national accelerator laboratory

TM-175
2000

CONCEPTUAL DESIGN OF THE EXPERIMENTAL AREAS

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May 1969

ABSTRACT:

This report describes an updated conceptual design for the external proton-beam lines, target facilities and experimental areas which are planned to be included in the initial program of research at the NAL 200-BeV synchrotron.

1. Introduction

The facilities described in this report will carry the proton beam from the main-accelerator extraction in the Transfer Hall of the Main-Ring enclosure to the Target Stations. Conventional facilities (structures, paved areas, and utilities distribution) are provided for secondary-beam transport and detection equipment beyond the target stations. What is described herein would provide for an initial research program of the same overall scope as that outlined in the NAL Design Report (Section 14.2), January 1968, and in the 200-BeV Accelerator Construction Project Schedule 44, which was submitted to the U.S. Atomic Energy Commission in 1968.

Technical equipment for secondary beams, which is beyond the scope of the accelerator facility and of this report, has been discussed elsewhere.[1] Here we will discuss secondary beams and detectors only as they relate to this conceptual design of the experimental areas.

It is to be emphasized that the concepts discussed in this report are subject to change in many details during the design period that is to follow. We believe that the broad outlines of these concepts are firm enough to serve as a basis for the design.

Initial thinking on design concepts for experimental areas is described in the National Accelerator Laboratory Design Report[2] in Chapters 13 (particularly Sec. 13.3), 14, and 15 (particularly Sec. 15.3). Since publication of the Design Report, considerable effort has gone into reviewing, refining, and revising these concepts. The work has included a Summer Study held at Aspen, Colorado, in July and August 1968, with participation of many high-energy physicists from all parts of the United States.

This report describes an updated conceptual design of the experimental areas which has been developed subsequent to the 1968 Summer Study. It is on the basis of these design concepts that NAL has received, in May 1969, AEC authorization to proceed with detailed design specification (Title I Design) of the experimental areas.

During and immediately following the 1968 Summer Study two major decisions concerning experimental areas were reached by the NAL staff.

The first decision concerns the internal-target area previously planned to be at Long Straight-Section B. It had been thought that the properties of internal targets such as multiple traversals by the circulating proton beam might be significant in improving secondary particle yields for certain specific experiments. Extensive investigations in the Summer Study failed to unearth any experiments for which internal targets are crucial, and it has therefore been decided to drop them from the plans, both because the same funds can be used more efficiently for a corresponding expansion of the external-beam target facilities, and because their use as a general facility would produce a level of radioactivity in the main ring that would make maintenance extremely difficult and expensive and would lower the reliability of accelerator operation.

Should a specific research need for an internal target arise in the future, however, the design of the Main-Ring Enclosure has been carried out to preserve the option of constructing an internal-target station and associated experimental area at some later time.

The second major decision concerns a large bubble chamber. There has been considerable discussion as to the usefulness of a bubble chamber for strong-interaction physics in the new higher energy range. Investigations in the 1968 Summer Study showed that bubble chambers will be useful for strong-interaction experiments, at least up to secondary particle energies of approximately 70 BeV, but that their major unique capability will probably be in neutrino-interaction experiments. In these experiments, a very large hydrogen-deuterium bubble chamber will be a unique tool capable of providing data hitherto unavailable. It has therefore been decided to provide for targeting and secondary beam facilities for such a large bubble chamber, with these facilities to be designed to produce both neutrino and separated charged-particle beams. The bubble chamber itself, and those facilities and items of equipment specifically related to its operation as a detector are not included herein, and are the subject of a separate proposal.[3]

With these two decisions made, the Laboratory staff has concentrated its efforts on developing a conceptual layout of the experimental areas. In this work, the size of the research program and number of secondary beams as discussed in Sec. 14.2 of the Design Report have been regarded as minimum conditions to be met. These minimum goals may be summarized as follows:

Number of experiments set up	12
Number of experiments in operation	9
Number of "electronic" setups	10
Number of "electronic" experiments per year	20
Number of bubble chamber setups	2

It is expected that about one-fourth of the research program will be carried out by resident staff and about three-fourths by visiting users. On the basis of the conceptual design studies described in this report, we believe that the experimental areas can be constructed with a potential scope for the initial research program that is at least equivalent to the scope described in the

NAL Design report and summarized above. All of the experimental areas described here will be constructed within the expected total construction authorization of $250 million.

The conceptual designs presented in this report will be reviewed at the 1969 Summer Study. Different designs which may be developed during the summer of 1969 could be incorporated into the plans for any of the experimental areas 1, 2, or 3, if subsequent detailed studies by the Laboratory staff indicate that the new concepts would be more suitable than the design concepts outlined in this report.

2. General Description

The proposed layout of the external-beam lines, target stations, and experimental areas on the site is shown in the master plan of Figure 1. Figure 2 is an expanded view of the experimental areas. After acceleration, the proton beam is extracted from the main ring in the Transfer Hall at point T over a time that can be varied from one revolution period (20 microseconds) up to the full length of the flat-top

(1 second). The beam emerges from the Transfer Hall and moves in a northeasterly direction. The beam line runs 1350 feet to the first splitting station at S1. Here the beam can be split, with part or all of it being sent straight ahead to a target at T1 to make secondary particles for a bubble chamber at E1; while the remainder of the proton beam is deflected eastward toward the other experimental areas.

The split portion of the beam is bent through an angle of 7.5°. It travels 1350 feet, past the shops and laboratories of the industrial area, to the second splitting station, S2. Here the beam can be split again, either travelling straight on to the second target station, T2, or being bent eastward, again through 7.5°, toward the third target area, 3. The experimental facilities can be expanded in the future, should this prove desirable, by adding more splitting stations and target stations farther along the same curved line. In the design concept outlined in the Design Report, the primary beam line was straight; and the beam was diverted at the splitting stations to the targets. The principal advantage of the new concept is that it provides greater lateral space between the experimental areas for the same total amount of bending of the proton beams.

As presently conceived, the bending and focusing of the proton-beam line will be carried out by magnets either identical to or very similar to those of the main accelerator. Similarly, the housing of the proton beam will make use of the pre-formed sections designed for the main-accelerator enclosure. Sections of beam-transport pipe will be used immediately downstream of each splitting station to decouple the splitting stations from each other and to localize radioactivity.

The target stations are the points of greatest radio-activity in the entire accelerator facility. With the present design concepts, the targets and nearby equipment will be surrounded by massive shielding and will be removable by rail to a target laboratory for maintenance and repairs.

The three target stations and secondary-beam areas will differ from each other, in order to provide a variety of facilities. The first area, (1), will provide beams to a bubble chamber. The main purpose of this station is to provide a neutrino beam. The beam must be very long, will be a dominant feature of this area and will determine its characteristics. Counter-spark-chamber experiments may also use the neutrino and charged-particle beams at area 1. The second area (2) will be a conventional area providing an assortment of about six charged and neutral particle secondary beams for counter-spark-chamber experiments. It will consist of a large experimental hall with overhead-crane coverage and will be similar to the experimental areas that exist at present-day accelerators. It is expected that in this area the experimenter will use the secondary beams that are available and that the beams will not be rebuilt for special purposes.

The third area will also be for counter-spark-chamber experiments, but this area will be more flexible than the second area and will be capable of accommodating a more varied array of secondary beams. Since we do not yet have a detailed picture of what the experimental demands will be, this area is discussed as though it were very similar to the second area. Thus half the available resources are allocated to it but its form remains somewhat undefined. These three areas are described in more detail in Sections 4 and 5 below.

3. Beam Transport and Splitting Stations

The proton beam is transported from the Transfer Hall in a straight line to the first splitting station, S1. Beyond this point, the beam-transport system is comprised of a straight section about 600 ft in length followed by a bending section of about the same length. The beam is split in the straight section, with a fraction extracted from the main transport line to go to a target station, T1, and the remainder going through the bending section to be carried to the next splitting station, S2.

Beam splitting is carried out by use of a series of septum devices. The system is similar to the system used to extract the beam from the main accelerator. The first thin electrostatic septum is positioned close to the beginning of the straight transport section, as shown in Figure 2. The split beam is given a vertical impulse. After a 90° betatron phase advance to achieve maximum amplitude, it clears the septum of the second device shown in Figure 2, which bends the beam further upward to miss the leading magnet at the end of the straight section. The beam is then transported at an upward angle from the 725.5-ft elevation at the splitting station to the 753-ft elevation at the target stations, where it is brought back to the horizontal plane. The horizontal distance traversed during this change of elevation is one thousand feet. In this traversal the beam is focused by a series of quadrupoles spaced 200 ft apart. At the 753-ft elevation, the beam is transported 200 ft to the target. The quadrupoles in this last 200 ft must be moveable in order to provide for changing of target elements.

The unsplit part of the beam is bent 7.5° in the curved section toward the next splitting station.

4. Areas 2 and 3

Areas 2 and 3 are designed primarily for use with counter-spark-chamber experiments and share common target-station features, which are discussed here. As we have mentioned previously in this report, neither the equipment to accomplish the research experiments nor the secondary beam transport equipment are included in this conceptual layout of experimental area facilities.

a. Target Stations T2 and T3. All the technical components associated with the target - target mechanisms, collimators, and possibly the first focusing magnets for secondary beams -

are to be mounted in a "target box." The target box is a steel enclosure, approximately 100 ft long and 3 ft by 3 ft in cross section. The target box itself is fixed in a permanent position. It is surrounded by massive fixed concrete and earth shielding.

Components are brought into it and placed by a railroad train. The target box contains ledges for the support of components and rails for the train. A target assembly is installed on the train in the target laboratory described below and is moved to the target box, where it is lowered onto the support ledges by remotely operated jacks. The train is then removed from the target box. Thus, a major function of the target box is to provide rigid support for the target assembly. Another important function is to make it possible to locate radiation shielding very close to the target and the proton beam stop.

The target laboratory is envisaged as a prefabricated steel-frame building similar in size to the temporary laboratories in the Village (10,000 sq ft). It will have an additional area of approximately 5,000 sq ft for power supplies, shops, and light laboratories. The trainrail system inside the building will run between shielding walls. Remote manipulators and a crane will be used to carry out operations on the train, with television cameras for viewing.

It is estimated that approximately one target-box changing operation will be carried out per year. The concepts outlined here are a lean but expandable design to accomplish this purpose; it is expected that operational experience might well modify the methods used.

b. Design Basis. The variety of facilities required for the counter-spark-chamber experiments is very great. On the basis of past experience, there will be, on the one hand, a large and continuing demand from users for what might be called conventional beams, while on the other hand, some experiments will demand a wide range of specialized beams that will pose complicated design problems.

A workable conceptual design using conventional elements to produce an array of conventional secondary beams has been carried out. This tentative design is taken as the basis for the layout of area 2 . The underlying assumption is that there will always be a demand for conventional beams, that a satisfactory selection can be designed and built, and that the experimenters will use these beams as they are without requiring extensive rebuilding. Based on these assumptions, it is possible to design a beam-transport area that is very crowded with magnets, power, water, shielding, collimators and controls, but that is relatively inexpensive to build and operate because it is designed as a unit, and buildings and facilities have to be provided only for a specific array of magnets. This has been the intent behind the design of area 2. Such an area is not well suited to experiments requiring the full-intensity primary beam, very short hyperon or K° beams, or maximum-intensity beams of pions, muons, or neutrinos as they are presently understood. Therefore, more specialized beams have been allocated to area 3 while the area 2 has been designed to produce a large number of conventional beams as inexpensively as possible.

c. Secondary Beam Layout. In addition to the studies on main-ring magnets to be used for the primary proton beam transport, and as a guide to laying out the experimental areas, a detailed beam-design program has been undertaken using main-ring magnets. These magnets are moderately well matched to the problem. Their quality is slightly better than what is needed to produce high-energy beams of 100 MeV/c resolution. Thus, this design is entirely realistic and could certainly be built. A design that might actually be constructed would incorporate a number of obvious improvements, such as specialized magnets at the front ends of beams to increase the solid angle. Table I lists the properties of the six beams as presently conceived. Figure 3 shows a possible layout of these beams in the building together with the shielding necessary to absorb muons from pion decays near the primary target and to shield the beam lines. The experimental hall shown has approximately 75,000 sq ft of floor area. Figure 4 is a cross section through the muon shield 120 ft downstream from the primary target.

Table I. Yields of Secondary Particle Beam for 10^{13} Interacting Protons and a 100 MeV/c Momentum Bite (after T. G. Walker, NAL 1968 Summer Study, Report No. B5-24)

Beam Number	Production Angle (mrad)	Momentum (GeV/c)	π^- Yield	Proton Yield
1,4	20	30	3×10^6	10^6
		20	10×10^6	10^6
2,5	10	80	3×10^5	2×10^6
		40	4×10^6	10^6
3,6	3.5	200	-	2×10^9
		150	5×10^4	3×10^7
		100	10^6	2×10^7
		50	5×10^6	3×10^6

5. Area 1

This area is primarily intended to provide secondary beams for use in a bubble chamber. It is assumed that the specific beams provided will be a high-intensity broad-energy-spectrum neutrino beam and an rf-separated π and K meson beam with a maximum momentum of approximately 80 BeV/c. The designs of the target station and beam area described herein are somewhat independent of whether the neutrino beam is produced by a current-sheet (magnetic-horn) focusing system or a quadrupole focusing system and also of the details of the rf-separated beam design.

Target-station T1 has several features that make it unique. First and most important, the neutrino-beam elevation is set at 733.5 ft, which is nominally 15 ft below ground level, to minimize the cost of the muon-stopping shield. Second, because there are relatively few transport elements in the neutrino beam, the design of this target building will differ materially from that of the buildings in target areas 2 and 3.

a. Target Building T1. The proposed method of mounting the target and beam-transport elements is to suspend them from concrete mounting pads. These pads are aligned on ledges in the side walls of a concrete trench 300 feet long and 11 feet wide, as can be seen in Fig. 5. Portable shielding is placed over the mounting pads to fill the trench partially, as can be seen also in Fig. 5, so as to provide a lower-background environment where electrical and mechanical connections can be made to the beam elements. Beam elements and portable shielding blocks will be of standard widths so that any beam-transport element can be removed by an overhead crane without disturbing the other elements. A radioactive transport element can be removed from the target station in a special casket mounted on a railroad flatcar that enters the target building at the up-stream end, in a manner similar to that used in stations 2 and 3. Along the primary proton-beam direction, a space 300 feet long by 5 feet by 5 feet is available in the target-station building and could contain either a current-sheet meson-focusing system or the front end of a quadrupole meson-focusing system.

A single target might be the source of both the neutrino beam and the charged particle beam. It is possible to envision an extraction system for the circulating protons that would give a high-intensity fast-extracted proton burst at the beginning of the flat-top, followed one second later by a low-intensity burst. If both these bursts were extracted into target station T1, this target station could, without moving beam-transport elements and using only one target, produce a neutrino beam followed one second later by a charged-particle beam to a bubble chamber. It would also be possible to transport slow-extracted protons into area 1, for counter-spark-chamber experiments using the neutrino or charged-particle beam.

It might at some future time be desirable to transport 200-BeV protons to a target close to the bubble chamber, for the production of short beams of short-lived particles. For moderate proton beam intensities $\lesssim 10^9$/burst, the charged-particle secondary transport channel at area 1 might be modified for this purpose.

b. Neutrino Beam. The neutrino beam might, for example, have two or three pulsed focusing elements mounted in the 300-ft long target station. These elements would produce a nearly parallel π and K meson beam of one sign while defocusing particles of the opposite sign. The neutrino beam is provided by the decays of these parent mesons. To provide a long, low-cost decay path for the mesons, a 5-ft diameter pipe is extended for 1,650 ft beyond the target-station building. This provides a total decay length of 1,950 ft. Following the decay region is a shield of iron and earth to stop all known particles except the neutrinos. The 5-ft diameter decay pipe somewhat reduces the lower-energy neutrino flux, but at present it appears to be a good choice because the emphasis is likely to be on the higher-energy interactions. The pipe diameter also determines the transverse dimension of the muon shield and significantly affects the cost of that part of the beam. A more detailed investigation of this optimization will be made. The present design basis of the muon shield is that its thickness shall be kept constant and its average density increased when the proton energy is increased from 200 to 400 BeV. A shield thickness of 970 ft has been chosen tentatively. At 200-BeV operation, the shield thickness would be 1/3 iron and 2/3 earth.

c. Charged Beams. Charged beams can be obtained from target T1 through the collimator mounted in the sidewall of the target-station trench at a production angle of about 25 mrad. The charged beam from the collimator at elevation 733.5 ft is deflected to ground level where it emerges from the downstream end of the target-station building about 20 ft from the neutrino-beam axis. A vacuum pipe transports the beam at ground level to the bubble chamber, where it is deflected to the center of the bubble chamber at elevation 733.5 ft.

To continue a study of resonances and other strong interaction effects, a three-stage rf-separated beam of 80 BeV/c maximum momentum is proposed. Such a beam can easily be constructed in the 2700 feet available from the target T1 to the bubble chamber. Since the bending of high energy beams is expensive, beam configurations are being investigated that will minimize the total bending angle, the amount of extra tunnel needed, and the muon leakage through the neutrino shield.

6. Superconducting Beam-Transport Magnets

A significant fraction of the cost of the experimental areas will be in the installation of electrical power and cooling-water systems for magnets in the secondary beam areas. However, extensive use of superconducting magnets could potentially save much of these installation costs. This report therefore contains a brief discussion of the superconducting magnet program at NAL. The reader is reminded that the superconducting magnets for secondary beam areas are not included in the $250M construction authorization, but will be funded from a separate capital equipment budget.

An investigation into the economics of superconducting beam-transport magnets has revealed that the most economical installation would make use of iron magnets operating at or below 20 kG. In such a configuration, the superconductor is used to magnetize the iron and the ampere-turns are kept at a minimum. Operation of the beam-transport magnets at higher fields does not appear to offer significant advantage in the experimental areas, but this point needs more investigation.

The main problems of field uniformity and superconductor magnetization are minimized by the fact that the volume of superconductor is small and the field is shaped mainly by the iron.

Figure 6 is a proposed configuration for a superconducting bending magnet. Table II shows the pertinent magnet parameters.

Table II. Superconducting Magnet Parameters

Field	18 kG
Ampere-turns	70,000
Gap height	4 cm
Gap width	10 cm
Length	4 m
Refrigeration required	5-10 W
Power required for operation	3.5 kW
Total weight	4,000 lb

The iron is at helium temperature, as is the beam tube. For regions where thermal loads due to incident radiation are large, other designs with beam tube and iron at higher temperatures will be required.

The "magnet" iron and superconductor are encased in a stainless-steel helium container. Helium liquid at approximately atmospheric pressure is introduced at one end of the magnet and is vented as gas at the other end. Part of the vent gas is returned to the refrigerator, and the rest is first used to reduce the heat leak down the electrical leads.

The helium container is surrounded by a thermal radiation shield cooled to about 80°K by intermediate-temperature helium gas from the refrigerator.

The magnet is energized with leads running from room temperature to helium temperature. These leads are optimized for minimum heat leak and require 3 liters of liquid helium per 1000 amperes per pair of leads. This heat leak is proportional to current and consequently favors lower-current conductors.

7. Physical Plant

The general configuration and technical components of the beam-transport system and the experimental areas have been described above. This section describes the physical plant in these areas.

a. Structure. Proton beams extracted from the accelerator will be carried underground through a beam-transport enclosure of the standard 10-ft diameter cross section. At critical points, because of radiation, the standard enclosure will be replaced by 200-ft long sections of transport pipe 12 in. by 18 in. in cross section. This system of beam-transport enclosure and pipe will connect with a concrete splitting station of rectangular cross section and about 300 ft long. The splitting station is designed to allow the beam either to travel ahead, rising to a target, or to pass to the next splitting station through a similar system of beam-transport enclosures and pipes.

Target-station T1 will be located in a narrow concrete enclosure about 350 ft long and buried in earth shielding. This enclosure will have two levels. The target will be located in the lower level at elevation 733.5 ft, separated from the upper level by blocks of portable shielding. The portable shielding will be handled by a 40-ton crane located at the ceiling of the upper level.

Targets T2 and T3 will be located in the steel target boxes. These target boxes will be cast in heavy concrete 16 feet in thickness, covered with 25 ft of additional earth shielding. Each target box and its pre-target box area will be located at the grade elevation of 748 ft. The beam-transport system connecting the pre-target box area at grade with the respective splitting station below ground will necessarily be inclined.

The beam-transport enclosures, splitting stations, and the three target stations will all have a system of vehicle and personnel accesses and utility buildings and galleries, which will be located at the existing grade. The size and construction methods will follow those determined by the main-ring design for similar buildings. The present site plan also includes in the experimental areas one special access for each of the target-handling systems, seven utility buildings, two utility galleries, four major vehicle-access buildings, 2 minor vehicle-access buildings, and four personnel emergency exits.

The major experimental areas, E2 and E3, will be located immediately downstream of target stations T2 and T3 at the approximate existing grade elevation of 748 ft. The experimental area E2, following target station T2, will consist of a 750-ft long building designed to enclose a fan-shaped configuration of secondary beams. The total area of this building will be about 75,000 sq ft of experimental space with an additional 10,000 sq ft of enclosed support area. The experimental space will be serviced by a 40-ton crane or other materials-handling devices of similar capacity. There will be a paved area of 200,000 sq ft immediately surrounding experimental building E2.

The experimental complex E3 is less well defined at this time, but it is thought that the array of secondary beams will be housed in a series of smaller buildings extending for more than a thousand feet. Total areas of these buildings may reach 100,000 sq ft. Four hundred thousand square feet of paving will be provided to accommodate this complex.

b. Mechanical Equipment.

General. Mechanical-equipment requirements for the experimental areas include conditioned-air purge for beam-transport enclosures, splitting stations and Target Station T1. Heating and ventilation will be required for Target Stations T2 and T3 and the experimental buildings E2 and E3. Cooling water for magnets and other equipment will be distributed throughout the experimental areas. Industrial water will be distributed for fire protection and toilet rooms.

LCW Systems. A distributed low-conductivity water (LCW) system for experimental-area equipment cooling will be designed on a local cooling basis. It is planned to utilize cooling tower stations supplying 96° LCW.

Air-Purge Systems. Equipment will be local, using package systems. These systems will be located in typical utility buildings, similar to those of the main accelerator, located at convenient points along the beam line.

Building Heating and Ventilating. Winter heating for target-station and experimental area buildings will be by local systems within the respective buildings served. Ventilation will be supplied by louvered air intakes and roof exhaust fans.

c. Power Distribution. Electrical power will be distributed underground at 13.8 kV, 3 phase, 60 Hz, from the main substation to stationary unit-load substations and plug-in stations, located near the splitting stations, target stations and experimental areas, supplying ac power for the magnets at 480 V, 3 phase, 60 Hz. The distributed power capacity for experimental use is approximately 60 MW, the maximum power available at the main substation for experimental use is limited to 30 MW. Several portable substations rated at 2500 kVA will be provided to supply power to non-fixed experimental loads.

Electrical power for facility requirements will be supplied by separate feeders connected to a number of unit load substations located for distribution at approximately 480/227 V for motor and lighting loads. Dry transformers will be used for 120/208 V power requirements.

8. Schedule

It is planned to design and construct the experimental areas in three parts, corresponding to the three areas, 1, 2, and 3. Table III shows the principal milestones for each of these areas.

Table III. Schedule Milestones

	Begin Design Specification	Begin Construction Design	Begin Construction	Complete Construction
Area 2	9-1-69	4-1-70	11-1-70	4-1-72
Area 1	12-1-69	12-1-70	7-1-71	7-1-72
Area 3	9-1-70	12-1-71	7-1-72	7-1-73

9. Acknowledgements

The conceptual design for experimental areas at NAL, is the product of the work of many individuals in addition to the authors of this report. Other contributors to the design work include E. L. Goldwasser, R. A. Carrigan, Y. W. Kang, A. W. Key, Z. J. J. Stekly, T. O. White, R. Mobley, J. Simon, and P. V. Livdahl. We also acknowledge the assistance of several others in the preparation of this report, including F. Cole, P. Reardon, J. Sanford, and members of our engineering and secretarial staffs.

[1]National Accelerator Laboratory Memo MM-148, "Projected Experimental Equipment Costs FY 1969-1975," E. J. Bleser and A. L. Read (unpublished).

[2]National Accelerator Laboratory Design Report, Second Printing July 1968, Universities Research Association, under the auspices of the United States Atomic Energy Commission.

[3]Brookhaven National Laboratory Report No. 12400, "25-Foot Cryogenic Bubble Chamber Proposal," March 1969.

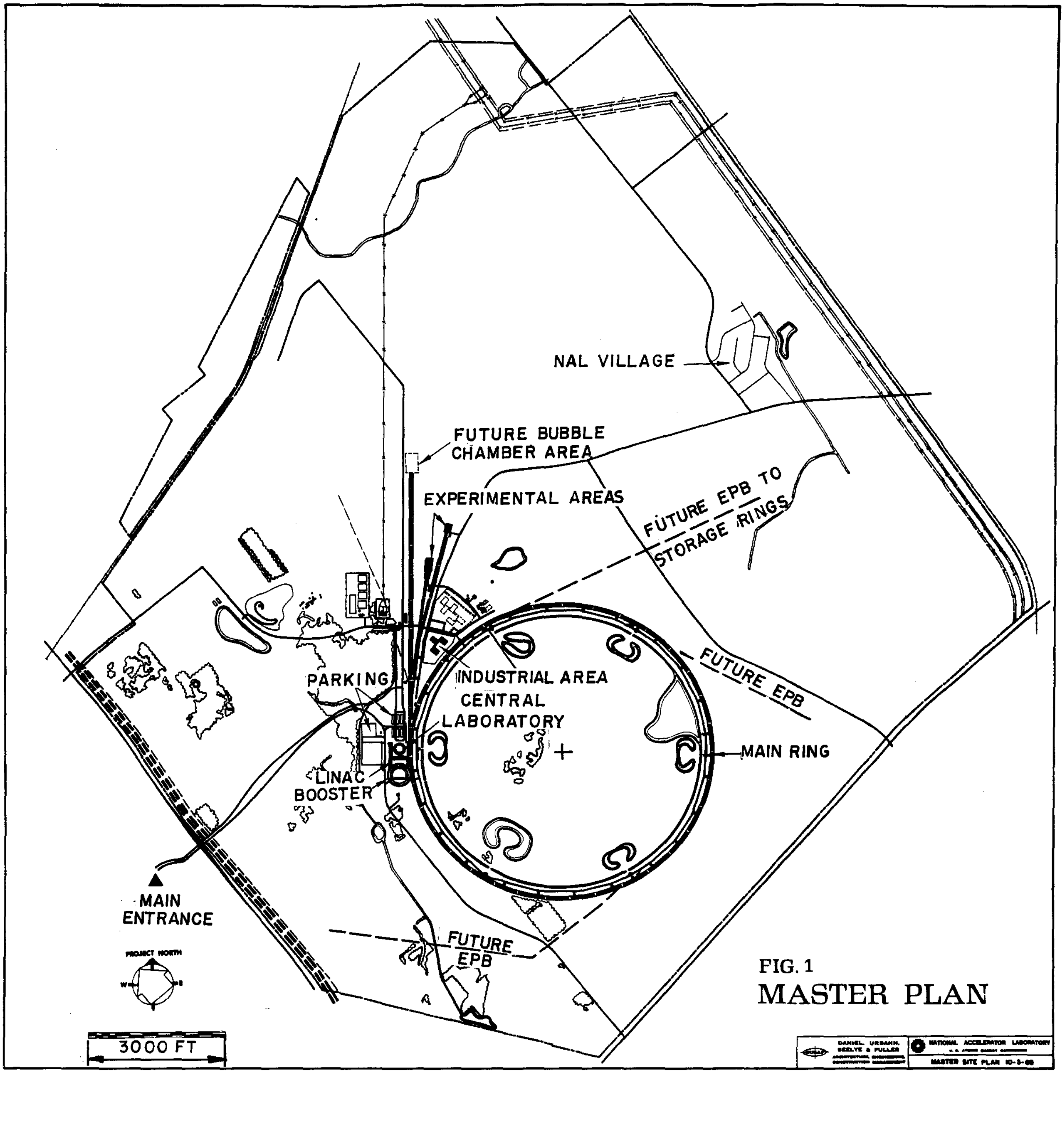

Figure 1 - Site Master Plan

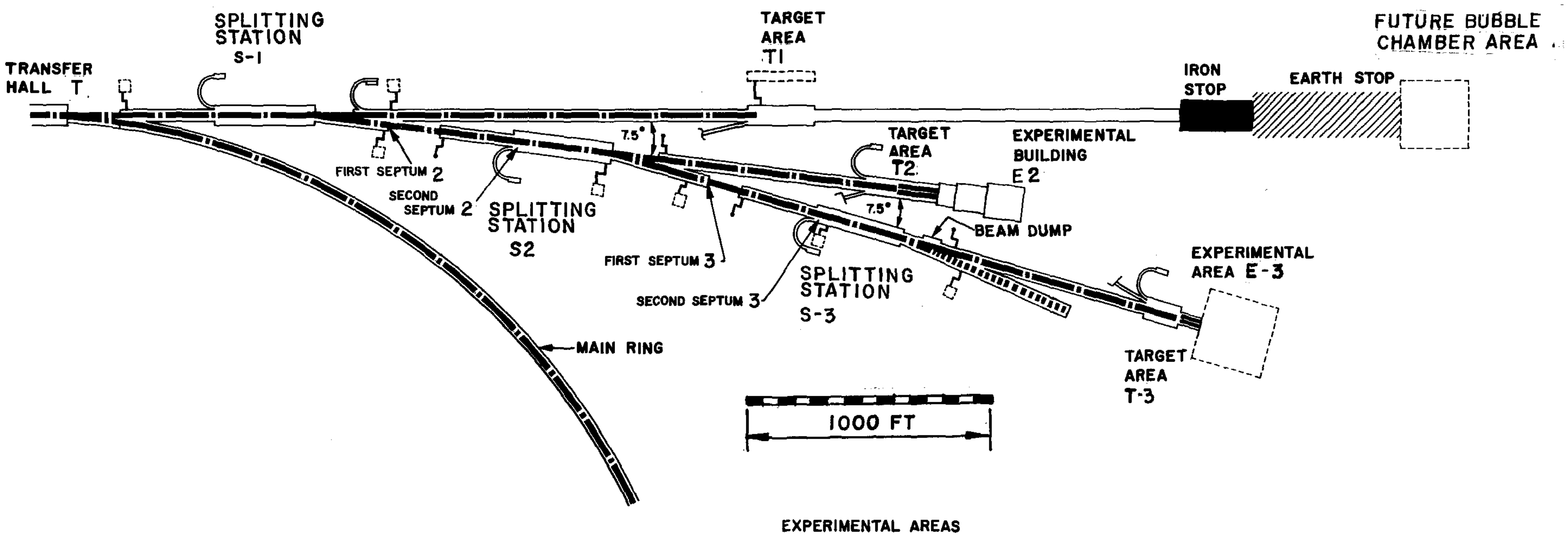

Figure 2 - Experimental Areas Master Plan

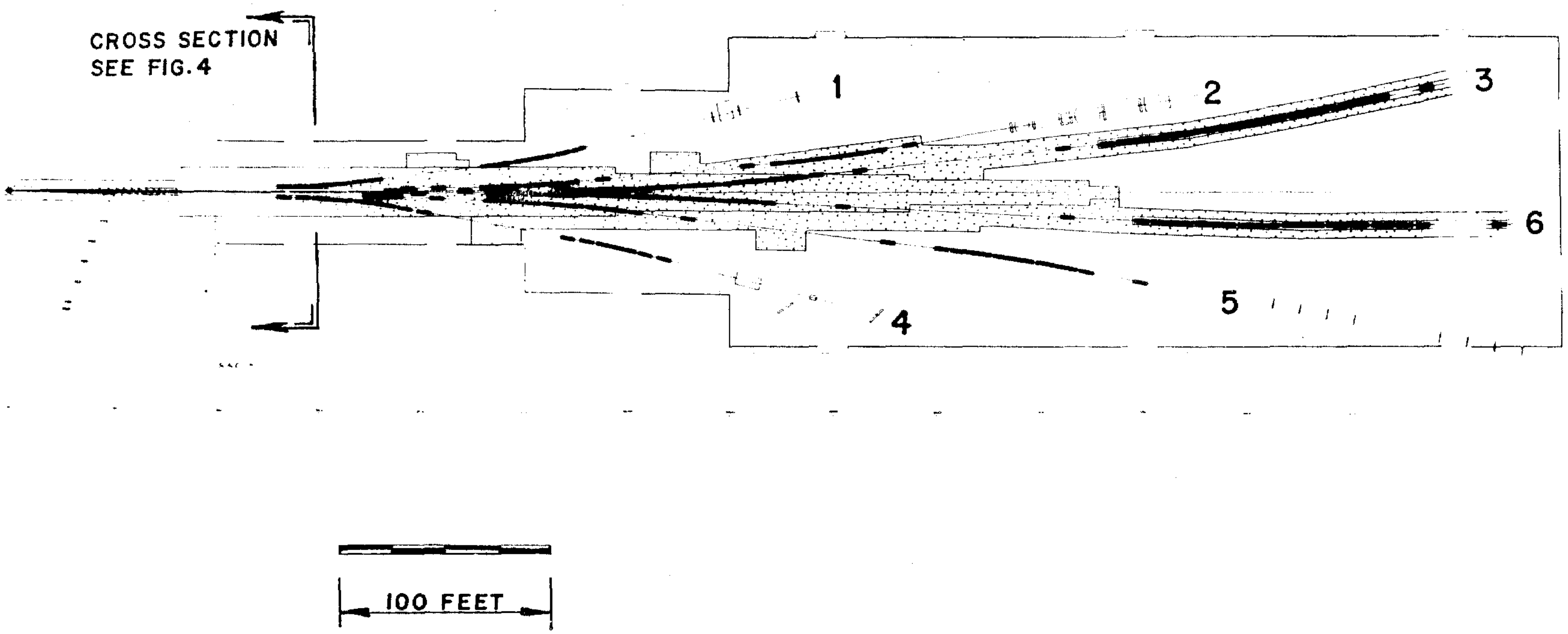

Figure 3
Experimental Area 2

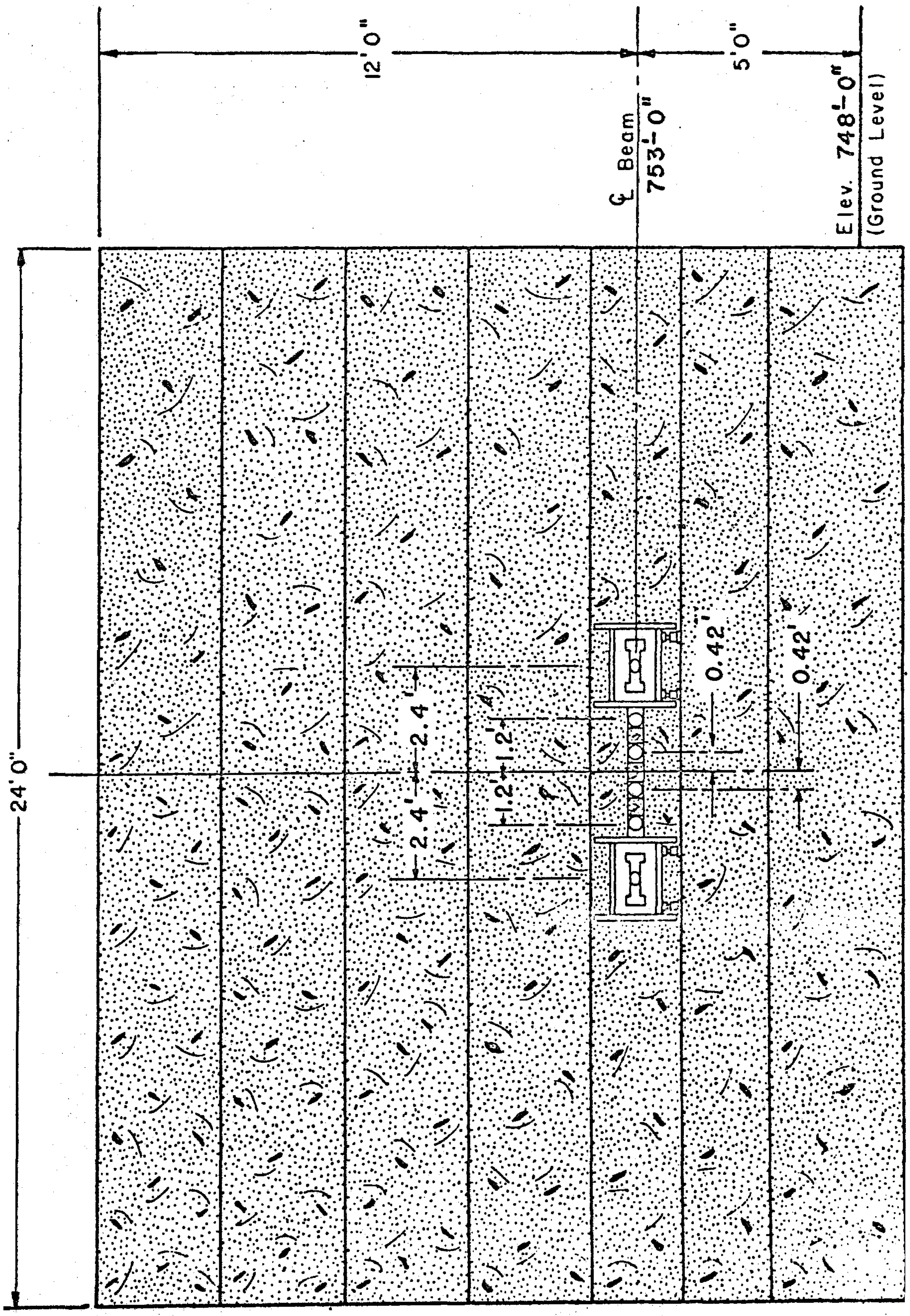

Figure 4

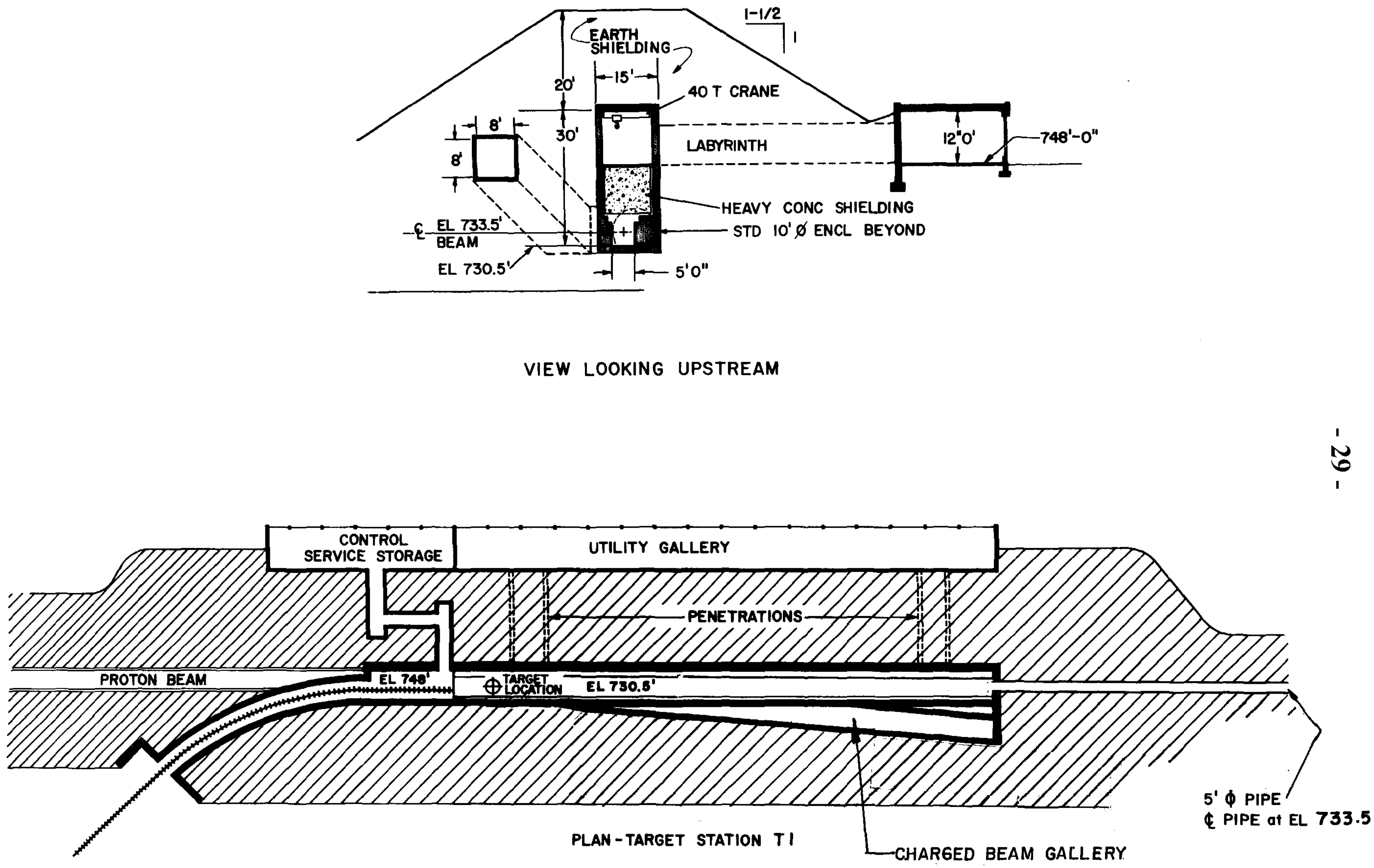

Figure 5 - Target Station T1

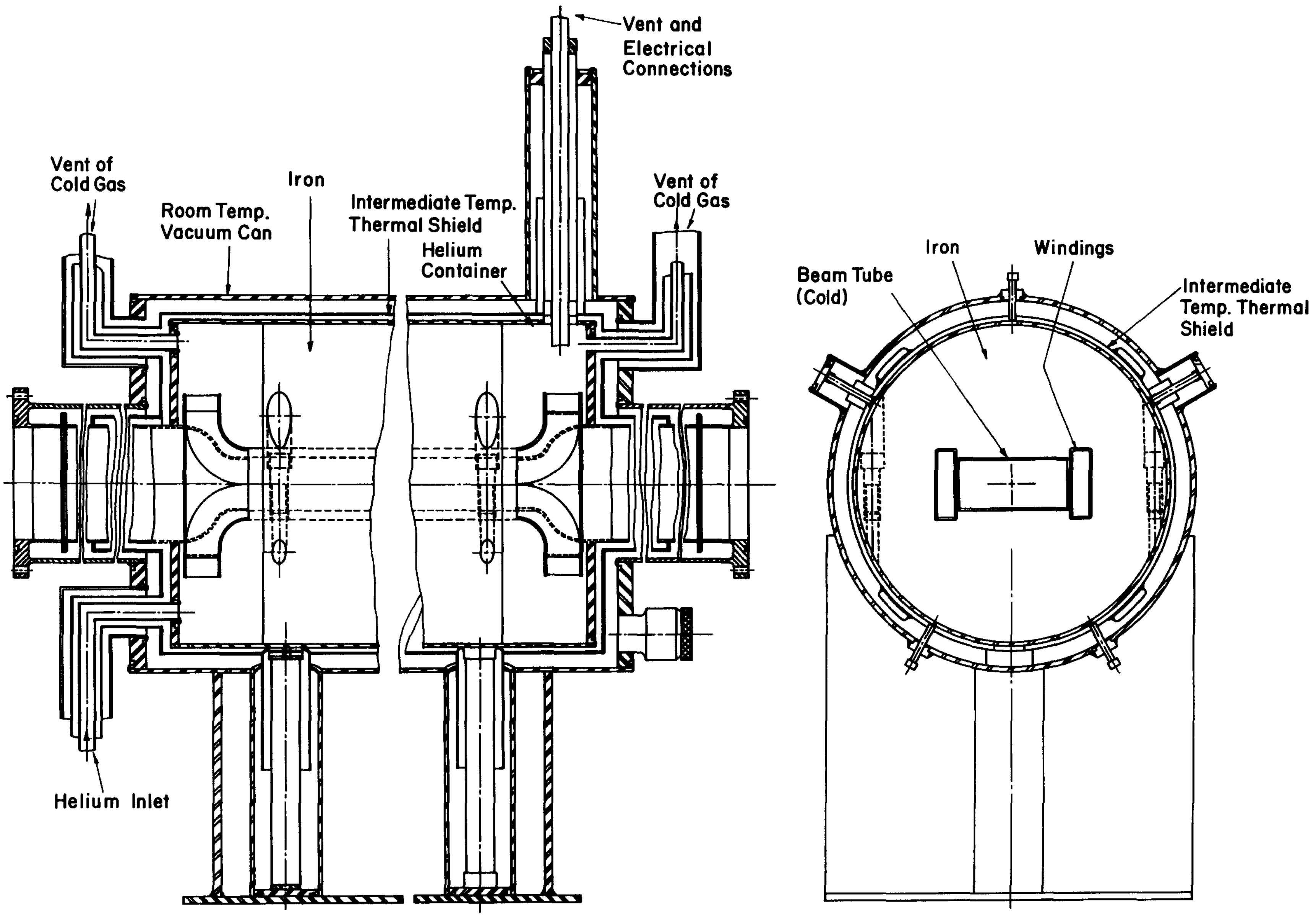

Figure 6 - Superconducting Beam
Transport Magnet