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Conceptual Operations Report for a Repository at the Yucca Mountain Site

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by
Dravo Engineers, Inc.
for
Sandia National Laboratories
P.O. Box 5800
Albuquerque, NM 87185

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ABSTRACT

This study develops conceptual operations scenarios for underground mining development and waste emplacement at the prospective nuclear waste repository in tuff at the Nevada Test Site. Methods and operations required for mining, transportation and material handling, maintenance and shop practice, construction, large-diameter hole drilling, and waste emplacement and storage are presented for both the horizontal and vertical emplacement methods. These methods were developed from all current information collected by the Nevada Nuclear Waste Storage Investigations project and operations data from underground mines. Underground mining and waste emplacement operations will require the following. The underground operations of the horizontal and vertical emplacement methods require approximately 188 and 548 employees, respectively. The total power consumption for the underground operations, excluding mine lighting and instrumentation, is 1,815 kVA for the horizontal emplacement method (assuming a shaft-headframe material handling system is employed) and 2,945 kVA for the vertical emplacement method (assuming a 20% grade ramp material handling system is employed). The amount of water required for the mining operations in both emplacement methods is approximately 38 gal/ft of drift. This does not include the water required for dust control and pilot hole drilling. Thirty-six mobile units are required for the horizontal emplacement method and 73 mobile units are required for the vertical emplacement method.

PREFACE

The analyses and evaluations reported in this document were performed during the period from March to November 1983. They are based on information and plans that were available then. Additional technical information has now been gathered, and the project plans have been developed further. Because this study attempts to quantify individual operations, many of its conclusions will remain valid as new data are obtained. The report may not, however, accurately represent current knowledge and plans, and it should not be considered a statement of the current status of the Nevada Nuclear Waste Storage Investigations project.

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GLOSSARY

Access Drift	A drift in the repository that connects the parallel emplacement drifts. Access drifts serve as passageways for waste transporters and are used as haulageways for muck, materials, and equipment.
Apron Feeder	A machine consisting of a series of overlapping metal plates (aprons) that run in an endless chain. The machine is used for transferring materials (such as muck) at a constant feed rate.
B-Line Circuit	A type of explosive cord used to detonate a series of blasting caps.
Brattice	A board or plank lining, or other partition, used in a mine passage to confine the air and force it into working places. It keeps the intake air from leaking into the return airway. Temporary brattices are often made of cloth.
Bulkhead	A tight partition of masonry, steel, or concrete used to control ventilation and to separate construction activities from waste emplacement activities.
Canister	As used in this document, a metal container for solid radioactive waste. A canister provides physical containment but no shielding against penetrating gamma radiation. During transfer from work station to work station, shielding is provided by a cask.
Collar	The junction of a mine shaft and the ground surface.
Conveyor	Any material-handling machine designed to move individual articles such as solids, or free-flowing bulk materials over a horizontal, inclined, declined, or vertical path of travel with continuous motion.
Cycle	The sequence of operations before one operation or event is repeated.
Design Criteria	Rules, regulations, codes, standards, and design-dependent constraints that govern the design of the repository. These criteria have been developed to ensure that facility design, construction, and performance objectives will be met.

Drift	Horizontal, or nearly horizontal, mined passageway. In this document, the term "access drift" is used to describe the tunnels that provide access to the emplacement drifts.
Drill Pattern	The placement of a number of boreholes in accordance to a predetermined geometric arrangement.
Emplacement Drift	Drift in which radioactive waste packages are disposed in either horizontal or vertical boreholes.
Face	The surface exposed by excavation. A surface on which mining operations are being performed.
Feeder Breaker	A component of the muck-handling system that is fed by load-haul-dump (LHD) vehicles and that breaks up the mined rock and feeds it to the main conveyor.
Ground Support (or control)	Methods by which underground openings are artificially supported to provide long-term stability; e.g., rockbolts, steel sets, shotcrete.
Head Frame	The steel frame at the top of a shaft that carries the sheave or pulley for the hoisting rope, skip-dumping gear, or cage-unloading facilities.
Hot Cell	A heavily shielded containment structure, usually constructed of concrete and equipped to permit remote viewing and handling of highly radioactive material. It is used during the removal of waste from the shipping cask, repackaging, and transferring the waste to the waste transporter.
In-Hole Powered Roller System	A conveyor installed in a horizontal borehole that moves waste disposal packages to or from their positions inside the borehole.
Jumbo	An electrically powered, hydraulically controlled drilling machine consisting of a carriage or mobile platform on which the drills are mounted.
Loading Pocket Flask	A container that weighs, sizes, and loads muck into skips.

1.0 INTRODUCTION

The work described in this report was performed for Sandia National Laboratories (SNL) as a part of the Nevada Nuclear Waste Storage Investigations (NNWSI) project. Sandia is one of the principal organizations participating in the project, which is managed by the U.S. Department of Energy's (DOE) Nevada Operations Office. The project is a part of the DOE's program to safely dispose of the radioactive waste from nuclear power plants.

The DOE has determined that the safest and most feasible method currently known for the disposal of such wastes is to emplace them in mined geologic repositories. The NNWSI project is conducting detailed studies of an area on and near the Nevada Test Site (NTS) in southern Nevada to determine the feasibility of developing a repository.

This study develops conceptual operation scenarios for all underground mining development and canister emplacement operations for the horizontal and vertical emplacement methods. The scope of this work was to define the methods and operations required for developing the underground repository, including

- mining,
- transportation and material handling,
- maintenance and shop practice,
- construction,
- large-diameter hole drilling,
- ventilation, and
- waste emplacement and storage operations.

The final results of the study include the manpower, utility, equipment, and general support requirements for each operation.

This study is based on studies previously done by Dravo Engineers, Inc. (Dravo, 1983), SNL (1983a, 1983b), and The Robbins Co. (1983). The results of this study are consistent with the results of the other investigations. Since the completion of this study, additional design development and program guidance have modified a number of the assumptions presented here. These modifications will result in differences in the parameters describing both horizontal and vertical emplacement; however, the principal conclusion regarding the comparison of the two methods will remain unchanged.

2.0 TECHNICAL APPROACH

The operational scenarios developed in this study are based on SNL design criteria, the preliminary mine configurations and ventilation plans developed by Dravo (1983), and additional information gathered from vendor data, Dravo's historical records, and field data collected at several mines that were visited during this study (Appendix A).

The design criteria used for this study are consistent with the design criteria used in an earlier Dravo report (1983) and are summarized in Table 1.

TABLE 1

DESIGN CRITERIA USED IN DEVELOPING CONCEPTUAL OPERATION SCENARIOS FOR THE REPOSITORY

Criteria	Unit
Total number of shifts for mine operations	3 shifts/day, 5 days/week
Working hr/shift	5.5
Repository operating schedule	225 day/yr
Panel emplacement capacity	700 canisters
Repository hole spacing (horizontal)	157 ft
Repository hole spacing (vertical)	30 ft
Canister emplacement rate	10 canisters/day
Canisters/borehole (horizontal)	35
Canisters/borehole (vertical)	1
Drift size (horizontal)	20 ft wide x 15 ft high
Drift size (vertical)	20 ft wide x 22 ft high
Advance/cycle[a]	12 ft
Total required advance/day (horizontal)[a]	63 ft
Total required advance/day (vertical)[a]	349 ft

[a] Data from Dravo, 1983.

3.0 MINING

3.1 Staffing and Organization

Mining of the emplacement and access drifts requires a total of 67 men for the horizontal emplacement method (Table 2) and 228 men for the vertical emplacement method (Table 3). The mining operations are supervised by the production superintendent who controls the mine through three shift superintendents. Each shift superintendent supervises four crews, one crew for each of the following operations:

- o drilling,
- o blasting,
- o mucking, and
- o ground control.

Each crew is supervised by a foreman who specializes in the particular operation. The organization of the mining operations is presented in Figure 1 in Appendix B.

3.2 Mining Production Requirements

The required mining production for the horizontal emplacement method is 63 ft/day; 349 ft/day is the required production for the vertical emplacement method (Dravo, 1983). To achieve the required production for the horizontal emplacement method, the production superintendent must ensure that 5.25 cycles are completed each day. This is calculated as follows using data from Table 1:

$$\text{number of cycles } (5.25) = \frac{\text{total required advance } (63 \text{ ft})}{(12 \text{ ft}) \text{ advance/cycle}} \quad . \qquad (1)$$

For the vertical emplacement method, 29 cycles must be completed each day. This is calculated as follows using data from Table 1:

$$\text{number of cycles } (29) = \frac{\text{total required advance } (349 \text{ ft})}{(12 \text{ ft}) \text{ advance/cycle}} \quad . \qquad (2)$$

Summaries of the mining operation cycles for both emplacement methods are presented in Tables 2 and 3. Based on these estimated cycle times, each crew can achieve the necessary production if one working face is always available. Using data from Tables 2 and 3, the minimum number of working faces required for each emplacement method was calculated as follows:

$$\begin{array}{c}\text{required number of} \\ \text{working faces}\end{array} = \frac{\text{total required advance}}{(\text{daily advance/working face})} \qquad (3)$$

TABLE 2

MANPOWER REQUIREMENTS AND CREW CYCLES FOR MINING OPERATIONS IN THE HORIZONTAL EMPLACEMENT METHOD

Operation	Men/ Crew	Crews/ Shift	Crews/ Day	Total Manpower	Estimated Cycle Time/ Round (hr)	Maximum Cycles/Day/ Crew
Drilling[a]	2	1	3	6	2.50	6.6
Blasting[a]	3	1	3	9	2.50	6.6
Mucking[a]	3	1	3	9	2.15	7.6
Ground Control						
Scaling	1	1	3	3	1.16	14.0
Rockbolting[b]	3	1	3	9	2.83	5.8
Screening	3	1	3	9	1.58	10.4
Supervision[c]	7	1	3	21	NA[d]	NA
TOTAL			21	66	12.72	NA[d]

[a] Includes foreman.
[b] Includes ground control foreman.
[c] Includes superintendents, engineers, and clerical staff.
[d] NA--Not applicable.

TABLE 3

MANPOWER REQUIREMENTS AND CREW CYCLES FOR MINING OPERATIONS IN THE VERTICAL EMPLACEMENT METHOD

Operation	Men/ Crew	Crews/ Shift	Crews/ Day	Total Manpower	Estimated Cycle Time/ Round (hr)	Maximum Cycles/Day/ Crew
Drilling[a]	1	5	15	18	2.90	5.6
Blasting[a]	2	5	15	33	2.90	5.7
Mucking[a]	2	5	15	33	2.70	6.1
Ground Control						
Scaling	1	2	6	6	1.16	14.2
Rockbolting[b]	3	5	15	48	2.83	5.8
Screening	3	2	6	18	1.58	10.4
Supervision[c]	24	1	3	72	NA[d]	NA
TOTAL	NA	NA	75	228	14.07	NA

[a] Includes one foreman/shift.
[b] Includes one ground control foreman/shift.
[c] Includes superintendents, engineers, and clerical staff.
[d] NA--Not applicable.

where

$$\text{daily advance/ working face} = \text{no. of cycles/day} \times \text{(12 ft) advance/cycle}$$

and

$$\text{no. of cycles/day} = \frac{\text{16.5 hr/day}}{\text{estimated hr/cycle}} \quad .$$

The minimum number of working faces required for the horizontal emplacement method is 4.0, and the minimum number of working faces required for the vertical emplacement method is 24.8. The vertical emplacement method requires a greater number of working faces than the horizontal method because of its higher required daily advance rate (349 ft/day) (Table 1). The minimum required number of working faces does not account for breaks in production resulting from contingency, mechanical failures, utility installation, and surveys. If allowances are made for production breaks, the horizontal and vertical emplacement methods will require a minimum of 6 and 29 working faces, respectively.

3.3 Operational Descriptions

The sequence of underground operations for the vertical emplacement method is depicted in Figures 2, 3, and 4 in Appendix B. The sequence of underground operations for the horizontal emplacement method is identical. The equipment and utilities required by each mining operation in horizontal and vertical emplacement are summarized in Tables 4 and 5, respectively. A detailed description of each mining operation for both emplacement methods is presented below.

3.3.1 Drilling

Blasthole drilling is done by a single operator using a 2-boom electro-hydraulic drilling machine called a jumbo. The jumbo is self-contained except for the power feed cable. The water required for drilling is provided by a 300-gal tank mounted on the frame of the jumbo. If an air mist hole flushing system is used in conjunction with an onboard compressor, less than 1 gal of water/blasting hole will be required. If a conventional water flushing system is used, 10-15 gal/blasting hole will be required.

The jumbo is moved between locations by diesel power, but once the jumbo is set up, it operates on the 480-V power from the cable. The jumbo can store 300 ft of cable on a reel. In addition, 1,000-ft-long extensions would be located in the main access drifts near power distribution centers that would enable the jumbos to operate throughout the repository. The jumbo would drill 60 blasting holes/cycle for horizontal emplacement, and 72 blasting holes/cycle for vertical emplacement.

The jumbo has an average availability of 65%, which means each jumbo will be in maintenance 35% of the working hours. This estimate of the jumbo's availability and the availability of the other mining equipment is calculated as follows:

$$\text{equipment availability} = \frac{\text{actual operating hr + idle hr}}{\text{total working hr}} \tag{4}$$

where

actual operating hours, idle hours, and total working hours were obtained from mining industry data.

As a result of the jumbo's 35% down time, an appropriate number of spare units must be purchased to maintain scheduled production rates for both emplacement methods. The number of jumbos required for horizontal and vertical emplacement is 1 and 5, respectively (Tables 4 and 5).

The cycle times for the drilling operation in the horizontal and vertical emplacement methods are 2.50 hr (Table 2) and 2.90 hr (Table 3), respectively. These were based on the following time estimates for each drilling activity:

- o move into positon and connect power cable--20 min,
- o mark blasting hole pattern on drilling face--5 min,
- o drill 30 blasting holes with each boom at a 7-ft/min penetration rate (2 min/hole + 2 min/realignment and position x 30 holes)--120 min (horizontal), or
- o drill 36 blasting holes with each boom at a 7-ft/min penetration rate (2 min/hole + 2 min/realignment and position x 36 holes)--144 min (vertical), and
- o disconnect power cable and move to next area--5 min.

The drilling operation is under the direction of a foreman with the following responsibilities:

- o supervise all drilling operations,
- o ensure that a working face is available for each drilling machine,
- o ensure the machines receive proper maintenance, and
- o supervise the operations of the raise and borehole drilling crews (Section 7).

3.3.2 Blasting

Ammonium nitrate and fuel oil (ANFO) is the principle explosive agent expected for production blasting at the repository. It is assumed that a control blasting technique will be used for production blasting, and as a result, the perimeter holes will be loaded with a low-energy explosive, e.g., Tovex 90, Kleencut, in small-diameter

TABLE 4

EQUIPMENT AND UTILITY REQUIREMENTS FOR MINING OPERATIONS IN THE HORIZONTAL EMPLACEMENT METHOD

Operation	Type of Equipment	No. of Units[a]	Utilities Required/Vehicle: Electricity (kVA)	Utilities Required/Vehicle: Water (gal)	Water/lf of Drift (gal)
Drilling	2-boom electro-hydraulic jumbo	1	37	24/hr[b]	5
Blasting	Diesel-powered ANFO loader	1	0	0	0
Mucking	8-yd^3 LHD vehicle	1	0	0	0
	10,000-gal water truck	0.33[c]	0	400/cycle	33
Ground Control					
Scaling	Diesel-powered scaler	1	0	0	0
Rockbolting	Automatic roof bolter	1	0	0	0
Screening	Scissor-lift truck	1	0	0	0
Supervision[d]	Boss buggies	6	0	0	0
	Assorted mine fans	Variable	215	0	0

[a] Does not include provisions for spare equipment.
[b] Assumes the use of an air mist hole flushing system.
[c] Only required 33% of the time.
[d] Includes superintendents, engineers, and clerical staff.

TABLE 5

EQUIPMENT AND UTILITY REQUIREMENTS FOR MINING OPERATIONS IN THE VERTICAL EMPLACEMENT METHOD

Operation	Type of Equipment	No. of Units[a]	Utilities Required/Vehicle: Electricity (kVA)	Utilities Required/Vehicle: Water (gal)	Water/lf of Drift (gal)
Drilling	2-boom electro-hydraulic jumbo	5	187	120/hr[b]	5
Blasting	Diesel-powered ANFO loader	5	0	0	0
Mucking	8-yd^3 LHD vehicle	5	0	0	0
	10,000-gal water truck	1	0	400/cycle	33
Ground Control					
Scaling	Diesel-powered scaler	2	0	0	0
Rockbolting	Automatic roof bolter[b]	5	0	0	0
Screening	Scissor-lift truck	2	0	0	0
Supervision[c]	Boss buggies	15	0	0	0
	Assorted mine fans	Variable	640	0	0

[a] Does not include provisions for spare equipment.
[b] Assumes the use of an air mist hole flushing system.
[c] Includes superintendents, engineers, and clerical staff.

cartridges. The rounds will be initiated by non-electric blasting caps using delays between holes in a predetermined drill pattern.

The actual loading will be done by a crew of two using a completely self-contained ANFO loader. This self-propelled, diesel-powered vehicle will have the following features:

- onboard compressor (200 ft^3/min),
- 1,000 lb ANFO storage tank,
- utility basket with boom (basket controlled), and
- storage cabinet for gel explosives and blasting caps.

The first activity of each blasting shift is to refill the storage cabinet with enough explosives required for all of the blasting to be done by the shift. The required amount of explosives/shift is approximately two rounds of supplies (600 lb of ANFO), 200 lb of control blasting agent, and 150+ blasting caps.

After stocking the storage cabinet, the crew takes the ANFO loader to the drilled face and places the correct delay cap by each blasting hole to be loaded. The perimeter blasting holes (±26) are loaded with control blasting agent. The collar of each of these holes is stemmed to prevent the unconfined explosives from being forced out of the hole by the initial blast. After the perimeter blasting holes have been loaded, the production blasting holes (center holes) are loaded with ANFO. The ANFO is loaded with compressed air that forces the pelletized ANFO through a plastic tube into each hole. After all the holes are loaded, each cap fuse protruding from each blasting hole is tied to a B-line circuit. This explosive cord is then detonated by a single electric blasting cap using a self-contained control box which is located in a safe area.

The availability of the blasting equipment is estimated to be 85%. The blasting equipment required for the horizontal and vertical emplacement methods are presented in Tables 4 and 5.

The amount of time required for one blasting cycle in the horizontal and vertical emplacement methods is 2.50 hr (Table 2) and 2.90 hr (Table 3), respectively. The blasting cycle in the vertical emplacement method requires more time than in the horizontal emplacement method because of the larger required drift size (Table 1). These cycle times are based on the following time estimates for each blasting activity:

- move equipment into position and set it up--15 min,
- load @ 2 min/hole x 60 holes (horizontal)--120 min, or
- load @ 2 min/hole x 72 holes (vertical)--144 min, and
- connect fuses--15 min.

The initiation of blasting is carefully controlled by the blasting foreman and the shift superintendent. A minimum of two blasts/shift is required for the horizontal emplacement method, and a minimum of nine blasts/shift is required for the vertical emplacement method in orderto maintain required production rates (Table 1). All loaded rounds are generally blasted at the end of each shift. However, if delays should occur (e.g., no working faces are available for blasting during a shift), it is possible to blast at lunch break with minimal delay.

The blasting safety procedures are as follows:

- all workers will report to a central area, lunch room, or shaft station,
- every worker will be accounted for by the superintendent,
- the blast area will receive a final pre-blasting inspection by the foreman,
- all fans will be turned off and the blast will be detonated by the foreman from a safe area, and
- the fans necessary to remove the exhaust fumes to the return airway will be turned on for 1/2 hr following blasting; after the exhaust fumes have dissipated from the working area, the workers will return to each working face and the remaining fans will be started.

3.3.3 Mucking

One of the most critical areas in maintaining production is the transport of muck out of the mine. The mucking equipment proposed for the repository are Load-Haul-Dump (LHD) vehicles. These diesel-powered vehicles were chosen in lieu of the loader and truck haulage method for mucking at the repository for the following reasons:

- based on vendor data, the LHD is more efficient at hauling muck over distances less than 2,000 ft, and the loader and truck method is more efficient for hauls greater than 2,000 ft; the average haul in the repository (average distance from working faces to the conveyors) is 1,480 ft which is well within the optimum operating range of the LHD;
- twice the quantity of diesel pollutants is produced by the loader and truck haulage equipment in comparison with the LHD vehicles;
- the 20- to 22-ft-wide drifts are not large enough for loader and truck haulage equipment;
- loaders require more roof height than is provided by the drifts (15 ft high) in the horizontal emplacement method (Table 1); and
- the LHD vehicles require a smaller crew than the loader and truck haulage method.

Dravo proposed using 13-yd^3 LHD vehicles for both the horizontal and vertical emplacement methods in an earlier study (Dravo, 1983). However, results from subsequent research and recent observations made on a field trip to Dravo Lime's Maysville Limestone Mine (Appendix A) indicate that a smaller, more versatile unit would be more suitable for the mucking operations at the repository. An 8-yd^3 LHD vehicle, which is 8 ft shorter and 2 ft narrower than the 13-yd^3 model, can match the output of the 13-yd^3 model because of its greater speed and versatility on steep grades. The 8-yd^3 model also uses 20% less horsepower than the 13-yd^3 model and, therefore, emits fewer pollutants into the air stream. The increase in average speed required by the smaller vehicle would be about 3 mph. This is easily within the operating range of the 8-yd^3 model if haulage roads are properly maintained.

The availability of 8-yd^3 LHD vehicles is estimated to be 60% and the number of LHD vehicles required by the horizontal and vertical emplacement methods are 1 and 5, respectively (Tables 4 and 5).

Before actual mucking can begin, water must be placed on the muckpile to dilute the gases from the explosives and to reduce the dust that could be raised by mucking. It is estimated that 300 to 400 gal of water will be required to spray the muck pile. This would be done by a water truck with a spray nozzle. This truck would also be used for road maintenance and dust control throughout the repository. One water truck is required full-time in the vertical emplacement method (Table 5) and one water truck is required 33% of the time in the horizontal emplacement method (Table 4).

The number of muck loads to be hauled to the conveyor after one blasting round in the vertical and horizontal emplacement methods are 21 and 27 loads, respectively. These estimates were calculated as follows:

$$\text{number of loads/blasting round (horizontal)} = \frac{\text{252 ton/round (Dravo, 1983)}}{\text{12 ton/load}} = \text{21 loads} \tag{5}$$

or

$$\text{number of loads/blasting round (vertical)} = \frac{\text{324 ton/round (Dravo, 1983)}}{\text{12 ton/load}} = \text{27 loads} \;, \tag{6}$$

where

$$\text{12 ton/load} = \frac{\text{8-yd}^3 \text{ capacity x 27 ft}^3 \text{ x 109 lb/ft}^3}{\text{2,000 lb/ton}} \;.$$

The cycle time for hauling one load is estimated to be 5.45 min for both emplacement methods. This cycle time is based on the sum of the following times required for each mucking activity:

- o load muck onto LHD vehicle--30 sec,
- o haul muck to feeder breaker--126 sec,
- o dump muck onto conveyor--15 sec,
- o turn LHD vehicle around--30 sec, and
- o return LHD to working face--126 sec.

Based on the number of loads required for each emplacement method (Equations 5 and 6), and the cycle time/load (5.45 min), the cycle time for mucking all loads/blasting round was estimated to be 2.15 hr for horizontal emplacement (Table 2) and 2.70 hr for vertical emplacement (Table 8). These time estimates were calculated as follows:

$$\text{horizontal mucking cycle time} = (5.45 \text{ min/load} \times 21 \text{ loads}) + [\text{clean-up time } (15 \text{ min})] = 129 \text{ min } (2.15 \text{ hr}) \quad . \tag{7}$$

$$\text{vertical mucking cycle time} = (5.45 \text{ min/load} \times 27 \text{ loads}) + [\text{clean-up time } (15 \text{ min})] = 162 \text{ min } (2.70 \text{ hr}) \quad . \tag{8}$$

The mucking would be supervised by a foreman who

- o ensures that the working face is available for mucking,
- o ensures that each vehicle receives daily preventive maintenance,
- o assists in ventilation monitoring so that each working area is not overly saturated with diesel emissions,
- o ensures that traffic flows smoothly and safely, and
- o monitors operator performance.

3.3.4 Ground Control

The safe support of underground openings is important for safety and long-term stability of the openings. For most ground support systems, the degree of stability is increased by reducing the length of time between excavation and support. Therefore, the efficient installation of rockbolts and screen is an integral part of the production cycle. It is assumed in this study that 8-ft epoxy rockbolts and wire screen will be the principle ground support method at the repository.

The ground support cycle consists of three operations:

- o scaling,
- o rockbolting, and
- o screen installation.

The cycle times for the three operations are the same for both emplacement methods because the area of the underground openings is approximately the same for both methods.

Scaling is the removal of loose rock from the roof, walls, or drilling face for safety purposes. This operation is done with a diesel-powered scaler specifically designed for this purpose. This machine consists of a chassis with outriggers for stability. An articulating hydraulic boom is mounted on the chassis of the scaler. On the end of the boom is a scaling "tooth" designed to loosen and remove any unstable rock. During the estimated cycle time for scaling, 1.16 hr (Tables 2 and 3), the scaler

- o moves into position and is set up--10 min,
- o scales back--25 min,
- o scales working face and walls--25 min, and
- o moves from the working area--10 min.

Rockbolting, conducted after scaling, supports the rocks around the excavation in order to maintain the arched repository rooms. At the repository, rockbolts will be placed in a 4-ft center-to-center pattern. Rockbolts, 8 ft in length, are proposed for use at the repository, but longer rockbolts may be required in highly fractured areas. Epoxy-grouted rockbolts are the most suitable rockbolts for the repository because they do not corrode rapidly. Other types of rockbolts such as split sets and mechanical shells would be suitable for temporary openings, but their tendency to corrode rapidly would limit their use for providing long-term stability to the repository.

An automated rockbolter would install the rockbolts. The boom-mounted device can remotely drill a hole, inject resin, and insert the rockbolts. The rockbolts are then rotated a predetermined number of revolutions to mix the epoxy resin according to the manufacturer's specifications. Rockbolters will be useful at the repository because the boom-mounted bolting device can rotate 180° to bolt the walls and roof in the arched repository rooms. Two people normally operate this equipment: one person runs the controls and the other person feeds rockbolts and resin to the bolting unit.

During a typical rockbolting cycle for the repository, 2.83 hr (Tables 2 and 3), the rockbolter

- o moves into position and sets up--10 min,
- o bolts @ 5 min/rockbolt x 30 rockbolts--150 min, and
- o moves from the working area--10 min.

The last task in the ground support cycle is the installation of screen or wire mesh on the repository walls and roof. The wire mesh is installed immediately after rockbolting is completed to prevent falling of small rocks loosened by rockbolting. For the long-term stability of the repository, a galvanized mesh of at least 9 gauge would be required for screening. This material is commonly made in 5-ft-wide rolls of a specified length.

The most common method of screen or mesh installation is to begin installing each roll at the bottom of one wall, and continue up and down the arch to the bottom of the opposite wall; thus the screening is installed perpendicular to the direction of the drift. Each successive roll will overlap the preceding roll by 10%, which ensures full coverage of the rooms.

Three men and a scissor-lift truck are required for screening. Two men can unroll the screen from a lifting bed on the truck and attach it to the threaded ends of the rockbolts protruding 2 to 3 in.

from the rockbolt plates. While the two crew members attach the screen, the third crew member will operate the truck.

A typical screening cycle, requiring three rows of screen and taking 1.58 hr (Tables 2 and 3), includes

- o moving the scissor-lift truck into position and setting it up--10 min,
- o placing and bolting three rolls of screen @ 25 min/roll--75 min, and
- o moving the truck from the working area--10 min.

The ground control equipment required for both emplacement methods are presented in Tables 4 and 5. The availability of all ground control equipment is expected to be 85%.

The entire ground control operation is under the direction of a foreman who

- o ensures that a working area is always available to each task crew,
- o determines the types of support required in each area,
- o monitors crew performance, and
- o ensures that each piece of equipment receives preventative maintenance.

4.0 UNDERGROUND TRANSPORTATION AND MATERIAL HANDLING

4.1 Material Handling Systems

Flow charts of the two types of material handling systems, a shaft headframe, and a 20% grade ramp, proposed for use at the repository, are presented in Figures 5 and 6, respectively. A shaft-headframe system is depicted for the horizontal emplacement method and a 20% grade ramp is depicted for the vertical emplacement method, for illustrative purposes only. Both types of material handling systems can be used in both emplacement methods.

4.1.1 Overview of Material Handling Systems

The major pieces of equipment common to the material handling systems for both emplacement methods are

- o underground mobil equipment (LHD vehicles),
- o feeder breakers,
- o extendable access drift conveyors,
- o main haulage conveyors,
- o underground surge bins,
- o bin reclaim feeders and conveyors, and
- o surface bins.

In addition, the shaft-headframe system requires a loading pocket flask and a production shaft hoisting system.

As noted in Subsection 3.3.3, the initial movement of excavated rock is done by LHD vehicles. The LHD vehicles transfer the rock from the working face to the closest feeder breaker. The feeder breakers, using a rotating drum with cutter teeth, produce 8-in. rock and feed this muck to extendable conveyors located in the panel access drifts. As the access drift conveyors advance, the feeder breaker advances, and another section of conveyor is placed behind the feeder breaker. The panel access conveyors feed muck to the main haulage conveyors located in the east side accessway. The main haulage conveyors transfer the muck from the mine development area to the underground surge bin located near the production shaft or the bottom of the ramp, depending on which type of material handling system is used (Figures 5 and 6).

All conveyors used in transportation and waste handling should be cable-suspension conveyors with fixed sides and idlers. This type of conveyor is easy to clean and maintain. A crew will be assigned to install new conveyor sections as needed and perform maintenance on existing belt systems. This crew will consist of approximately six workers for both emplacement methods.

4.1.2 Shaft-Headframe Material Handling System

If the shaft-headframe system is selected as the method for transporting muck from the underground surge bin to the surface, a drum hoist used in conjunction with two bottom dump skips is proposed (Figure 5). These skips operate in relative balance and are loaded at the loading pocket. They are filled by the bin reclaim conveyor with the load controlled both volumetrically and by weight so the skips cannot be overloaded. As one skip dumps to the surface bin, the other skip is being loaded at the loading pocket. On the surface, the surface bin collects the rock from both skips and transfers the rock by apron feeder to a surface conveyor for disposal.

The loading and hoisting process is controlled by a hoistman who oversees the automatic controls. Loading and hoisting are monitored by instruments that directly input all process data (from the underground storage bin to the surface disposal area) into the master control room. Should a system failure occur, the operation will automatically stop and the problem area will be indicated to the hoistman. The hoistman will then contact the appropriate maintenance personnel to investigate and repair the problem.

In addition to rockhoisting duties, the hoistman is responsible for the operation of the men and materials transport cage. If the cage is automatic, only one hoistman is required for the entire operation. Should manual hoisting be used, an additional hoistman is required to operate the men and materials cage.

In order to transfer the materials by cage, a coordinated system of cage loading and unloading must be maintained. This is done by surface and underground attendants working in concert. The materials are loaded and unloaded by forklift. Each load is placed, in succession, on the surface near the entrance to the elevator, and a scheduled movement of materials from the surface to the mine is maintained. The shaft foreman, who reports to the maintenance superintendent, supervises the activities of the shaft-headframe system (Figure 1).

The power requirements for the shaft-headframe system in the horizontal and vertical emplacement methods are 588 kVA and 1,624 kVA, respectively (Table 6). The greater power requirements of the vertical emplacement method are a result of the larger volume of muck transported in this method.

4.1.3 Twenty-Percent Grade Ramp Material Handling System

If a 20% grade ramp system is selected for material handling, the loading pocket flask and production shaft-hoisting equipment are unnecessary because the muck is loaded directly onto a conveyor (Figure 6). However, a system of supply loading and unloading similar to the shaft-headframe system is required. The operation of the conveyor belt and slope car would be controlled by the hoistman, and materials would be transported by surface and underground attendants.

TABLE 6

POWER REQUIREMENTS[a] FOR THE SHAFT-HEADFRAME AND 20% GRADE RAMP MATERIAL HANDLING SYSTEMS

Type of Handling System	Power Consumption[b] ton/day	kW-hr/yr	kW	kVA	Total Connected hp
Horizontal Emplacement					
Shaft-Headframe	1,500	1,939,474	470.1	588	655
20% Grade Ramp	1,500	725,013	175.8	220	220
Vertical Emplacement					
Shaft-Headframe	10,000	5,360,884	1,299.0	1,624	1,690
20% Grade Ramp	10,000	3,605,294	874.0	1,093	1,040

[a] These power estimates are assumed to be accurate within ±30%.
[b] This is based on an 80% power factor.

The ramp activities would be controlled by a foreman who is under the supervision of the maintenance superintendent (Figure 1).

The power requirements for the 20% grade ramp system in the horizontal and vertical emplacement methods are 220 kVA and 1,093 kVA, respectively (Table 6).

4.2 Underground Transportation

All underground transportation is expected to be conducted with diesel-powered mobile equipment. Trucks designed for underground use will transport all materials and workers from the shaft or ramp to the working areas. Traffic control systems will be installed underground because these transport vehicles will be traveling at ≥15 mph. Mirrors will be placed at major intersections so lights can be seen around corners. Stop signs will also be placed at major intersections so that LHD vehicle movement will be fluid. It is also proposed that all major traffic areas be lighted.

5.0 MAINTENANCE

A preventative maintenance program provides cost-effective, adequate maintenance, and ensures that production mining remains on schedule. Although replacement equipment are available for breakdowns, uninterrupted progress of mining is not assured unless mechanics, parts, and facilities are readily available to repair equipment. A preventative maintenance program includes

- computerized data files on all pieces of equipment that are accessible underground, e.g., drawings, parts lists, repair history and instructions, and planned maintenance schedules;
- all maintenance requests and descriptions of work performed, reported on written orders and preventative maintenance orders preprinted by a computer; and
- a preventative maintenance planner and clerk to maintain this system and to revise maintenance schedules on a regular basis in consultation with the maintenance supervisors.

The mining maintenance department is managed by the maintenance superintendent, who is responsible for overseeing the diverse activities of the various groups that are directed and supervised by the general maintenance foreman. Shop and maintenance activities are supervised by the machine shop foreman, electric shop foreman, mobile equipment foreman, and shaft and slope foreman. An organization chart of the mining maintenance operations is presented in Figure 1.

The underground shop facilities will serve as the maintenance, repair, and warehouse storage areas. The underground shop facilities include

- lunch rooms,
- shops,
- diesel-fuel storage,
- lube storage,
- explosive magazines,
- offices,
- first aid and training room,
- emergency vehicle parking,
- warehouse and storage,
- electric substation,
- electric power distribution system, and
- instrumentation and computer center.

The maintenance area includes

- fuel and lube bay,
- wash bay,
- vehicle repair bays,
- idler repair shops,
- welding shop,

- o electrical and instrumentation repair shop,
- o drill repair shop,
- o tire shop, and
- o shop parking area.

A larger number of maintenance areas will be required for the vertical emplacement method than for the horizontal emplacement method because the vertical emplacement method requires more equipment (Tables 4 and 5).

All crafts, e.g., electricians, drill repair, will need to have one person available for repairs at all times. In addition, lubrication and fuel crews will have to be available for all shifts. Therefore, the maintenance department will work 3 shifts/day, 5 days/week. This may be increased to weekend work depending on the workload. The maintenance area manpower requirements are summarized in Table 7. The total manpower requirements for the horizontal and vertical emplacement methods are 34 and 73, respectively. The vertical emplacement method requires more personnel to support the extra equipment required by this method.

TABLE 7

MAINTENANCE CREW REQUIREMENTS FOR THE HORIZONTAL AND VERTICAL EMPLACEMENT METHODS

	Horizontal		Vertical	
Maintenance Area	Men/Shift	Total[a]	Men/Shift	Total[a]
Drill Repair	1	3	2	6
Electrician	1	3	3	9
Mechanic	3	10[b]	13	40[b]
Hoist and Deckman	4	12	4	12
Warehouse	2	6	2	6
TOTALS	11	34	24	73

[a] This assumes three shifts/day.
[b] This includes a foreman.

The underground warehouse would store the majority of the parts necessary for maintaining and repairing the underground equipment. The availability of parts underground greatly decreases the repair and/or maintenance time for equipment. Maintaining the warehouse would require a crew of two/shift and a computer inventory system. The warehouse computer system would have a complete list of parts required for every piece of mobile equipment, a location code for each part in stock, and current inventory for each stocked part. The warehouse clerk would input the data on every part that is received and used, and the computer system would automatically output the necessary purchases needed to replenish the parts inventory.

6.0 CONSTRUCTION OPERATIONS

Construction operations for repository development include

- o utility and conveyor installation,
- o road and drift maintenance,
- o bulkhead construction, and
- o vault door preparation.

Each of these operations would have a supervising foreman. A construction superintendent would coordinate all supervising foremen. The organization of the construction operations is presented in Figure 1. The manpower, equipment, and utility requirements of these operations for the horizontal and vertical emplacement methods are summarized in Tables 8 and 9.

6.1 Utility and Conveyor Installation

The general duties of the crews that install utilities and conveyors include

- o installation and repair of auxillary fans,
- o installation and repair of ducting for drift development,
- o installation and removal of conveyor sections, and
- o moving the electrical transformers and distribution centers.

The majority of this work is preplanned and scheduled; therefore, the work can be done by one shift. A crew of 7 is required for the horizontal emplacement method (Table 8), and a crew of 13 is required for the vertical emplacement method (Table 9). The equipment requirements for this crew vary with the task, but in general, scissor-lift trucks and mobile cranes would be required for most assignments. The horizontal emplacement method requires one scissor-lift truck and mobile crane (Table 8), and the vertical emplacement method requires two scissor-lift trucks and mobile cranes (Table 9). The availability of this equipment is assumed to be 85%.

6.2 Road and Drift Maintenance

The crews assigned to this task would be responsible for road repair, grading, and ground support. This crew would maintain the roads and drifts in the mine development areas. The horizontal emplacement method requires one shift of a 7-man crew, and the vertical emplacement method requires two shifts of a 13-man crew. The vertical emplacement method requires more manpower due to the increased miles of mine development and larger drift height required by this method. The equipment requirements for the road and drift maintenance crews are

- o scissor-lift truck,
- o shotcrete truck (self-contained),
- o road grader,

TABLE 8

MANPOWER, EQUIPMENT, AND WATER REQUIREMENTS FOR CONSTRUCTION OPERATIONS IN THE HORIZONTAL EMPLACEMENT METHOD[a]

	Manpower				Equipment		Water	
Operation	Men/Crew	Crews/Shift	Crews/Day	Total	Type	No. of Units[b]	Water (gal/min)	Water/lf Drift (gal)
Utility and Conveyor Installation	7	1	1	7[c]	Scissor-lift truck	1	0	0
					Mobile Crane	1	0	0
Road and Drift Maintenance	7	1	1	7	Scissor-lift truck	1	0	0
					Shotcrete truck	1	5	5
					Road grader	1	0	0
					Rockbolter	1	0	0
					10,000-gal water truck	0.33[d]	0	0
Bulkhead Construction	5	1	2	10[c]	Boom truck	1	0	0
					Bulkhead seal pump	1	0	0
Vault Door Preparation	3	1[e]	1	3	Boom truck	1	0	0
					Concrete pump	1	0	0
					Concrete truck	1	0	25/hole

[a] Power requirements are not included because this equipment requires no electrical power.
[b] This number does not include provisions for spare equipment.
[c] This includes a foreman.
[d] Equipment will be used only 33% of the time.
[e] Part-time crew.

TABLE 9

MANPOWER, EQUIPMENT, AND WATER REQUIREMENTS FOR CONSTRUCTION OPERATIONS IN THE VERTICAL EMPLACEMENT METHOD[a]

Operation	Manpower: Men/Crew	Manpower: Crews/Shift	Manpower: Crews/Day	Manpower: Total	Equipment: Type	Equipment: No. of Units[b]	Water: Water (gal/min)	Water: Water/lf Drift/(gal)
Utility and Conveyor Installation	13	1	1	13[c]	Scissor-lift truck	2	0	0
					Mobile crane	2	0	0
Road and Drift Maintenance	13	1	2	26	Scissor-lift truck	1	0	0
					Shotcrete truck	1	5	5
					Road grader	1	0	0
					Rockbolter	1	0	0
					10,000-gal water truck	1	0	0
Bulkhead Construction	15	1	2	31[c]	Boom truck	2	0	0
					Bulkhead seal pump	2	0	0
Vault Door Preparation	10	1	2	21[c]	Boom truck	2	0	0
					Concrete pump	2	0	0
					Concrete truck	2	0	25/hole

[a] Power requirements are not included because this equipment requires no electrical power.
[b] This number does not include provisions for spare equipment.
[c] This includes a foreman.

- o water truck, and
- o rockbolter.

The number of units required in each emplacement method is presented in Tables 8 and 9. The availability of this equipment is assumed to be 85%.

6.3 Bulkhead Construction

The repository design criteria (Dravo, 1983) require that two separate ventilation systems be maintained: one for mine development and one for waste emplacement and storage. The bulkheads and air locks required to maintain the separate ventilation systems must be continuously erected and removed. In addition, the air-coursing bulkheads and brattices required for mine development, waste emplacement, and storage must be maintained. In order to maintain two ventilation systems, a greater number and higher quality of bulkheads and stoppings are required by the repository than what is typically required in an underground mine.

Because most bulkheads must be removed as the emplacement operations advance, it is proposed that highly mobile structural steel and sheet metal bulkheads be used in the repository. These bulkheads are widely used in the coal industry because they can be installed rapidly, are adaptable to a variety of openings, and have low leakages. In addition, these bulkheads have the proper shock-absorbing characteristics needed for blasting operations.

The installation and removal of these bulkheads in the horizontal emplacement method requires one crew of five for two shifts (Table 8). The vertical emplacement method requires a crew of 15 for two shifts (Table 9) due to the larger number and size of the bulkheads required for ventilation in this method.

The equipment required for bulkhead construction are a boom truck containing torch and welding equipment and a mine bulkhead seal pump used to spray a foam sealer around joints on the bulkhead. One boom truck and one bulkhead seal pump are required for the horizontal emplacement method (Table 8), and two boom trucks and two bulkhead seal pumps are required for the vertical emplacement method (Table 9). The availability of this equipment is assumed to be 85%.

6.4 Vault Door Preparation

Before sealing the emplacement boreholes with heavy metal doors, the boreholes must be prepared for sealing. The sealing preparation involves placing a concrete pad over the borehole entrance with the inserts used for bolting the vault door in place. According to The Robbins Co. (1983), the horizontal boreholes require mounting the pad vertically on the wall before drilling. The Robbins Co. report does not mention a pad requirement for the vertical emplacement method, but it is assumed to be a requirement for both methods in this study.

This task must be accomplished after the drifts are excavated and before emplacement borehole drilling in both methods.

The horizontal method requires only one door pad every 3 to 4 days [when 35 canisters/borehole are emplaced at a rate of 10 canisters/day (Table 1)]. A crew of three, working on a part-time basis, can install the door pads at this rate if they use a reusable form rockbolted to the drift wall. Because this operation does not require a full-time crew, it can be conducted by another crew, e.g., utility and conveyor installation crew. The vertical emplacement method requires the completion of 10 door pads/day [1 canister/borehole is emplaced at a rate of 10 canisters/day (Table 1)]. A 10-man crew, working two shifts, can install the door pads at this rate.

The equipment required for vault door preparation in both emplacement methods are boom trucks or small mobile cranes, concrete pumps, and concrete transport vehicles. The number of units required by each emplacement method is presented in Tables 8 and 9. The availability of this equipment is assumed to be 85%.

7.0 BOREHOLE DRILLING

For this study, the boreholes are assumed to be those holes used for waste canister emplacement or ventilation raises. The principal source of operations data for this section comes from The Robbins Co. (1983). In The Robbins Co. report, horizontal and vertical boreholes are drilled with different equipment under different operating scenarios. The manpower, equipment, and utility requirements for borehole drilling in the horizontal and vertical emplacement methods are summarized in Table 10.

7.1 Horizontal Borehole Drilling

The major objective of drilling horizontal boreholes is to create a hole 30 to 42 in. in diameter and 600 ft long (The Robbins Co., 1983). The boreholes are designed to hold 35 waste canisters each. To drill a borehole of this accuracy, size, and depth will require a machine that is not currently available. Therefore, the operation scenario for horizontal drilling is based on design specifications of new technologies described by The Robbins Co. (1983) and Dravo's engineering judgment. Existing raise drills and box drills could drill these holes but not to the required degree of accuracy. The drill-hole accuracy required at the repository represents a significant deviation from accuracies required by current mining practices, and therefore, new technologies must be considered.

The Robbins Co. (1983) has proposed a remote-controlled tunnel-boring machine (a modified box drill) that steers while boring by moving the rear of the machine so that the drilling head is always aimed at the face. The design problems associated with this type of equipment are related to miniaturization and packaging. A laser system remotely guides the equipment by using a target mounted on the drilling unit that provides automatic feedback to the operator. The rock chips and muck produced by the boring action are removed from the cutterhead by a vacuum system that transfers the chips to the haulage route and deposits them in a hopper to be emptied by a LHD vehicle (Subsection 3.3.3).

A crew of two/shift is required to run the drilling unit efficiently and to move the unit between work sites. Two additional workers will be required for electrical and hydraulic repair of the drilling equipment in the work area. The cycle time for drilling a 600-ft horizontal borehole is estimated to be 131.2 hr. During this cycle the drilling unit

- o moves into position and is set up--16.0 hr;
- o drills the initial 12 ft of the borehole @ 6 ft/hr penetration rate (12 min allowed for adding two pipes)--2.2 hr;
- o drills an additional 588 ft adding 147, 4-ft pipes--88.2 hr; and
- o removes the drill from the working face and removes 149 pipes--24.8 hrs.

TABLE 10

MANPOWER, EQUIPMENT, AND UTILITY REQUIREMENTS FOR BOREHOLE DRILLING IN THE HORIZONTAL AND VERTICAL EMPLACEMENT METHODS[a]

Type of Borehole	Manpower				Equipment			Utilities	
	Men/Crew	Crews/Shift	Crews/Day	Total	Type	No. of Units[b]	Elec. (kVA)	Water (gal/min)	Water/Borehole (gal)
Emplacement									
Horizontal	2	3	9	18	Box-hole drill[c]	3	900	20	Recycled
Vertical	2	8	24	48	Raise drill	3	225	20	Recycled
					Reamer	5	800	0	0
Raise									
Horizontal	2	1	1	2	Raise drill	1	75	10	500/hole[d]
Vertical	2	1	1	[e]	[f]		0	10[g]	500/hole[d]

[a] These data are based on a report by The Robbins Co. (1983).
[b] This number does not include provisions for spare equipment.
[c] This is the Robbins Co. remote-controlled tunnel-boring machine which is a modified box-hole drill.
[d] The water is only needed for drilling the pilot hole.
[e] The manpower required for raise drilling is included in the total manpower requirements for drilling the emplacement boreholes.
[f] No additional drilling equipment is required for raise drilling beyond what is required for drilling the emplacement boreholes.
[g] This is the additional water needed for raise drilling with the same equipment used for drilling emplacement boreholes.

If the drilling crew works 5 days/week, then the production requirement is one borehole every 3.5 days [35 canister/borehole 10 canister/day (Table 1)]. At this rate each drilling unit would produce one borehole every 7.95 days. This was calculated as

$$\frac{131.2 \text{ hr/borehole}}{16.5 \text{ hr/day}} = 7.95 \text{ days/borehole.} \qquad (9)$$

Assuming an equipment availability of 75% (estimated from industry experience), three complete drilling units would be required to maintain the required production rate. This is based on

$$\frac{7.95 \text{ days/borehole} \times 75\% \text{ avail}}{3.5 \text{ days/borehole}} = 3 \text{ drilling units} \quad . \qquad (10)$$

The utility requirements for each drill unit are 20 gal/min of water at 50 psi and 300 kVA power at 480 V (Table 10).

7.2 Vertical Borehole Drilling

One vertical borehole, 30 ft deep, is required for emplacing a single canister (Table 1). The Robbins Co. (1983) concluded that a two-pass hole system would best comply with the repository design requirements and the drilling conditions for vertical emplacement. A description of the activities required for vertical drilling is presented below.

7.2.1 Pilot-Hole Drilling

A pilot hole is required to guide the reamer bit. A single, 11-in.-diameter pilot hole is drilled 32 ft deep with a standard Robbins 32R modified raise drill. This drill is mounted on a crawler in operating position. All other components required for drilling are mounted on the frame of the drill except for a trailer-mounted compressed air system (The Robbins Co., 1983).

The pilot hole is drilled with a crew of two: one drill operator and one assistant who waters, injects air, and clears the muck from the hole. Adding drill pipe is automatic but is usually conducted under close surveillance by the crew. After the desired hole depth is obtained, the bit is withdrawn and all extra drill pipe is stored on the crawler. The raise drill is then moved to the next working area. The operation cycle, estimated to be 3.83 hr, is detailed below:

- o align machine and connect services--20 min,
- o position reaction jacks--20 min,
- o drill pilot holes--180 min,
- o withdraw pipe sections--10 min, and
- o move drill to next working area--10 min.

If pilot drilling operates 3 shifts/day, the maximum number of pilot holes drilled daily would be 4.31. This is based on

$$\frac{16.5 \text{ hr/day}}{3.83 \text{ hr/pilot hole}} = 4.31 \text{ pilot holes/day} \quad . \tag{11}$$

When an equipment availability of 75% (according to industry experience) is included in the calculation, each machine will produce 3.23 pilot holes/day. Three machines are required to comply with the design criterion of 10 canisters/day (Table 1). The utility requirements for each drill unit are 10 gal/min of water at 50 psi and 75 kVA at 460 V (Table 10).

7.2.2 Reaming

The second step in the drilling of the vertical boreholes is reaming. Reaming enlarges the pilot holes from an 11-in. diameter to a 4-ft diameter. Reaming is done with a crawler-mounted raise-boring machine (reamer) similar to the machine used for drilling the pilot hole. The difference between the reamer and the raise drill is that the reamer has a vacuum system for muck removal, which is used in conjunction with an offset drive, and a circular guide column to enhance borehole stability. The crew requirements for reaming are the same as for pilot hole drilling.

Reaming is started by moving the reamer over a pilot hole and securing the reamer by extending the reaction jacks. The vacuum system and the drill are connected to each other and to the utility services. The reamer hole is drilled in the same manner as the pilot hole by adding pipe sections as required. When the hole reaches the desired depth, the vacuum system is turned off and the reamer is withdrawn from the hole. All extra pipes are stored on the reamer and all services are disconnected from the vacuum system and the drill. The vacuum cart is then hitched to the drill transporter, and the entire system is moved to the next work area.

The reaming operation cycle, estimated to be 5.92 hr, is provided below:

- align reamer over pilot hole and connect services--20 min;
- connect vacuum system and position the reaction jacks--15 min;
- activate reamer and vacuum, add pipe, and dump muck--285 min;
- withdraw pipe--20 min; and
- move reamer to next ream-hole position--15 min.

If reaming operates 3 shifts/day, the maximum number of boreholes drilled/day would be 2.79 as calculated below.

$$\frac{16.5 \text{ hr/day}}{5.92 \text{ hr/borehole}} = 2.79 \text{ boreholes/day} \quad . \tag{12}$$

If an equipment availability of 75% is included in the calculation (based on industry experience), each machine will produce 2.09 boreholes/day. Based on this estimate, five machines are required to emplace 10 canisters/day (Table 1). The utility requirements for each drill unit are 10 gal/min at 50 psi, and 160 kVA of electric power at 460 V (Table 10).

7.3 Raise Drilling

If the repository is to follow the slope of the formation and the emplacement drifts are to be level (Dravo, 1983), then raises will be required to ventilate adjoining panels in both emplacement methods. According to Dravo (1983), a single raise is required for each mining panel or every 700 canisters. The equipment required to drill the vertical emplacement boreholes would be satisfactory for drilling the 4-ft-diameter and 96-ft-long raises.

The activities required for raise drilling are to 1) drill with a raise drill, an 11-in.-diameter hole that is 96 ft deep and connects with an access drift, and 2) attach a 4-ft raise bit to the drill column and pull it up to the drill. The same two-man crew that drills the emplacement holes will drill the raises. During the cycle time for raise drilling in both emplacement methods, predicted to be 24.83 hr, the following activities occur:

- align machine and connect services--20 min,
- position reaction jacks--10 min,
- drill pilot hole--576 min,
- install reamer bit--10 min,
- raise 4-ft hole--864 min,
- move the drill off hole--10 min, and
- remove the drill from the hole--10 min.

The muck produced by the reamer would be hauled away by an LHD vehicle stationed in the work area. If a 75% equipment availability of the raise drill is included in the calculation (based on industry experience), this operation would require 33 hr or two working days. If the schedule does not permit the use of a raise drill on a regular work day, the ventilation raise drilling could be done on weekends.

A spare raise drill machine and reamer would already be available for drilling raises in the vertical emplacement method. Raise drilling equipment would have to be purchased for the raise drilling in the horizontal emplacement method. Because an emplacement borehole is required for every 700 canisters in both the horizontal and vertical methods, a raise would only need to be drilled every 3 months.

8.0 VENTILATION

Ventilation engineering, which is an integral part of mine planning, is performed by a full-time staff consisting of a mine ventilation engineer and trained ventilation technicians (Figure 1). This group is responsible for

- o keeping plans and circuits current with new developments,
- o performing routine surveys and inspections,
- o performing special investigations,
- o locating fans and bulkheads for the construction crews, and
- o testing new methods and materials used in ventilation and dust control.

Because ventilation is critical in mining operations, the primary controls that regulate fans, louvers, regulators, and doors are controlled by the ventilation engineers. All regulators are positioned and marked, sealed with a wire or with a sign placed on them to indicate their required air volume.

Secondary circuits are planned by ventilation engineers, and all installations are based on written work orders. Daily inspections of the controls and circuits are made in order to keep up with mining production. In addition to ensuring that the required air volume is circulated, the ventilation department monitors airborne dust and diesel emission levels. These inspections are conducted by remote instruments and manual inspection at the work sites.

The maintenance of the separate ventilation systems required for mine development and waste emplacement is also the responsibility of the ventilation department. The staff must maintain a separation between the two ventilation systems, ensure a negative pressure drop from development ventilation to emplacement ventilation, and plan and maintain both systems.

In addition to the inspections made by the ventilation engineering department, the shift monitors inspect each working area during each shift to ensure that the level of ventilation, dust, diesel emission, and radiation meet existing standards. These inspections are supervised by the Manager of Safety and Quality Assurance. This group has the authority to stop work in an area that does not meet existing standards.

The level of effort estimated for ventilation operations is based on Dravo's historical records and accepted practices in industry. The horizontal emplacement method is estimated to need one mine ventilation engineer and three ventilation technicians. The vertical emplacement method is estimated to need one mine ventilation engineer and six ventilation technicians.

9.0 WASTE EMPLACEMENT OPERATIONS

The actual emplacement of waste requires three operations in both the horizontal and vertical emplacement methods: door handling, transporter operating, and general maintenance. The organization of the waste emplacement operation is presented in Figure 7 of Appendix B. The manpower and equipment requirements of this operation for the horizontal and vertical emplacement methods are summarized in Tables 11 and 12.

This section establishes the manpower and equipment requirements for the three waste emplacement operations based on data from SNL (1983a). Although the nature and packaging of the waste is subject to change, the manpower, equipment, and organization should remain relatively constant.

9.1 Door Preparation

Under the supervision of a repository foreman, the door preparation crew will be responsible for all door preparation activities before, during, and after emplacement. Door preparation for the horizontal emplacement method begins with the removal of the protective cover from the opening. The shield door is then placed over the opening by a piece of equipment specifically designed for this purpose; a crawler-mounted, hydraulically operated crane. A transporter docking and alignment system is installed on the floor pad and attached to previously installed anchor points. Through use of another specially designed piece of equipment, the in-hole powered roller system is installed and utilities are connected. The roller system is tested with a cold canister to assure proper operation.

The hole is then ready for the transporter crew to emplace 35 canisters. When the hole is full, the door crew will reverse the operation by remotely placing a precast concrete plug after the last canister. The crew will then place a final closure plug in the hole, retrieve the in-hole powered roller system through the use of a retrieval machine capable of mating with the emplacement door, and remove the shield door and transporter docking device.

If continuous canister emplacement is to be maintained, one complete cycle must be completed every 3 days to comply with the design criteria (Table 1).

A door preparation crew for the horizontal emplacement method would consist of one foreman and six workers operating three pieces of equipment (Table 11). Interference between door preparation crews and transport crews may dictate that the door preparation and waste emplacement operations take place during different shifts. This can be accomplished by using weekend crews or rotating shifts.

TABLE 11

MANPOWER AND EQUIPMENT REQUIREMENTS FOR WASTE EMPLACEMENT OPERATIONS IN THE HORIZONTAL EMPLACEMENT METHOD

	Manpower				Equipment	
Operation	Men/ Crew	Crews/ Shift	Crews/ Day	Total	Type	No. of Units[a]
Door Preparation[b]	7[b]	1	1	7	Door placing alignment unit	1
					Power unit	1
					Roller unit	1
Transporter Operation	3	1	3	9	Transporter	2
					Emplacement conveyor	1
Maintenance	4[b]	1	3	12	Service truck	1
					Lube truck	1
Supervision, Quality Control, and Safety	5	1	3	15	Boss buggies	5

[a] This number does not include provisions for spare equipment.
[b] This includes a foreman.

TABLE 12

MANPOWER AND EQUIPMENT REQUIREMENTS FOR WASTE EMPLACEMENT OPERATIONS IN THE VERTICAL EMPLACEMENT METHOD

	Manpower				Equipment	
Operation	Men/ Crew	Crews/ Shift	Crews/ Day	Total	Type	No. of Units[a]
Door Preparation	6[b]	2	6	39	Door placing alignment unit	2
					Plugging unit	2
Transporter Operation	3	1	3	9	Transporter	2
					Emplacement conveyor	1
Maintenance	8[c]	1	3	24	Service truck	1
					Lube truck	1
Supervision, Quality Control, and Safety	7	1	3	21	Boss buggies	6

[a] This number does not include provisions for spare equipment.
[b] This does not include a foreman.
[c] This includes a foreman.

The door preparation crew for the vertical emplacement method would have the same responsibilities and operating scenarios as the horizontal emplacement crews, with two exceptions: an in-hole powered roller system is not required and a door must be prepared for each canister, thus increasing the workload 35 times.

As a result, a door must be placed and removed every 1.65 hours (16.5 hours/day ÷ 10 canisters/day). To accomplish this, two crews are estimated to be required on every shift, and emplacement must take place in more than one drift to minimize interference from transporter operations. It is estimated that two six-man crews operating four pieces of equipment, and one foreman per shift would be required for this operation (Table 12).

9.2 Transporter Operation

The transporter operation is the most important activity in the repository. Transporter operation for the horizontal emplacement method consists of two transporters working in concert, one loading on the surface and one emplacing waste. It is assumed that an operating emplacement hole is always available to the transporter.

The transporter operator drives to a hot-cell loading point (surface or underground) and leaves his machine while it is loaded. When loading is certified as complete, the operator drives to the designated hole and onto the alignment device. The operator again leaves his machine, and the remote operator stationed nearby completes the emplacement cycle.

Two transporter units must be operating to achieve the required production rates (Table 1), one in transit and one emplacing waste. The cycle time of the transporter operation is 3.3 hr for both emplacement methods. This was calculated as

$$\frac{16.5\ \text{hr/day}}{10\ \text{canisters/day}} = 1.65\ \text{hr/cycle} \times 2\ \text{transporters} = 3.3\ \text{hr} \quad . \quad (13)$$

The remote operation of the transporter at the emplacement holes could be easily handled by a single operator. The horizontal emplacement crew requires two transporter operators and one emplacement operator (Table 11). The transporter operation for the vertical emplacement method is identical in scope to that for the horizontal emplacement method except the transporter must be able to lift the canister vertically. This is not expected to change the operation scenarios or crew size (Table 12).

9.3 Maintenance

A separate maintenance department for waste emplacement must

- perform preventative maintenance on shield doors, alignment devices, and the power roller system;
- perform preventative maintenance and repair on transporters and other underground equipment needed in the emplacement area;
- maintain roads and accessways in the repository area; and
- operate the repository hoist system (if required).

The maintenance department would have the same organization for both the horizontal and vertical emplacement methods. However, due to the higher door preparation workload in the vertical emplacement method (see Subsection 9.1), the maintenance crew size and facilities would be substantially larger than for the horizontal emplacement method.

The maintenance crew for the horizontal emplacement method would include one foreman, one electrician, and two mechanics for three shifts (Table 11). The maintenance crew for the vertical emplacement method would include one foreman, two electricians, and four mechanics for three shifts. In addition, road maintenance (for the vertical emplacement method only) would involve a crew of two for three shifts (Table 12).

9.4 Quality Control and Safety

In addition to waste emplacement crews, the repository will require Quality Assurance and Quality Control personnel to assure that the operations are performed according to predetermined guidelines.

10.0 RECOMMENDATIONS

Based on the results of this study the following areas are recommended for further study:

- Develop operations data on mechanized mining machines or continuous miners to study the feasibility of using these types of equipment at the repository in lieu of conventional mining equipment;

- Generate a detailed equipment list that includes detailed specifications, power requirements, current market cost, expected life, and operating costs of each equipment item to be used at the repository;

- Generate a detailed development plan for a unit panel and the entire repository for both the horizontal and vertical emplacement methods; and

- Increase the level of detail of the operational data for the mining operations of both emplacement methods, particularly with respect to cycle times and crew interference in the repository drifts.

11.0 REFERENCES

Dravo Engineers, Inc. 1983. An Evaluation of the Effects of Horizontal and Vertical Emplacement on Mining at the Yucca Mountan Repository Site. SAND83-7443.

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APPENDIX A

Field Data Collected at the Dravo Lime's Maysville Limestone Mine

Internal Correspondence

To JOHN ROSSINI

Date 5/19/83

From TOM GOODELL

Subject TRIP REPORT - DRAVO-LIME - MAYSVILLE, KENTUCKY

The purpose of this trip was to gather actual data to be used by Dravo for the operations study assigned by Sandia, and to observe the efficiency of ramped access. The plan was to spend the first day (May 9) by myself to gather detailed information about each operation, drill penetration rates, cycle times, etc. The second day was to be spent with Ken Beall of Sandia to observe the overall mine operation and, in particular, the shaft and slope used at this mine.

GENERAL MINE DESCRIPTION

Dravo-Lime's Maysville mine is a 11,000 ton per day operation, employing approximately 130 people. Its principal purpose is to provide feed for three rotary kilns producing Thiorsobic lime for stack gas SO_2 removal.

The mine is located 950 feet below the surface and is serviced by a 3,000 ft. ramp at 30% grade and a 14 ft. diameter shaft. The principal purpose of the ramp is for rock removal (conveyor) and mine supply (hoist and railcar). The purpose of the shaft is for man access only.

The underground operation uses much the same equipment as proposed by Dravo for the repository in Tuff, i.e., large capacity LHD's, electro-hydraulic drill jumbo's, mechanized roof bolters, underground conveyors, etc.

The following is a summary of the observations made:

Drilling

Drilling is done by electro-hydraulic drill jumbo's, manufactured by Ingersol-Rand. With a single operator, 42 14' x 2" diameter holes are drilled with a V-cut pattern designed to produce a small percentage of fines. The jumbo is completely self-contained except for the power feed cable. Water is provided by a 300 gallon tank mounted on the frame. In conjunction with an on-board compressor, an air-mist hole flushing system uses less than one gallon of water per hole. A normal water flush system would require 10-15 gallons per hole. The carriage is moved from location to location by diesel power, but once set up, the jumbo operates on the 480v power from the cable. The jumbo itself stores 300 ft. of cable on a reel. In addition, 1,000 ft. long "extensions" are strategically located from area distribution centers giving the jumbo a wide range to operate within the mine.

Dravo

Actual drilling time averages 3½ minutes per hole. Two minutes of this is actual drilling time and the balance is boom alignment and hole flushing. Allowing for set-up and move time, each drilling face requires about three hours to drill. The bits used are throw away type and average about 480 ft. of drilling per bit.

Blasting

The loading of explosives is done with a crew of two, using a self-contained ANFO loader. The unit has a 1500 lb. explosive storage capacity, a 200 cfm on-board compressor and storage capacity for blasting caps and cartridge explosives. About 20 minutes per face is required for loading.

ANFO, which is short for Ammonium Nitrate and Fuel Oil, is the principal explosive used here. A single stick of dynamite per hole is used to initiate the ANFO. Dravo uses Nonel blasting caps. These non-electric caps are easier and safer than electric caps. The average consumption of explosives is .8 to .9 lbs. per ton of rock.

All blasting is done at the end of the shift after a check has been made that the entire mine has been cleared. The three-hour delay before the next crew starts work allows ample time for the explosive fumes to clear.

Mucking

The most critical operation at any high tonnage mine is the rapid movement of broken rock to the crusher. Here at Dravo-Lime, the method is to use loaders and trucks. Two types of loaders and trucks are used here. The first loader is a Wagner ST11 LHD. This load, haul dump unit was first used to do the entire job, as is indicated by its name, but proved too slow and unreliable for the required production. The other loader is a 988 caterpillar loader. This machine is more productive and reliable for loading trucks, but requires a minimum 18 ft. roof height. The trucks are 20-ton Jarvis Clark mine trucks with end dumps and a caterpillar 40-ton "ejecto dump" off-highway truck.

The system with the LHD's is for the unit to load, raise its bucket and have the truck maneuver under the bucket. This is done because the truck has greater mobility than the LHDs. The 988 conventional loader is more maneuverable and loads the trucks from a single position. The trucks average haul is 1500 to 2000 ft. with a top speed of 15 mph. These units dump into either a feeder breaker or jaw-type crusher, where the remainder of the material handling is done by conveyor.

Because some toxic funes remain after each blast and the loading of this broken limestone creates dust, water must be sprayed on each muck pile prior to mucking. A 10,000 gallon truck with a front discharge applies approximately 700 gallons to each pile before mucking. It appears that 60 to 70% of this water remains in the muck and is carried out by the trucks. The remainder dissipates into the air or ground.

The road conditions are excellent. This is mainly due to the bedding planes common to sedimentary formations. This provides for high-speed haulage and minimal tire wear.

Ground Support

The limestone is cut in a square pattern leaving a flat roof or back in a competent bedding plane. This makes ground support relatively easy to install and maintain. Three types of rockbolts are used at Maysville: mechanical shell, epoxy, and split set. All bolts are placed with automated equipment made by Fletcher or Joy. The selection of bolts depends on the long-term purpose of the opening. The shell type and split sets are subject to corrosion. As a result, major access ways and highback or benching areas use epoxy bolts. Management is doing extensive market research on roof boltersto find the best machine for their application. A demonstration of a new Joy machine was taking place during our visit.

Scaling is done with three basic machines: A Getman scaler, a French-built scaler and two back-hoes with a tooth mounted instead of a bucket. Of all, the French machine is superior for reliability and speed. The machine is built from the ground up as a mine scaler and has a high availability. Scaling is done after mucking. Upon completion of scaling, the drillino cycle can again be started. Rockbolts can lag behind the workinq face as much as 50 ft. and, therefore, is not necessarily part of the cycle.

Crushing and Material Handling

Dravo uses two types of crushers to reduce the rock to 10 inches minus size. The first type used is a jaw-type crusher used in conjunction with a viberatory screen or "Grizzly". The two jaw crushers installed at Maysville are functional but have basic problems as follows:

(1) An operator is required at all times for frequent hang-ups or minor repairs.

(2) A large amount of fines fall through the grizzly initially causing overloading of the belt.

(3) The equipment is large and requires a great deal of excavation to install.

(4) The moving gear is subject to frequent breakdown.

The second system is the use of Stamler feeder breakers. These simple drum and feeder machines prove very effective for crushing the 18,000 PSI limestone and neatly feeding the belt at a constant rate. They require no operator and have excellent availability. They are semi-mobile and Dravo plans to move them about every six months.

Underground, Dravo uses cable suspension conveyor belts exclusively. The broken and crushed rock is moved from the crushers to an underground surge chamber holding 10,000 tons or one day's production. From the storage area, the rock is conveyed to surface up a slope at 18° on a 42 inch belt. This belt moves an average of 550 ton per hour out of the mine.

Shaft and Slope

As mentioned before, the shaft is 14 ft. in diameter and 980 ft. deep. It is used for man access and ventilation only. The cage is 5 ft. wide by 10 ft. long and 20 ft. high. It has two decks each with a capacity for 20 men. The hoist is a fully automatic friction type using 10 each 3/4 inch diameter ropes in conjunction with a counter-weight. It requires no hoistman and is controlled much like an elevator in a building. There is a great deal of turbulance in the shaft due to some 300,000 cfm of air traveling in the shaft around the limited airspace left by the cage. For safety, the cage has an overspeed device which clamps the steel guide rail in an emergency situation. The cage is equipped with cage controls and a telephone. The shaft is completely dry and utilities are neatly hung in the shaft.

The slope is another story. This functional access way has basic design flaws that, if corrected, would greatly improve its function.

The slope is oriented 18° to horizontal which is maximum grade for conveyor haulage. On one side of the opening is a 42 inch conveyor suspended on chains. On the opposite side is a rail system (36 inch gauge) used in conjunction with a slope hoist to supply materials and equipment for the underground operations. The slope also serves as the ventilation exhaust opening for the mine. Major problem areas are as follows:

(1) The slope bottom was not concreted causing track maintenance problems and difficult conveyor spill clean-up.

(2) The conveyor was placed too close to the wall making idler repair or replacement difficult. The return idlers are frequently buried in spill from the conveyor.

(3) No enough room was left for the slope flat car for large pieces of equipment.

(4) Ground support did not allow for the long-term effects of mine exhaust air on open shale formations.

Despite these problems, the slope serves its function as design but changes in design could reduce long-term maintenance cost and downtime.

Maintenance

During our visit, both the production supervisor and the mine manager stressed the importance of a good maintenance program in efficient mine production. It is not enough to have stand-by equipment available for breakdowns if the manpower is not readily available to repair down equipment. As a result, Dravo-Lime has maintenance people working underground 24 hours a day, 7 days a week. These 43 people are responsible for both repairs and preventative maintenance. Except for major engine overhauls, all repairs are done underground. No equipment is ever returned to surface once placed underground. The shop facilities contain a complete warehouse. This computer-controlled warehouse contains most replacement parts for every piece of underground equipment. No surface storage is used as all new parts arriving on site are immediately sent to the underground warehouse. In addition to the usual shop facilities, a complete hydraulic drill repair shop has been built providing a considerable savings to Dravo.

Ventilation

Ventilation at Dravo-Lime is provided by two Joy 60 inch fans placed underground. These fans are powered by 200 hp motors and supply some 300,000 cfm of ventilation air at 4¼ inches of water gauge. The air is coursed around the mine by brattice seals and supplemental fans. The air finds its own course through the room and pillar network and in some areas ventilation is poor. The shop air becomes extremely dirty towards the end of each shift because it is located in the mine return airway. Dravo-Lime has no one person in charge of ventilation and changes are made as a group decision among supervisors. This is the weakest area observed at the mine. As the working area expands, the mine will have to address this problem.

Organization and Supervision

Underground operations are under the supervision of a production superintendent and a maintenance superintendent, who, in turn, are responsible to the mine manager.

Under the production superintendent are drilling, mucking, ground control and utility crews, each of which have a foreman in charge. These crews work two 8-hour shifts a day from 7:00 a.m. to 3:00 p.m. and 6:00 p.m. to 2:00 a.m. The time gap between shifts allows for the mine air to purge itself of excess diesel exhaust and blast fumes. This time also allows mechanics uninterrupted time to do preventative maintenance on production equipment.

The maintenance department has (4) rotating crews working a 6 and 2 schedule such that each man will work 6 days on and 2 days off; thus, maintaining 24-hour continuous coverage.

The production and maintenance departments are monitored through the use of computers placed underground. This system gives supervisors update information on equipment production, down-time, maintenance schedules, warehouse inventory and consumable consumption. This inexpensive system is the best application of computer technology to mining I have yet seen.

General Comments

The Dravo-Lime Maysville operation is a room and pillar operation designed to produce maximum tonnage in a minimal area. The tons produced per manshift are therefore much greater than can be expected at a nuclear waste repository where the objective is to produce safe stable openings. A great many similarities exist, however, that make the operations at Dravo-Lime of interest in the development of conceptual mine design for N.N.W.S.I.: the equipment and operations are similar if the repository is to be mined conventionally; the rock has similar strengh (15,000 psi vs. 18,000 psi); and the mine uses both a shaft and slope as proposed for the repository.

The Dravo-Lime management was extremely open and informative to both myself and Ken Beall. As a result, I was able to bring back actual data with which to apply to future estimates and studies. I recommend that key people from Sandia visit this operation sometime during the conceptual stage of the N.N.W.S.I. project.

APPENDIX B

Sequence of Underground Mining Operations and Material Handling Systems

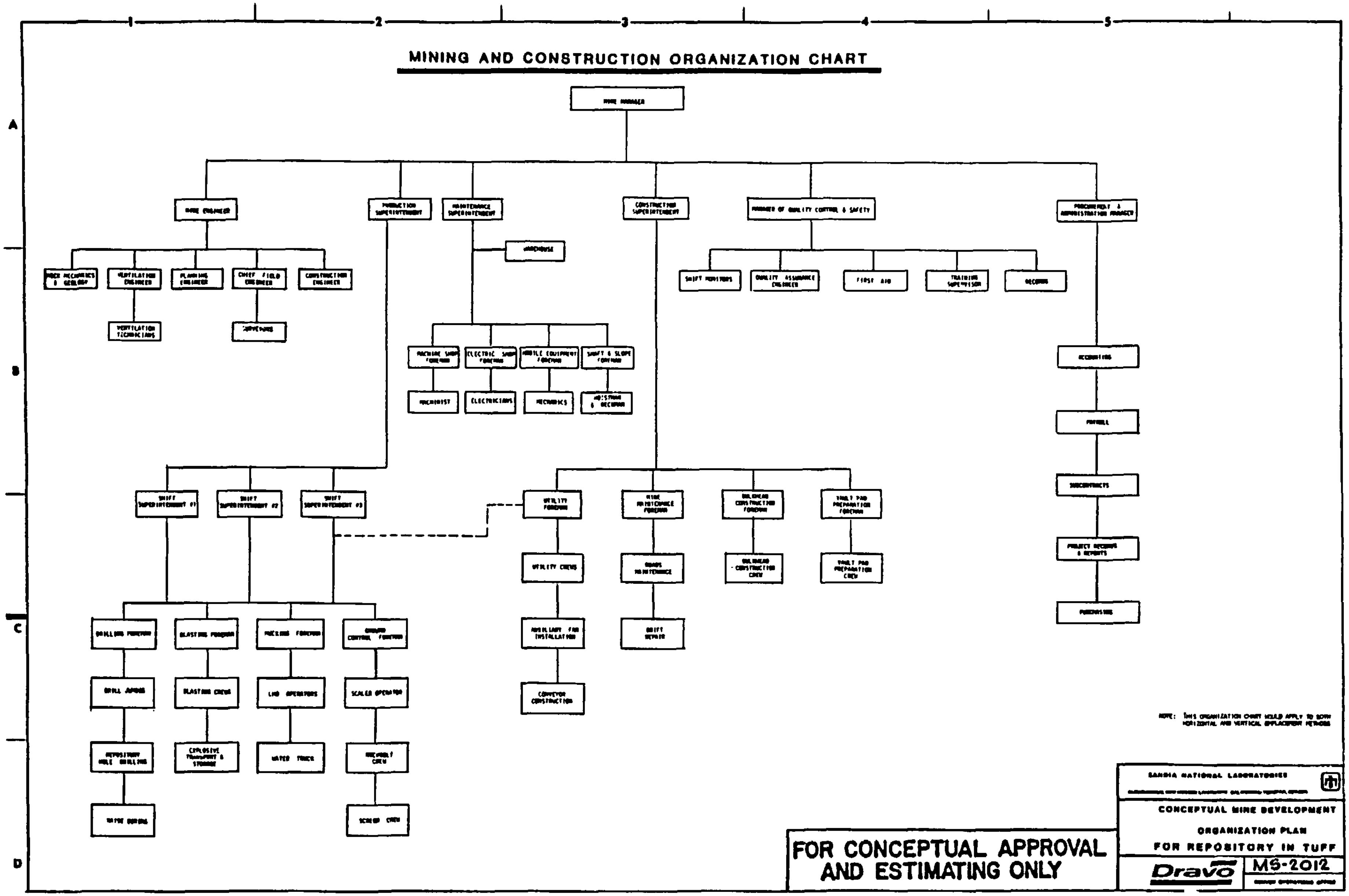

Figure 1. Organization Plan for Mining and Construction Operations

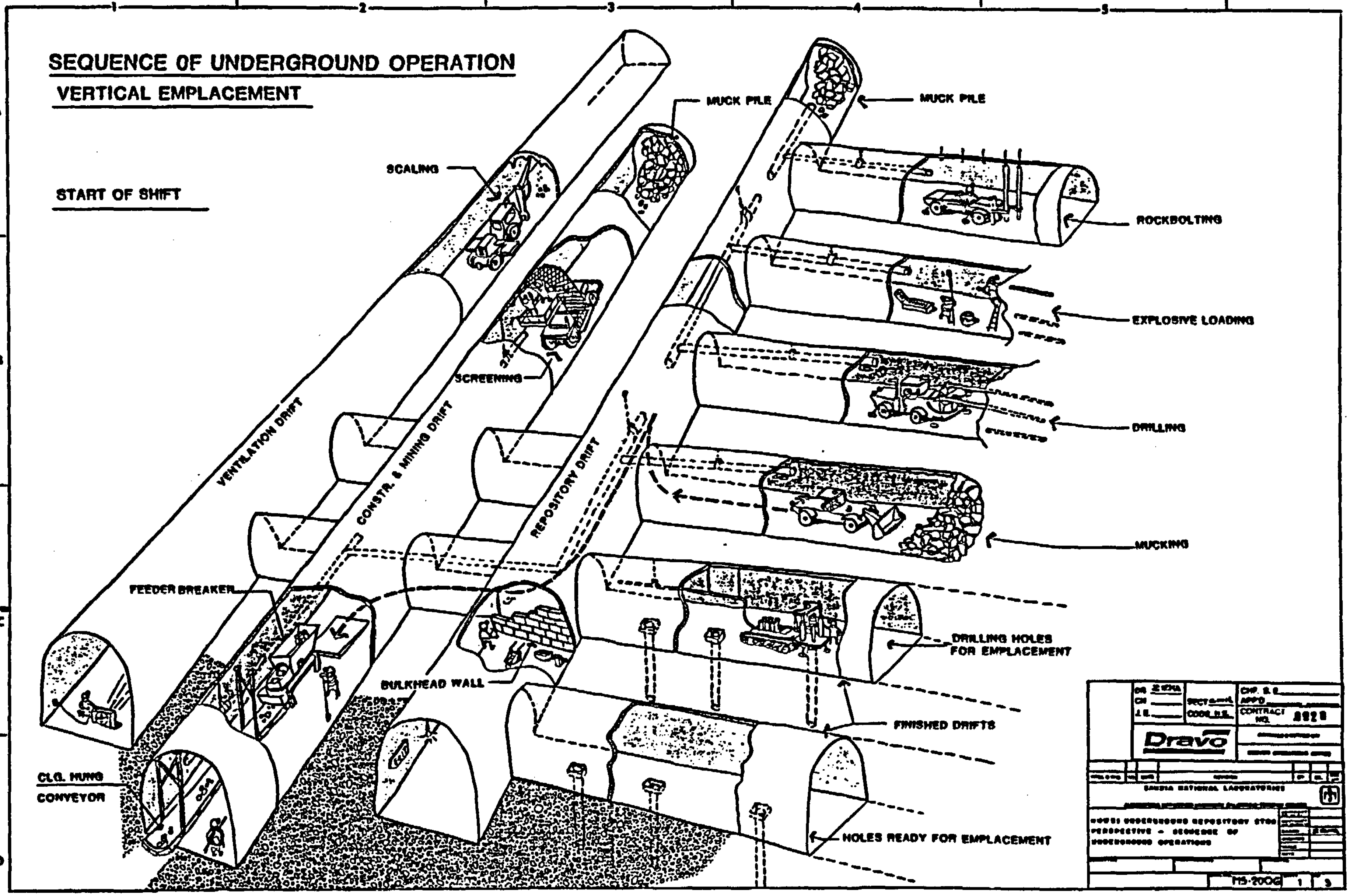

Figure 2. Sequence of Underground Mining Operations in the Vertical Emplacement Method (Start of Shift)

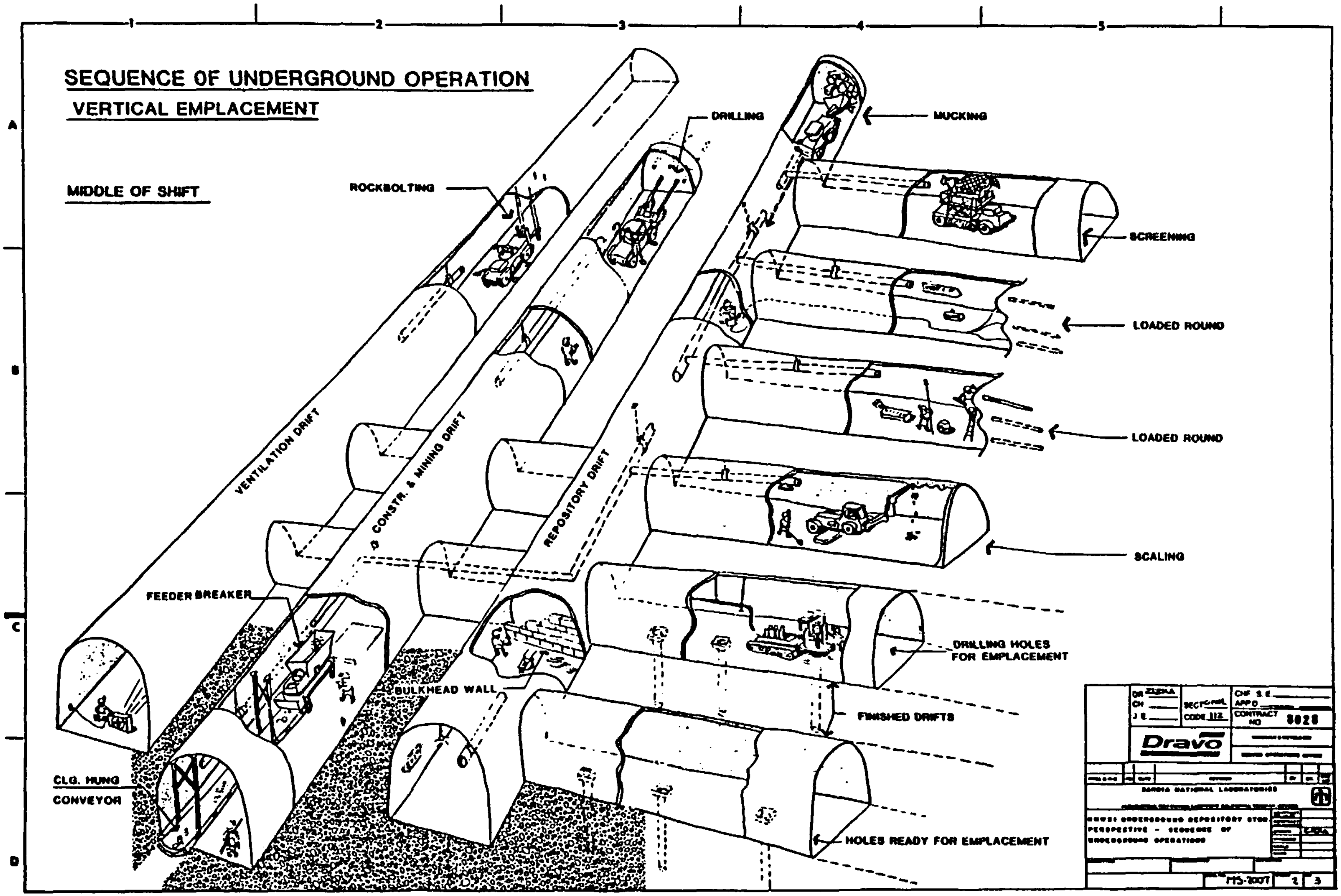

Figure 3. Sequence of Underground Mining Operations in the Vertical Emplacement Method (Middle of Shift)

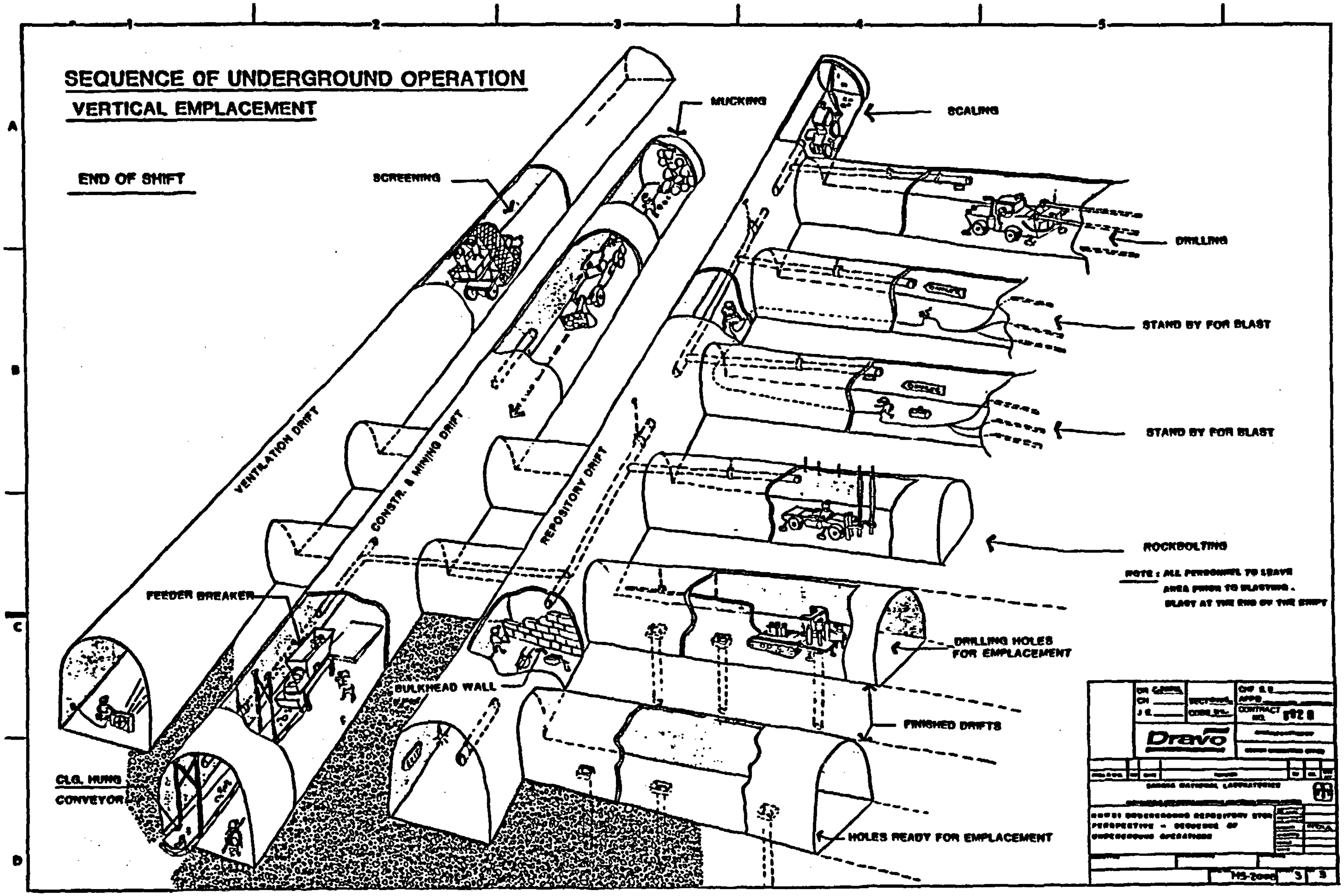

Figure 4. Sequence of Underground Mining Operations in the Vertical Emplacement Method (End of Shift)

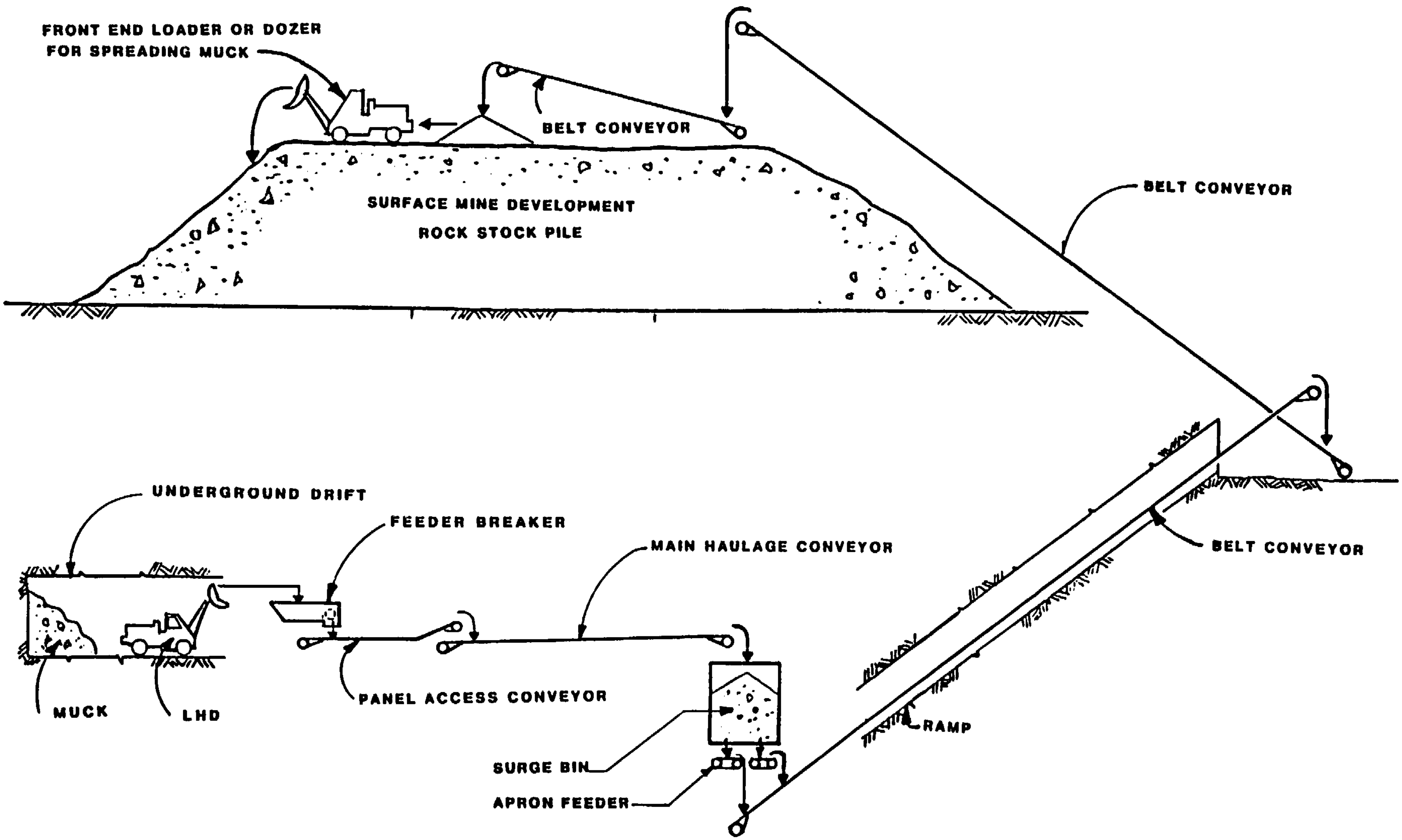

Figure 5. Shaft-Headframe Material Handling System

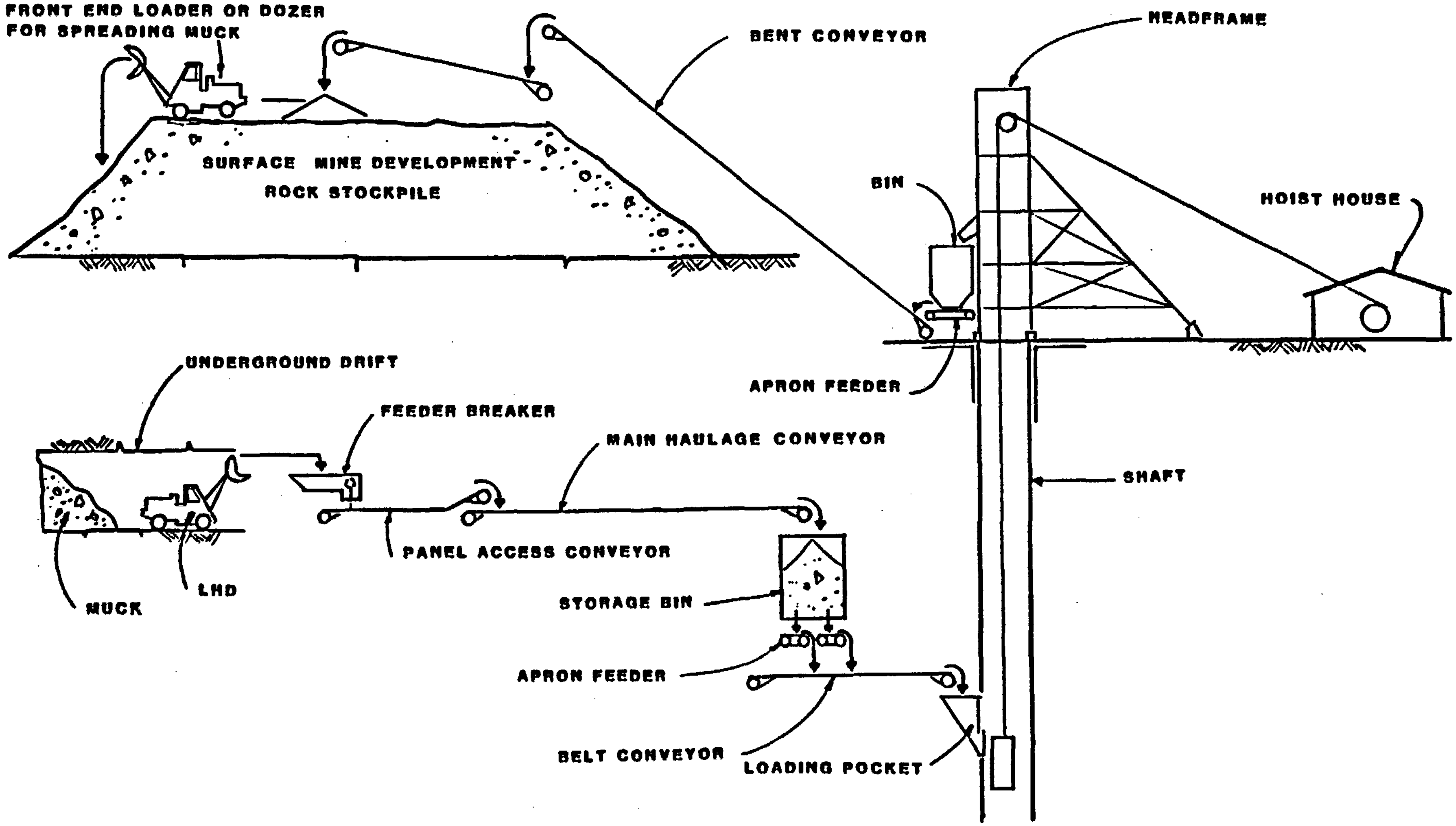

Figure 6. Twenty-Percent Grade Ramp Material Handling System

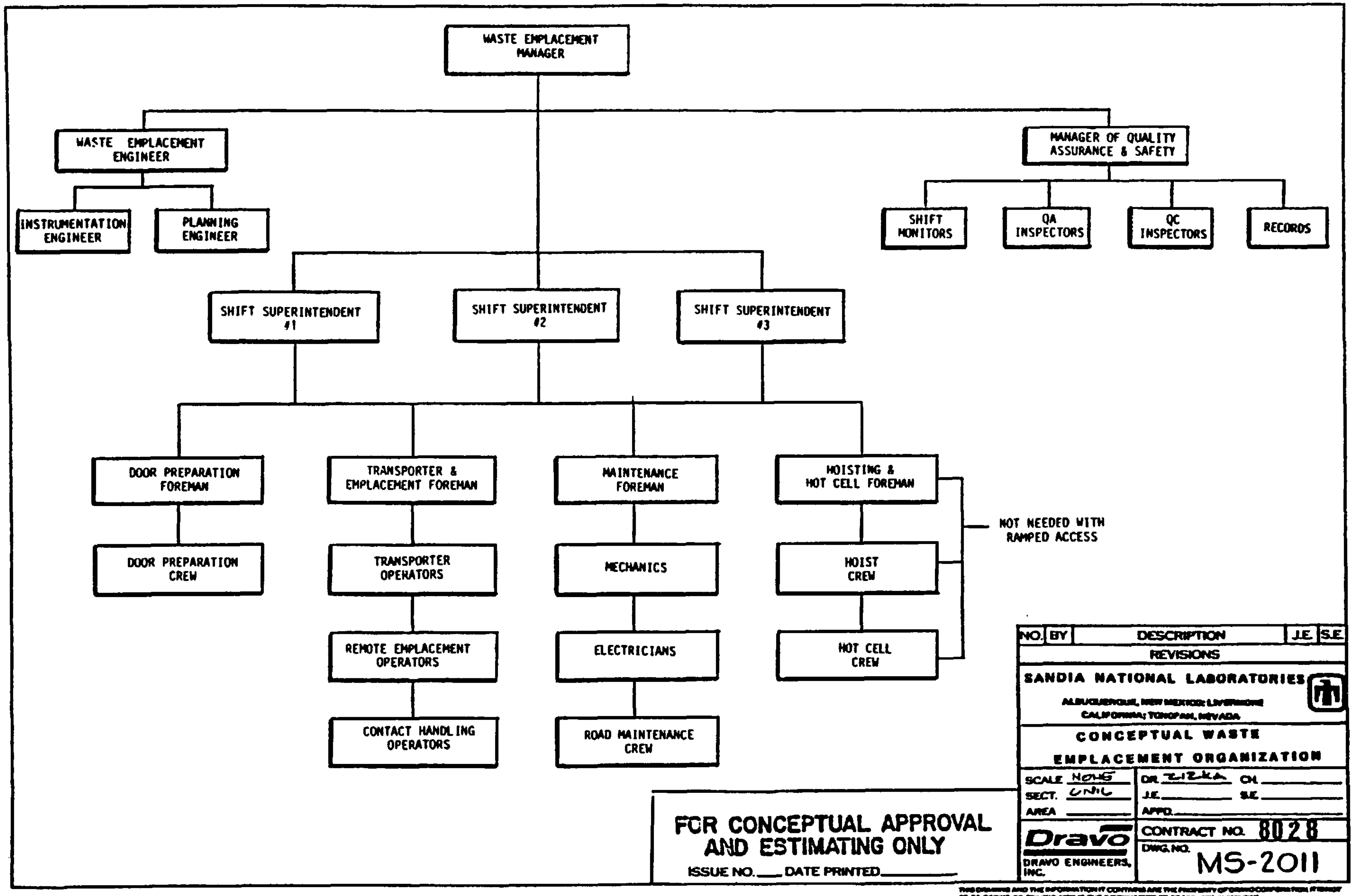

Figure 7. Organization Plan for Waste Emplacement Operations

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