RENEWAL APPLICATION
APPENDIX I2B

SHAFT SEALING CONSTRUCTION PROCEDURES

SHAFT SEALING SYSTEM
COMPLIANCE SUBMITTAL DESIGN REPORT

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Appendix B Abstract

This renewal application appendix describes equipment and procedures used to construct the shaft seals as specified in Renewal Application Appendix I2. Existing or reasonably modified construction equipment is specified, standard mining practices are applied, and a general schedule is provided at the end of this renewal application appendix. This renewal application appendix describes the following activities:

- pre-sealing activities for the sub-surface and surface,
- construction and operation of a multi-deck stage,
- installation of special concrete (sumps, shaft station monoliths, and concrete plugs),
- installation of compacted clay columns,
- emplacement and dynamic compaction of WIPP salt,
- installation of neat asphalt and asphaltic mastic mix,
- grouting of concrete plugs and the country rock behind existing shaft liners,
- removal of portions of the existing shaft liners, and
- emplacement of compacted earthen fill.

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RENEWAL APPLICATION
APPENDIX 12B

SHAFT SEALING CONSTRUCTION PROCEDURES

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I2B1 Introduction

This renewal application appendix describes construction specifications for placement of shaft seal materials. Flexibility is incorporated in construction specifications to facilitate placement of several different material types. Engineering materials used to seal the full length of the shaft include earthen fill, compacted clay, tamped crushed salt, asphalt, concrete, and a combination of concrete and asphalt in concrete-asphalt waterstops. Renewal Application Appendix I2D (Supplemental Information) provides details of the materials. A full-length shaft seal of this type has never before been constructed; however, application of available technology and equipment, standard construction practices, and common materials provides confidence that the system can be placed to satisfy the design requirements.

A primary feature of the construction specification is development of a work platform from which seal materials are placed. Although the proposed multi-deck stage (galloway) proposed here is engineered specifically for shaft sealing operations, it is similar to stages used for construction of shafts. Inherently flexible, the multi-deck stage facilitates several construction methods required for the various materials specified for the shaft seal system. It provides an assembly of a slickline and header for transport of flowable materials from the surface to the placement horizon. A crane device is attached to the base of the stage to facilitate compaction, and an avenue through the stage provides a means to transport bulk material. It is understood that procedures specified here may change during the tens of years preceding construction as a result of equipment development, additional testing, or design changes. Further, it is acknowledged that the construction methods specified are not the only methods that could place the seal materials successfully.

A few assumptions are made for purposes of evaluating construction activities. These assumptions are not binding, but are included to assist discussion of general operational scenarios. For example, four multi-deck stages are specified, one for each shaft. This specification is based on shaft-sinking experience, which indicates that because of the wear encountered, it is advisable to replace rather than rebuild stages. However, much of the equipment on the multi-deck stage is reused. For scheduling purposes, it is assumed that sealing operations are conducted in two of the four shafts simultaneously. The Air Intake and Exhaust Shafts are sealed first, and the Waste and Salt Handling Shafts are sealed last. With this approach, shaft sealing will require about six and a half years, excluding related work undertaken by the Waste Isolation Pilot Plant (**WIPP**) Operating Contractor. Sealing the shafts sequentially would require approximately eleven and a half years. To facilitate discussion of scheduling and responsibilities, it is assumed that sealing operations will be conducted by a contractor other than the WIPP Operating Contractor.

Years from now, when actual construction begins, it is probable that alternatives may be favored. Therefore, construction procedures note alternative methods in recognition that changes are likely and that the construction strategy is sufficiently robust to accommodate alternatives. This Renewal Application Appendix contains both general and very specific information. It begins with a discussion of general mobilization in Section 2. Details of the multi-deck construction stage are provided in Section 3. Section 4 contains descriptions of the construction activities. Information presented here is supplemented by several engineering drawings and sketches contained in Appendix ~~E~~ I2E of the Renewal Application. The topical information and the level of provided detail substantiate the theory that reliable shaft seal construction is possible using available technology and materials.

I2B2 Project Mobilization

The duty descriptions that follow are for discussion purposes. The discussions do not presuppose contractual arrangements, but simply identify tasks necessary for shaft seal construction.

I2B2.1 Subsurface

Prior to initiation of sealing activities, the WIPP Operating Contractor will remove installations and equipment on the repository level. A determination of items removed will be made before construction begins. Such removal would include, but is not limited to, gates and fences at the shaft; equipment such as winches, ventilation fans, pipelines; and communication and power cables. Additionally, the following items will be removed from the shafts:

- cables, counterweights, and sheaves;
- existing waterlines; and
- electrical cables not required for sealing operations.

The following equipment will be stored near the shaft on the repository level by the Sealing Contractor prior to initiation of sealing activities:
a concrete header, hopper, and pump;

- a concrete pump line to distribute concrete; and
- an auxiliary mine fan and sufficient flexible ventilation tubing to reach work areas required for installation of the shaft station concrete monolith.

The subsurface will be prepared adequately for placement of the shaft station monolith. Determination of other preparatory requirements may be necessary at the time of construction.

I2B2.2 Surface

The Operating Contractor will remove surface facilities such as headframes, hoists, and buildings to provide clear space for the Sealing Contractor. Utilities required for sealing activities (e.g., air compressors, water, electrical power and communication lines) will be preserved. The Sealing Contractor will establish a site office and facilities required to support the construction crews, including a change house, lamp room, warehouse, maintenance shop, and security provisions. Locations will be selected and foundations constructed for headframes, multi-deck stage winches, man/equipment hoist, and exhaust fan. A drawing in Renewal Application Appendix ~~E~~

I2E (Sketch E-4) depicts a typical headframe and associated surface facilities. The hoist and winches will be enclosed in suitable buildings; utilities and ventilation ducting will be extended to the shaft collar. The large ventilation fan located near the collar is designed to exhaust air through the rigid ventilation duct, resulting in the movement of fresh air down the shaft. Air flow will be sufficient to support eight workers to the depth of the repository level. The following facilities will be procured and positioned near the shaft collar:

- a concrete batch plant capable of weighing, batching, and mixing the concrete to design specifications;
- a crushing and screening plant to process WIPP salt and local soil;
- an insulated and heated pug mill, asphalt pump, asphalt storage tank, and other auxiliary equipment; and
- pads, silos, and structures to protect sealing materials from the weather.

The Sealing Contractor will construct a temporary structural steel bulkhead over the shaft at the surface. The bulkhead will be sufficiently strong to support the weight of the multi-deck stage, which will be constructed on it. When the multi-deck stage is completed, the headframe will be erected. The headframe (depicted in Renewal Application Appendix ~~E~~ I2E, Sketch E-3) will be built around the multi-deck stage, and a mobile crane will be required during fabrication. When the headframe is completed, cables for hoisting and lowering the multi-deck stage will be installed. Cables will run from the three winches, over the sheaves in the headframe, down and under the sheaves on the multi-deck stage, and up to anchors in the headframe. The headframe will be sufficiently high to permit the multi-deck stage to be hoisted until the lowest component is 3.05 m (10 ft) above surface. This will facilitate slinging equipment below the multi-deck stage and lowering it to the work surface, as well as activities required at the collar during asphalt emplacement.

The multi-deck stage will be lowered to clear the collar, allowing the installation of compressed-air-activated steel shaft collar doors, which will serve as a safety device, permitting safe access to the man cage and bucket, while preventing objects from falling down the shaft. Following installation of these doors, workers will utilize the multi-deck stage to traverse the shaft from the collar to the repository horizon, inspecting it for safety hazards and making any necessary repairs. After this inspection, the multi-deck stage will return to the surface.

I2B2.3 Installation of Utilities

In preparation for placement of shaft seal materials, requisite utilities will be outfitted for operations. The multi-deck stage will descend from the collar to the repository horizon. As added assurance against unwanted water, a gathering system similar to the one currently in place at the bottom of the concrete liner will be installed and moved upward as seal emplacement proceeds. Water collected will be hoisted to the surface for disposal. Additionally, any significant inflow will be located and minimized by grouting. After installation of the water gathering system, the following utilities will be installed from surface to the repository horizon by securely fastening them to the shaft wall:

- 5.1-cm steel waterline with automatic shut-off valves every 60 m;
- 10.2-cm steel compressed-air line;
- power, signal, and communications cables;
- 15.2 cm steel slickline and header; and
- a rigid, cylindrical, ventilation duct, which would range from 107 cm in diameter in the three largest shafts to 91 cm in diameter in the Salt Handling Shaft.

I2B3 Multi-Deck Stage

The multi-deck stage (galloway) provides a work platform from which all sealing operations except placement of asphalt are conducted. The concept of using a multi-deck stage is derived from similar equipment commonly employed during shaft sinking operations. Plan and section views of conceptual multi-deck stages are shown in Renewal Application Appendix ~~E~~ I2E, Sketches E-1 and E-2. The construction decks specified here are modified from typical shaft sinking configurations in two important ways to facilitate construction. Conceptual illustrations of these two modifications are displayed in Figures I2B-1 and I2B-2. Figure I2B-1 illustrates the multi-deck performing dynamic compaction of salt. Figure I2B-2 illustrates the multi-deck stage configured for excavation of the kerf required for the asphalt waterstop in Salado salt.

A device called a polar crane mounted below the lower deck can be configured for either dynamic compaction or salt excavation. The crane can rotate 360º horizontally by actuating its geared track drive. Its maximum rotational speed will be approximately two revolutions per minute. The crane can be controlled manually or by computer (computerized control will swiftly position the tamper in the numerous drop positions required for dynamic compaction). When excavation for the concrete-asphalt waterstops is required, the tamper, electromagnet, and cable used for dynamic compaction will be removed, and a custom salt undercutter will be mounted on the polar crane trolley. Geared drives on the crane, trolley, and undercutter will supply the force required for excavation. In addition to the special features noted above and shown in Figures I2B-1 and I2B-2, the multi-deck stage has the following equipment and capabilities:

- Maximum hoisting/lowering speed is approximately 4.6 m (15 ft) per minute.
- A cable, electromagnet, and tamper will be attached to the polar crane during dynamic compaction. The cylindrical tamper consists of A-36 carbon steel plates bolted together with high-tensile-strength steel bolts. It is hoisted and dropped by the polar crane using the electromagnet. The tamper will be mechanically secured to the polar crane before personnel are allowed under it.

- Range-finding lasers will facilitate the accurate positioning of the multi-deck stage above the work surface and allow the operator to determine when the surface is sufficiently level. The distance indicated by each laser will be displayed on a monitor at the crane control station.

- Flood lights and remotely controlled closed-circuit television equipment will enable the crane operator to view operations below the multi-deck stage on a monitor.

- Fold-out floor extensions that accommodate the variance in shaft diameter between the unlined and lined portions of the shaft will be provided for safety.

- A cutout in each deck, combined with a removable section of the polar crane track, will permit stage movement without removal of the rigid ventilation duct (which is fastened to the shaft wall).

The multi-deck stage is equipped with many of the features found on conventional shaft sinking stages, such as:

- three independent hoisting/lowering cables,

- man and material conveyances capable of passing through the multi-deck stage and accessing the working surface below,

- a jib crane that can be used to service the working surface below,

- removable safety screens and railings, and

- centering devices.

Three sets of double locking devices are provided to secure the multi-deck stage to the shaft wall. A suitable factor of safety for these locking devices is judged to be 4. The area of the grips securing the deck is calculated from static principles:

$$FS = \mu(Co)(A)/W \qquad \text{(B-1)}$$

where:

FS = factor of safety
μ = steel/salt friction coefficient = 0.15 (see Table 20.1 in McClintock and Aragon, 1966; and Van Sambeek, 1988)
Co = compressive strength of WIPP salt, which varies from 172 kg/cm^2 to 262 kg/cm^2 (Van Sambeek, 1988)
W = total vertical weight
A = total gripper pad surface area.

Manipulating the equation to solve for required area, applying a factor of safety of 4, selecting the heaviest work stage (753,832 kg) and the minimum compressive strength value for salt (assuming that the locking pressure equals the minimum compressive strength of salt), the following gripper surface area (*A*) is:

> $A = 4(753{,}832\text{ kg})/0.15(172\text{ kg/cm}^2) = 11{,}416.5\text{ cm}^2$, and each of the six gripper pads would be 1902.8 cm^2.

As designed, each gripper pad area is 2167.2 cm^2, resulting in a factor of safety (**FS**) of 4.56. Additionally, although tension in the hoisting cables is relaxed while the multi-deck stage is in the locked configuration, the cables are still available to hold the work-deck, should the locking devices fail.

I2B4 Placement of Sealing Materials

Construction activities include placement of materials in three basic ways: (1) by slickline (e.g., concrete and asphalt), (2) by compaction (e.g., salt and earthen fill), and (3) by physical placement (e.g., clay blocks). Materials will be placed at various elevations using identical procedures. Because placement procedures generally are identical regardless of elevation, they will be described only once. Where differences occur, they will be identified and described. In general, placement of shaft seal elements is described from bottom to top.

I2B4.1 Concrete

Concrete is used as a seal material for several different components, such as the existing sumps in the Salt Handling Shaft and the Waste Shaft, the shaft station monoliths, concrete plugs, and concrete-asphalt waterstops. Existing sumps are shown in Renewal Application Appendix ~~E~~ I2E, Drawings SNL-007, Sheets 6 and 21. Shaft station monoliths are shown in Drawings SNL-007, Sheets 6, 11, 16, and 21. Concrete plugs are depicted on Drawings SNL-007, Sheets 4, 5, 9, 10, 14, 15, 19, and 20. Lower, middle, and upper concrete-asphalt waterstops are shown in Drawing SNL-007, Sheet 22. Construction material for all concrete members will be Salado Mass Concrete (**SMC**).

As specified, all SMC will be mixed on surface to produce a product possessing the characteristics defined in Renewal Application Appendix ~~A~~ I2A. Concrete will be transferred to its placement location within the shaft via slickline and header. The slickline (shown in Figure I2B-1) is a steel pipe fastened to the shaft wall. Vertical drops as great as 656 m to the repository horizon are required. Such concrete transport and construction are common in mining applications. For example, a large copper mine in Arizona is placing concrete at a depth of 797 m using this procedure. A header attached to the bottom of the slickline is designed to absorb kinetic energy generated by the falling material. The header, a steel pipe slightly larger in diameter than the slickline and made of thicker steel, diverts the flow 45°, absorbing most of the impact. Because the drop generates considerable force, the header will be securely supported by a reinforced steel shelf bolted to the shaft wall. A flexible hose, in sections approximately 3 m long and joined by quick-connect fittings, will be attached to the header.

I2B4.1.1 Shaft Station Monolith

Construction of the shaft station monoliths is preceded by filling two existing sumps with SMC. Initially, sufficient hose will be used to convey the concrete to the bottom of the sump. The discharge will remain below the concrete surface during placement to minimize air entrainment. Sections of hose will be withdrawn and removed as the SMC rises to the floor of the repository horizon in a continuous pour. Subsequent to filling the sump, arrangements will be made to place the concrete monolith.

A small mine fan will be located above the rigid suction-duct inlet to ensure a fresh air base. Masonry block forms will be constructed at the extremities of the shaft station monolith in the drifts leading from the station. Temporary forms, partially filling the opening, will be erected at the shafts to facilitate the placement of the outermost concrete. These temporary forms will permit access necessary to ensure adequate concrete placement. SMC will be transported via the slickline to the header, which will discharge into a hopper feeding the concrete pump, and the pump will be attached to the pumpcrete line. The pumpcrete line, suspended in cable slings near the back of the drifts, will be extended to the outer forms. A flexible hose, attached to the end of the pumpcrete line, will be used by workers to direct emplacement. The pumpcrete line will be withdrawn as emplacement proceeds toward the shaft.

When the concrete has reached the top of the temporary forms, they will be extended to seal the openings completely, and two 5-cm-diameter polyvinyl chloride (**PVC**) pipes will be incorporated in the upper portion of each form. Both pipes will be situated in a vertical plane oriented on the long axis of the heading and inclined away from the station at approximately 70º to the horizontal. The upper end of the top pipe will extend to just below the back, and the upper end of the lower pipe will be located just below that of the top pipe. SMC will be injected through the lower pipe until return is obtained from the upper pipe, ensuring that the heading has been filled to the back. The header will then be moved to a position in the shaft above the designed elevation at the top of the shaft station monolith and supported by a bracket bolted to the shaft wall. After the outer concrete has achieved stability, the temporary interior forms may be removed. Equipment no longer required will be slung below the multi-deck stage and hoisted to surface for storage and later use. The station and shaft will be filled to design elevation with concrete via the slickline, header, and flexible hose. The slickline is cleaned with spherical, neoprene swabs (“pigs”) that are pumped through the slickline, header, and hose.

I2B4.1.2 Concrete-Asphalt Waterstops

Lower, middle, and upper concrete-asphalt waterstops in a given shaft are identical and consist of two SMC sections separated by an asphalt waterstop. Before the bottom member of the lower concrete component is placed, the multi-deck stage will be raised into the headframe; the polar crane will be mounted below the lower deck; and the salt undercutter will be mounted on the crane trolley. The multi-deck stage will then return to the elevation of the concrete component. Two undercutter bars will be used to make the necessary excavations for upper, middle, and lower asphalt-concrete waterstops and the concrete plug above the Salado ~~Formation~~. Notches for the plugs will be excavated using a short, rigid cutter bar (length less than half the radius). The kerf for the asphalt waterstop will be excavated using a long cutter bar that can excavate the walls to a depth of one shaft radius. These operations will be conducted as required as seal placement proceeds upward.

The lower concrete member (and all subsequent concrete entities) will be placed via the slickline, header, and flexible hose, using the procedure outlined for the shaft station monolith. Construction of vertical shaft seals provides the ideal situation for minimizing interface permeability between the rock and seal materials. Concrete will flow under its own weight to provide intimate contact. A tight cohesive interface was demonstrated for concrete in the small-scale seal performance tests (**SSSPTs**). The SSSPT concrete plugs were nearly impermeable without grouting. However, interface grouting is usually performed in similar construction, and it will be done here in the appropriate locations.

I2B4.1.3 Concrete Plugs

An SMC plug, keyed into the shaft wall, is situated a few meters above the upper Salado contact in the Rustler ~~Formation~~. A final SMC plug is located a few meters below surface in the Dewey Lake ~~Redbeds~~. This plug is emplaced within the existing shaft liner using the same construction technique employed for the concrete-asphalt waterstops.

I2B4.2 Clay

I2B4.2.1 Salado and Rustler Compacted Clay Column

Blocks of sodium bentonite clay, precompacted to a density of 1.8 to 2.0 g/cm^3, will be the sealing material. This density has been achieved at the WIPP using a compaction pressure of 492.2 kg/cm^2 in a machine designed to produce adobe blocks (Knowles and Howard, 1996). Blocks are envisioned as cubes, 20.8 cm on the edge, weighing approximately 18 kg, a reasonable weight for workers to handle. The bentonite blocks will be compacted at the WIPP in a new custom block-compacting machine and will be stored in controlled humidity to prevent desiccation cracking. Blocks will be transported from surface in the man cage, which will be sized to fit through the circular “bucket hole” in the multi-deck stage. The conveyance will be stacked with blocks to a height of approximately 1.8 m.

Installation will consist of manually stacking individual blocks so that all interfaces are in contact. Block surfaces will be moistened with a spray of potable water as the blocks are placed to initiate a minor amount of swelling, which will ensure a tight fit and a decrease in permeability. Peripheral blocks will be trimmed to fit irregularities in the shaft wall and placed as close to the wall as possible. Trimmed material will be manually removed with a vacuum. Dry bentonite will be manually tamped into remaining voids in each layer of blocks. This procedure will be repeated throughout the clay column. The multi-deck stage will, in all cases, be raised and utilities removed to the surface as emplacement of sealing materials proceeds upward.

Dynamic compaction construction is an alternative method of clay emplacement that could be considered in the detailed design. Dynamic compaction materials being considered are:

- sodium bentonite/fine silica sand, and
- highly compressed bentonite pellets.

Boonsinsuk et al. (1991) developed and tested a dynamic (drop hammer) method for a relatively large diameter (0.5-m) hole, simulated with a steel cylinder, that gave very good results on 1 : 1 dry mass mixtures of sodium bentonite and sand, at a moisture content of 17% to 19%. The alternatives have the advantages of simplifying emplacement.

I2B4.3 Asphalt

Asphalt, produced as a distillate of petroleum, is selected as the seal material because of its longevity, extremely low permeability, history of successful use as a shaft lining material, and its ability to heal if deformed. Shielded from ultraviolet radiation and mixed with hydrated lime to inhibit microbial degradation, the longevity of the asphalt will be great. Emplaced by tremie line at the temperature specified, the material will be fluid and self-leveling, ensuring complete contact with the salt.

Construction of an asphalt column using heated asphalt will introduce heat to the surrounding salt. The thermal shock and heat dissipation through the salt has not been studied in detail. Performance of the asphalt column may be enhanced by the introduction of the heat that results from acceleration of creep and healing of microfractures. If, upon further study, the thermomechanical effects are deemed undesirable or if an alternative construction method is preferred at a later date, asphalt can readily be placed as blocks. Asphalt can “cold flow” to fill gaps, or the seams between blocks can be filled with low-viscosity material.

I2B4.3.1 Concrete-Asphalt Waterstops

Electrically insulated, steel grated flooring will be constructed over the shaft at the surface. A second, similar flooring will be built in the shaft 3 m below the first. These floors will be used only during the emplacement of asphalt and asphaltic mastic mix (**AMM**) and will be removed at all other times. A 12.7 cm ID/14 cm OD, 4130 steel pipe (tremie line) in 3 m lengths will be electrically equipped for impedance heating, then insulated and suspended in the shaft from slips (pipe holding devices) situated on the upper floor. The tremie line cross-sectional area is smallest at the shoulder of the top thread, where tensional yield is 50,000 kg; the line weight is 20.8 kg/m. Heavier weights are routinely suspended in this manner in the petroleum and mining industries.

Neat, AR-4000-graded petroleum-based asphalt cement will be the sealing material for asphalt waterstops. Neat asphalt from the refinery will be delivered to the WIPP at approximately 80ºC in conventional, insulated refinery trucks and pumped into a heated and insulated storage tank located near the shaft. The multi-deck stage will be hoisted into the headframe and mechanically secured for safety. Asphalt, heated to 180ºC ±5º, will be pumped down the shaft to the fill elevation through the heated tremie line. Viscosity of the neat asphalt for the waterstops will be sufficiently low to allow limited penetration of the Disturbed Rock Zone (**DRZ**). Installation of asphalt in each of the concrete-waterstops is identical.

As the pipe is lowered, workers on the lower deck will attach the wiring required for heating circuits and apply insulation. Workers on the top deck will install flanged and electrically insulated couplings as required (the opening in the slip bowl will be large enough to permit the passage of these couplings). Properly equipping and lowering the pipe should progress at the rate of one section every 10 minutes. The lower asphalt waterstop requires approximately 607 m of pipe for a casing weight of 12,700 kg. Additionally, electrical wire and insulation will weigh about 7250 kg for a total equipped tremie line weight of 20,000 kg. Therefore, the safety factor for the tremie line is 50,000 kg/20,000 kg, or 2.5.

To minimize air entrainment, the lower end of the tremie line will be immersed as much as 1 m during hot asphalt emplacement. Therefore, the lower 3 m of casing will be left bare (to simplify cleaning when emplacement has been completed).

Initially the tremie line will be lowered until it contacts the concrete plug (immediately underlying the excavation for the waterstop) and then raised approximately 0.3 m. Asphalt emplacement will proceed as follows:

- The impedance heating system will be energized, heating the tremie line to 180ºC ±5º, and the asphalt in the storage tank will be heated to approximately 180ºC ±5º.
- Heated, neat asphalt will be pumped down the tremie line at a rate approximating 13 L/min. This low rate will ensure that the asphalt flows across the plug from the insertion point, completely filling the excavation and shaft to the design elevation.
- The tremie line will be raised 3 m and cleaned by pumping a neoprene swab through it with air pressure. Impedance heating will be stopped, and the line will be allowed to cool. When cool, the line will be hoisted, stripped, cleaned, disassembled, and stored for future use.

Sealing operations will be suspended until the air temperature at the top of the asphalt has fallen to approximately 50ºC for the comfort of the workers when they resume activity at the fill horizon. Temperature will be determined by lowering a remotely read thermometer to an elevation approximately 3 m above the asphalt at the center of the shaft. The temperature of the asphalt at the center of the shaft will be 50ºC in about a month, but active ventilation should permit work to resume in about two weeks (see calculations in Appendix D ~~of Appendix I2~~ in the Supplemental Information).

When sufficient cooling has occurred, workers will descend in the multi-deck stage and cover the hot asphalt with an insulating and structural material such as fiber-reinforced shotcrete, as illustrated in Figure I2B-3. To accomplish this, they will spray cementitious shotcrete containing fibrillated polypropylene fibers (for added tensional strength), attaining a minimum thickness of approximately 0.6 m.

I2B4.3.2 Asphaltic Mastic Mix Column

Asphaltic mastic mix ~~(AMM)~~ for the column will be prepared on surface in a pug mill. Viscosity of the AMM can be tailored to provide desired properties such as limited migration into large fractures.

- AMM will be prepared by mixing the ingredients in the pug mill, which has been heated to 180ºC ±5º. The mix will be pumped from the pug mill through the tremie line to the emplacement depth. AMM is self-leveling at this temperature, and its hydrostatic head will ensure intimate contact with the shaft walls.

- Pumping rate will be approximately 200 L/min for efficiency, because of the larger volume (approximately 1,224,700 L in the Air Intake Shaft). To facilitate efficient emplacement and avoid air entrainment, the tremie line will not be shortened until the mix has filled 6 vertical meters of the shaft. Back pressure (approximately 0.84 kg/cm^2) resulting from 6 m of AMM above the discharge point will be easily overcome from surface by the hydraulic head.

After 6 vertical meters of AMM have been placed:

- Impedance heating current will be turned off and locked out (the hot line will drain completely).

- To prevent excessive back pressure resulting from AMM above the insertion point, the line will be disconnected from the pump and hoisted hot. Two sections will be stripped, removed, cleaned with a "pig," and stacked near the shaft.

- Electrical feed will be adjusted (because of the decreased resistance of the shortened line).

- The tremie line will be reconnected to the pump.

- The impedance heating system will be energized.

- When the temperature of the line has stabilized at 180ºC ±5º, pumping will resume.

This procedure will be followed until the entire column, including the volume computed to counteract 0.9 m of vertical shrinkage (calculations in Appendix ~~I2~~D in the Supplemental Information), has been placed. The line will be disconnected from the pump and cleaned by pumping "pigs" through it with air pressure. It will then be hoisted, stripped, removed in 3 m sections, and stacked on surface for reuse.

Sealing operations will be suspended following removal of the tremie line, and ventilation will be continuous to speed cooling. The column will shrink vertically but maintain contact with the shaft walls as it cools. When the air temperature at 3 m above the asphalt has cooled sufficiently, workers will descend on the multi-deck stage and cover the hot asphalt with fibercrete as described for the concrete-asphalt waterstop (Section B4.3.1) and illustrated in Figure I2B-3.

Note: Near the top of the Salado ~~Formation~~, portions of the concrete liner key, chemical seal rings, and concrete and steel shaft liners will be removed. Liner removal will occur before emplacement of AMM. For safety, exposed rock will be secured with horizontal, radial rock bolts and cyclone steel mesh. A range-finding device, fastened to the shaft wall approximately 3 m above the proposed top of the asphaltic column, will indicate when the hot AMM reaches the desired elevation. A remotely read thermometer, affixed to the shaft wall approximately 2 m above the proposed top of the column, will show when the air temperature has fallen sufficiently to resume operations. The intake of the rigid ventilation duct will be positioned approximately 3m above the proposed top of the column, and ventilation will be continuous throughout emplacement and cooling of the asphaltic column. After the multi-deck stage has been hoisted into the headframe and mechanically secured for safety, emplacement of AMM will proceed.

I2B4.4 Compacted Salt Column

Crushed, mine-run salt, dynamically compacted against intact Salado salt, is the major long-term shaft seal element. As-mined WIPP salt will be crushed and screened to a maximum particle dimension of 5 mm. The salt will be transferred from surface to the fill elevation via the slickline and header. A flexible hose attached to the header will be used to emplace the salt, and a calculated weight of water will be added. After the salt has been nominally leveled, it will be dynamically compacted. Dynamic compaction consists of compacting material by dropping a tamper on it and delivering a specified amount of energy. The application of three times Modified Procter Energy (**MPE**) to each lift (one MPE equals 2,700,000 Joules/m^3) will result in compacting the salt to 90% of the density of in-place rock salt.

Approximately 170 vertical meters of salt will be dynamically compacted. Dynamic compaction was validated in a large-scale demonstration at Sandia National Laboratories during 1995. As-mined WIPP salt was dynamically compacted to 90% density of in-place rock salt in a cylindrical steel chamber simulating the Salt Handling Shaft (Ahrens and Hansen, 1995). Depth of compaction is greater than that achieved by most other methods, allowing the emplacement of thicker lifts. For example, dropping the 4.69 metric ton tamper 18 m (as specified below) results in a compaction depth of approximately 4.6 m, allowing emplacement of lifts 1.5 m high. Most other compaction methods are limited to lifts of 0.3 m or less. Lift thickness will be increased and drop height decreased for the initial lift above the concrete plug at the base of the salt column to ensure that the concrete is not damaged. Drop height for the second and third lifts will be decreased as well. Although the tamper impact is thereby reduced, three MPE will be delivered to the entire salt column.

If lifts are 1.5 m thick, the third lift below the surface will receive additional densification during compaction of overlying lifts, and this phenomenon will proceed up the shaft. Construction will begin by hoisting the multi-deck stage to the surface and attaching the cable, electromagnet, and tamper to the hoist on the polar crane. The multi-deck assembly will be lowered to the placement elevation, and moisture content of the crushed and screened salt will be calibrated. Then the salt will be conveyed at a measured rate via a weighbelt conveyor to a vibratorequipped hopper overlying the 15.2 cm ID slickline. The salt will pass down the slickline and exit a flexible hose connected to the header. A worker will direct the discharge so that the upper surface of the lift is nominally level and suitable for dynamic compaction. A second worker will add potable water, in the form of a fine spray, to the salt as it exits the hose. Water volume will be electronically controlled and coordinated with the weight of the salt to achieve the desired moisture content.

The initial lift above the SMC will be 4.6 m, and drop height will be 6 m. This increased lift thickness and reduced drop height are specified to protect the underlying SMC plug from damage and/or displacement from tamper impact. Compaction depth for a drop height of 6 m is approximately 3.7 m. Ultimately, the tamper will be dropped six times in each position, resulting in a total of 132 drops per lift in the larger shafts. The drop pattern is shown in Figure I2B-4. A salt lift 1.5 m high will then be placed and leveled. Following compaction of the initial lift, the multi-deck stage will be positioned so the base of the hoisted tamper is 10 m above the surface of the salt.

The multi-deck stage will then be secured to the shaft walls by activating hydraulically powered locking devices. Hydraulic pressure will be maintained on these units when they are in the locked position; in addition, a mechanical pawl and ratchet on each pair will prevent loosening. The safety factor for the locking devices has been calculated to be approximately 4.5. After locking, tension in the hoisting cables will be relaxed, and centering rams will be activated to level the decks. Prior to positioning the stage, tension will be applied to the hoisting cables; the centering rams will be retracted; and the locking devices will be disengaged.

The work deck will be hoisted until the base of the retracted tamper is 23 m above the surface of the salt, where it will be locked into position and leveled as described above. This procedure, repeated throughout the salt column, allows emplacement and compaction of three lifts (1.5 m thick) per multi-deck stage move. Depth of compaction for a drop height of 18 m is approximately 4.6 m. Therefore, the third lift below the fill surface will receive a total of 9 MPE (274,560 m kg/m^3), matching the energy applied in the successful, large-scale demonstration.

The compactive effect expands laterally as it proceeds downward from the base of the tamper and will effectively compact the salt into irregularities in the shaft wall, as demonstrated in the large-scale demonstration. Although other techniques could be used, dynamic compaction was selected because it is simple, can be used in the WIPP shafts, and has been demonstrated (Hansen and Ahrens, 1996).

The tamper will be dropped from the hoisted position by turning off the power to the electromagnet. Immediately upon release, the crane operator will "chase" the tamper by lowering the electromagnet at twice hoisting speed; the magnet will engage the tamper, allowing it to be hoisted for the subsequent drop. Initially, the tamper will be dropped in positions that avoid impact craters caused by preceding drops. The surface will then be leveled manually and the tamper dropped in positions omitted during the previous drop series.

Experience gained during the large-scale salt compaction demonstration indicated that a considerable volume of dust is generated during the emplacement of the salt, but not during dynamic compaction. However, because the intake of the rigid vent duct is below the multi-deck stage, workers below the stage will wear respirators during emplacement. They will be the only workers affected by dust during dynamic compaction.

The Air Intake Shaft will require 22 drop positions (Figure I2B-4). Application of one MPE requires six drops in each position, for a total of 132 drops per lift. Three MPE, a total of 396 drops per lift, will be applied to all salt. After each compaction cycle, the salt surface will be leveled manually and the tamper will be dropped in positions omitted in the preceding drop series. Two lifts, each 1.8 m high, will then be sequentially placed, leveled, and compacted with two MPE, using a 6 m drop height.

Dynamic compaction ensures a tight interface. Salt compacted during the large-scale dynamic compaction demonstration adhered so tenaciously to the smooth interior walls of the steel compaction chamber that grinders with stiff wire wheels were required for its removal.

I2B4.5 <u>Grout</u>

Ultrafine sulfate-resistant cementitious grout (Ahrens et al., 1996) is selected as the sealing material. Specifically developed for use at the WIPP, and successfully demonstrated in an in situ test, the hardened grout has a permeability of 1×10^{-21} m^2. It has the ability to penetrate fractures smaller than 6 microns and is being used for the following purposes:

- to seal many of the microfractures in the DRZ and ensure a tight interface between SMC and the enclosing rock, and
- to solidify fractured rock behind existing concrete shaft liners, prior to removal of the liner (for worker safety).

The interface between concrete plugs in the Salado ~~Formation~~ (and one in the Rustler ~~Formation~~, a short distance above the Salado) will be grouted. A 45º downward-opening cone of reverse circulation diamond drill holes will be collared in the top of the plugs, drilled in a spin pattern (see Figure I2B-5), and stage grouted with ultrafine cementitious grout at 3.5 kg/cm^2 below lithostatic pressure. Stage grouting consists of:

- drilling and grouting primary holes, one at a time;
- drilling and grouting secondary holes, one at a time, on either side of the primary holes that accepted grout; and
- (if necessary) drilling and grouting tertiary holes on either side of secondary holes that accepted grout.

Note: For safety, all liner removal tasks will be accomplished from the bottom deck. In areas where the steel liner is removed, it will be cut into manageable pieces with a cutting torch and hoisted to the surface for disposal. Mechanical methods will be employed to clean and roughen the existing concrete shaft liner before placing the Dewey Lake SMC plug in the shafts.

The work sequence will start 3 m below the lower elevation of liner removal. A 45° upward-opening cone of grout injection holes, drilled in a "spin" pattern (Figure I2B-6), will be drilled to a depth subtending one shaft radius on a horizontal plane. These holes will be stage grouted as described in Section 4.5. Noncoring, reverse circulation, diamond drill equipment will be used to avoid plugging fractures with fine-grained diamond drill cuttings. Ultrafine cementitious grout will be mixed on the surface, transferred via the slickline to the upper deck of the multi-deck stage, and injected at 3.5 kg/cm^2 gage below lithostatic pressure to avoid hydrofracturing the rock. Grout will be transferred in batches, and after each transfer, a "pig" will be pumped through the slickline and header to clean them. Grouting will proceed upward from the lowest fan to the highest. Recent studies conducted in the Air Intake Shaft (Dale and Hurtado, 1996) show that this hole depth exceeds that required for complete penetration of the ~~Disturbed Rock Zone (DRZ)~~ DRZ. Maximum horizontal spacing at the ends of the holes will be 3 m.

The multi-deck stage will then be raised 3 m and a second fan, identical to the first, will be drilled and grouted. This procedure will continue, with grout fans 3 m apart vertically, until the highest fan, located 3 m above the highest point of liner removal, has been drilled and grouted. Ultrafine cementitious grout was observed to penetrate more than 2 m in the underground grouting experiment conducted at the WIPP in Room L-3 (Ahrens and Onofrei, 1996).

When grouting is completed, the multi-deck stage will be lowered to the bottom of the liner removal section and a hole will be made through the concrete liner. This hole, approximately 30 cm in diameter, will serve as "free-face" to which the liner will be broken. Similar establishment and utilization of free face is a common practice in hard rock mining (e.g., the central drill hole in a series drilled into the rock to be blasted is left empty and used as free-face to which explosives in adjacent holes break the rock). Radial, horizontal percussion holes will be drilled on a 30-cm grid (or less, if required), covering the liner to be removed. Hydraulic wedges, activated in these holes, will then break out the liner, starting adjacent to the free face and progressing away from it, from the bottom up. Broken fragments of the concrete liner will fall to the fill surface below.

A mucking "claw," suspended from the trolley of the polar crane, will collect the broken concrete and place it in the bucket for removal to the surface. As many as three buckets can be used to speed this work.

I2B4.6 Compacted Earthen Fill

Local soil, screened to a maximum particle dimension of 13 mm, will be placed and compacted to inhibit the migration of surficial water into the shaft cross section. Such movement is further decreased by a 12-m high SMC plug at the top of the Dewey Lake ~~Redbeds~~.

I2B4.6.1 Lower Section

Emplacement of the compacted earthen fill will proceed as follows:

- Moisture content of the screened soil will be determined.
- The soil will then be transferred via the slickline, header, and flexible hose from surface to the fill elevation. The moisture content optimal for compaction will be achieved using the same procedure as described for compacted salt (Section B4.4). The soil will be emplaced in lifts 1.2 m high (depth of compaction is approximately 3.7 m) and dynamically compacted using a drop height of 18.3 m.
- The fill will be dynamically compacted until its hydraulic conductivity to water is nominally equivalent to that of the surrounding formation.

This procedure will continue until the lower section has been emplaced and compacted. Care will be exercised at the top of the column to ensure that all soil receives sufficient compaction.

I2B4.6.2 Upper Section

The upper section contains insufficient room to employ dynamic compaction. Therefore the screened soil, emplaced as described above, will be compacted by vibratory-impact sheepsfoot roller, vibratory sheepsfoot roller, or a walk-behind vibratory-plate compactor. Because of the limited compaction depth of this equipment, lifts will be 0.3 m high. The top of the fill will be coordinated with the WIPP Operating Contractor to accommodate plans for decommissioning surface facilities and placing markers.

I2B4.7 Schedule

Preliminary construction schedules are included on the following pages. The first schedule is a concise outline of the total construction schedule. It is followed by individual schedules for each shaft. The first schedule in each shaft series is a truncated schedule showing the major milestones. The truncated schedules are followed by detailed construction schedules for each shaft. These schedules indicate that it will take approximately six and a half years to complete the shaft sealing operations, assuming two shafts are simultaneously sealed.

~~I2B5 List of~~ References

Ahrens, E.H., and F.D. Hansen. 1995. *Large-Scale Dynamic Compaction Demonstration Using WIPP Salt: Fielding and Preliminary Results*. SAND95-1941. Albuquerque, NM: Sandia National Laboratories. (Copy on file in the Sandia WIPP Central Files, Sandia National Laboratories, Albuquerque, NM [SWCF] as WPO31104.)

Ahrens, E.H., and M. Onofrei. 1996. "Ultrafine Cement Grout for Sealing Underground Nuclear Waste Repositories," *2nd North American Rock Mechanics Symposium (NARMS 96), Montreal, Quebec, June 19-21, 1996*. SAND96-0195C. Albuquerque, NM: Sandia National Laboratories. (Copy on file in the SWCF as WPO31251.)

Ahrens, E.H., T.F. Dale, and R.S. Van Pelt. 1996. *Data Report on the Waste Isolation Pilot Plant Small-Scale Seal Performance Test, Series F Grouting Experiment*. SAND93-1000. Albuquerque, NM: Sandia National Laboratories. (Copy on file in the SWCF as WPO37355.)

Boonsinsuk, P., B.C. Pulles, B.H. Kjartanson, and D.A. Dixon. 1991. "Prediction of Compactive Effort for a Bentonite-Sand Mixture," *44th Canadian Geotechnical Conference, Preprint Volume, Calgary, Alberta, September 29-October 2, 1991.* Paper No. 64. Waterloo, Ontario: Canadian Geotechnical Society. Pt. 2, 64/1 through 64/12. (Copy on file in the SWCF.)

Dale, T., and L.D. Hurtado. 1996. "WIPP Air-Intake Shaft Disturbed-Rock Zone Study," *4th International Conference on the Mechanical Behavior of Salt, Montreal, Quebec, June 17-18, 1996*. SAND96-1327C. Albuquerque, NM: Sandia National Laboratories. (Copy on file in the SWCF.)

Hansen, F.D., and E.H. Ahrens. 1996. "Large-Scale Dynamic Compaction of Natural Salt," *4th International Conference on the Mechanical Behavior of Salt, Montreal, Quebec, June 17-18, 1996*. SAND96-0792C. Albuquerque, NM: Sandia National Laboratories. (Copy on file in the SWCF as WPO39544.)

Knowles, M.K., and C.L. Howard. 1996. "Field and Laboratory Testing of Seal Materials Proposed for the Waste Isolation Pilot Plant," *Proceedings of the Waste Management 1996 Symposium, Tucson, AZ, February 25-29, 1996*. SAND95-2082C. Albuquerque, NM: Sandia National Laboratories. (Copy on file in the SWCF as WPO30945.)

McClintock, F.A., and A.S. Aragon. 1996. *Mechanical Behavior of Materials*. Reading MA: Addison-Wesley.

Van Sambeek, L.L. 1988. *Considerations for the Use of Quarried Salt Blocks in Seal Components at the WIPP*. Topical Report RSI-0340. Rapid City, SD: RE/SPEC Inc. (Copy on file in the SWCF as WPO9233.)

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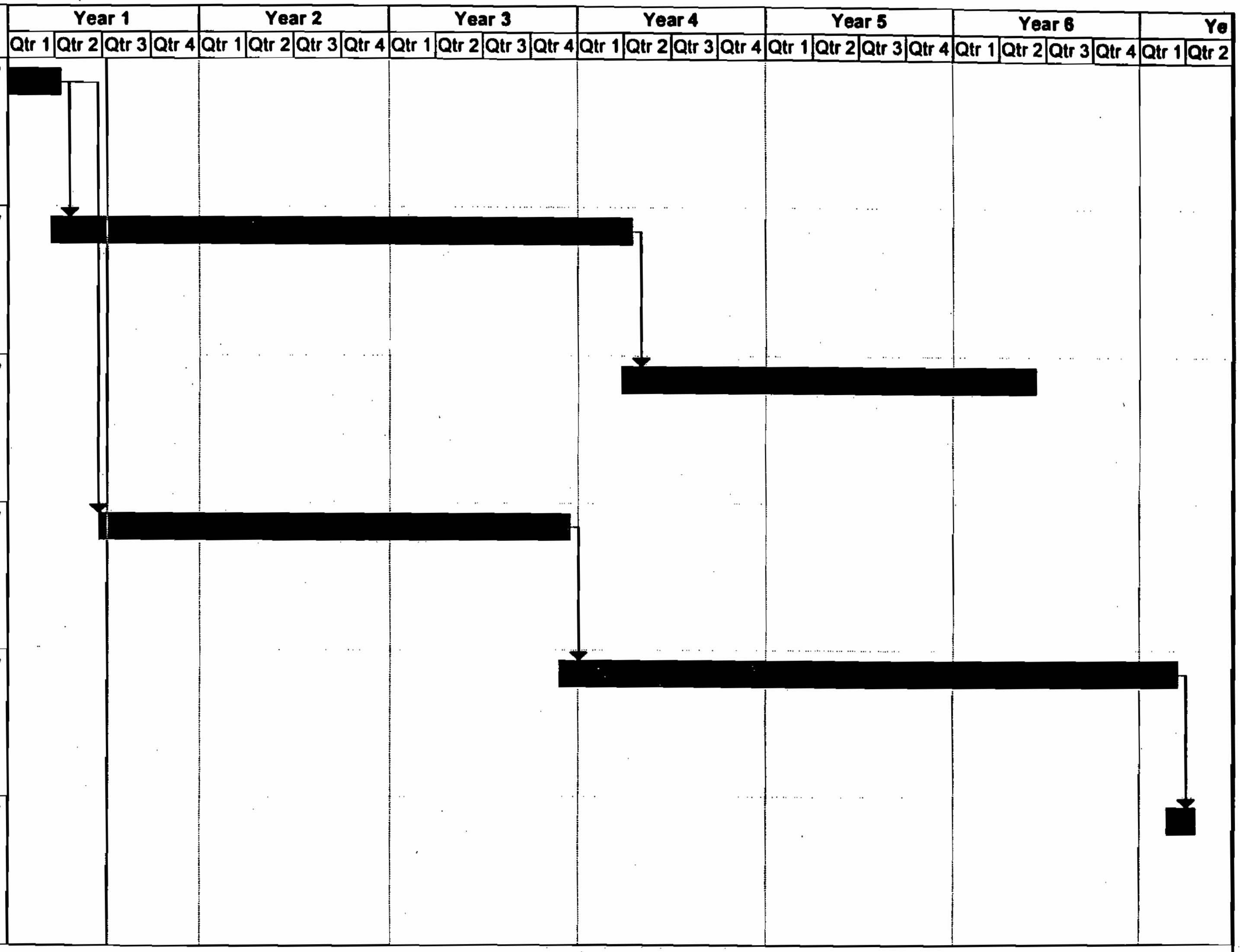
SEALING SCHEDULE – ALL SHAFTS

ID	Task Name	Duration
1	Project Mobilization	15w
2	Air Intake Shaft Shaft	159.85w
3	Salt Shaft	115.19w
4	Exhaust Shaft	129.23w
5	Waste Shaft	172.71w
6	Project Demobilization	8w

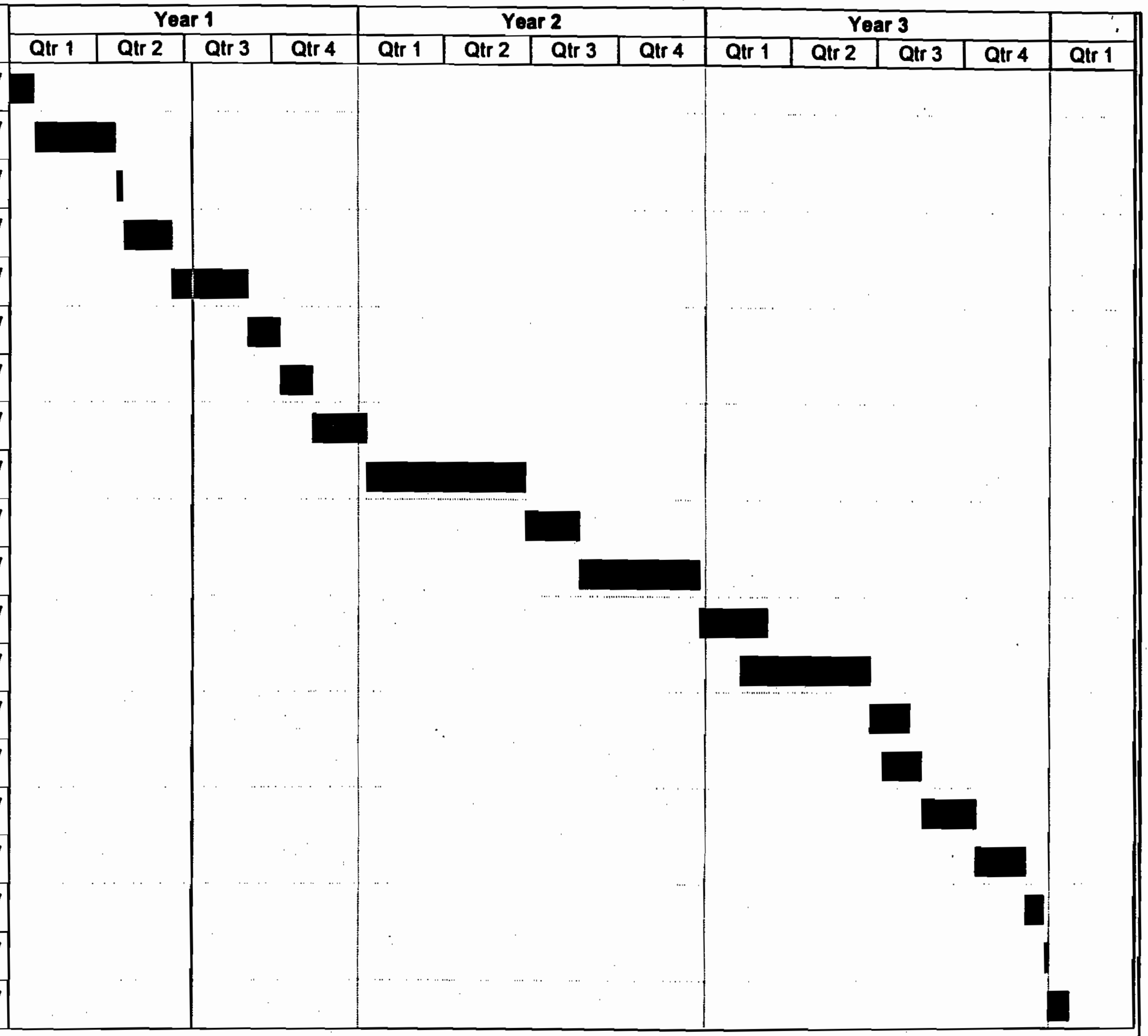


Project:SHAFT SEALING SCHEDULE
Date: Tue 7/9/96

Task
Progress
Milestone
Summary
Rolled Up Task
Rolled Up Milestone
Rolled Up Progress

SEALING SCHEDULE – AIR INTAKE SHAFT

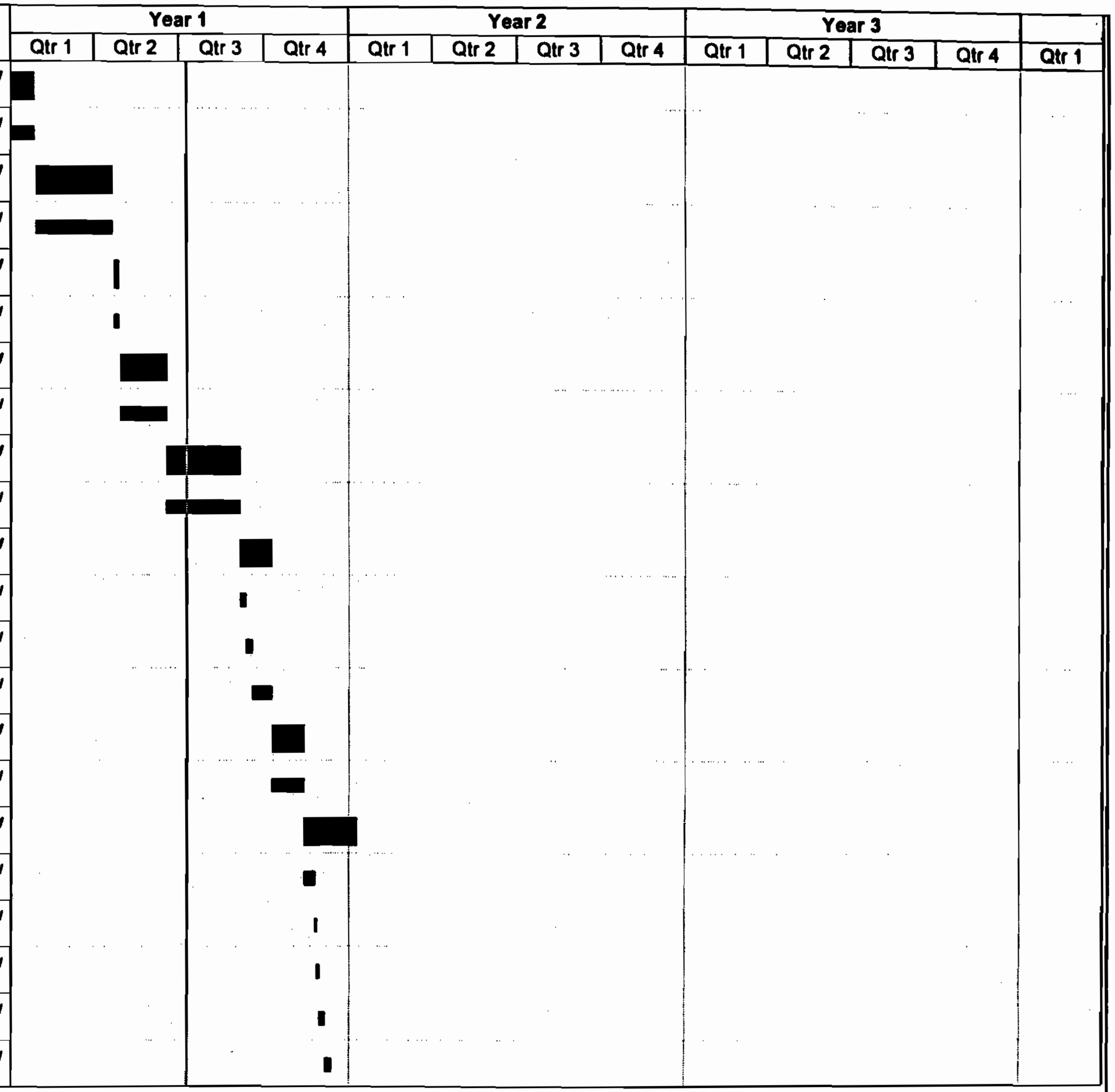
ID	Task Name	Duration
1	Mobilization	4w
3	Plant Set-up	12w
5	Inspect & Scale Shaft-2151'	1w
7	Install Construction Utilities	7.17w
9	Drill & Grout Lining	11.5w
11	Shaft Station Monolith-37'	4.78w
15	Lower Salado Compacted Clay Column-93.5'	4.96w
17	Lower Concrete-Asphalt Waterstop-50'	8.25w
26	Compacted Salt Column-563.5'	23.58w
28	Middle Concrete-Asphalt Waterstop-50'	8.25w
37	Upper Salado Compacted Clay Column-344'	18.24w
39	Upper Concrete-Asphalt Waterstop-50'	10.25w
48	Asphalt Column-138.3'	19.41w
56	Concrete Plug-20'	5.99w
61	Remove Concrete Shaft Lining	5.71w
63	Rustler Compacted Clay Column-234.7'	8.36w
65	Compacted Earthen Fill-473'	7.59w
67	Concrete Plug-40'	2.96w
71	Compacted Earthen Fill-57'	0.65w
73	Demobilization	3.2w



Project: AIR INTAKE SHAFT SEALING SCHEDULE
Date: Tue 7/9/96

Task
Progress
Milestone
Summary
Rolled Up Task
Rolled Up Milestone
Rolled Up Progress

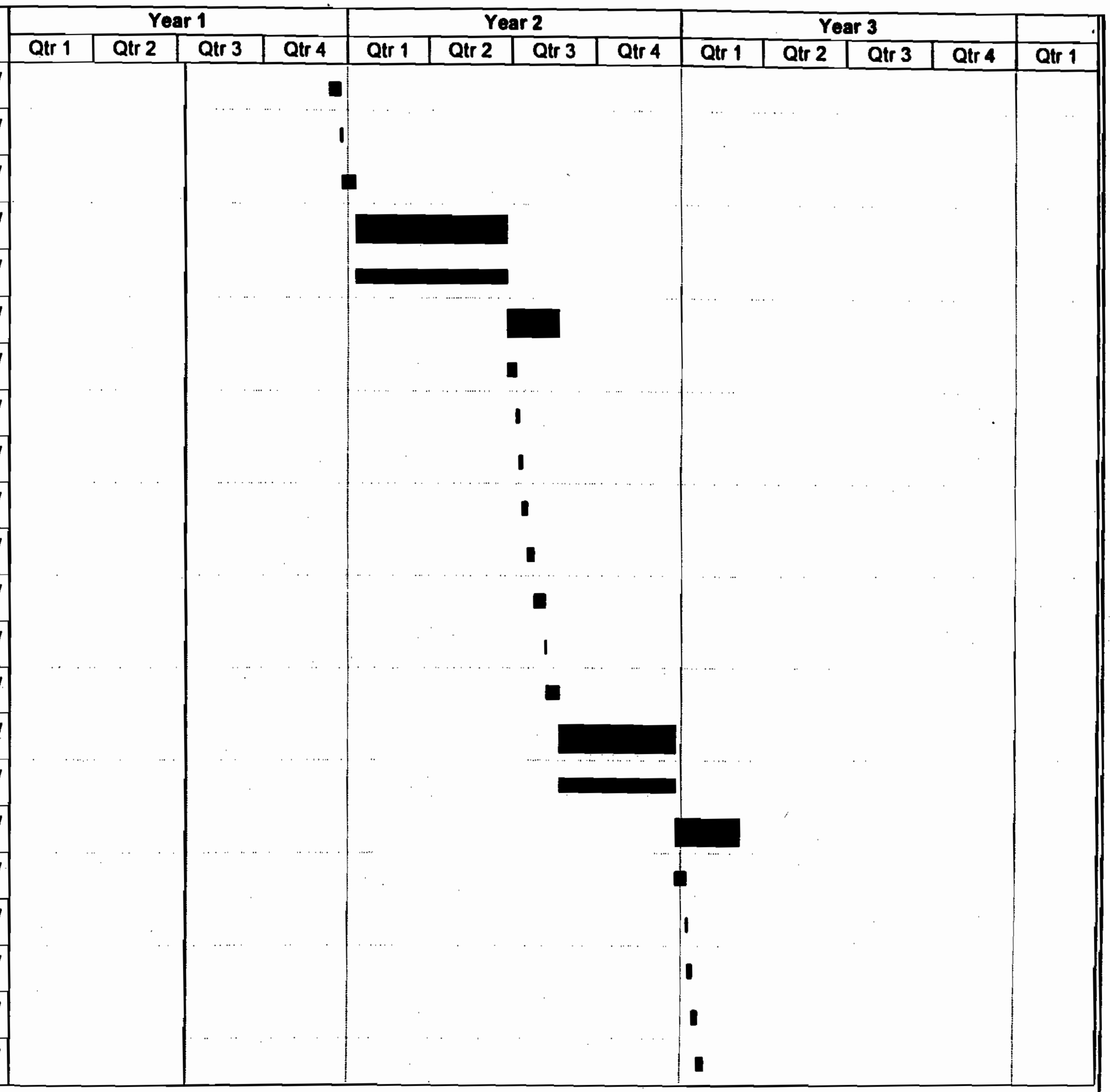
ID	Task Name	Duration
1	**Mobilization**	4w
2	Mobilize	4w
3	**Plant Set-up**	12w
4	Plant Set-up	12w
5	**Inspect & Scale Shaft-2151'**	1w
6	Inspect & Scale Shaft	1w
7	**Install Construction Utilities**	7.17w
8	Install Utilities	7.17w
9	**Drill & Grout Lining**	11.5w
10	Drill & Grout Lining	11.5w
11	**Shaft Station Monolith-37'**	4.78w
12	Construct Bulkheads	0.8w
13	Pour Concrete (37' high)	0.98w
14	Cure Concrete	3w
15	**Lower Salado Compacted Clay Column-93.5'**	4.96w
16	Emplace Bentonite Blocks (93.5' high)	4.96w
17	**Lower Concrete-Asphalt Waterstop-50'**	8.25w
18	Excavate for Lower Plug	1.67w
19	Pour Concrete-Lower Plug (23' high typ.)	0.28w
20	Excavate Waterstop	0.63w
21	Place Asphalt (4' high typ.)	0.72w
22	Cool-down Asphalt	1w



Project: AIR INTAKE SHAFT SEALING SCHEDULE
Date: Tue 7/9/96

Task
Progress
Milestone
Summary
Rolled Up Task
Rolled Up Milestone
Rolled Up Progress

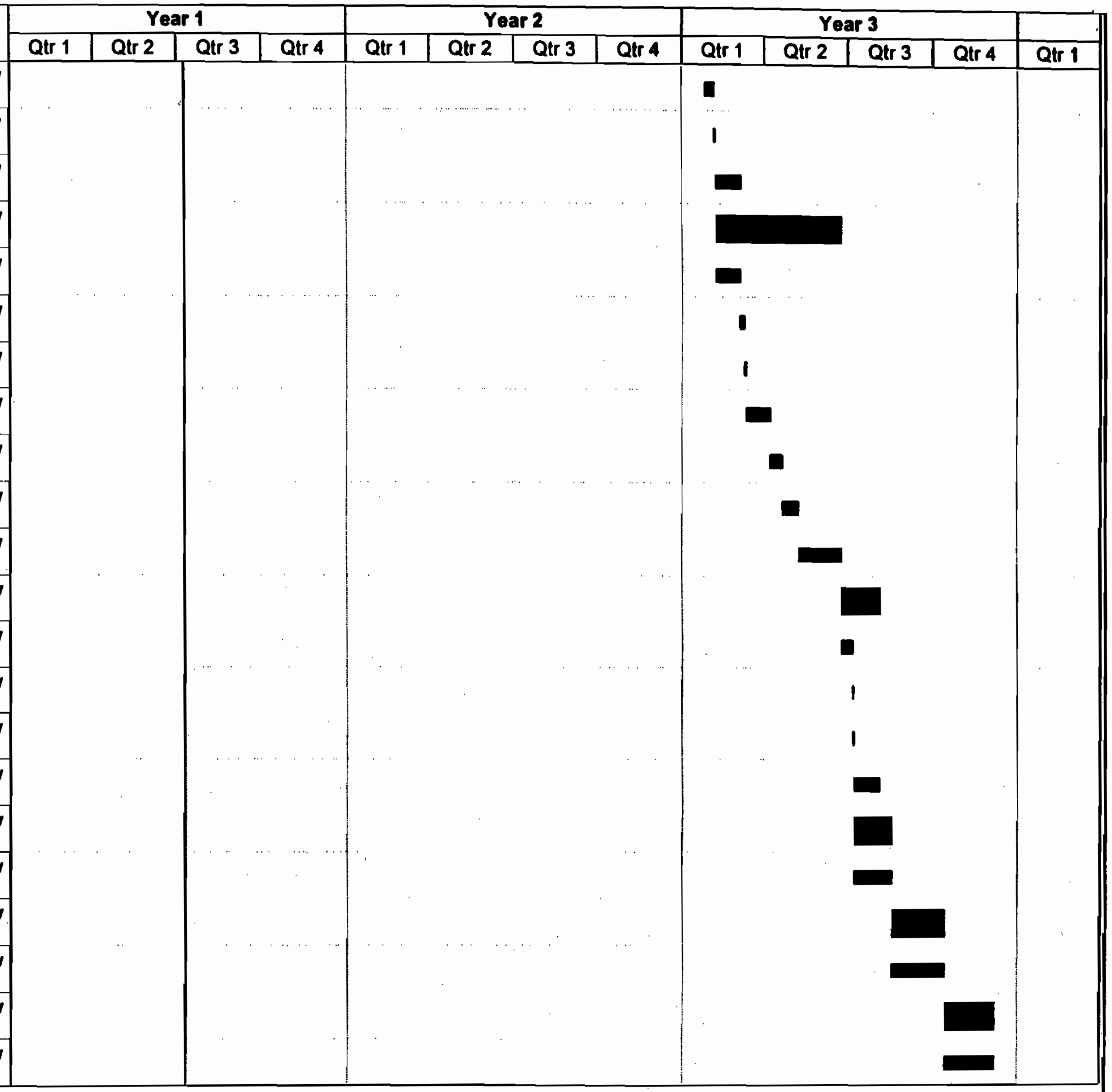
ID	Task Name	Duration
23	Excavate for Upper Plug	1.67w
24	Pour Concrete-Upper Plug (23' high typ.)	0.28w
25	Cure Concrete	2w
26	**Compacted Salt Column-563.5'**	**23.58w**
27	Emplace & Compact Crushed/Screened Salt	23.58w
28	**Middle Concrete-Asphalt Waterstop-50'**	**8.25w**
29	Excavate for Lower Plug	1.67w
30	Pour Concrete-Lower Plug	0.28w
31	Excavate Waterstop	0.63w
32	Place Asphalt	0.72w
33	Cool-down Asphalt	1w
34	Excavate for Upper Plug	1.67w
35	Pour Concrete-Upper Plug	0.28w
36	Cure Concrete	2w
37	**Upper Salado Compacted Clay Column-344'**	**18.24w**
38	Emplace Bentonite Blocks	18.24w
39	**Upper Concrete-Asphalt Waterstop-50'**	**10.25w**
40	Excavate for Lower Plug	1.67w
41	Pour Concrete-Lower Plug	0.28w
42	Excavate Waterstop	0.63w
43	Place Asphalt	0.72w
44	Cool-down Asphalt	1w



Project: AIR INTAKE SHAFT SEALING SCHEDULE
Date: Tue 7/9/96

Task | Summary | Rolled Up Progress
Progress | Rolled Up Task
Milestone | Rolled Up Milestone ◇

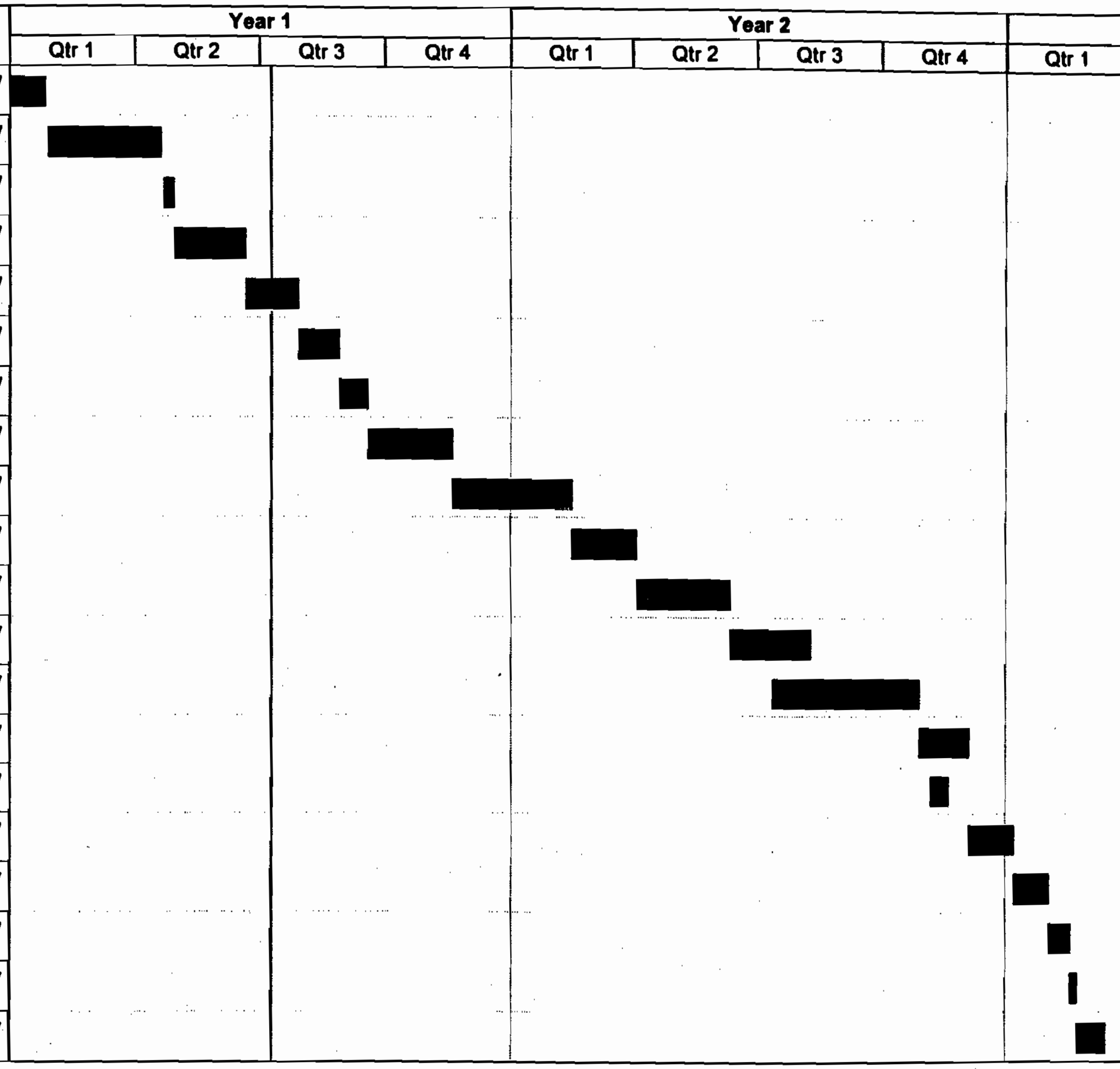
ID	Task Name	Duration
45	Excavate for Upper Plug	1.67w
46	Pour Concrete-Upper Plug	0.28w
47	Cure Concrete	4w
48	**Asphalt Column-138.3'**	19.41w
49	Remove Lining in Key	3.76w
50	Remove Chemical Seal Rings	0.6w
51	Mobilize to Emplace Asphalt	0.3w
52	Asphalt in Salt Section	3.62w
53	Asphalt in Lower Lined Section	1.93w
54	Complete Asphalt Emplacement	2.77w
55	Cool-down Asphalt	6.43w
56	**Concrete Plug-20'**	5.99w
57	Remove Concrete Lining & Rock	1.65w
58	Remove Liner Plate	0.13w
59	Pour Concrete(20' high)	0.21w
60	Cure Concrete	4w
61	**Remove Concrete Shaft Lining**	5.71w
62	Remove 86' of lining--4 zones	5.71w
63	**Rustler Compacted Clay Column-234.7'**	8.36w
64	Emplace & Compact Bentonite(234.7' high)	8.36w
65	**Compacted Earthen Fill-473'**	7.59w
66	Emplace & Compact Earthen Fill(473' high)	7.59w



Project: AIR INTAKE SHAFT SEALING SCHEDULE
Date: Tue 7/9/96

Task — Summary — Rolled Up Progress
Progress — Rolled Up Task
Milestone — Rolled Up Milestone ◇

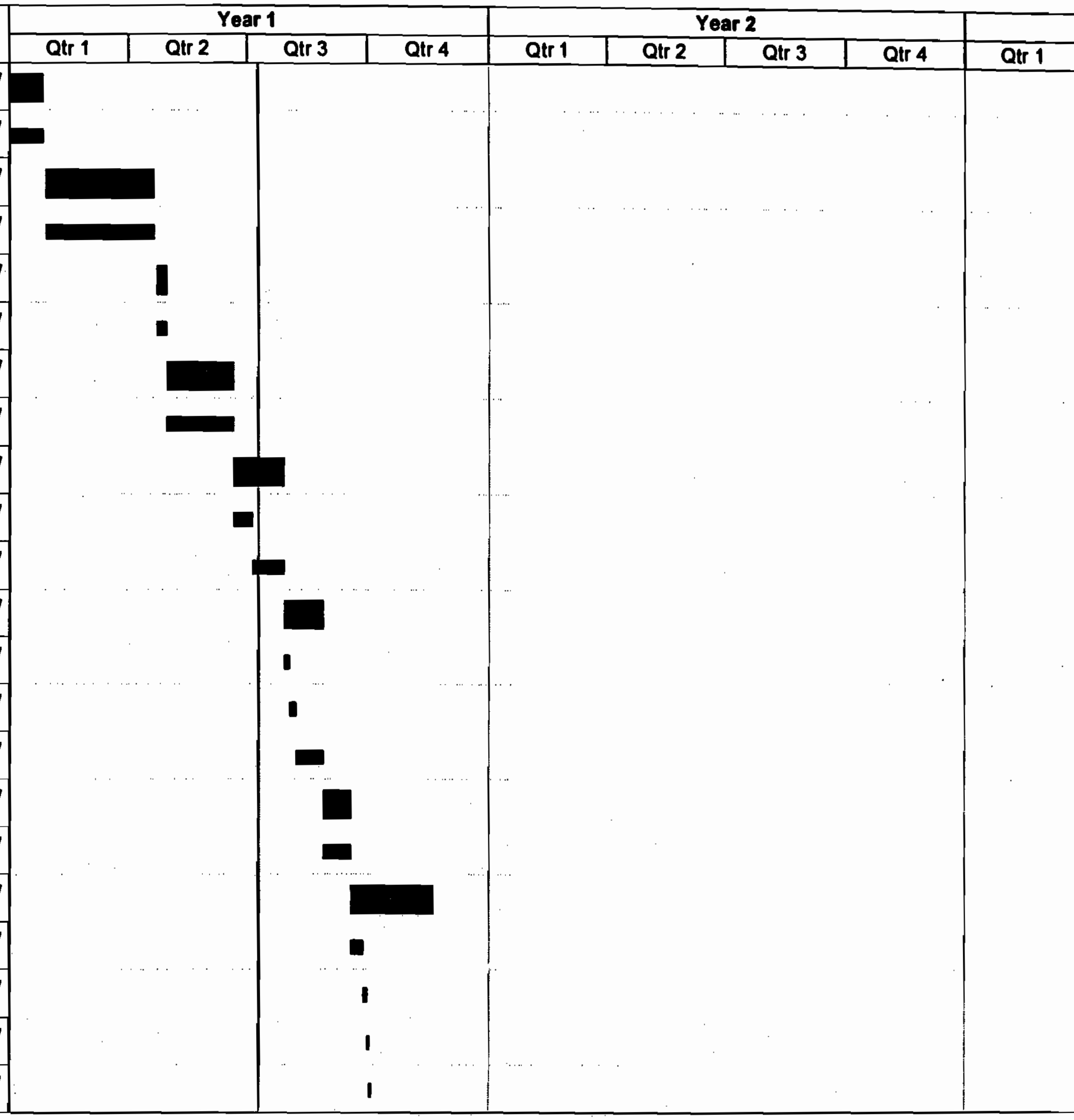
ID	Task Name	Duration
1	Mobilization	4w
3	Plant Set-up	12w
5	Inspect & Scale Shaft-2164.5'	1.06w
7	Install Construction Utilities	7.6w
9	Drill & Grout Lining	5.35w
12	Shaft Station Monolith-37'	4.44w
16	Lower Salado Compacted Clay Column-107'	3.06w
18	Lower Concrete-Asphalt Waterstop-50'	8.74w
27	Compacted Salt Column-560'	12.67w
29	Middle Concrete-Asphalt Waterstop-50'	6.74w
38	Upper Salado Compacted Clay Column-335'	9.58w
40	Upper Concrete-Asphalt Waterstop-50'	8.74w
49	Asphalt Column-140'	15.33w
57	Concrete Plug-20'	5.32w
61	Remove Concrete Shaft Lining	1.9w
63	Rustler Compacted Clay Column-234'	4.81w
65	Compacted Earthen Fill-449'	3.65w
67	Concrete Plug-40'	2.45w
71	Compacted Earthen Fill-92.5'	0.65w
73	Demobilization	3w



Project: SALT HANDLING SHAFT SEALING SCHEDULE
Date: Tue 7/9/96

Task | Summary | Rolled Up Progress
Progress | Rolled Up Task
Milestone | Rolled Up Milestone

ID	Task Name	Duration
1	**Mobilization**	4w
2	Mobilize	4w
3	**Plant Set-up**	12w
4	Plant Set-up	12w
5	**Inspect & Scale Shaft-2164.5'**	1.06w
6	Inspect & Scale Shaft	1.06w
7	**Install Construction Utilities**	7.6w
8	Install Utilities	7.6w
9	**Drill & Grout Lining**	5.35w
10	Drill Grout Holes	2.14w
11	Grout Lining	3.21w
12	**Shaft Station Monolith-37'**	4.44w
13	Construct Bulkheads	0.8w
14	Pour Concrete (37' high)	0.64w
15	Cure Concrete	3w
16	**Lower Salado Compacted Clay Column-107'**	3.06w
17	Emplace Bentonite Blocks (107.0 ' high)	3.06w
18	**Lower Concrete-Asphalt Waterstop-50'**	8.74w
19	Excavate for Lower Plug	1.38w
20	Pour Concrete-Lower Plug (23' high-typ)	0.17w
21	Excavate Waterstop	0.34w
22	Place Asphalt (4' high-typ)	0.3w



Project: SALT HANDLING SHAFT SEALING SCHEDULE
Date: Tue 7/9/96

Task | Summary | Rolled Up Progress
Progress | Rolled Up Task
Milestone | Rolled Up Milestone ◇

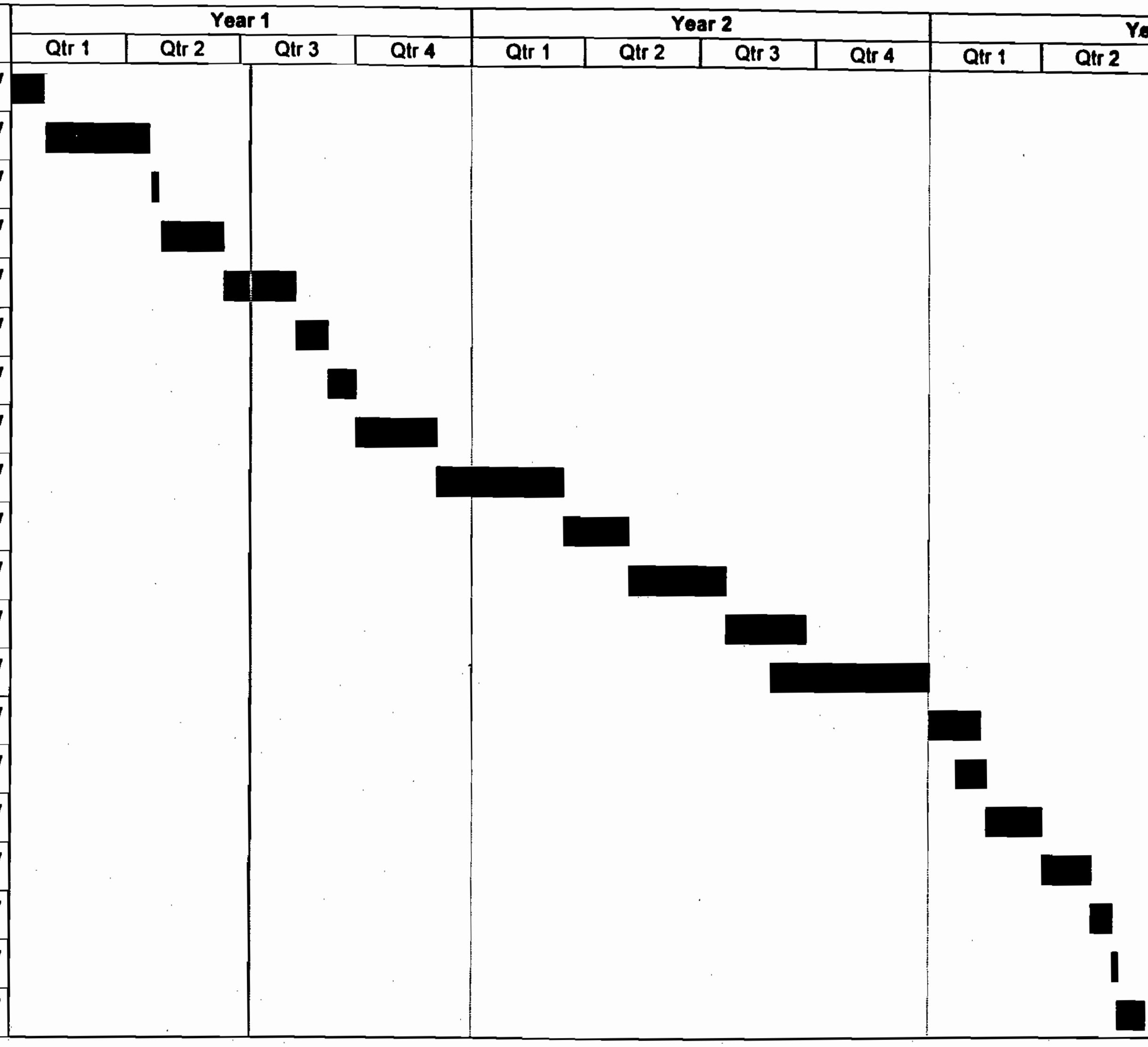
ID	Task Name	Duration	Year 1 Qtr 1	Year 1 Qtr 2	Year 1 Qtr 3	Year 1 Qtr 4	Year 2 Qtr 1	Year 2 Qtr 2	Year 2 Qtr 3	Year 2 Qtr 4	Qtr 1
67	**Concrete Plug-40'**	2.45w									
68	Clean Existing Surface	0.34w									
69	Pour Concrete	0.11w									
70	Cure Concrete	2w									
71	**Compacted Earthen Fill-92.5'**	0.65w									
72	Emplace & Compact Earthen Fill (92.5'high)	0.65w									
73	**Demobilization**	3w									
74	Demob	3w									

Project: SALT HANDLING SHAFT SEALING SCHEDULE
Date: Tue 7/9/96

Task
Progress
Milestone
Summary
Rolled Up Task
Rolled Up Milestone ◇
Rolled Up Progress

SEALING SCHEDULE – EXHAUST SHAFT

ID	Task Name	Duration
1	Mobilization	4w
3	Plant Set-up	12w
5	Inspect & Scale Shaft-2159.5'	1w
7	Install Construction Utilities	7.2w
9	Drill & Grout Lining	8.26w
12	Shaft Station Monolith-33'	3.69w
16	Lower Salado Compacted Clay Column-98'	3.16w
16	Lower Concrete-Asphalt Waterstop-50'	9.19w
27	Compacted Salt Column-559'	14.37w
29	Middle Concrete-Asphalt Waterstop-50'	7.19w
38	Upper Salado Compacted Clay Column-340'	11.01w
40	Upper Concrete-Asphalt Waterstop-50'	9.19w
49	Asphalt Column-142.5'	18.43w
57	Concrete Plug-20'	5.87w
61	Remove Concrete Shaft Lining	3.23w
63	Rustler Compacted Clay Column-234.5'	6.62w
65	Compacted Earthen Fill-466.4'	5.44w
67	Concrete Plug-40'	2.69w
71	Compacted Earthen Fill-56.1'	0.44w
73	Demobilization	3w



Project: EXHAUST SHAFT SEALING SCHEDULE
Date: Tue 7/9/96

Task

Progress

Milestone

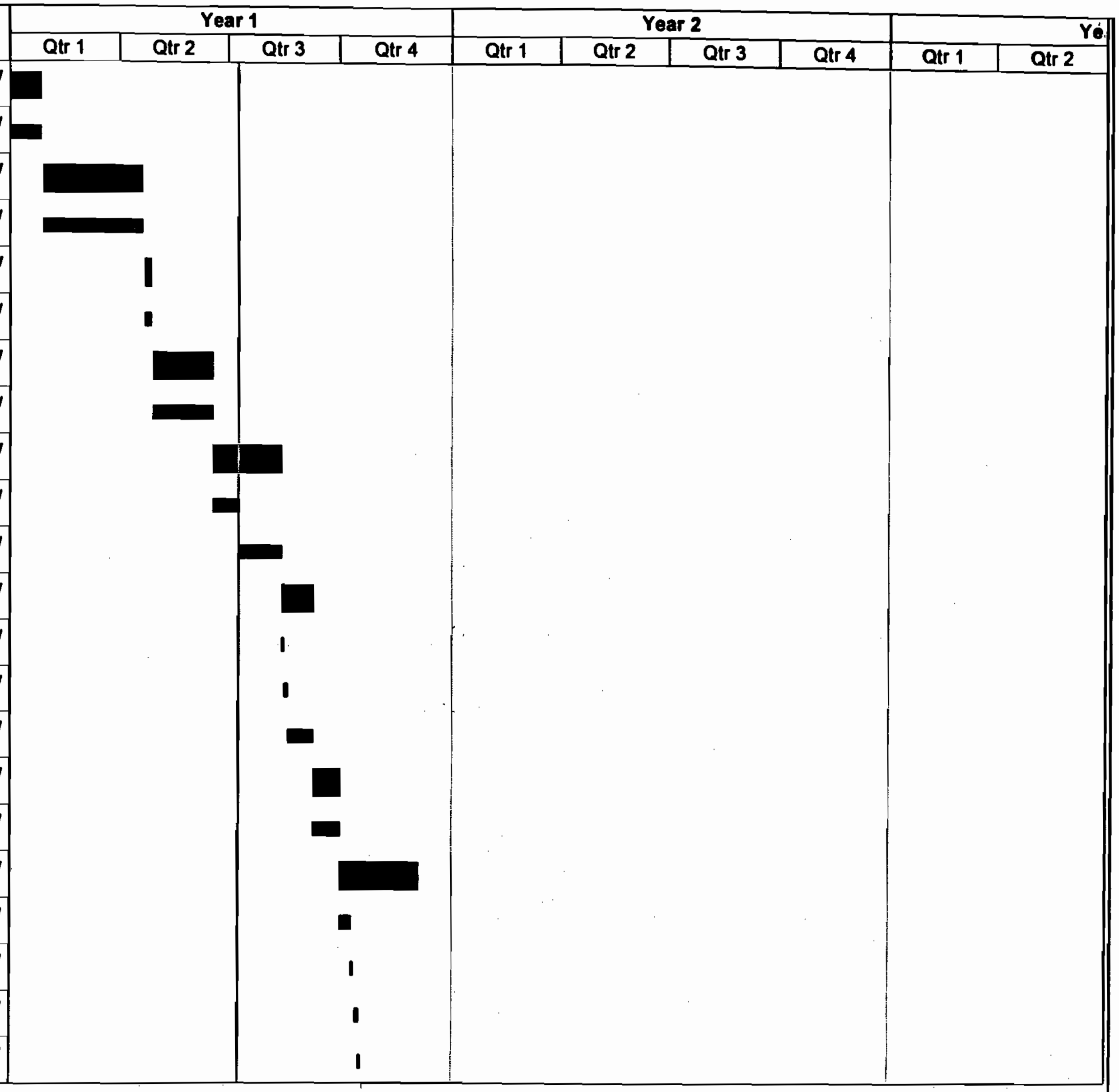
Summary

Rolled Up Task

Rolled Up Milestone ◇

Rolled Up Progress

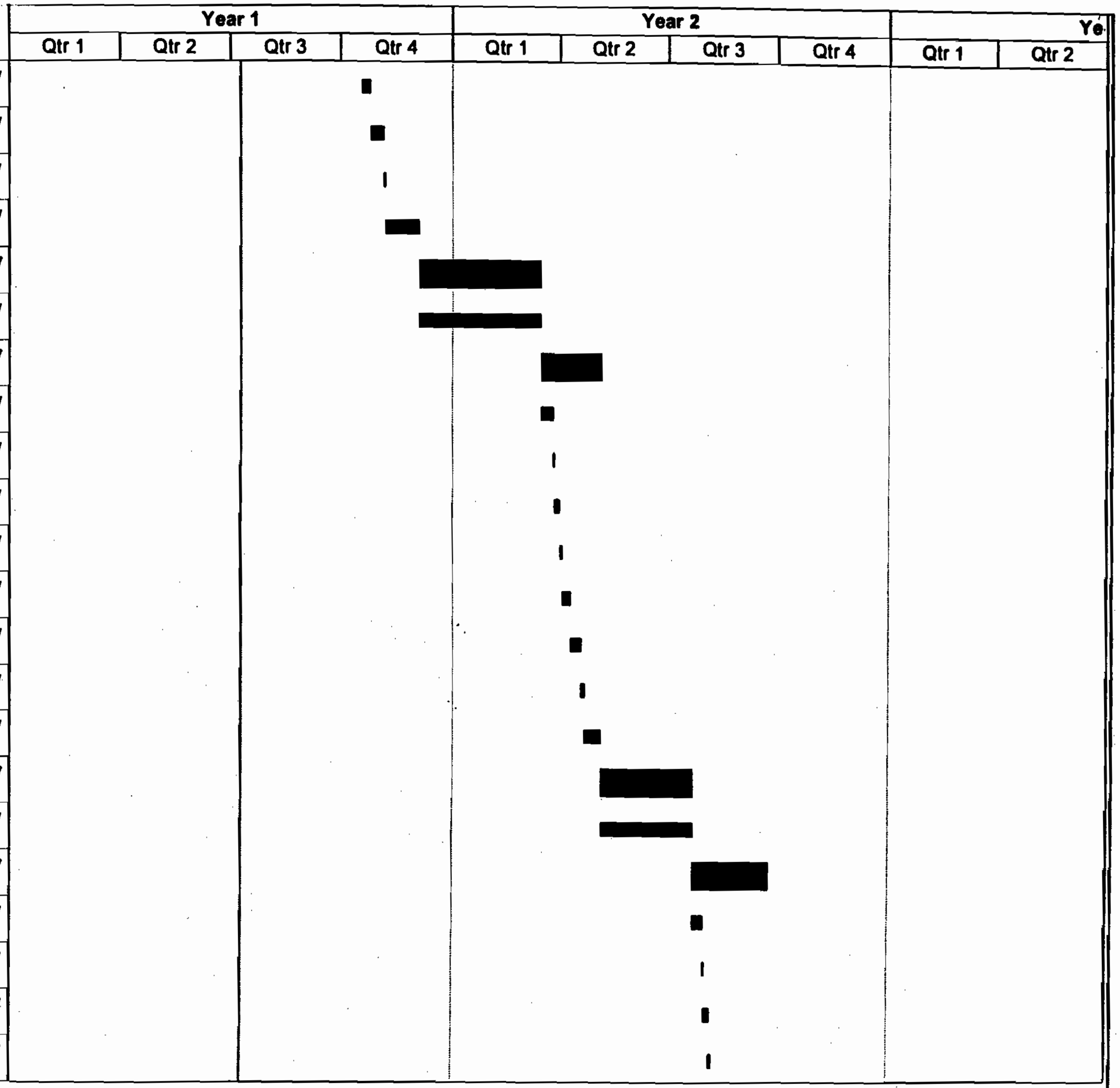
ID	Task Name	Duration
1	**Mobilization**	4w
2	Mobilize	4w
3	**Plant Set-up**	12w
4	Plant Set-up	12w
5	**Inspect & Scale Shaft-2159.5'**	1w
6	Inspect & Scale Shaft	1w
7	**Install Construction Utilities**	7.2w
8	Install Utilities	7.2w
9	**Drill & Grout Lining**	8.26w
10	Drill Grout Holes	3.3w
11	Grout Lining	4.96w
12	**Shaft Station Monolith-33'**	3.69w
13	Construct Bulkheads	0.4w
14	Pour Concrete (33' high)	0.29w
15	Cure Concrete	3w
16	**Lower Salado Compacted Clay Column-98'**	3.18w
17	Emplace Bentonite Blocks (98 ' high)	3.18w
18	**Lower Concrete-Asphalt Waterstop-50'**	9.19w
19	Excavate for Lower Plug	1.45w
20	Pour Concrete-Lower Plug (23' high-typ)	0.22w
21	Excavate Waterstop	0.47w
22	Place Asphalt (4' high-typ)	0.38w



Project: EXHAUST SHAFT SEALING SCHEDULE
Date: Tue 7/9/96

Task
Progress
Milestone
Summary
Rolled Up Task
Rolled Up Milestone ◇
Rolled Up Progress

ID	Task Name	Duration
23	Cool-down Asphalt	1w
24	Excavate for Upper Plug	1.45w
25	Pour Concrete-Upper Plug (23' high-typ)	0.22w
26	Cure Concrete	4w
27	**Compacted Salt Column-559'**	**14.37w**
28	Emplace & Compact Crushed/Screened Salt	14.37w
29	**Middle Concrete-Asphalt Waterstop-50'**	**7.19w**
30	Excavate for Lower Plug	1.45w
31	Pour Concrete-Lower Plug	0.22w
32	Excavate Waterstop	0.47w
33	Place Asphalt	0.38w
34	Cool-down Asphalt	1w
35	Excavate for Upper Plug	1.45w
36	Pour Concrete-Upper Plug	0.22w
37	Cure Concrete	2w
38	**Upper Salado Compacted Clay Column-340'**	**11.01w**
39	Emplace Bentonite Blocks(340' high)	11.01w
40	**Upper Concrete-Asphalt Waterstop-50'**	**9.19w**
41	Excavate for Lower Plug	1.45w
42	Pour Concrete-Lower Plug	0.22w
43	Excavate Waterstop	0.47w
44	Place Asphalt	0.38w



Project: EXHAUST SHAFT SEALING SCHEDULE
Date: Tue 7/9/96

Task — Summary — Rolled Up Progress
Progress — Rolled Up Task
Milestone — Rolled Up Milestone ◇

ID	Task Name	Duration
45	Cool-down Asphalt	1w
46	Excavate for Upper Plug	1.45w
47	Pour Concrete-Upper Plug	0.22w
48	Cure Concrete	4w
49	**Asphalt Column-142.5'**	**18.43w**
50	Remove Lining in Key	3.15w
51	Remove Chemical Seal Rings	0.5w
52	Mobilize to Emplace Asphalt	2w
53	Asphalt in Salt Section	2.64w
54	Asphalt in Lower Lined Section	1.44w
55	Complete Asphalt Emplacement	2.27w
56	Cool-down Asphalt	6.43w
57	**Concrete Plug-20'**	**5.87w**
58	Remove Concrete Lining & Rock	1.7w
59	Pour Concrete (20' high)	0.17w
60	Cure Concrete	4w
61	**Remove Concrete Shaft Lining**	**3.23w**
62	Remove 84' of lining--4 zones	3.23w
63	**Rustler Compacted Clay Column-234.5'**	**6.62w**
64	Emplace & Compact Bentonite(234.5' high)	6.62w
65	**Compacted Earthen Fill-486.4'**	**5.44w**
66	Emplace & Compact Earthen Fill(486.4' high	5.44w

Year 1: Qtr 1, Qtr 2, Qtr 3, Qtr 4 | Year 2: Qtr 1, Qtr 2, Qtr 3, Qtr 4 | Ye[ar 3]: Qtr 1, Qtr 2

Project: EXHAUST SHAFT SEALING SCHEDULE
Date: Tue 7/9/96

Task | Summary | Rolled Up Progress
Progress | Rolled Up Task
Milestone | Rolled Up Milestone ◇

ID	Task Name	Duration
67	**Concrete Plug-40'**	2.69w
68	Clean Existing Surface	0.47w
69	Pour Concrete	0.22w
70	Cure Concrete	2w
71	**Compacted Earthen Fill-56.1'**	0.44w
72	Emplace & Compact Earthen Fill (56.1'high)	0.44w
73	**Demobilization**	3w
74	Demob	3w

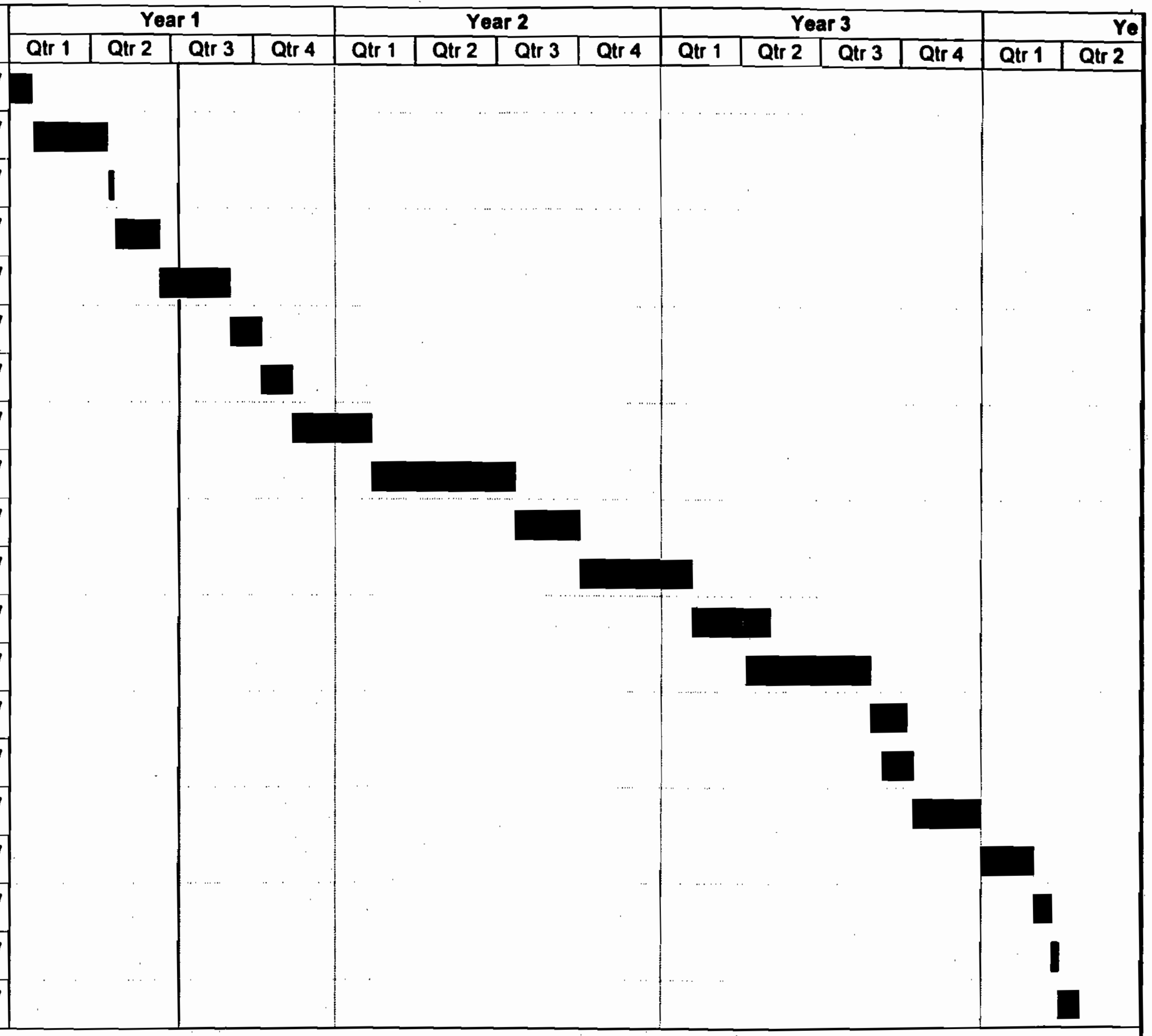
Timeline columns: Year 1 (Qtr 1, Qtr 2, Qtr 3, Qtr 4); Year 2 (Qtr 1, Qtr 2, Qtr 3, Qtr 4); Ye[ar 3] (Qtr 1, Qtr 2)

Project: EXHAUST SHAFT SEALING SCHEDULE
Date: Tue 7/9/96

Task | Summary | Rolled Up Progress
Progress | Rolled Up Task
Milestone | Rolled Up Milestone ◇

SEALING SCHEDULE – WASTE SHAFT

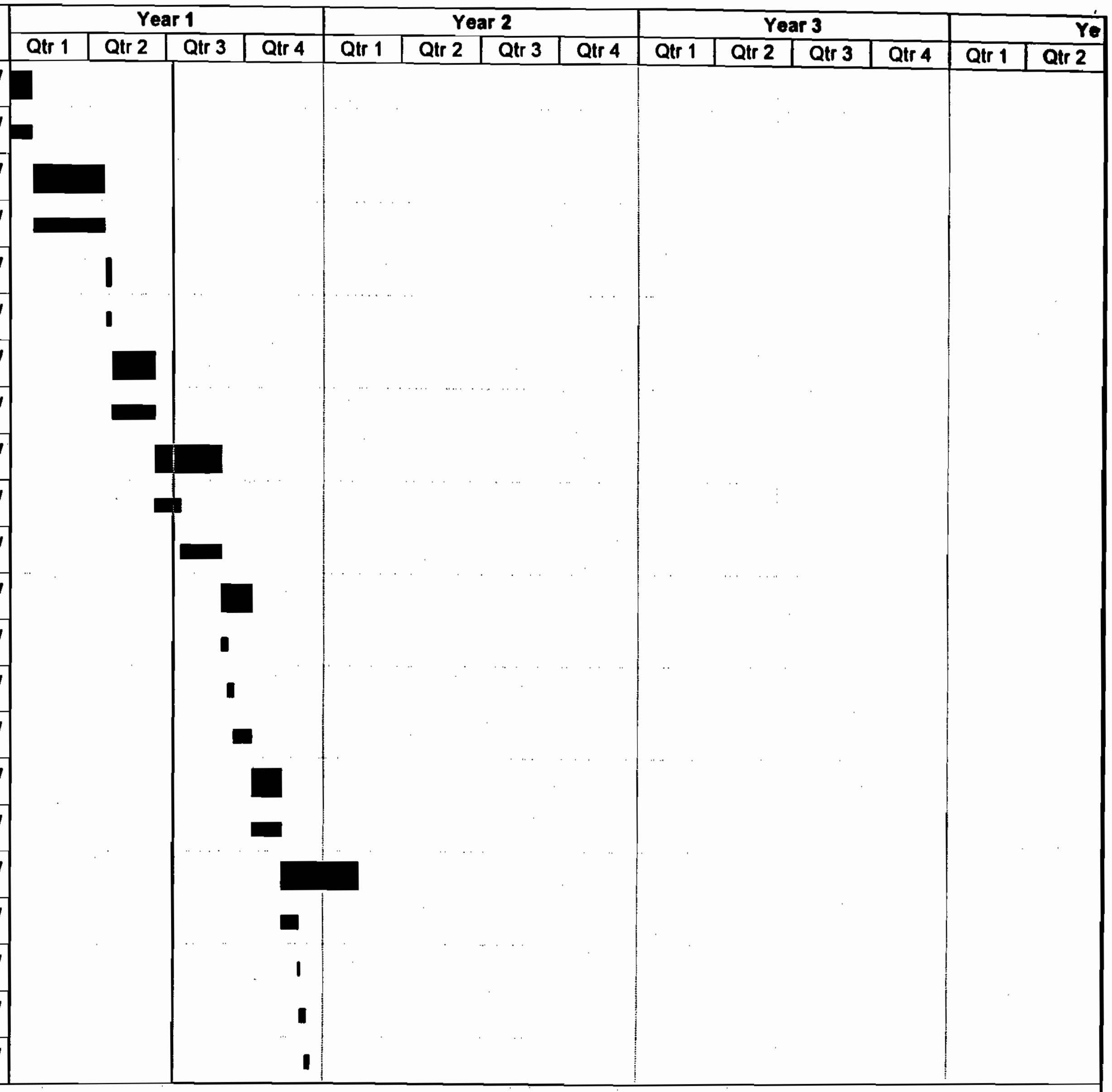
ID	Task Name	Duration
1	Mobilization	4w
3	Plant Set-up	12w
5	Inspect & Scale Shaft-2159.5'	1w
7	Install Construction Utilities	7.2w
9	Drill & Grout Lining	11.21w
12	Shaft Station Monolith-37'	5.17w
16	Lower Salado Compacted Clay Column-96'	5.01w
18	Lower Concrete-Asphalt Waterstop-50'	12.57w
27	Compacted Salt Column-555.5'	22.87w
29	Middle Concrete-Asphalt Waterstop-50'	10.57w
38	Upper Salado Compacted Clay Column-351.5'	17.86w
40	Upper Concrete-Asphalt Waterstop-50'	12.57w
49	Asphalt Column-142.3'	20.71w
57	Concrete Plug-20'	5.98w
61	Remove Concrete Shaft Lining	5.07w
63	Rustler Compacted Clay Column-234.7'	10.99w
65	Compacted Earthen Fill-447'	8.25w
67	Concrete Plug-40'	3.04w
71	Compacted Earthen Fill-61.5'	1.14w
73	Demobilization	3.5w



Project: WASTE HANDLING SHAFT SEALING SCHEDULE
Date: Tue 7/9/96

Task | Summary | Rolled Up Progress
Progress | Rolled Up Task
Milestone | Rolled Up Milestone ◇

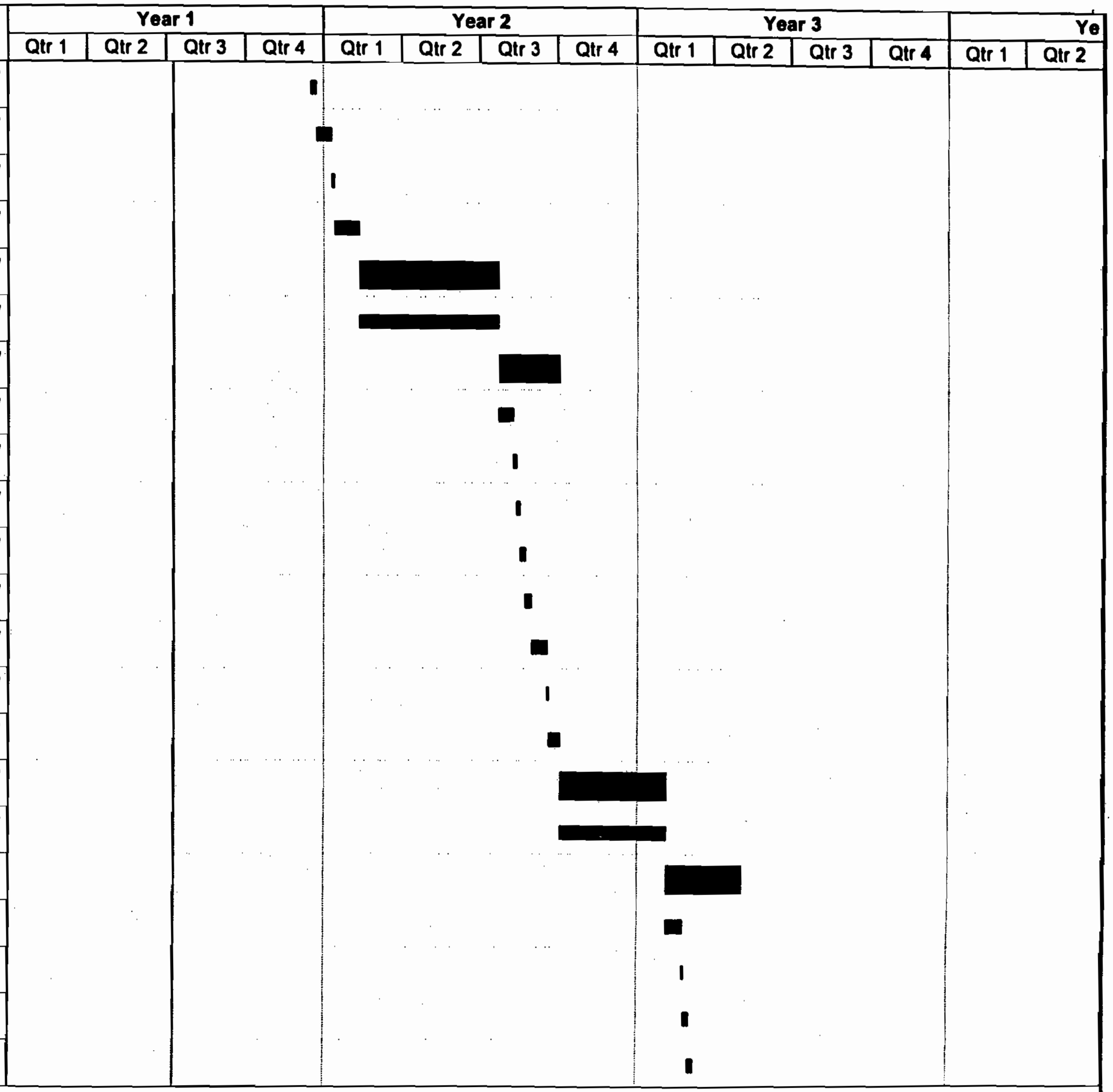
ID	Task Name	Duration
1	**Mobilization**	4w
2	Mobilize	4w
3	**Plant Set-up**	12w
4	Plant Set-up	12w
5	**Inspect & Scale Shaft-2159.5'**	1w
6	Inspect & Scale Shaft	1w
7	**Install Construction Utilities**	7.2w
8	Install Utilities	7.2w
9	**Drill & Grout Lining**	11.21w
10	Drill Grout Holes	4.48w
11	Grout Lining	6.73w
12	**Shaft Station Monolith-37'**	5.17w
13	Construct Bulkheads	1w
14	Pour Concrete (37' high)	1.17w
15	Cure Concrete	3w
16	**Lower Salado Compacted Clay Column-96'**	5.01w
17	Emplace Bentonite Blocks (96 ' high)	5.01w
18	**Lower Concrete-Asphalt Waterstop-50'**	12.57w
19	Excavate for Lower Plug	2.72w
20	Pour Concrete-Lower Plug (23' high-typ)	0.27w
21	Excavate Waterstop	0.84w
22	Place Asphalt (4' high-typ)	0.75w



Project: WASTE HANDLING SHAFT SEALING SCHEDULE
Date: Tue 7/9/96

Legend		
Task	Summary	Rolled Up Progress
Progress	Rolled Up Task	
Milestone	Rolled Up Milestone ◇	

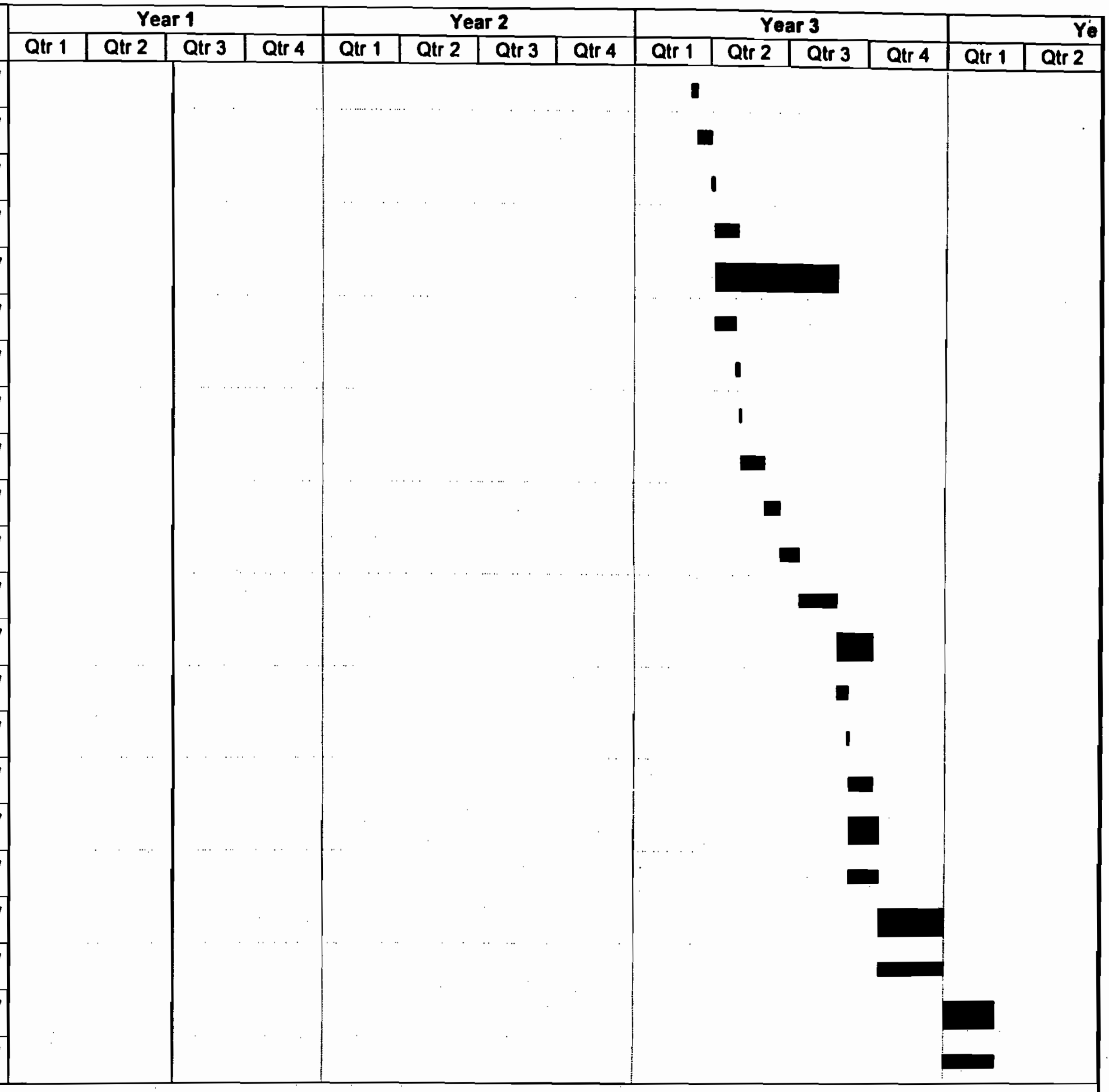
ID	Task Name	Duration
23	Cool-down Asphalt	1w
24	Excavate for Upper Plug	2.72w
25	Pour Concrete-Upper Plug (23' high-typ)	0.27w
26	Cure Concrete	4w
27	**Compacted Salt Column-555.5'**	**22.87w**
28	Emplace & Compact Crushed/Screened Salt	22.87w
29	**Middle Concrete-Asphalt Waterstop-50'**	**10.57w**
30	Excavate for Lower Plug	2.72w
31	Pour Concrete-Lower Plug	0.27w
32	Excavate Waterstop	0.84w
33	Place Asphalt	0.75w
34	Cool-down Asphalt	1w
35	Excavate for Upper Plug	2.72w
36	Pour Concrete-Upper Plug	0.27w
37	Cure Concrete	2w
38	**Upper Salado Compacted Clay Column-351.5'**	**17.86w**
39	Emplace Bentonite Blocks(351.5' high)	17.86w
40	**Upper Concrete-Asphalt Waterstop-50'**	**12.57w**
41	Excavate for Lower Plug	2.72w
42	Pour Concrete-Lower Plug	0.27w
43	Excavate Waterstop	0.84w
44	Place Asphalt	0.75w



Project: WASTE HANDLING SHAFT SEALING SCHEDULE
Date: Tue 7/9/96

Task | Summary | Rolled Up Progress
Progress | Rolled Up Task
Milestone | Rolled Up Milestone ◇

ID	Task Name	Duration
45	Cool-down Asphalt	1w
46	Excavate for Upper Plug	2.72w
47	Pour Concrete-Upper Plug	0.27w
48	Cure Concrete	4w
49	**Asphalt Column-142.3'**	**20.71w**
50	Remove Lining in Key	3.8w
51	Remove Chemical Seal Rings	0.6w
52	Mobilize to emplace asphalt	0.3w
53	Asphalt in Salt Section	4.01w
54	Asphalt in Lower Lined Section	2.33w
55	Complete Asphalt Emplacement	3.24w
56	Cool-down Asphalt	6.43w
57	**Concrete Plug-20'**	**5.98w**
58	Remove Concrete Lining & Rock	1.73w
59	Pour Concrete (20' high)	0.25w
60	Cure Concrete	4w
61	**Remove Concrete Shaft Lining**	**5.07w**
62	Remove 84' of lining--4 zones	5.07w
63	**Rustler Compacted Clay Column-234.7'**	**10.99w**
64	Emplace & Compact Bentonite (234.7' high)	10.99w
65	**Compacted Earthen Fill-447'**	**8.25w**
66	Emplace & Compact Earthen Fill (447' high)	8.25w



Project: WASTE HANDLING SHAFT SEALING SCHEDULE
Date: Tue 7/9/96

Task | Summary | Rolled Up Progress
Progress | Rolled Up Task
Milestone | Rolled Up Milestone ◇

ID	Task Name	Duration
67	**Concrete Plug-40'**	3.04w
68	Clean Existing Surface	0.64w
69	Pour Concrete	0.4w
70	Cure Concrete	2w
71	**Compacted Earthen Fill-61.5'**	1.14w
72	Emplace & Compact Earthen Fill (61.5' high)	1.14w
73	**Demobilization**	3.5w
74	Demob	3.5w

Project: WASTE HANDLING SHAFT SEALING SCHEDULE
Date: Tue 7/9/96

Task
Progress
Milestone
Summary
Rolled Up Task
Rolled Up Milestone ◇
Rolled Up Progress

FIGURES

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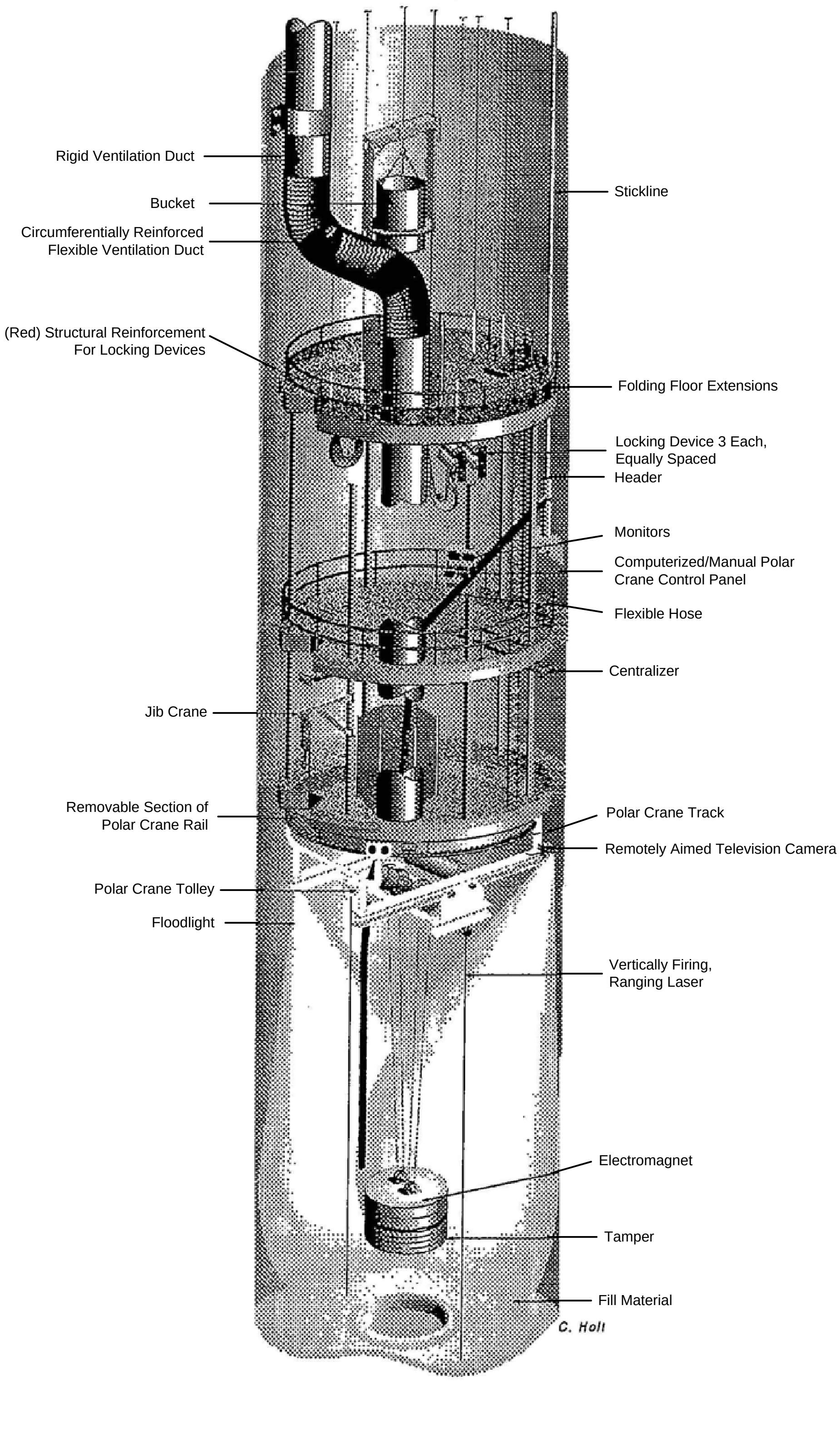

Figure I2B-1
Multi-deck Illustrating Dynamic Compaction

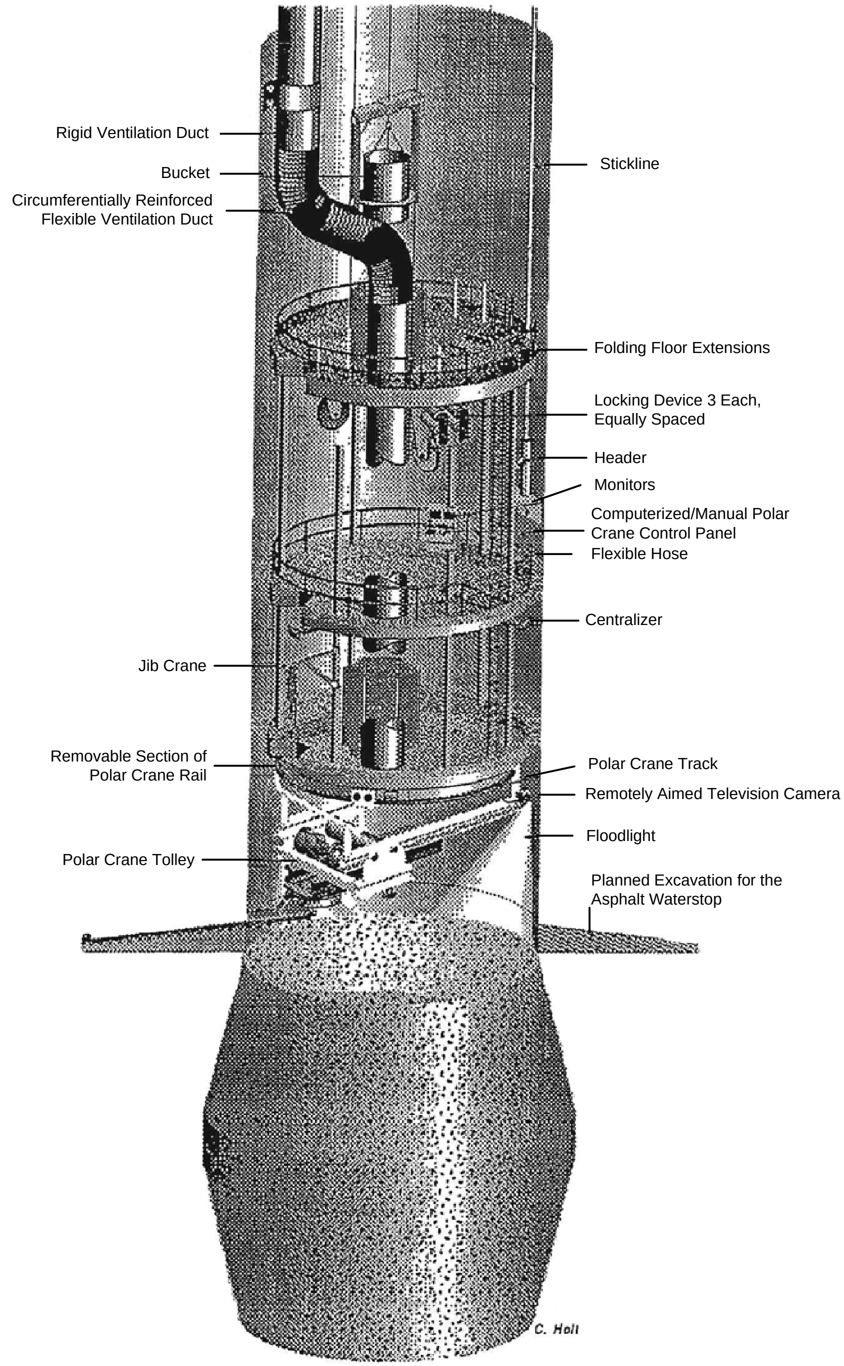

Figure I2B-2
Multi-deck Stage Illustrating Excavation for Asphalt Waterstop

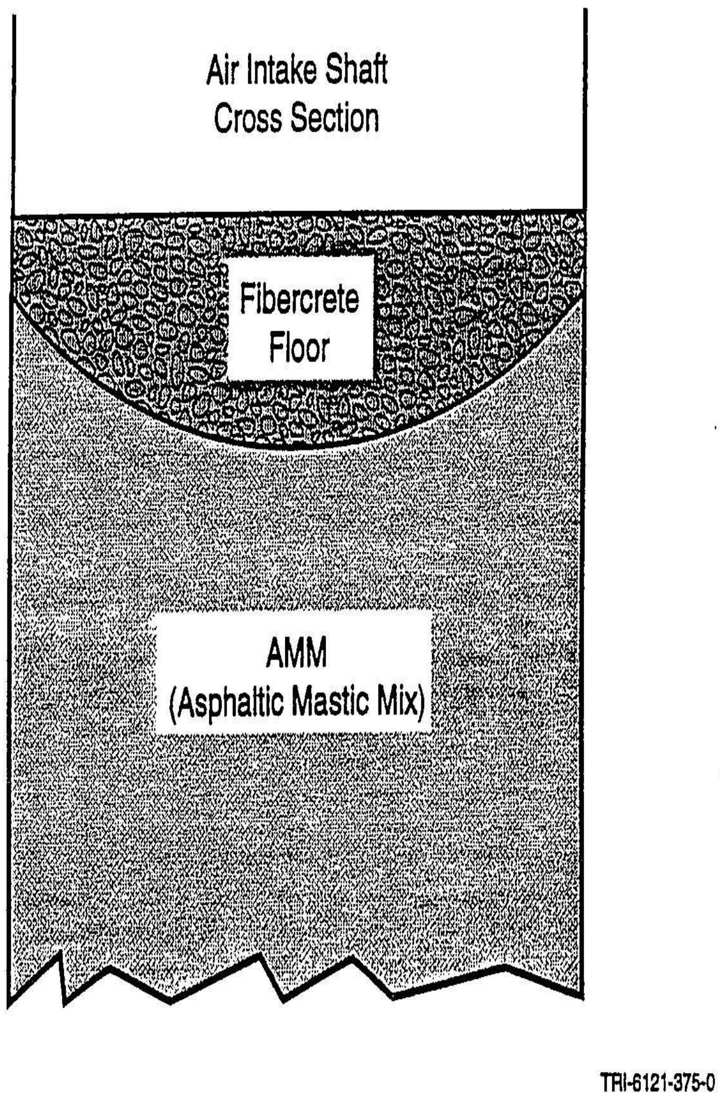

Figure I2B-3
Typical Fibercrete at Top of Asphalt

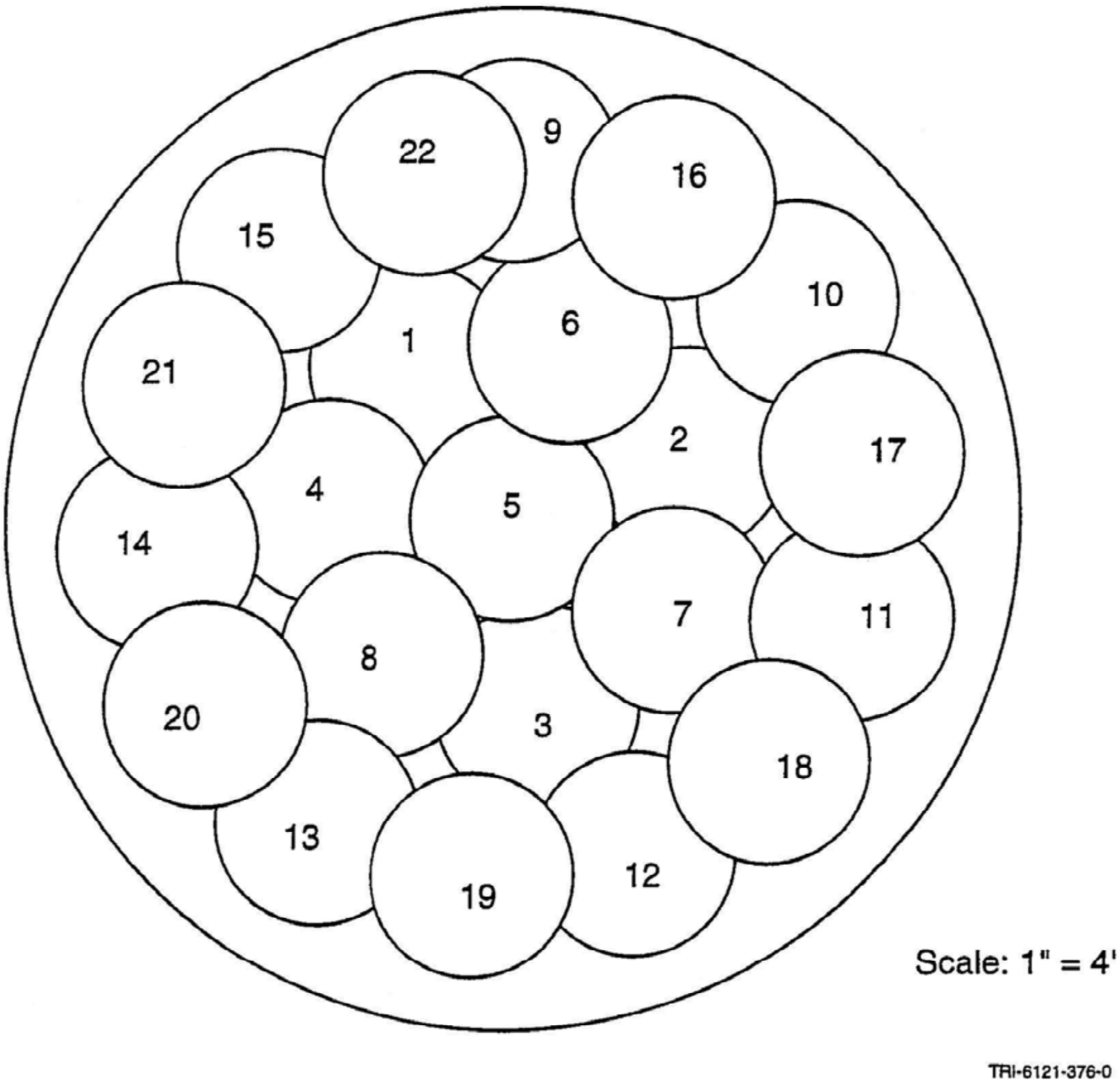

Figure I2B-4
Drop pattern for 6-m-diameter shaft using a 1.2-m-diameter tamper

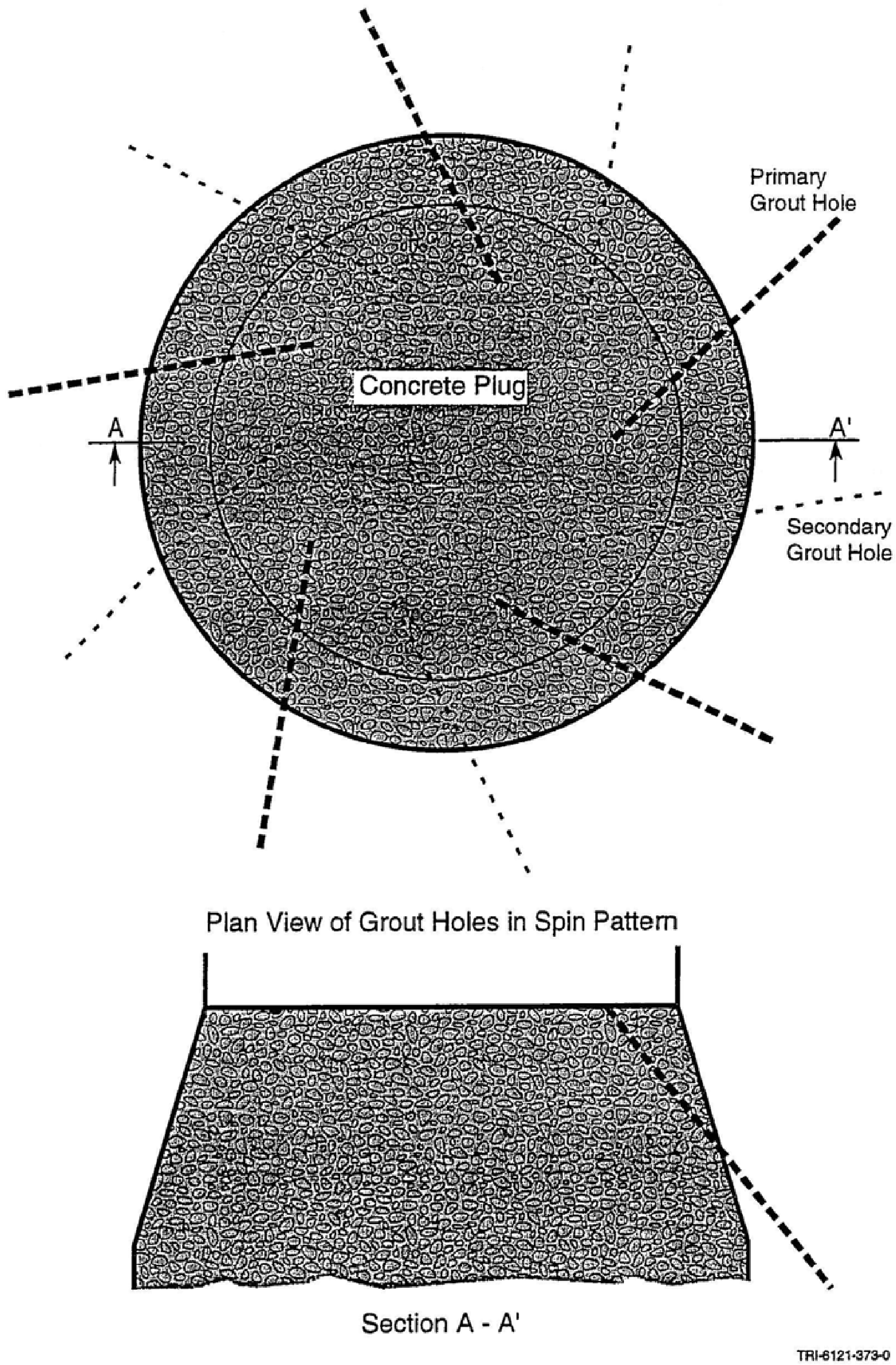

Figure I2B-5
Plan and Section Views of Downward Spin Pattern of Grout Holes

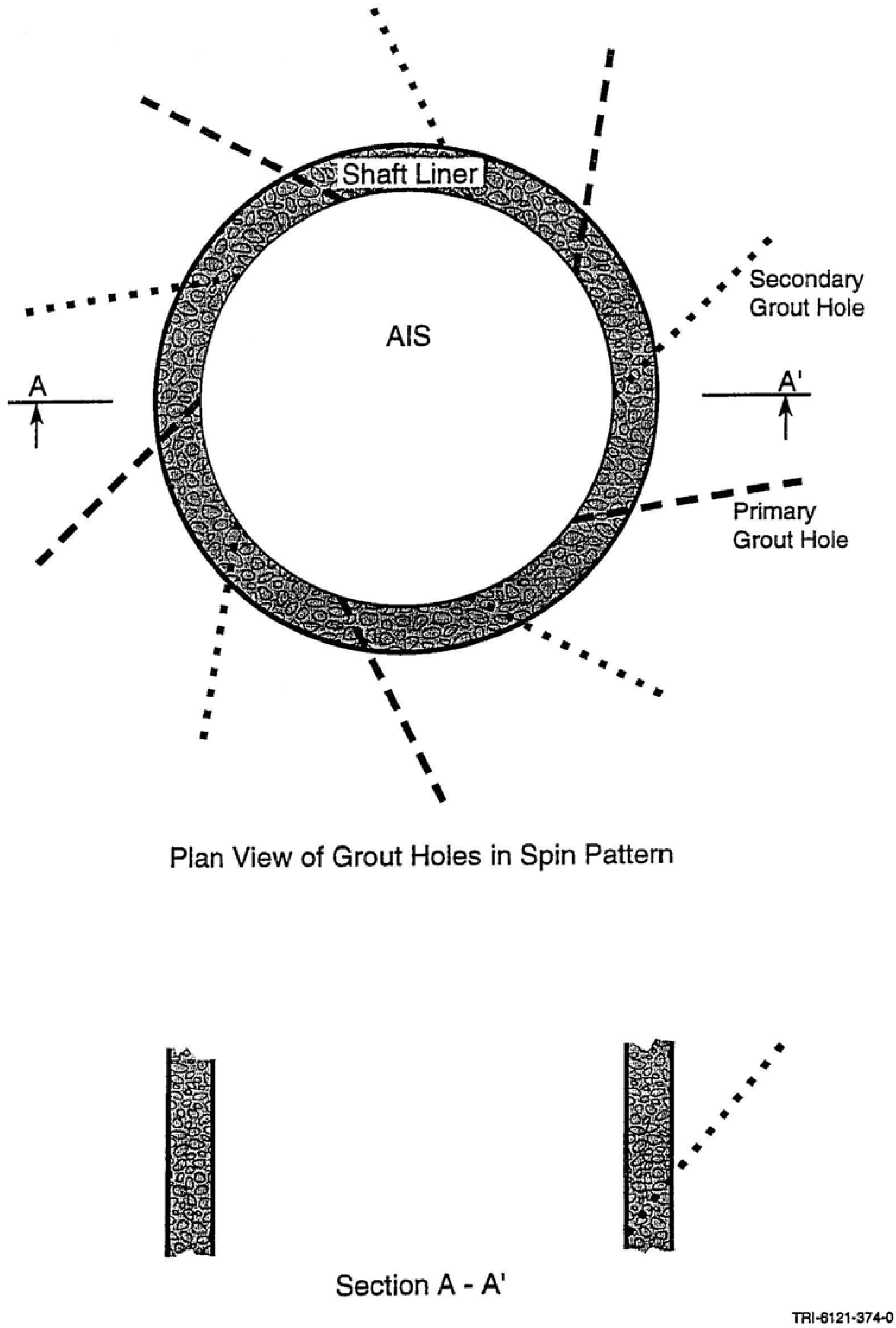

Figure I2B-6
Plan and Section Views of Upward Spin Pattern of Grout Holes