaft sealing bulkheads at strategic locations

- Backfill the central access tunnels, installing tunnel sealing bulkheads at strategic locations

- Dismantle and backfill the CTA, service shaft complex and the maintenance/storage area and install sealing bulkheads at strategic locations

- Ream the service shaft to remove the concrete lining and any wall rock degradation, re-equip the shaft and backfill and install shaft sealing bulkheads at strategic locations

- Decontaminate and dismantle the UFPP and associated facilities

- Dismantle all other surface facilities, services and infrastructure, and

- Prepare the safety assessments and apply for approval to release the site

All sealing and decommissioning activities are scheduled for 3 shifts/day, 360 days per annum.

3.5 CLOSURE PHASE PLAN

The purpose of the Closure Phase is to:

- Remove instruments from all surface boreholes and backfill and seal each borehole, except those that are needed for monitoring in the post-closure period

- Recondition the site surface to a state suitable for public use with the provision that subsurface use be restricted, and

- Prepare the safety assessments and apply for approval to release the site.

The activities and related data for this phase is the same as described for the facility described in **Annex 3** and as previous studies[4] Closure work is assumed to occur over 1 shift/day, 230 days per annum.

4 Emplacement Room Development and Used Fuel Emplacement Sequencing

Essential to the excavation process is the ability to safely excavate the emplacement rooms, whilst storage of the UFCs is in progress in other parts of the facility. There are a number of factors to consider:

- The excavation must be done in such a manner that the structural integrity of the adjacent panel is not compromised
- The emplacement, hence excavation, will retreat towards the Service Shaft Complex
- Separated ventilation flows from emplacement and mining operations, isolating the blasting fumes, diesel fumes and dust from the excavation process are all key issues
- Initially the mining contractor would excavate 39 emplacement rooms. The location of these rooms would be in the upper and lower half of Section A and the lower half of Section B (see Fig. 2a). Task allotment in the excavation process includes:
- Pouring of concrete floors in all excavated emplacement rooms
- Establishing rail track access across the emplacement panel and a minimum of four emplacement rooms.

The emplacement sequence will commence in the lower panel of Section B, and then proceed to Section A. At this particular juncture, emplacement is isolated to the left of the central access corridor (Fig. 2b), allowing the campaign excavation to proceed on the right-hand side of the repository.

During the second excavation campaign (Fig. 2b) an additional 26 rooms will be provided. The excavation activity will be isolated to the upper panel of Section B and the lower panel of Section D. As in the first excavation campaign, completion of the excavation work will include:

- Pouring of concrete floors in all excavated Emplacement Rooms.
- Establishing rail across the Emplacement Panel and a minimum of four Emplacement Rooms.

The excavation time has been estimated to take 935 days (Appendix C) or approximately 2.6 years on a basis of operating 365 days per year to provide the 26 emplacement rooms. Initial studies indicate that it will take approximately 7.5 years to fill a 26-room section on a basis of operating 230 days per year.

[4] Engineering for a Disposal Facility Using the In-Room Emplacement Method, pg. 39, P. Baumgartner, D.M. Bilinsky, Y. Ates, R.S. Read, J.L. Crosthwaite, D.A. Dixon, AECL-11595-96-223, June 1996.

The time differential will allow emplacement activities to be completed in Section A and move into the upper Section B/lower Section D emplacement area.

When the third excavation campaign commences (Fig. 2c), Section C will be the centre of mining activity. Since the excavation takes place along two emplacement panel accessways excavation time will be 15 days longer at 949 days (Appendix C), but well within the time required to emplace 2,808 UFCs in Section B/D. In providing an additional 26 emplacement rooms, Figure 2d demonstrates the excavation sequence recommended by Baumgartner et al[5] in relation to the emplacement activity, and those portions of the repository that are filled and sealed to entry. The central access corridor will be utilized for fresh air delivery, with fresh air splitting from this central airway to the perimeter drifts (Fig 1d).

The final section to be excavated will be the upper panel of Section D. Since only 13 Emplacement Rooms are to be excavated, approximately 1.2 years on a basis of operating 365 days per year, will be required to complete the facility excavation.

For safety purposes, the ventilation in areas of the facility where UFCs are being transported or handled during emplacement is completely separate from that of the areas where excavation activities are in progress.

5 Cask and Buffer Block Movement

Due to the size of the UFC, casks to the emplacement room will require a 25 m centreline turning radius. Entrance to the emplacement room will not be “Y” shaped as described in previous documentation[6] so as to prevent the creation of zones of potential rock weakness within the DGR. Therefore, ingress and egress to and from the emplacement room panels will be in one direction. For safety reasons, to the extent possible, traffic flow will be uni-directional, moving in a clockwise direction to eliminate the possibility of head on collisions with other rail traffic (buffer material, concrete, etc.).

In transporting the casks and materials to the emplacement site, rail cars will be towed. Since each emplacement panel will have its own access drift (Figure 1a), the combination of single emplacement room access and uni-directional traffic flow, will allow the cask and buffer material train to be drawn past the entrance, then backed in.

Upon dispatching its material, the train will return to the Waste Shaft area either by the central access or perimeter drift in a clockwise direction, according to the established uni-directional flow of the cask transportation system. Figure 2e illustrates traffic flows during room emplacement activities in the Upper and Lower Panels of Section B and D respectively, whilst emplacement room excavation is being undertaken in Section C.

Marshalling drifts have been established above the Waste Shaft’s perimeter access drift, to provide space for organizing “unit trains” of clay-based sealing material. The marshalling drift to the right of the Waste Shaft will be for full rail cars, whilst the marshalling yard to the left of the Waste Shaft will be utilized as a temporary storage area for empty rail cars returning from the emplacement room. Within the Waste Shaft Station there is a cask car storage area, sized to

[5] Engineering for a Disposal Facility Using the In-Room Emplacement Method, pg. 39, P. Baumgartner, D.M. Bilinsky, Y. Ates, R.S. Read, J.L. Crosthwaite, D.A. Dixon, AECL-11595-96-223, June 1996.
[6] Engineering for a Disposal Facility Using the In-Room Emplacement Method, Fig. 37, pg. 130, P. Baumgartner, D.M. Bilinsky, Y. Ates, R.S. Read, J.L. Crosthwaite, D.A. Dixon, AECL-11595-96-223, June 1996.

provide sufficient storage for the UFC cask and clay-based sealing material cars required on a daily basis.

6 Ventilation

6.1 VENTILATION REQUIREMENTS

The ventilation requirement for the DGR is based on two factors:

- The air volume requirement to provide proper dilution of excavation contaminates
- Air velocities to control the heating effect from emplaced UFCs on the exposed tunnel surfaces.

Based upon CTECH's experience, should sufficient fresh air be supplied to ventilate operating diesel powered equipment underground, then the issues pertaining to radioactive materials (radon gas and radon daughter by-products) will also be met.

In Reference 4, the underground facility ventilation rate was not specified. In addition, with the current preference for a "campaign" excavation process, where a mining contractor would be mobilized/demobilized as required, the quantity of diesel powered mining and excavation equipment may vary. On the basis of the equipment fleet proposed on page 51 of 443 (WEDS) of the November 14, 2001 Cost Estimate[7] prepared by the Nuclear Waste Management Division of OPG, approximately 1125 kW of equipment is listed. Utilizing Ontario Government legislated air requirements[8] of 0.06 $m^3/s/kW$, 67.5 m^3/s of air will be required for diesel-powered equipment utilized in the excavation process. Since this equipment may not be centralized along one emplacement panel access drift and because of its highly mobile nature, CTECH recommends increasing this air volume required by approximately 50% to 100 m^3/s. As this equipment is expected to work in more than one emplacement panel, equal amounts of air must be allotted to each panel.

Utilizing heat stress tables[9] and reviewing temperature data for Pinawa, Manitoba and Kenora, Ontario, the highest average daily maximum surface air temperature[10,11] recorded during the "summer months" – May through September was 25^o C (77^o F).

In this instance, if input air temperatures were 25^o C, and ambient tunnel wall temperatures were 35^{o}C, maintaining a minimum air velocity of 0.5 m/s in the central and perimeter drift accesses would keep the effective temperature (air) in the drift below 27^o C[12,13]. Considering cross-

[7] Cost Estimate for Disposal Facility for Used Fuel Owned by Ontario Power Generation, New Brunswick Power, Hydro Quebec and Atomic Energy of Canada Limited – Detailed Cost Information at Lowest Level of WBS File: 06819-03780 (UFM) T10, 14 November 2001

[8] Occupational Health and Safety Act and Regulations for Mines and Mining Plants, Section 183.1(3), Ontario Ministry of Labour, 1996

[9] Fan Engineering – An Engineers Handbook On Fans and Their Applications, R. Jorgensen – Editor, 8th Edition, Buffalo Forge Company, Buffalo, New York, 1984.

[10] Pinawa WNRE, Manitoba Temperature Data, Environment Canada, 1963 to 1990

[11] Kenora A, Ontario Temperature Data, Environment Canada, 1938 to 1990

[12] Industrial Ventilation – A Manual of Recommended Practice, 13th Edition, American Conference of Governmental Hygienists, Lansing Michigan, pg. 3-1 – 3-7.

sectional area of these drifts, the 0.5 m/s velocity is equivalent to air volumes of 15 m^3/s. Emplacement worker exposures to these "hot" areas would be minimal, since these "hot" areas are on the "exhaust" side of the repository where air velocities would be in excess of 0.5 m/s, and ventilation for temperature control becomes less demanding.

During the actual UFC emplacement activity, the elliptical shaped room would require 12 m^3/s of airflow utilizing the 0.5 m/s velocity criteria. It is noted that the Reference 4[14] documentation specifies 14 m^3/s. Utilizing the Reference Document 4 air volume and assuming five (5) emplacement rooms are being ventilated at any one time, 70 m^3/s would be a minimum air volume required per emplacement panel. The 14 m^3/s ventilation rate would allow the operation of 233 kW of diesel-powered locomotives to operate in each emplacement room.

Allowing for room excavation and emplacement to take place simultaneously and considering the air requirements of the Service Shaft Complex, the DGR's air volume requirements of the DGR is provided in Table 2.

Table 2 DGR Estimated Air Volume Requirements

Location	Emplacement Activities Only	Emplacement and Excavation Activities
Service Shaft Complex Waste Shaft (upcast) Maintenance Complex Shaft (upcast)	 20 m^3/s 50 m^3/s	 20 m^3/s 50 m^3/s
Emplacement Room Excavation	--	100 m^3/s
Used Fuel Emplacement	70 m^3/s	70 m^3/s
Total Air Volume Requirement	**140 m^3/s**	**240 m^3/s**

6.2 VENTILATION FACILITIES

With respect to the positioning of the main fans, exhaust fans will be required on:

- Maintenance Facility Exhaust Raise
- Upcast Ventilation Shaft

During the winter months the Service Shaft must be heated to prevent freezing of the shaft and sheave wheels. A push-pull arrangement will be incorporated into the shaft design, with a blowing fan on surface and a suction fan located underground. The surface fan will deliver 260 m^3/s of heated air, with 240 m^3/s being drawn down the Service Shaft, and the excess 20 m^3/s upcasting through the headframe of the Service Shaft. A fan placed underground within the Service Shaft Complex will draw the required maximum of 240 m^3/s down the Service Shaft, placing the Service Shaft Complex under positive pressure. Since the exhaust shaft in the

[13] Fan Engineering – An Engineers Handbook On Fans and Their Applications, R. Jorgensen – Editor, 8th Edition, Buffalo Forge Company, Buffalo, New York, 1984 pg. 20-2 – 20-8.
[14] Engineering for a Disposal Facility Using the In-Room Emplacement Method, pg. 41, P. Baumgartner, D.M. Bilinsky, Y. Ates, R.S. Read, J.L. Crosthwaite, D.A. Dixon, AECL-11595-96-223, June 1996.

Upcast Shaft Complex will only draw a maximum of 170 m^3/s, the surplus air delivered via the Service Shaft will upcast the Maintenance Complex Shaft and the Waste Shaft.

Estimated duties are:

- Service Shaft Surface Fan 190 – 260 m^3/s
- Service Shaft Underground Fan 140 – 240 m^3/s

During the non-heating season the surface Service Shaft fan will be turned off.

6.3 DISCUSSION ON THE PRIMARY EXHAUST VENTILATION RAISE

The maximum air volumes to be exhausted, estimated in Section 5.1, are approximately half those reported in the 1992 AECL Report[15] (240 m^3/s versus 462 m^3/s). For most part of the operating life of the facility the 140 m^3/s required during "emplacement activities only" represents approximately 30% of the previously prescribed air requirement.

Differences occur due to:

- A change in emplacement method
- A change in backfilling methods utilizing bulldozers to place and wheeled compactors to prepare the bentonite cover
- Method of cask transportation (track versus trackless)
- Cask size and weight
- DGR development (continuous versus campaign extraction) involving development of more rooms at any one time across more panels, which requires more diesel powered equipment. In the AECL 1992 report, 3,471 containers[15] per year were to be placed underground. Presently less than 400 cask movements per year are now required.

With the reduction in air volume requirements, CTECH recommends eliminating one of the primary exhaust raises. With the advent of the "campaign excavation" concept, the requirement for a dual exhaust raise system becomes unnecessary.

Utilizing the "campaign excavation" methodology, where continual on-going mining is not taking place, the need for a separate exhaust raise system for each activity (excavation and UFC emplacement) becomes redundant. In Figures 2a through 2d, in which the ventilation air flows are superimposed on the excavation, UFC emplacement and emplacement room sealing process, it is demonstrated that the separation of exhaust airflows from each activity are achieved. During the initial UFC emplacement sequence, UFC emplacement is such that the emplacement process retreats from exhaust towards fresh air (Service Shaft Complex). When campaign mining recommences, the emplacement activity is over 1.3 km from where the two exhaust flows merge, prior to exhausting up the single ventilation raise, which now serves as the Exhaust Shaft Complex described in Reference 4.

[15] Used Fuel Disposal Centre – A Reference Concept Vol. I, II, III, AECL-CANDU, J.S. Redpath Mining Consultants, Golder Associates, The Ralph M. Parsons Company, April 1992, pg. 103 and 54.

In the AECL 1992 Report, the emplacement room excavation and preparation were on going, requiring increased air volume requirements. Under this operating plan the dual primary exhaust raises serve two purposes:

- Provided a "clean" exhaust air flow to the HEPA (High Efficiency, Particulate Air) radioactive filters, whilst allowing the "dirty" exhaust airflow from the continuous excavation process not to blind the pressure sensitive HEPA filtration system
- Reduced the underground facility's airflow resistance.

HEPA air filtration systems are capable of filtering sub-micron particulate matter. These filters are made of porous paper containing a high percentage of glass fibres less than 1 μm in diameter, pleated into a rigid frame. Special HEPA filters are guaranteed to be 99.9999% efficient for 0.3 μm particles. To achieve this kind of filtering efficiency HEPA filters are limited to a 1.27 m/s face velocity at 250 Pa.

On the basis of the AECL 1992 report, the emplacement panels' exhaust shaft will handle 178 m^3/s, whilst the excavation panel exhaust fan will handle 190 m^3/s. In this instance, the minimum surface area of approximately 140 m^2 of filtration-media area would be required to handle the 178 m^3/s. If a single raise was utilized with the AECL 1992 airflows, the HEPA filter would require at least 290 m^2 (~3,120 ft^2) of filtration-media area. In addition, a pre-filter would also be required to eliminate excessive dust loading and premature 'blinding" on the HEPA filter from the excavation process, resulting in a large, cumbersome facility. CTECH would not recommend this configuration for the airflows specified in the AECL 1992 report.

With the underground facility's reduced air volume requirements, the maximum air volume exhausting a single raise would be 170 m^3/s when "emplacement and excavation activities" coincided, and reducing to 70 m^3/s when "emplacement activities only" were in progress. Under this operating regime, the HEPA filtration system would be constructed in such a manner that a variable speed, variable pitch fan could, if the need arose, exhaust into the HEPA filter system. This would be controlled by a series of control gates or dampers directing the facility's exhaust to the HEPA filtration system. Since the air volume is less than what was to be handled by the AECL 1992 reports emplacement panels' exhaust shaft, a slightly smaller or similarly sized emergency (stand-by) HEPA filtration system would be activated as air exhaust volumes and conditions demanded.

6.4 MINE EGRESS

In addition, the AECL 1992 report indicated that the upcast ventilation shaft that provides ventilation to the excavation panels would be equipped with an emergency evacuation hoisting system[16], thereby providing an alternate means of egress from the DGR.

In the AECL 1992 report, the Excavation Panel Exhaust Raise was used as a second means of egress. CTECH is of the opinion that an exhaust raise, which may be contaminated with smoke and blasting fumes**,** should not be used for this purpose. An alternate means of egress is required for various circumstances, including:

[16] Used Fuel Disposal Centre – A Reference Concept Vol. I, II, III, AECL-CANDU, J.S. Redpath Mining Consultants, Golder Associates, The Ralph M. Parsons Company, April 1992, pg. 53.

- Access to Normal Egress: In this example the Service Shaft hoist/conveyance is not available for service due to mechanical problems
- Emergency Situation (life threatening): In this example a mine fire isolates the workforce underground
- Location of Workers with respect to the Underground Workings: In this example the need would be based upon logistics and perhaps a life-threatening situation. It may be cheaper to provide an alternate means of ingress and egress versus extended travel times to the jobsite. Alternatively, if the majority of workers are in an area of limited egress opportunities, an approved man-cage for emergency egress can be fitted to the Waste Shaft conveyance or the skip compartment in the Service Shaft. In the event of an emergency situation such as a mine fire, utilizing an exhaust shaft/raise as a means of escape is not the preferred choice.

To safeguard underground miners and emplacement workers in the advent of an underground fire or other emergency situation, CTECH recommends the use of strategically placed permanent and portable refuge stations. Such facilities are mandatory in an underground facility according to Ontario's Occupational Health and Safety Act and Regulations for Mines and Mining Plants R.R.O. 1990, Regulation 654, and are recommended for the DGR. The strategic placement of refuge stations will reduce worker risk in the event of an underground fire providing a means of retreat to a safe location, especially when, for instance, the workers may be trapped behind a fire. The affected workers, upon notification would retreat to such a facility and wait either for rescue or release from the refuge station by properly trained (Ontario Mine Rescue) individuals.

> *Note - The Ministry of Labour have been demonstrating the use of portable refuge stations in Provincial Mine Rescue competitions since 1991.

With respect to the location of the workforce, as the OPG's operation proceeds, the workforce, emplacement and excavation personnel will be retreating from the Exhaust Shaft Complex towards the Service Shaft Complex. As a result, CTECH recommends that an alternate means of egress be established in the Service Shaft Complex by providing the ability for the Service Shaft Skip Compartment and for the Waste Shaft UFC conveyance to be quickly converted to "man-carrying" status in the event of unusual circumstances. In the case of the Service Shaft's skip compartment conversion, a man-carrying insert can be placed and secured within the rock skip and manual conveyance signals installed at each loading and unloading station. In the case of the Waste Shaft conveyance, an appropriate sized "man-cage" could be positioned and secured within the confines of the Waste Shaft conveyance.

7 Conclusions and Recommendations

Excavation of the DGR is recommended to be by drill and blast methods utilizing engineered blast designs to provide for very smooth wall blasting to minimize the EDZ. A comparison of drill and blast techniques and TBMs has resulted in the conclusion that drill and blast techniques will provide satisfactory EDZ characteristics and provide a more flexible tool than TBMs.

Excavation is recommended to be carried out in three phases. The first phase will be an underground evaluation phase involving site selection and construction of an exploration shaft, CTA and other underground infrastructure. The second phase comprises the balance of the planned shafts and access tunnels and the commencement of emplacement room excavation and installation of services for emplacement. The third phase comprises the operations phase of the DGR when the remaining emplacement rooms are constructed. Excavation of the emplacement rooms in the third phase is intermittent and conducted by means of mining campaigns by a mine contractor.

The emplacement rooms are recommended to be 315 m in length and accommodate 108 UFCs in each. The rooms will be 4.2 m high and 7.14 m wide and elliptical in shape. Accessways and other tunnels will be 4.2 m high by 7.0 m wide and rectangular in shape with an arched back.

The DGR construction schedule calls for concurrent emplacement of UFCs and campaign mining. Excavation and emplacement will both retreat towards the Service Shaft complex with the general airflow being from the Service Raise Complex to the Primary Exhaust Raise. Airflows for emplacement and excavation operations will always be maintained separate.

Cask and buffer block movement will always be uni-directional in a clockwise direction. Such an arrangement, as opposed to an unrestricted flow of traffic, is a more safe arrangement and reduces excavation requirements for emplacement room access.

Ventilation requirements for the DGR will be based on the airflows required for a drill and blast method of excavation and air velocities to control the heating effect from the stored UFCs.

Although normal excavation strategy will provide for excavation and emplacement activities always to take place at opposite sides of the repository, there is a concern related to potential damage to emplaced UFCs and associated clay-based sealing materials during blasting operations or the likely potential for such damage if professional blasting standards and engineered blasts are not followed. Accordingly, it is recommended that blast vibrations be monitored as a precautionary measure.

APPENDIX A

Mining Construction Techniques

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Mining Construction Techniques

Introduction

The Deep Geologic Repository (DGR) is proposed to comprise of a series of underground rooms and access tunnels excavated in a granitic pluton at a depth of 1000 m below surface. Geotechnical studies have recommended that the storage rooms cross section be elliptical to minimize the effect of the expected non-isotropic rock stresses.

The DGR Design Update Report has chosen an elliptical cross-section emplacement room with approximate internal dimensions of 7.14 m along the horizontal axis and 4.20 m along the vertical axis, resulting in an aspect ratio of 1.7.

The access tunnels linking the container emplacement rooms are, for the purposes of this study, assumed to be rectangular in shape 10.00 m wide by 4.40 high with an arched back (i.e. of similar dimensions to those assumed in the Baumgartner et al 1996 study). Several factors, including a different assumed fuel inventory, have, however, resulted in different repository dimensions for the current study.

The proposed layout of the DGR (Figure 1a) has an area of 1.78 km^2. The repository is now subdivided into four (4) Sections having each 26 emplacement rooms with a length of approximately 315.02 m.

The purpose of this analysis is to compare the merits of drill and blast (D&B) mining techniques with tunnel boring machine (TBM) techniques, and to recommend which technique should be reflected in the DGR Design Update report.

Geotechnical Considerations

A listing of the major geotechnical considerations is provided below. This report excludes a detailed discussion of these areas.

Important geotechnical factors in selecting a method of excavation relate to:

- Rock mass quality with Rock Mass Rating (RMR) or similar rating system identified
- Rock strength
- Rock stress state
- Water pressure/inflows.

TBM or D&B techniques both require knowledge of these parameters. Important D&B considerations are water inflows, grouting requirements (if any) and ground support.

Practical and Technical Considerations

Rate of Progress

The rate of progress of a D&B, which can range from 3 m to 5 m per day, is dependent on many factors. Holen[17] has expressed the general statement that a good weekly advance for cross sections of 50 m^2 would be 80m and more than 100 m for smaller cross-sections. For TBM, a good production rate per week may be in the range between 150 m and 400 m dependent on the rock conditions, machine parameters and diameter.

D&B can be undertaken on as many fronts as the layout and logistics allows with the use of additional equipment sets. This would be advantageous if speed of construction was of prime importance. However, this is unlikely to be the case. Similar flexibility would also be possible using mobile mining equipment. However, increased capitalization would be necessary.

Rock hardness and degree of fracturing are important factors in determining the rate of progress of a TBM, as are the logistics that accompany the machine. The utilization of the TBM, i.e., actual time spent boring rather than maintenance or other activities, significantly affects overall progress. If rate of progress were solely dependent upon penetration rate (mm/revolution) it would be relatively simple to determine the rate of progress. In papers published by Holen, Bruland[18] and Cigla et al[19], determination of penetration rate in all three papers were a function of:

- Intact rock properties
- Rock mass properties
- Cutter and cutting geometry
- Machine specifications
- Operational parameters.

The first three items are dependent on detailed rock analysis, which is not currently available for the DGR. The assumed uniaxial compressive strength of the granites in which the DGR will be excavated can provide tunnel bore manufacturers insights into expected penetration rates. However, Cigla cautions that mechanical cutting predictions relying only on the compressive strength alone may provide inaccurate results.

In foliated/bedded rock, according to Bruland and referenced by Cigla, the orientation of the foliation planes with respect to the machine advance direction can have a significant effect on advance rates. Lovat of Toronto[20] was contacted by CTECH to discuss TBM advance rates. Lovat reported that it had had some experience in tunnel boring in granites, and taking a conservative approach, thought that with proper geotechnical analysis, penetration rates of approximately 0.6 m/hr could be achieved for circular openings.

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[17] TBM vs. Drill and Blast Tunnelling, H. Holen, Statkraft AS

[18] Prediction Model for Performance and Cost, A. Bruland, The Norwegian University of Science and Technology, Norway

[19] Application of Tunnel Boring Machines in Underground Mine Development, M. Cigla, S. Yagiz, L. Ozdemir, Excavation Engineering and Earth Mechanics Institute, Department of Mining Engineering, Colorado School of Mines, Golden, Colorado, USA

[20] Lovat, 441 Carlingview Drive, Toronto, Ontario

Items that can affect the borer's performance are:

- Assembly and disassembly of the TBM and back-up (discharge conveyors)
- Excavation of tip stations, niches and branchings
- Rock support in zones of poor quality
- Time for dealing with unexpected rock mass conditions
- Complimentary rock support and lining
- Major TBM breakdowns
- Invert cleanup
- Haulage capacity.

In modeling exercises referenced in the Colorado School of Mines paper (Cigla et al.) a utilization factor of 30% is attributed to boring through granite producing a 5 m per day advance rate.

Downtime on a drill jumbo can be extensive as well, but the cost differential between that of a drill jumbo and a TBM or Mobile Miner is such that it provides the excavation contractor opportunity to have numerous jumbos available as spare units, thereby increasing drilling time at the face.

Experience in Norway[21], and elsewhere, indicates that TBM advance rates can significantly exceed those of D&B, but rates are clearly a function of rock type and ground conditions.

Status of Technology

Control of the excavation damage zone (EDZ) is one of the most significant aspects of DGR design. TBMs will provide very good EDZ characteristics, but D&B can also limit EDZ to acceptable limits through engineered blast designs to provide very smooth walls. According to the published literature, experiments at the Underground Research Laboratory in Pinawa have demonstrated the ability of D&B techniques to provide very good excavation control with relatively little blast damage when controlled blasting techniques and well-designed perimeter blasting techniques are used.

Elliptical shaped rooms are required for stability purposes. Circular shaped emplacement rooms are not an option for the DGR. According to Lovat, the present ability of conventional TBMs to provide an elliptical cross section is limited to those ellipses with a major/minor axis aspect ratio of 2.0 or less. The elliptical shape is accomplished by mounting two smaller cutting wheels outboard of the main cutting wheel. Unfortunately, the shape would not be perfectly elliptical. Lovat suggested a road header might be used to complete the desired shape.

According to a literature search by CTECH, two Japanese[22] [23] companies have applied for patents on a tunnel bore machine with an angled cutting face. The rationale is that when a

[21] TBM vs Drill & Blast Tunnelling, Holen, Statkraft Anlegg AS
[22] Shield Boring Machine, K. Katsumi, Taisei Corp., Patent Number JP 1193691, Application Number JP-19970398929-19971226

sphere is sliced at an angle other than 90^o to one's plane of sight, an ellipse is produced. In reviewing their patent application it seems feasible for soft rock formations, but CTECH is hesitant to recommend this approach for hard ground, where the machines cutter thrust in the advancing direction would be diminished.

According to a literature search carried out by CTECH, Mitsubishi Heavy Industries of Japan has experimented with a twin head TBM. The unit consists of two overlapping heads with cutters in both heads being limited to two diametrically opposed sectors covering approximately 15% of the TBM face area. The spacing is such that there is no interference between the two heads when boring. In 1999, the device was described as experimental[24].

The Mobile Miner produced by Robbins and the Continuous Mobile Miner build by Wirth are more flexible machine that are reported to be able to turn in approximately 11 m. However, both machine have had limited use and in the opinion of CTECH would require more field experience before either could be considered for the DGR application.

Excavation System Flexibility

Holen[25] in his paper cites the conventional TBMs turning radius as the greatest hindrance to flexibility of use. A stripped down TBM can pass a minimum radius of 40 to 80 m, but, with its trailing gear in place, turning radii of 150 to 450 m can be expected. In addition, it can be expected that an additional 3 to 6 weeks of non-production time would be required for each move and re-assembly, once a starting chamber was made available for the re-assembly (Holen). As a result, conventional TBMs are best suited for "line drive" tunnelling, going from point A to B, and according to Holen and Bruland, the minimum economic length of drive for choosing a conventional TBM excavation method is 5 to 6 km.

The Mobile Miner produced by Robbins and Wirth are more flexible tunneling machines compared to conventional TBMs and can turn in approximately 11 m radii. However, in the opinion of CTECH, these machines have had limited use and thus at this time would require more field experience before being considered for the DGR.

The Japanese have also developed TBMs that can turn very tight radii, including right-angle turns. However, as the production machines have only been soft ground and only a few prototype hard rock machines have been build, CTECH considers these machines are not sufficiently proven to be considered for the DGR.

In general, drill jumbos are more flexible than conventional TBMs. The turning radius of a 3-boom jumbo will range from 9 to 11 m depending on boom length. Once on the level and assembled no further work is required other than normal maintenance procedures. Since the drill unit is small in comparison to the TBM, it can excavate the rock mass on many fronts.

D&B techniques allow virtually any underground design to be constructed with there being no impediment to the establishment of relatively tight turning radii to provide an effective 90^o turn-off. It is on this premise that the current layout is based. Although Mobile Miners can turn tight curves, they must still be considered in the prototype arena for hard rock use. Conventional

[23] Large Section Shield Boring Machine, M. Setsuo, Ohbayashii Corp., Patent Number JP 2000120386, Application Number JP-19980298058-19981020

[24] Development of Non-circular Section Mechanism for Hard Rock, F. Ishise et al. Mitsubishi Heavy Industries 1999

[25] TBM vs. Drill and Blast Tunnelling, H. Holen, Statkraft SA

TBM techniques, by contrast, require a turning radius of 150 m or more and thus using such approaches, it will not be possible to excavate emplacement rooms out from the main access in the layout proposed with D&B.

Considering the issues raised by the TBMs turning radius assuming the use of a conventional TBM with no special turning characteristics, a re-assessment of the DGR layout is in order with more continuous tunnels and less right angle turns if TBM methods were to be adopted. A preliminary review of potential layouts by CTECH using TBMs indicates that an efficient design would be difficult to achieve.

Problems that are immediately apparent are:

- Large area and length of tunnel required to turn at 90^o
- Intersections of tunnels need to be at 90^o or thereabouts in order to avoid the very wide cross-over spans resulting from tangential or near-tangential intersections
- According to conventional wisdom, in a normal commercial environment, the economics of tunnel boring only become advantageous when continuous drives of more than 5 km are considered. In the case of development of the DGR, cost is not the most critical item.

Relative to proven conventional TBMs, the drill jumbo is flexible in respect of conformance with typical mine designs. The conventional TBM is inflexible.

Transportation

According to the United States Department of Energy (DOE) website[26] [27], the TBM used for excavation at its Yucca Mountain NWF, with its trailing equipment in place, weighted 860 tons and measured 140 m in length. Although it is larger in gross diameter than what is envisaged for the DGR with the outboard cutting wheels for the elliptical shape, CTECH estimates a conventional TBM of similar magnitude would be required. Transportation of the TBM to the DGR site would be achieved by special transports. Transportation underground would require breaking the unit down into parts and a re-build once located on the repository level. The degree of dismantling required is a function of the size of the shaft conveyance compartment and the shaft’s hoisting capacity.

The drill and blast equipment (drill jumbos, load-haul dump, haulage trucks, etc.) would also require dismantling and re-assembly underground.

Phased Approach to Development

Currently it is intended to carry out an underground evaluation of the proposed DGR site prior to licensing and construction of the full-scale facility DGR. This will involve the excavation of a shaft to the required depth of 1000 m and some geotechnical and excavation work being carried out. This will allow construction and operation designs to be completed.

Regardless of whether D&B or boring is carried out, the initial underground excavation probably will be carried out using D&B techniques, as up to 100 m of development will be required in which the TBM would be set up. If the underground evaluation phase of the construction were

[26] http://www.ymp.gov/factsheets/doeymp0001.htm
[27] http://www.ymp.gov/factsheets/images/tbmgraphics.htm

being carried out by D&B techniques, the use of TBM techniques would not be hindered. Initial excavation by D&B would be necessary for the TBM designer and manufacturer to gather data for the design of the TBMs, if such were being contemplated. The layout selected for the underground evaluation phase would be designed to be used in the later operations, with enlargement if necessary.

Excavation Damage

The major concern with respect to excavation damage for drill and blast technology is the creation of stress fractures emanating from the rock face back into the rock mass providing a zone of weakness, and vibration (shock-wave) through the rock mass caused during blasting. The effect of blasting will generate an EDZ.

Recent developments in drill technology, combined with planned and engineered drilling, hole loading and stemming can minimize the stress fractures normally associated with hard rock mining. Many of the drill manufacturers provide on-board computerized drilling capability, in which not only allows the operator to correctly position the drill, but will also log all pressures related to drilling and the position of the drilled holes. This would be very useful in designing explosive and stemming loads for the emplacement room.

Once a site is selected and during the exploration phase[28] of the DGR, excavation damage data can be updated and assessed on a regular basis and modification of drilling parameters can be made accordingly.

The on-going development of actual excavation damage data during the "exploration phase" may affect the timely transition from exploration to DGR facility development if tunnel boring is chosen. Once all the rock parameters are determined delivery time of a new TBM can vary between 6 to 12 months.

[28] Engineering for a Disposal Facility Using the In-Room Emplacement Method, P. Baumgartner et al., AECL-11595, COG-96-223, June 1996

Health and Safety

Ventilation

For the purpose of this Appendix, CTECH comments on ventilation pertain to the issue of D&B versus tunnel boring excavation methods, rather than any issues related to radiation effects and temperature, which are important considerations during emplacement activities.

In D&B excavation methods, two potential health concerns are:

- The generation of diesel fumes and particulate matter
- The generation of blasting fumes.

The effects of the first concern can be minimized by:

- Providing proper dilution rates for the operating diesel fleet
- Minimizing the effect of the diesel fleet on the project by utilizing electric load-haul-dump machines and electric trolleys back to the service shaft.

The impact of blasting gases on the facility during the placement of the UFC can be minimized by:

- Providing dedicated exhaust routes for radionuclide and blasting fume production
- Ensuring the excavation and preparation of the emplacement rooms take place on the opposite side of the repository from emplacement.

TBM methods do not generate the blasting and diesel contaminates as D&B. Dust control is a problem common to both methods, but dust can be a particular problem for the TBM technique with dust being generated from the rotation of the cutting heads. In the opinion of CTECH it is likely that by the very nature of the boring process a higher portion of the dust generated in TBM methods will be in the respirable range (< 5 μm), and therefore could present a potential health hazard. However, good engineering design practice and the implementation of dust control procedures should essentially eliminate hazards arising from dust for both TBM and D&B methods.

Current Practice by Active Nuclear Fuel Waste Disposal Authorities

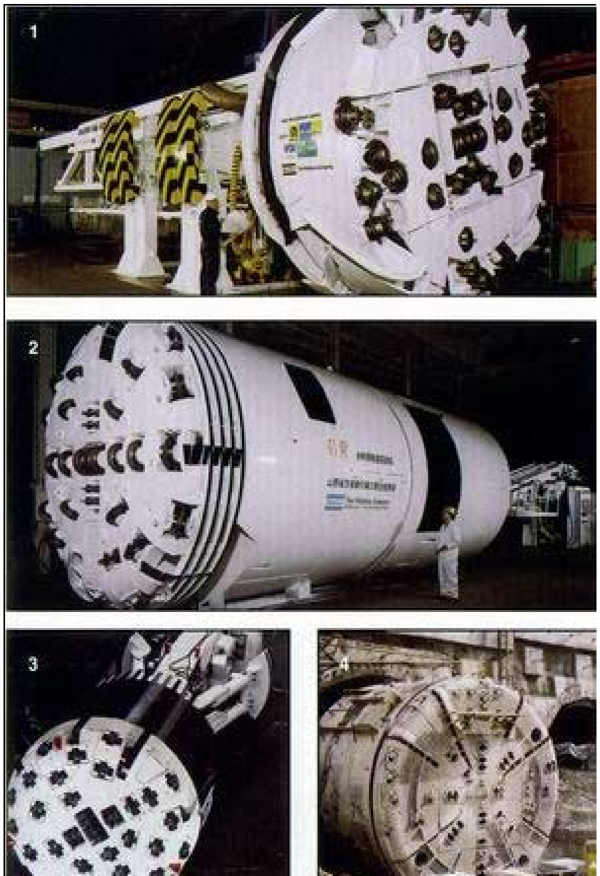
An investigation carried out by Golder Associates (Golder) on behalf of CTECH, on the current directions being considered by various agencies worldwide for excavating emplacement rooms and ancillary underground facilities for the DGR has revealed that the major focus on method selection of most agencies is not on cost nor on rate of progress (although both are important) but is primarily on wall control and secondly on flexibility for achieving desired excavation geometries.

Excavation using D&B methodology is still being considered by a number of agencies, as they have long experience in its use and consider it as more flexible than machine methods. However modern advances using non-circular mobile mining machines as illustrated in the right hand photographs in Figure 1 (overleaf), rather than the conventional civil tunnel boring machines (TBMs), as illustrated in the left illustrations, is leading to changes in appreciation of the flexibility and performance available from machines.

Based on an overview assessment of the various available techniques the advantages and disadvantages of each major method has been summarized, as per the following matrix table:

Table 1 –Comparison Matrix of Drill and Blast approaches with Machine Methods

	ADVANTAGES							DISADVANTAGES						
	Quality Profile	Flexibility	High Speed	Low Cost	Tight Curves	Fast Set-up	Proven Technology	Vibrations	Fumes	Slow Speed	High Cost	Slow Set-up Time	Low Flexibility	Prototype
Drill & Blast		☑	▪		☑	☑	☑	☒	☒	☒				
Conventional TBM	☑		☑				☑				☒	☒	☒	
Mobile Miner	☑	☑	☑	☑	☑	☑								☒
Esoteric Machines	☑	☑	☑								☒	☒		☒



Various conventional CIVIL-type TBM's with long trailing equipment. High quality wall control but limited flexibility and turning radii (150m)

Traditional Drill Jumbo for D&B excavation. Significant flexibility, but reduced wall control compared with machine mined

Continuous Mobile Miner, capable of tight (11m) radius turns, good wall profile control and mining non-circular shapes

Commercial Mobile Miner, capable of tight radius turns and mining non-circular shapes

Figure 1 – Comparative Illustrations of Available Excavation Equipment

In the above Table 1 the term Esoteric Machine refers to the various hybrid and complex machines that are currently in use or in development in countries such as Japan, a few of these types of machine are illustrated in Figure 2.

Figure 2 – Various types of esoteric multi-face machines mainly for soft ground excavation. Note: some multi-face prototypes are already in development for hard-rock utilization.

None of the agencies consulted has as yet completed a thoroughly rigorous review of the advantages and limitations of each of the newer approaches as a means for optimizing the selection. However, the Japanese, Swedes, Americans and the Swiss have advanced further than the Canadian program in conducting at least partial trials of a number of methods. These trials and the various studies that have followed have lead to their programs at least having tentative ideas on methodologies. Table 2 summarizes the information collected from the various agencies, while the following discussion sheds some light on the currently very diverse viewpoints on the best and most appropriate selection of methodology.

Table 2 –Comparison Matrix of Nuclear Agencies Excavation Method Selections

	DRILL & BLAST							TBM							SELECTION		
	Primary Design	Alternative	Considerations …….	… Cost	… EDZ Minimization	… Rate of Progress	… Flexibility	Primary Design	Alternative	Considerations …….	… Cost	… EDZ Minimization	… Rate of Progress	… Flexibility			
Sweden (SKB)	☑	▪	▪		②	▪	❶	▪	☑	▪		❶		▪	☑	|	
US (Yucca Mtn)			▪				▪	☑		▪		❶	▪	▪		|	☑
Finland (Okiluoto/Posiva)	☑	▪	▪	▪	②	▪	❶		▪	▪	▪	▪		▪	☑	|	
Korea (KAERI/Kigam)	☑	▪	▪						▪	▪				▪	☑	|	
Switzerland (Grimsel)	▪	▪	▪	▪	▪	▪		☑	▪	▪		❶		▪		|	☑
JNC (Japan)		☑	▪	▪	▪	▪	②	☑	▪	▪	▪	❶		▪		|	☑
Enresa (Spain)	▪	▪	▪					☑	▪	▪		❶		▪		|	☑

Note: The table indicates the ranking of the factors by the agencies, with ❶ being most important and ② being next important.

JNC (Japan) indicate that their preference will be to use TBM methods for the repository, but they indicate that are not committed to it. Their rock lab (which is due to start into construction in 2005) will use D&B methods due to logistical constraints.

The Swedes have done extensive comparisons of D&B versus TBM, with specific comparison testing conducted in the ASPO hard rock laboratory. These tests indicated a net penetration rate of 1.36 m/hour (1-3 m/hour is an industry standard) with an average utilization ot the TBM when boring of 30% (again well within the industry range of 20 - 60 %). For the trials it was found that at these utilizations the advance rates for the TBM per week were of the order of 30 - 50 m, and that almost the same was achieved by D&B methods. On the basis of these comparisons SKB have decided tentatively that the use of TBM technologies may be unnecessarily restrictive in flexibility and may not necessarily produce a significantly safer repository. However, they are still carrying forward use of TBMs as an option.

Currently, the US is the only agency that is firmly committed to use of TBM methods (ref Figure 3 – which shows the Yucca Mountain machine – which is basically of the conventional circular face Civil–type of construction). This decision was based almost entirely on Performance Assessment and Safety considerations mainly related to the depth of the EDZ created around a machine driven excavation versus that created by D&B methods.

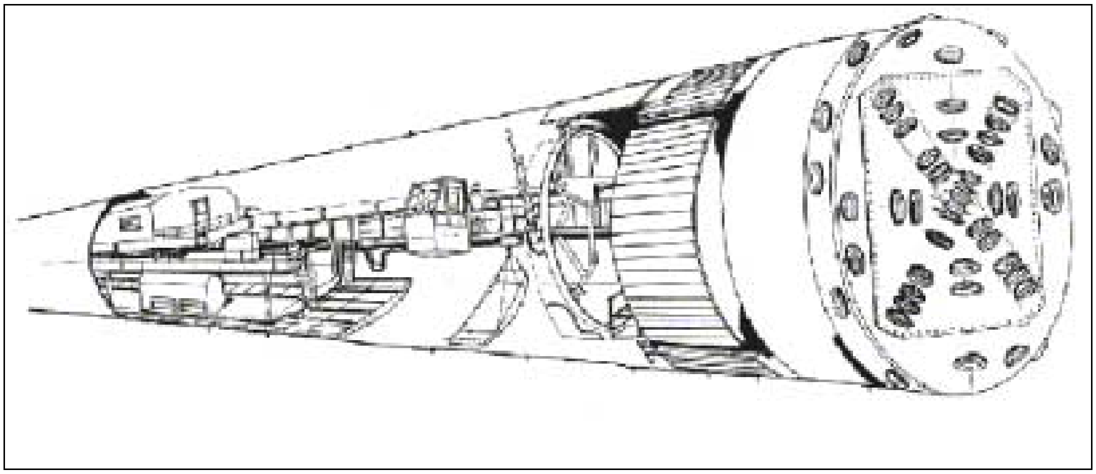


Figure 3 - Yucca Mountain TBM Concept

Enresa, for the Spanish program view the decision in much the same way, and as a consequence are focusing their development concepts on use of TBM techniques because of the evidence that it produces a smaller EDZ. Although, they have not undertaken an independent financial evaluation of TBMs versus D&B they maintain that the decision must be based on Performance Assessment (PA) of which method constitutes the better safety case. Based on their studies of the available evidence they have concluded that machine excavation methods create less damage to the rock mass walls, thus they consider D&B an unacceptable option for the repository.

At the opposite end of the scale, by contrast, at the present time the Finnish program uses 100% D&B, and has no plans for TBM usage. This decision is partly historical, as all the ILW/LLW repositories that have been constructed in Sweden and Finland were built using D&B methods, so there is a fair degree of familiarity and comfort with the technology. In general, the rock is good (mainly self supporting), and smooth wall blasting leaves little damage. Further, the SKB and Posiva programs have quite specific and particular requirements for the shapes and sizes of their repository openings, for which D&B is ideally suited.

As is evident from Table 3, both TBM and D&B methods have been selected as the approach of choice by different DGR programs. However with the advent of significant and novel technological developments in machine mining which aid performance and flexibility it is clear that more refinement and optimization of selection decisions is still needed, and that changes in direction may yet occur with several of the programs. The Swiss program, provides an insight into the thrust of current focus, as this program is already advancing along optimization lines on the basis of risk minimization decision analysis approaches, with suggestions of a hybrid of various approaches as being the optimum way forward. Based on trials undertaken at the rock laboratory at Grimsel where both blasting and TBM were used to investigate drilling technologies and their implications on PA issues, the Swiss are currently considering use of three different excavation methodologies for the proposed LLW repository at Wellenberg (marl formation, central Switzerland), as follows:

- For the access tunnels and entranceways / and in adjacent rock formations: - D&B (using smooth blasting methods)

- Within the repository host rock: - a combination of TBM (operational tunnels) and "Teilschnitt-Maschine" (mobile miner/road-header)
- For the emplacement caverns: - smooth-wall blasting or road-header.

Ongoing work is focussing on optimizing the selection criteria on the basis of cost and time optimization for the access tunnels; and on EDZ minimization for the emplacement rooms and tunnels

Similar, but very preliminary, optimization planning studies are in progress related to the methodologies likely for use for the proposed HLW/ILW repository proposed for construction in a clay formation in northern Switzerland (reference level of the repository: 650 m below ground). For this planned facility, concept planning is currently considering:

- For the access tunnels / ramp: - road header or soft blasting
- For the access shafts: - raise boring or conventional shaft sinking (depending on evaluation of expected mining risks)
- For the ILW-emplacement tunnels: - smooth-wall blasting
- For the HLW-emplacement tunnels: - TBM.

In this case, again, ongoing studies are continuing focusing on optimizing the selection criteria, with current thinking being that cost / time optimization and minimization of engineering risks will dominate the selection procedures for the access tunnels; while EDZ minimization will be the sole constraint for the emplacement tunnels

The Canadian program can and should benefit from these types of risk minimization studies and the long and extensive hard-rock mining experience embodied in the Canadian mining industry. The increased use of advanced mechanized mining in ore extraction and the thrust of the civil tunnel boring machine manufacturers towards more functionality of their high end machines gives confidence that much more flexible, high performance mining TBMs will be available that will be better suited to excavating the required repository room complexes.

Conclusions

Currently, the technical feasibility of boring an elliptically shaped heading in hard rock has not been proven, although machine excavation equipment is certainly capable of cutting typical high strength plutonic rock as demonstrated by the successful raise boring completed at AECL's URL facility.

D&B techniques are more flexible than TBM techniques.

TBM techniques eliminate the inherent hazards of blasting and ventilation of blasting fumes, but good design and proper procedures can reduce this potential hazard to acceptable limits.

Although rock disturbance is minimized by the use of boring methods, the damage resulting from D&B techniques can be minimized by good blast design.

The requirement of an underground evaluation phase of the construction most likely being carried out by D&B techniques would not necessarily hinder the use of TBM techniques and would be necessary for the TBM designer and manufacturer to complete the design of the TBMs, if such were being contemplated.

Recommendation

In the opinion of CTECH and at this time, the technical feasibility of boring an elliptically shaped heading has not been demonstrated to the level that the method can be recommended with certitude in respect of construction of the DGR.

APPENDIX B

Blasting Vibration Control

APPENDIX B

Blasting Vibration Control

Purpose of Blasting Vibration Control

According to the normal excavation strategy, blasting operations will not take place near emplacement operations. However, the possibility exists that during on-going excavation activities, the vibration created by blasting may affect adjacent emplacement rooms in which either emplacement activities are on-going or UFCs have been emplaced.

The purpose of this Appendix is to suggest a practical method to limit ground movement within the repository during the excavation process, especially in the vicinity of emplaced UFCs. There is no discussion on the effect of blast design and blast vibration on the EDZ arising from development activities.

CTECH suggests the use of Peak Particle Velocity (PPV), frequency and Scaled Distance Factor to determine the possible seismic effects in design and monitoring of the blasts.

The scaled distance is related to the weight of explosive charge and the distance from the blast. These parameters influence seismic effects and therefore the ground vibration resulting from the blasts.

Description of Methodology

According to literature, most of the experiments examining PPV, a particle velocity of less than 51 mm/s (~2 in/sec) has been shown to create no damage[29]. This assumes frequency is greater than about 50 Hz. Therefore, CTECH will utilize a 51 mm/s velocity as a maximum allowable PPV in determining the weight of explosives per detonation.

For the purpose of PPV and Scaled Distance Factor determinations:

- If the Charge Length/Charge Diameter ratio is greater than 6, it is defined as a Cylindrical Charge
- If the length of Charge/Charge Diameter ratio is less than 6, it is defined as a Spherical Charge.

The drill holes produced in the excavation process are therefore considered cylindrical charges. The scaled distance equation[30] used to maintain PPV below 51 mm/s for a cylindrical charge is:

$$D_s = D/(W)^{1/2} \qquad (1)$$

Where D_s is scaled distance, D is distance from blast and W is weight of explosive.

Therefore, manipulating Equation 1, the weight of the explosive can be estimated by:

$$W = (D/D_s)^2 \qquad (2)$$

[29] Explosives and Rock Blasting, Field Technical Operations, Atlas Powder Company, 1987, pg. 332, 333

[30] Explosives and Rock Blasting, Field Technical Operations, Atlas Powder Company, 1987, pg. 333 - 339

Further limitations[31] are provided for the Equation 2, as to whether the blast site is monitored utilizing seismic equipment or not.

A. Seismic Instrumented Site:

Use of a D_s factor of 13.44 m/(kg)$^{1/2}$ (20 ft/(lb)$^{1/2}$) is recommended for sites using the seismic measurement instruments if a peak particle velocity of less than 51 mm/s is to be obtained.

B. Non-seismic Instrumented Site:

Use of a D_s factor of 33.61 m/(kg)$^{1/2}$ (50 ft/(lb)$^{1/2}$) is recommended for sites that are not instrumented. This factor includes a factor of safety to allow high seismic energy generation.

Estimation of the Maximum Explosives Charge

It is recommended that instrumentation be installed to monitor PPV for the OPG project. Table 1 indicates the maximum allowed charge per blast where at least an 8 ms delay occurs between adjacent hole detonations.

> *Note: As the time increases between adjacent hole detonations PPV is reduced. The 8 ms delay between adjacent is an explosive industry minimum norm[32] used in blast design. However, depending upon OPG's requirements the time delay between adjacent holes may be greater than 8 ms.

Assuming a 3.65 m (~12 ft) round is drilled for the panel access drifts and emplacement rooms, with a 0.61 m (~2 ft) collar (i.e. the unloaded portion of a hole), a 3.04 m (~10 ft) hole length will be charged. Holes that are to be charged are typically 38 mm in diameter.

[31] Explosives and Rock Blasting, Field Technical Operations, Atlas Powder Company, 1987, pg. 338
[32] Explosives and Rock Blasting, Field Technical Operations, Atlas Powder Company, 1987, pg. 284

Table 1: Maximum Allowed Explosives Charge

Distance from blast		D_s factor of 33.61		D_s factor of 13.44	
M	Ft	w (lb)	w (kg)	w (lb)	w (kg)
5	16.4	0.11	0.05	0.67	0.31
10	32.8	0.43	0.20	2.69	1.22
15	49.2	0.97	0.44	6.05	2.75
20	65.6	1.72	0.78	10.76	4.88
25	82.0	2.69	1.22	16.82	7.63
30	98.4	3.87	1.76	24.22	10.99
35	114.8	5.27	2.39	32.96	14.95

W = Maximum weight of explosive charge

Assuming that ammonium nitrate fuel oil (ANFO) type explosives are utilized as the blasting agent, which is a conservative assumption as less powerful explosives are likely to be used, the mass of the explosive will vary with the drilled hole diameter. In this example that does not represent an actual blast hole loading design, since the diameter of the drill holes are 38 mm (~1 ½"), the density of ANFO is 0.8 g/cc [33] and the charged length of the drill hole is 3.04 m (10 ft). The resultant weight of explosives determined from explosive loading density tables[34] is 0.91 kg/m (0.61 lb/ft). Therefore each drill hole will contain 2.77 kg (~6.1 lb) of explosive.

Figure 1: Maximum Allowed Explosives Charge

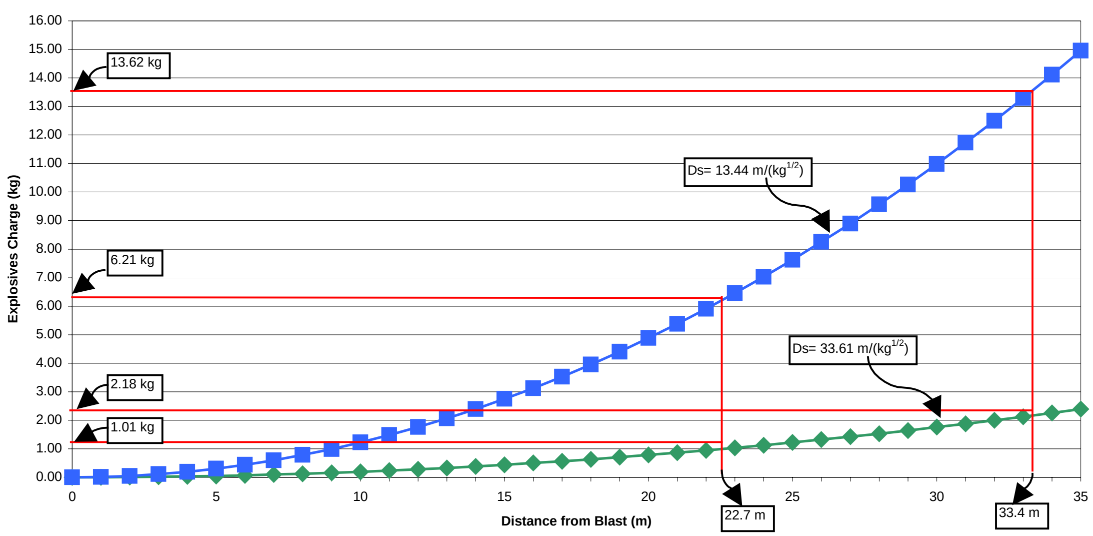


Table 1 is represented graphically in Figure 1, demonstrating the Amount of Explosive Charge versus Distance from Blast, to maintain PPV below 51 mm/s. From Figure 1:

[33] Explosives Handbook, E.I Dupont, 1974, pg 41.
[34] Explosives and Rock Blasting, Field Technical Operations, Atlas Powder Company, 1987, Appendix C pg. 582

- If a non-seismic monitored blast occurs during emplacement room excavation, explosive charges must be kept below 1.01 kg per detonator when approaching an excavated emplacement room (i.e. 22.7 m)
- If seismic monitored blast occurs during emplacement room excavation, explosive charges must be kept below 6.21 kg per detonator when approaching an excavated emplacement room (i.e. 22.7 m).

According to the normal excavation strategy, blasting operations will not take place near emplacement rooms which have been already filled or those where emplacement operations are in progress. However, if blasting was necessary near to the concrete bulkhead and grout zone sealing of an emplacement room, the following guidelines should be observed, while recognizing that regulators may demand more stringent factors:

- If a non-seismic monitored blast occurs during excavation, explosive charges must be kept below 2.18 kg per detonator
- If seismic monitored blast occurs during excavation, explosive charges must be kept below 13.62 kg per detonator.

Recommendations

CTECH recommends:

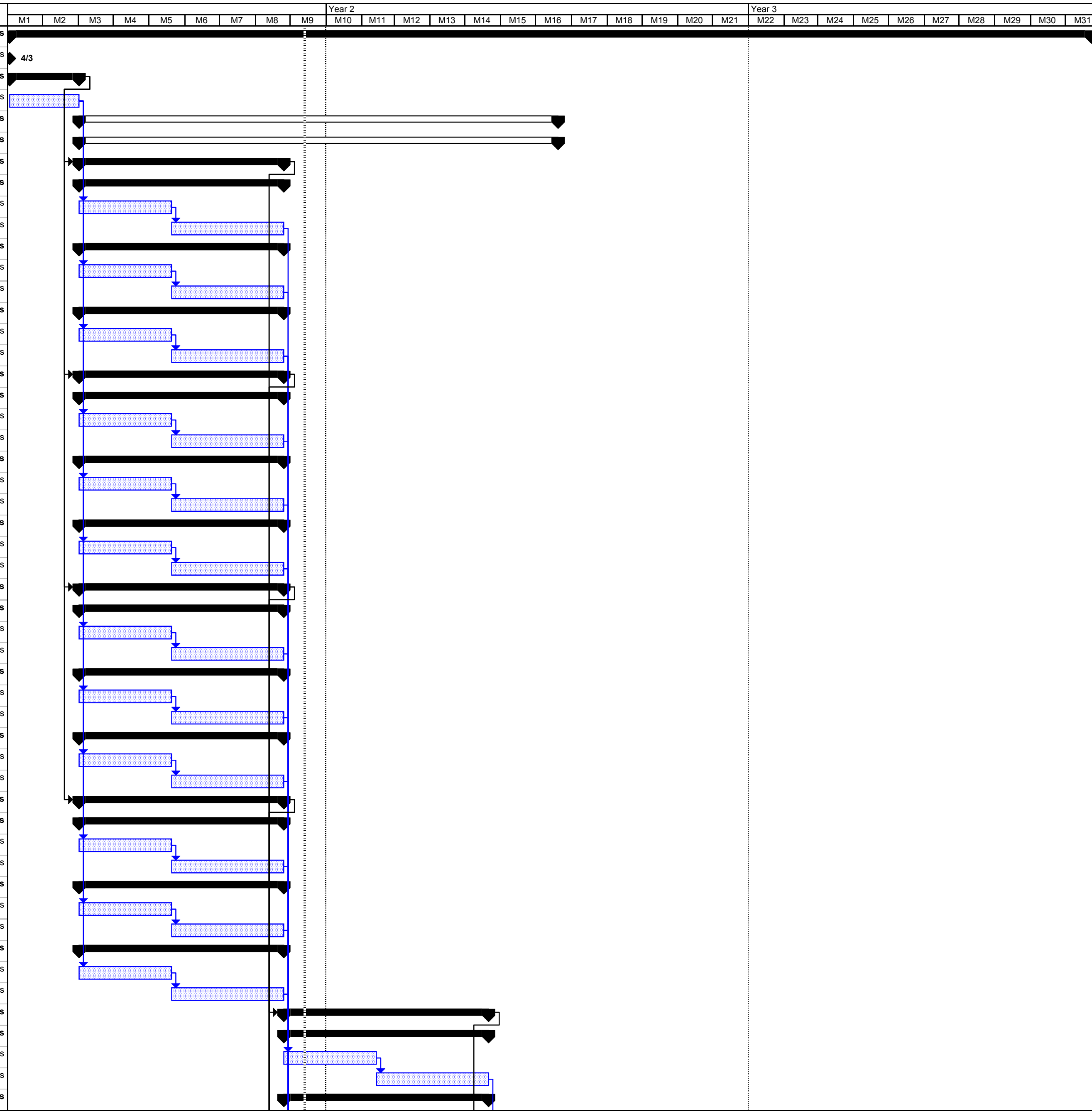
- Monitoring of the blasts for Peak Particle Velocity, to ensure the PPV does not exceed 51 mm/s, thereby allowing normal blasting advance and procedure
- For non-monitored blasting, reduce the hole length, hence explosive charge, if the excavation activity were to take place near an emplacement room or concrete/grout seal.

APPENDIX C

Campaign Mining Schedules

OPG-DGR Vault Excavation -Upper Half Section B/Lower Half Section D

ID	Task Name	Duration
1	**OPG-DGR Vault Excavation Project**	**935 days**
2	Award Contract	0 days
3	**Vault Excavation Mobilization**	**60 days**
4	Mobilization	60 days
5	**Vault Excavation Upper B/Lower D**	**414 days**
6	**Mine Block B/D**	**414 days**
7	**Jumbo No. 1**	**177 days**
8	**Mine Emplacement Room Upper B1 (UB1)**	**177 days**
9	Develop 290 m Pilot	80 days
10	Slash290 m Emplacement Room	97 days
11	**Mine Emplacement Room Upper B2 (UB2)**	**177 days**
12	Develop 290 m Pilot	80 days
13	Slash 290 m Emplacement Room	97 days
14	**Mine Emplacement Room Lower D1 (LD1)**	**177 days**
15	Develop 290 m Pilot	80 days
16	Slash 290 m Emplacement Room	97 days
17	**Jumbo No. 2**	**177 days**
18	**Mine Emplacement Room Lower D2 (LD2)**	**177 days**
19	Develop 290 m Pilot	80 days
20	Slash 290 m Emplacement Room	97 days
21	**Mine Emplacement Room Lower D3 (LD3)**	**177 days**
22	Develop 290 m Pilot	80 days
23	Slash 290 m Emplacement Room	97 days
24	**Mine Emplacement Room Upper B3 (UB3)**	**177 days**
25	Develop 290 m Pilot	80 days
26	Slash 290 m Emplacement Room	97 days
27	**Jumbo No. 3**	**177 days**
28	**Mine Emplacement Room Upper B4 (UB4)**	**177 days**
29	Develop 290 m Pilot	80 days
30	Slash 290 m Emplacement Room	97 days
31	**Mine Emplacement Room Upper B5 (UB5)**	**177 days**
32	Develop 290 m Pilot	80 days
33	Slash 290 m Emplacement Room	97 days
34	**Mine Emplacement Room Lower D4 (LD4)**	**177 days**
35	Develop 290 m Pilot	80 days
36	Slash 290 m Emplacement Room	97 days
37	**Jumbo No. 4**	**177 days**
38	**Mine Emplacement Room Lower D5 (LD5)**	**177 days**
39	Develop 290 m Pilot	80 days
40	Slash 290 m Emplacement Room	97 days
41	**Mine Emplacement Room Lower D6 (LD6)**	**177 days**
42	Develop 290 m Pilot	80 days
43	Slash 290 m Emplacement Room	97 days
44	**Mine Emplacement Room Upper B6 (UB6)**	**177 days**
45	Develop 290 m Pilot	80 days
46	Slash 290 m Emplacement Room	97 days
47	**Jumbo No. 1**	**177 days**
48	**Mine Emplacement Room Lower D7 (LD7)**	**177 days**
49	Develop 290 m Pilot	80 days
50	Slash 290 m Emplacement Room	97 days
51	**Mine Emplacement Room Upper B7 (UB7)**	**177 days**

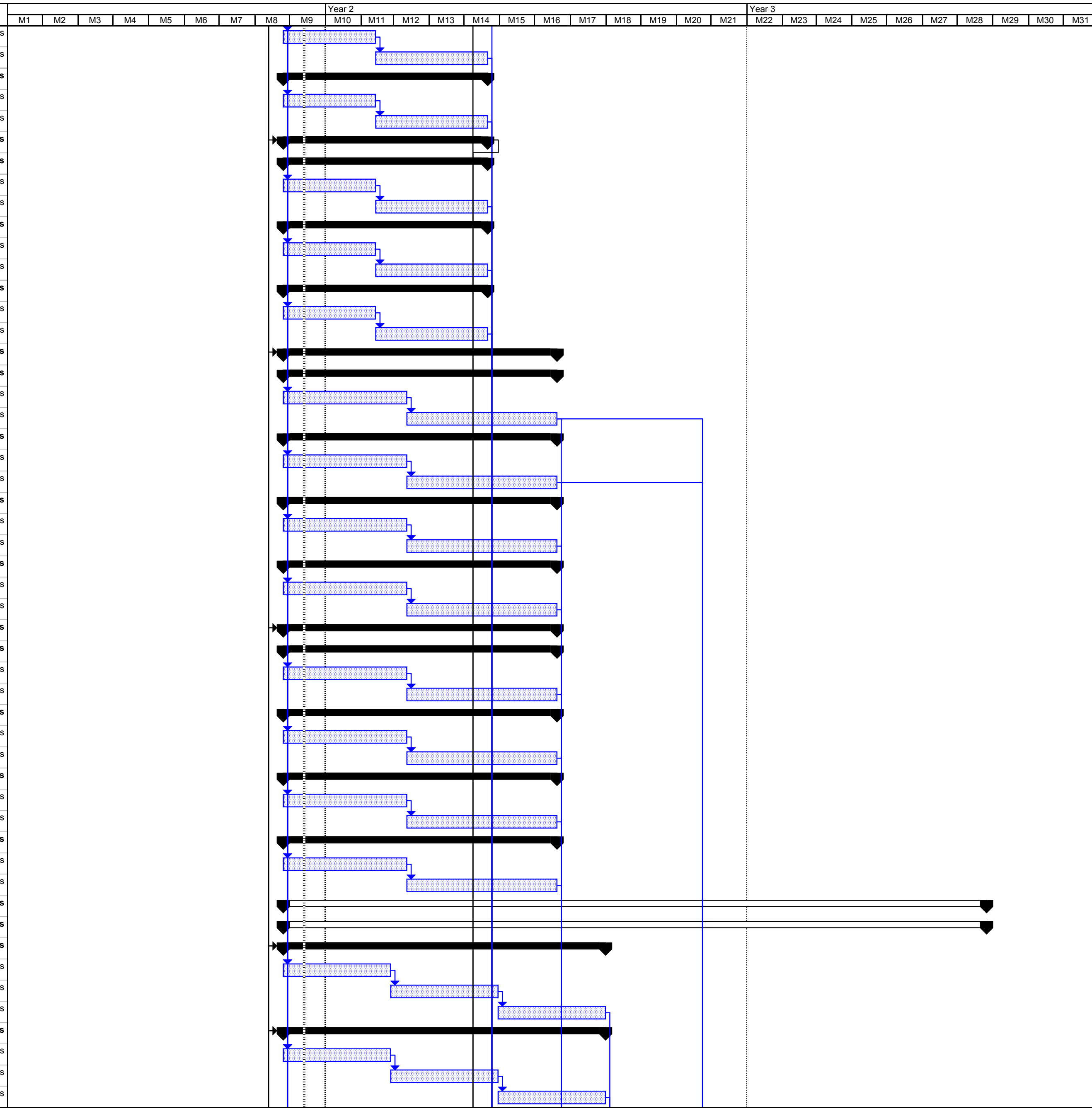


Project: OPG Project1
Date: Fri 12/13/02

Task | Split | Progress | Milestone | Summary | Rolled Up Task | Rolled Up Split | Rolled Up Milestone | Rolled Up Progress | External Tasks | Project Summary

OPG-DGR Vault Excavation -Upper Half Section B/Lower Half Section D

ID	Task Name	Duration
52	Develop 290 m Pilot	80 days
53	Slash 290 m Emplacement Room	97 days
54	**Mine Emplacement Room Upper B8 (UB8)**	**177 days**
55	Develop 290 m Pilot	80 days
56	Slash 290 m Emplacement Room	97 days
57	**Jumbo No. 2**	**177 days**
58	**Mine Emplacement Room Upper B9 (UB9)**	**177 days**
59	Develop 290 m Pilot	80 days
60	Slash 290 m Emplacement Room	97 days
61	**Mine Emplacement Room Lower D8 (LD8)**	**177 days**
62	Develop 290 m Pilot	80 days
63	Slash 290 m Emplacement Room	97 days
64	**Mine Emplacement Room Lower D9 (LD9)**	**177 days**
65	Develop 290 m Pilot	80 days
66	Slash 290 m Emplacement Room	97 days
67	**Jumbo No. 3**	**237 days**
68	**Mine Emplacement Room Lower D10 (LD10)**	**237 days**
69	Develop 290 m Pilot	107 days
70	Slash 290 m Emplacement Room	130 days
71	**Mine Emplacement Room Upper B10 (UB10)**	**237 days**
72	Develop 290 m Pilot	107 days
73	Slash 290 m Emplacement Room	130 days
74	**Mine Emplacement Room Upper B11 (UB11)**	**237 days**
75	Develop 290 m Pilot	107 days
76	Slash 290 m Emplacement Room	130 days
77	**Mine Emplacement Room Upper B12 (UB12)**	**237 days**
78	Develop 290 m Pilot	107 days
79	Slash 290 m Emplacement Room	130 days
80	**Jumbo No. 4**	**237 days**
81	**Mine Emplacement Room Lower L11 (LD11)**	**237 days**
82	Develop 290 m Pilot	107 days
83	Slash 290 m Emplacement Room	130 days
84	**Mine Emplacement Room Lower D12 (LD12)**	**237 days**
85	Develop 290 m Pilot	107 days
86	Slash 290 m Emplacement Room	130 days
87	**Mine Emplacement Room Lower D13 (LD13)**	**237 days**
88	Develop 290 m Pilot	107 days
89	Slash 290 m Emplacement Room	130 days
90	**Mine Emplacement Room Upper B13 (UB13)**	**237 days**
91	Develop 290 m Pilot	107 days
92	Slash 290 m Emplacement Room	130 days
93	**Concrete Emplacement In Upper B/Lower D**	**609 days**
94	**Concrete Emplacement**	**609 days**
95	**Concrete Crew No. 1**	**279 days**
96	UB1	93 days
97	UB2	93 days
98	UB3	93 days
99	**Concrete Crew No. 2**	**279 days**
100	UB4	93 days
101	UB5	93 days
102	UB6	93 days

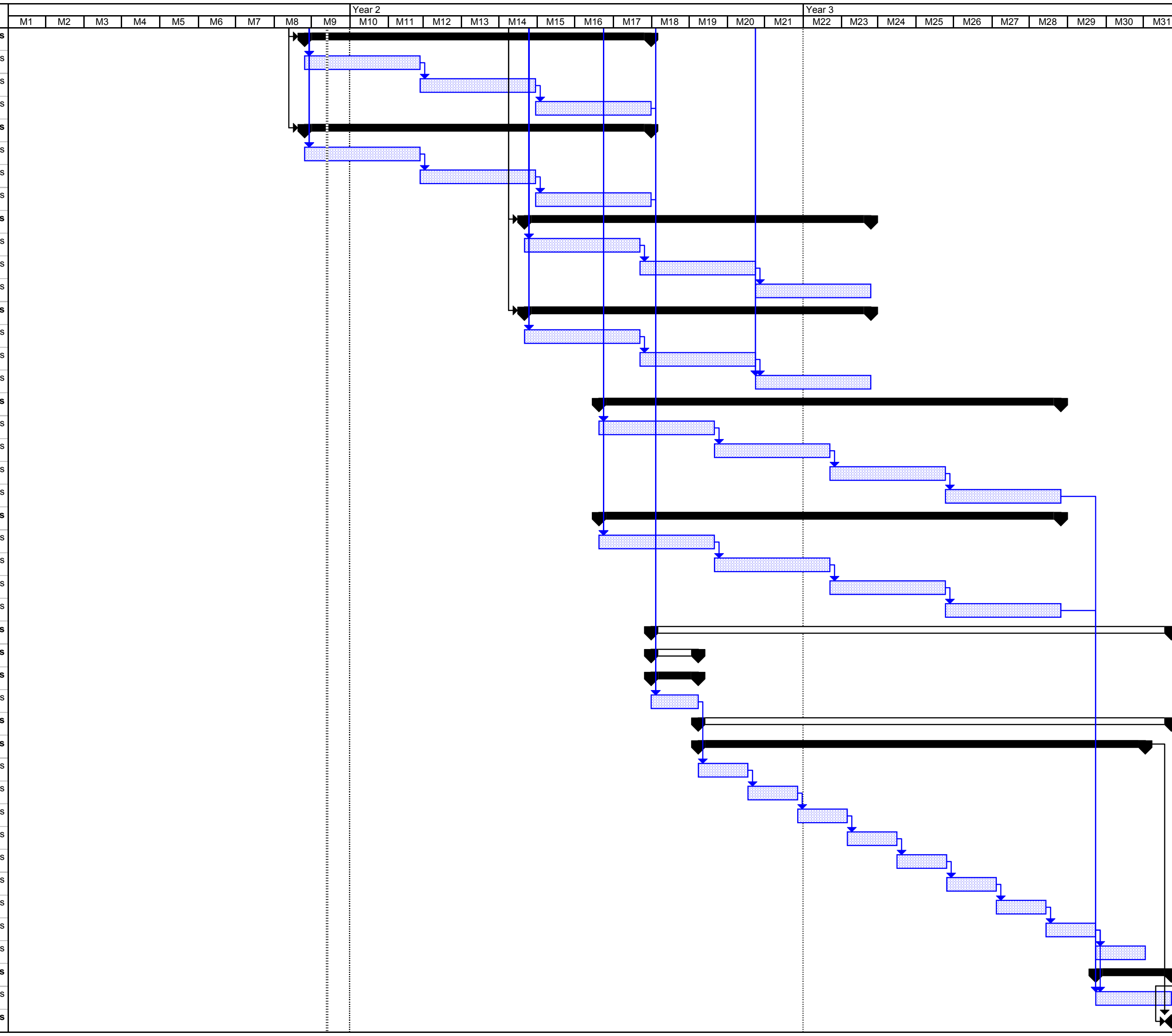


Project: OPG Project1
Date: Fri 12/13/02

Task	Progress	Summary	Rolled Up Split	Rolled Up Progress	Project Summary
Split	Milestone	Rolled Up Task	Rolled Up Milestone	External Tasks	

OPG-DGR Vault Excavation -Upper Half Section B/Lower Half Section D

ID		Task Name	Duration
103		**Concrete Crew No. 3**	**279 days**
104		LD1	93 days
105		LD2	93 days
106		LD3	93 days
107		**Concrete Crew No. 4**	**279 days**
108		LD4	93 days
109		LD5	93 days
110		LD6	93 days
111		**Concrete Crew No. 1**	**279 days**
112		LD7	93 days
113		LD8	93 days
114		LD9	93 days
115		**Concrete Crew No. 2**	**279 days**
116		UB7	93 days
117		UB8	93 days
118		UB9	93 days
119		**Concrete Crew No. 3**	**372 days**
120		LD10	93 days
121		LD11	93 days
122		LD12	93 days
123		LD13	93 days
124		**Concrete Crew No. 4**	**372 days**
125		UB10	93 days
126		UB11	93 days
127		UB12	93 days
128		UB13	93 days
129		**Prepare SectionB/D for Emplacement (Track, Vent, etc)**	**419 days**
130		**Install Track Across Emplacement Rooms**	**38 days**
131		**Install Track and Switch Gear Between Vault Upper B/Lower D**	**38 days**
132		Across Emplacement Rooms LD/UB1 - LD/UB 6 (12 Rooms)	38 days
133		**Install Track in 9 out of 26 Emplacement Rooms**	**381 days**
134		**Track Crew No. 1**	**360 days**
135		UB1	40 days
136		UB2	40 days
137		UB3	40 days
138		UB4	40 days
139		UB5	40 days
140		LD1	40 days
141		LD2	40 days
142		LD3	40 days
143		LD4	40 days
144		**Install Track and Switch Gear Between Vault Upper B/Lower D**	**61 days**
145		Across Emplacement Rooms LD/UB7 - LD/UB 13 (14 Rooms)	61 days
146		**End of Mining - 26 Rooms ready for Emplacement**	**0 days**

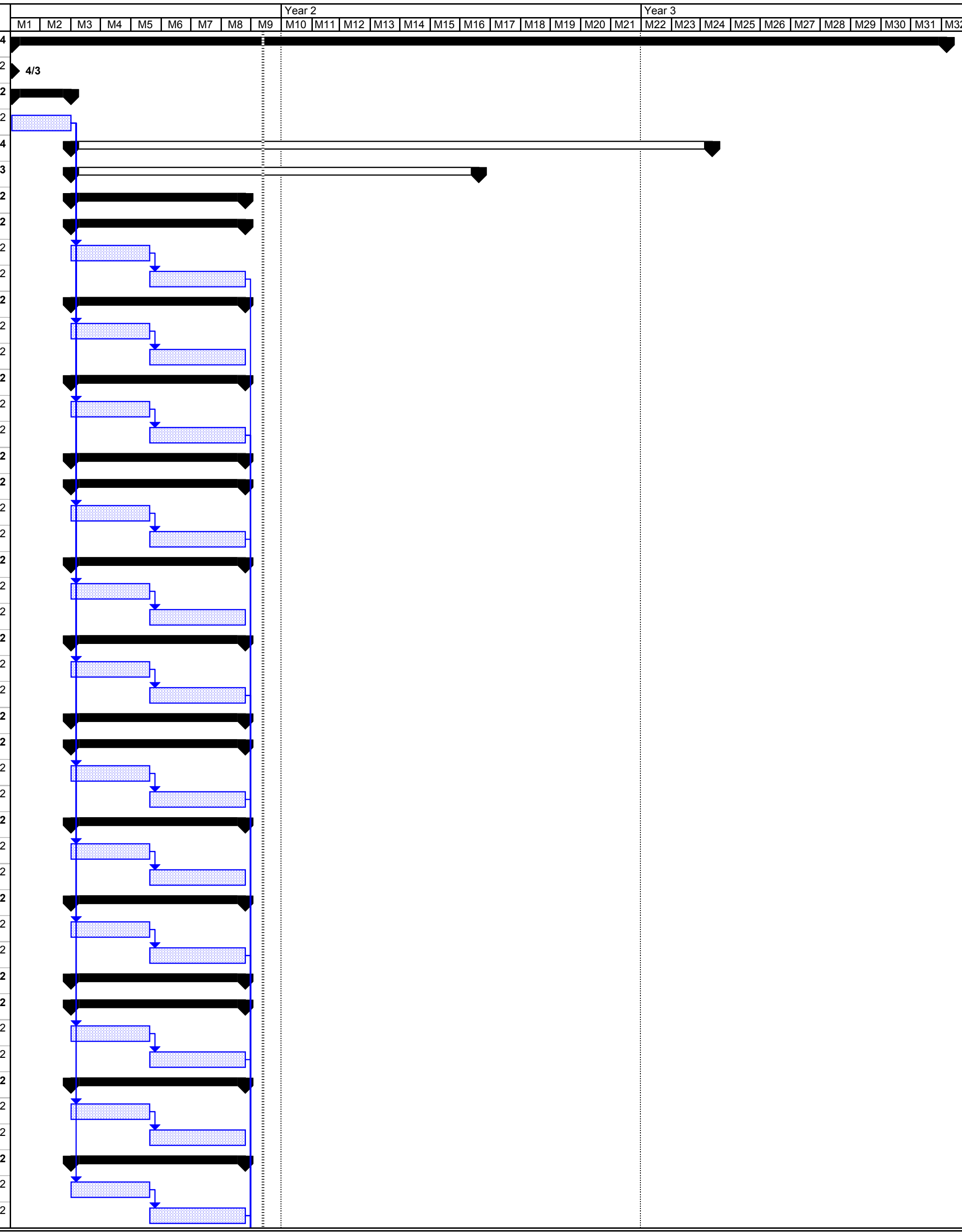


Project: OPG Project1
Date: Fri 12/13/02

Task		Progress		Summary		Rolled Up Split		Rolled Up Progress		Project Summary	
Split		Milestone		Rolled Up Task		Rolled Up Milestone		External Tasks			

OPG - DGR Vault Excavation - Upper Half Section A/Section B

ID	Task Name	Duration	Start	Predecessors	Finish
1	**OPG-DGR Vault Excavation Project**	**949 days**	**Wed 4/3/02**		**Sat 11/6/04**
2	Award Contract	0 days	Wed 4/3/02		Wed 4/3/02
3	**Vault Excavation Mobilization**	**60 days**	**Wed 4/3/02**		**Sat 6/1/02**
4	Mobilization	60 days	Wed 4/3/02		Sat 6/1/02
5	**Vault Excavation Upper/Lower C**	**651 days**	**Sun 6/2/02**		**Sat 3/13/04**
6	**Mine Lower C**	**414 days**	**Sun 6/2/02**		**Sun 7/20/03**
7	**Jumbo No. 1**	**177 days**	**Sun 6/2/02**		**Mon 11/25/02**
8	**Mine Emplacement Room Lower C1 (LC1)**	**177 days**	**Sun 6/2/02**		**Mon 11/25/02**
9	Develop 290 m Pilot	80 days	Sun 6/2/02	4	Tue 8/20/02
10	Slash 290 m Emplacement Room	97 days	Wed 8/21/02	9	Mon 11/25/02
11	**Mine Emplacement Room Lower C2 (LC2)**	**177 days**	**Sun 6/2/02**		**Mon 11/25/02**
12	Develop 290 m Pilot	80 days	Sun 6/2/02	4	Tue 8/20/02
13	Slash 290 m Emplacement Room	97 days	Wed 8/21/02	12	Mon 11/25/02
14	**Mine Emplacement Room Lower C3 (LC3)**	**177 days**	**Sun 6/2/02**		**Mon 11/25/02**
15	Develop 290 m Pilot	80 days	Sun 6/2/02	4	Tue 8/20/02
16	Slash 290 m Emplacement Room	97 days	Wed 8/21/02	15	Mon 11/25/02
17	**Jumbo No. 2**	**177 days**	**Sun 6/2/02**		**Mon 11/25/02**
18	**Mine Emplacement Room Lower C4 (LC4)**	**177 days**	**Sun 6/2/02**		**Mon 11/25/02**
19	Develop 290 m Pilot	80 days	Sun 6/2/02	4	Tue 8/20/02
20	Slash 290 m Emplacement Room	97 days	Wed 8/21/02	19	Mon 11/25/02
21	**Mine Emplacement Room Lower C5 (LC5)**	**177 days**	**Sun 6/2/02**		**Mon 11/25/02**
22	Develop 290 m Pilot	80 days	Sun 6/2/02	4	Tue 8/20/02
23	Slash 290 m Emplacement Room	97 days	Wed 8/21/02	22	Mon 11/25/02
24	**Mine Emplacement Room Lower C6 (LC6)**	**177 days**	**Sun 6/2/02**		**Mon 11/25/02**
25	Develop 290 m Pilot	80 days	Sun 6/2/02	4	Tue 8/20/02
26	Slash 290 m Emplacement Room	97 days	Wed 8/21/02	25	Mon 11/25/02
27	**Jumbo No. 3**	**177 days**	**Sun 6/2/02**		**Mon 11/25/02**
28	**Mine Emplacement Room Lower C7 (LC7)**	**177 days**	**Sun 6/2/02**		**Mon 11/25/02**
29	Develop 290 m Pilot	80 days	Sun 6/2/02	4	Tue 8/20/02
30	Slash 290 m Emplacement Room	97 days	Wed 8/21/02	29	Mon 11/25/02
31	**Mine Emplacement Room Lower C8 (LC8)**	**177 days**	**Sun 6/2/02**		**Mon 11/25/02**
32	Develop 290 m Pilot	80 days	Sun 6/2/02	4	Tue 8/20/02
33	Slash 290 m Emplacement Room	97 days	Wed 8/21/02	32	Mon 11/25/02
34	**Mine Emplacement Room Lower C9 (LC9)**	**177 days**	**Sun 6/2/02**		**Mon 11/25/02**
35	Develop 290 m Pilot	80 days	Sun 6/2/02	4	Tue 8/20/02
36	Slash 290 m Emplacement Room	97 days	Wed 8/21/02	35	Mon 11/25/02
37	**Jumbo No. 4**	**177 days**	**Sun 6/2/02**		**Mon 11/25/02**
38	**Mine Emplacement Room Lower C10 (LC10)**	**177 days**	**Sun 6/2/02**		**Mon 11/25/02**
39	Develop 290 m Pilot	80 days	Sun 6/2/02	4	Tue 8/20/02
40	Slash 290 m Emplacement Room	97 days	Wed 8/21/02	39	Mon 11/25/02
41	**Mine Emplacement Room Lower C11 (LC11)**	**177 days**	**Sun 6/2/02**		**Mon 11/25/02**
42	Develop 290 m Pilot	80 days	Sun 6/2/02	4	Tue 8/20/02
43	Slash 290 m Emplacement Room	97 days	Wed 8/21/02	42	Mon 11/25/02
44	**Mine Emplacement Room Lower C12 (LC12)**	**177 days**	**Sun 6/2/02**		**Mon 11/25/02**
45	Develop 290 m Pilot	80 days	Sun 6/2/02	4	Tue 8/20/02
46	Slash 290 m Emplacement Room	97 days	Wed 8/21/02	45	Mon 11/25/02

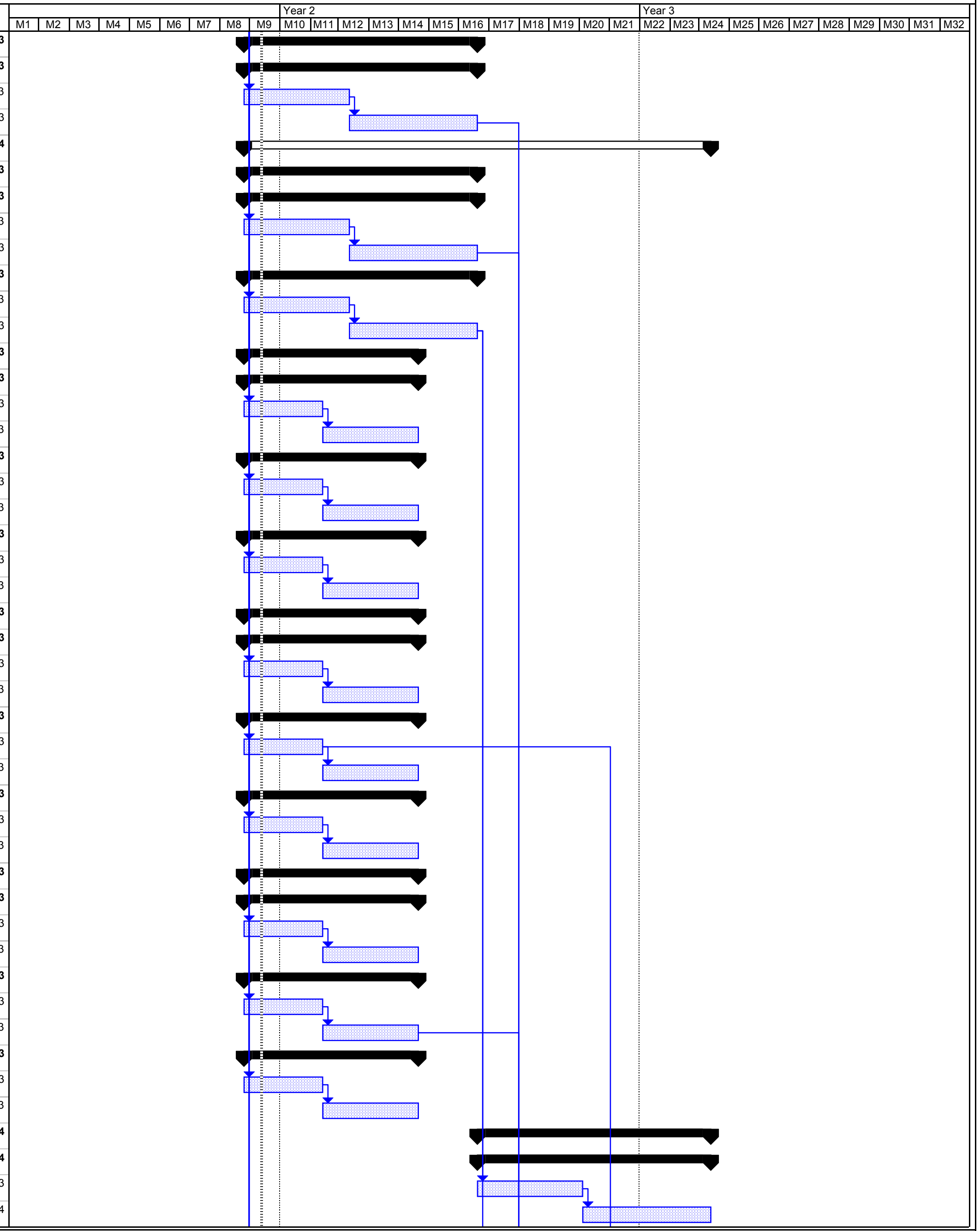


Project: OPG Project1
Date: Fri 12/13/02

Task | Progress | Summary | Rolled Up Split | Rolled Up Progress | Project Summary
Split | Milestone | Rolled Up Task | Rolled Up Milestone | External Tasks

OPG - DGR Vault Excavation - Upper Half Section A/Section B

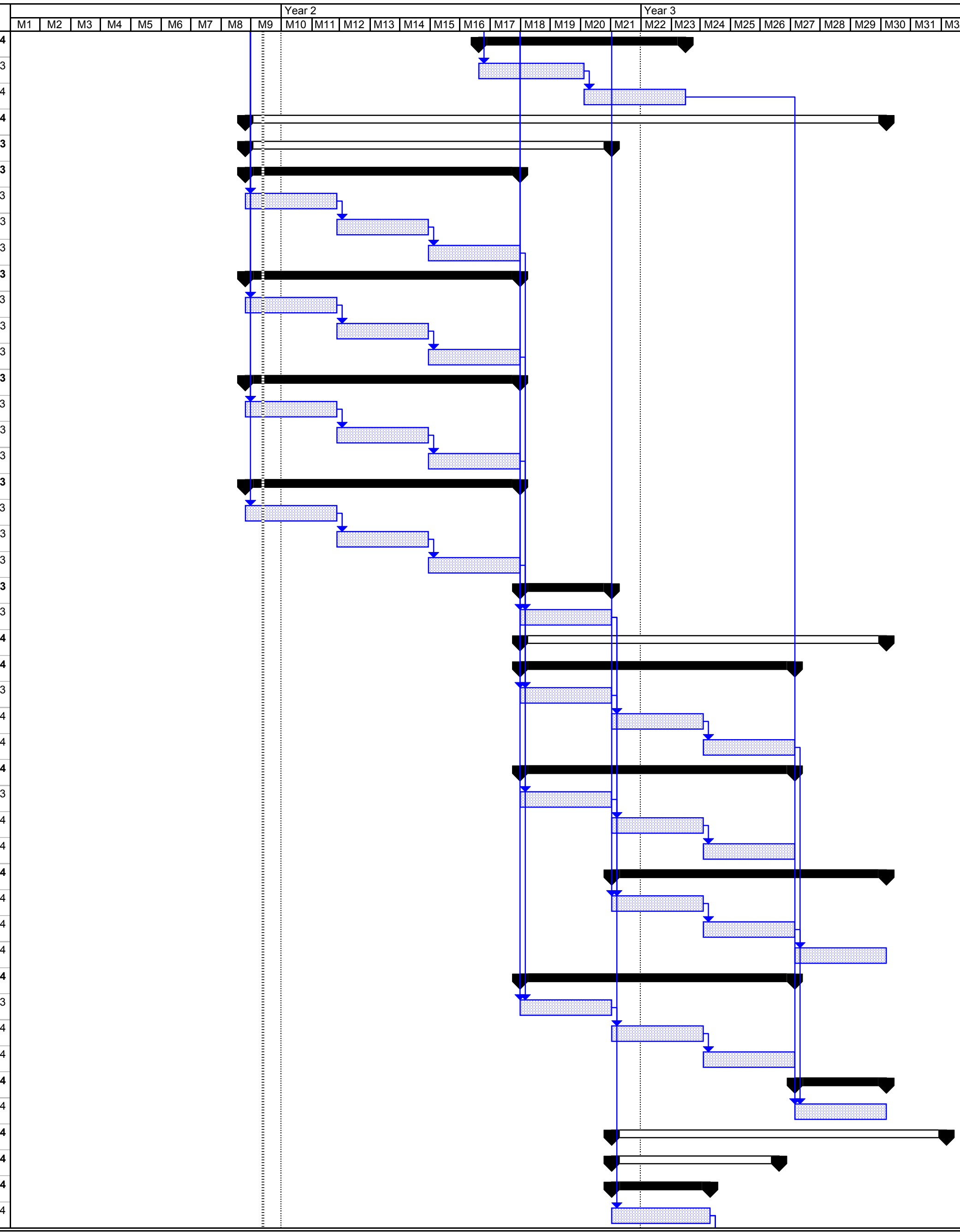
ID	Task Name	Duration	Start	Predecessors	Finish
47	**Jumbo No. 1**	**237 days**	**Tue 11/26/02**		**Sun 7/20/03**
48	**Mine Emplacement Room Lower C13 (LC13)**	**237 days**	**Tue 11/26/02**		**Sun 7/20/03**
49	Develop 290 m Pilot	107 days	Tue 11/26/02	16	Wed 3/12/03
50	Slash 290 m Emplacement Room	130 days	Thu 3/13/03	49	Sun 7/20/03
51	**Mine Upper C**	**474 days**	**Tue 11/26/02**		**Sat 3/13/04**
52	**Jumbo No. 1**	**237 days**	**Tue 11/26/02**		**Sun 7/20/03**
53	**Mine Emplacement Room Upper C1 (UC1)**	**237 days**	**Tue 11/26/02**		**Sun 7/20/03**
54	Develop 290 m Pilot	107 days	Tue 11/26/02	16	Wed 3/12/03
55	Slash290 m Emplacement Room	130 days	Thu 3/13/03	54	Sun 7/20/03
56	**Mine Emplacement Room Upper C2 (UC2)**	**237 days**	**Tue 11/26/02**		**Sun 7/20/03**
57	Develop 290 m Pilot	107 days	Tue 11/26/02	16	Wed 3/12/03
58	Slash 290 m Emplacement Room	130 days	Thu 3/13/03	57	Sun 7/20/03
59	**Jumbo No. 2**	**177 days**	**Tue 11/26/02**		**Wed 5/21/03**
60	**Mine Emplacement Room Upper C3 (UC3)**	**177 days**	**Tue 11/26/02**		**Wed 5/21/03**
61	Develop 290 m Pilot	80 days	Tue 11/26/02	26	Thu 2/13/03
62	Slash 290 m Emplacement Room	97 days	Fri 2/14/03	61	Wed 5/21/03
63	**Mine Emplacement Room Upper C4 (UC4)**	**177 days**	**Tue 11/26/02**		**Wed 5/21/03**
64	Develop 290 m Pilot	80 days	Tue 11/26/02	26	Thu 2/13/03
65	Slash 290 m Emplacement Room	97 days	Fri 2/14/03	64	Wed 5/21/03
66	**Mine Emplacement Room Upper C5 (UC5)**	**177 days**	**Tue 11/26/02**		**Wed 5/21/03**
67	Develop 290 m Pilot	80 days	Tue 11/26/02	26	Thu 2/13/03
68	Slash 290 m Emplacement Room	97 days	Fri 2/14/03	67	Wed 5/21/03
69	**Jumbo No. 3**	**177 days**	**Tue 11/26/02**		**Wed 5/21/03**
70	**Mine Emplacement Room Upper C6 (UC6)**	**177 days**	**Tue 11/26/02**		**Wed 5/21/03**
71	Develop 290 m Pilot	80 days	Tue 11/26/02	36	Thu 2/13/03
72	Slash 290 m Emplacement Room	97 days	Fri 2/14/03	71	Wed 5/21/03
73	**Mine Emplacement Room Upper C (UC7)**	**177 days**	**Tue 11/26/02**		**Wed 5/21/03**
74	Develop 290 m Pilot	80 days	Tue 11/26/02	36	Thu 2/13/03
75	Slash 290 m Emplacement Room	97 days	Fri 2/14/03	74	Wed 5/21/03
76	**Mine Emplacement Room Upper C8 (UC8)**	**177 days**	**Tue 11/26/02**		**Wed 5/21/03**
77	Develop 290 m Pilot	80 days	Tue 11/26/02	36	Thu 2/13/03
78	Slash 290 m Emplacement Room	97 days	Fri 2/14/03	77	Wed 5/21/03
79	**Jumbo No. 4**	**177 days**	**Tue 11/26/02**		**Wed 5/21/03**
80	**Mine Emplacement Room Upper C9 (UC9)**	**177 days**	**Tue 11/26/02**		**Wed 5/21/03**
81	Develop 290 m Pilot	80 days	Tue 11/26/02	46	Thu 2/13/03
82	Slash 290 m Emplacement Room	97 days	Fri 2/14/03	81	Wed 5/21/03
83	**Mine Emplacement Room Upper C10 (UC10)**	**177 days**	**Tue 11/26/02**		**Wed 5/21/03**
84	Develop 290 m Pilot	80 days	Tue 11/26/02	46	Thu 2/13/03
85	Slash 290 m Emplacement Room	97 days	Fri 2/14/03	84	Wed 5/21/03
86	**Mine Emplacement Room Upper C11 (UC11)**	**177 days**	**Tue 11/26/02**		**Wed 5/21/03**
87	Develop 290 m Pilot	80 days	Tue 11/26/02	46	Thu 2/13/03
88	Slash 290 m Emplacement Room	97 days	Fri 2/14/03	87	Wed 5/21/03
89	**Jumbo No. 1**	**237 days**	**Mon 7/21/03**		**Sat 3/13/04**
90	**Mine Emplacement Room Upper C12 (UC12)**	**237 days**	**Mon 7/21/03**		**Sat 3/13/04**
91	Develop 290 m Pilot	107 days	Mon 7/21/03	58	Tue 11/4/03
92	Slash 290 m Emplacement Room	130 days	Wed 11/5/03	91	Sat 3/13/04



Project: OPG Project1
Date: Fri 12/13/02

Task	Progress	Summary	Rolled Up Split	Rolled Up Progress	Project Summary
Split	Milestone	Rolled Up Task	Rolled Up Milestone	External Tasks	

ID		Task Name	Duration	Start	Predecessors	Finish
93		**Mine Emplacement Room Upper C13 (UC13)**	**210 days**	**Mon 7/21/03**		**Sun 2/15/04**
94		Develop 290 m Pilot	107 days	Mon 7/21/03	58	Tue 11/4/03
95		Slash 290 m Emplacement Room	103 days	Wed 11/5/03	94	Sun 2/15/04
96		**Concrete Emplacement In Rooms**	**651 days**	**Tue 11/26/02**		**Mon 9/6/04**
97		**Lower C Rooms**	**372 days**	**Tue 11/26/02**		**Tue 12/2/03**
98		**Concrete Crew No. 1**	**279 days**	**Tue 11/26/02**		**Sun 8/31/03**
99		LC1	93 days	Tue 11/26/02	10	Wed 2/26/03
100		LC2	93 days	Thu 2/27/03	99	Fri 5/30/03
101		LC3	93 days	Sat 5/31/03	100	Sun 8/31/03
102		**Concrete Crew No. 2**	**279 days**	**Tue 11/26/02**		**Sun 8/31/03**
103		LC4	93 days	Tue 11/26/02	20	Wed 2/26/03
104		LC5	93 days	Thu 2/27/03	103	Fri 5/30/03
105		LC6	93 days	Sat 5/31/03	104	Sun 8/31/03
106		**Concrete Crew No. 3**	**279 days**	**Tue 11/26/02**		**Sun 8/31/03**
107		LC7	93 days	Tue 11/26/02	30	Wed 2/26/03
108		LC8	93 days	Thu 2/27/03	107	Fri 5/30/03
109		LC9	93 days	Sat 5/31/03	108	Sun 8/31/03
110		**Concrete Crew No. 4**	**279 days**	**Tue 11/26/02**		**Sun 8/31/03**
111		LC10	93 days	Tue 11/26/02	40	Wed 2/26/03
112		LC11	93 days	Thu 2/27/03	111	Fri 5/30/03
113		LC12	93 days	Sat 5/31/03	112	Sun 8/31/03
114		**Concrete Crew No. 3**	**93 days**	**Mon 9/1/03**		**Tue 12/2/03**
115		LC13	93 days	Mon 9/1/03	50,109	Tue 12/2/03
116		**Upper C Rooms**	**372 days**	**Mon 9/1/03**		**Mon 9/6/04**
117		**Concrete Crew No. 1**	**279 days**	**Mon 9/1/03**		**Sat 6/5/04**
118		UC1	93 days	Mon 9/1/03	55,101	Tue 12/2/03
119		UC2	93 days	Wed 12/3/03	118	Thu 3/4/04
120		UC3	93 days	Fri 3/5/04	119	Sat 6/5/04
121		**Concrete Crew No. 2**	**279 days**	**Mon 9/1/03**		**Sat 6/5/04**
122		UC4	93 days	Mon 9/1/03	105	Tue 12/2/03
123		UC5	93 days	Wed 12/3/03	122	Thu 3/4/04
124		UC6	93 days	Fri 3/5/04	123	Sat 6/5/04
125		**Concrete Crew No. 3**	**279 days**	**Wed 12/3/03**		**Mon 9/6/04**
126		UC7	93 days	Wed 12/3/03	115,74	Thu 3/4/04
127		UC8	93 days	Fri 3/5/04	126	Sat 6/5/04
128		UC9	93 days	Sun 6/6/04	127	Mon 9/6/04
129		**Concrete Crew No. 4**	**279 days**	**Mon 9/1/03**		**Sat 6/5/04**
130		UC10	93 days	Mon 9/1/03	113,85	Tue 12/2/03
131		UC11	93 days	Wed 12/3/03	130	Thu 3/4/04
132		UC12	93 days	Fri 3/5/04	131	Sat 6/5/04
133		**Concrete Crew No. 1**	**93 days**	**Sun 6/6/04**		**Mon 9/6/04**
134		UC13	93 days	Sun 6/6/04	120,95	Mon 9/6/04
135		**Prepare Section C for Emplacement (Track, Vent, etc)**	**340 days**	**Wed 12/3/03**		**Sat 11/6/04**
136		**Install Track Across Emplacement Rooms**	**170 days**	**Wed 12/3/03**		**Thu 5/20/04**
137		**Track Crew No. 1**	**100 days**	**Wed 12/3/03**		**Thu 3/11/04**
138		Repair Track and Switch Gear Across Vault Lower C	100 days	Wed 12/3/03	115	Thu 3/11/04

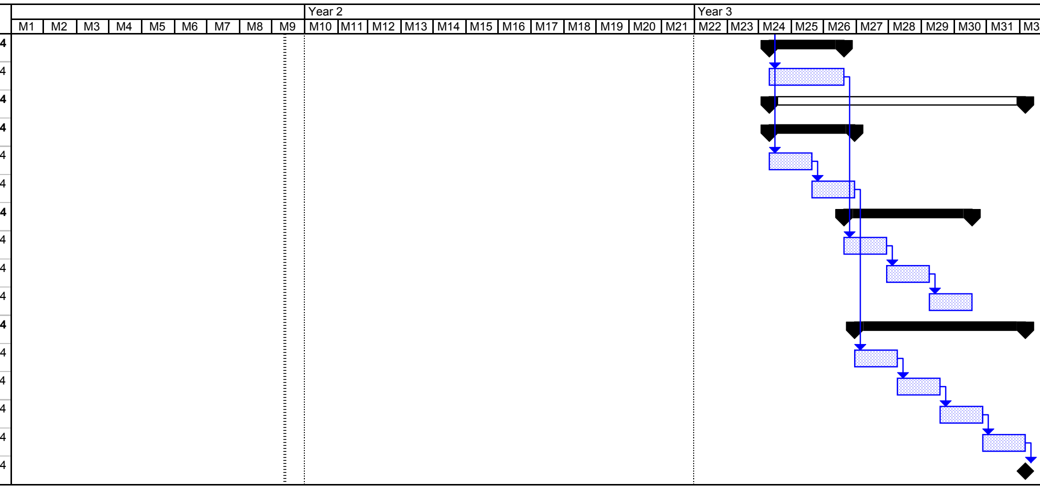


Project: OPG Project1
Date: Fri 12/13/02

Task	Progress	Summary	Rolled Up Split	Rolled Up Progress	Project Summary
Split	Milestone	Rolled Up Task	Rolled Up Milestone	External Tasks	

OPG - DGR Vault Excavation - Upper Half Section A/Section B

ID		Task Name	Duration	Start	Predecessors	Finish
139		**Track Crew No. 1**	**70 days**	**Fri 3/12/04**		**Thu 5/20/04**
140		Install Track and Switch Gear Across Vault Upper C	70 days	Fri 3/12/04	138	Thu 5/20/04
141		**Install Track in 9 out of 26 Emplacement Rooms**	**240 days**	**Fri 3/12/04**		**Sat 11/6/04**
142		**Track Crew No. 2**	**80 days**	**Fri 3/12/04**		**Sun 5/30/04**
143		LC1	40 days	Fri 3/12/04	138	Tue 4/20/04
144		LC2	40 days	Wed 4/21/04	143	Sun 5/30/04
145		**Track Crew No. 1**	**120 days**	**Fri 5/21/04**		**Fri 9/17/04**
146		LC3	40 days	Fri 5/21/04	140	Tue 6/29/04
147		LC4	40 days	Wed 6/30/04	146	Sun 8/8/04
148		LC5	40 days	Mon 8/9/04	147	Fri 9/17/04
149		**Track Crew No. 2**	**160 days**	**Mon 5/31/04**		**Sat 11/6/04**
150		LC6	40 days	Mon 5/31/04	144	Fri 7/9/04
151		LC7	40 days	Sat 7/10/04	150	Wed 8/18/04
152		LC8	40 days	Thu 8/19/04	151	Mon 9/27/04
153		LC9	40 days	Tue 9/28/04	152	Sat 11/6/04
154		End of Mining - 26 Rooms ready for Emplacement	0 days	Sat 11/6/04	153	Sat 11/6/04

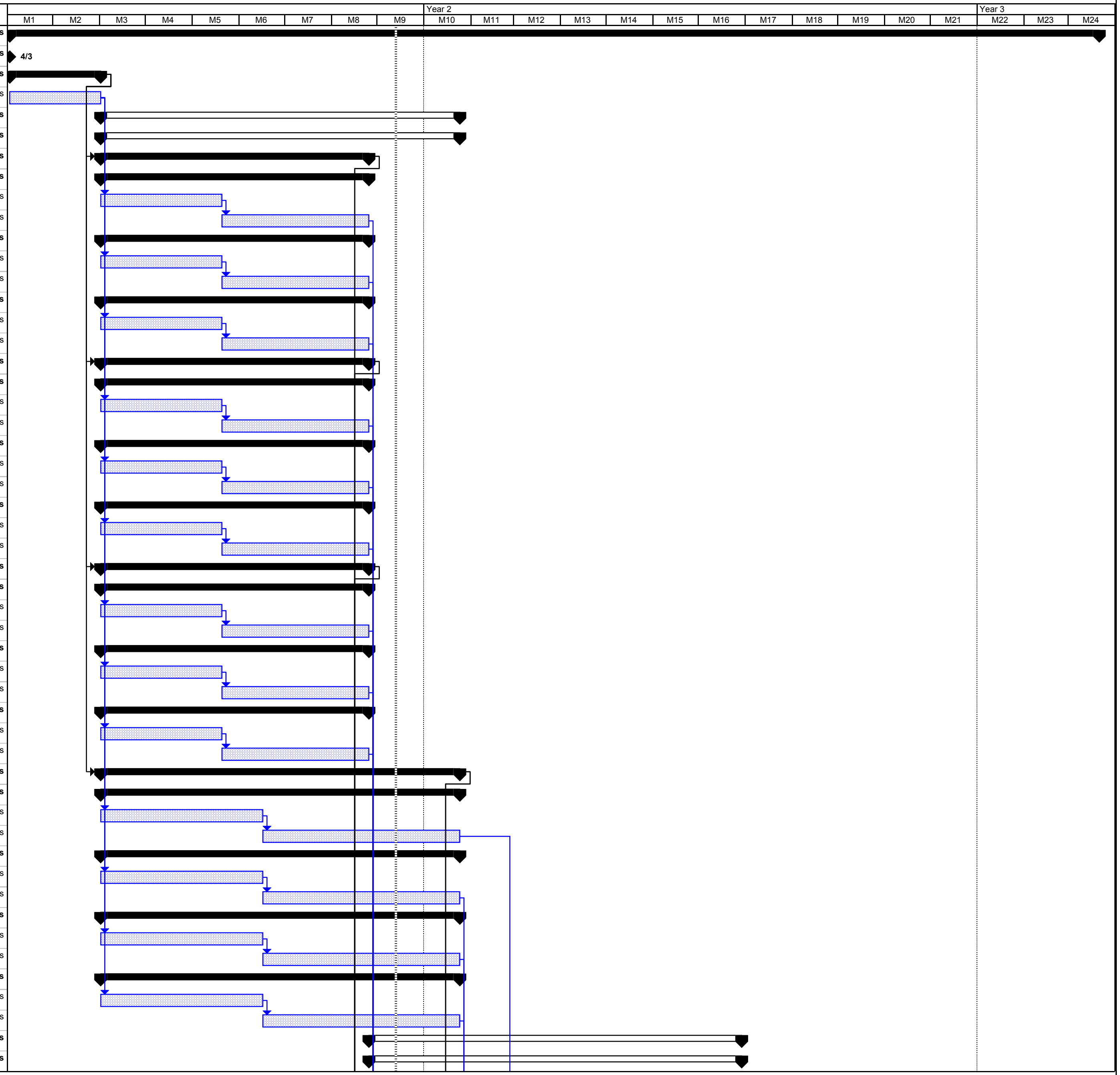


Project: OPG Project1
Date: Fri 12/13/02

Task	Progress	Summary	Rolled Up Split	Rolled Up Progress	Project Summary
Split	Milestone	Rolled Up Task	Rolled Up Milestone	External Tasks	

OPG - DGR Vault Excavation - Upper Half Section D 13 Rooms

ID	Task Name	Duration
1	**OPG-DGR Vault Excavation Project**	**719 days**
2	**Award Contract**	**0 days**
3	**Vault Excavation Mobilization**	**60 days**
4	Mobilization	60 days
5	**Vault Excavation Upper D**	**237 days**
6	**Mine UpperD**	**237 days**
7	**Jumbo No. 1**	**177 days**
8	**Mine Emplacement Room Upper D1 (UD1)**	**177 days**
9	Develop 290 m Pilot	80 days
10	Slash290 m Emplacement Room	97 days
11	**Mine Emplacement Room Upper D2 (UD2)**	**177 days**
12	Develop 290 m Pilot	80 days
13	Slash 290 m Emplacement Room	97 days
14	**Mine Emplacement Room Upper D3 (UD3)**	**177 days**
15	Develop 290 m Pilot	80 days
16	Slash 290 m Emplacement Room	97 days
17	**Jumbo No. 2**	**177 days**
18	**Mine Emplacement Room Upper D4 (UD4)**	**177 days**
19	Develop 290 m Pilot	80 days
20	Slash 290 m Emplacement Room	97 days
21	**Mine Emplacement Room Upper D5 (UD5)**	**177 days**
22	Develop 290 m Pilot	80 days
23	Slash 290 m Emplacement Room	97 days
24	**Mine Emplacement Room UpperD6 (UD6)**	**177 days**
25	Develop 290 m Pilot	80 days
26	Slash 290 m Emplacement Room	97 days
27	**Jumbo No. 3**	**177 days**
28	**Mine Emplacement Room Upper D7 (UD7)**	**177 days**
29	Develop 290 m Pilot	80 days
30	Slash 290 m Emplacement Room	97 days
31	**Mine Emplacement Room Upper D8 (UD8)**	**177 days**
32	Develop 290 m Pilot	80 days
33	Slash 290 m Emplacement Room	97 days
34	**Mine Emplacement Room Upper D9 (UD9)**	**177 days**
35	Develop 290 m Pilot	80 days
36	Slash 290 m Emplacement Room	97 days
37	**Jumbo No. 4**	**237 days**
38	**Mine Emplacement Room Upper D10 (UD10)**	**237 days**
39	Develop 290 m Pilot	107 days
40	Slash 290 m Emplacement Room	130 days
41	**Mine Emplacement Room Upper D11 (UD11)**	**237 days**
42	Develop 290 m Pilot	107 days
43	Slash 290 m Emplacement Room	130 days
44	**Mine Emplacement Room UpperDA12 (UD12)**	**237 days**
45	Develop 290 m Pilot	107 days
46	Slash 290 m Emplacement Room	130 days
47	**Mine Emplacement Room UpperD13 (UD13)**	**237 days**
48	Develop 290 m Pilot	107 days
49	Slash 290 m Emplacement Room	130 days
50	**Concrete Emplacement In Rooms**	**246 days**
51	**Upper D Rooms**	**246 days**

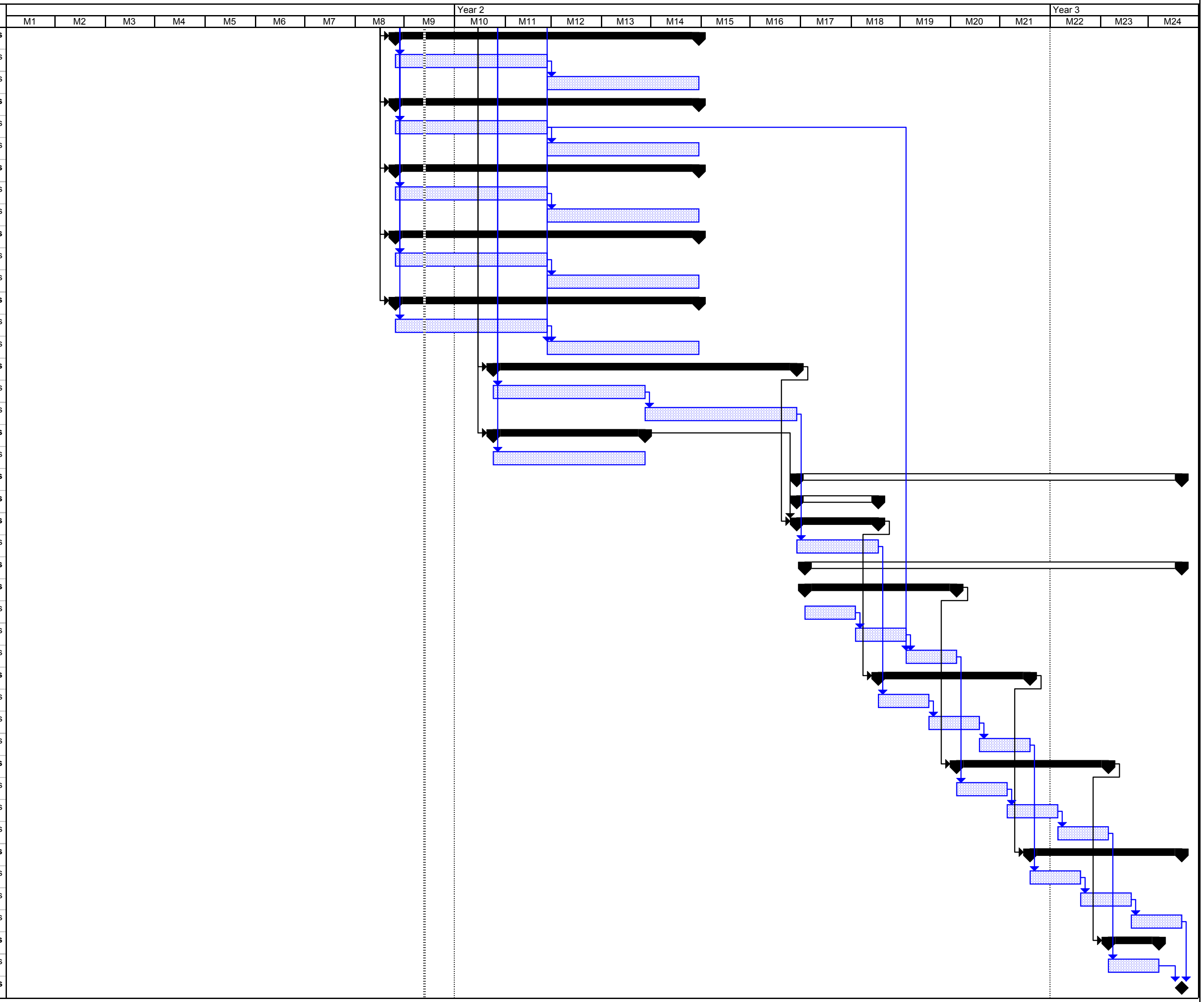


Project: OPG Project1
Date: Fri 12/13/02

Task		Progress		Summary		Rolled Up Split		Rolled Up Progress		Project Summary	
Split		Milestone		Rolled Up Task		Rolled Up Milestone		External Tasks			

OPG - DGR Vault Excavation - Upper Half Section D 13 Rooms

ID	Task Name	Duration
52	**Concrete Crew No. 1**	**186 days**
53	UD1	93 days
54	UD2	93 days
55	**Concrete Crew No. 2**	**186 days**
56	UD3	93 days
57	UD4	93 days
58	**Concrete Crew No. 3**	**186 days**
59	UD5	93 days
60	UD6	93 days
61	**Concrete Crew No. 4**	**186 days**
62	UD7	93 days
63	UD8	93 days
64	**Concrete Crew No. 5**	**186 days**
65	UD9	93 days
66	UD10	93 days
67	**Concrete Crew No. 6**	**186 days**
68	UD11	93 days
69	UD12	93 days
70	**Concrete Crew No.5**	**93 days**
71	UD13	93 days
72	**Prepare Upper Section D for Emplacement (Track, Vent, etc)**	**236 days**
73	**Install Track Across Emplacement Rooms**	**50 days**
74	**Track Crew No. 1**	**50 days**
75	Install Track and Switch Gear Across Vault Upper D	50 days
76	**Install Track in 13 Emplacement Rooms**	**231 days**
77	**Track Crew No. 2**	**93 days**
78	UD1	31 days
79	UD2	31 days
80	UD3	31 days
81	**Track Crew No. 1**	**93 days**
82	UD4	31 days
83	UD5	31 days
84	UD6	31 days
85	**Track Crew No. 2**	**93 days**
86	UD7	31 days
87	UD8	31 days
88	UD9	31 days
89	**Track Crew No. 1**	**93 days**
90	UD10	31 days
91	UD11	31 days
92	UD12	31 days
93	**Track Crew No. 2**	**31 days**
94	UD13	31 days
95	**End of Mining - 13 Rooms ready for Emplacement**	**0 days**



Project: OPG Project1
Date: Fri 12/13/02

Task	Progress	Summary	Rolled Up Split	Rolled Up Progress	Project Summary
Split	Milestone	Rolled Up Task	Rolled Up Milestone	External Tasks	

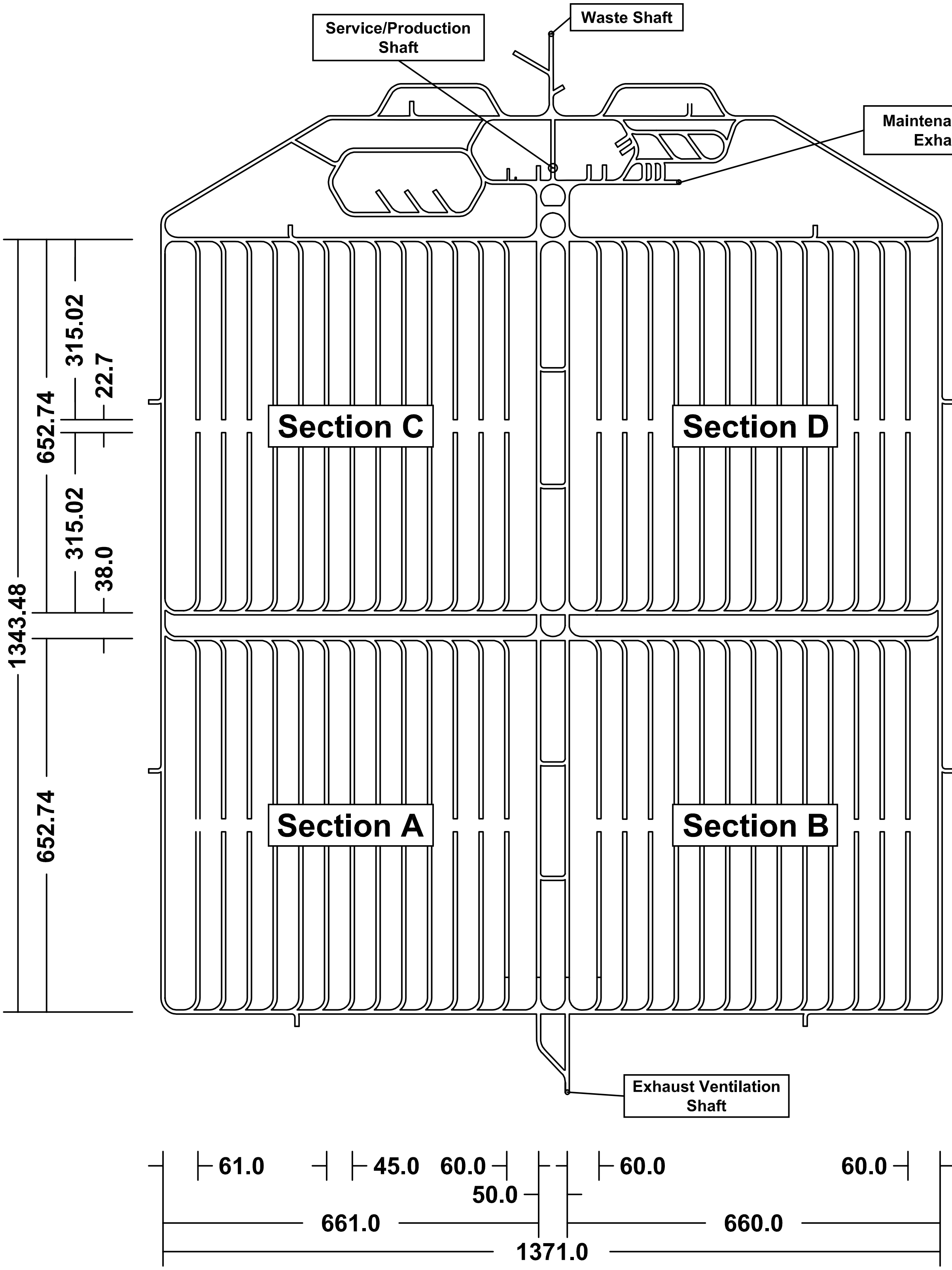


Fig. 1a - General Layout - Proposed Plan of Used Fuel Disposal Vault (Rev. 3)

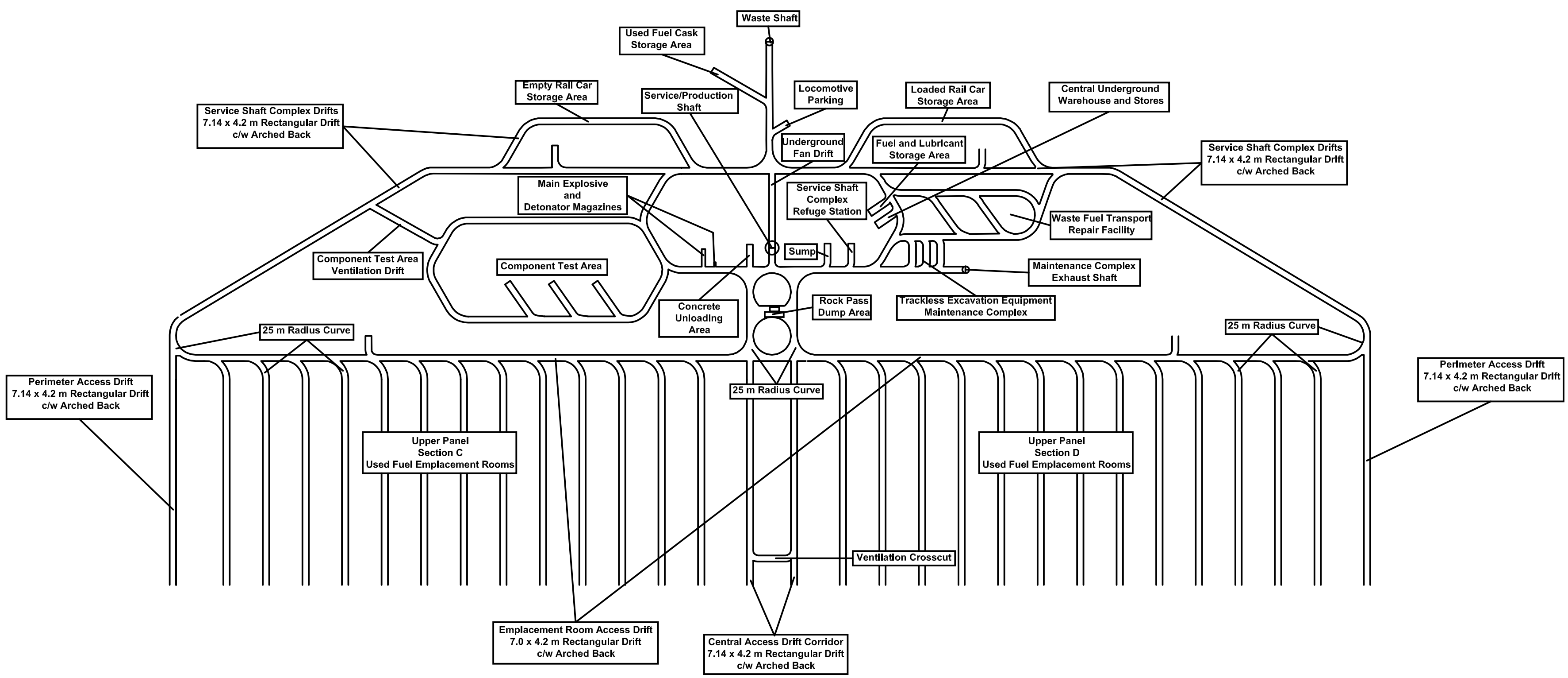


Fig. 1b - Detail of Service Shaft Area (Rev. 3)

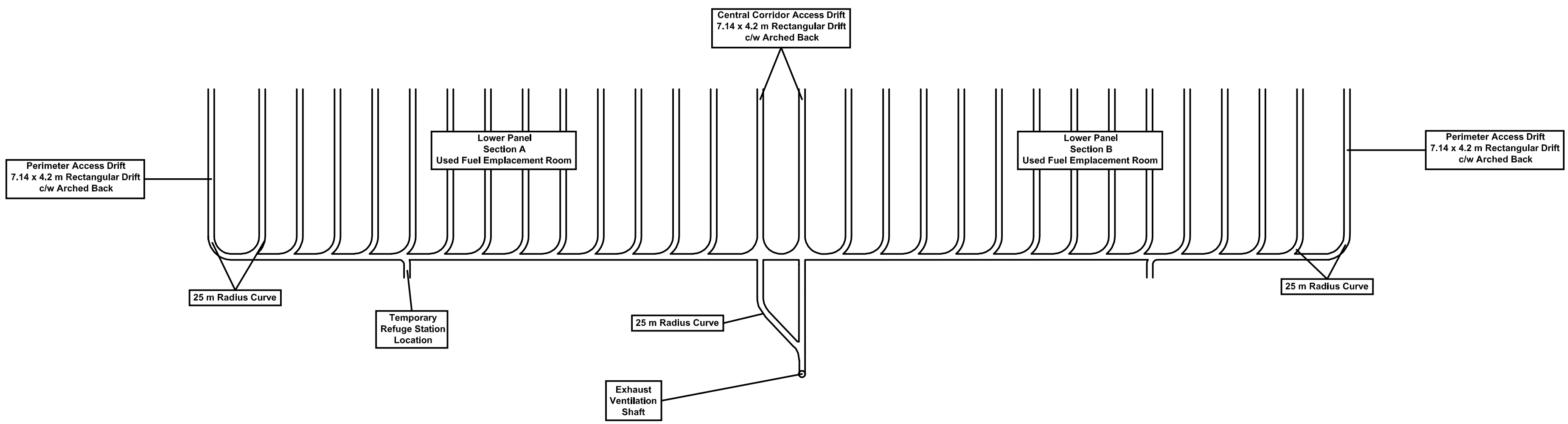


Fig. 1c - Detail of the Upcast Shaft Complex (Rev. 2)

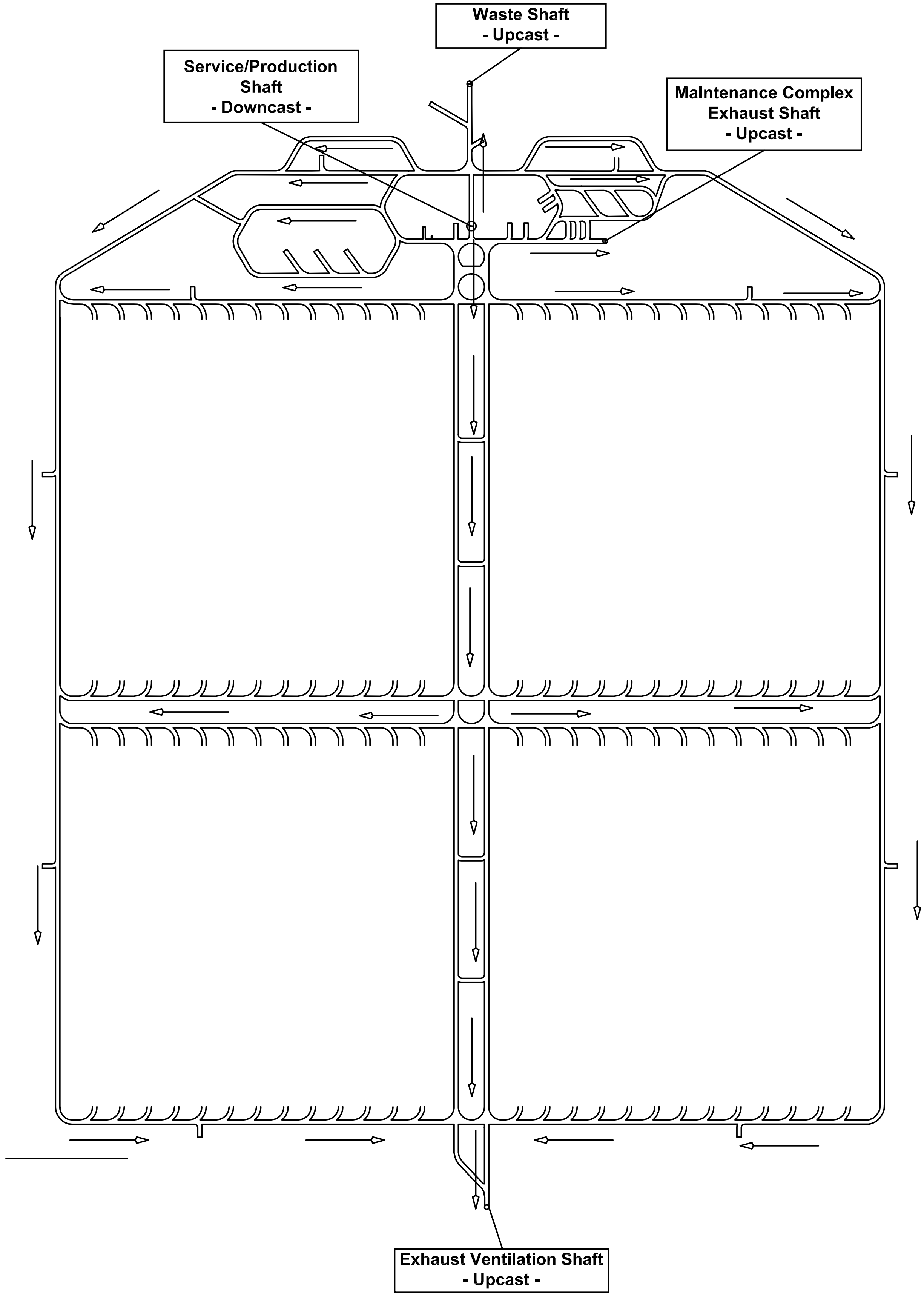


Fig. 1d - Ventilation Schematic for the Used Fuel Disposal Vault

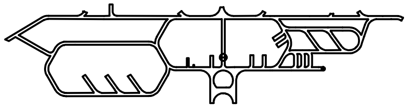


Fig. 1e (i)

Initial Exploration Development
Developing a Test Component Area and determining the proper Repository orientation.

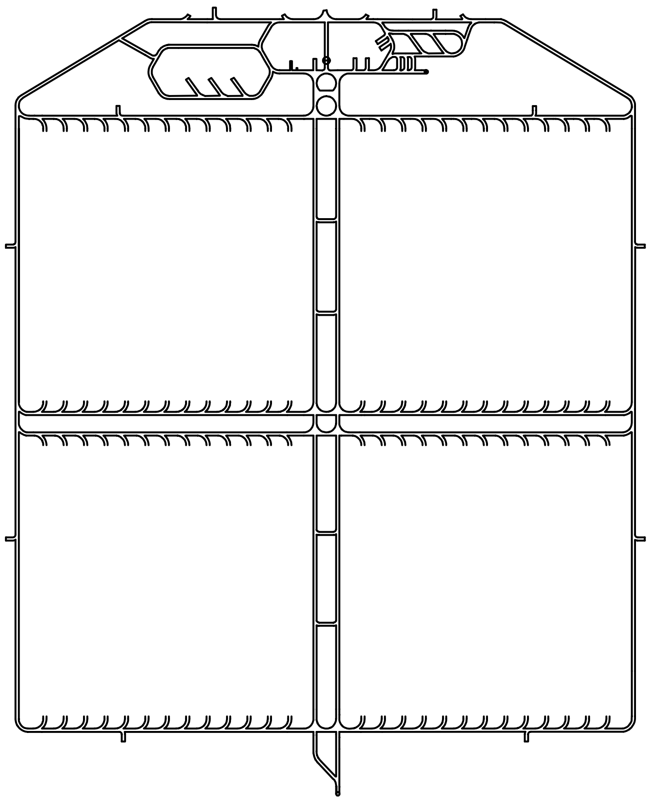


Fig. 1e (ii)

Repository Development
Establishing the perimeter, central and repository panel access drifts, plus the waste fuel transport repair facility and exhaust ventilation shaft.

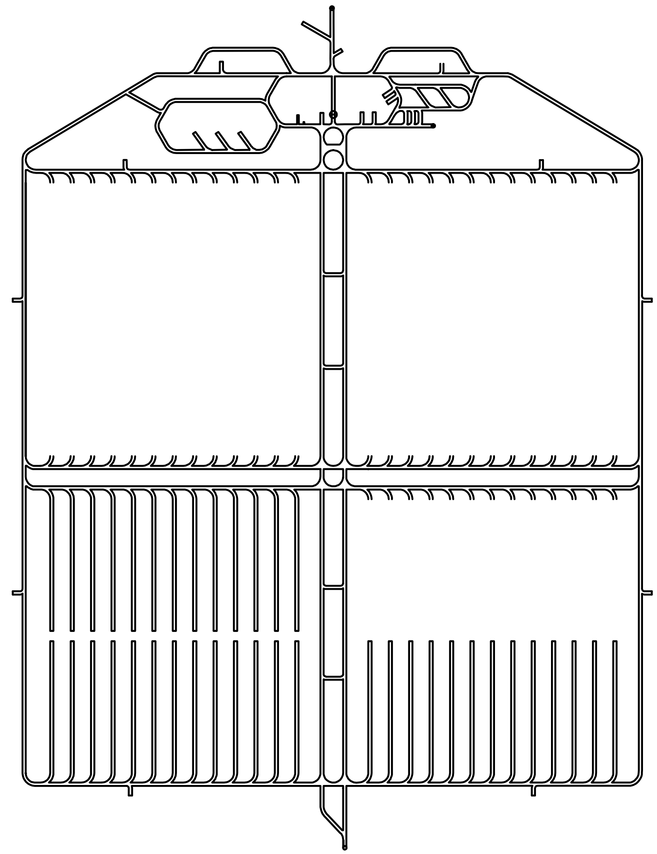


Fig. 1e (iii)

Repository Development - Repository Panel Development
Establish the Waste Shaft, empty and loaded rail car areas and 39 emplacement rooms.

Fig. 1e - Proposed Pre-Emplacement Development Sequence

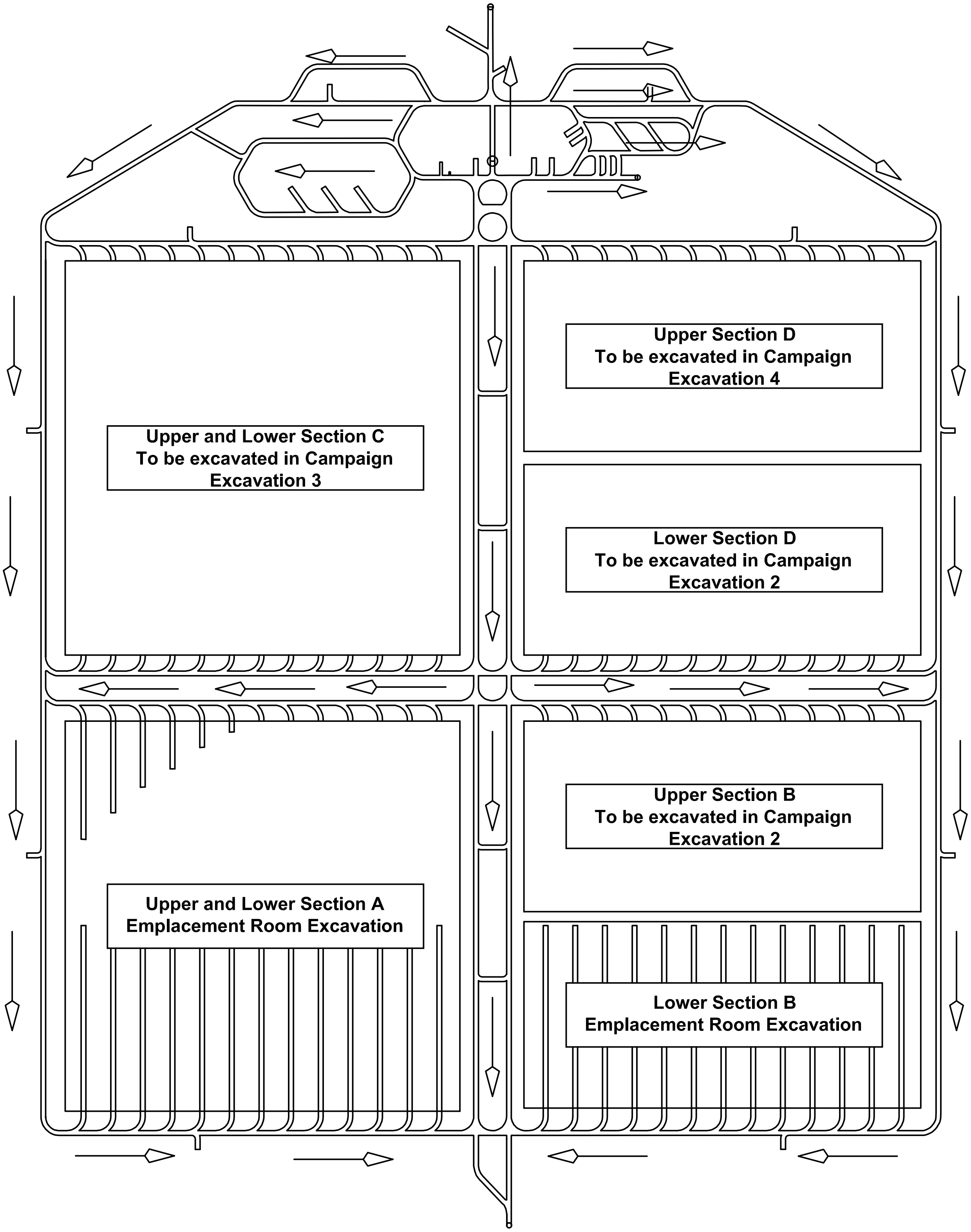
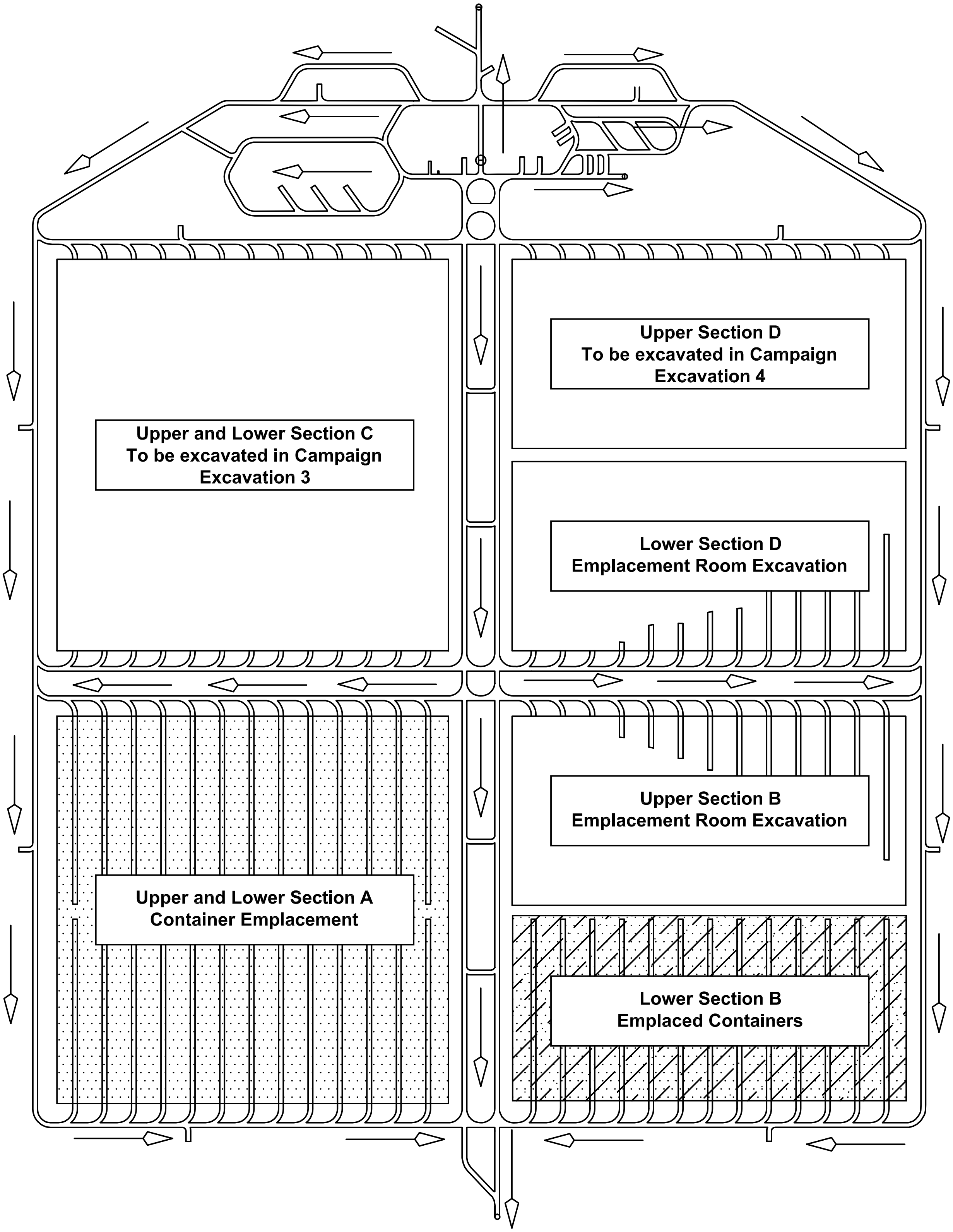
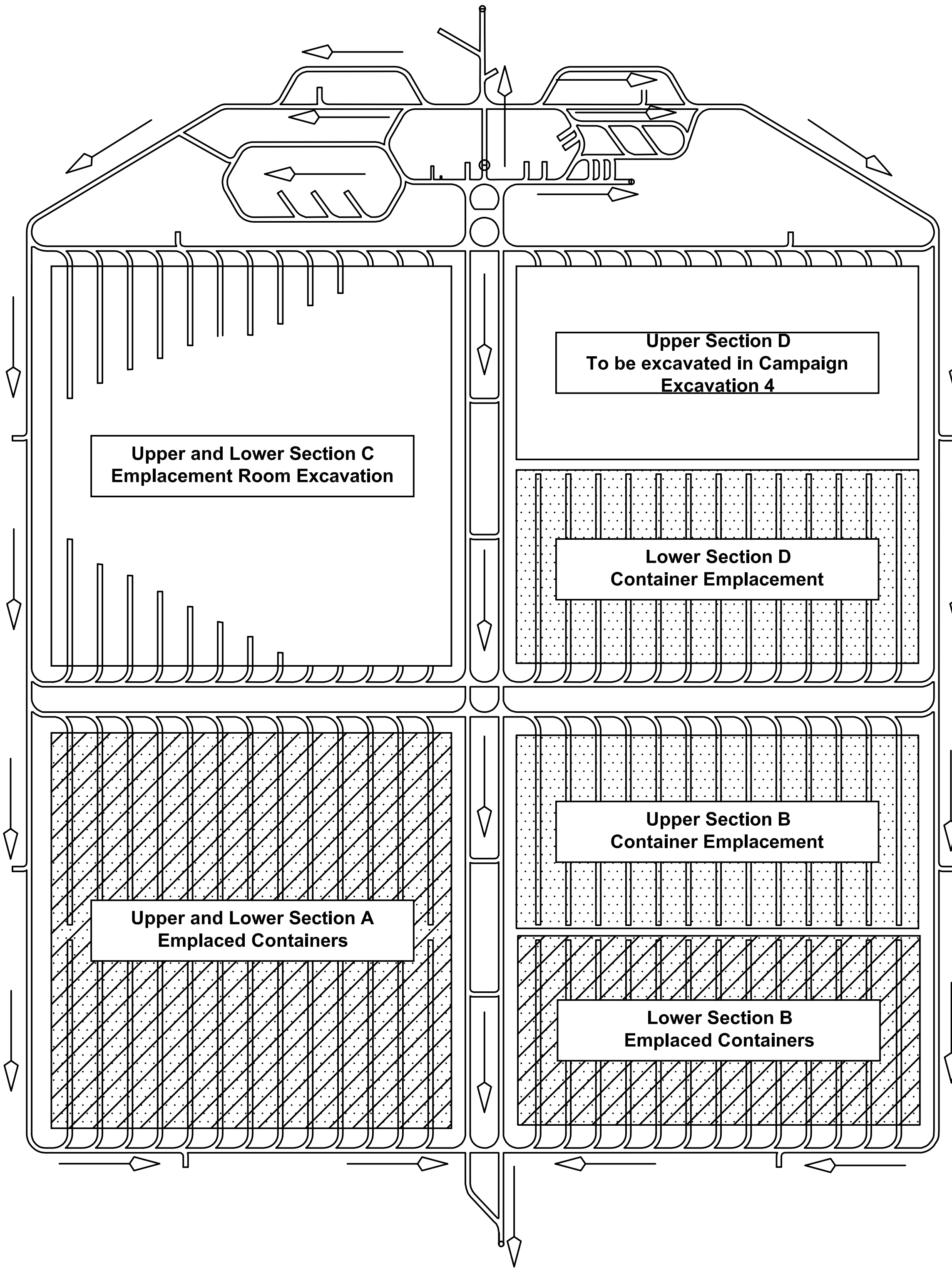


Fig. 2a - Demonstrating Initial Section Excavation Sequence
(Initial 39 emplacement room excavation)



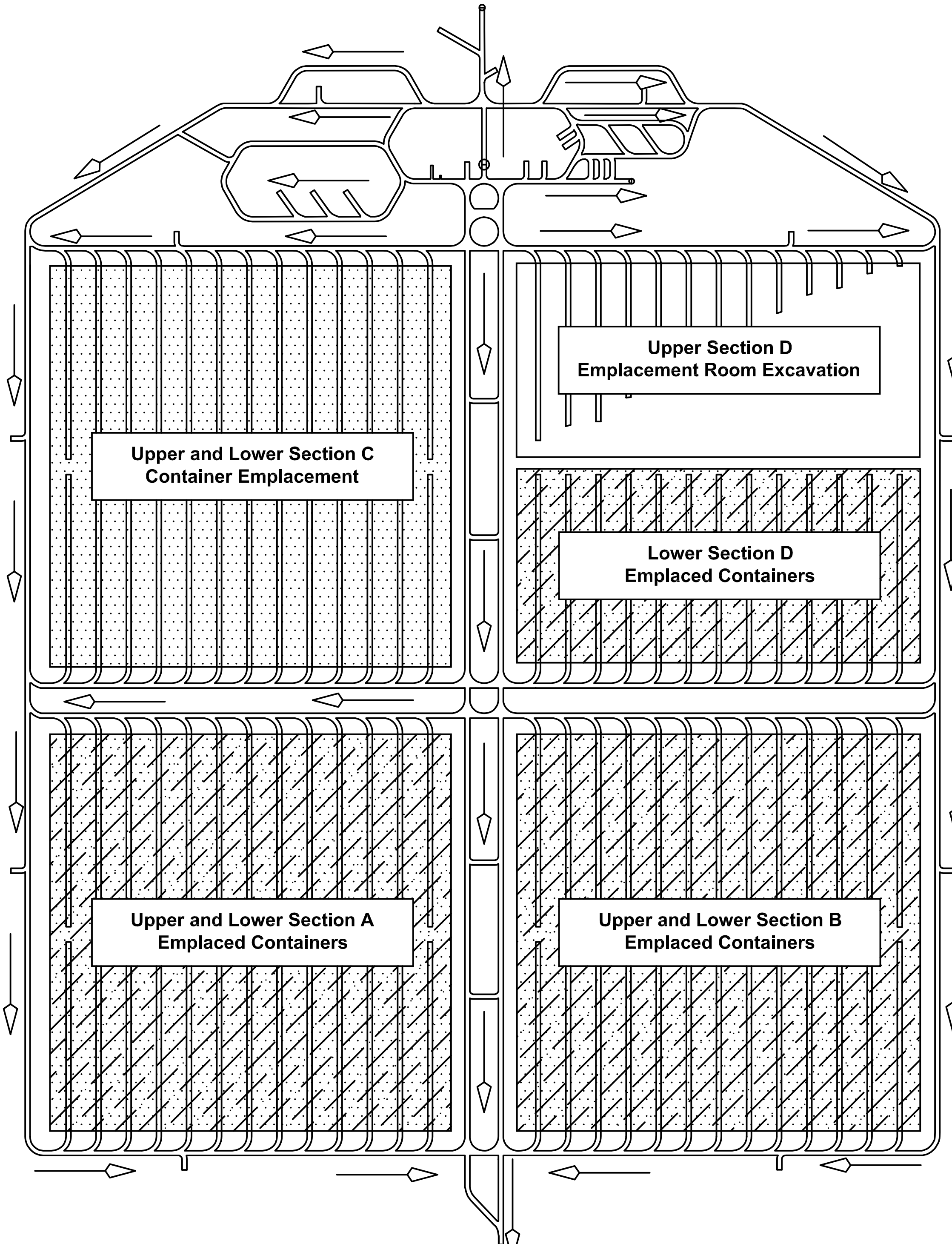
Note: Airflow direction demonstrates non-mixing of excavation and emplacement air.

Fig. 2b - Demonstrating Section Excavation and Waste Emplacement Sequence during Campaign Excavation 2 (26 emplacement rooms excavated)



Note: Airflow direction demonstrates non-mixing of excavation and emplacement air.

Fig. 2c - Demonstrating Section Excavation and Waste Emplacement Sequence during Campaign Excavation 3 (26 emplacement rooms excavated)



Note: Airflow direction demonstrates non-mixing of excavation and emplacement air.

Fig. 2d - Demonstrating Section Excavation and Waste Emplacement Sequence during Campaign Excavation 4 (13 excavation rooms excavated)

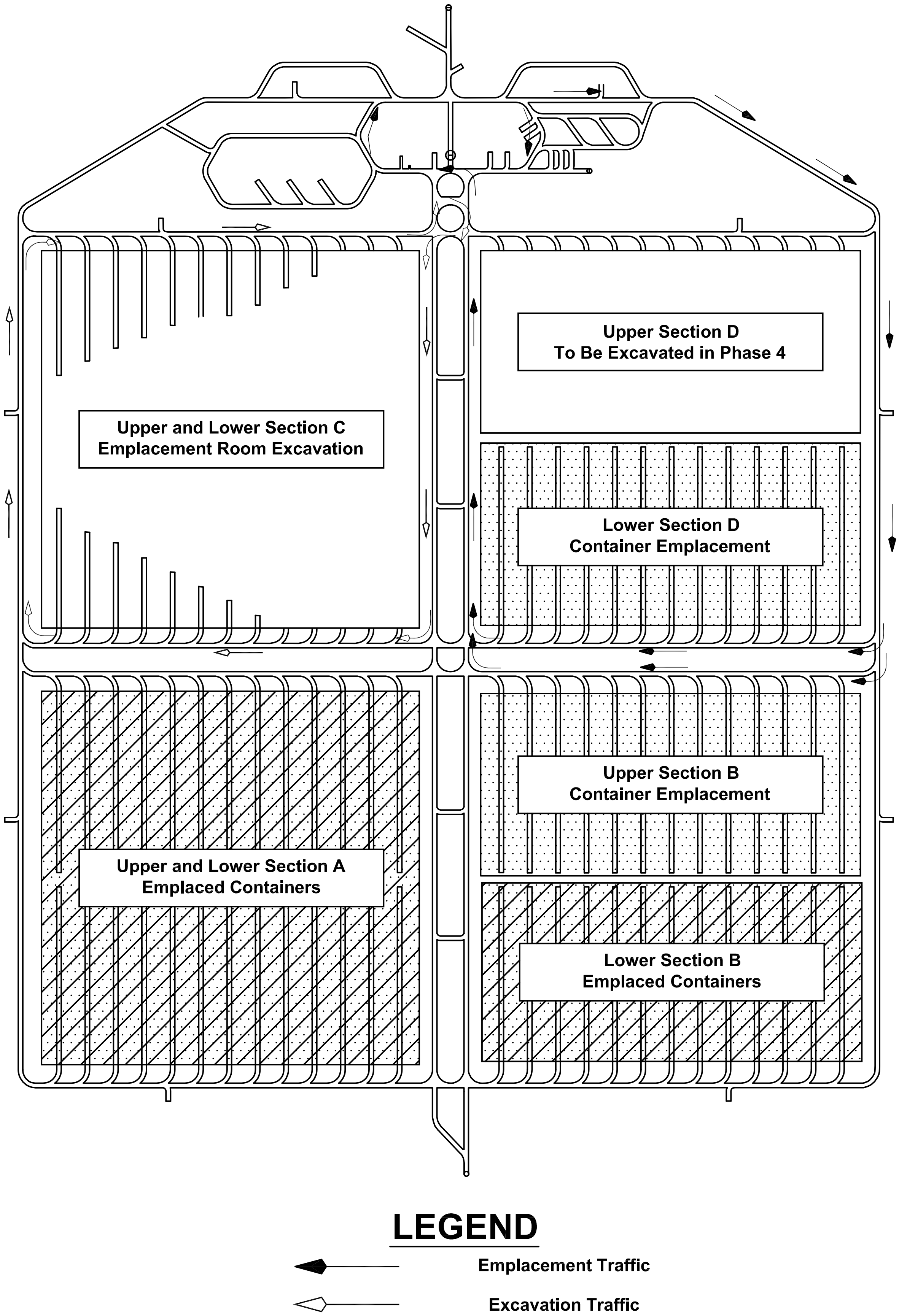
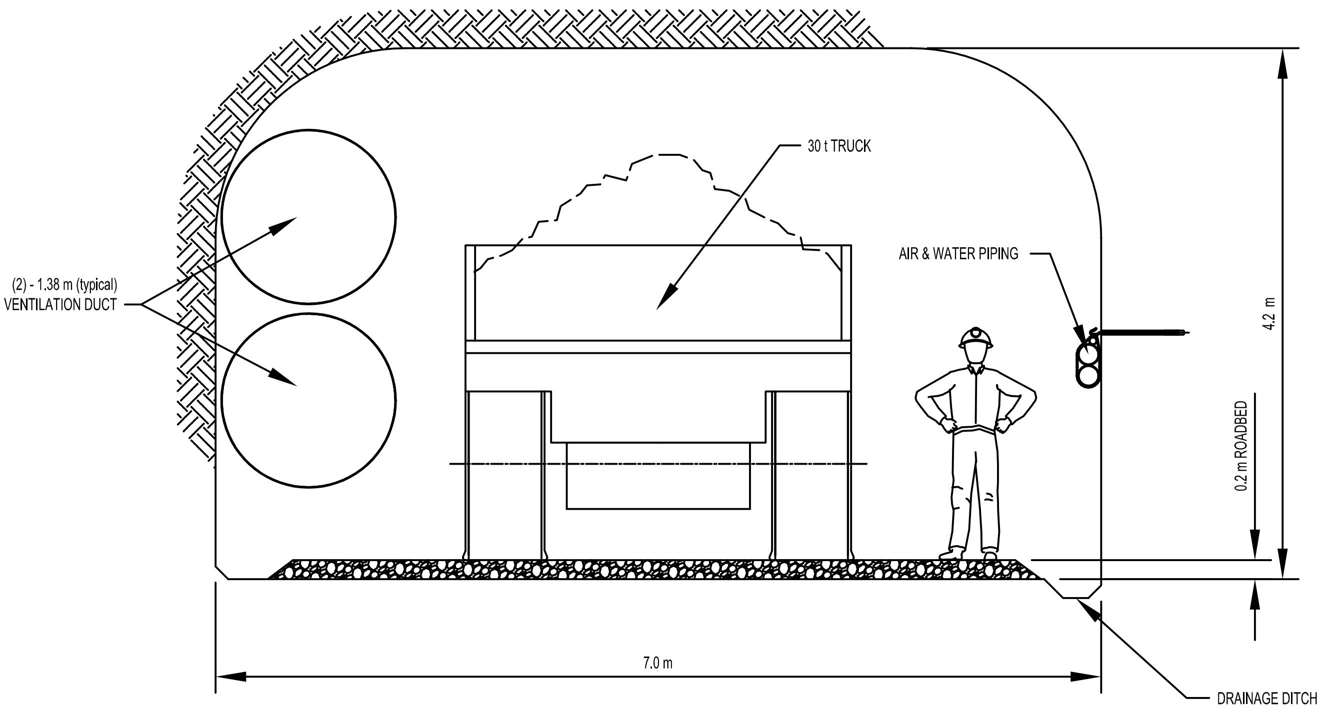


Fig. 2e - Demonstrating Clockwise movement of traffic during emplacement in Upper Panel B and Lower Panel D, whilst 26 emplacement rooms are excavated in Section C



NOTE:
- LAYOUT MAY BE MIRRORED DEPENDING ON WHETHER AN UPPER OR LOWER EMPLACEMENT PANEL IS BEING DEVELOPED.

FIG.3 7.0 m x 4.2 m WASTE FUEL REPOSITORY ACCESS DRIFT
(DEMONSTRATING THE SPATIAL RELATIONSHIPS)

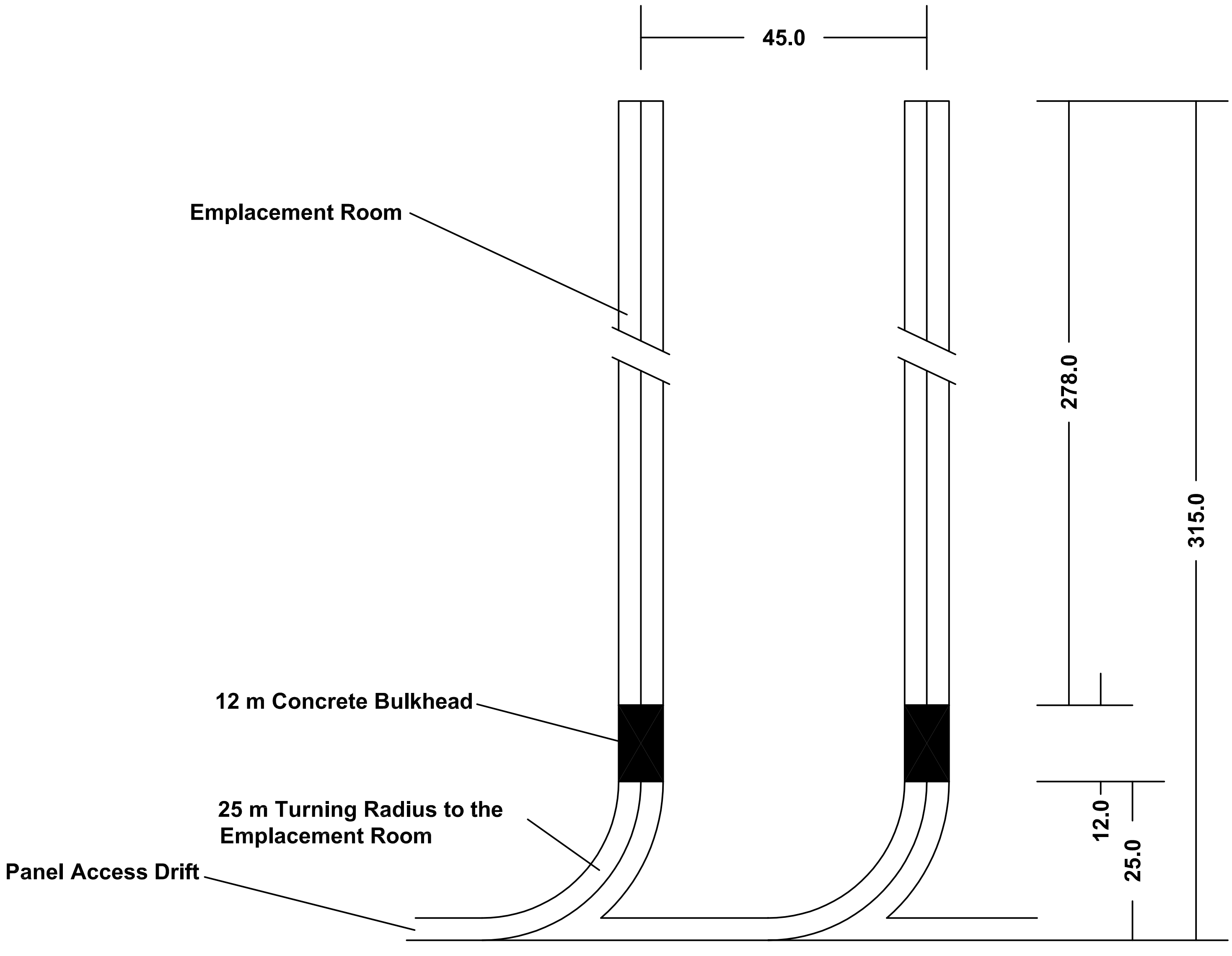


Fig. 4 - Demonstrating the position of the 12 m thick Concrete Bulkhead relative to the emplacement rooms and panel access drift.