Sector Service Area Shafts

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This note describes needs and some possible configurations for the SSC sector service areas with particular emphasis given to the shafts which connect ground level facilities with the collider ring. Its purposes are to provide guidance and some specification to the Architectural Engineering/Construction Management firm who will be contracted to perform the final design, as well as to stimulate discussion and illuminate areas that need further study.

List of Illustrations

Sector Service Area

1. Description

The collider ring is divided into ten sectors each of which forms a basic functional unit of the ring. Each sector has its own refrigeration plant, power supplies, personnel and equipment access, all of which are provided at the service area. A conceptual perspective drawing, fig. 1, shows what a service area facility might look like.

Nominally, each service area centers around a shaft, which is a concrete lined vertical hole, 30 ft. in dia., which extends from the ground to the level of the collider tunnel. Shaft length may vary, from 30-1500 ft. depending on the site chosen, with an average shaft depth estimated to be 300 ft. deep (for modeling purposes only). A 200-300 ft. long entry tunnel then connects the shaft to the main tunnel (fig. 8). A shorter side tunnel, ≈50 ft. long, used initially for tunnel construction (mucking), is sealed for radiation protection, with 15-20 ft. of concrete shielding, leaving an alcove at the base of the shaft which can be used for refrigeration components, power supplies, etc. A duct is located under the floor of this side tunnel and contains the magnet power buses and refrigeration transfer lines which connect to the ring at the feed spool. At the spool, a power alcove is present for a small valve box and a distribution transformer.

The above-mentioned shaft and connecting tunnels represent one possible construction scenario for lowering a tunnel boring machine (TBM) to depth in many different types of geologies and depths. Tunneling contractors may propose other scenarios which look somewhat different than the above-mentioned plan. Some site scenarios may exist which can take advantage of "cut and cover" or other construction methods. Deep tunnel depths present certain problems of their own. See the section on Site Variations for a discussion of these.

There are three phases of service for each service area:

1. Construction (of the tunnel itself, plus the buildings)
2. Installation (of tunnel services, magnet strings, cabling,etc.)
3. Operation (includes security, maintenance and repair)

This paper deals mainly with operational requirements; the construction and installation requirements will be the subject of a later paper.

2. Major Systems

2.1. Refrigeration

The main components of the rerigeration system are:

1. Compressor plant.
2. Cold box (2 parts).
3. Transfer line, cold, connecting the cold box to the feed spool.
4. Liquid cryogen storage dewars.
5. Helium gas storage tank fram.

The components described below are derived from the CDR plant design, commissioned from CCI, combined with a 1.2x increase in size. Currently, advance planning for a possible upgrade capacity increase of 1.4x is being suggested, which is not reflected in the description which follows.

2.1.1. Refrigerant piping

If all refrigeration were located above ground, including the cold box, an 18- 24" O.D. transfer line would carry refrigeration to the magnets in the tunnel.* This line would contain two 4°K feeds, two 4°K return lines, one 4°K gas return, two 20° and two 80° K shield lin This pipe would accommodate the two coldest heat exchangers at magnet level and might swell to ≈24-30" O.D. for approx. 6 feet at magnet level. A pump and subcooler, (dimensions on the order of several feet) may also be present at magnet level. A separate 6-8" O.D. (est.) helium gas return pipe for lead boil-off is also necessary.

Sector Service Area

In the case of the cold box being located at magnet level, with the compressor plant and liquid storage located above ground, the only cold lines in the shaft would be for liquid storage supply and return.
All pipes from the compressor plant are at room temperature. There are 6 pipes, ranging from 4-12" O.D. which run from the cold box to the compressor plant.

* P. VanderArend, memo to J. Sanford, 3/87, plus discussion w/ M. McAshan, 11/87

2.1.2. Cold box

The cold box is a vacuum insulated container, in which resides a number of heat exchangers and turbo-expanders. There are two parts to the cold box, a heat exchanger box, and a valve box, with two 2 ft. dia. lines connecting the two. The heat exchanger box might measure as much as 12 ft. dia. x 30 ft. high (CDR design x 1.2). The valve box has dimensions of ≈8 ft. dia.x 27 ft., and is mounted horizontally at the base of the heat exchanger box.

Installing the cold box at magnet level (vs. above ground) would save on operating costs ≈$20/ft.-yr. per refrigerator, or, for a 300 ft. average shaft depth, about $60,000/yr, collider total. This must be weighed against the additional cost and complexity of installation and maintenance at depth. Locating the cold box at magnet level is not a design necessity for shaft depths of up to 1000 ft. For shafts deeper than 1000 ft., a pump and subcooler can be added (each measuring ≈16" dia.x 6' long) to the shaft transfer line.* It is quite possible the pump and subcooler will be present at magnet level regardless of depth.

If the cold box is located at magnet level, an LCW supply and return line (for the quench protection energy dumps) would be tapped to cool the expander bearings and dissipate the work done. Oil skids would be present near the base of the cold box for bearing supply. The cold box, as envisioned does not seriously interfere with the proposed scheme of lowering magnets, though visibility and personnel access to the lowered magnets is hindered. This cold box would be serviceable, in situ, upon the removal of its "lid" which would have the same nominal dimensions as the cold box. The lid would be light enough (or sectioned) to lift completely out of the shaft and be set aside with a crane, in order to provide overhead safety and peace-of-mind for crews working on the cold box components. Since the cold box is not located in the center of the shaft, the crane would need transverse hook movement capability, which would preclude the use of a mine hoist for lifting it (see sec. 2.5.4 for description).

* ref. P. VanderArend, memo to J. Sanford, 3/87 plus conversation

2.1.3. Compressors

These items will be located at the surface, near the cooling towers. Screw compressors are typically very noisy, so they are housed in their own building. As the input and output is ambient temperature gas only, and there is little cost associated with pumping gas up or down sizeable shaft lengths,there is no great need to locate them at or near magnet level. Possible reasons for locating them at magnet level would be to minimize ground level environmental impact (noise and space limitations).

Floor space requirements for a compressor plant building are estimated ≈500-600 sq. meters, which is also what HERA has provided for each of their compressor plants, which have the same output capacity as a sector plant. See sec. 2.1.6 for details. Massive foundations should not be needed as there are no large reciprocating compressors used.

2.1.4. Cooling water

Waste heat generated is estimated at 4.2 MW per sector. 70% of this heat is generated by the refrigerator compressors. The other 30% comes from (LCW cooled) power supply waste heat, energy dump cooling, and waste heat from the turbine expander bearings. Two cooling towers are indicated, each with approximate dimensions of a 10 ft cube. Total water flow rate is 965 GPM (690 GPM from compressors, 275 from other) at a total temperature rise of 30°F (inlet temp=115°F; outlet temp 85°F). Water wells will be drilled to provide makeup water. LCW requirements are 220 GPM. Piping in the shaft will be sized for 300 GPM min. (4" sch. 40 pipe). A 6 ft. dia. x 6 ft. high LCW makeup water tank plus a pump and several small polishing filters are necessary.

2.1.5. Refrigerant storage

Liquid helium capacity required is currently 240,000 liters (8000 cu ft). A 12' O.D. dewar would provide 10' I.D. useable cross-section. Three 40' long tanks x 12' O.D., similar in shape to those pictured in figure 1, would be needed. A single dewar, if used, would have dimensions ≈20' dia. x 30 ft. long, or high. To minimize heat leak this tank(s) should be located as near to the shaft as is possible, though allowance has been made in the refrigeration cycle model for ≈200 ft. of connecting line between the tank and the shaft. Helium gas storage requirements are 660,000 SCF, which can be stored, at 16 atm, in 20 tanks, each measuring 8 ft. dia. x 40 ft. long, or equivalent.

Liquid nitrogen storage (20,000 liters) will also be needed and should be located as close the shaft as is feasible. One dewar, 12' O.D.' x 40' long would suffice. Nitrogen gas will be discharged to the atmosphere, during cooldown.

2.1.6. Deep shaft considerations

Shaft depths of 1000 ft. or more may require a substantial amount of equipment located at tunnel level, to reduce pressure differentials. This is necessary in order to maintain a certain temperature range for the magnets which keeps the magnetic field within allowable limits. Locating the cold box assembly , or some part of it, at magnet level would eliminate this pressure differential.

If, for environmental reasons, it is desired to put the compressor plant downstairs, an additional 3600 sq ft of floor space (9 first stage compressor skids, 4 second stage skids, @ 20'x6' each*** with a 4 ft walkway between) would be required. With a 12x20 ft (arched) ceiling, this equals ≈2000 cu yds of excavation. Minimum cost for excavation, in good rock is ≈$200/cu yd. min. (rock)* or $400,000 minimum excavation cost for these components. Many associated components, such as filters, valves and pumps are not reflected in this estimation, however. A typical cryogenic plant at HERA (they have three in one building) has ≈900 sq meters floor area, in which are located the compressors, oil/water removal equip., gas coolers, cold boxes and valve box. The compressor plant (plus oil removal) portion takes up a little over half of this area, or ≈600 sq m. This plant has approx. the same output as that of a typical sector plant for SSC. Note that gas and liquid storage is not included. An underground cavern 60 meters long, 10 meters wide and 10 meters tall (maximum, with arched roof) represents an approximate estimated size. The narrow configuration saves on excavation and support costs by minimizing the extra excavation and support for the roof arch , and little difficulty is seen with this plant arrangement. As no components are estimated to be more than 3 meters tall, the ceiling height should allow component removal up and over other existing components. Estimated minimum excavation cost, in sound rock, for this configuration would be [(60x10x10] cu. meters x $220/cu. meter = $1,300,000. Providing the same space at ground level is estimated to cost ≈ $300,000, including sound insulation.

Waste heat from compressors would be removed with industrial water, which would require pumping to the surface cooling towers. To pump 960 GPM up an elevation of 1000 ft. would require ≈ 300 hp. Pumping would be done in 200 ft. stages. Pipe size for 960 GPM would be 6"-8" sch. 40.

Gas storage and pumping would be at ground level, as there is negligible cost involved in pumping gas up and down these heights. Liquid refrigerant storage can be located either at ground level, or at magnet level. Ground level storage, combined with pumps at magnet level would require the development of circulation pumps which are not commercially available at this time. They are not technically unfeasible however, and estimated cost after development is ≈$100k/pump**. Liquid helium (60,000 gal) and nitrogen (20,000 gal) storage at magnet level would require additional excavation to accommodate four insulated tanks, (three helium, and one nitrogen) each ≈12 ft. dia.x 35-40 ft. long, or equivalent. Estimated minimum excavation cost (with several feet clearance) = $400,000 (≈2000 cu. yds. @ $200/cu. yd).

* unit cost from M. Riddle, RTK
** P. VanderArend, conversation, 9/87
*** M. McAshan, conversation 8/87

2.2. AC Power Distribution

2.2.1. Transformers

There are several types, 35-13.8 kV, 35 kV-4160 V, 13.8 kV-480V, 480-120/240. The 35-13.8 kV and 35 kV- 4160 V are located at ground level, and can be seen in fig. 1. The 13.8 kV-480V are located at 1 km intervals along the tunnel in special alcoves, toward the inside of the ring. The 480-120/240 transformers are small and are located every 315 ft. along the tunnel. Size of these transformers does not present a transportation problem through either the shaft or tunnel .

2.2.2. Cabling

Present plans specify two 35 kV and one 13.8kV, 3-conductor copper, 500 MCM (thousand circular mil) cables, armored and jacketed, which will circle the ring. All cables will be routed up to the ground at both service and exit/vent shafts, for connection at ground level switchboxes. Continuous length cable (no splices) will be used for reliability, making the longest section of 35 kV cable ≈2.5 miles long. 13.8 kV cable sections are 1 km long, transformer-to-transformer. Cables can be installed and guaranteed by the manufacturer as a turnkey cable system. Fire retardant, non-toxic, halogen-free cable is readily available. Maximum tension that can be applied from clamps on the jacket is typically 1000 lbs. At ≈13 lbs/ft. the maximum distance between the supports of a vertically mounted cable would be 77 ft.

2.3. Magnet Power Supplies

2.3.1. Main Bus

If used, normally conducting buses would be no larger than 2" x 2" square copper conductor, 4 per shaft. Power dissipation, per conductor, is ≈1 kW/ft, at full current, which will necessitate cooling. If power supplies are located at ground level, operating cost for each sector is then estimated (@$0.07/kW-hr, 80% usage) to be $2000/ft-year; cost differential for a 50 ft. shaft depth equals ≈$100,000/shaft-year. LCW cooling requirements for a 30 ft. section of each bus is ≈7 GPM (30°F temp change). Cost of the conductor itself is ≈$300/ft of shaft depth (4 buses), or $90,000 for a 300 ft. deep shaft.

Operating costs can be reduced by using larger diameter buses, a super-conducting bus, or by locating the power supplies at magnet level, close to the feed box. Locating power supplies at magnet level will require a floor space of ≈34'x20' (based on the Fermilab SSC design). It is proposed that these components be located in the side tunnel, against the shielding blocks to minimize the bus length.

2.3.2. Instrumentation cabling

Instrumentation cabling will be a minimum in the shaft, with cabling primarily limited to computer links that service the sector refrigeration, and main magnet power supplies. Cabling is CATV 75 ohm co-ax cable. Twelve cables are used in the tunnel for all communication, control, accelerator timing, quench protection and fast abort triggers. A subset of these lines will connect to the sector computer, through a duct mounted along the shaft.

2.3.3. Energy dumps

These are part of the quench protection system, and serve to dissipate the stored magnetic energy of the sector. They are estimated to be 3.5' in all dimensions, with 4 per sector located near the shaft, and another 4 located at each exit/vent shaft. LCW is piped to and from these dumps to a ground level heat exchanger.

2.4. Personnel Transport

2.4.1. Elevator/Stairs

The elevator will see heavy use during the installation phase, and reduced usage during maintenance. It should be designed to accommodate not only large numbers of people, but should also be useful as a freight elevator, leaving the crane for use in moving the heavier items. The elevator should provide a certain amount of fire resistance, as it is the primary means of escape. The stairwell should only see use during extreme emergency, in the event that backup power to the elevator is lost. For shallow tunnel depths it may see occasional use as overflow access. It will need to accommodate emergency personnel carrying fire fighting and first aid equipment, including loaded stretchers.

The LEP configuration for a typical machine shaft has been designed to provide a fire-resistance protection of 90 minutes for both the elevator enclosure and the elevator cage itself. Figure 6 shows a cross-section. The elevator carries a maximum of 33 people. They use 0.5 sq. meter floor area and 200 lb. per person for design. Current experience at LEP (they are in the installation phase) is that demand is exceeding capacity for elevator use. It is not known at this time if they understand the problem yet. The LEP machine shaft stairwells have been designed accordingly with the above criteria and a similar configuration has been incorporated into the design shown in figure 2.

2.4.2. Crane Platform

The cables and piping along the shaft wall will need to be installed, and on an infrequent basis, inspected, repaired or modified. One solution is to follow the practice at LEP and install stairwells next to the cable trays. LEP shafts incorporate stairwells for cable installation in order to be able to station cable pullers and people at various levels, for pulling some rather stiff power cables. Pipes are also installed from the stairwell. They use continuous cable lengths in the shafts, eliminating the need for testing equipment.

A cable tray stairwell presents a hindrance to crane access to the cold box, if one is present in the shaft. Alternatively, a service platform, suspended from the shaft crane to perform these tasks might be considered, in order to save space in the shaft (provide a larger lowering area) and save on the costs of installing permanent stairwells. One platform can be used for all ten shafts. The platform can also be positioned where desired. Cable laying, with small diameter cable can be done by mounting the cable reel on the platform and laying the cable in the tray as the platform is lowered. For large diameter, heavy cabling with large reels, the cable will likely be reeled from ground level into the shaft. For the task of pipe installation and repair, the platform may require the addition of a small, second level platform (not shown), for positioning pipes at both ends. For platform stabilization, the magnet guide rails can be used, though a third guide rail will need to be installed. A concept is shown in figure 7. Mining operations routinely perform similar activities, using similar equipment, and their safety regulations which cover this type of activity typically specify high factors of safety, low acceleration/deceleration, and runaway, rail clamping "dogs" that prevent sudden dropping of the platform should the crane drum runaway or cable break. Crane design factors of safety are normally ≈5 for material loads and ≈7 for personnel loads Therefore, a 15 ton rated crane would be limited to ≈11 tons when loaded with a platform, personnel, equipment, and material.

2.4.3. Personnel Access control

Personnel access is to be controlled such that it is known, at all times, who is in and who is not in the shafts and tunnels. This will require a manned gate or electronic ID system at each elevator/stairwell entrance. Additional personnel accounting may need to be performed at the start of the entry tunnel to keep track of those in the tunnel. Key interlocks can be used, however there may be large numbers of people present during shutdown, and key interlocks do not assure that more than one person cannot use the same key for entry. LEP is investigating the use of single person admittance doors to provide positive accounting; these may well prove to be a hindrance to many activities.

The service area as a whole may need to be considered, due to public perception, as a nuclear facility, and thus a potential , though unlikely, site for sabotage. This is the case with LEP, at CERN, and strict security measures, including high fences, electronic intruder detection alarms, electronic I.D. admittance systems, are utilized to safeguard the facility.

2.4.4. Deep shaft considerations

Emergency egress may require safe rooms or alcoves at regular intervals along the stairwell (and/or elevator), to allow people to rest periodically while ascending. Longer transit times may require larger elevator capacity, or high speed capability.

2.5. Magnet and Equipment Transport

2.5.1. Safety

The shaft has a centrally located area for crane usage of aprox. 6 ft.x 27 ft. however, the entire area exclusive of the protected elevator/stairwell should be considered a hazardous area for falling objects. Objects falling from heights greater than 50 ft. can ricochet dangerously upon hitting the floor, or cold box, if present. It would be desirable to allow material handling concurrent with personnel access to and from the tunnel. It would be safest to simply prohibit personnel from the bottom of the shaft on a routine basis, allow them into the zone only for special tasks, such as unhooking dipoles, or repairing refrigeration components, after safeguards have been initiated for these operations. A protected walkway from the elevator/stairwell to the side tunnel would provide this access and would require additional excavation at the bottom of the shaft. In addition, a solid door separating the entry tunnel from the bottom of the shaft, should be built; one which would withstand the force of a substantially heavy ricocheting object dropped from the top of the shaft.

2.5.2. Magnet Replacement

For time reasons, 10 magnet replacements per year have been established as a maximum allowable, with 5 working days allotted for each event.* Fast replacement is essential. There is one day allotted for section warm-up, which is enough time to deliver a magnet from the campus area storage building, to a particular shaft, and then to the site for installation. It will be desirable to match the replacement to its neighboring magnets from as large a group of spares as possible. Controlled storage of the spares will likely be best performed at one central location, above ground.

As currently configured (figure 8), no area exists for magnet storage in the entry tunnel area of the shaft. This space will be needed for transporter routing and shielding. If underground storage of magnets is desired, this entry tunnel will need considerable extension.

Maximum travel time for a magnet delivery from a single ring location to any other point in the ring would be 26 miles/5 mph=5 hrs. 5 hours is probably too long for 2 people to spend sitting in a slow-moving magnet transporter, so driver substitution halfway would be necessary. Alternatively, two diametrically opposed shafts, one at the campus area, and one at the far cluster area could be used for magnet loading. A replacement magnet can be ready and waiting at the installation site as soon as the defective one was removed from the string. Magnet handling equipment (15 ton crane, lift fixture, wall slots, guide rails, etc.)

would not need to be present and operating in more than two shafts, after the collider is completely built and operating.

* SSC-5, Report on Operations and Commisssioning

2.5.3. Dipole Installation

Weight

Dipole weight is estimated at approximately 12 tons. A strongback style lift fixture which cradles the dipole and allows rotation about the center of mass would weigh around 2-3 tons. This is the heaviest load the crane would see, so a 15 ton severe service crane is indicated (deep shafts will require a 20 ton crane due to extra weight of cable). To minimize the complexity of handling, the dipoles should be built such that the lifting fixture attaches directly to the upper mounts. This allows the magnet to be lifted directly off the floor, or truck bed and loaded directly onto transporters, once down the shaft.

Magnet handling constraints

The process of lowering dipoles into the shaft and onto the underground transporters is a process that needs to be fast, efficient, safe, and easy on the magnets. The dipoles are designed to withstand maximum (static) loads of:

1.5 g in the axial (longitudinal) direction
2.0 g in the vertical direction (along supports)
1.0 g in the transverse direction

Suspending the dipoles (near)vertically (at rest or moving at a constant velocity) will subject them to approx. 1.0 g in the axial direction, after which an additional 0.5g max. is left for total applied force (=1.5g braking force). This leaves no room for error, though, and it would be necessary to limit additional braking force to 0.1-0.2 g for a better safety factor. This process must be absolutely smooth and controlled; however, modern crane controls can routinely handle such delicate tasks. A typical crane hook speed for a 20 ton overhead crane is ≈35 feet per minute, or 0.58 fps. Applying a total braking force of 1.1 would require [0.58 fps/(0.1)32 fpsps]= 0.18 seconds to stop the load, which is negligible. Stopping distance is a negligible 0.64". Crane speeds of up to 150 fpm are possible, and would similarly require 0.8 sec to stop (1.0 ft stopping distance at hook), at 1.1g braking force. The hook speed will be ramped down well before it reaches the final few feet of its travel, so no problem is anticipated here. The guide rail/lift fixture system needs to be straight and smooth to avoid jarring loads during the descent. The quadrupoles, and spool pieces will also need delicate handling, however, they are short enough to be loaded conventionally into a 30 ft dia. shaft without tilting them from the horizontal. The only requirement here, is to prevent them from rotating around the vertical axis while lowering. This can be accomplished by using the guide rails, though simply locking the crane hook might suffice.

Lowering scheme

Lowering dipoles into the shaft first requires tilting them at a steep angle to allow them to travel down the shaft, then righting them as they reach tunnel level. A proposed scheme is shown in figure 3. This scheme utilizes a set of guide wheels and rails in conjunction with a swing arm which captures the leading guide wheel as it leaves its guide rail, thus guiding the magnet back into a horizontal position, at floor level. A strongback lifting fixture holds the magnet from its top supports, shown in figure 5. This allows lowering the magnet directly onto a waiting transporter at the bottom of the shaft; after unloading, the lift fixture is then sent up empty to pick up the next magnet. A slot is cut into the wall, at the bottom of the shaft, and installed with a curved section of guide rail for the trailing end of the dipole. This allows the block lines to stay clear of the shaft wall, and allows a near vertical hang for the dipole, reducing or possibly eliminating the need for one of the two possible transverse movements of the crane drum. The lift fixture is not unhooked from the crane blocks, nor uncoupled from the guide rail system. The motion of the lift fixture, with or without its dipole, is completely constrained, and reduces the magnet handling problem to a simple raise/lower crane operation. The lift fixture can be designed to lower not only dipoles, but also pipes, cable trays, etc., should lengths greater than 27 ft. long be feasible and desirable to use.

A similar method (slot with boom arm) could also be used for guiding the dipoles into the shaft, however, a potentially simpler scheme is shown in figure 4. A large diameter drum is used to guide and rotate the dipole until its other end can be fed onto the shaft guide rail. The drum then continues to rotate the dipole completely into the shaft, feeding the other end of the dipole lift fixture into its guide rail set. This scheme has the obvious advantage of not requiring a slot in the top of each shaft, plus the drum may be transported to different service areas as needed. The crane, however will need transverse hook movement coordinated with vertical hook movement, in order to keep the block lines vertical. A computerized crane controller will be necessary, which is a standard item these days.

For initial pickup from a truck bed, a brake would be set on the lifting fixture to hold the dipole in a horizontal position. This is necessary because the lifting fixture is designed to pivot around its center of mass, both with and without the dipole attached. Rotation around the combined center of mass is desirable to minimize the load on the guide rails, the capacity of the lift fixture brake, and the risk of damage and injury should the brake fail.

Other considerations

The crane will need dual controls, which automatically switch from upstairs to downstairs control, as upstairs operators will not be able to see and spot the magnets onto the transporters, once they go down the shaft, and vice versa. This system would require automatic braking to occur in the event the downstairs operator was not at the controls when the load reached the lower part of the shaft. Two operators need to be present while operating the crane, one upstairs and one below, each in communication with each other, for the crane to be operable. This will ensure that no one is caught unawares by a sudden crane start-up. Deep shafts and fast lowering speeds indicate a need for high-capacity braking capability. Monitoring accelerometers mounted on the first magnets, or dummy loads should be used to analyse the complete loading cycle, to identify potential problems. Computer control of the crane can be used for more repeatable crane operation, during certain parts of the cycle, if needed.

2.5.4. Deep shaft considerations

A 15-20 ton traveling overhead drum crane with a hook travel of 1000 ft. costs approx. $300,000, as opposed to $150,000 for a 100 ft. hook travel design. Drum size would be around 8' dia.x 8' long or equiv. Travel times become accordingly longer, though fast lift speeds (≈200 fpm) are possible. A large drum crane design will likely require orienting the axis of the drum parallel to the long dimension of the lowering zone. This will have the effect of reducing the transverse travel capability of the crane. This is not seen to be a problem, as all loads except the cold box can be lowered along the centerline of the shaft.

An alternative to installing such a crane is to use adjacent shafts for lowering magnets, transformers, pipes, and cables and then use transporters to travel the extra distance in the tunnel, however, the refrigeration components, as mentioned in the preceeding paragraph, might not fit through the tunnel.

A large (temporary) boom crane, such as those used at construction sites, could be used to lower these items into the shaft, as these cranes often have substantial hook travel.

Handling the sector magnets with such a crane might also be done, however this process would be substantially slower and riskier to the magnets, due to the large amount of manual control and communication going on between load spotters and crane operators. Such a crane would need a fair amount of control modification to prove efficient. Either the roof and possibly the sides of the building over the shaft would be removed as this type of crane is much too tall to operate inside the building.

Another alternative would be to use a mine hoist (no horizontal hook movement), which typically has a long hook travel capability. This type of crane typically uses a stationary, ground mounted winding drum located off to the side of the shaft, in conjunction with a pulley suspended over the shaft on an tripod support. Provision for moving loads underneath the hook would be separate from the crane. This can be accomplished using a rolling transfer platform mounted on rails. A separate crane located to the side would be necessary to pick loads up off of truck beds, (or perhaps from a set-aside storage area adjacent to the truck unloading aisle) and transfer them to the transfer platform.

As shaft depth increases, danger from falling objects increases. From any one person's viewpoint, it becomes more and more difficult to tell what is going on at the opposite end of the shaft. The need for a shaft hatch which will close the shaft may occur. The logical place for a hatch would be at the top of the shaft, to prevent falling objects from gaining velocity and possibly puncturing a lower hatch. The design must accommodate the ventilation requirements on the shaft.

2.5.5. Transit times

Times for a typical crane operation cycle can be (rather roughly) estimated using different crane speeds. Given a shaft depth of 300 ft.,two possible crane speeds, a 40 ft.transverse movement from truckbed to shaft, and a well designed and executed procedure for operation, a typical crane cycle for loading a dipole onto a transporter might look like something like this:

Task	(Gu)estimated Time(minutes)	
1. Lower lift fixture onto dipole	3	
2. Mount dipole to lift fixture	5	
3. Unmount dipole from truck bed	3	
4. Lift dipole off truck bed	2	
5. Move dipole over shaft (40 ft.)	2	
6. Connect one end of dipole to guide system	2	
7. Guide other end of dipole onto guide rail	1	
8. Lower dipole down shaft (300 ft.)	10 (30 FPM)	2 (150 FPM)
9. Spot dipole onto waiting transporter	2	
10. Mount dipole to transporter	3	
11. Un-mount dipole from lift fixture	2	
12. Raise lift fixture up shaft	10 (30 FPM)	2 (150 FPM)
13. Disconnect lift fixture from guide system	2	
14. Move lift fixture to waiting dipole on truckbed	2 (30 FPM)	1 (100 FPM)
Total cycle time =	49 minutes	=31 minutes

2.6. Miscellaneous Services

2.6.1. Transporter Support

A fleet of rubber tired vehicles will be needed to transport magnets, equipment, and people. Due to the large distances involved, these transporters will need bi-directional travel capability and passing capability. The transporters are normally guided and take their power through a "third rail", mounted along the tunnel wall. Battery backup power allows movement when not attached to the third rail. Because the transporters are an important means of egress, the third rail should take its power from high priority power source such as the tunnel mounted 13.8kV-480V transformers. They will enter and leave the tunnel via the entry tunnel and must be able to be spotted accurately under the shaft to facilitate swift loading of equipment carts and magnets. Figure 8 shows a schematic of the paths this transporter should take. The guide rail will be installed only in the collider tunnel itself along the wall where there is no normal foot traffic, including the entry tunnel and alcove areas.

Where the transporter enters the entry tunnel it must be accurately guided along the curved path to avoid collision with the shielding blocks. The entry tunnel, from the airtight doors to the collider ring should be considered off limits to foot traffic, thus allowing a guide rail to be mounted on the floor. As the transporters emerge from the entry tunnel into the shaft they will need proper guidance for accurate location under the shaft. Either a painted guide line, read by optical sensors, or, perhaps a buried magnetic one, which the transporter can sense through several inches of concrete, would provide this capability. Note that a similar system may be necessary all along the tunnel, in order to prevent transporter-magnet collisions during passing maneuvers, or while passing the isolation boxes, which have u-tubes projecting into the center right-of-way.

The bi-directional capability will likely require steering units on both ends for tunnel travel. As the transporters are rather long, it will be safest to always require driver presence on the leading end of the transporter. In other words, no backing-up allowed; a single driver would be required to get off the transporter, walk to the other end, get back on, then drive in the reverse direction. As such, the magnet lowering slot proposed in this paper would need to be extended a short distance (additional excavation at the base of the shaft) to accommodate a manned steering unit on the end of the transporter, including walking access to it.

2.6.2. Sump Pump System

Sumps, with internal pumps are located in the shaft, below tunnel floor level, They measure approx. 6 ft.long x 6ft.wide x 10 ft. high. There is one pump at each service area, and one pump at each exit/vent shaft. Each pump receives flow from 1.25 miles of drain pipe from both directions. Current plans are to avoid installing waste water disposal equipment at the exit/vent shafts, so their sump pumps discharge to the two adjacent service area shafts through a return pipe laid in the tunnel floor. These branching discharge lines should be sized to allow discharge in the event of blockage in one branch. The pumps are 250 GPM deep well types and the motors will be sized according to shaft depth, at approx. 15 hp/100ft shaft depth. A 6-8" dia. discharge line will lead to the surface to a settling pond, or sewer line, if one is nearby.

2.6.3. Lights

Lights should be installed along the shaft walls to allow viewing the progress of equipment lowering, locating possible leaks, electrical shorts, loose pipe mounts etc. which may occur.

2.6.4. Emergency power

This will be provided by switching to alternate 35 kV feeders which are brought up to the surface at each service area. It is essential that power failures due to shorts be detected, ohterwise the alternate feeder will also be lost immediately after switching it in.

Emergency power should be made on a priority basis, to limit loading, if needed. Highest priority is given to the ventilation fans, elevators, sump pumps, EMCS system, all alarms, transporter power and safe exit indicators. Second priority is given to the refrigeration system to avoid loss of helium. Main magnet and other power is at third priority. Since tunnel power is used for high priority items, all tunnel power will be high priority.

2.6.5. Ventilation

Present planning is for controlled access to the underground area near the shaft during collider operation, with the entry and collider tunnels off limits, and sealed from the shaft with airtight doors. Ventilation of the tunnel is accomplished with the 4 ft dia. duct shown in figs 1 and 2, and nominally occurs only during maintenance and repair, however the possibility exists whereby continual ventilation may be necessary to reduce radon, hydrogen sulfide, carbon dioxide, or other hazardous gas levels. To allow continual monitoring and possible treatment of tunnel air, the shaft itself is not used as a tunnel vent. Ventilation must also be provided, both for the underground area of the shaft (exclusive of the tunnel), as well as a separate air supply, at overpressure, in the stairwell and elevator column (to prevent smoke ingress in case of fire).

CERN specifies, for the LEP tunnel, a maximum air velocity of 0.5 m/s =(1.5 ft./sec)= 90 fpm, average (French Mining Code). Minimum air velocity is 30 fpm by Federal OSHA standards. Tunnel cross-sectional area is approx 50 sq. ft., thus, maximum air flow rate, by this standard would be (90x50) cu ft/sec= 4500 cfm. CERN also specifies a minimum of 15 cfm/worker for underground working areas which is consistent with ASHRAE * minimum air flow standards (other regulations, such as OSHA, specify maximum pollutant levels and compliance might require higher airflow rates). This would allow 4500/15 = 300 workers maximum in each half sector. This minimum flow requirement is much lower than Federal regulations for underground *construction* which specify 200 cfm/person, minimum. This would limit the number of workers to 4500/200 = 23 per half-sector. Local air purification at pollutive sources can be used to maintain air quality for certain pollutive operations, such as welding and cleaning. This is done at LEP using portable hoods equipped with suction fans and charcoal filters.

The shaft is open during collider operation and will thus need a separate air supply for ventilation during this time. Positive ventilation must be delivered to the most remote underground areas from the shaft , which will necessitate a system of overhead ducts. The supply might possibly be fed from the pressurized staiwell/elevator shaft, though this system may need to be a closed loop system, as is done at LEP for positive isolation and maximum safety. In addition, the presence of cryogenic lines and possibly the cold box in the shaft may require separate high capacity purge ventilation ducts in the shaft. Should a leak occur, substantial amounts of cold and/or liquid nitrogen will settle in the bottom of the shaft and need to be purged. Heated air might be delivered to the bottom of the shaft once the leak is stopped, or the cold gas might be sucked out through a duct (possibly heated). One ventilation duct (not shown) similar to the tunnel ventilation duct shown, would be necessary. A possible location for this duct, in the shaft, is next to the stairwell .

* American Society of Heating, Refrigeration and Air Conditioning Engineers

2.6.6. Survey

Two monuments will be located at the floor of the shaft, sightable from directly above, to allow transfer of survey from above ground to tunnel level. These monuments should be spaced out from the shaft wall at least 0.5 meter, to avoid sighting through net landmarks. This would possibly require a small hatch in the ceiling, with provisions for erecting a tower above it to locate the plummet. Should this not be feasible, an alternate scheme is to locate the optical plummet at ground level, overhanging the shaft, and use additional monuments to connect the plummet to the geodetic network.

2.6.7. Radiation shielding

The shaft area at magnet level requires a minimum of 15-20 ft. of shielding laterally for hadron production (neutrons). The mucking tunnel is sealed just prior to operation, with concrete shielding blocks. Transporter travel through the entry tunnel will preclude the use of a labyrinth with right angled tunnel legs. The desired attenuation coefficient (1.0E-6)* from a point on the ring near the mouth of the entry tunnel to the bottom of the shaft working area will have to be achieved either through the use of a shielding block maze, a moveable shield, or by providing a curved configuration to the entry tunnel. Figure 8 shows a shielding block layout concept which is (first-order) estimated, by use of solid angles, to provide this attenuation. More complete analysis is necessary to confirm its effectiveness. For the cut and cover site a curved tunnel configuration is envisioned, shown in fig. 9. Neutron attenuation in curved tunnels follows an simple exponential decay function, and at least 200 ft. of curved tunnel with a bend radius of 100 ft. is provided, which is estimated to fully provide the desired attenuation (200 ft =13.8£ , where attenuation length £=0.145R; R in meters*. This will allow free access to the bottom of the loading zone during collider operation.

The tunnel will be sealed from the entry tunnel and shaft during operation for ventilation safety, thus a set of stiff, sealable doors will be needed which will withstand local air pressure deviations which may occur from shaft to shaft (from winds, weather disturbances, etc).

* SSC-SR-1031, J.D. Cossairt, Checking the Numbers for SSC Labyrinths, April 1987
* SSC-SR-1031, G. Stevenson, Neutron Attenuation in Labyrinths, Ducts and Penetrations at High Energy Proton Accelerators

2.7. Ground Level Facilities

2.7.1. Crane queue storage space

This is primarily an installation problem. Unless just-in-time delivery scheduling is implemented and quickly optimized, the use of a certain amount of set-aside, ground-level storage will assure that crews working in the tunnel are supplied with materials and components as they need them. Just how much is necessary depends primarily on the availability and efficiency of the campus-to-service area transportation system. Recent experience at LEP has been one of tunnel and shaft construction delays resulting in large stockpiles of magnets and other items building up in storage areas. Subsequently, the simultaneous (rather than sequential) availability of the shafts and tunnel sections has placed an unusually high demand on the delivery systems (cranes, trucks, etc.).

2.7.2. Truck access

Truck unloading will be a constant activity during installation, with possibly several trucks waiting simultaneously to unload cargo. Truck traffic should be routed in a circular pattern, much like a drive-thru restaurant, which will speed the process of aligning a 40 ft. (or longer!) truck bed with the pick-up crane. Trucks should move forward only, as much time is wasted when trucks have to back-up in a loading zone. It is therefore suggested that the truck unloading zone be located alongside the shaft, rather than butting up against it, as figure 1 shows (look closely!). In addition the crane rails should be extended such that the truck can drive directly underneath the crane (not shown).

3. Site variations

3.1. Cut and cover (30-50 ft.) site

If cut and cover construction methods are used for a shallow tunnel, and no 30 ft dia shaft is present, then many constraints are removed from the service area design. Any facilities at magnet level will be constructed in a typical above-ground manner at magnet depth, then backfilled over. The underground space need not contain arches, and may have roof widths of up to 100 ft with straight beam ceilings. Since the elevation difference would not be more than 50 ft., most components can remain above-ground. Penetrations from surface to ground are much less limited in size, configuration, location, and/or number. A possible layout might resemble figure 9. Power supplies, and refrigeration are located above ground and connect to the collider rings via an 8 ft dia. (or smaller) shaft. The shaft is filled internally around the pipes and cables with sand for neutron shielding. Access to the tunnel is through the curved tunnel which provides the necessary neutron shielding. This allows the equipment access hatch to be left open during ring operation. The access hatch can easily be constructed to allow horizontal dipole lowering directly onto the transporters. A tunnel ventilation shaft should be routed through the entry tunnel to avoid possible neutron skyshine which might occur from using a vertical duct rising out of the tunnel.

3.2. Twin shaft site

A certain method of shaft construction, used for medium to deep shafts, utilizes a "starter" shaft, of ≈ 8 ft. dia. which is drilled to depth first, off to the side of where the main shaft will be. Next, a tunnel is excavated from the bottom of this shaft to the bottom of the main shaft site and a full diameter cavern is dug. A borehole is drilled from the surface straight down into the center of this cavern which will become the center line of the main shaft. A "raise bore" cutter head is then assembled from small parts in the cavern and is connected to a large diameter "pull-bore" drilling apparatus at the surface with a large diameter drill string. The shaft is then bored from the bottom up, the cuttings being mucked out through the original small diameter shaft.

The point here is that one is left with an additional small diameter shaft, which can be put to good use. Magnet power buses, and refrigeration lines could be routed directly to the feed box (without traveling under the shielding blocks), as long as service access is available. Service would likely need to be done from man-cages, lowered from a mine hoist. The same shaft could double as a tunnel ventilation shaft, should neutron attenuation not be a problem.

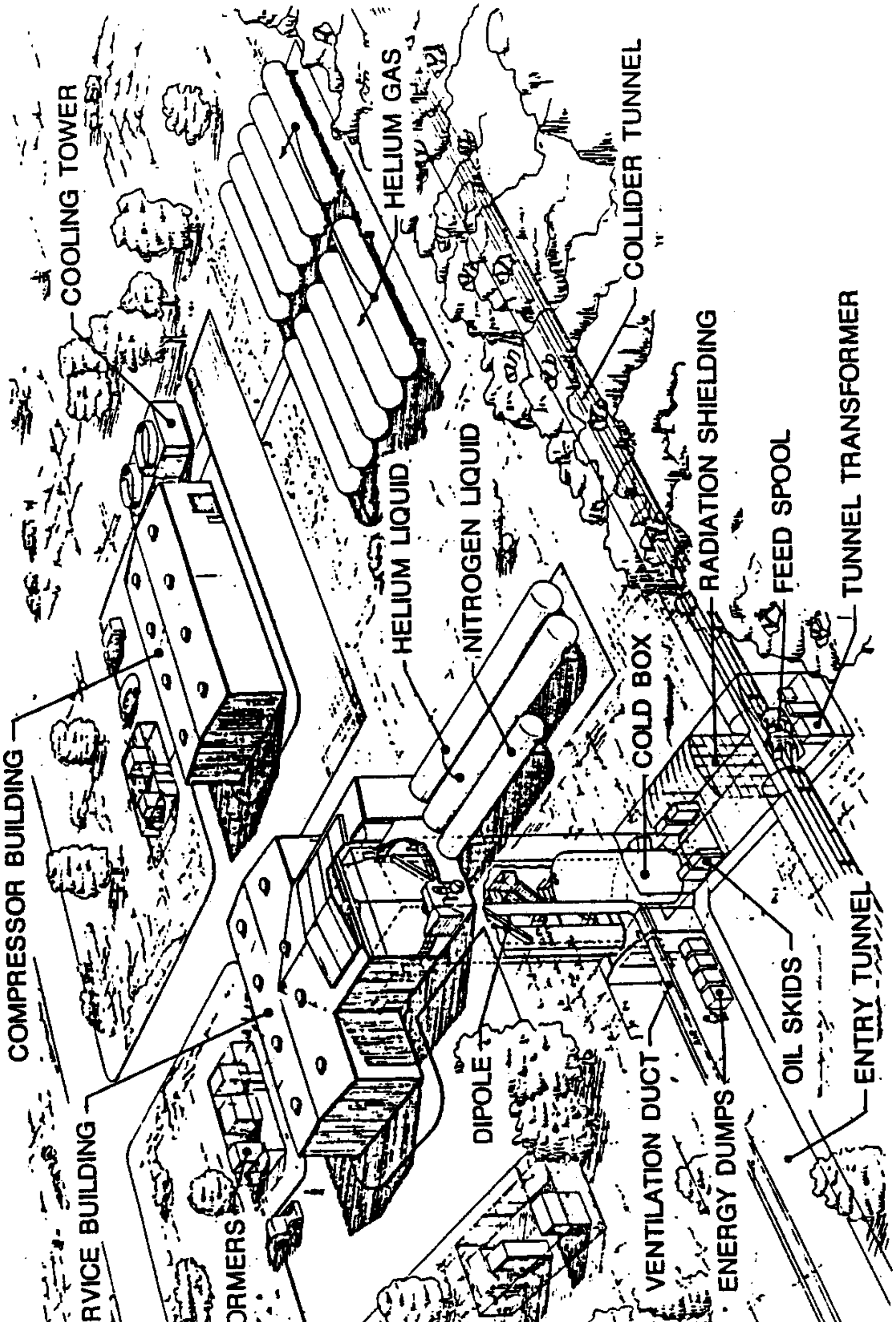

COOLING TOWER
HELIUM GAS
COLLIDER TUNNEL
TUNNEL TRANSFORMER
FEED SPOOL
RADIATION SHIELDING
COLD BOX
NITROGEN LIQUID
HELIUM LIQUID
COMPRESSOR BUILDING
SERVICE BUILDING
TRANSFORMERS
DIPOLE
VENTILATION DUCT
ENERGY DUMPS
OIL SKIDS
ENTRY TUNNEL

FIGURE 1

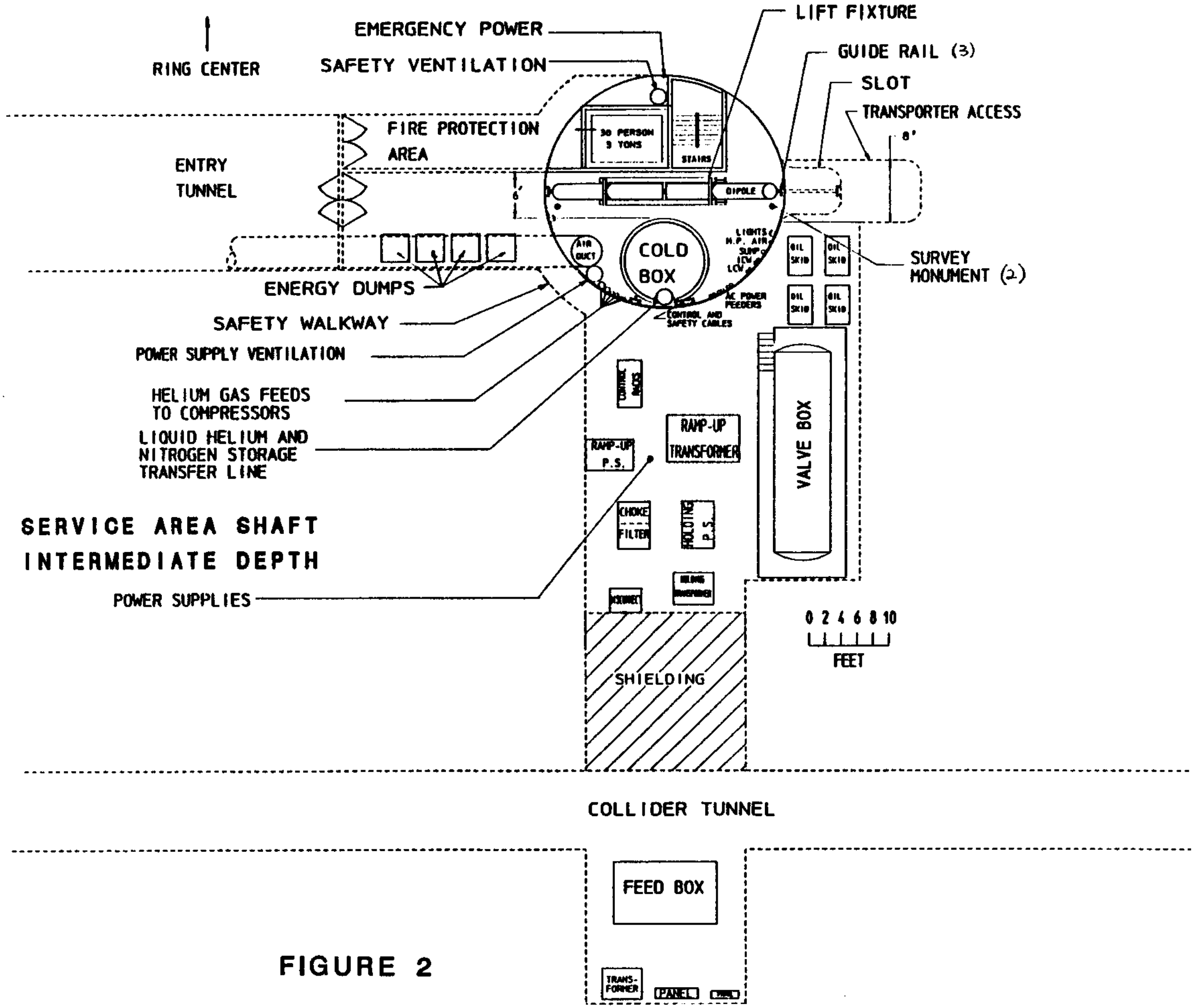

RING CENTER
EMERGENCY POWER
SAFETY VENTILATION
LIFT FIXTURE
GUIDE RAIL (3)
SLOT
TRANSPORTER ACCESS
8'
FIRE PROTECTION
AREA
ENTRY
TUNNEL
30 PERSON
3 TONS
STAIRS
DIPOLE
6'
AIR DUCT
COLD
BOX
SURVEY
MONUMENT (2)
OIL SKID
OIL SKID
OIL SKID
OIL SKID
ENERGY DUMPS
SAFETY WALKWAY
POWER SUPPLY VENTILATION
HELIUM GAS FEEDS
TO COMPRESSORS
LIQUID HELIUM AND
NITROGEN STORAGE
TRANSFER LINE
AC POWER FEEDERS
CONTROL AND
SAFETY CABLES
CONTROL RACKS
RAMP-UP
TRANSFORMER
RAMP-UP
P.S.
VALVE BOX
CHOKE
FILTER
HOLDING
P.S.
SERVICE AREA SHAFT
INTERMEDIATE DEPTH
POWER SUPPLIES
0 2 4 6 8 10
FEET
SHIELDING
COLLIDER TUNNEL
FEED BOX
TRANS-
FORMER
PANEL

FIGURE 2

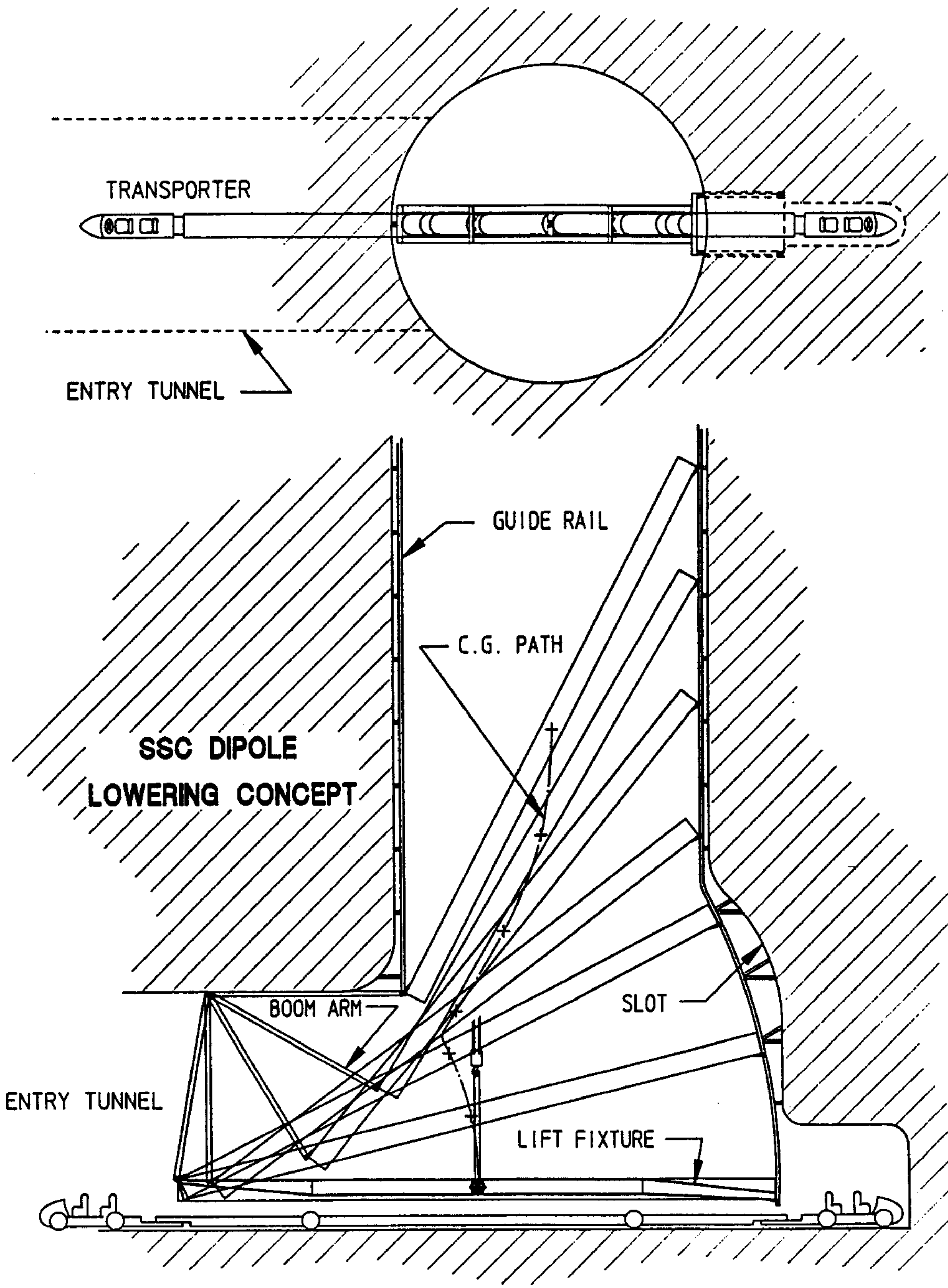
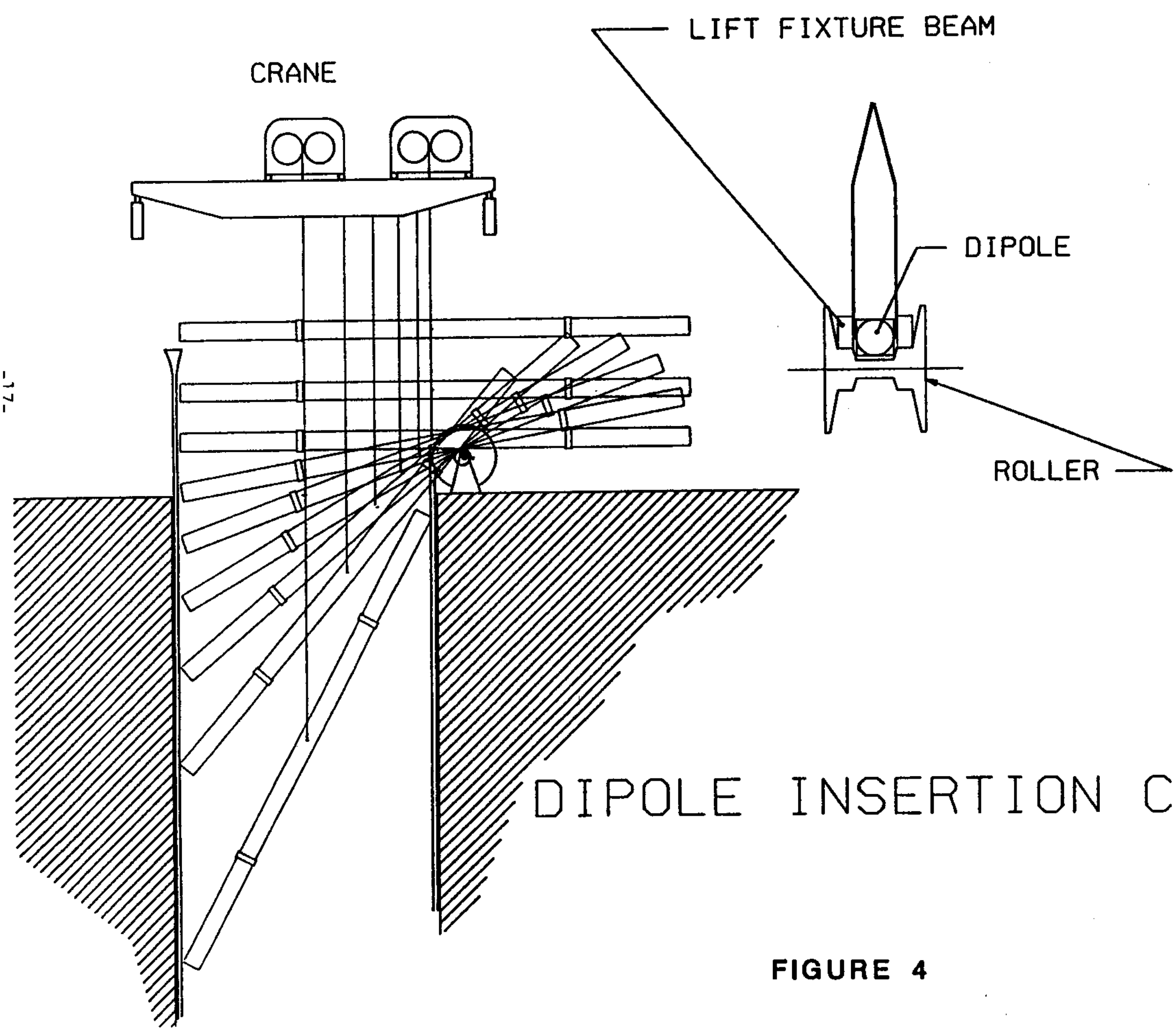
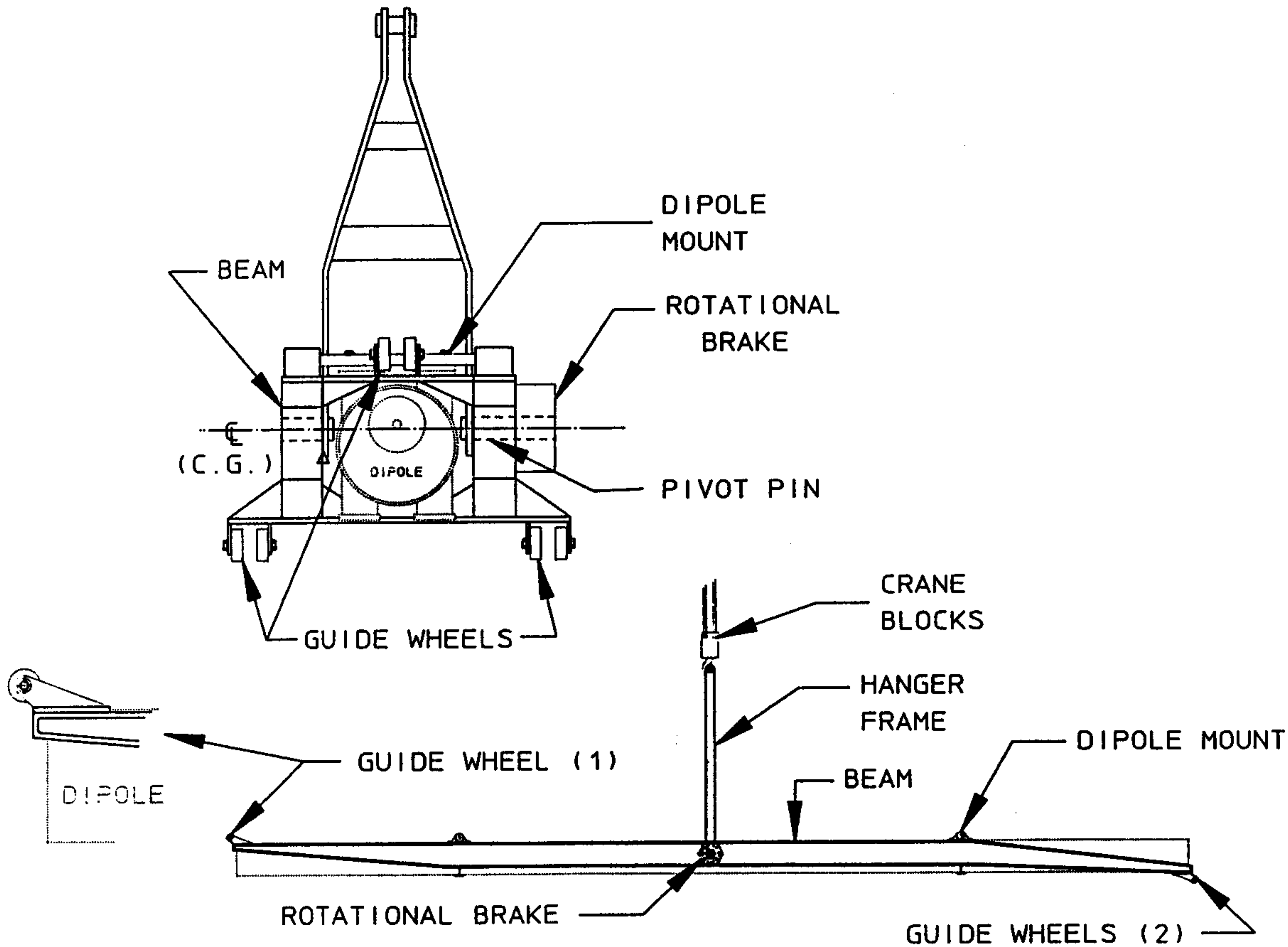

TRANSPORTER
ENTRY TUNNEL
GUIDE RAIL
C.G. PATH
SSC DIPOLE
LOWERING CONCEPT
BOOM ARM
SLOT
ENTRY TUNNEL
LIFT FIXTURE

FIGURE 3



DIPOLE INSERTION CONCEPT

FIGURE 4



SSC DIPOLE
LIFT FIXTURE CONCEPT

FIGURE 5

LEP MACHINE SHAFT, TYP.

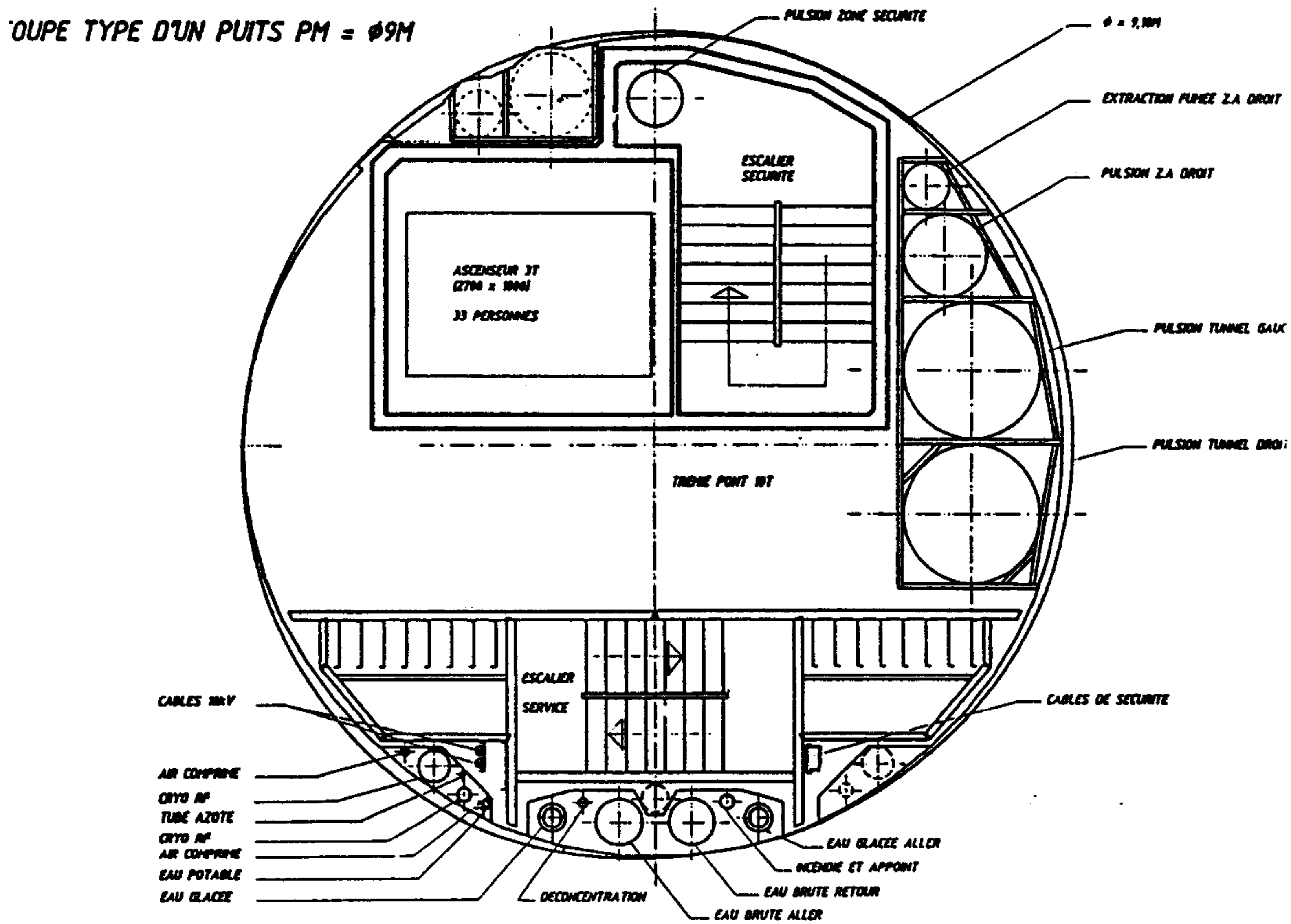


FIGURE 6

SERVICE PLATFORM CONCEPT

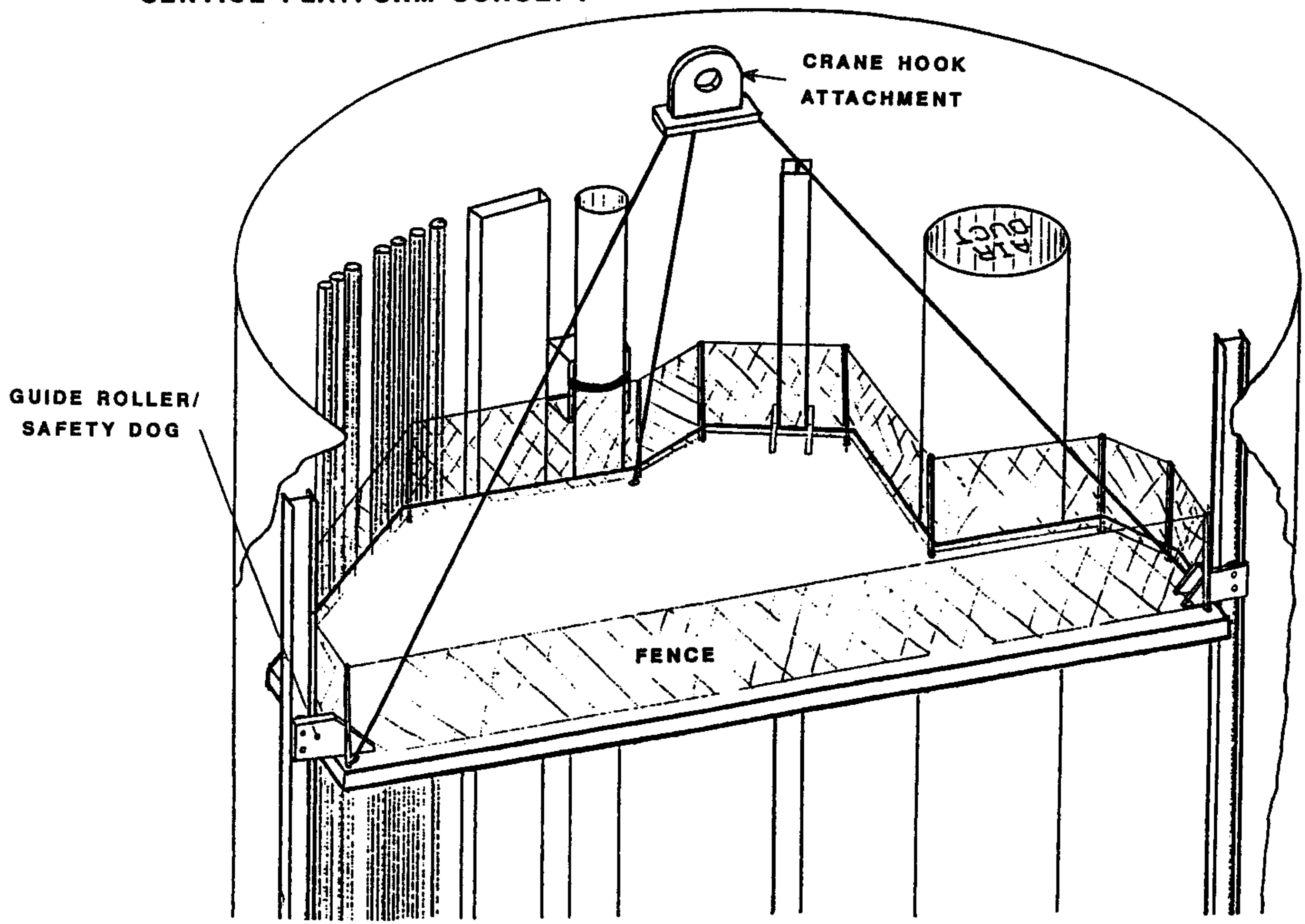


FIGURE 7

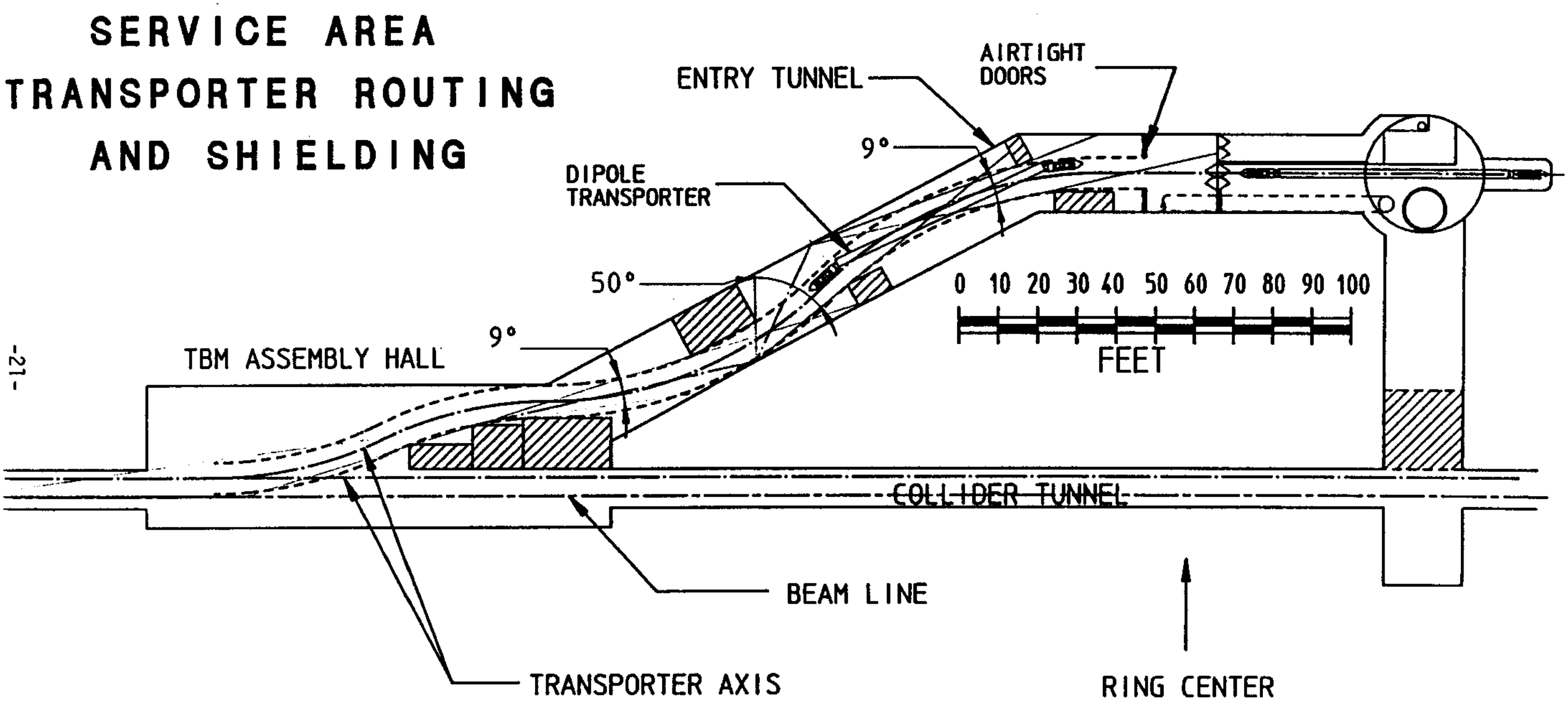

SERVICE AREA
TRANSPORTER ROUTING
AND SHIELDING
ENTRY TUNNEL
AIRTIGHT DOORS
DIPOLE TRANSPORTER
9°
50°
9°
TBM ASSEMBLY HALL
0 10 20 30 40 50 60 70 80 90 100
FEET
COLLIDER TUNNEL
BEAM LINE
TRANSPORTER AXIS
RING CENTER

FIGURE 8

SHALLOW, CUT AND COVER SITE VARIATION

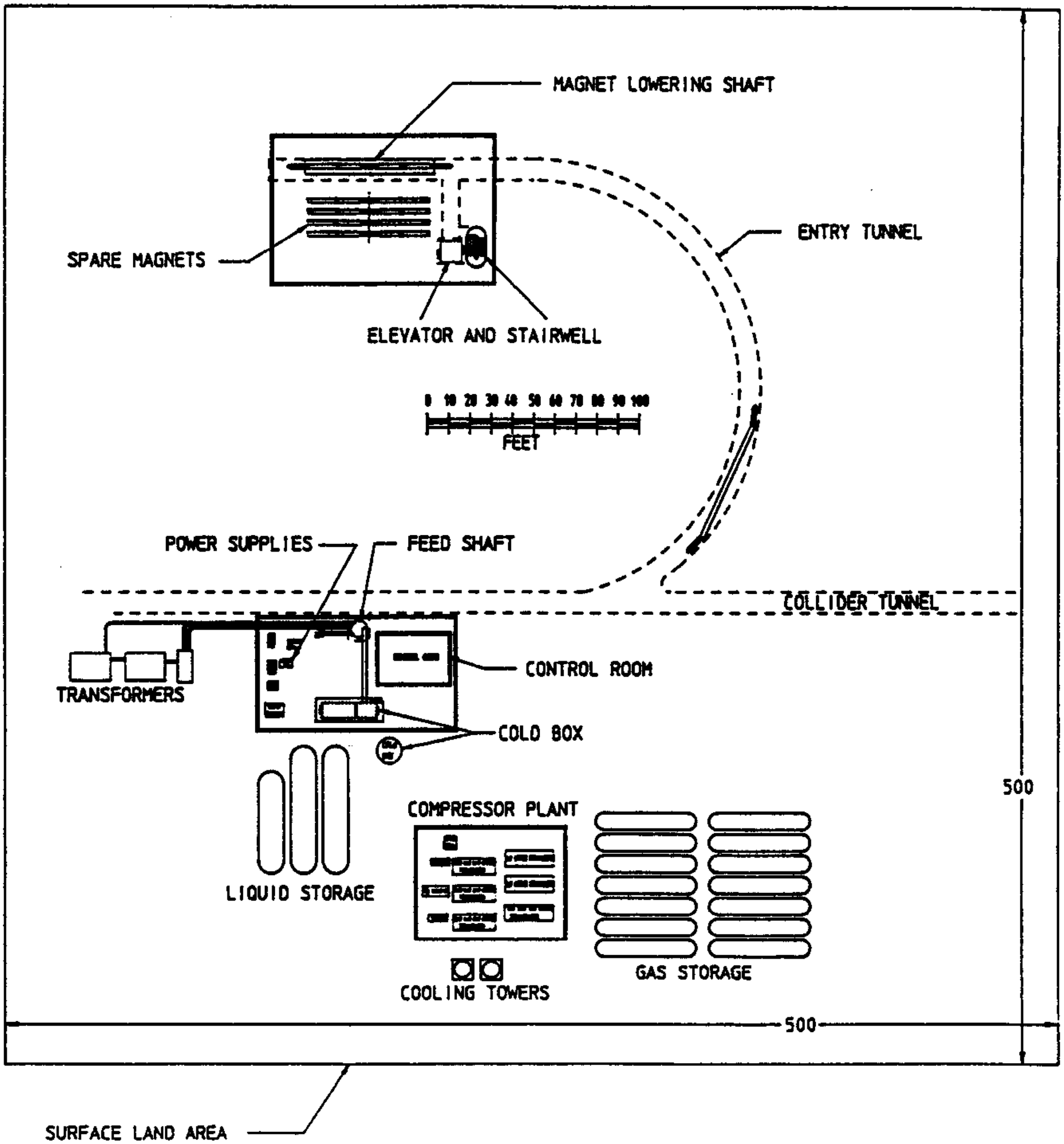
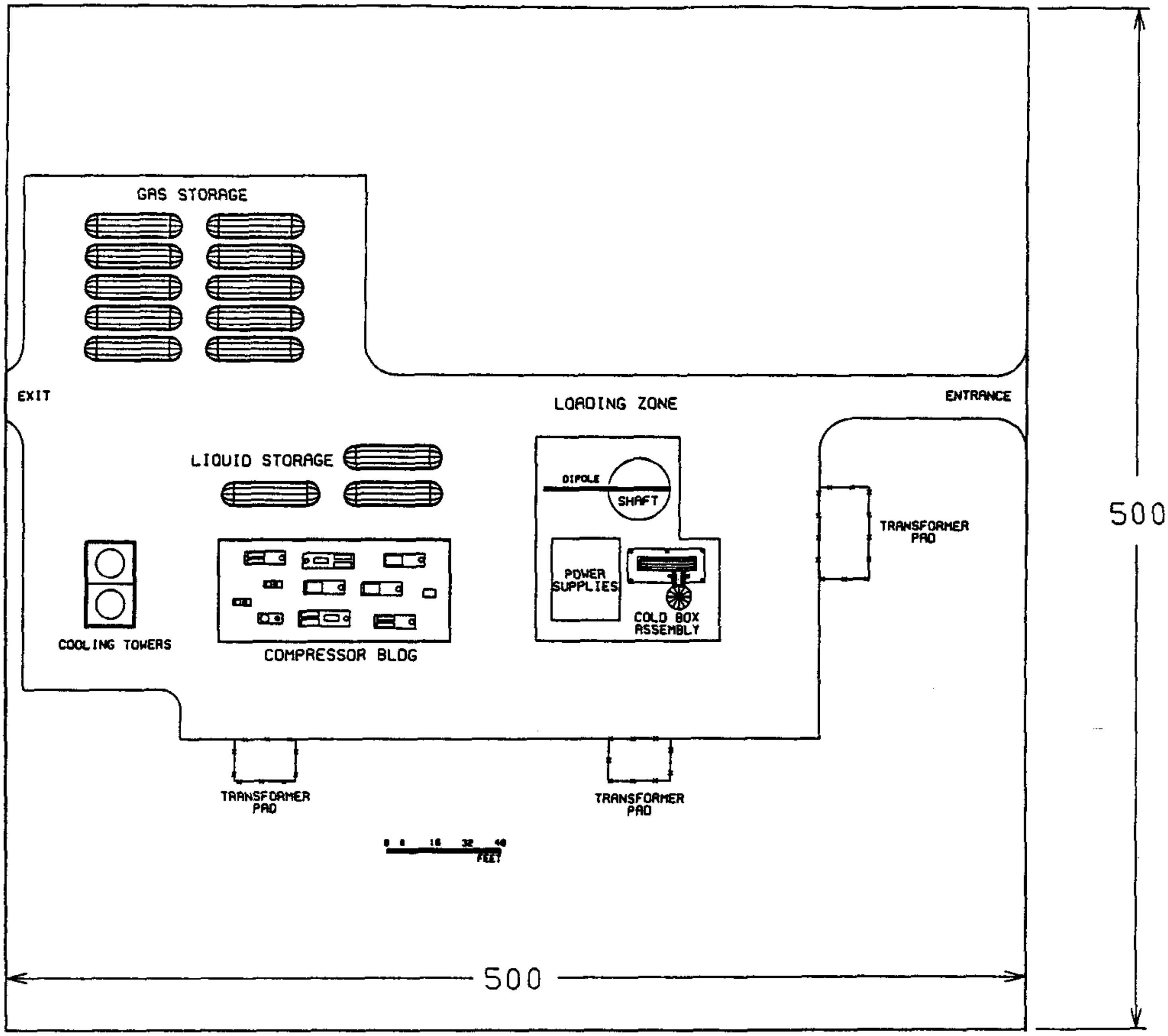


FIGURE 9



SERVICE AREA
BUILDING LAYOUT

FIGURE 10