Conceptual Design Report

Antiproton - Proton Collider Upgrade 20 GeV Rings

Project No. 90-CH-400

Technical Components and Civil Construction

May 1988

Fermi National Accelerator Laboratory

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COLLIDER UPGRADE: 20 GEV RINGS
CONCEPTUAL DESIGN REPORT

May 16, 1988

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I. INTRODUCTION AND SUMMARY

This report contains a description of the design and cost estimate of two new 20 GeV rings which will be required to support the upgrade of the Fermilab Collider with a luminosity goal of $5x10^{31}cm^{-2}s^{-1}$. The new rings include an antiproton post-accumulator, denoted the Antiproton Super Booster (ASB), and a proton post-booster, denoted the Proton Super Booster (PSB). The siting of the rings is shown in Figure I-1. Both rings are capable of operation at 20 GeV, eliminating the need for ever again injecting beam into the Main Ring below transition, and significantly enhancing Main Ring performance. The Antiproton Super Booster is designed to accept and accumulate up to $4x10^{12}$ antiprotons from the existing Antiproton Accumulator, and deliver them to the Main Ring at 20 GeV for acceleration and injection into the Collider. It is also designed to accept diluted antiprotons from the Main Ring at 20 GeV for recooling. The PSB accepts 8.9 GeV protons from the existing Booster and accelerates them to 20 GeV for injection into the Main Ring. The PSB is designed to operate at 5 Hz. The siting shown in Figure I-1 has the attractive feature that it removes all Main Ring injection hardware from the A0 straight section, opening the possibility of installing a third proton-antiproton interaction region in the Tevatron Collider.

The locations, circumferences, operating energies, and optics of the rings are chosen to minimize the operational impact of adding two new rings to the Fermilab accelerator complex. By utilizing currently existing injection and extraction systems in the present accelerators perturbations to operations during the construction period will be minimzed. By always delivering beam to the Main Ring, be it protons or antiprotons, from sources operating with the same energy, similar circumferences, and the similar transition energies, complex reprograming of Main Ring injection sequences will be minimized. By choosing the circumferences of the new rings to be close to their counterparts in the present complex the need for developing entirely new modes of operation is also minimized. Both of the new rings are based on conventional technology or modest extensions thereof--meaning they do not rely on the use superconducting magnets or new accelerator physics concepts.

The Total Project Cost (TPC) of the 20 GeV Rings Project is estimated to be $124,200,000 including a Total Estimated Cost (TEC) of $103,800,000 and $20,400,000 in associated R&D, pre-operating, and capital equipment costs. Included within the scope are all technical and conventional construction components associated with the rings themselves, with beamlines needed to tie these rings into the existing accelerator complex, and with modifications to the Main Ring required to accommodate the 20 GeV injection energy. Specifically covered under R&D will be the cost of the state-of-the-art ASB stochastic cooling system, special component prototype

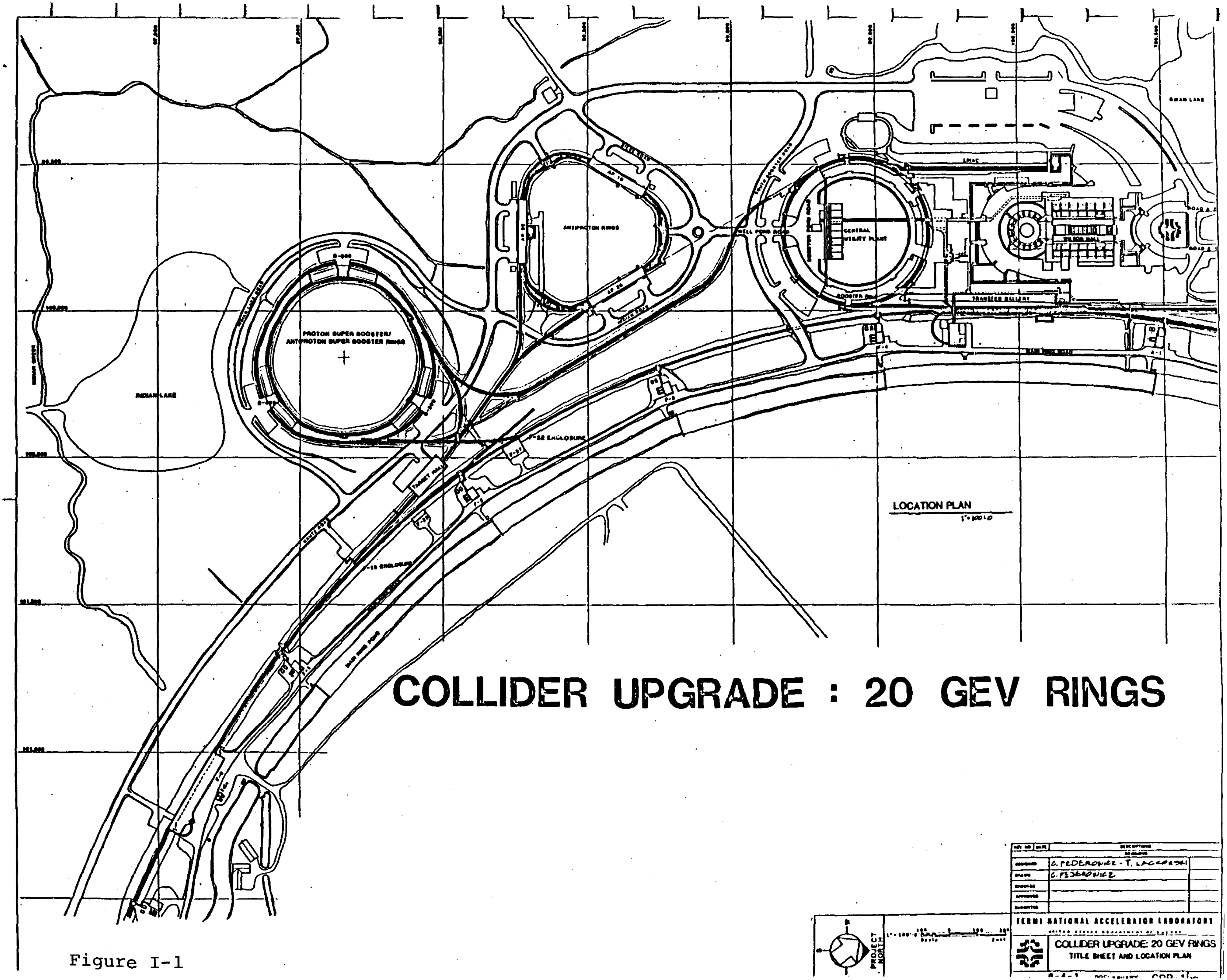

COLLIDER UPGRADE : 20 GEV RINGS
LOCATION PLAN
PROTON SUPER BOOSTER/
ANTIPROTON SUPER BOOSTER RINGS
ANTIPROTON RINGS
INDIAN LAKE
CENTRAL
UTILITY PLANT
WILSON HALL
LINAC
TRANSFER GALLERY
TARGET HALL
F-58 ENCLOSURE
F-18 ENCLOSURE
SWAN LAKE
WELL POND ROAD
PROJECT NORTH
FERMI NATIONAL ACCELERATOR LABORATORY
COLLIDER UPGRADE: 20 GEV RINGS
TITLE SHEET AND LOCATION PLAN

Figure I-1

fabrication, and modifications to the Main Ring and Tevatron required for deceleration of antiprotons to 20 GeV. It is proposed to complete construction of the Antiproton Super Booster, Proton Super Booster, and associated beamlines over a three and one-quarter year period starting on October 1, 1989. Design of conventional construction will be overseen by the Fermilab Construction Engineering Services Group. Design of technical components will be done by Accelerator Division personnel, and fabrication by the Technical Support Section and Accelerator Division. To the extent feasible construction and procurement will be accomplished through fixed-price contracts awarded on the basis of competitive bids. It is anticipated that the construction and operation of the two new 20 GeV rings will require the addition of approximately 30 permanent Fermilab staff members.

II.1 Need

The luminosity upgrade is based on running multiple batches of protons and antiprotons on separated orbits in the Tevatron. A set of beam parameters which would produce the desired luminosity are given in Table I-1. Beams containing 6×10^{12} protons and 3×10^{12} antiprotons with (normalized) transverse emittances of 12π mm-mr are required. It is unclear what the required regeneration rate for collider beams will be, but it will probably lie in the range 12-24 hours. It is expected that luminosity degradation due to emittance dilution will be much more significant than luminosity degradation due to beam loss, thus allowing us to enhance collider operations by recovering and recooling spent antiprotons.

Table I-1: Beam Parameters for the Luminosity Upgrade

	Protons	Antiprotons	
Energy	0.9-1.	0.9-1.	TeV
Number of bunches	96	96	
Particles/bunch	6×10^{10}	3×10^{10}	
Transverse emittance (95%)	12π	12π	mm-mr
β^*	0.5	0.5	meters

Antiproton economics represent one of the outstanding problems to be solved in the proposed upgrade. There are two shortcomings in the existing Antiproton Source: 1)the accumulation rate is not high enough to support the upgrade; and 2)nowhere within the complex is there a place in which 3×10^{12} antiprotons can be stored. With two interaction regions each running at an initial luminosity of $5\times10^{31}\mathrm{cm}^{-2}\mathrm{s}^{-1}$ antiprotons are being lost from the collider at a rate of 3.2×10^{10}/hour (assuming a proton-antiproton cross section of 90mb). If, however, it were to become necessary to replace the entire antiproton beam every 24 hours the effective loss rate would be 1.3×10^{11}/hour. Replenishing antiprotons at either of these rates is beyond the present performance of the Antiproton Source, but is within range of upgrades currently under development, foreseen to result in accumulation rates of about 1.5×10^{11}/hour. The design value for the total number of antiprotons which can be stacked in the existing Accumulator is 5×10^{11}. It is believed that in actuality 1×10^{12} may be achievable, but that 3×10^{12} certainly is not. The Antiproton Super Booster fulfills the need to increase by an order of magnitude the ability to store antiprotons awaiting use in the collider.

The performance of the Fermilab Main Ring (the old 400 GeV accelerator) also needs to be enhanced significantly to meet the needs of the upgrade. This accelerator is presently used for three purposes: 1)acceleration and coalescing of proton and antiproton bunches containing 7×10^{10} particles for injection into the Tevatron Collider; 2)acceleration of Booster batches containing 1.5×10^{12} protons, followed by bunch rotation, for antiproton production targeting; and 3)acceleration of 1.8×10^{13} protons in twelve Booster batches for injection into the Tevatron and delivery to fixed target experiments. The Main Ring presently suffers from poor beam transmission during the period from beam injection (at 8.9 GeV) through transition (at 17.5 GeV). It is felt that the difficulties are the result of major perturbations to the optics and aperture of the ring caused by the installation of overpasses at B0 and D0 as well as the new 120 GeV proton and 150 GeV antiproton extraction systems. Beam transmission is correlated with the beam intensity, being worse at higher intensity. Measurements have shown that the beam lifetime at 8.9 GeV is only in the range 3-4 seconds for Booster batches containing 1.5×10^{12} protons, while at 20 GeV a 600 second lifetime and substantially improved aperture are observed. The impact of limitations on the Main Ring performance are felt during all phases of operation. The 20 GeV capability of the two new rings will remove these limitations once and for all.

I.2 Operating Scenarios

The Proton Super Booster participates in all aspects of accelerator operations during the upgrade era. These include supplying protons to the Main Ring destined for collisions with antiprotons in the Tevatron, for antiproton production, and for fixed target experiments. The need for a rapid cycling (>1 Hz) PSB arises almost entirely from its role in antiproton production. The PSB will also be required to supply protons to the Main Ring with varying bunch spacings, depending on the application--for fixed target and antiproton production operations at 18.8 nsec (53.1 MHz), and for collider operations at 132 nsec (7.6 MHz). The circumference of the PSB is chosen to be compatible with both of these spacings.

For collider operations a total of 1.7×10^{12} protons will be delivered to the PSB from the 8 GeV Booster in 84 bunches, 48 of which will be removed by the the PSB super damper. Following acceleration to 20 GeV the remaining protons will be coalesced into 12 bunches containing 6.0×10^{10} protons each. These are then extracted and sent to the Main Ring for delivery to the Collider. The 8 GeV Booster is presently capable of delivering this quantity of beam with a transverse emittance of about 10π mm-mr. It is expected that the PSB will preserve this emittance. Eight cycles are required to fill the Collider.

During fixed target and antiproton production the PSB accepts protons from the 8 GeV Booster at the maximum intensity which that machine can deliver--presently 3×10^{12} protons in 84 bunches, and projected to be 5×10^{12} in 84 bunches following the 400 MeV Linac Upgrade. These protons are accelerated to 20 GeV and delivered to the Main Ring. Twelve cycles of the PSB are needed to fill the Main Ring for fixed target operations and six cycles are anticipated for antiproton production. The expected beam emittances at these intensities are 20π mm-mr (95%, normalized) and 0.25 eV-sec (95%).

The ASB is of course only involved in the collection of antiprotons for use in the Collider. The ring will serve as a place in which the number of antiprotons required to refill the collider can be collected. The existing Antiproton Source will still fulfill the primary accumulation role. Antiprotons will be produced and accumulated in the existing Antiproton Source at a rate which is projected to be 1.5×10^{11}/hour. Every hour or so the total accumulation of antiprotons in the Antiproton Accumulator will be extracted and sent to the ASB. An RF system in the ASB will move these antiprotons close to the edge of the existing core and they will absorbed into the core in a leisurely manner over the next hour. The primary feature which distinguishes the ASB from the Antiproton Accumulator, and allows the storage of an order of magnitude more antiprotons, is the absence of a stack-tail cooling system. This is a direct consequence of the antiproton acceptance periods in the two machines--2 seconds in the Accumulator versus hours in the ASB.

A possible accumulation scenario might look as follows:

1. The ASB is loaded every three hours with 4.5×10^{11} antiprotons from the Accumulator. These antiprotons have a total longitudinal emittance of about 16 eV-sec and a momentum spread when delivered from the Accumulator h=84 system of 0.3% (full width).

2. A shuttered kicker is used to inject the antiprotons into the ASB on an orbit which is roughly 0.7% displaced from the core orbit.

3. The antiprotons are then moved close to the core using a low voltage, low harmonic, RF system, and are absorbed into the core over the next hour. All of this takes place at 8.9 GeV.

Over a period of about 24 hours the ASB will be filled with the total number of antiprotons required for replenishment of the collider. Accumulation occurs at 8.9 GeV. The entire core is then accelerated in the ASB to 20 GeV in preparation for injection into the Main Ring. Approximately $4x10^{11}$ antiprotons will be removed from the core and positioned on the extraction orbit using a 7.6 MHz RF system to give the desired bunch spacing. A shuttered kicker isolating the beam to be extracted from the remnant core will be fired to extract 12 bunches containing $3x10^{10}$ antiprotons each. The Main Ring is filled with 96 antiproton bunches by repeating the procedure eight times.

The ASB will also be able to recover spent antiprotons decelerated through the Tevatron and Main Ring down to 20 GeV for recooling. The antiprotons will be injected into the ASB from the Main Ring at 20 GeV in eight shots with the beam stacked in longitudinal phase space. The momentum spread of the beam will be large enough to necessitate cooling at 20 GeV for about an hour before deceleration to 8.9 GeV where antiprotons can again be accepted from the Accumulator. The aperture provided in the ASB is sufficient for accommodation of a factor of four dilution in the antiprotons prior to recovery.

II. THE ANTIPROTON SUPER BOOSTER

Before launching into the description of the specific design of the Antiproton Super Booster it is worth examining a few general principles which ultimately lead to specifications on the desired lattice characteristics. As we shall see the longitudinal and transverse phase space densities we hope to provide, taken with the cooling system characteristics, force us into a specific type of lattice design.

The phase space densities which we require to be delivered from the ASB are 10π mm-mr (95% normalized) in both transverse planes and 0.2 eV-sec/bunch longitudinally. The total longitudinal emittance of 29 eV-sec/$4\text{x}10^{12}$ antiprotons represents a phase space density a factor of two higher than in the existing Antiproton Source. The transverse phase space densities are a factor of ten higher than in the existing Source.

In order to reach the phase space densities required we will be using cooling systems operating over the band 8-16 GHz. For a ring containing $N=4\text{x}10^{12}$ antiprotons with a system bandwidth W=8 GHz the optimized cooling time is,

$$\tau_c = N/W = 500 \text{ sec.}$$

This cooling rate is realized only in the presence of infinite signal-to-noise and perfect mixing in the cooling system. The primary competition to the stochastic cooling comes from intrabeam scattering. The beam heating time due to intrabeam scattering for the beam parameters given above and the lattice we will describe below is about 2000 seconds (transversely, the heating of the longitudinal phase space is much slower). In order to have confidence that the specified beam densities can be achieved we must insure that the achieved cooling time is less than about 1000 seconds--that is we must design a nearly optimized system.

The stochastic cooling is optimized by choosing the transition energy of the ASB so that it is matched to the bandwidth of the cooling system and the desired momentum spread. The requirement is,

$$6(\sigma_p/p)h\eta = 1$$

where h is the ratio of the highest frequency in the cooling band to the revolution frequency, $\eta=(\gamma_t^{-2}-\gamma^{-2})$, and σ_p/p is the rms momentum spread in the beam. This requirement results in adjacent Schottky bands just overlapping at the high end of the bandwidth of the cooling system and produces optimum mixing. For f_{max}=16 GHz and a total longitudinal emittance of 29 eV-sec at 8.9 GeV, the requirement on η becomes

$$\eta = .009$$

independent of the circumference of the ring. For cooling at 8.9 GeV this η corresponds to a γ_t of 7.1 or 22.0. A transition gamma of 7.1 is the more convenient goal since it is a more 'natural' value for a circumference close to that of the existing Accumulator and because it also provides nearly optimal cooling (good mixing) of recovered beams at 20 GeV.

The cooling systems in the ASB will include horizontal and vertical betatron systems, and a momentum cooling system. These systems are analogous to the core cooling systems in the existing Accumulator. No stack-tail type system is needed because of the long time between consecutive antiproton injections and the limited dynamic range in particle densities. For optimum cooling transverse pickups and kickers need to be located at zero dispersion points close to an odd integer times 90^{o} of betatron phase advance apart. They should be located as close to each other as possible within the ring in order to minimize transit time jitter, yet far enough apart to allow position signals to travel a significantly shorter distance to the kickers than the beam travels. Pickups and kickers separated by one third the circumference of the ASB seems to be the optimum arrangement (and the one used in TeV I). The easiest way to achieve this arrangement is with a ring of superperiodicity three and a tune which is close to an odd integer times 0.75.

The requirements on the lattice for momentum cooling include the existence of a high dispersion region for the pickups and a zero dispersion region for the kickers. With a ring of sixfold symmetry and superperiodicity three the kickers can be halfway around the ring from the pickups. In all instances it is desirable to provide low beta functions at kicker locations.

Based on the considerations discussed above we can specify the ideal ASB lattice as follows:

1. $\gamma_t = 7$. This optimizes mixing at both 8.9 GeV and at 20.0 GeV.

2. **Momentum Aperture (full width) = 1.7%.** This is needed to accommodate accumulation from the existing Accumulator and recovery from the collider.

3. **Transverse acceptance = 8π mm-mr.** This should be very generous since antiprotons from the Accumulator will have an emittance of 2π, and those recovered from the collider will have 1.9π at 20 GeV assuming a normalized emittance of $4\text{x}10\pi$.

4. **High dispersion straight section with $\alpha_p > 5$ meters and with at least 2 meters of free space reserved for momentum cooling pickups.**

5. **Tunes near an odd integer times 0.75, and sixfold symmetry with a superperiodicity of three.** This is to provide correct betatron phase advance between stochastic cooling pickups and kickers and to otherwise optimize cooling.

6. **Zero dispersion straight sections with 10 meters of free space reserved for betatron pickups and kickers, and momentum kickers.**

7. The usual requirements of straight sections for RF, injection, and extraction.

II.1 Overview

The parameters describing the Antiproton Super Booster are given in Table II-1. A layout of the ring showing the utilization of the straight sections is shown Figure II-1. As discussed above the ring has six-fold symmetry with a superperiodicity of three. The ASB is designed to have nearly the same circumference as the existing Accumulator (513 meters versus 474 meters). The transition gamma is 7.0. Through efficient space utilization the ring is capable of operating up to 20 GeV with bending fields of 15.9 kGauss. The ring has three zero dispersion straight sections each 10.7 meters long, and three high dispersion (α_p=7.8 m) straight sections each 7.7 meters long. In addition to stochastic cooling equipment and RF, there is room for one injection system (servicing both 8.9 GeV injection from the Accumulator and 20 GeV recovery from the Main Ring) and one extraction system.

II.2 Lattice

The ASB lattice is shown in Figure II-2. What is shown is one sixth of the ring. The ring is mirror symmetric around each of the endpoints of the figure and has a superperiodicity of three. The lattice is built up of pseudo-FODO cells with close to 90° phase advance per cell. The zero dispersion straight sections are 10.7 meters long and house the RF systems, momentum kickers, and betatron pickups and kickers. The high dispersion straight section is created by removing bending from the lattice 270° upstream of the straight section. The free space in each high dispersion straight section is 7.7 meters. These areas accommodate the momentum cooling pickups as well as injection and extraction kickers. The free space existing 270° away from the high dispersion straight sections is occupied by injection and extraction

Table II-1: Antiproton Super Booster (ASB) Machine Parameters

Circumference	513.65	meters
Accumulation Energy	8.9	GeV
Peak Energy	20.0	GeV
Harmonic Number (@53 MHz)	91	
Horizontal Tune	6.61	
Vertical Tune	6.61	
Transition Gamma	7.0	
η @ Low Energy	.009	
η @ Peak Energy	.018	
Maximum No. of Antiprotons	4×10^{12}	
Transverse Emittance (Normalized)	10π	mm-mr
Full Momentum Spread	20	MeV
Longitudinal Emittance	30	eV-sec
Longitudinal Density	2×10^{5}	eV^{-1}
Cooling System Bandwidth	8-16	GHz
Transverse Acceptance (Unnormalized)	8π	mm-mr
Momentum Acceptance	1.7	%
Number of Straight Sections	6	
Length of Zero Dispersion SS	10.7	meters
Length of High Dispersion SS	7.7	meters
Number of Dipoles	84	
Dipole Length	3.1	meters
Dipole Field (Max)	15.9	kGauss
Number of Quadrupoles	72	
Magnet Style	TeV I	

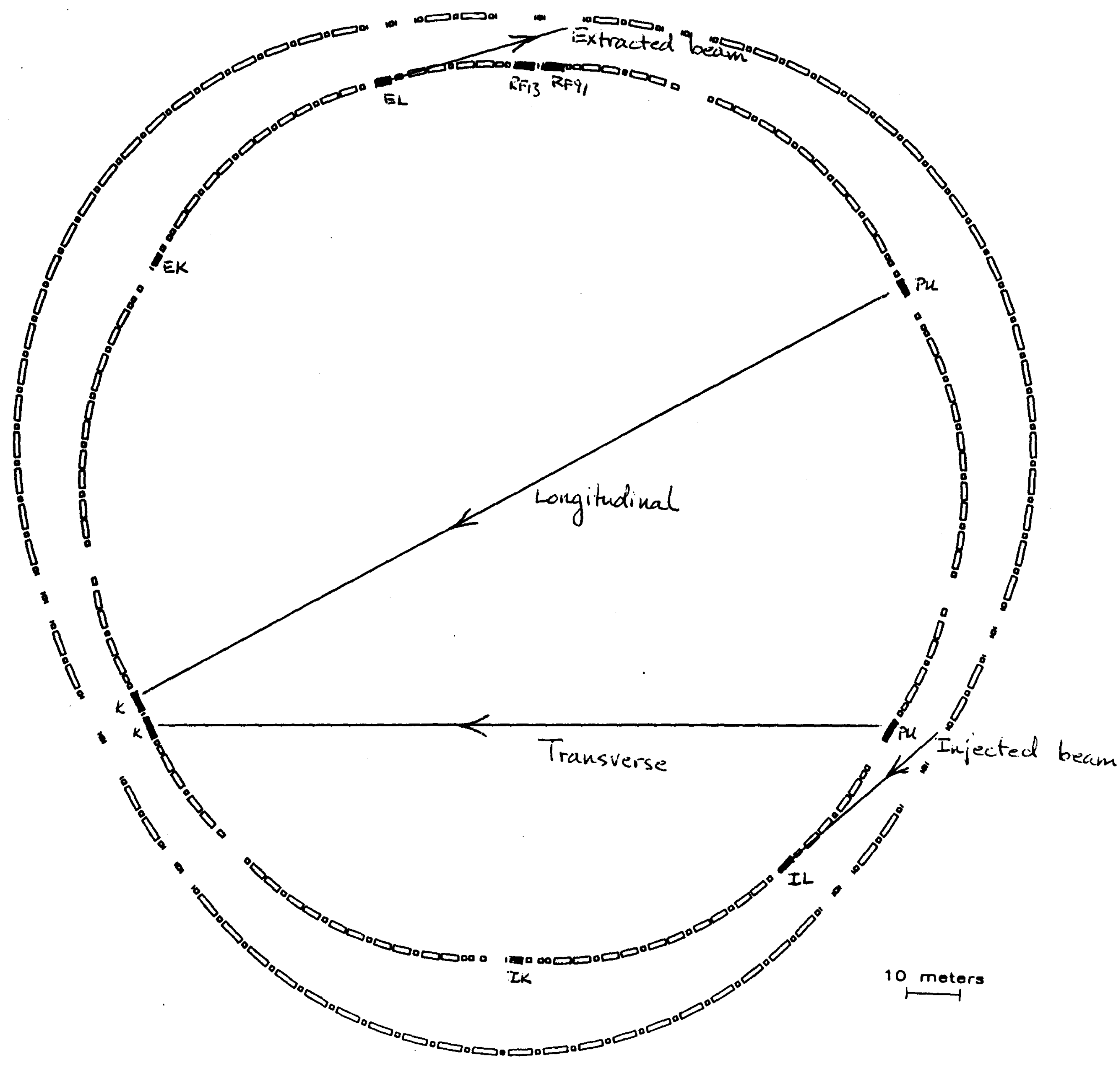
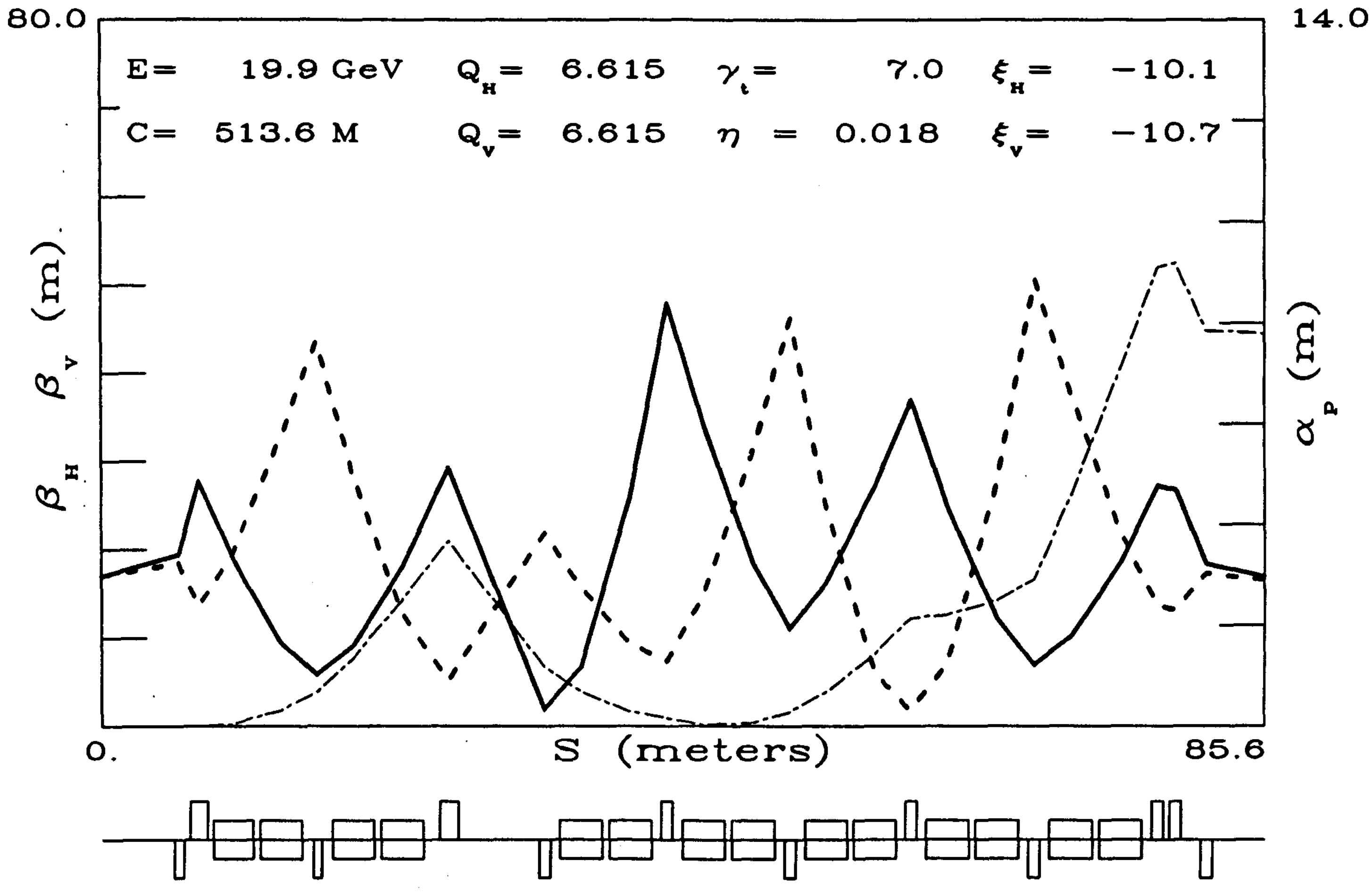

Extracted beam
EL
RF13
RF91
EK
PU
Longitudinal
K
K
PU
Transverse
Injected beam
IL
IK
10 meters

Figure II-1



THE ASB LATTICE

Figure II-2

Lambertson magnets. Seventy centimeters of free space is provided between each dipole and quadrupole for installation of sextupoles and beam position monitors. The lattice shown utilizes six different lengths of quadrupole magnets situated on three separate power busses. Eighteen 30 Ampere shunts are also distributed among the quadrupoles to facilitate tuning. The desired machine aperture can be obtained with (TeV I style) magnets designed and built for the existing Antiproton Source. A total of 54 'small quadrupoles', 18 'large quadrupoles', 72 'small dipoles', and 12 'large dipoles' are required.

II.3 Stochastic Cooling

Beam cooling systems are required in the ASB to increase the longitudinal density of antiprotons delivered from the Antiproton Accumulator to 2×10^5/eV while attaining normalized emittances of 10π mm-mr in both transverse planes. Cooling is also needed to counteract beam heating mechanisms. The heating mechanisms due to residual gas scattering are discussed in the vacuum section. They are relatively unimportant compared to the intrabeam scattering heating. High beam currents and rapid heating rates require high bandwidth cooling systems. For this reason, we propose to build 8-16 GHz stochastic cooling systems to maintain the desired beam density with a comfortable margin for error.

Intrabeam Scattering Rates

Heating rates due to intrabeam scattering have been computed using the formalism of Piwinski [1], the lattice functions for the ASB, and the desired beam sizes. The calculated rates are as follows:

Table II-2: Calculated Heating Times Due to Intrabeam Scattering (Hours)

	8.9 GeV		20 GeV	
$\Delta p/p$ (%)	.1	.05	.05	.02
Momentum	12.0	1.1	3.4	0.3
Transverse H	1.2	0.6	1.1	0.6
Transverse V	17.	-19.	-90.	-43.

At each energy the table gives two momentum spreads, the larger is approximately the design value; the smaller is shown for reference. Note that the transverse heating time is approximately proportional to the momentum spread, but that the momentum heating time grows rapidly with increasing momentum spread.

1. A. Piwinski, Proc. 9th Int. Conference on High Energy Accelerators, 405 (1974).

Cooling System Layout

The proposed cooling systems are horizontal and vertical betatron cooling systems consisting of an array of pickups and kickers separated by 1/3 the circumference of the ring (see Figure II-1), and a momentum system with the pickup and kicker separated by 1/2 the ring. There is room for additional, lower frequency systems as well. These systems are potentially useful in cooling beams with large momentum spread, as discussed below.

Betatron Cooling

Betatron cooling for the ASB ring is straightforward. The cooling rate is given by:

$$\frac{d\epsilon}{dt} = -\frac{W}{N}\left(2g - g^2(M+U)\right)\epsilon$$

where ϵ=emittance, N=number of particles, W=cooling system bandwidth, M=mixing parameter (discussed below) and U is the noise-to-signal ratio. The cooling term (first term inside the parenthesis) depends only on the gain. The optimum gain depends on the heating term coefficients M and U. For dense beams, such as we are considering for the ASB, U can be made small. The mixing factor (M) at the peak of the momentum distribution for octave cooling bandwidths and non-overlapping Schottky bands is given by:

$$M = \frac{\beta^2 E \, \Psi(E) \, \ln 2}{2 \, W \, T \, \eta \, N}$$

The value of η which makes M=1 was a major design consideration for the ASB lattice. For $E=8.9\times10^9$ eV ($\beta\simeq1$), $\Psi(E)=2\times10^5$/eV, $W=8\times10^9$ Hz, η=.009, $N=4\times10^{12}$, one obtains $M\simeq1$. Thus, at the optimum gain, for the ideal case of M=1 and U=0, the cooling rate is simply:

$$\tau_c = \frac{N}{W} = 500 \text{ sec}$$

This cooling time is small compared to the horizontal heating time of 2000-4000 sec. Based on a simulation of the proposed system and our operating experience with the Antiproton Source cooling systems, it is reasonable to expect τ_c=1000 sec can actually be achieved. At 20 GeV the increase in η from .009 to .018 almost exactly compensates for the increase in energy, so that the mixing is still nearly optimized. The heating rates, as can be seen from Table II-2, are somewhat faster, but the cooling rate still exceeds the heating rate by a comfortable margin.

Some parameters of the proposed system are shown in Table II-3. The largest uncertainty is the pickup and kicker structure sensitivity. The numbers quoted represent an extrapolation of our experience with existing 2-4 GHz pickups and R&D work on 4-8 GHz pickups. While the sensitivities and loss factors are intended to be conservative, there is no guarantee that it will be possible to achieve the values specified. A schematic diagram of the system is shown in Figure II-3.

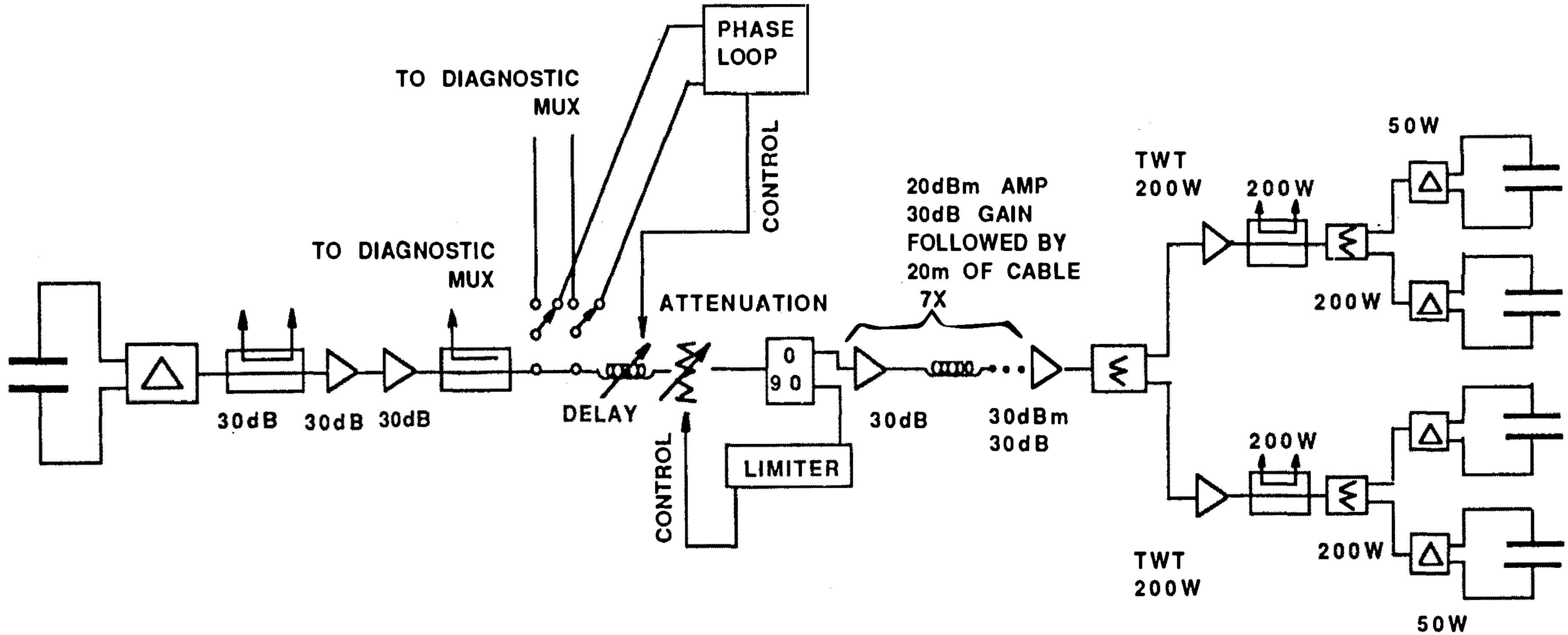
Table II-3: Cooling System Specifications

	H	ΔP	
Frequency Band	8-16	8-16	GHz
Number of pickup loops	64	64	
Pickup impedance	50	50	Ω
Pickup sensitivity	.8	.8	
Pickup resistor noise temp	300	300	^oK
Amplifier noise temperature	600	600	^oK
Nominal Operating power	50	100	W
Installed Power	400	800	W
Number of kicker loops	64	64	

Momentum Cooling

The momentum cooling is slightly more involved. The basic system is assumed to be the same as the Accumulator core cooling system (see Figure II-3). The pickup consists of two sets of electrodes: one set near the outside edge of the beam and one set near the inside edge of the beam. The total pickup signal is derived from the subtraction of the two electrodes. Each electrode can be timed individually. Unlike the Accumulator system, it is proposed that the radial separation of the electrodes be variable.

In a momentum cooling systems the heating is proportional to the gradient of the beam distribution in momentum. The variable electrode spacing and timing will allow more precise control of the points where the gradients occur, i.e., one can control the beam position and width. When the pickup electrodes are both timed for particles on the central momentum the gain function is as shown in Figures II-4 (difference of the two electrodes). Note that on the central momentum the phase is exactly 0^o or 180^o, but for off-momentum particles there is a phase error due to the (undesired) mixing between pickup and kicker. Figure II-5 shows the obtained beam momentum distribution for this system with a beam of 4×10^{12} particles at 8.9 GeV. The sigma is 4.3 MeV. The total beam of 4×10^{12} particles is close to the maximum amount of beam that can be stored with the system in this configuration. As the beam current is further increased the width of the beam will grow because of the increased heating from intrabeam scattering.

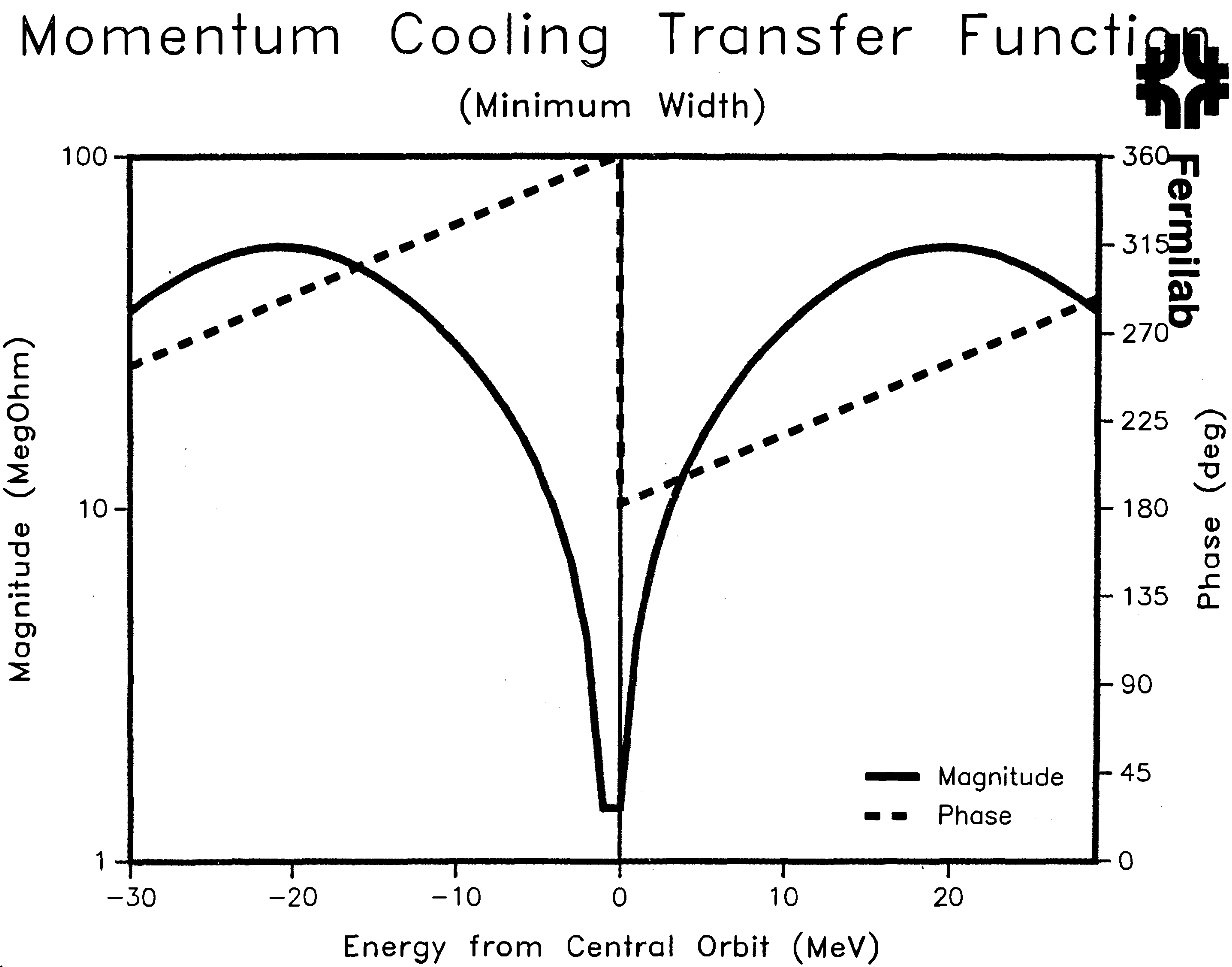


8-16 GHz COOLING

FOR ANTI-PROTON DEPOSITORY

HORIZONTAL OR VERTICAL

Figure II-3



Momentum Cooling Transfer Function
(Minimum Width)
100
10
1
Magnitude (MegOhm)
360
315
270
225
180
135
90
45
0
Phase (deg)
Magnitude
Phase
−30
−20
−10
0
10
20
Energy from Central Orbit (MeV)
Fermilab

Figure II-4

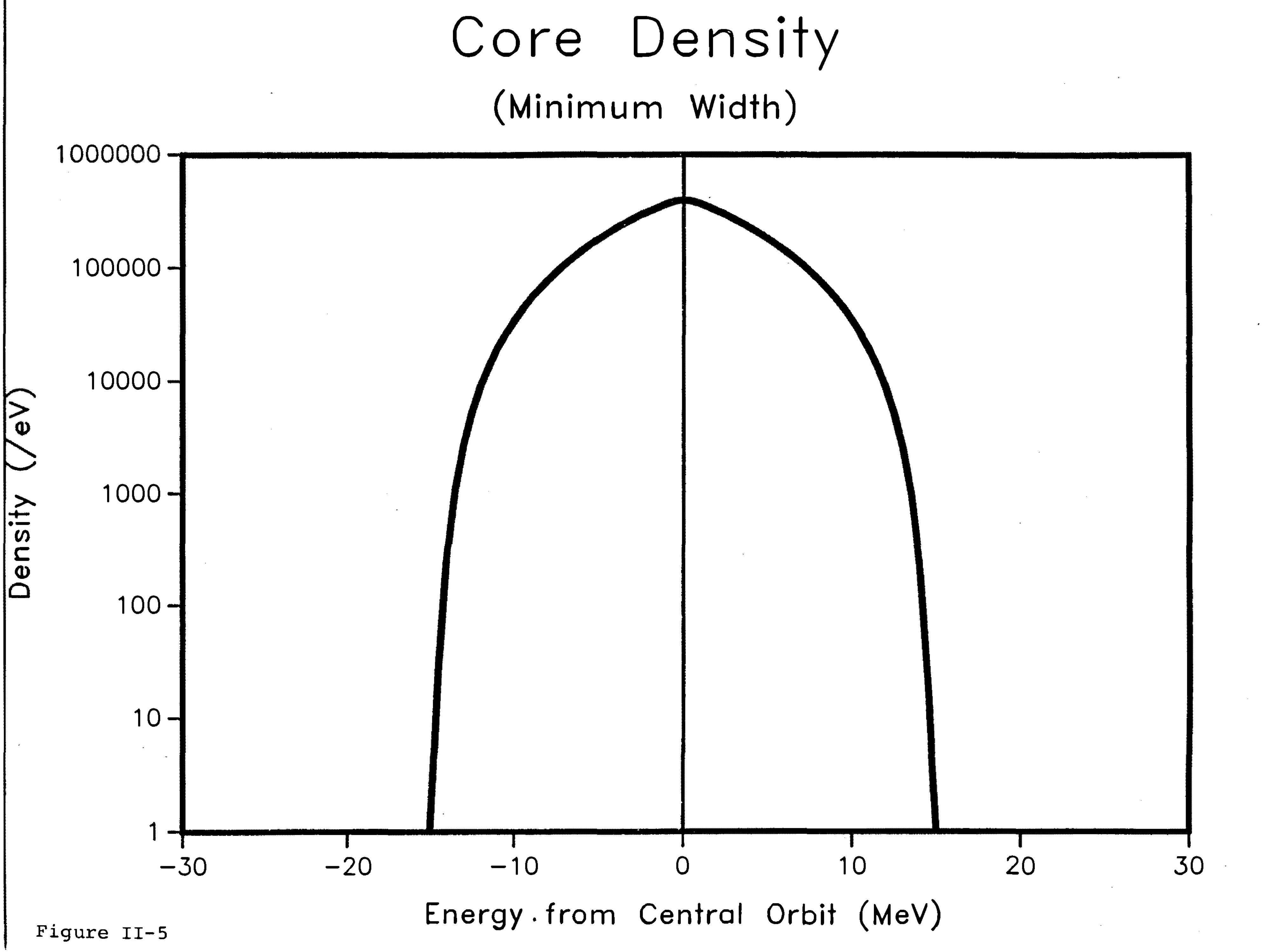

Core Density
(Minimum Width)
1000000
100000
10000
1000
100
10
1
Density (/eV)
−30
−20
−10
0
10
20
30
Energy from Central Orbit (MeV)

Figure II-5

This will force the edges of the beam past the point where the gain has the correct phase for cooling.

One can maintain larger momentum spreads by rephasing the inner and outer electrodes. As an example, the outer electrode can be phased for $\Delta E=+20$ MeV and the inner electrode for $\Delta E=-20$ Mev. The corresponding gain function is shown in Figure II-6. The resulting beam distribution is shown in Figure II-7. In this case a wider, flatter beam distribution is obtained. The sides of the distribution are sharper, corresponding to the improved cooling at the edges of the distribution. This configuration does have a major limitation, however. The phase of the gain at the center of the distribution is destabilizing, and the distribution obtained tends to be unstable. To avoid this problem, a noise spectrum was applied to the central portion of the beam to reduce the gradient and increase the stability margin. A careful examination of Figure II-7 will reveal the break-points in the step-wise discontinuous noise spectrum which was applied in this example.

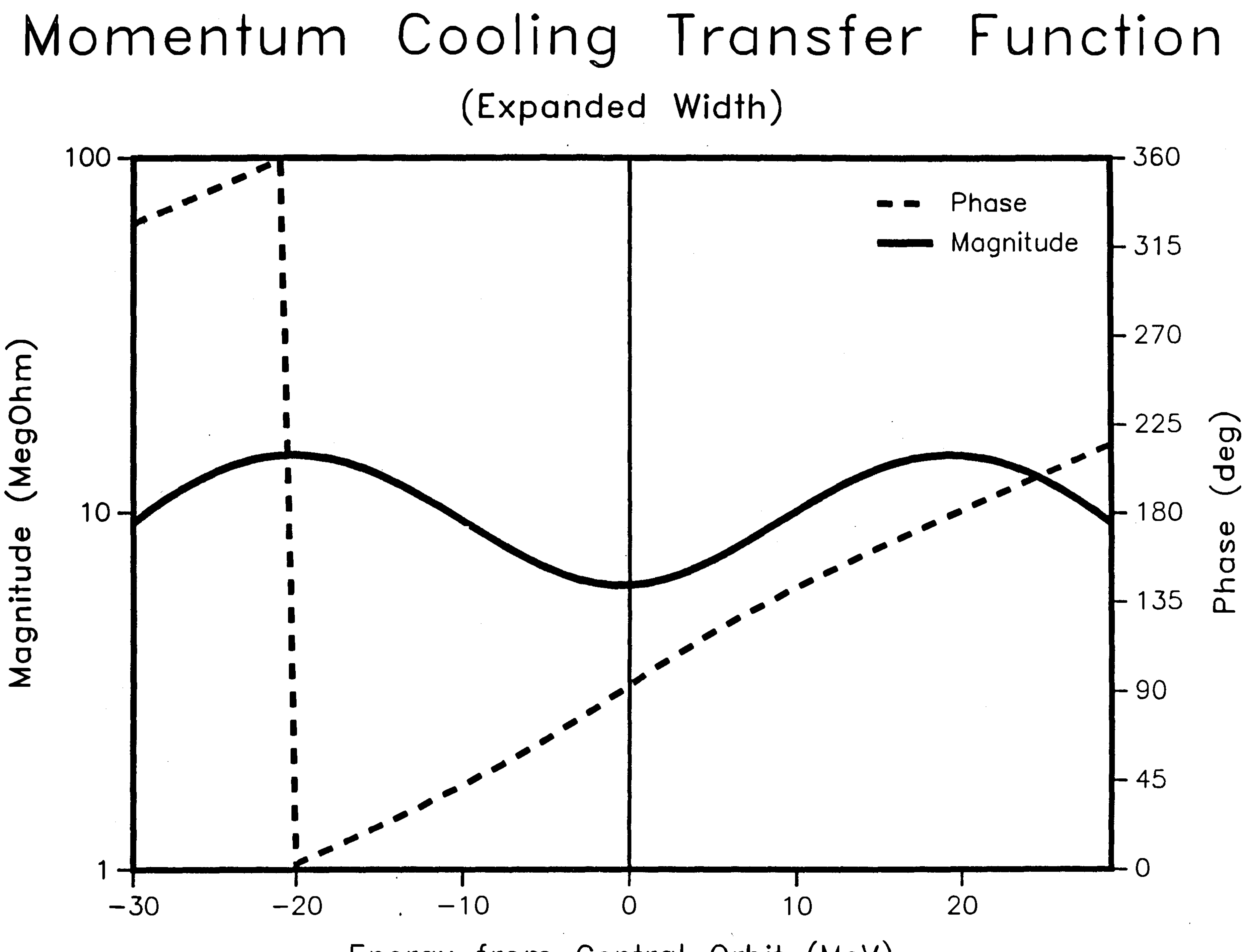
<u>Antiproton Recovery</u>

The recovery of antiprotons from the Tevatron presents special problems for the cooling system. The estimated momentum spread ($\Delta p/p=1\%$) must be cooled by a factor of three before the beam can be decelerated. It appears possible to achieve this cooling with the 8-16 GHz cooling system described above. One would begin with the plates at radial positions of $\pm 0.5\%$ in $\Delta p/p$ and phased for these momenta. As the edges of the distribution moved in one would decrease the separation and rephase the system for the new positions. The entire operation should not exceed an hour. The betatron cooling systems will not be able to function until the momentum spread is reduced to 0.3%, but the emittance growth over this period of time should be tolerable.

Another approach to the mixing problem of large momentum spread beams would be to use a lower frequency cooling system (or systems), say one at 2-4 GHz. Such a system would cover four times the momentum range of an 8-16 GHz system, but suffer from a cooling rate 16 time slower. It is anticipated that hardware for this low frequency system will be available from currently planned upgrades to the Antiproton Source. A lower frequency system could also be used for betatron cooling of recovered antiprotons. The relative positions of the pickup and kicker in the lattice would require a filter to correct phase differences between upper and lower betatron sidebands.

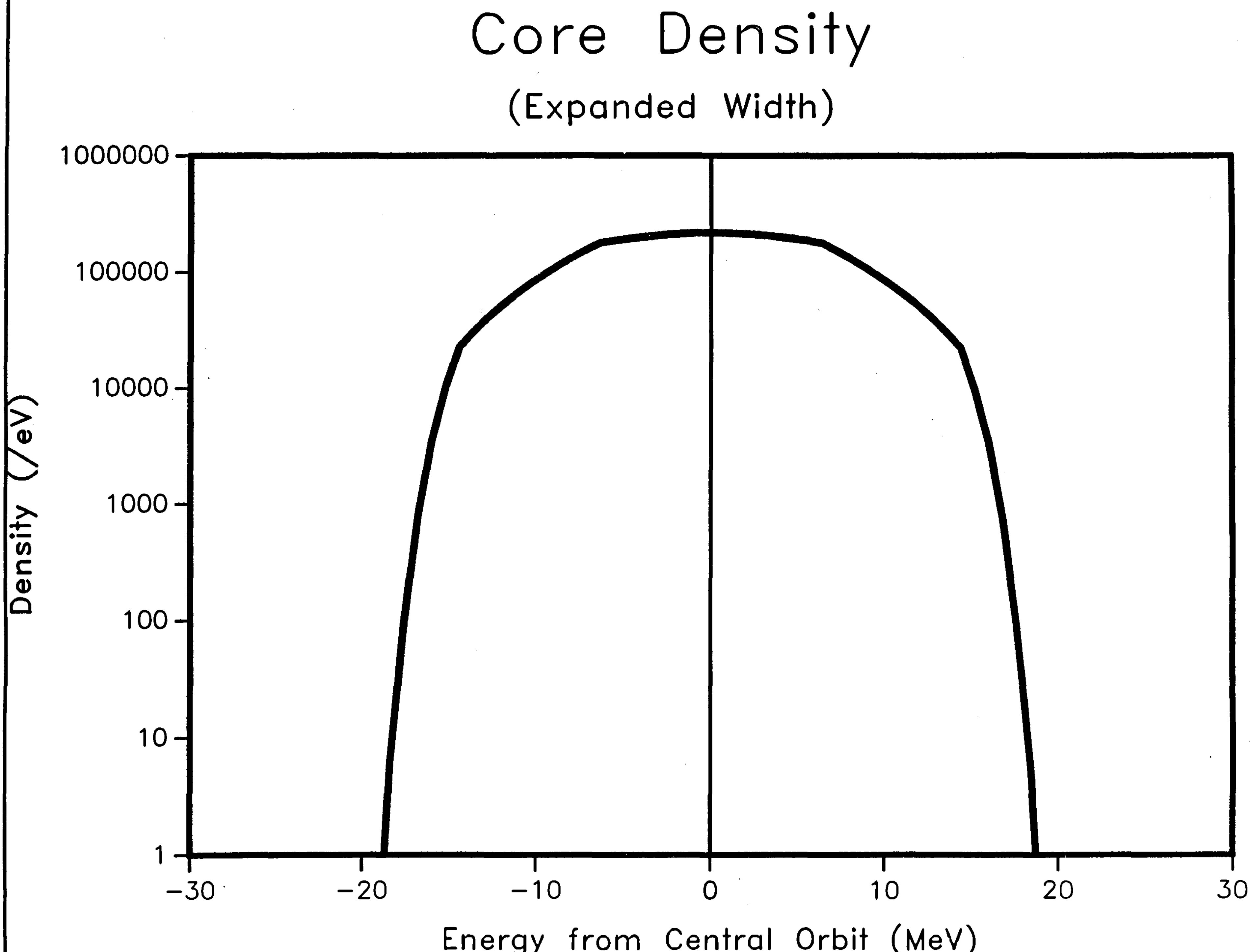
<u>Cooling System Hardware</u>

There are currently no 8-16 GHz cooling systems in existence, and these systems would therefore have to be developed. Cooling in the 4-8 GHz band has been demonstrated at the CERN AA. Most of the technology for 8-16 GHz is currently available or appears to be a relatively straight-forward



Momentum Cooling Transfer Function
(Expanded Width)
Phase
Magnitude
100
10
1
360
315
270
225
180
135
90
45
0
-30
-20
-10
0
10
20
Magnitude (MegOhm)
Phase (deg)
Energy from Central Orbit (MeV)

Figure II-6


Core Density
(Expanded Width)
1000000
100000
10000
1000
100
10
1
Density (/eV)
−30
−20
−10
0
10
20
30
Energy from Central Orbit (MeV)
Figure II-7

extrapolation of existing techniques. Some critical items are worth mentioning:

a. The pickup and kicker need to be designed. It appears that loop technology will still work in this frequency range. The pickup design is not particularly critical because the large beam current provides a relatively large Schottky signal. A number of different geometries are possible, but the conceptual design is based on a scaled version of an FNAL 4-8 GHz prototype loop pickup as shown in Figure II-8. We feel confident that such a design will extract an adequate beam signal at 8-16 GHz. The major difficulty is expected to be the suppression of (undesired) resonances. This issue must be addressed empirically; the number and complexity of the resonant modes in a structure of this sort can only be identified in a fairly naive manner.

b. The losses in 150 m of cable are prohibitive in single mode coaxial cable. The conceptual design calls for repeater amplifiers every 20 m of cable. This scheme has not been tested.

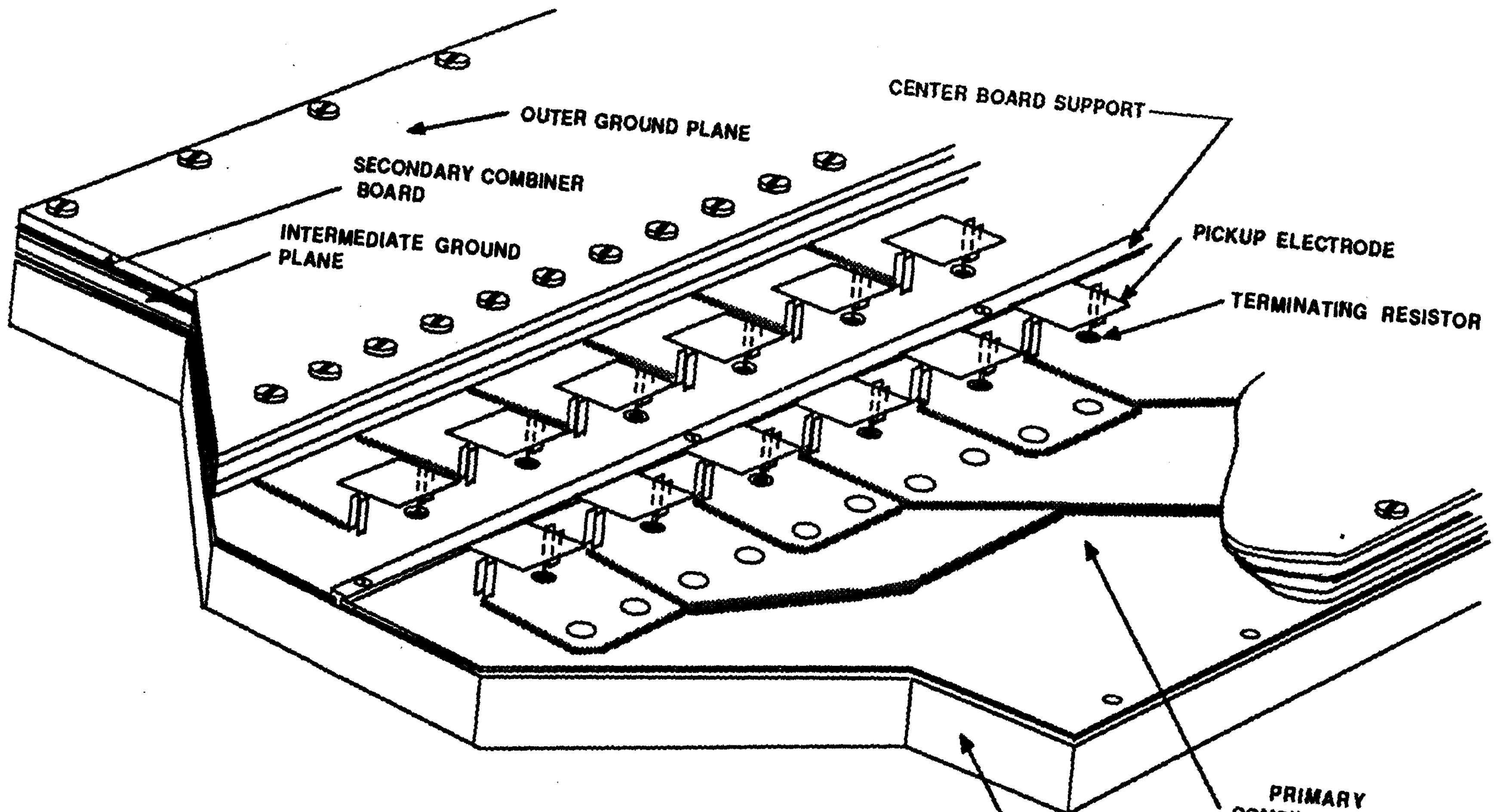
c. We know from our experience with 2-4 GHz cooling that the timing cannot be assured over extended periods of time, presumably because of thermal drifts. A phase-locked loop would be required to maintain proper system timing. This system seems straight-forward, but the concept is untested.

d. The high signal loss will probably require substantial pre-distortion of the gain function. Experience with 2-4 GHz systems is encouraging, but the frequency difference is too large to extrapolate with confidence.

<u>4-8 GHz Cooling</u>

In the event that construction of 8-16 GHz cooling systems were discovered to be unfeasible the fallback position would be to build the ASB using 4-8 GHz technology as is currently being developed for the Antiproton Source. Although some degradation of the performance of the ASB would likely result, we do not see this eventuality compromising the performance of the upgraded collider in any significant way.

Specifically, if we were to attempt to maintain the design longitudinal phase space density ($2\mathrm{x}10^5$/eV) the stochastic cooling rate would be reduced by a factor of four (two for bandwidth and two for mixing) completely eliminating any safety factor relative to the heating rate due to intrabeam scattering. A more likely scenario is that we would try to produce a phase space density of $1\mathrm{x}10^5$/eV. In this case the cooling rate would only be



8-16 GHz BEAM PICKUP

ELECTRODE ASSEMBLY

LOWER PLANE SHOWN

Figure II-8

reduced by a factor of two (we would gain back the mixing factor) and the transverse heating rate due to intrabeam scattering would also decrease by a factor of two leaving the safety factor unchanged relative to the planned 8-16 GHz system. The consequences of the reduced longitudinal density and cooling time are minimal. The longitudinal emittance of the antiproton bunches in the collider would increase from about 0.2 to 0.4 eV-seconds, an increase which is not expected to compromise performance significantly. We would probably also find the optimum time between transfers into the ASB from the Accumulator to be longer than if a 8-16 GHz system were used.

II.4 Magnets

The ASB requires a full complement of dipole, quadrupole, sextupole, and octupole magnets for its operation. For the most part these magnets can be similar to those built for the Antiproton Source. As such new design work and the production of new tooling can be minimized. A summary of magnet requirements and design parameters is contained in Table II-4.

The aperture and strength requirements of the dipole magnets are modest and could easily be satisfied by TeV I style dipoles. Cross sectional profiles of the TeV I 'small' and 'large' dipoles are given in Figures II-9 and II-10. The physical aperture corresponding to $8\pi x 8\pi x 1.7\%$ ($HxVx\Delta_p/p$) is 90x40 mm^2 (HxV) with the exception of the last two magnets within each sector where the horizontal aperture required becomes 190 mm. The good field aperture of the TeV I 'SDB' magnet is about 100x60 mm^2 and the required operating current for 15.9 kGauss (20 GeV operation) is around 1100 amps. The length of an SDB is about 2% shorter than the dipole magnet specified here. The final two magnets adjacent to the high dispersion region will be TeV I style 'large dipoles' at about 2/3 the length of those built for the Antiproton Source. The good field aperture of a TeV I 'LDA' is about 250x60 mm^2 and it operates at the same current as the small dipole. Both styles of dipole will have to be built with a considerably smaller sagitta than used in Tev I.

The dipole magnets built for the Antiproton Source show significant saturation effects at full excitation (17 kGauss). The ends of these magnets were carefully shaped to provide a field uniformity of $2.5x10^{-4}$ over the full aperture at 17 kGauss. It is known that the field uniformity in these magnets changes as the excitation is reduced and the magnets come out of saturation. Thus, there is every reason to expect that the ends of these magnets will have to be redesigned for use in the ASB and that means of minimizing changes in field quality over the operating range of 8.9 to 20 GeV will have to be developed. This redesign represents one of the substantial R&D projects associated with the ASB.

The aperture requirements of the quadrupole magnets are the virtually the same as the dipoles. The TeV I 'small quadrupole', with a good field aperture of 125 mm is more than sufficient everywhere except immediately adjacent to the high dispersion region. Outside of these regions the entire ring can be built out of previously designed and assembled SQBs, SQCs, SQDs, and SQEs. None of these small quadrupoles would be required to run above 360 Amperes at 20 GeV. The three quadrupoles adjacent to each

Table II-4: ASB Magnet Parameters

Dipole	Small	Large	
Length	3.122	3.122	meters
Field at 8.9 GeV/c	7.1	7.1	kGauss
Field at 20.0 GeV/c	15.9	15.9	kGauss
Good Field Aperture	10.2x5.8	25.4x5.8	cm^2
Maximum Current	1100	1100	Amps
Coil Resistance	14.4	14.8	mΩ
Coil Inductance	112	160	mH
Peak Power	17.4	17.9	KW
Stored Energy	67.7	96.8	KJ
Number Required	72	12	

Quadrupoles	SQB	SQC	SQD	SQE	LQD	LQE	
Length	64.	70.	83.	131.	87.	83.	cm
Maximum Gradient	130.	130.	146.	130.	63.	63.	kG/m
Maximum Current	319.	319.	356.	319.	820.	820.	Amps
Coil Resistance	39.3	41.6	46.4	64.6	8.8	8.5	mΩ
Coil Inductance	60.2	66.0	77.9	123.	34.4	32.6	mH
Peak Power	4.0	4.2	5.9	6.6	5.9	5.7	KW
Stored Energy	3.1	3.4	4.9	6.3	11.6	11.0	KJ
Number Required	6	6	30	12	6	12	

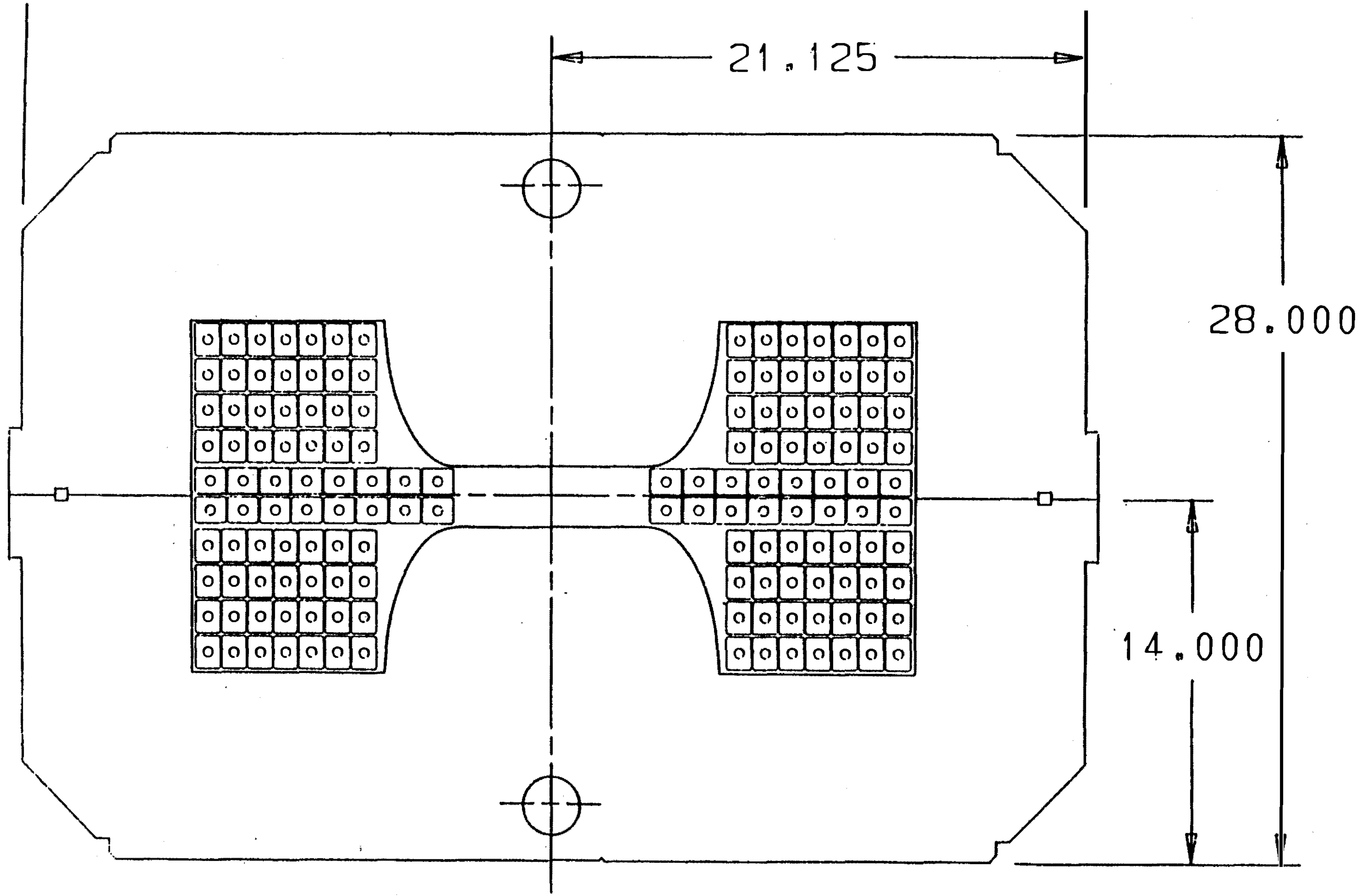


Figure II-9

SMALL DIPOLE

units are in inches

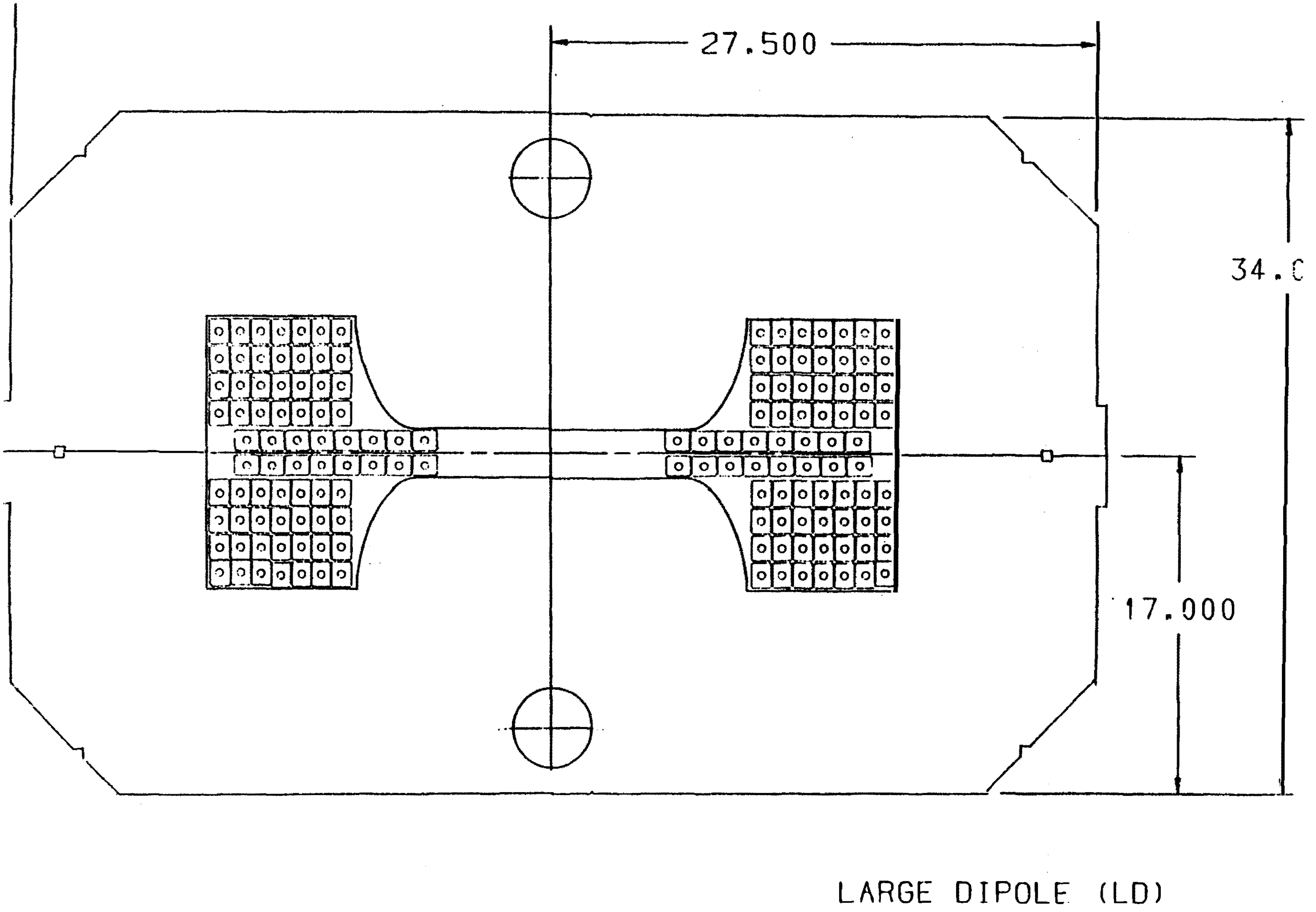


Figure II-10

units are in inch

high dispersion region are LQEs and LQDs. These magnets will operate at 800 Amperes--well below the excitation used in the Antiproton Source. Cross sections of the small and large quadrupoles are shown in Figures II-11 and II-12.

The small quadrupoles as used in the Antiproton Source and as planned in the ASB do not exhibit saturation effects. The large quadrupoles as used in the Antiproton Source however are highly saturated and, as in the case of the dipole magnets, have ends designed to give good field uniformity at currents around 1200 A. At 800 A, as required in the ASB, saturation effects should be negligible. Thus, the large quadrupole ends will have to be redesigned to provide good field quality at the lower excitation.

Four families of sextupole magnets will be used to control chromaticity and to reduce third order resonance widths. A total of 36 magnets are required. Twenty four of these can be copies of those made for the Antiproton Debuncher ring (aperture = 143 mm) while the other twelve will be copies of the large aperture sextupoles installed in the high dispersion regions of the Antiproton Accumulator. It is anticipated that octupoles will also be needed to control tune versus momentum variations. Twelve magnets of the type implemented in the Antiproton Accumulator powered by two buses will be used.

Twelve correction dipoles are provided for adjustment of orbits in the injection and extraction areas.

II.5 Power Supplies

Since the ASB acts primarily as a storage ring either at 8.9 GeV or 20 GeV the power supply requirements are relatively stringent. With acceleration and deceleration in the ASB being at a very low rate, a single 1250 volt/1125 ampere power supply connected in series with the 84 magnet load is adequate. Regulation requirements, particularly during storage, are very tight. The 10 parts per million (ppm) regulation is the same as for the present Accumulator Ring.

There are three main quadrupole power supplies with 18 30 ampere shunts connected across selected magnets in the series strings to provide the necessary tune and harmonic correction control. In addition, there are 4 sextupole loops, 2 octupole loops and 12 trim dipoles with independent control. The quadrupoles have a 10ppm while the shunts and the rest of the power supplies are 100 ppm regulation. This is again consistent with the present operation of the Accumulator Ring.

Primary AC power for all these supplies needs to be on a "quiet" feeder in order to insure good regulation and stability during stores. All supplies will derive their input power from the 480 Volt AC line with the exception of the main dipole supply which will be driven off its own transformer linked directly to the 13.8 kV feeder.

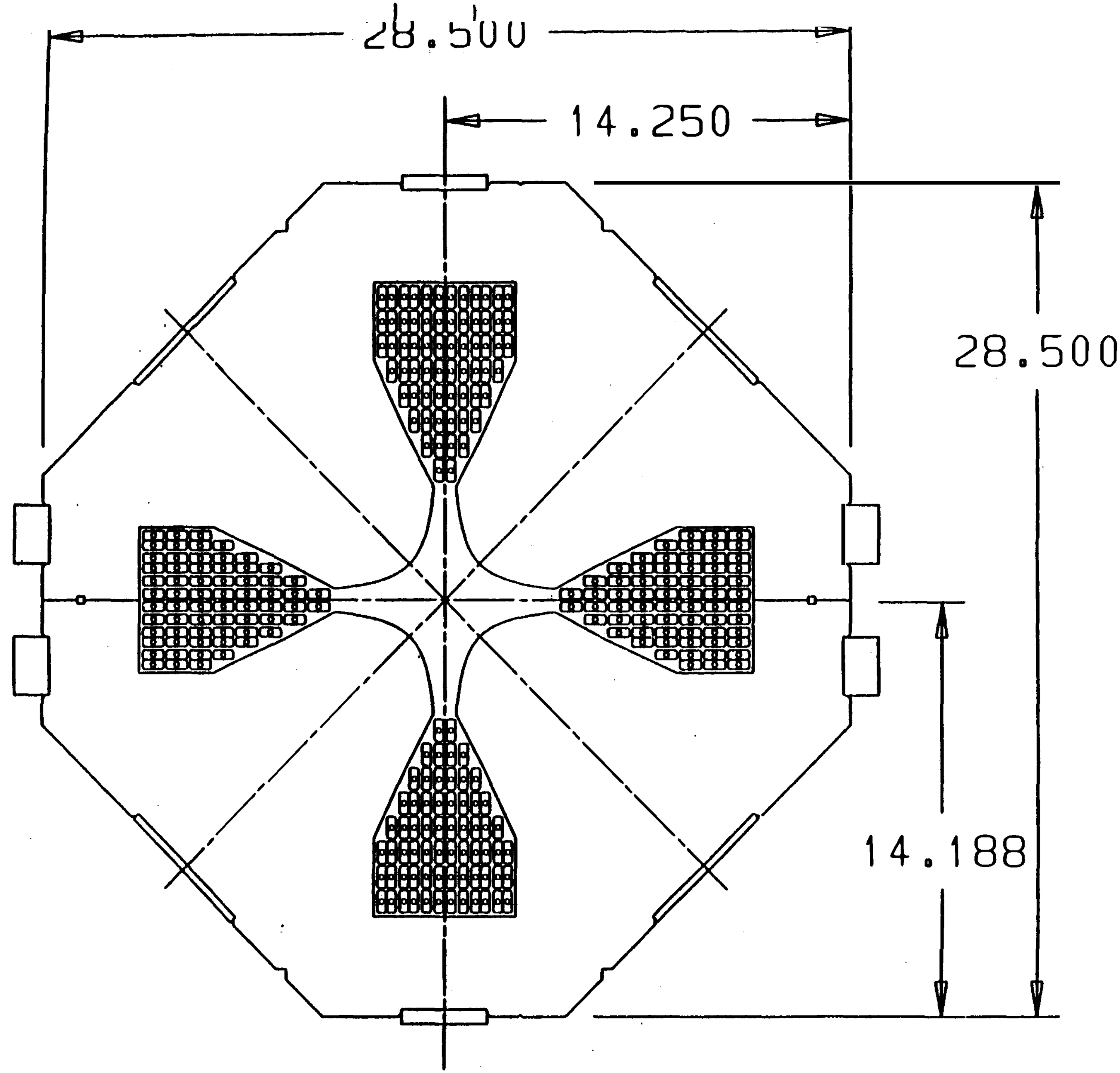


Figure II-11

SMALL APERTURE QUAD (SQ)

units are in inches

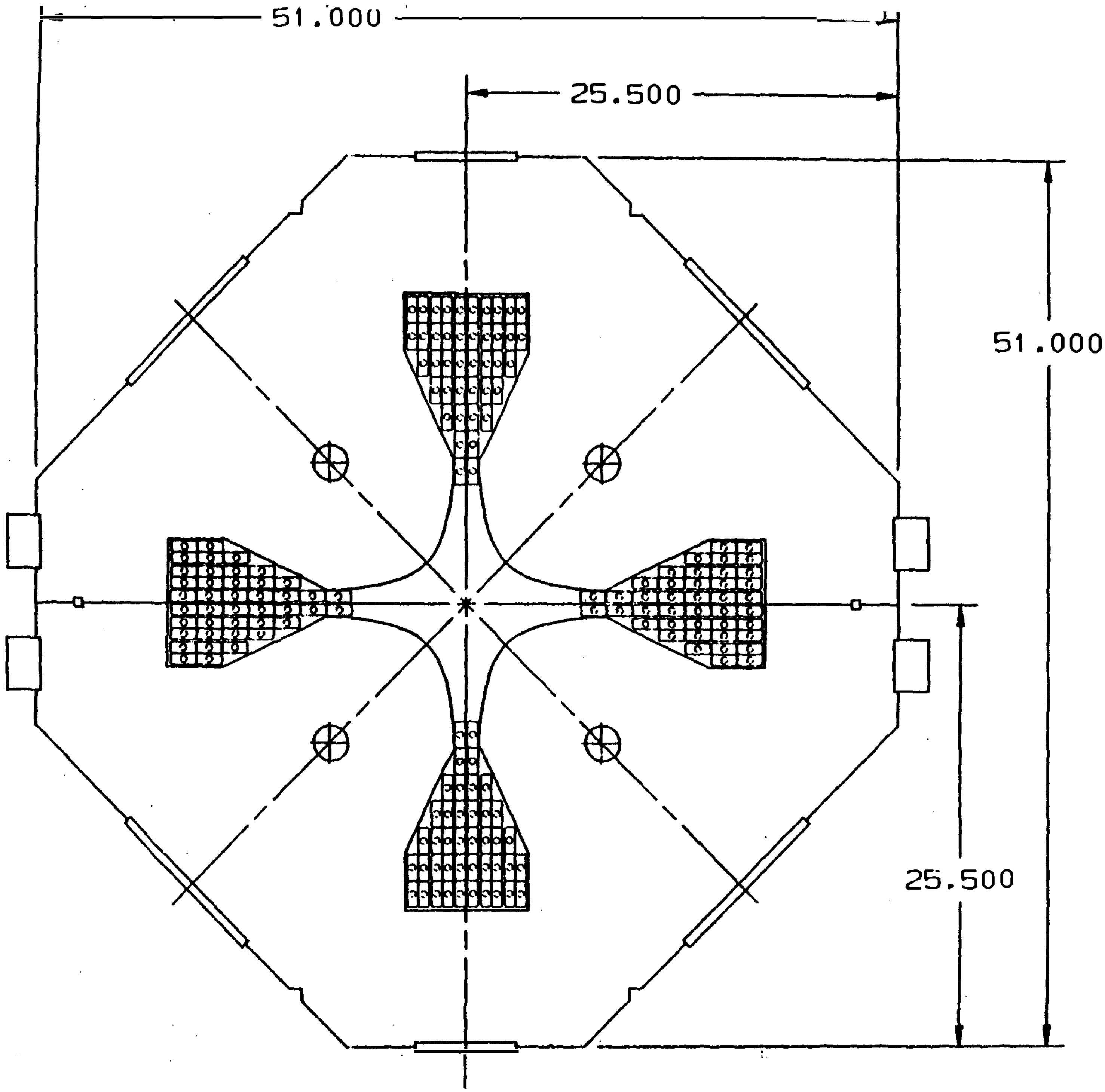


Figure II-12

LARGE QUAD (LQ)

units are in inches

II.6 RF

The specification of the RF requirements for the 20 GeV ASB requires rather specific schemes for beam manipulations, for loading the ASB from the Accumulator, and for antiproton recovery (loading the ASB from the Main Ring). The following schemes are adopted and form the basis for the RF specification. The longitudinal beam parameters and parameters for the RF system for loading from the Accumulator are given in Table II-5. The table listing the same parameters for recovery is presented as Table II-6. The bucket areas shown all correspond to stationary buckets, since the assumption is made that all energy changes occur slowly.

Loading the ASB from the Accumulator

Every three hours 4.5×10^{11} antiprotons will have been collected in 16 eV-sec in the Accumulator. The unloading sequence involves capturing the entire Accumulator core with the existing h=84 system, accelerating it to the extraction orbit and transferring it to the injection orbit in the ASB. The antiprotons are captured via a direct bunch-to-bucket transfer with the h=91 system and are decelerated to the stacking orbit where they are allowed to debunch. The injected beam requires 0.3% of momentum aperture. Nine repetitions (over a period of 27 hours) fills the ASB with 4×10^{12} antiprotons.

Unloading the ASB to the Main Ring

The original 144 eV-sec loaded from the Accumulator is cooled to 30 eV-sec. The entire core is then accelerated to 20 GeV with the h=91 RF system. Then, one tenth of the stack is captured with an h=13 system and moved to the extraction orbit. The h=13 voltage is suddenly increased to rotate the bunches so that they can be captured in one out of every seven buckets of the h=91 system. The h=91 system is turned on to match to the bunches, and then the voltage is increased for transfer to the Main Ring. The beam is extracted to the Main Ring, captured in matched buckets, and accelerated from 20 to 150 GeV. The beam is then transferred to the Tevatron. This process is repeated eight times to fill the collider.

As may be noted from Table II-5 the momentum spread of the antiproton beam gets very small as it is unstacked and so we might expect the beam to become unstable. We can derive a limit on the longitudinal impedance of the ASB based on the parameters in the table and the Keil-Schnell criterion. What we find is that Z/n needs to be less than about 15Ω to satisfy the Keil-Schnell criterion. Implications of this are addressed in the section on RF hardware below.

Table II-5: ASB RF Parameters (Accumulation)

ϵ_L = longitudinal emittance (eV-sec)
A_b = bucket area (eV-sec)
ΔE_b = bucket height (half, MeV)
Δt = bunch length (full, nanosec)
ΔE = bunch height (full, MeV)
$\delta p/p$ = bunch relative momentum spread (full, %)
E = total energy (GeV)
N_b = number of bunches in machine

V_{RF} = RF Voltage (kV)
h = harmonic number
f_{RF} = RF frequency (MHz)
Np/bunch = number of antiprotons per bunch

	Condition	E	N_b	ϵ_L/bunch	h	V_{RF}	f_{RF}	A_b	ΔE_b	Δt	ΔE	$\delta p/p$	$N\bar{p}$/bunch
1	Accumulator unstack	8.9	84	.19	84	86	52.8	.38	15.8	10.6	24.3	.27	5.4×10^{9}
2	ASB stack	8.9	84	.19	91	40	52.8	.38	15.8	10.6	24.3	.27	5.4×10^{9}
3	ASB accelerate	8.9	91	.33	91	145	52.8	.66	27.5	10.6	42.33	.476	4.4×10^{10}
		20	91	.33	91	99	53	.66	27.5	10.6	42.33	.21	4.4×10^{10}
4	ASB capture	20	13	.21	13	.028	7.5	.21	1.24	133	2.48	.0125	3.0×10^{10}
5	ASB unstack	20	13	.21	13	.350	7.5	.74	4.34	53	5.1	.0255	3.0×10^{10}
6	ASB bunch rotate	20	13	.21	13	7.9	7.5	3.51	20.7	10.6	24.3	.122	3.0×10^{10}
7	ASB recapture	20	13	.21	91	32.6	53	.42	17.5	10.6	27.0	.135	3.0×10^{10}

Prior to transfer into Main Ring the ASB RF voltage should be set to match the buckets in the Main Ring. Because Main Ring is near transition the corresponding η is very small (η=.00653). The condition for matching is that the voltage in Main Ring is .4437 times the voltage in the ASB. It is likely that the ASB voltage will have to be adiabatically increased to match Main Ring.

Table II-6: ASB RF Parameters Recovery

ϵ_L = longitudinal emittance (eV-sec)
A_b = bucket area (eV-sec)
ΔE_b = bucket height (half, MeV)
Δt = bunch length (full, nanosec)
ΔE = bunch height (full, MeV)
$\delta p/p$ = bunch relative momentum spread (full, %)
E = total energy (GeV)
N_b = number of bunches in machine

V_{RF} = RF Voltage (kV)
h = harmonic number
f_{RF} = RF frequency (MHz)
$N\bar{p}$/bunch = number of antiprotons per bunch

	Condition	E	N_b	ϵ_L/bunch	h	V_{RF}	f_{RF}	A_b	ΔE_b	Δt	ΔE	$\delta p/p$	$N\bar{p}$/bunch
1	Tev Inject to Main Ring	150	143	.84	1113	158	53	1.67	69.5	10.6	107	.07	3.0×10^{10}
2	MR Decelerate to 20 GeV	20	143	.84	1113	272	53	1.67	69.5	10.6	107	.53	3.0×10^{10}
3	MR Pre-Bunch Rotation	20	143	.84	159	37.4	7.5	11.5	67.7	10.6	107	.53	3.0×10^{10}
4	MR After Bunch Rotation	20	143	.84	159	37.4	7.5	11.5	67.7	77.4	16.8	.084	3.0×10^{10}
5	MR Coasting Beam	20	143	.9	159	.790	7.5	1.81	10.7	77.4	16.8	.084	3.0×10^{10}
6	ASB Capture	20	143	.9	13	2.1	7.5	1.81	10.7	77.4	16.8	.084	3.0×10^{10}

Loading the ASB from the Main Ring

As discussed earlier it is assumed that the antiproton longitudinal emittance in the Tevatron will have blown up by a factor of four (to 0.8 eV-sec/bunch) during colliding beam operation. During this time we have been stacking from the Accumulator, and the ASB is now filled. The ASB is ramped to 20 GeV and the following sequence of operations is carried out. The antiproton beam in the Tevatron is decelerated to 150 GeV and transferred to the Main Ring. The beam populates one out of every seven buckets, with 96 of the 1113 buckets filled. The momentum spread of this beam is large but it is possible to decelerate to 20 GeV without special manipulations. The minimum $\delta p/p$ achievable at 20 GeV is obtained when the bucket is reduced to the size of the beam. For a longitudinal emittance of .84 eV-sec the full $\delta p/p$ is .345%. Note that this is very close to the momentum spread injected into the present Main Ring from the present Booster. However for this proposal we assume that a constant bucket area will be maintained during deceleration resulting in a $\delta p/p$ of .53%. At 20 GeV the 53 MHz system is turned off, and a 7.5 MHz system is snapped on to a voltage which performs a bunch rotation. The resulting bunches have a $\delta p/p$ of .08%. These bunches are then held by the 7.5 MHz system while eight transfers are made into the ASB. The transfer is a bunch-to-bucket transfer into the ASB. These antiprotons are stacked in longitudinal phase space next to the existing ASB core. The total momentum aperture required for this procedure is about .8% in addition to the .3% occupied by the injection orbit.

After the ASB has been loaded with recovered antiprotons the Tevatron can be reloaded by pulling antiprotons out of the core through the recovered stack in the manner previously described. The ASB will then contain only recovered antiprotons with a longitudinal emittance of 100 eV-sec and a normalized transverse emittance of perhaps 40π mm-mr. The ASB must remain at 20 GeV until the beam has been cooled to about 30 eV-sec. If this can be done in three hours or less, while the Accumulator is being filled, no antiproton production time is lost. When the beam is cool enough the ASB can be ramped down to 8.9 GeV. It is unknown what fraction of the antiprotons will be recovered in this manner. However, if even 50% are recovered the effective antiproton production rate is doubled, and if 90% could be recovered the effective rate goes up by a factor of ten.

The momentum aperture required in the ASB is 1.7%. ***The momentum aperture requirement is dominated by the antiproton recovery scheme.***

Hardware RF Requirements in the ASB

The design of the two RF systems required in the ASB is dictated by the need to keep the impedance seen by the beam low in order not to exceed the previously discussed limit on Z/h. If two H=91 cavities are to be used their shunt impedance would have to be in the neighborhood of 700 ohms at the 53.1 MHz operating frequency. At the required accelerating voltage of 72.5 kV the cavity power would be 4.4 MW, a prohibitive level.

We propose a cavity loaded to present a shunt impedance of 20 kohms across its gaps taking advantage of the fact that these cavities are not required to be operational as antiproton are removed from the core. Fast shorts will be developed to lower the cavity gap impedance during the offtime of the cavity. Power will be provided with a 150 kW amplifier identical to those now used in the Main Ring. Further reduction of gap impedance will be accomplished using feedback when the RF is operating. Since the acceleration rate in the ASB is low it may be advantageous to provide the frequency range using mechanical tuners. If not, a tuning system similar to that in the Main Ring will be used.

The H=13 system for the ASB requires a shunt impedance on the order of 200 ohms at 7.5 MHz. The proposed solution is to use a pair of ferrite loaded quarter wave resonators with a ceramic gap in the center. The impedance of each half will be loaded to 50 ohms with external resistors. This system will require a power level of 160 KW. Each cavity will be driven push pull via a 100 kW RF amplifier. Since the drive power can be transmitted over a 50 ohm matched impedance system, the amplifier and associated hardware will be upstairs in the equipment gallery. No tuning will be required for the cavity. The present costing is predicted on using tube type technology, but an effort will be made to incorporate solid state amplifiers.

II.7 Vacuum Systems

To achieve beam lifetimes of hundreds of hours several mechanisms by which the antiproton beam interacts with the residual gas molecules in the ASB must be minimized: particle loss by single Coulomb scattering, multiple scattering and nuclear interactions; beam heating by multiple Coulomb scattering; energy loss by ionization; and effects of neutralization by trapped positive ions. An analysis of these mechanisms [1] indicates that an ASB vacuum requirement of 1.0×10^{-10} Torr is adequate for achieving beam lifetimes in excess of 500 hours. This vacuum specification does not require the development of any new vacuum technology. The same principles and techniques used in the successful design of the Antiproton Accumulator vacuum system should result in satisfying the ASB vacuum requirement.

1. A.G. Ruggiero, "Vacuum Considerations for the Accumulator Ring", Fermilab Pbar Note #194 (1982), unpublished.

Sputter ion pumps will be used to pump the chamber down to 1.0×10^{-8} Torr or less. Ion-pumps with a true pumping speed of 100 l/sec., placed between every other dipole, would be adequate in this range. To reduce the pressure from 1.0×10^{-8} to 1.0×10^{-10} Torr, the vacuum system design exploits the very large pumping speeds that can be achieved with titanium sublimation pumps in this regime (after an in-situ bakeout of the chamber at moderately-high temperatures). The length and aperture of the dipole magnets produces a conductance limited system which requires a sublimation pump at the end of every dipole. The required pumping speed of 1000 l/sec (or greater) can be achieved with the style of sublimation pump used in the Accumulator vacuum system.

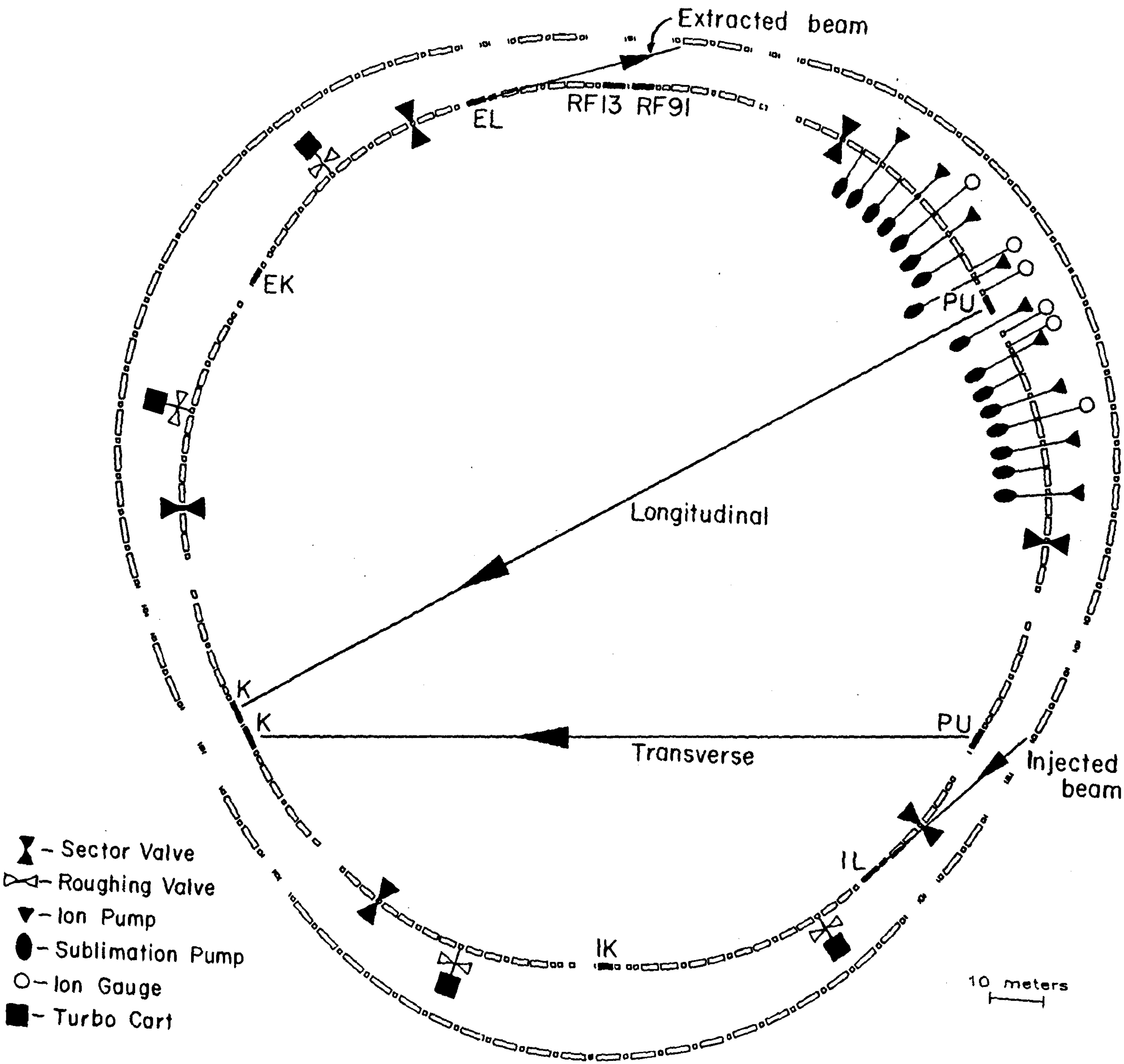
An in-situ bakeout of at least $250^{\circ}C$ will be required to reduce the specific outgassing rate to less than 1.0×10^{-12} Torr-liter/sec/cm^2. The role of the bakeout system, the careful choice of vacuum materials, and the presence of a large number of bellows to accommodate the significant thermal expansion of the chamber are all of paramount importance in satisfying the vacuum specification.

Figure II-13 shows the vacuum system layout over one-sixth of the ASB ring. Six all-metal, sector valves are used to isolate each sector during bakeout to prevent vacuum contamination of the other sectors. Pump down during bakeout employs mobile turbopump carts which can be shared by different sectors of the ASB. Six Pirani gauges, six cold-cathode gauges and thirty-six ionization gauges are used to measure the ring pressure from 10^{-3} Torr down to the operating pressure.

II.8 Injection and Extraction

Antiprotons are injected into the ASB from two separate sources: from the Antiproton Accumulator at 8.9 GeV; and from the Main Ring at 20 GeV. Both of these injections occur in the same physical location and are handled by a common set of hardware (Lambertson and kicker magnets). The antiprotons are injected onto an orbit displaced 0.7% above the central momentum of the ASB. About one eighth of the circumference of the ring is traversed between the injection Lambertson and the kicker (see Figure II-1). The kicker is located in a high dispersion straight section where the injection orbit is well separated from the accumulated antiproton core. The kicker may or may not be shuttered as in the Antiproton Source. The transverse aperture available on the injection orbit is the same as in the remainder of the machine, i.e. 8π transversely and 0.3% in momentum space.

Extraction of antiprotons from the ASB is geometrically identical to injection except that it takes place in a different sector of the ring. Injection and extraction are both accomplished using a horizontal kick which moves the antiproton beam across the septum of a Lambertson magnet located



Extracted beam
RF13 RF91
EL
EK
PU
Longitudinal
K
K
PU
Transverse
Injected beam
IL
IK
10 meters
Sector Valve
Roughing Valve
Ion Pump
Sublimation Pump
Ion Gauge
Turbo Cart

Figure II-13

270^{o} in betatron phase away. The displacement caused by the kicker and Lambertson magnets is not sufficient to clear the physical aperture of the quadrupole located immediately upstream (in the case of injection, downstream in the case of extraction) of the Lambertson magnet. A special quadrupole (two total) will need to be developed in which the injected or extracted beam passes through a hole in the iron yoke of the magnet. Characteristics of the required injection and extraction magnets are listed in Table II-7.

II.9 Instrumentation

The instrumentation for the Antiproton Super Booster will be similar to that in the existing Fermilab Antiproton Accumulator.

The beam position system will use the standard Fermilab 53 MHz processing electronics connected to Tevatron style 50Ω strip line detectors. The system will be able to display first turn orbits, turn by turn oscillations and closed orbits. The system will work for both bunched antiprotons and test proton bunches at both 8.9 GeV and 20 GeV. A detector will be provided at each quadrupole. The loss monitor system will be built with Tevatron system ion chambers. These chambers will also be located at every quadrupole in the ring.

Since the ASB is a storage ring a high accuracy D.C. current transformer of the type used in the Accumulator Ring will be employed. This second harmonic type transducer has the stability necessary to measure the beam intensity and lifetime required in this type of storage ring.

For measurement of coasting beams in the ASB, three Schottky detectors of the type used in the Accumulator will be needed, one longitudinal and two transverse. The detectors are medium Q resonant detectors which will facilitate measurements of the longitudinal beam profile, tunes, chromaticities and emittances. A resonant frequency of approximately 78 MHz is a good compromise for avoiding RF harmonics while giving good sensitivity for momentum spread and chromaticity measurements.

The damper system for the ASB is designed primarily to suppress unbunched beam transverse coherent instabilities. The bandwidth of the system will cover the lowest sidebands up to one hundred megahertz. It will also utilize a revolution frequency notch filter to enable damping of bunched beams during the unstacking process prior to transfers to the main ring. Again this damper is patterned after the existing Accumulator damper system.

The ASB will have beam scrapers for measuring the acceptance of the machine in both planes, and a momentum scraper to aid in beam dynamics measurements.

II.10 Controls

The entire Fermilab accelerator complex, from the ion source to the Tevatron and current antiproton rings, is controlled by a uniform system

Table II-7: ASB Injection/Extraction Magnets

8.9 GeV Injection (Shuttered) Kicker

Length	3.0	meters
Field	289.	Gauss
Risetime	---	
Falltime	130	nsec
Aperture(HxV)	33x23	mm^2

20.0 GeV Injection (Shuttered) Kicker (This is the same device as above)

Length	3.0	meters
Field	650.	Gauss
Risetime	---	
Falltime	130	nsec
Aperture(HxV)	33x23	mm^2

20.0 GeV Extraction (Shuttered) Kicker

Length	3.0	meters
Field	650.	Gauss
Risetime	90.	nsec
Falltime	---	
Aperture(HxV)	33x23	mm^2

Injection/Extraction Lambertsons

Number Required	2	
Field	10.0	kGauss
Length	3.0	meters
Aperture(H)	30	mm

known as ACNET. Each accelerator subsystem has a front end computer which drives a link attached to all appropriate hardware for that subsystem; all links constructed recently are CAMAC while some older systems utilize different technologies. Application program and file storage, as well as a central database detailing all electronic components, are under control of VAX computers networked to the front ends. Also connected to this network are a number of operator consoles, attached in such a manner that any console can monitor and control any accelerator. This control system is currently being upgraded in a number of important aspects, with more modern hardware and software being added--however the basic structure described is not being changed. A schematic diagram of ACNET as it currently exists (without upgrades) is presented in Figure II-14.

The ASB (as well as the Proton Super Booster) fits naturally into the existing system. To the current complement of ten front ends will be added one for this new machine; there exist sufficient network bandwidth and VAX computer cycles that this addition can be made with minimal impact. This computer will drive a CAMAC link running to and around the new ring; this link will connect to a number of crates and relay racks, and will have a number of cable terminations, determined by the experience with similar equipment in the current Antiproton Source. The amount of cable and number of repeaters specified are appropriate to provide this link, as well as to distribute timing signals and real-time accelerator data, and to extend the lab-wide token ring network to this new machine. All beamlines associated with the ASB will be serviced by the same front end computer and CAMAC link.

Five consoles of the type being specified for the controls upgrade will be included and will afford the opportunity to commission and operate this new accelerator either from the current Main Control Room or from more local service buildings. Since most of the new hardware connected to the control system will be copies of existing modules, the software effort necessary for support is expected to be manageable. However it is presumed that special requirements of the ASB and the advance of technology will lead to the installation of some currently unsupported hardware, with the resulting software implications. It is estimated that three person-years of effort will be required for the creation of such software, plus an additional half year devoted to beamline specific projects. Based on the Antiproton Source experience, entry of information concerning all new modules into the system database will involve a significant effort, often required on an urgent basis.

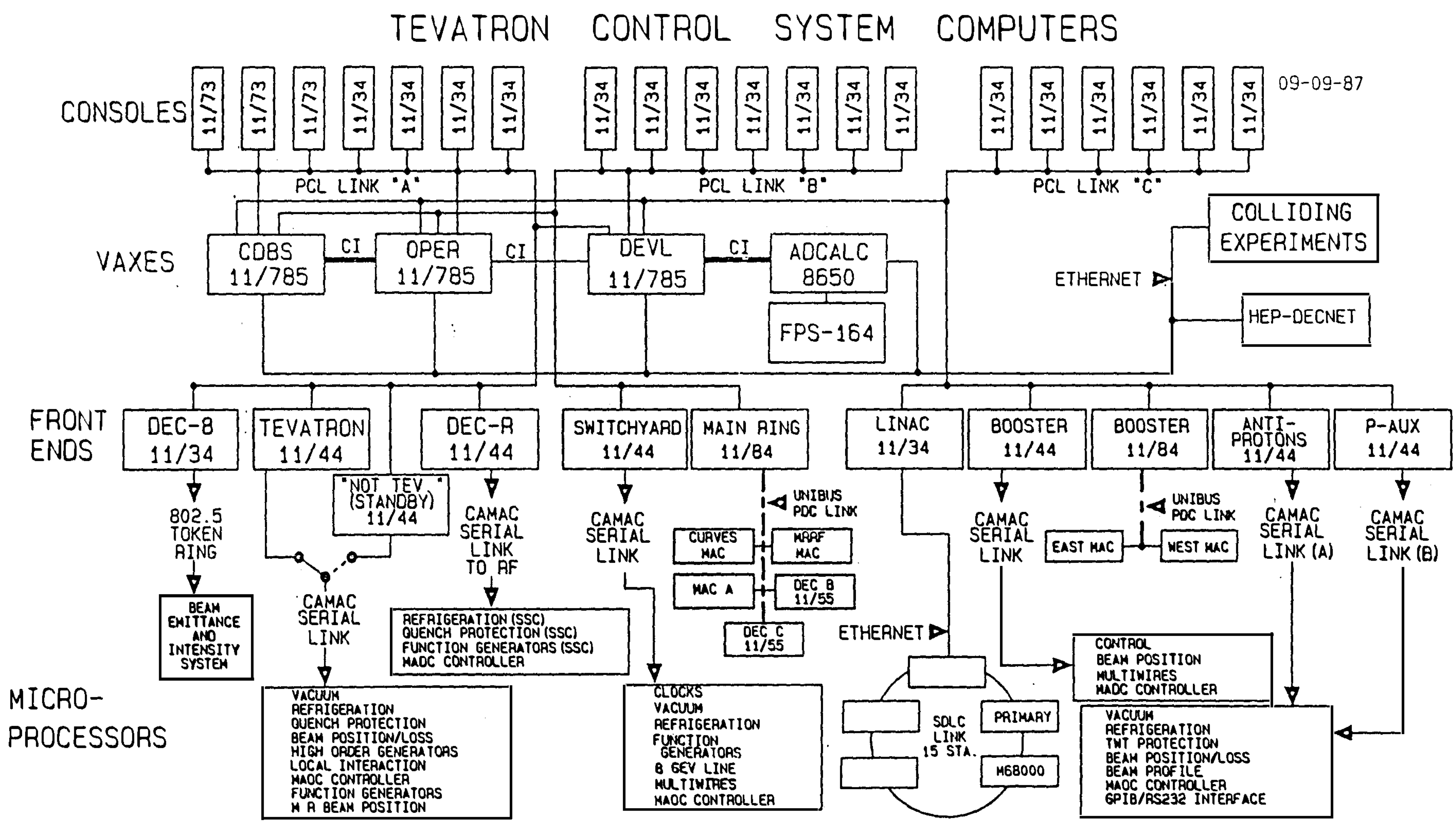

TEVATRON CONTROL SYSTEM COMPUTERS
09-09-87
CONSOLES
11/73
11/73
11/73
11/34
PCL LINK "A"
PCL LINK "B"
PCL LINK "C"
COLLIDING EXPERIMENTS
VAXES
CDBS 11/785
CI
OPER 11/785
DEVL 11/785
ADCALC 8650
FPS-164
ETHERNET
HEP-DECNET
FRONT ENDS
DEC-8 11/34
TEVATRON 11/44
DEC-R 11/44
SWITCHYARD 11/44
MAIN RING 11/84
LINAC 11/34
BOOSTER 11/44
BOOSTER 11/84
ANTI-PROTONS 11/44
P-AUX 11/44
"NOT TEV" (STANDBY) 11/44
802.5 TOKEN RING
CAMAC SERIAL LINK TO RF
CAMAC SERIAL LINK
UNIBUS PDC LINK
CURVES MAC
MRRF MAC
MAC A
DEC B 11/55
DEC C 11/55
EAST MAC
WEST MAC
CAMAC SERIAL LINK (A)
CAMAC SERIAL LINK (B)
BEAM EMITTANCE AND INTENSITY SYSTEM
REFRIGERATION (SSC)
QUENCH PROTECTION (SSC)
FUNCTION GENERATORS (SSC)
MADC CONTROLLER
ETHERNET
CONTROL
BEAM POSITION
MULTIWIRES
MADC CONTROLLER
MICRO-PROCESSORS
VACUUM
REFRIGERATION
QUENCH PROTECTION
BEAM POSITION/LOSS
HIGH ORDER GENERATORS
LOCAL INTERACTION
MADC CONTROLLER
FUNCTION GENERATORS
M R BEAM POSITION
CLOCKS
VACUUM
REFRIGERATION
FUNCTION GENERATORS
8 GEV LINE
MULTIWIRES
MADC CONTROLLER
SDLC LINK 15 STA.
PRIMARY
M68000
VACUUM
REFRIGERATION
TWT PROTECTION
BEAM POSITION/LOSS
BEAM PROFILE
MADC CONTROLLER
GPIB/RS232 INTERFACE

Figure II-14

III. THE PROTON SUPER BOOSTER

The primary purpose of the 20 GeV Proton Super Booster is to provide a proton beam for injection into into the Main Ring above transition. However, in designing the ring we have tried to keep in mind the three distinct roles that this machine will be expected to play during the upgraded collider era: first, as the source of protons for fixed target operation: second, as the source of protons for antiproton production; and third, as the source of protons for the collider. The real impact of these varied responsibilities is to force us to design a ring which is moderately rapid cycling. We are presently proposing a 5 Hz cycling rate for the PSB. An additional responsibility of the PSB will be the formation of the 132 nsec bunch spacing required for collider operations.

III.1 Overview

Protons destined for the collider will be injected into the Proton Super Booster from the existing Booster in a bunch-to-bucket transfer. The bunch spacing will be 18.9 nsec (52.8 MHz) with a total of 84 bunches delivered. The total number of protons required depends on the details of how the 132 nsec bunch spacing is created. In the scenario described in Section III.5 the 132 nsec bunch spacing is formed by coalescing three of every seven bunches with the remaining four bunches discarded. (Another scenario under consideration is adiabatic debunching of the beam followed by recapture at a lower frequency.) Since we ultimately require 6×10^{10} protons/bunch in the collider (after coalescing of three to one) we require 2×10^{10} protons/bunch, or 1.7×10^{12} total protons, in the ring. It is expected that the PSB should be able to preserve the beam emittances delivered from the existing Booster at these intensities. At the moment the 8 GeV Booster is capable of delivering this intensity of beam with a normalized transverse emittance of about 10π mm-mr, and a longitudinal emittance of about 0.15 eV-sec. Following the 400 MeV linac upgrade it is expected that the transverse emittances of beams delivered from the 8 GeV Booster will be even smaller. This anticipated transverse phase space density is 20% higher than what is specified for the collider and so leaves some room for dilution during beam transfers. Following coalescing of proton bunches the projected longitudinal emittance for a proton bunch containing 6×10^{10} protons becomes .50 eV-sec. This longitudinal emittance is about twice what we project for the antiproton bunches emanating from the 20 GeV ASB. Twelve bunches containing 7×10^{11} protons are extracted on each Booster cycle. Eight cycles of the PSB are required to load the collider.

No coalescing is necessary (or even desirable) for either antiproton production or fixed target operation. It is thought that following the linac upgrade the 8 GeV Booster will be capable of delivering about 5×10^{12} protons/batch (6×10^{10}/bunch) with a transverse emittance of about 20π and with a longitudinal emittance of perhaps 0.25 eV-sec. The PSB should be able to accelerate this beam without dilution. Machine studies underway in the Main Ring indicate that with injection occurring at 20 GeV a substantial fraction of this beam should be accelerated and delivered to either the antiproton production target or to the Tevatron for acceleration and delivery to fixed target experiments. At present the Main Ring is capable of accelerating only about a third of this beam quantity. A total of twelve PSB cycles will be required to load the Main Ring during fixed target operations and a total of six cycles will be required during antiproton production.

The layout of the 20 GeV PSB is given in Figure III-1 and the machine parameters are listed in Table III-1. The ring is concentric with the Antiproton Super Booster with a mean radius 12.6 meters larger. The PSB resides in its own tunnel, allowing access to the ASB while the PSB is running. The transition gamma is nearly identical to that of the ASB. This represents an operational simplification in that antiprotons and protons look the same as seen by the Main Ring RF system. As in the ASB the beam is not required to cross transition in the PSB during acceleration.

The design aperture of the PSB as listed in the Table III-1 is significantly larger than the beam emittance given in the table. This is because the emittances in the table are meant to reflect the performance of the PSB during collider filling, while the acceptances are made compatible with fixed-target and antiproton production operation.

III.2 Lattice

The lattice of the PSB is shown in Figure III-2. What is shown is one half of one superperiod, i.e. one sixth of the ring. The lattice is symmetric around the endpoints of the figure. The lattice is basically the Antiproton Source Debuncher lattice with the long straight sections eliminated. The lattice is built from 60° cells with missing magnets used to suppress the dispersion. The ring contains six dispersionless straight sections each 8.3 meters long. These straights contain the h=105 RF cavities and the injection/extraction Lambertson magnets. In addition there are twelve 5.8 meter long straight sections in which the dispersion is about 2 meters. These straight section accommodate the h=15 RF, injection/extraction kickers, damper pickups and kickers, and assorted diagnostics. Seventy centimeters of free space is provided between each dipole and quadrupole for installation of sextupoles and beam position monitors. Three lengths of quadrupole magnets are required, powered through two separate buses. Tuning of the PSB is accomplished through direct adjustment of the two quadrupole buses.

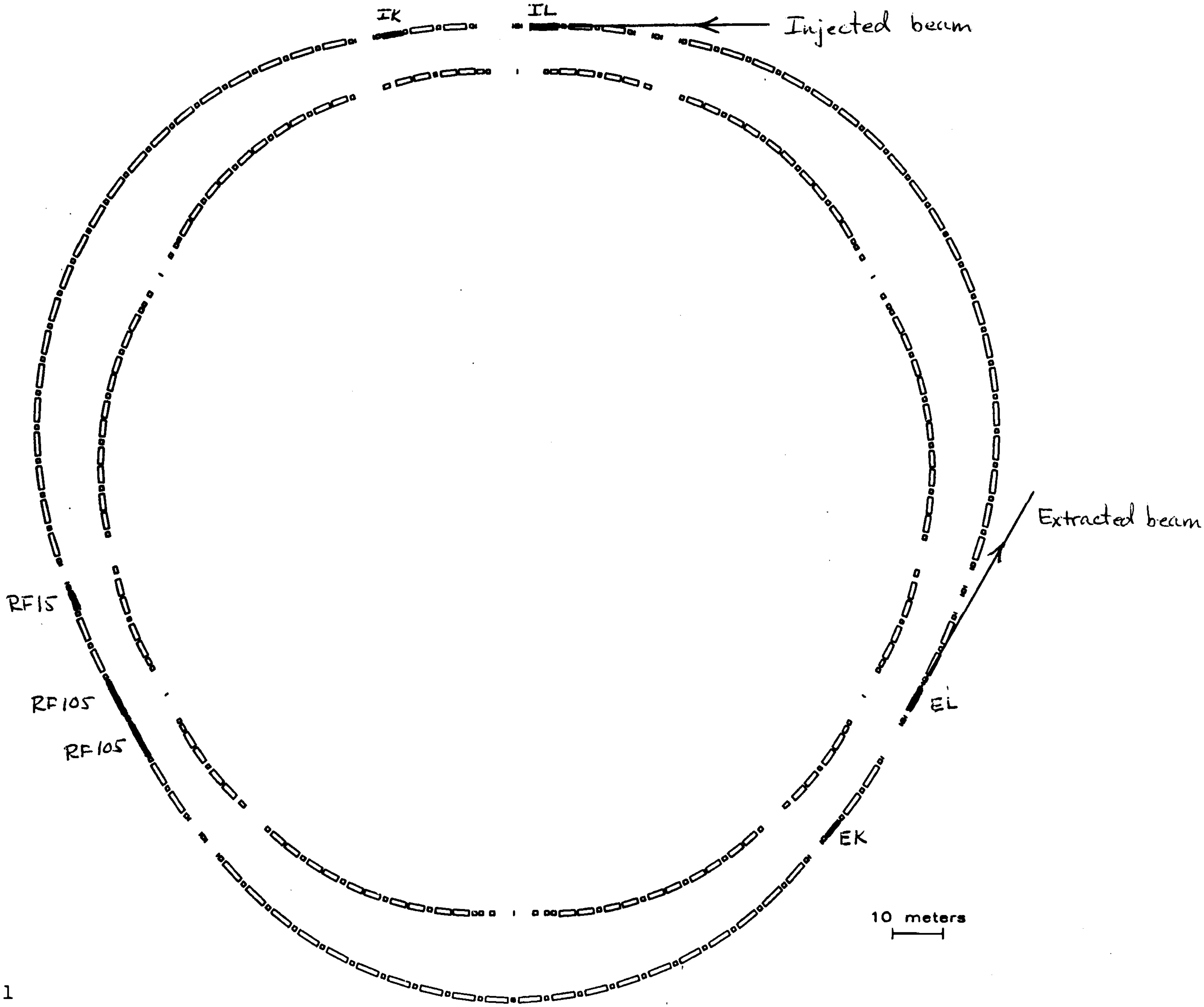
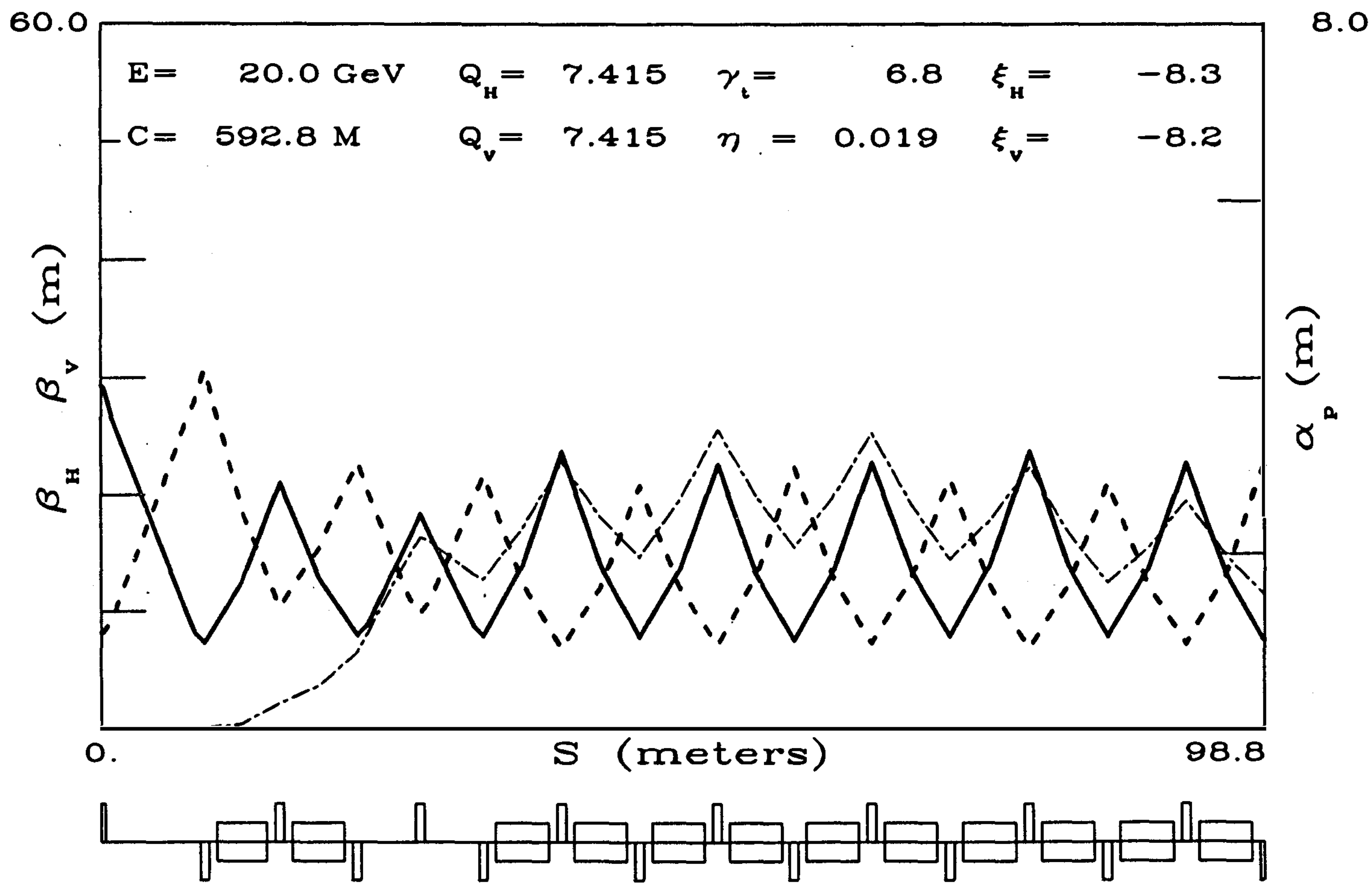

IK
IL
Injected beam
Extracted beam
RF15
RF105
RF105
EL
EK
10 meters

Figure III-1

Table III-1: Proton Super Booster (PSB) Machine Parameters

Circumference	592.76	meters
Injection Energy	8.9	GeV
Peak Energy	20.0	GeV
Cycle Time	0.2	sec
Harmonic Number (@53 MHz)	105	
Horizontal Tune	7.41	
Vertical Tune	7.41	
Transition Gamma	6.8	
Number of Bunches	84	
Protons/Bunch	$2.\times 10^{10}$	
Transverse Emittance (Normalized)	10π	mm-mr
Longitudinal Emittance/Bunch	0.15	eV-sec
Momentum Spread (Max, full width)	0.4	%
Transverse Acceptance (Unnormalized)	8π	mm-mr
Momentum Acceptance	0.6	%
β_{max} (Arcs)	23	meters
β_{max} (Straights)	30	meters
Maximum Dispersion	3.4	meters
Number of Straight Sections	18	
Total Length in Straight Sections	120	meters
RF Frequency (Injection)	52.8	MHz
RF Frequency (Extraction)	53.0	MHz
RF Voltage	540	KV
Synchronous Phase (Max)	33	degrees
Number of Dipoles	72	
Dipole Length	4.4	meters
Dipole Field (Max)	13.1	kGauss
Number of Quadrupoles	90	



THE PSB LATTICE

Figure III-2

III.3 Magnets

The Proton Super Booster (PSB) uses conventional iron core magnets. A total of 72 dipole, 90 quadrupole, 60 sextupole, and 8 correction magnets are required. In order to minimize core losses while cycling at 5 Hz, laminations are made of 1.270 mm (50 mil) thick M-22 steel. The modest peak fields, 13.1 kGauss in the dipole and 8.25 kGauss at the quadrupole pole tip, will allow the avoidance of saturation effects during acceleration. Cross sections of the dipole and quadrupole magnets are shown in Figure III-3. The fundamental magnet parameters are listed in Table III-2. The magnet apertures are sufficient for accommodating transverse emittances of 8π mm-mr and a momentum spread of 0.6%. The dipole magnet is 4.4 meters long while three length of quadrupoles will be built ranging from 0.64 to 0.75 meters. The dipole magnets will be built with a sagitta of about 4.8 cm. Both magnets will require a field uniformity over the aperture of about 10^{-3}.

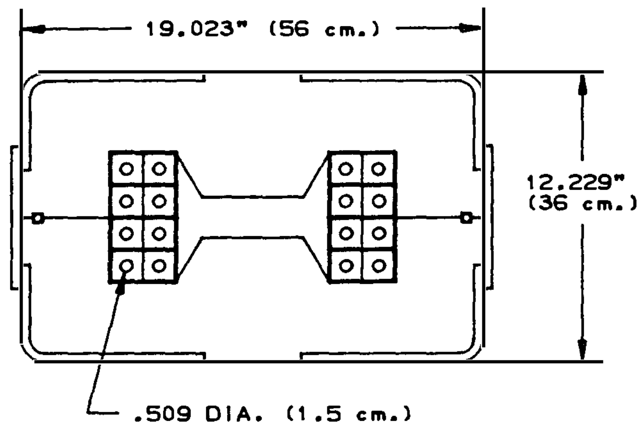
Since the PSB will accelerate beam from 8.9 GeV to 20 GeV at a rate of 5 Hz, keeping the necessary power supply voltage low requires a low inductance magnet, implying a low number of turns. In addition the high rms current arising when this accelerator is running at a high duty factor leads to a large conductor cross section in order to keep the dissipated power manageable. The dipole magnet thus has a total of 8 turns of 4 cm square conductor providing a magnet inductance of 1.4 mH and a magnet resistance of 1.1 mΩ. Similarly, the 0.75 m quadrupole magnet inductance and resistance are 1.7 mH and 0.7 mΩ respectively.

Special magnets are also necessary for the PSB, such as injection magnets and correction elements. The injection magnets are not described here as they are virtually identical to the magnets of this type presently in use at Fermilab. However, new chromaticity correction sextupole magnets and position correction dipole magnets have been designed for use in the PSB. These magnets are again low inductance devices and use very little power while applying maximum correction. They are described in Table III-3.

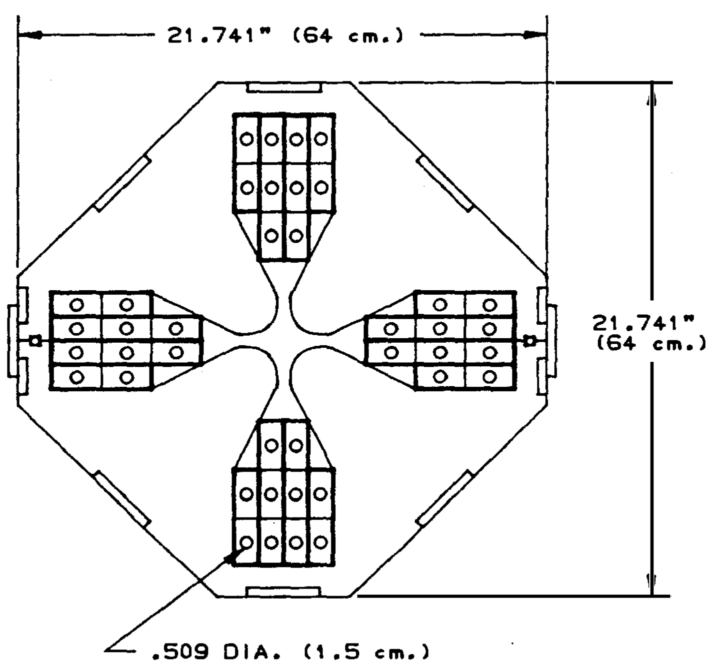
III.4 Power Supplies

The PSB power supply system is required to excite the magnets from the injection energy of 8.9 GeV to the extraction energy of 20 GeV in approximately 100 milliseconds. Both dipole and quadrupole magnets described above are designed to be low inductance, low resistance devices to minimize the demands on the power supply system.

The dipole power system consists of three 1500 volt supplies, two of which are rated for 4800 amperes rms and a third rated at 6600 amperes rms. The higher power unit is used to maintain an extended flattop time



PROTON SUPER BOOSTER
DIPOLE MAGNET



PROTON SUPER BOOSTER
QUADRUPOLE MAGNET

Figure III-3

Table III-2: PSB Magnet Parameters

	Dipole		Quadrupole	
Strength	13.1	kGauss	165.	kG/m
Length	4.4	meters	0.64-0.75	meters
Full Aperture	12.6x5.0	cm^2	5.0	cm
Turns/pole	4		5	
Maximum Current	6600	A	820	A
Coil Resistance	1.1	mΩ	0.7	mΩ
Coil Inductance	1.4	mH	1.7	mH
Peak Power	48	kW	467	W
Number Required	72		90	

Table III-3: PSB Correction Magnet Parameters

	Dipole		Sextupole	
Strength	2.7	kGauss	475.	kG/m^2
Length	25	cm	20	cm
Aperture	12.6x5.0	cm^2	5.0	cm
Turns/pole	50		6	
Maximum Current	110	A	16	A
Coil Resistance	62	mΩ	15	mΩ
Coil Inductance	2.5	mH	1.0	mH
Power	750	W	4	W
Number Required	8		60	

when not ramping at the 200 millisecond repetition rate. This scenario is required for RF manipulations during collider operations in the Tevatron. In this mode the two 4800 ampere supplies are placed in bypass while the high power unit supplies the necessary voltage to hold the ring at the 6600 ampere flattop level.

The three supplies are series connected to the 72 magnet load and are spaced symmetrically around the ring in three above ground service buildings. With a balanced system the voltage to ground never exceeds $\pm$ 750 volts. The supplies are 6 phase, 12 pulse, SCR type bridge rectifiers with bypass SCR's and passive filters on the output for ripple reduction. Primary ac power for each supply is taken off a 13.8kv feeder system dedicated to PSB power supplies.

The quadrupole magnets are powered on two independent busses of 45 magnets each, giving independent control of both horizontal and vertical tunes. Each supply is again a 12 pulse SCR type bridge rectifier with filtered output, in this case capable of 900 amperes.

Regulation

While the power supplies will be capable of 10 parts per million (ppm) regulation, it will be difficult to achieve this level due to the fast repetition rate and short dwell and flattop times since the resolution of the power supply response will be 1.4 msec (1/720 of a second). However, by using a computer controlled regulation scheme similar to that used by both the Main Ring and Tevatron power supplies, regulation to 100ppm should be achievable. This figure is consistent with what the present Booster is able to do when supplying beam to the Main Ring. The computer system will provide both a voltage profile and a current reference waveform used to drive the dipole supplies. The voltage profile on each subsequent cycle is updated with the error from the previous cycles allowing the regulation to learn in. With slower ramp rates and extended flattops the full 10ppm regulation should be achievable.

The reference waveforms for the quadrupole supplies will be generated in the same manner by the computer and will ensure that the quadrupole currents track the dipole current in the proper ratios to maintain the necessary tune control. Transductors in the power supplies will provide feeedback for current loop regulation. Each supply will also have its own voltage regulation loop.

Power Distribution

The power distribution system for the dipole and quadrupole power supplies will likely have to be separated from all other feeders. The peak power and high reactive power make it unlikely that any other load will tolerate the power line disturbances generated at 5 hertz. This system would then require a separate 345kV/13.8kV transformer at the master substation. In addition a static power factor (PF) correction to compensate the peak reactive power will further increase disturbances on this line. A PF correction system sized to compensate for the peak reactive power of the load will look capacitive for most of the accelerator cycle. This, however, should not be a problem for the total site PF since virtually every other load looks inductive. The static correction on a single feeder should only improve the overall site power factor.

Other Considerations

Other methods of providing the 5 Hz capability for the PSB have been studied and found to be less attractive than the system described here. In particular resonant systems were considered. Resonant systems were ultimately rejected because of their higher operating costs (associated with a modest savings in capital expenses), and because of the lack of flexibility inherent in such systems. Details of the reasoning which led to the choice of the ramped system described here are given in Appendix IV.

Table III-4: Power Supply Parameters

	Dipoles	Quadrupoles	
Injection Current	2935	365	Amps
Extraction Current	6595	820	Amps
Load Resistance	.12	.07	Ohms
Load Inductance	.1	.077	Henries
Voltage	4500	450	Volts
RMS Power at 5 Hz	2800	26.4	Kilowatts
Peak Power	29700	370	Kilowatts
Number of Supplies	3	2	
Number of Magnets	72	45	

III.5 RF

The RF parameters for the PSB are listed in Table III-5. It is possible to maintain an acceleration rate of 145 GeV/sec accompanied by a bucket area in excess of 0.4 eV-sec with a total RF voltage of 580 KV.

This design assumes that proton bunch coalescing will be done in the PSB rather than in the Main Ring as it is done now. It is necessary to supply 6×10^{10} protons in each of the populated buckets. With the increased efficiency anticipated in transporting protons through the upgraded

Table III-5: PSB RF Parameters

ϵ_L = longitudinal emittance (eV-sec)
A_b = bucket area (eV-sec)
ΔE_b = bucket height (half, MeV)
Δt = bunch length (full, nanosec)
ΔE = bunch height (full, MeV)
$\delta p/p$ = bunch relative momentum spread (full, %)
E = total energy (GeV)
N_b = number of bunches in machine

V_{RF} = RF Voltage (kV)
h = harmonic number
f_{RF} = RF frequency (MHz)
Np/bunch = number of protons per bunch

	Condition	E	N_b	ϵ_L/bunch	h	V_{RF}	f_{RF}	A_b	ΔE_b	Δt	ΔE	$\delta p/p$	Np/bunch
1	Inject from Booster	8.9	84	.25	105	46	52.8	.4	16.58	11.9	28.6	.32	6.0×10^{10}
2	Accelerate		84	.25	105	580	53	.4		11.9			
3	Flattop	20	84	.25	105	45	53	.4	16.58	11.9	28.6	.14	6.0×10^{10}
4	Coalescing												
	Flattop, coalesce cycle	20	36	.15	105	9	53	.18		15.6	13.7	.07	2.0×10^{10}
	7.5 MHz capture	20	12	.45	15	3.4	7.5	2.0	8.1	51.2	13.7	.07	6.0×10^{10}
	bunch rotation	20	12	.45	15	42	7.5	7.2	42.3	11.9	58.5	.29	6.0×10^{10}
	53 MHz Recapture	20	12	.50	105	217	53	.88	36.6	11.9	58.5	.29	6.0×10^{10}

linac, the 8 GeV Booster, and the new PSB the number of protons per bucket before coalescing may approach the required $6x10^{10}$. However the design proposed is based on the assumption that coalescing capabilities will still be needed. The assumption is made that the Booster will be able to provide $2.0x10^{10}$ per bunch in 0.15 eV-sec, a figure that is achieved in the present linac-booster combination. The scheme that is presented here calls for a super damper in the PSB that is capable of ejecting beam on a bunch by bunch basis. Of the 84 injected bunches four consecutive bunches will be kicked out followed by three retained bunches. The next four will be kicked out and so on. This will result in twelve groups of three bunches with the central bunch of each group spaced every seventh bucket. After acceleration to 20 GeV the 53 MHz RF system is adiabatically turned down so that the beam spreads out in phase to populate the full extent of the 53 MHz buckets while shrinking the momentum spread. Meanwhile the 7.5 MHz system is turned on with a bucket which matches the beam. Bunch rotation is them performed to compress the time spread of the bunch to 10 nsec. Finally the 53 MHz system is turned back on and the voltage is set to transfer to Main Ring. Care must be taken in the design of the vacuum chamber and other machine components to keep the longitudinal impedance low. The threshold is determined by the coalescing process at which time the $\delta p/p$ is as low as .05%.

Hardware Specification

The required H=105 RF for the PSB will be provided by four accelerating cavity systems similar to those in the present Fermilab Main Ring Accelerator H=1113 system. The planned rate of acceleration and required frequency range closely matches that of the existing MR system. Each cavity will operate at 145 kV during the acceleration cycle. In the event of a station failure, uninterrupted operation can be provided by three cavity operation at 193 kV.

Due to multipactoring, the lowest voltage that the present cavity design can operate at is 30 kV. Pairs of cavities will be paraphased to accomplish the low ring voltage required of coalescing. For better low voltage control, design considerations will be given to lowering the multipactor voltage by moving the ceramic windows in the cavities closer to the accelerating gap. This may be possible because the maximum operating voltage at the gaps is 193 kV with three cavities operating. Excluding heating problems, Main Ring cavities have been operated at 270 kV without excessive sparking.

The RF voltage on the cavity will be controlled by programming high voltage via a series tube modulator. In order to provide proper anode programs for four or three cavity operation, pairs of cavities will have individual modules as well as the required paraphasing low level programs.

Cavity tuning will be accomplished by ferrite tuners that are loop coupled into the cavity. A programmable high current bias supply will provide the necessary current to vary the ferrite permeability and tune the cavity to resonance. Cavity tuning will be maintained by an error signal derived by a phase detector which monitors the cavity drive and cavity voltage.

Fast phase and amplitude loops will be introduced in the drive signal chain and feedback from the gap voltage will be used to reduce the cavity impedance at the fundamental operating frequency and reduce noise introduced by the high level circuits.

A common 30 kV, 100 A anode power supply will supply dc high voltage to the four series tube modulators in the PSB. This is a larger supply than necessary but is common with existing equipment and with proper switch gear at the 30 kV high voltage level it may be possible to use it reliably and safely to supply power to the ASB stations.

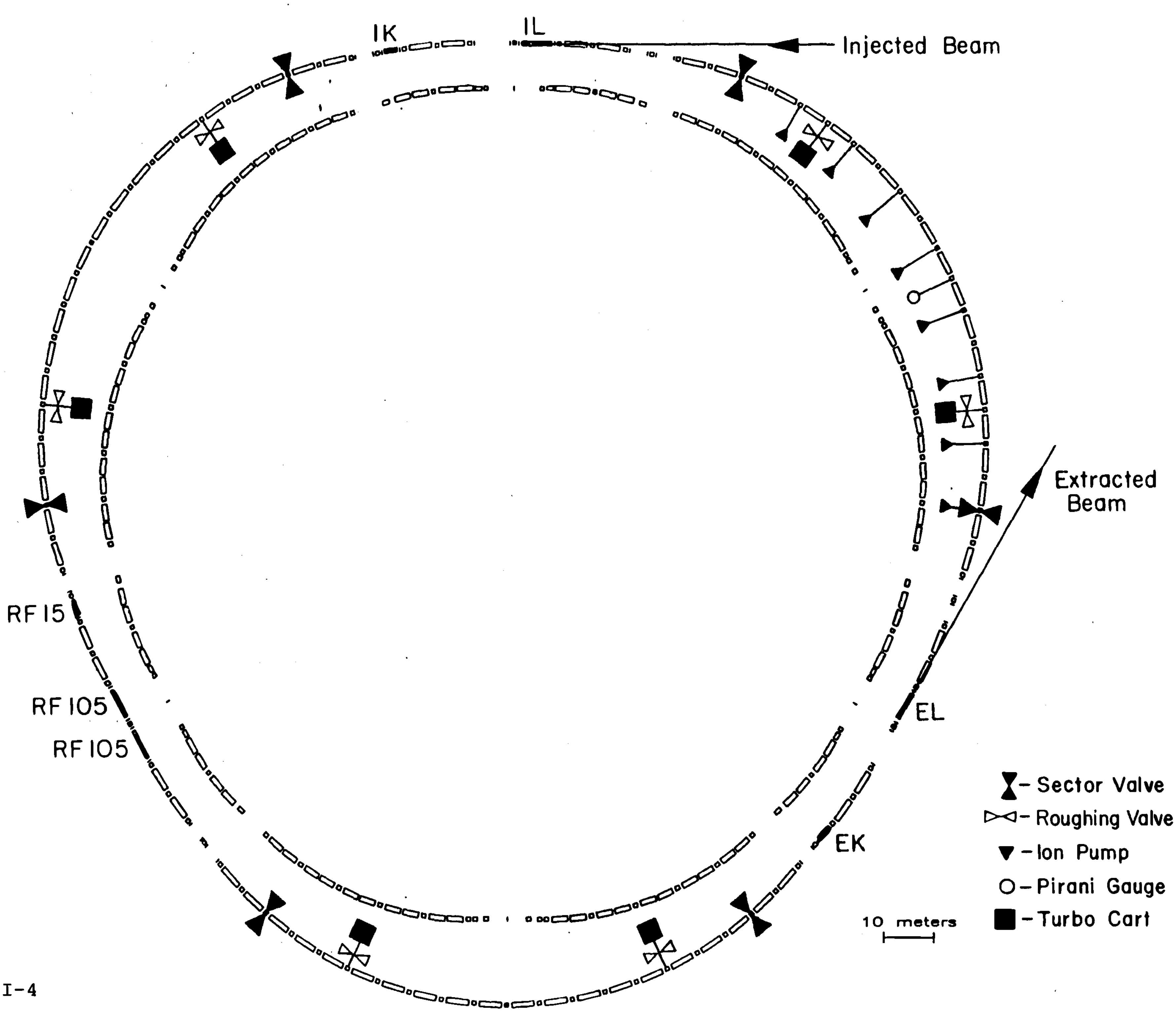
To meet the needs for the 7.5 MHz, H=15 RF systems we propose two cavities of type that are suggested to run at H=159 in the Main Ring. Modifications include reestablishing the bias current bus and addition of a bias tuning circuit.

III.6 Vacuum

The vacuum requirements for the PSB ring are modest and conventional; an average pressure of 1.0×10^{-8} Torr is sufficient to ensure negligible beam loss. Standard turbopumps are used to evacuate the chamber down to less than 10^{-5} Torr, at which point sputter ion pumps are used to achieve the required pressure of less than 10^{-8} Torr. With an ion pump at the end of each FODO cell (i.e., one ion pump at every other dipole magnet) a pumping speed of 200 l/sec or greater is required. Ion pumps with a pumping speed of 270 l/sec are used throughout the existing Fermilab complex and have proven to be reliable and to require only minimal maintenance.

Figure III-4 shows the vacuum system layout over one-sixth of the PSB ring. Six sector valves are used to isolate subsections of the ring and mobile turbocarts which can be shared with the ASB are employed. The use of two turbocarts to pump down a given sector will allow the ion pumps to be energized after a few hours of pumping. Instrumentation to measure the ion pump leakage current, together with six Pirani-Penning gauges are adequate for measuring and monitoring the PSB pressure.

The vacuum chamber itself is constructed of 0.060" thick stainless steel tubing. We have looked at potential problems of using a conducting vacuum chamber in a rapid cycling machine and have concluded that induced eddy currents are unlikely to present a problem. The induced magnetic fields are about 1×10^{-3} of the guide field in the dipoles and the dissipated energy is about 65 Watts/meter/cycle.



IK
IL
Injected Beam
Extracted
Beam
RF 15
RF 105
RF 105
EL
EK
10 meters
Sector Valve
Roughing Valve
Ion Pump
Pirani Gauge
Turbo Cart

Figure III-4

III.7 Injection and Extraction

The PSB contains an 8.9 GeV injection system and a 20. GeV extraction system. A beam dump is also provided in the PSB to Main Ring transfer line for use during commissioning and/or studies periods. The injection and extraction systems are geometrically identical and are located as shown in Figure III-1. Injection from the Booster and extraction to the Main Ring are both done using Lambertson magnets in the zero dispersion straight sections in conjunction with kicker magnets in straight sections located 90° away. Each kicker displaces the beam horizontally across the septum of the Lambertson magnet which provides a vertical bend sufficient to clear the outer aperture of the adjacent quadrupole.

The required kicker and Lambertson magnet characteristics are listed in Table III-6. The kicker strengths are modest and a 395 nsec gap is present in the beam to accommodate kicker rise/fall times. The Lambertson magnets are identical to many already built at Fermilab for similar purposes. The geometry of the beamlines in the injection region of the PSB and the ASB is shown in Figure III-5.

III.8 Instrumentation

The beam position system for the PSB is patterned after the existing systems in the Fermilab Booster and Tevatron. The pickups located at each quadrupole will be 50 ohm strip line pickups and the processing electronics the Fermilab standard amplitude to phase conversion style with a center frequency of 53 MHz. The system will be capable of producing first turn orbits, turn by turn readouts, and closed orbits. The loss monitor system will utilize ion chambers at each quadrupole in the ring and be of the same style as the present Tevatron system.

The PSB will employ a second harmonic D.C. current transducer similar to the one proposed for the ASB. This will enable accurate acceleration efficiency measurements and will be used for D.C. storage studies.

In order to analyze longitudinal and transverse instabilities, the PSB will be equipped with a broad band longitudinal pickup and two broad band transverse pickups, one for each plane. These detectors should be very useful in studies of coupled bunch and head tail instabilities common to such high intensity rings.

The PSB Dampers system will be patterned after the Tevatron bunch-by-bunch system. The system will allow damping of injection oscillations and coherent instabilities, as well as providing the capability of knocking out selected bunches or heating the beam transversely in either plane.

The PSB will have beam scrapers for measuring the acceptance of the machine in both planes and a momentum scraper to aid in beam transfer function measurements.

Table III-6: PSB Injection/Extraction Magnets

8.9 GeV Injection Kicker

Length	3.0	meters
Field	290	Gauss
Risetime	---	
Falltime	250	nsec
Aperture(HxV)	25x25	mm^2

20.0 GeV Extraction Kicker

Length	3.0	meters
Field	650	Gauss
Risetime	250	nsec
Falltime	---	
Aperture(HxV)	25x25	mm^2

Injection/Extraction Lambertsons

Number Required	2	
Field	10.0	kGauss
Length	4.0	meters
Channel Aperture (HxV)	40x150	mm^2
Field Free Aperture (HxV)	50x30	mm^2

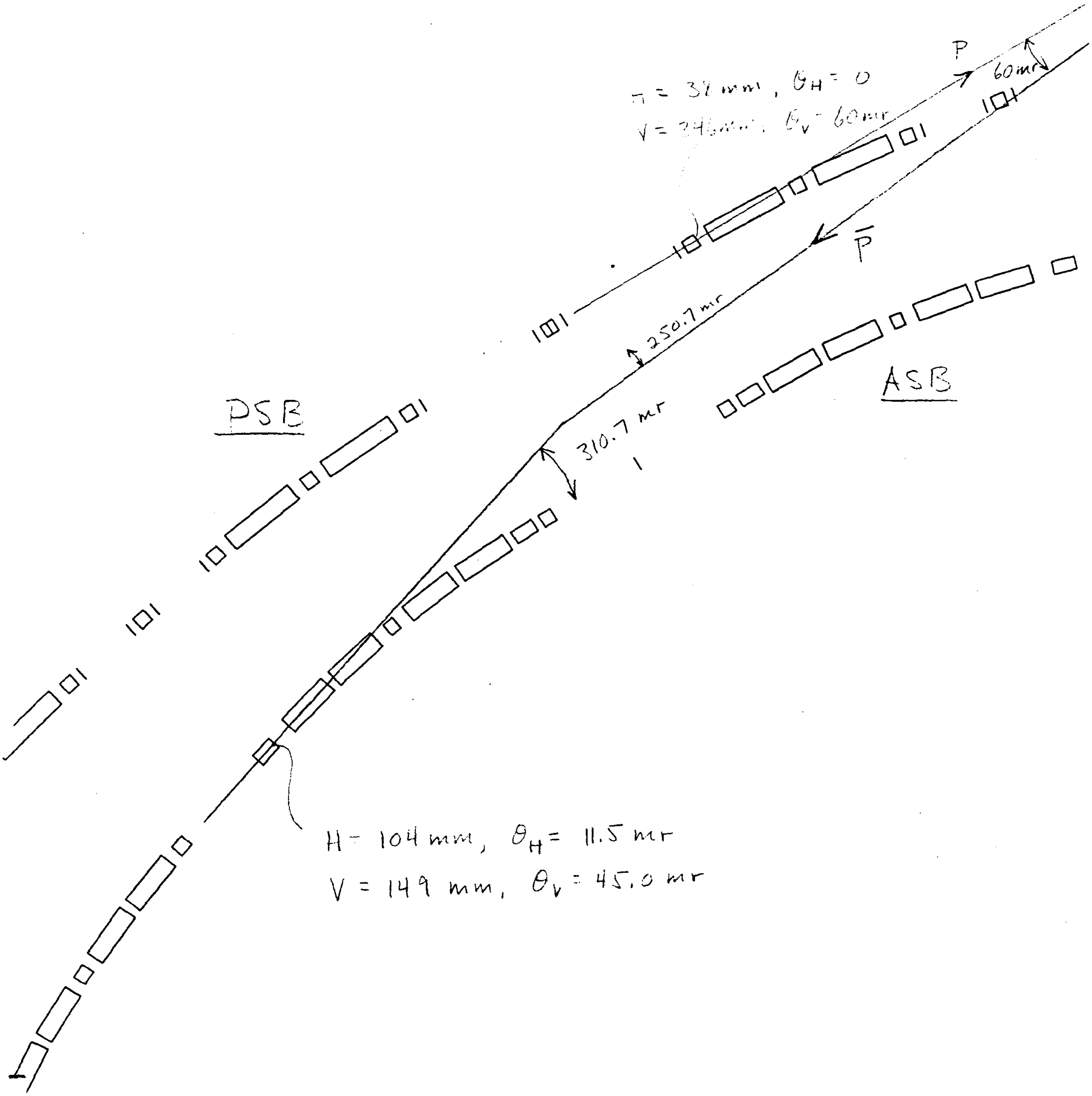

H = 38 mm, θ_H = 0
V = 246 mm, θ_V = 60 mr
P
60 mr
$\bar{P}$
250.7 mr
PSB
ASB
310.7 mr
H = 104 mm, θ_H = 11.5 mr
V = 149 mm, θ_V = 45.0 mr

Figure III-5

III.9 Controls

A description of the ACNET control system and the method in which it will be extended for the ASB have been given in Section II.10. All remarks presented there hold equally well for the PSB, namely that the extension of the system by addition of a new front end computer and CAMAC link is a well understood process. At the current level of design detail no obvious differences between the two rings in controls requirements have arisen.

IV. BEAMLINES

Four beamlines are required to transport the proton and antiproton beams between the various accelerators in the primary operational modes. For tuning and diagnostic purposes, three other beamlines can be implemented by retuning sections of the primary lines. These beamlines and their specific functions are summarized in Table IV-1. The locations of the various beamlines are shown in Figure IV-1. All but one of the connections to existing accelerators utilize extraction/injection systems already in place. The only totally new injection system is at F-32 in the Main Ring which will become the 20 GeV proton injection point.

Magnet requirements

The beam lines have been designed using magnet designs common to other applications in the Super Booster rings. In addition, several C-magnets are required to facilitate beam splitting and to allow some portions of beam pipe to be common to 2 beamlines. Standard Lambertson and pulsed kicker magnets are required for injection an extraction.

The geometry of beamlines SB-1, SB-2 and SB-3 is such that the 4.436 m, 1.31 T PSB dipole and the 0.75 m, 16.5 T/m PSB quadrupole magnets described in Tables III-2 and III-3 are suitable for most applications. The 3.122 m, 15.9 kG ASB dipoles are used for SB-4.

The C-magnets required to separate SB-1 from the existing AP-4 line and to allow SB-1 and SB-4, and SB-2 and SB-3 to share sections of beam pipe are specified to have an effective length of 4.438 m and maximum field 1.31 T (the same parameters as the PSB dipoles). Because of these common regions, the SB-5 and SB-6 beamline functions are easily obtained by retuning the appropriate lines. A second advantage of the common sections is that matching quadrupoles can be shared between the two lines.

In addition to the C-magnets, 5 Lambertson style septum magnets are required for injection into and extraction from the Super Booster rings and Main Ring. The beam line geometries have been obtained assuming the Lambertson magnets are similar to those commonly used elsewhere at Fermilab.

Optics

The beamline optical design is simplified by the use of a standard FODO cell structure, QF-B-B-B-QD-B-B-B- in the arcs. The standard cell optics are shown in Figure IV-2 for one case. The optics are reasonably close to those of the Super Booster rings and the straight sections of sufficient length that matching should not be a problem. Considerable flexibility is also available in retuning the existing AP-3 and AP-4 lines to expedite matching. Details of the matching sections are not yet complete.

TRANSPORT, a standard program for calculating the optical properties of beamlines, has been used to study the proposed lines. Solutions have been found for the four lines that satisfy the geometric constraints and allow considerable freedom in the placement the quadrupoles required to match the optical properties of the different rings.

Table IV-1: Beamlines

SB-1 Booster to Proton Super Booster; protons at 8.9 GeV/c. This line splits from the existing AP-4 line near the end of the Booster AP-4 enclosure. The AP-4 line remains functional.

As part of SB-5, this line will also transport 8.9 GeV/c protons from the Booster to the Antiproton Super Booster for tuning purposes.

SB-2 Antiproton Accumulator Ring to ASB; antiprotons at 8.9 Gev/c. This line extends the Accumulator end of the existing AP-3 beamline. That portion of AP-3 from the start of the new SB-2 line to the upstream end of the target vault will be decommissioned.

As part of SB-6, a portion of this line nearest the ASB will also transport 20 GeV/c antiprotons from the Main Ring to the ASB.

SB-3 Proton Super Booster to Main Ring; protons at 20 GeV/c. This is an entirely new line, including injection into the Main Ring.

As part of SB-6, a portion of this line transports antiprotons at 20 GeV/c from the Main Ring to the ASB.

SB-4 Antiproton Super Booster to Main Ring; antiprotons at 20 GeV/c. New beamline transports beam from the ASB extraction to existing AP-3 line just upstream of the antiproton target vault.

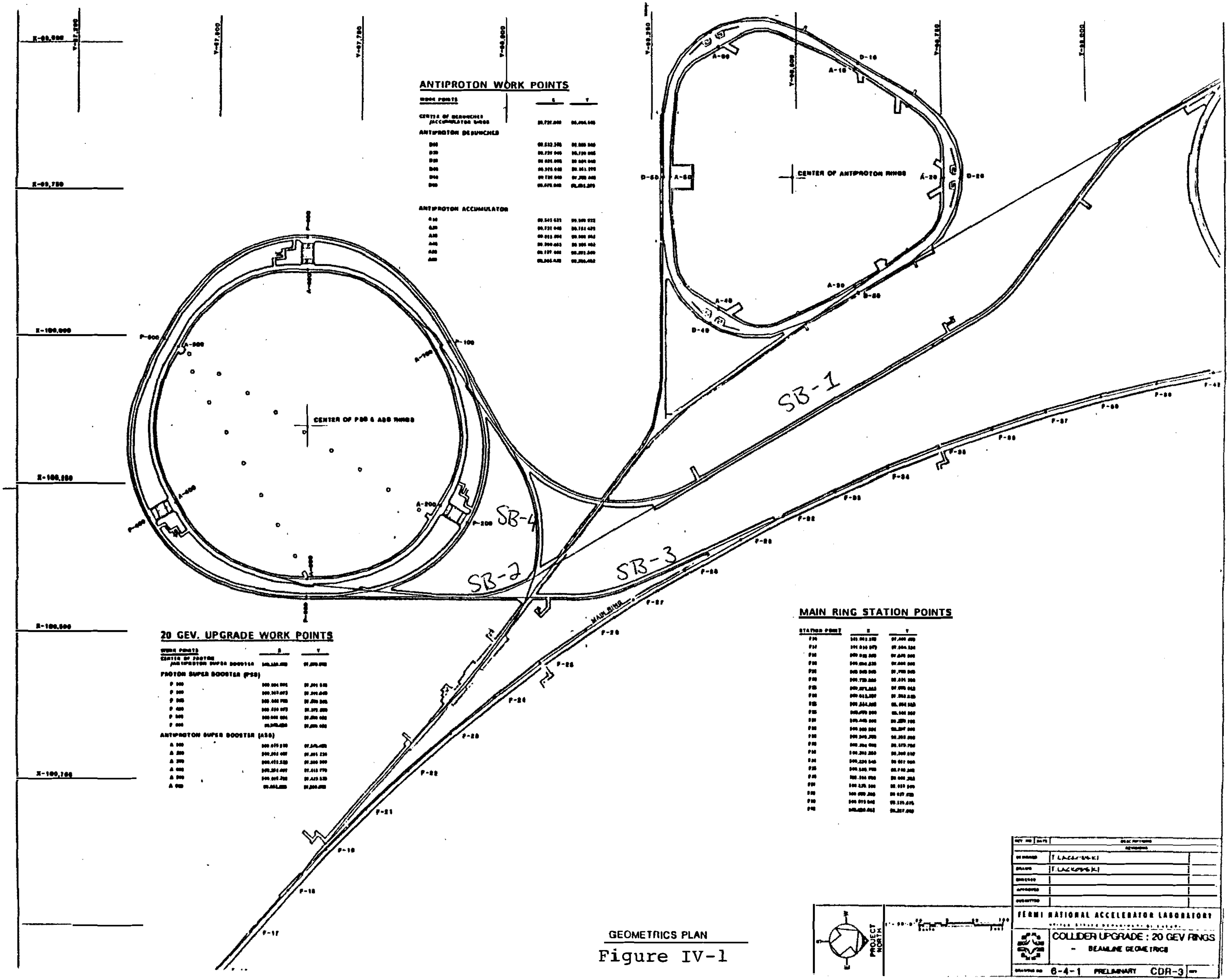
As part of SB-5, a portion of this line transports protons at 20 GeV/c from the Main Ring to the ASB for tuning.

Three secondary beamlines are required and comprise sections of the primary lines:

SB-5 Booster to ASB; protons at 8.9 GeV/c; reverse injection for tuning. The line comprises that portion of SB-1 from the Booster to the cross-over to SB-4 and into ASB.

SB-6 Main Ring to ASB; recovery of dilute antiprotons at 20 GeV/c. The line comprises that portion of SB-3 from Main Ring to the cross-over to SB-2 and into ASB.

SB-7 Booster to ASB; protons at 8.9 GeV/c; forward injection for commissioning/tuning. This line comprises portions of SB-1 and SB-2.



GEOMETRICS PLAN

Figure IV-1

Table IV-2: Beamline Magnet Requirements

Line	Length (m)	Bend (°)	Dipoles	C-Magnets	Quads	Lambertsons
SB-1	559	*30 90.4	30	3	30	1
SB-2	230	63.4	16	3	14	1
SB-3	254	25.4	8	0	16	2
SB-4	236	101	27	1	18	1

Standard cell lattice functions

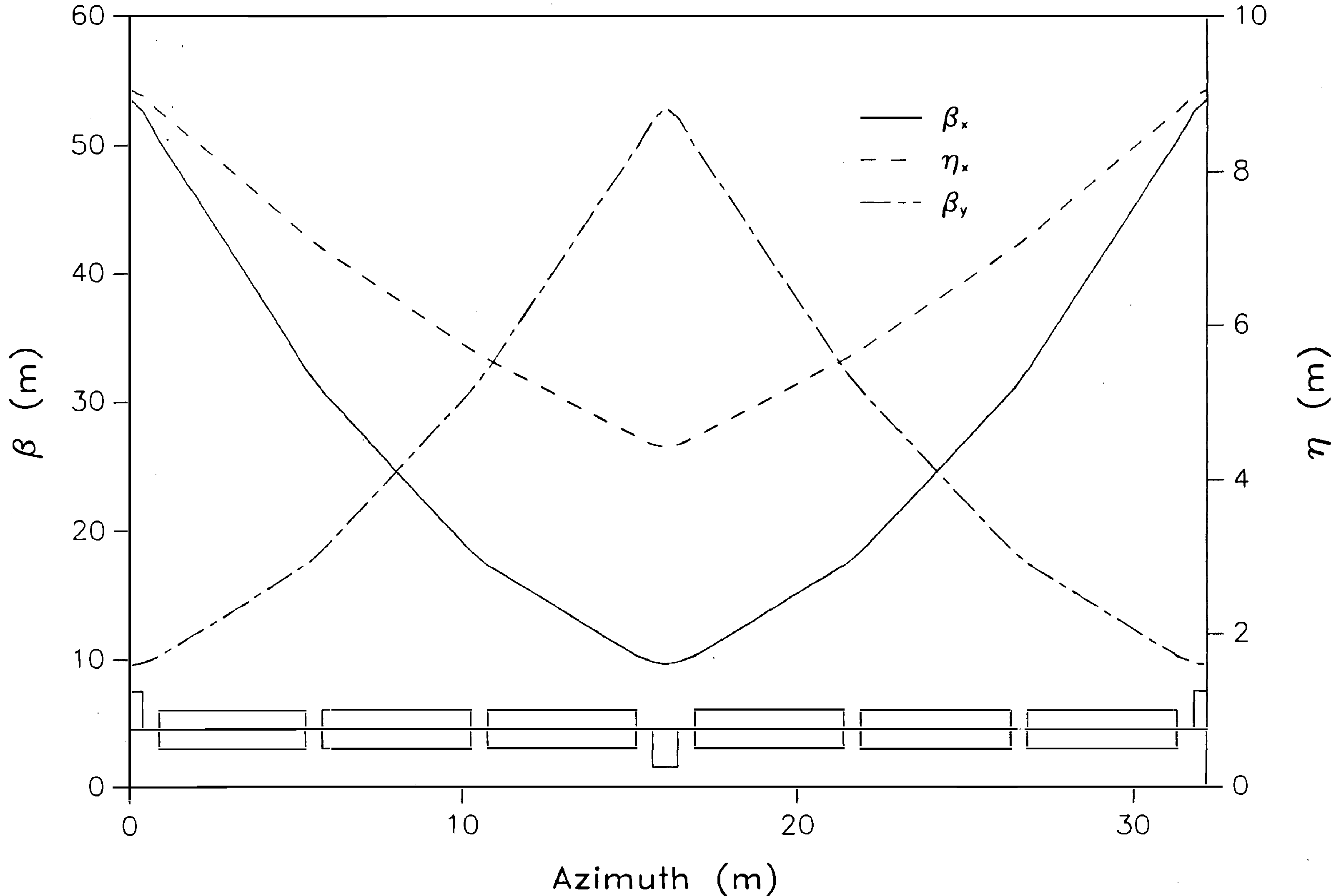


Figure IV-2

V. CONVENTIONAL CONSTRUCTION

V.1 Overview

The conventional construction for the 20 GeV Rings includes all below-grade beamline enclosures, shielding, above-grade buildings, roads, lake, parking, utilities and services to accommodate the equipment for and operation of the 20 GeV Rings.

New construction is similar to presently used and proven construction methods at Fermilab. The architectural style of the new buildings reflects, and is harmonious with, existing adjacent buildings. Existing topography and vegetation have been carefully observed in the layout of the new construction.

Safety provisions for radiation, fire protection and conventional safety are included in this conceptual design. Energy efficient construction techniques will be incorporated into all new structures. Quality assurance provisions will be part of all project phases, conceptual, preliminary and final design, construction and construction management.

V.2 Beam Geometrics and General Layout

Beamline geometrics of the new 20 GeV Rings, the associated beamlines and the present Fermilab accelerator ring are illustrated on Drawing No. CDR-3. (All conventional construction drawings are included in Appendix III.) These geometrics are the definition about which the beam enclosures, radiation shielding, service buildings, roads and utility extensions are designed relative to the Fermilab site. Drawing No. CDR-2, a simulated aerial perspective, illustrates the 20 GeV Rings on the Fermilab site. This design is compatible with the Fermilab Site Development and Utilization Plan.

V.3 Radiation Shielding and Life Safety Criteria

All new construction will provide adequate personnel shielding. Consideration has been given to various operational conditions of the program and to the major components in the ring and beam enclosures. Four conditions are of interest:

a. Tune-up operations with 8.9 GeV protons from the Booster.

b. Acceleration operations with 8.9 to 20 GeV protons and antiprotons.

c. Recovery operations with 20 GeV antiprotons from the Main Ring.

d. Personnel access into selected portions of the beam and ring enclosures during proton operations.

The sources of radiation considered are:

1. Operation of the super booster rings at design intensities and energy with catastrophic point loss accidents. Two categories of accessible areas are considered: areas of the berm accessible to the public; and areas within service buildings restricted to radiation workers.

2. Operation of one ring while allowing access to the other ring by radiation workers, considering design intensities and energy with point loss accidents.

3. No targeting operations are involved in these areas.

4. Catastrophic loss of stored beam.

Shielding materials to be used include compacted earth, regular density concrete and steel plate. Various combinations and thicknesses of these materials will be proportioned according to the limitations of economic design and space. Areas of special shielding design are listed below:

1. The generic beam shielding.

2. Labyrinth accesses and stairways.

3. Equipment drop hatch shielding.

4. Service building shielding.

5. Adjacent rings or transport lines for access to one while others may be operating.

6. Cable ducts and penetrations from service buildings to the tunnel enclosures.

Life Safety access control into the various beam enclosures, labyrinths, stairs and buildings is maintained by a series of locked and interlocked barriers. Solid partition doors separate Main Ring Oxygen Deficient Hazardous (ODH) areas, while chain link gates separate area of access where ventilation is required. These barrier arrangements are shown on Drawing No. CDR-18.

V.4 Antiproton Super Booster Ring Enclosure

The Antiproton Super Booster (ASB) Ring Enclosure is a near circular below grade enclosure, approximately 1700 ft. long with a cross section varying from 10 ft. to 12 ft. wide and 8 ft. high. The enclosure plan and sections are shown on Drawing Nos. CDR-7, 15 & 17. The floor of the enclosure is at Elevation 723 ft. or 17' to 22' below existing grade. The ASB ring equipment is centered on Elevation 726.5 ft. or 3'-6" above the floor and is positioned next to the inner wall. Earth shielding berms over the ASB Ring Enclosure provide the required shielding.

The ASB Ring Enclosure is constructed on a reinforced concrete cast-in-place (CIP) base slab over compacted granular fill bearing on undisturbed glacial till. Both CIP and precast reinforced concrete wall and roof construction are used. Wider roof spans will be cast with upturned beams for economy. Footing drains, moistureproofing and granular backfills are used to insure a dry enclosure.

Cable trays, power bus, piping, lighting and other utilities are ceiling or wall mounted on both inner and outer walls. Numerous penetrations connect to the service buildings constructed above the ASB Ring Enclosure as to the Proton Super Booster Ring (PSB) Enclosure outside of the ASB Ring Enclosure.

Six personnel access stairs and three equipment access hatches are provided. Ventilation equipment and connections are near these accesses. These are described in Section 7 below.

A common earth berm above both ASB and PSB Ring Enclosures defines the location of the below grade structures. This berm is interrupted by the service buildings.

V.5 Proton Super Booster Ring Enclosure

The PSB Ring Enclosure is a near circular below grade enclosure that is concentric with and surrounds the ASB Ring Enclosure. The enclosure plan and sections are shown on Drawing Nos. CDR-7, 15 & 17. The PSB Ring Enclosure is approximately 1950 ft. long with a cross-section 8 ft. wide and 8 ft. high. The floor elevation at Elevation 723 ft. matches the ASB Ring Enclosure. The PSB ring equipment is centered on Elevation 726 ft. or 3'-0" above the floor and is positioned next to the outer wall. Earth shielding berms common with the ASB Ring Enclosure provide the required shielding.

The PSB Ring Enclosure is constructed on a reinforced base slab similar to the ASB Ring Enclosure. Precast concrete inverted "U" sections with tapered end faces will be used for most of the walls and roof sections. Similar precast sections have been widely used very successfully for other Fermilab construction. CIP concrete walls and roofs are used at access or transition areas.

Access, utilities, services, ventilation, moistureproofing and other details of construction closely parallel the ASB Ring Enclosure.

V.6 Beam Transfer and Transition Enclosures

The Beam Transfer Enclosures connect the new 20 GeV PSB and ASB Ring Enclosures to the existing 8 GeV Booster, Antiproton Rings, Antiproton Target Hall and Main Ring Enclosures and are shown on Drawing No. CDR-3. The new Beam Transfer Enclosures are approximately 1650 ft. long with a cross-section commonly 8 ft. wide and 8 ft. to 11 ft. high. Floors are level and are at Elevation 722.5, 723.0, and 726.0 ft. to match the various enclosures. The Beam Transfer equipment is centered on both level and sloping beam lines varying between Elevation 725 ft. to 732.5 ft.

A special transition enclosure is required at Station F-29 in the existing Main Ring Enclosure. Precast arch sections will be removed and new, wider, rectangular CIP sections will be installed. This will be quite similar to the Station F-18 Enclosure made for the Antiproton Target Hall connection. Other special transition enclosures are required where the new Beam Transfer Enclosures intersect the existing enclosure near the Target Hall and where floor elevation changes occur in the Beam Transfer Enclosures.

Construction details of the Beam Transfer Enclosures are very similar to the PSB and ASB Ring Enclosures. Equipment accesses are from connecting enclosures. Additional personnel accesses are provided on very long enclosure lengths.

V.7 Service Buildings, Personnel and Equipment Access

Four service buildings contain the technical components associated with the 20 GeV Rings. Three new 20 GeV Rings Service Buildings 200, 400 and 600 derive their numbers from the PSB and ASB Sectors over which the buildings are sited. These buildings interrupt the berm and with the berm, emphasize the shape and location of the 20 GeV Rings below. A fourth structure, Service Building F-27 is a rebuilt and enlarged power supply building sited in the Main Ring berm. These buildings are shown on Drawings Nos. CDR-12 through CDR-16.

The three 20 GeV Ring Service Buildings are identical in exterior appearance and nearly identical in interior construction and function. Each building is 34 feet wide and 230 ft. long and approximately 14 to 17 ft. high. Sloping textured concrete walls along the long dimension are interrupted with window, door and louver openings. The end walls are vertical with a massive appearance abutting into the earth berm. The architecture reflects the construction of the Antiproton Service Buildings and the Linac, Transfer and Cross Gallery.

Access into the three service buildings and the ASB and PSB Ring Enclosures below is through personnel doors and stairs at the both ends of the service buildings. At the midpoints of the buildings are equipment and personnel doors leading to the staging areas and equipment drop hatches which serve both Ring Enclosures below. Movable shield doors on Elevation 723 ft. separate the hatch areas from the Ring Enclosures.

The existing Service Building F-27 must be partially demolished during the construction of the the Main Ring Enclosure at Station F-29. The rebuilt and enlarged Service Building F-27 is 50 ft. wide x 66 ft long and protrudes from the Main Ring Berm in appearance similar to other existing construction.

V.8 Laboratory Building

The 20 GeV Laboratory Building is sited between the Main Ring Berm and Kautz Road, approximately 150 ft. southwest of the existing Antiproton Target Hall. The building is 61 ft. wide by 148 ft. long and is similar in appearance with sloping precast concrete wall to the Target Hall. The south half of the building is high bay served with a 20 ton bridge crane. The north half has a mezzanine divided into laboratory, light shop, technician and office spaces. Early construction and occupancy of this lab building is required to effectively mobilize the technical component installations in the ASB and PSB Rings.

V.9 Structural Foundation Systems

All base slabs and piers under all 20 GeV Ring structures are founded on glacial till with high bearing capacity. Numerous soil borings in this and adjacent areas indicate the unsuitability of shallow foundations if founded on the high water bearing strata above this glacial till. Soil boring locations are shown on Drawing No. CDR-4.

Although the till varies in depths of 10 to 20 feet below grade, the requirements for the various beam enclosure structures place the base slab excavation well into the till except at a very few isolated areas. In these areas, a compacted granular backfill or lean concrete will replace the several additional feet required to reach glacial till.

The ABS and PSB Ring Enclosures also serve as the foundations for the three Service Buildings at Sectors 200, 400 and 600. Piers will extend above the ring enclosure roof and precast grade beams will support the CIP service building floors. Similar techniques have been successfully used for the Antiproton Source Service Building construction in nearly identical sub-grade conditions.

V.10 Primary Power, Feeders and Electrical Systems

The 20 GeV Rings are powered from a new 40 MVA 345/13.8 kV transformer in the Fermilab Master Substation (MSS). The northwest corner of the MSS is enlarged to accommodate the new transformer, 345 kV switchgear, and an outdoor 13.8 kV switchgear enclosure and cable vault. A new power ductbank/manhole system is routed south to the 20 GeV Rings area using using one lane of Road A-2 and Kautz Road. Construction is similar to the existing ductbank installed in the Main Ring Road. Substation work and ductbank are shown on Drawing Nos. CDR-25 and 26.

Three new and one existing 13.8 kV feeders serve the 20 GeV Service Buildings and Laboratory. New Feeders 71, 72 and 73 are installed through the new ductbank from the MSS and connect in a loop to Service Buildings 200, 400 and 600. Feeders 71 and 72, with appropriate air switches are connected to the pulsed power supply transformers and Feeder 73 is connected to the house power substations. Existing Feeder 24 is extended from the Main Ring Power Ductbank to serve the 20 GeV Laboratory and the enlarged Service Building F-27.

Lighting levels and typical power distribution are defined on the Electrical Criteria Drawings Nos. CDR-23 and 24.

V.11 Primary Cooling, Distribution and Mechanical Systems

The primary heat rejection medium for the 20 GeV Rings is lake water (LW) from a new six acre cooling lake located south of the 20 GeV Rings. In this area, Indian Lake is created from the borrow pit for the clay fill used to construct the 20 GeV Rings shielding berms. LW intake and discharge structures in Indian Lake are connected through a duplex pump and filter manhole to the Service Building 400. The site layout is shown on Drawing Nos. CDR-1 and 2.

Two process cooling water distribution systems are used for the 20 GeV Rings. The Low Conductivity Water (LCW) system operates at 95°F through directly connected LW heat exchangers and cools the ASB and PSB magnets and power supplies. The Chilled Water (CW) system operates at 45°F through water chillers and cools HVAC coils and special electronic closed loop systems.

LCW and CW piping headers are routed through all 20 GeV and beam enclosures and up into Service Buildings 200 and 600. Cooling for the Service Building F-27 and the 20 GeV Laboratory is obtained from the existing Main Ring Service Buildings F-1 and F-2.

Heating, ventilation, air conditioning and fire protection are defined on the Mechanical Criteria Drawing Nos. CDR-19, 20 and 21.

V.12 Underground Utilities and Services

Power ducts, communication ducts, industrial cold water (ICW) piping, domestic water (DOM) piping, lake water (LW) piping and sanitary sewers (SAN) will be extended from existing utility corridors along South Booster Road, Kautz Road and Main Ring Road. Utility routings are shown on Drawing No. CDR-6.

A new 13.8 kV power duct bank loop will encircle the 20 GeV Rings and branch into substations at the new Service Buildings 200, 400 and 600. This loop will connect to the new ductbank from the Master Substation and new ductbank branch will connect to the existing Main Ring ductbank at Service Building F-27. This branch will provide backup capability to the 20 GeV loop.

New communication ductbanks will connect the adjacent ends of the new Service Buildings 200, 400 and 600. Other new deeply laid ductbanks will connect the Ring Sectors 200, 300 and 500 with minimum length straight runs across the interior of the rings and will include periodic manholes for repeater stations. New duct banks will also connect the rebuilt Service Building F-27, the existing Target Hall and the new Beam Enclosures.

Industrial cold water (ICW) piping will be extended from Kautz Road to encircle the 20 GeV Rings and serve fire hydrants and hose cabinets in Service Buildings 200, 400 and 600. Lake Water (LW) piping will connect the new Indian Lake to Service Building 400 in which the primary cooling heat exchangers are located.

Domestic water (DOM) piping will parallel portions of the new ICW piping and will connect to Service Building 600. Domestic water is not required in other service buildings. New sanitary sewers (SAN) will connect Service Building 600 and the 20 GeV Laboratory to an existing sanitary sewer along Kautz Road. An existing lift station near the Antiproton Service Building AP-10 is enlarged to accommodate the increased load.

V.13 Survey and Alignment Control

A coordinated system of monuments, benchmarks and working points is planned for complete geometric control of the 20 GeV Rings during all phases of construction. Deep concrete piers will be set at construction start to define ring centers and major baselines. This control will be extended onto enclosure base slabs as construction progresses and will be tied into control of the existing survey systems of the Main Ring and the Antiproton Source. Provision is made for survey checks using available equipment hatches and accesses.

V.14 Roads, Drainage, and Landscaping

Road access to the 20 GeV Rings site is from existing Kautz Road. A new loop road around the site, Indian Lake Road, will connect to Kautz Road at two places. Early construction of this new road will provide both construction site access and access to the existing Target Hall and Rf Building. Parking and equipment access areas will be provided at the new 20 GeV Rings service.

The construction site is open cropland draining toward the southwest into Indian Creek. The new cooling lake, Indian Lake, will be constructed as a part of the general site preparation. Indian Lake will be integrated with the new site drainage patterns and the existing Swan Lake-Booster Pond cooling systems.

Special precautions will be made to protect large trees that are adjacent to the construction site. Within the construction site, topsoil will be segregated and later replaced. Crown vetch will be used on berm slopes and crests. The ring interior area will be returned to natural field grasses. Grass seed will be planted adjacent to roads and building areas.

VI. COST ESTIMATE

The Total Estimated Cost for the construction of the two new 20 GeV rings, associated beamlines, and required modifications to existing facilities is $103,800,000 in then-year dollars. The cost estimate is summarized in Table VI-1. An additional $20,400,000 will be required in direct R&D, pre-operating, and capital equipment costs to support the project. The cost estimate methodology is adapted from that used to estimate the Superconducting Super Collider (SSC). Our recent experience with the TeV I (Antiproton Source) construction project forms the basis for a large fraction of the cost estimate of this project.

VI.1 Methodology

A Work Breakdown Structure (WBS) was set up in order to identify all required components of the 20 GeV Rings project and to insure that each component was adequately specified and incorporated into the estimate. The WBS through forth level has already been shown in Table VI-1. The actual WBS used for the cost estimate extended through the sixth level.

All components are estimated at the lowest applicable level in 1988 dollars and then summed upwards. At the lowest level materials costs and labor (fabrication) hours are entered separately along with the basis for the estimate. Labor estimates are also associated with a craft code specifying the type of labor to be used. When materials costs are based on previous purchases of identical components they are escalated to 1988 prices using standard DOE inflation factors. The translation of craft codes into hourly costs is on the basis of local labor rates and is given in Table VI-2. Through this approach a categorized estimate of the total manpower required for completion of the project is created at the same time as the cost estimate.

The cost estimate is produced in 1988 dollars. Escalation to then year dollars is accomplished through a convolution of the spending profile with DOE construction project escalation rates. (See Appendix I - Schedule 44.)

VI.2 Technical Components

The technical components of the rings and beamlines include magnets, vacuum, RF, diagnostics, controls, and safety systems. Included in the estimate are materials, fabrication, and installation costs. The total cost estimate for these components is $47,921K (1988). All components are similar to components already built and installed at other locations within the Fermilab complex. The only truly extraordinary system required in the 20 GeV rings project is the 8-16 GHz cooling system which will be built and commissioned entirely using R&D funds.

Table VI-1: 20 GeV Rings Cost Estimate
(Dollar amounts in thousands)

WBS	Description				Total
1.	**20 GEV RINGS CONSTRUCTION (TEC)**				**103800**
1.1	**Technical Components**			**47900**	
.1	Proton Super Booster		15958		
.1	Magnets	5877			
.2	Vacuum	557			
.3	Power Supplies	2513			
.4	RF Systems	3894			
.5	Injection	285			
.6	Extraction	315			
.7	Instrumentation	733			
.8	Controls	563			
.9	Safety	212			
.10	Installation	1009			
.2	Antiproton Super Booster		20446		
.1	Magnets	12795			
.2	Vacuum	1543			
.3	Power Supplies	839			
.4	RF Systems	1870			
.5	Injection	411			
.6	Extraction	347			
.7	Instrumentation	605			
.9	Controls	563			
.10	Safety	205			
.11	Installation	1268			
.3	Beamlines		11517		
.1	Magnets	6288			
.2	Vacuum	648			
.3	Power Supplies	1896			
.4	Beam Dump	130			
.5	Main Ring Injection	876			
.6	Instrumentation	483			
.7	Controls	70			
.8	Safety	204			
.9	Installation	922			

1.2	**Conventional Construction**		**15000**	
.1	Site Preparation	228		
.2	MR Enclosure Modifications	1504		
.3	Ring Enclosures	4453		
.4	Beam Transfer Enclosures	1913		
.5	Service Buildings	1409		
.6	Exterior Utilities	1120		
.7	Interior Services	1466		
.8	Paving and Landscaping	188		
.9	Laboratory/Office Building	893		
.10	Primary Power and Feeders	1825		
1.3	**EDIA**		**10100**	
1.4	**Contingency**		**15500**	
1.5	**Escalation**		**15300**	
2.	**OTHER PROJECT COSTS**			**20400**
.1	**R&D**		**16400**	
.2	**Pre-operating**		**2400**	
.3	**Capital Equipment**		**1600**	
	TOTAL PROJECT COST			**124200**

Table VI-2: Cost Estimate Labor Codes & Rates ($/hour)

Fabrication		
Technician, relatively unskilled	T1	25.30
Technician, experienced/skilled	T2	30.00
Shops, average capability	S1	34.00
Shops, specialized/precision	S2	39.00
Factory support	F1	30.00
Installation		
Plumber, steam fitter, sheet metal	IP	35.00
Electrician	IE	35.40
Rigger, crane operator	IG	36.70
Technician	IT	20.00
ED&I		
Physicist	PH	35.40
Engineer	EN	30.00
Designer/coordinator	DC	27.20
Drafter	DR	20.00

VI.3 Conventional Construction

The conventional construction cost estimate includes separate enclosures for the two rings, beamline enclosures, service buildings, modifications to the Main Ring at F-32, and all associated utilities including primary power distribution through to the 480 V power panels and cooling water distribution through to headers in the tunnels. Also included are the requisite sitework and road development. Specifically provided for are a new cooling pond, additions required to the Master Substation and 13.8 KV power distribution system, and a new laboratory/office building providing space for the anticipated thirty new personell needed for the project.

The total conventional construction is estimated at $14,999K (1988). The cost estimate has been done using Means Standards and includes overhead and profit at 20%.

VI.4 Engineering Design Inspection & Administration (EDIA)

EDIA is estimated at 16% of total costs. The basis of this percentage is the Fermilab TeV I project.

VI.5 Contingency

Contingency has been estimated separately for all technical components at the forth level of the WBS. This is done because of a large variation in the uncertainty associated with the individual systems components. For example we believe we know the cost of most ASB components (excluding stochastic cooling) extremely well because this ring is nearly a copy of the existing Antiproton Accumulator, while the PSB magnet and power supply configuration may change significantly from that described here as we try to identify the optimum manner of building a rapid cycling accelerator. As a result we have ascribed a substantially higher contingency to the PSB than to the ASB (27% versus 18%). In addition we have assigned a contingency of 23% to beamline components and 18% to conventional construction for an overall contingency of 21.2%.

VI.6 Other Project Costs (R&D, pre-operating, capital equipment)

Specific R&D required to support the 20 GeV Rings project includes:

1. <u>Stochastic Cooling.</u> The development and testing (with beam) of the required 8-16 GHz cooling system will be completely funded as an R&D project. ($4000K)

2. Prototype ASB Magnets. These magnets are copies of existing Antiproton Source magnets but are required to operate over a different range of fields. A prototype small dipole, large dipole, and two large quadrupoles which meet the field quality specification over the entire operating range will be developed. As mentioned earlier this will involve redesign of the magnet ends and perhaps some improvement in the magnet steel quality. ($1500K)

3. Prototype PSB Magnets. These are newly designed magnets. A dipole and three quadrupoles which meet the field quality specification will be built using R&D funds. ($1500K)

4. PSB Power Supply Development. One of the three dipole supplies and the quadrupole-dipole tracking system will be funded through R&D.($2000K)

5. 7.6 MHz RF Development. A 7.6 MHz cavity and associated power amplifier will be built. ($1000K)

6. ASB Injection/Extraction Quadrupoles. Two quadrupole magnets with a field-free channel will be built as required for the ASB injection and extraction systems. ($500K)

7. Tevatron/Main Ring Modifications for Antiproton Deceleration. RF modifications needed for deceleration of antiprotons from 1 TeV to 20 GeV. ($500K)

8. Injection/Extraction Magnets. Includes the development of prototype 20 GeV kickers for the ASB and PSB. ($500K)

9. Accelerator Physics. Three full-time-equivalent physicists will be assigned to addressing accelerator physics questions (over three years). ($500K)

The costs in parenthesis include all associated personnel (physicists, engineers, draftsmen) costs estimated at 100 man-years. Not included here, but included in Table VI-1 is a 37% G&A surcharge. Pre-operating costs ($2400K) include the operation of the two rings during a four month commissioning period. Capital equipment required in support of R&D is estimated at 10% of R&D costs ($1600K).

VII. SCHEDULE

It is proposed that the 20 GeV Rings project be completed over the period October 1, 1988 through April 31, 1993. The schedule is shown in Tables VII-1 and VII-2. The period October 1, 1988 through September 30, 1989 will be devoted to R&D with preparatory engineering in support of construction beginning on October 1, 1989. The schedules shown reflect the spending profile given in the Schedule 44 (Appendix I) and the total manpower estimate shown in Table VII-3. Included in the schedule are four month commissioning periods for each of the rings. Included in the manpower estimate is fabrication and installation of technical components, ED&I for technical components and conventional construction, and support of the R&D program.

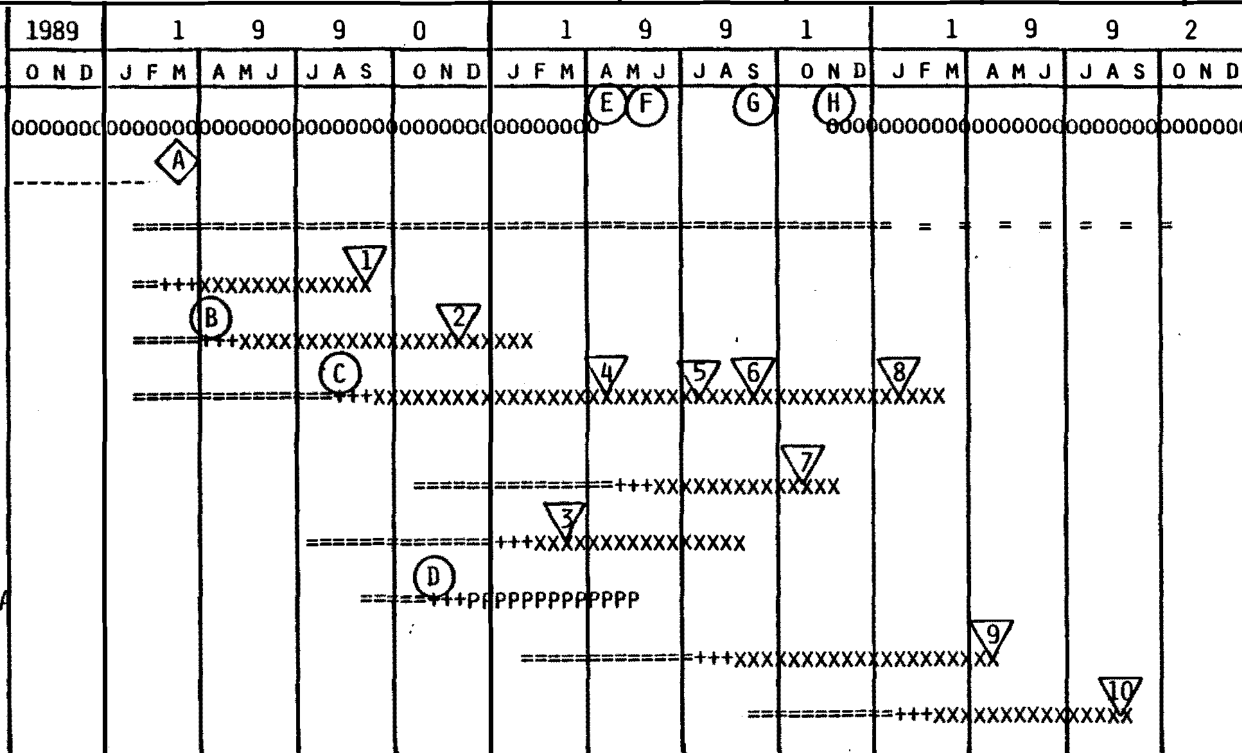
A set of project milestones is given in Table VII-4. As can be seen from the schedule it is planned to complete the Antiproton Super Booster some four to six months before the Proton Super Booster. Because of the separation of the two tunnels it will be possible to complete installation of the PSB while the ASB is running.

Table VII-1: Schedule for Technical Components/R&D
(D=Design, F=Fabricate, T=Test, I=Install, P=Procure, PO=Pre-operating)

	FY 1989	FY 1990	FY 1991	FY 1992	FY 1993
MILESTONES		1 23 4	5 6 7	8 9 10	11 12
R&D					
Design	D-----------				
Prototype ASB Small Dipole	D----P-----F	----T----			
Prototype ASB Large Dipole	D-----	P-----F---T-	---		
Prototype ASB Large Quadrupole	D----P-----F	----T----			
Protoype PSB Dipole	D----P---	--F----T----			
Prototype PSB Quadrupole	D-----	P------F---T	----		
8-16 GHz Cooling	D---------P-	---------F&T	-------------	-------I-PO-	-
7.6 MHz Cavity/Power Amplifier	D-----------	P------F----	-----T------	----I- PO-	-
PSB Power Supply Module	D-----------	P------F----	T-----------	I--T----	---PO--
TECHNICAL COMPONENTS					
ASB Magnets		P-----F--	-------------	----I----PO-	-
Vacuum		D--P--------	F-----------	--I------PO-	-
Power Supplies		D--P--------	F-----------	---I---T-PO-	-
RF		D--P--------	F-----------	----I---TPO-	-
Instrumentation		D-----P-----	----F-------	--I------PO-	-
Controls		D-------P---	--------F---	---I---T-PO-	-
Safety		D-------P---	--------F---	---I---T-PO-	-
PSB Magnets		D-----P-----	----F-------	-----------I-	---PO--
Vacuum		D-----------	P--------F--	----------I--	---PO--
Power Supplies		D-----------	P--------F--	-------I----	-T-PO--
RF		D-----------	P--------F--	------------I	--TPO--
Instrumentation		D-----------	P--------F--	---------I---	---PO--
Controls		D-----------	P----------F	-------I----	T--PO--
Safety		D-----------	P----------F	-------I----	T--PO--
Beamlines Magnets		D-----P-----	----F-------	----I----PO-	-I-PO--
Vacuum		D--P--------	F-----------	--I------PO-	-I-PO--
Power Supplies		D--P--------	F-----------	---I---T-PO-	-T-PO--
Instrumentation		D-----P-----	----F-------	--I------PO-	-I-PO--
Controls		D-------P---	--------F---	---I---T-PO-	-I-PO--
Safety		D-------P---	--------F---	---I---T-PO-	-I-PO--

FERMILAB SCHEDULE

PROJECT TITLE	NO.	DATE	REVISION DATE	PAGE
20 GeV RINGS - CIVIL CONSTRUCTION THREE YEAR OVERVIEW SCHEDULE	6-4-1	MAY 1988		1/1



DESCRIPTION OF WORK ITEMS		W.B.S NUMBER
ACCELERATOR OPERATIONS		
TITLE I DESIGN REPORT	6-4-2	
TITLE II & III E. D. & I.		
SITE PREPARATIONS	6-4-3	1.2.1
LABORATORY BUILDING	6-4-8	1.2.9
RING & BERM ENCLOSURES SERV. BLDGS. & UTIL.	6-4-5	1.2.3, 4,5,6
ACCELERATOR RING MOD.	6-4-4	1.2.2
PRIMARY POWER & FEEDERS	6-4-9	1.2.10
SUBSTATION EQUIP. PROC.	6-4-9A	1.2.10
INTERIOR RING SERVICES	6-4-6	1.2.7
PAVING & LANDSCAPING	6-4-7	1.2.8

D.O.E. & FERMILAB MILESTONES

- A Mar. 1990 — Title I Design Report approved by D.O.E.
- B Apr. 1990 — Release Bid Package for 20 GeV Lab Building
- C Aug. 1990 — Release Bid Package for Ring and Beam Line Enclosure
- D Nov. 1990 — Release Bid Package for 345 kV Master Substation Equipment
- E Apr. 1991 — Accelerator Operation OFF
- F May. 1991 — Tevatron Warmed Up. Accelerator Equipment Removed at F-28/32
- G Sep. 1991 — Start Installation of New PSB and ASB Ring Components
- H Nov. 1991 — Accelerator Operation ON.

CONSTRUCTION CONTRACT MILESTONES

- 1 Sep. 1990 — Site Preparation Subcontract Work Complete
- 2 Dec. 1990, — Benefical Occupancy of 20 GeV Lab Building
- 3 Mar. 1991 — Start Installation of Master Substation Equipment & Feeders
- 4 Apr. 1991 — Underground Utilities Complete. Beneficial Occupancy of Kautz Road and Utilities
- 5 Jul. 1991 — Beneficial Occupancy of 20 GeV Ring and Beam Enclosures except at Service Building Hatches
- 6 Sep. 1991 — Ben. Occup. of 20 GeV Ring Enclosures for Interior Services Subcontractor
- 7 Oct. 1991 — Beneficial Occupancy of Main Ring Enclosure at F-28/32
- 8 Jan. 1992 — Benificial Occupancy of 20 GeV Service Buildings
- 9 Apr. 1992 — Interior Services Installation Complete for all Ring & Berm Enclosures
- 10 Sep. 1992 — Paving, Landscaping and all Civil Construction Complete

LEGEND: 0000 OPERATIONS TIME; ---- CONCEPTUAL DESIGN; ==== FINAL DESIGN; ++++ BID TIME; XXXX CONSTRUCTION TIME; %%%% PROCUREMENT TIME; IIII INSTALLATION TIME; ▽ MILESTONE NUMBER

Table VII-3: 20 GeV Rings Manpower Estimates

Category	Total Man-Years
Technician/Machinist	256
Physicist	63
Engineer	68
Draftsman/Designer	164
Electrician	13
Plumber	15
Rigger	6
Total	585

Table VII-4: Major Project Milestones

Year	Milestone	Date	Description
1989			
	1	October 1	Start Project
1990			
	2	June 30	Complete measurement of prototype ASB dipole
	3	July 1	Start production of ASB magnets
	4	September 30	Complete measurement of prototype PSB dipole
	5	October 1	Go ahead for 8-16 GHz cooling
1991			
	6	February 1	Start production of PSB magnets
	7	September 1	Beneficial Occupancy of 20 GeV Ring Enclosures
	8	October 1	Beneficial Occupancy of Main Ring Enclosure at F28/32
1992			
	9	January 1	Beneficial Occupancy of 20 GeV Service Buildings
	10	July 1	ASB and beamlines under vacuum; Begin commissioning ASB
1993			
	11	January 1	PSB and beamlines under vacuum; Begin commissioning PSB
	12	May 1	Joint operation of ASB and PSB; Project complete

APPENDIX I - SCHEDULE 44

DEPARTMENT OF ENERGY
GENERAL SCIENCE AND RESEARCH - PLANT AND CAPITAL EQUIPMENT
FY 1990 BUDGET REQUEST
(TABULAR DOLLARS IN THOUSANDS. NARRATIVE MATERIAL IN WHOLE DOLLARS.)
CONSTRUCTION PROJECT DATA SHEETS

CHICAGO OPERATIONS
Field Office

HIGH ENERGY PHYSICS
FERMI NATIONAL ACCELERATOR

1. Title and location of Project:
Antiproton-Proton Collider Upgrade: 20 GeV Rings
Fermi National Accelerator Laboratory, Batavia, Illinois

2. Project No. 90-CH-400

3. Date A-E work initiated: 1st Qtr. FY 1990

3a. Date physical construction starts: 2nd Qtr. FY 1990

4. Date construction ends: 1st Qtr. FY 1993

5. Previous cost estimate: None

6. Current cost estimate: $103,800

Date: January 12, 1988

7. Financial Schedule:

Fiscal Year	Authorization	Appropriation	Obligation	Costs
1990	$103,800	$ 25,000	$ 25,000	$15,000
1991		50,000	50,000	40,000
1992		28,800	28,800	40,000
1993				8,800
Total	$103,800	$103,800	$103,800	$103,800

8. Brief Physical Description of Project

The project provides for the construction of two new circular accelerators, one for protons and the other for antiprotons, operating at 20 GeV in support of the upgrade of the Fermilab proton-antiproton collider program. The proton ring will also benefit the fixed target program. The project also includes the construction of four new beam lines, and injection and extraction equipment and tunnel modifications needed to transfer protons and antiprotons between the 20 GeV rings and the existing Antiproton Source, 8 GeV Booster, and Main Ring. The two accelerators are of nearly the same circumference (~500 and 600 meters), and will reside in separate concentric tunnels.

The outer ring, designated the Proton Super Booster (PSB), will accept protons from the existing 8 GeV Booster and accelerate them to 20 GeV for injection into the Main Ring. All protons destined for collider operations, antiproton production, or fixed target operations will pass through this ring. The PSB is a rapid cycling accelerator.

The inner ring, designated the Antiproton Super Booster (ASB), will accept and hold at 8 GeV repeated transfers of antiprotons from the existing Antiproton Accumulator. It will be capable of accelerating these antiprotons from 8 GeV to 20 GeV for injection into the Main Ring. The ASB will also be capable of recovering spent (dilute) antiprotons decelerated through the Collider and Main Ring to 20 GeV for recooling. The ASB typically will operate at fixed excitation interrupted by occasional slow acceleration and deceleration cycles.

Specifically provided for in the scope of the project are:

a. Construction of tunnels, buildings (about 85,000 sq ft total), and utilities necessary to implement the two rings and the four transport lines and beam dump. Downtime of the operating facility necessary for construction will be minimized.
b. The rapid cycling PSB with its necessary technical components, which include magnets, power supplies, vacuum, rf systems, injection/extraction, steering system, control and diagnostic equipment, etc.
c. The ASB with its necessary technical components as listed for the PSB. Excluded are the cooling systems which will be provided by R&D funds.
d. The 20 GeV proton and antiproton injection systems in the Main Ring. The 20 GeV proton injection system will also serve as a Main Ring antiproton extraction system for routing antiprotons back to the ASB for recooling.
e. Four new beamlines are required for delivery of: protons from the existing Booster to the PSB, antiprotons from the existing Accumulator to the ASB, protons or antiprotons to the Main Ring from the PSB and ASB. A total of about one kilometer of beam transport line is required. The beam lines include technical components such as magnets, power supplies, steering devices, kickers, dump, vacuum systems, diagnostics and controls.

9. Purpose, Justification of Need for, and Scope of Project

The overall purpose of this project is to increase the collision rate in the Antiproton-Proton Collider. The economics of efficient production and utilization of antiprotons is one of the outstanding problems to be confronted if luminosity in the proton/antiproton collider is to be substantially increased. The ASB that transfers to the Main Ring at 20 GeV addresses these issues.

Efficient transmission of the proton beam in the Main Ring via injection at 20 GeV not only addresses improved antiproton production, but also enhanced proton intensity extracted from the Tevatron for the fixed target operation. The PSB addresses these issues.

The total number of antiprotons required to be stored in the Tevatron is beyond the design accumulation capability of the Antiproton Source. The ASB provides approximately an order of magnitude improvement in accumulation capability over the existing Source primarily because it does not require a stack-tail cooling system associated with the pbar production stacking cycle - the ASB need only accept new antiprotons every hour or so from the Accumulator, while the Accumulator needs to be able to accept new antiprotons every two seconds from the Debuncher. In addition, by incorporating a 20 GeV acceleration capability into the ASB, spent antiprotons from the collider can be recovered and recooled. This will be an effective enhancement to antiproton production if, as expected, beam lifetimes in the Collider are long compared to the luminosity lifetime. (It is not efficient to recover spent antiprotons in the existing Accumulator due to poor Main Ring transmission below transition.) Main Ring performance, as measured through beam transmission and emittance preservation, is also expected to be significantly enhanced by raising the Main Ring injection energy above transition to 20 GeV. Recently completed machine studies have indicated a dramatic increase in the Main Ring beam lifetime at 20 GeV compared to the present injection energy of 8.9 GeV.

Taken together, the two Super Boosters will eliminate the need to inject any particle into the Main Ring below transition. Current Main Ring performance is characterized by poor beam transmission (60-75%) during the period from injection, at 8.9 GeV, through transition, at 17.5 GeV. This performance degrades drastically as the intensity delivered from the Booster increases - in fact, the 8 GeV Booster is never run at the limit of its intensity capabilities due to limitations in the Main Ring. With an improvement in Main Ring beam transmission, improvements in total intensity delivered from the Booster should be realized as increased beam delivered from the Tevatron to fixed target experimenters and as Main Ring beam delivered for pbar production. As discussed above, machine studies indicate that significantly enhanced performance can be expected from the Main Ring with a 20 GeV injection energy.

10. <u>Details of Cost Estimate</u>

	Item Cost	Total Cost
a. Engineering, design, and inspection at 16% of construction costs		11,500
b. Antiproton Super Booster (ASB) construction costs		$ 41,200
1. Conventional construction	$ 9,500	
2. Special facilities	31,700	
c. Proton Super Booster (PSB) construction costs		30,300
1. Conventional construction	4,700	
2. Special facilities	25,600	
d. Contingency at 25% of above cost		20,800
Total		103,800

11. Method of Performance

Design of facilities will be by the operating contractor and subcontractors as appropriate. To the extent feasible, construction and procurement will be accomplished by fixed-price contracts awarded on the basis of competitive bids.

12. Funding Schedule of Project Funding and Other Related Funding Requirements

	FY 1989	FY 1990	FY 1991	FY 1992	FY 1993	TOTAL
a. Total project cost						
1. Total facility costs						
(a) Construction line item	$ 0	$15,000	$40,000	$40,000	$8,800	$103,800
Total facility cost	$ 0	$15,000	$40,000	$40,000	$8,800	$103,800
2. Other project costs						
(a) Direct R&D costs necessary to complete construction	$ 2,700	$ 4,800	$ 4,100	$ 4,100	$ 700	$ 16,400
(b) Pre-operating costs	$ 0	$ 0	$ 0	$ 1,200	$ 1,200	$ 2,400
(c) Capital Equipment	$ 300	$ 400	$ 400	$ 400	$ 100	$ 1,600
Total other project cost	$ 3,000	$ 5,200	$ 4,500	$ 5,700	$ 2,000	$ 20,400
Total project costs	$ 3,000	$20,200	$44,500	$45,700	$10,800	$124,200*

b. Total related incremental annual funding requirements (estimated life of project: 15 years)
1. Facility operating cost, power $3,000
2. Personnel, M&S operating funds and AIP funds $5,100*

*G&A included where appropriate

13. Narrative Explanation of Total Project Funding and Other Related Funding Requirements

a. Total project costs
1. Total facility cost
(a) Construction line item - explained in items 8, 9, and 10.

2. Other project costs
(a) Direct R&D operating costs - This will provide for the design and development of components and

for the fabrication and testing of prototypes. R&D on all elements of the project to optimize performance and minimize costs of various subsystems will continue through early stages of the construction. The R&D to provide for the state of the art 8-16 GHz stochastic cooling systems necessary to preserve over long storage time the beam emittance in the ASB will continue throughout.

(b) Pre-operating costs - Includes operating costs for a commissioning period.

(c) Items included in these costs are test instruments, power supplies, electronics, and other general equipment to support 12.a.2.(a) and (b).

b. Total related incremental funding requirements - It is assumed that the Fermilab complex will continue to operate both the fixed target and collider programs, with each running about 40% of the time. This means the PSB will operate year-round while the ASB will be online half the year. The result is a net increase in operating power of 5 MW on average (about $3,000,000 per year at expected power rates in 1993$). The programmatic effort will require about 30 additional people to operate and maintain the new facility. AIP funds will be required as operational experience leads to the identification of means of enhancing operation of the facility.

14. Incorporation of Fallout Shelters in Future Federal Buildingss

Not applicable.

15. Incorporation of Measures for the Prevention, Control, and Abatement of Air and Water Pollution at Federal Facilities

The total estimated cost of this project includes the cost of those measures necessary to assure the facility will comply with Executive Order 12088.

16. Evaluation of Flood Hazards

This project will be located in an area not subject to flooding as determined in accordance with the requirements of Executive Order 11988.

17. Environmental Impact

This project is in compliance with the National Environmental Policy Act.

18. Accessibility to the Handicapped

Not applicable.

APPENDIX II - VERIFICATION CHECKLIST

FY90 ANTIPROTON COLLIDER UPGRADE: 20 GEV RINGS PROJECT VALIDATION CHECKLIST

I. Objectives

The Antiproton-Proton Collider Upgrade: 20 GeV Rings project objectives and performance parameters have been developed to support the programmatic needs and goals of the Laboratory. These have been defined in the light of much experience and a number of studies which have been made to understand the current limitations of the accelerator and how to improve the performance of the accelerator in order to support the High Energy Physics program in the future years. Additional information has been supplied to the Validation Review Committee.

II. Scope

A. Requirements

1. Facility Performance Requirements

Fermilab has kept both the High Energy Physics Program Office and the Batavia Area Office fully informed of the goals for the Antiproton-Proton Collider Upgrade and the improvements expected in the 20 GeV Rings phase of the Upgrade. There is a mutual understanding of the programmatic needs for the Upgrade-20 GeV Rings project.

2. Facility Requirements

The general requirements for the facility both in terms of real property, buildings and the hardware have been defined at the conceptual level of design. Materials documenting these requirements have been distributed to the Validation Review Committee.

3. Evaluation of Seismic and Tornado Hazards

The total estimated cost of the project includes the cost of those measures necessary to assure the facility will comply with DOE 6430.1. The project is located in an area of low seismic and tornado activity. The site is already equipped with a tornado warning system. The underground enclosures will provide an adequate tornado shelter area.

4. Safeguards and Security Requirements

Advice and guidance from cognizant safeguards and security personal will be utilized during the project planning and design stages. Any radiation hazards that are known to exist will be treated in the same manner as the hazards are now treated in the present operating accelerator complex under Accelerator Division controls. The facility does not involve items of a classified nature. Physical security will be provided in the same manner as that currently existing in the accelerator facility.

5. Location

Location is determined, to a large extent, by the existing beam lines and accelerator enclosures and technical requirements. Basically three alternative locations were considered. The area selected best fits both the technical requirements and provides the best site from a civil engineering perspective. The project is in compliance with the overall Site Development and Facilities Utilization Plan. Land acquisition is not required.

6. Function Definitions

Functions of all major structures, systems and components are defined to the extent appropriate for a conceptual design.

7. Matching of Existing Facilities to Demands

To the largest extent possible, available utilities, roads and accesses and other support facilities will be used.

8. Initial Complement of Equipment

The requirements for the initial complement of equipment have been defined. Cost estimates have been made based on similar equipment installed at Fermilab.

9. Quality Levels and Program Requirements

The quality levels and program requirements have been defined by many years of operation of the present facility. The levels and requirements have been incorporated into the conceptual design and cost estimate.

10. Emissions and Wastes

Emissions and wastes will be no different than those occurring in the presently operating accelerator. Total compliance with Federal and State emission and waste regulations will not be a problem.

11. Codes and Standards

The facility will operate within applicable local, state and national codes and standards.

12. Office Space

Office space where provided will conform to accepted square feet/person guidelines. Arrangements are similar to other Fermilab installations.

13. Space Requirements

Space for tunnel and equipment enclosures is in addition to current space. Where possible current equipment and tunnel enclosures will be utilized. This facility will require long term 30 additional people for operation and maintenance. Sufficient new office-technician space is included in this project.

B. Design (Conceptual)

1. Design Status

All designs, at this point, are at the conceptual level. Studies have been made based upon current experience, and general civil engineering practices. All major items have been scoped. The scope has been well defined from the programmatic requirements of the Laboratory. The 20 Gev Rings project has been included in the current Fermilab Site Development Plans and Facility Utilization. The schedule has been developed using time estimates based on similar work performed at Fermilab on projects of comparable nature. This project is very similar in nature to the recently completed TeV I project. Some of the technical systems are nearly identical and identical components without redesign can be used in some instances. Cost and schedule projections are thus based heavily on recent experience.

2. Site Conditions

Soil borings are available for areas in close proximity to the site considered. Recent nearby construction experience (TeV 1) has been used to prepare cost estimates.

3. Safety Hazards and Risks

Hazards and risks are characteristic of those already encountered in the accelerator complex and in its construction. No new unique hazards are expected.

4. Solar Energy Applications

Solar energy applications were considered but no application was found to be appropriate.

5. Design Cost Effectiveness

The design is cost effective at a conceptual design level. Further studies to minimize cost and lifecycle costs will be carried out in parallel with the Title I design. In particular, specific attention will be paid to the sizing of the magnets so as to determine the optimum for minimizing the sum of construction and operating costs.

6. Environmental Assessment

The environment surrounding the proposed construction site has been characterized to the extent that the entire Laboratory site is characterized. Topology and hydrology are documented. The impact of the proposed facility on the environment will be no different from the existing facility; no unique hazards are expected.

7. Prerequisite R&D

The necessary R&D required to design and specify the basic system has been done. Additional R&D is in progress to refine the design. R&D will be required to work out detailed designs and prototype fabrication of special components. These activities will continue to help refine the requirements that are necessary for specifying and accomplishing the construction of the special facilities.

In conjunction with the construction, R&D for the development and fabrication of the state of the art stochastic antiproton beam cooling systems will be necessary. Schedule of the required R&D costs has been provided in the project data sheets. R&D funding will be required for detailed design and prototype fabrication, and for development of equipment for beam deceleration and bunching manipulations in the existing accelerators.

8. Participants

The conceptual designs presented to the Validation Review Committee have been prepared by Fermilab staff members. In particular, members of the Accelerator Division and Construction Engineering Services have participated.

9. Uncertainties

Major areas of technical uncertainty are associated with the power supply for the PSB and with the aforementioned ASB stochastic cooling system. The former is a topic for further conceptual R&D and is a technical optimization problem not a cost or schedule issue. The latter, the cooling system, has, because of its state of the art nature, been removed from the construction project and will be accomplished with R&D funds. Here a different choice of operating frequency may be desirable, depending on how rapidly commercial components advance in this area.

10. Energy Conservation Report

An Energy Conservation Report will be prepared.

III. Schedule

All of the following factors have been considered at a depth appropriate at this conceptual design level in developing the schedule:

- budget cycle timing
- contractor selection duration
- Headquarters review and approvals
- prerequisite R&D schedule constraints
- dependency upon timing and amount of operating funds
- historical experience on design, procurement, and construction durations
- procurement lead times for equipment (particularly reflecting vendor quotes)
- logical sequence of design, procurement, and construction
- reasonable manpower levels, buildup and ramp down
- reasonable obligation and costing rates
- shift work or overtime work requirements
- work space constraints
- exposure constraints

IV. Estimate

A. General

1. Estimate Preparation

The estimates presented were prepared in January, 1988. The cost estimate is done in FY88 base year dollars with the escalation shown in "year of expenditure" dollars.

2. Estimate Basis

Estimates are based on preliminary engineering calculations, experience with similar projects done at Fermilab. Our recent experience with the TeV I (Antiproton Source) construction project forms the basis for a large fraction of the cost estimate for this project. The cost estimate methodology is adapted from that used to estimate the Superconductor Super Collider(SSC) Injection System as incorporated into the SSC Conceptual Design Report. Manpower estimates where appropriate have been derived from the TeV I Project.

3. Support of Estimates

Vendor quotes are not appropriate at conceptual level for this design. Catelogue prices have been used for components where appropriate.

4. Contingency

The contingency reflects the degree of confidence in the scope of work, development features, pricing methodology and complexity of the project. The contingency analysis provides for varying degree of certainty in the different components of the Work Breakdown Structure.

5. Escalation Rates

Escalation rates provided by DOE were used. The most recent information obtainable was dated August 1987.

6. Project Reviews

This is the first cost estimate for this project and is a bottoms up estimate. It has been reviewed by knowledgeable Fermilab staff and management.

7. Uniqueness

The unique feature of this facility is the antiproton cooling system for which technology is developing rapidly. For this reason the cooling system has not been included in the construction project but rather within related R&D. Discussion with persons knowledgeable in this field has taken place. Other technical components and civil construction are similar to work that has already been done at Fermilab.

8. Estimating Guides

Conventional construction items and standard equipment estimates were made using standard estimating guides. (Means & Richardson).

9. Indirect Costs

All known indirect costs have been included in the estimate.

10. Title I/Title II Estimates

Not applicable.

11. Experimental Components

There are no experimental components.

12. Procurement Strategy

To the extent feasible, construction and procurement will be accomplished by fixed-price contracts awarded on the basis of competitive bids.

B. Construction

1. Bulk Materials

Both engineering drawings and past experience were used to estimate the bulk material quantities.

2. Quantity Growth

Normal estimating methods for conceptual estimates allow for quantity growth.

3. <u>Bulk Material Pricing</u>

The bulk material costs are current and reflect local conditions.

4. <u>Labor Costs</u>

Labor estimates are based on (Davis-Bacon) at local rates where applicable and at an actual average rate for component fabrication and include applicable fringe and other hidden costs. Costs have been derived from the Tevatron I Project. The local labor market has critical skill construction labor available.

5. <u>Equipment Pricing</u>

Equipment pricing is based upon actual experience in the Tevatron I Project and other Fermilab construction.

6. <u>Special Process Spares</u>

Not applicable.

7. <u>Indirect Costs</u>

Indirect construction costs have been included.

8. <u>Labor Productivity</u>

Labor productivity is based on much local experience.

9. Labor Availability

All necessary craft labor is available in the Chicago area.

10. Pricing Variants

To the extent required for the conceptual design, the cost estimate reflects code, QA, scheduling, climatic, geographic, and other unique specification requirements.

11. Unitized Pricing

Not applicable.

C. Engineering and Management

1. Contractor Project Management

Contractor project management and engineering costs are included in the E.D.I.

2. ED&I Estimate

ED&I costs are estimated at the same percentage of construction costs as those for the recently completed Tevatron I Project at Fermilab.

3. Inspection

Inspection, QA and QC costs have been included.

4. Management

FNAL has considerable experience with Program Management Control systems as used in TeV I and II. We consider the management system responsible for this activity is mature and reasonable. Adequate personnel will be made available.

V. Funding and Costs Status

1. Basis for Planned Authorization, Appropriation, and Cost Schedule

The programmatic goal of the Antiproton-Proton Collider Upgrade: 20 GeV Rings project is to achieve an improvement in the Antiproton-Proton Collider luminosity and the Fixed Target intensity. This goal has been set by the demands of the physics experimental program. Increased luminosity in the early 1990's time scale is crucial to productive utilization of the Tevatron. This increased potential is necessary for a viable national high energy physics program in the pre-SSC era. The authorization of the proposal at the earliest possible time is urged. The appropriation and obligation schedule is predicated on issuing the long-lead contracts at the earliest possible time. The costing is based on an estimate of the effort done as a function of time. This project is planned on the basis of one ring becoming operational before the other. As the two rings are technically independent, this is possible and desirable. Any delay in authorization or appropriation will result in extending the time to operation of one or both rings.

2. Other Associated Project Costs

Other associated project costs include ($20.4M) R&D costs and $2.4M Preoperation costs and $1.6M Capital Equipment costs. When the project is complete there is expected to be a related annual funding increase for operating and improvement costs. These include power costs of \$3M and personnel and M&S costs of \$5.1M. It is estimated that 30 additional people will be required to maintain and operate the facility.

3. Funding Consistency

The annual funding proposed is consistent with the project schedule. The schedule has been developed on the basis of a Critical Path Network (CPN). The CPN will be revised, updated, and expanded as the R&D, design, and project advances.

4. Continuing Resolution Alternatives

In the event of a continuing resolution, if the DOE is not in a position to reprogram funds to this end, the project will be delayed proportionally.

5. Contributing Funding

External contributory funding is not considered for this project.

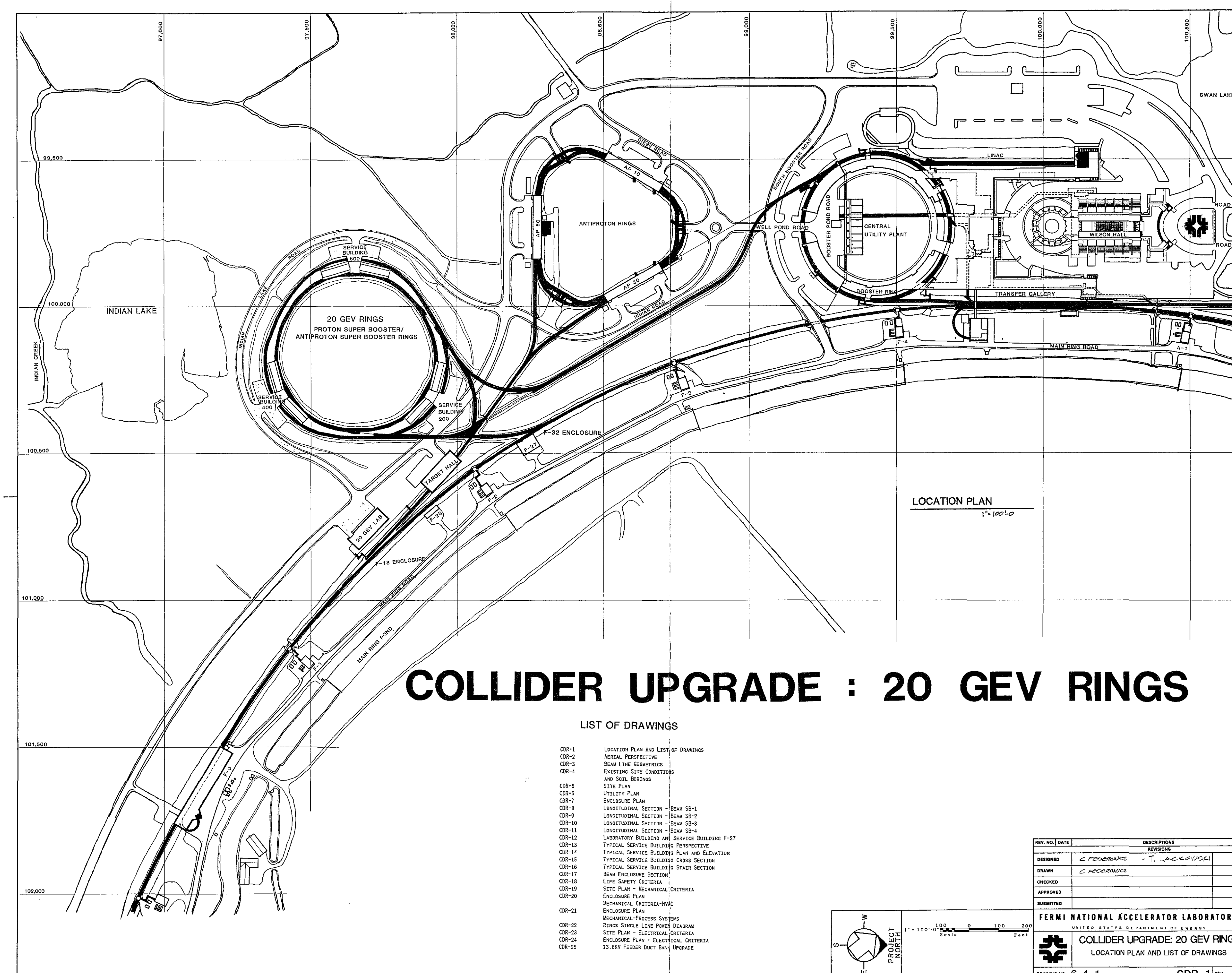
6. Incrementally Funded Construction Contracts

None.

7. Funding By Client or Consultant Agencies

Not applicable.

APPENDIX III - CONVENTIONAL CONSTRUCTION DRAWINGS



COLLIDER UPGRADE : 20 GEV RINGS

LIST OF DRAWINGS

CDR-1	Location Plan And List of Drawings
CDR-2	Aerial Perspective
CDR-3	Beam Line Geometrics
CDR-4	Existing Site Conditions and Soil Borings
CDR-5	Site Plan
CDR-6	Utility Plan
CDR-7	Enclosure Plan
CDR-8	Longitudinal Section - Beam SB-1
CDR-9	Longitudinal Section - Beam SB-2
CDR-10	Longitudinal Section - Beam SB-3
CDR-11	Longitudinal Section - Beam SB-4
CDR-12	Laboratory Building and Service Building F-27
CDR-13	Typical Service Building Perspective
CDR-14	Typical Service Building Plan and Elevation
CDR-15	Typical Service Building Cross Section
CDR-16	Typical Service Building Stair Section
CDR-17	Beam Enclosure Section
CDR-18	Life Safety Criteria
CDR-19	Site Plan - Mechanical Criteria
CDR-20	Enclosure Plan Mechanical Criteria-HVAC
CDR-21	Enclosure Plan Mechanical-Process Systems
CDR-22	Rings Single Line Power Diagram
CDR-23	Site Plan - Electrical Criteria
CDR-24	Enclosure Plan - Electrical Criteria
CDR-25	13.8KV Feeder Duct Bank Upgrade

PROJECT NORTH

1" = 100'-0" Scale 100 0 100 200 Feet

REV. NO.	DATE	DESCRIPTIONS
		REVISIONS

DESIGNED	C. FEDEROWICZ - T. LACKOWSKI
DRAWN	C. FEDEROWICZ
CHECKED	
APPROVED	
SUBMITTED	

FERMI NATIONAL ACCELERATOR LABORATORY

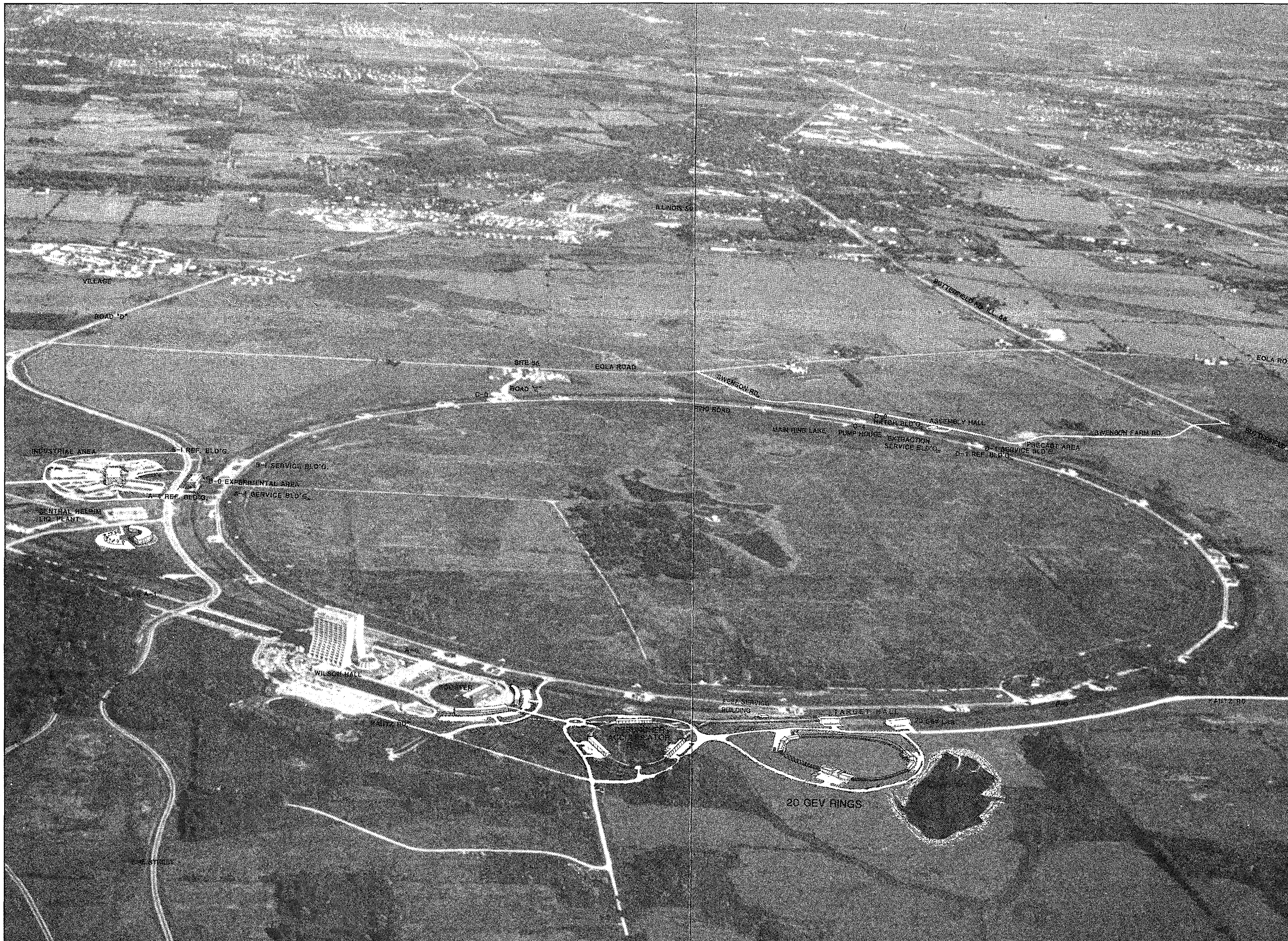
UNITED STATES DEPARTMENT OF ENERGY

COLLIDER UPGRADE: 20 GEV RINGS

LOCATION PLAN AND LIST OF DRAWINGS

DRAWING NO. 6-4-1 CDR-1 REV.

APRIL 1988



FERMI NATIONAL ACCELERATOR LABORATORY

UNITED STATES DEPARTMENT OF ENERGY

COLLIDER UPGRADE: 20 GEV RINGS

AERIAL PERSPECTIVE

PROJECT NORTH

DRAWING NO. 6-4-1 CDR-2 REV.

APRIL 1988

ANTIPROTON WORK POINTS

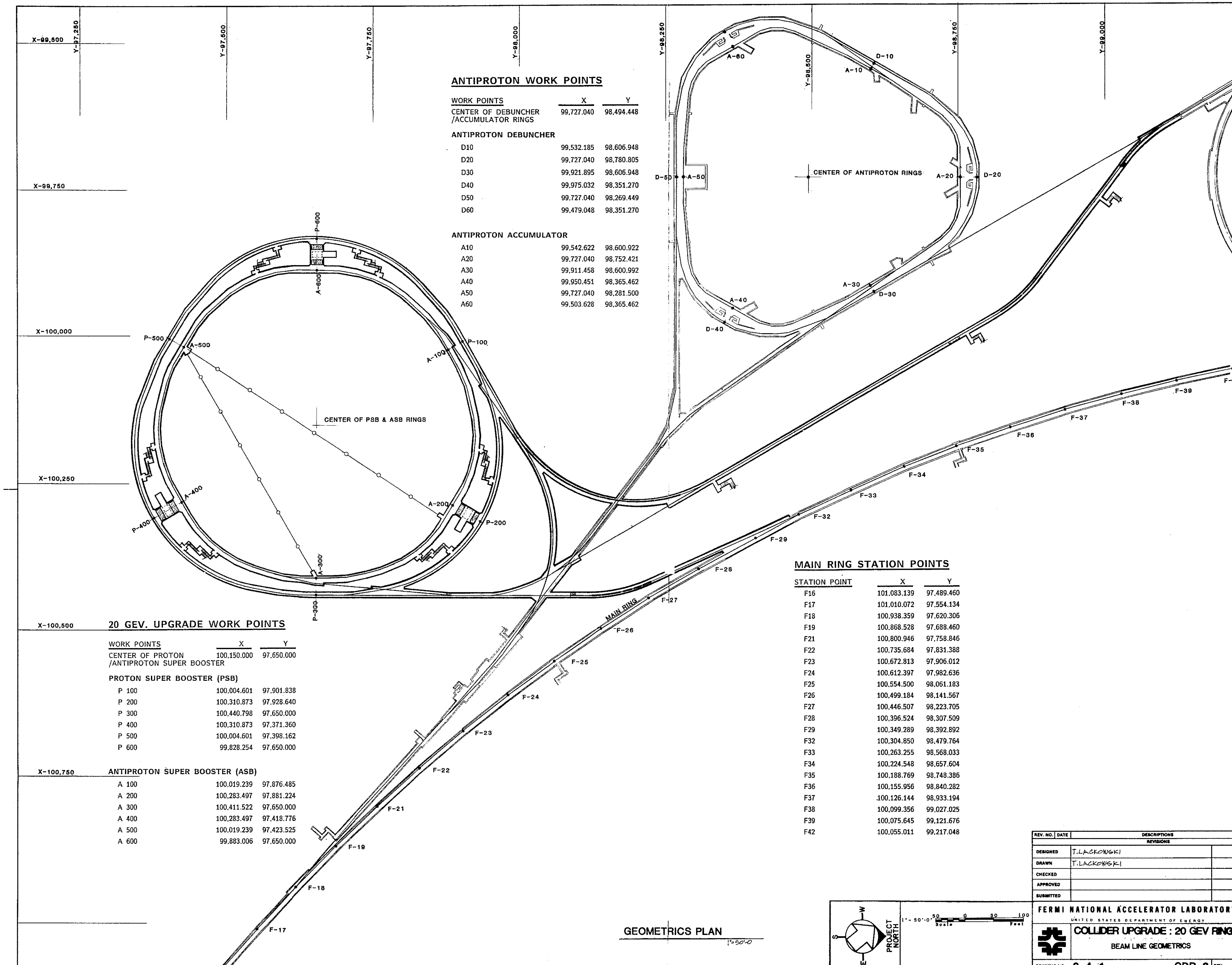
WORK POINTS	X	Y
CENTER OF DEBUNCHER /ACCUMULATOR RINGS	99,727.040	98,494.448
ANTIPROTON DEBUNCHER		
D10	99,532.185	98,606.948
D20	99,727.040	98,780.805
D30	99,921.895	98,606.948
D40	99,975.032	98,351.270
D50	99,727.040	98,269.449
D60	99,479.048	98,351.270
ANTIPROTON ACCUMULATOR		
A10	99,542.622	98,600.922
A20	99,727.040	98,752.421
A30	99,911.458	98,600.992
A40	99,950.451	98,365.462
A50	99,727.040	98,281.500
A60	99,503.628	98,365.462

20 GEV. UPGRADE WORK POINTS

WORK POINTS	X	Y
CENTER OF PROTON /ANTIPROTON SUPER BOOSTER	100,150.000	97,650.000
PROTON SUPER BOOSTER (PSB)		
P 100	100,004.601	97,901.838
P 200	100,310.873	97,928.640
P 300	100,440.798	97,650.000
P 400	100,310.873	97,371.360
P 500	100,004.601	97,398.162
P 600	99,828.254	97,650.000
ANTIPROTON SUPER BOOSTER (ASB)		
A 100	100,019.239	97,876.485
A 200	100,283.497	97,881.224
A 300	100,411.522	97,650.000
A 400	100,283.497	97,418.776
A 500	100,019.239	97,423.525
A 600	99,883.006	97,650.000

MAIN RING STATION POINTS

STATION POINT	X	Y
F16	101,083.139	97,489.460
F17	101,010.072	97,554.134
F18	100,938.359	97,620.306
F19	100,868.528	97,688.460
F21	100,800.946	97,758.846
F22	100,735.684	97,831.388
F23	100,672.813	97,906.012
F24	100,612.397	97,982.636
F25	100,554.500	98,061.183
F26	100,499.184	98,141.567
F27	100,446.507	98,223.705
F28	100,396.524	98,307.509
F29	100,349.289	98,392.892
F32	100,304.850	98,479.764
F33	100,263.255	98,568.033
F34	100,224.548	98,657.604
F35	100,188.769	98,748.386
F36	100,155.956	98,840.282
F37	100,126.144	98,933.194
F38	100,099.356	99,027.025
F39	100,075.645	99,121.676
F42	100,055.011	99,217.048



GEOMETRICS PLAN

1"=50'-0"

PROJECT NORTH

1" - 50'-0" Scale 50 0 50 100 Feet

REV. NO.	DATE	DESCRIPTIONS
		REVISIONS

DESIGNED	T.LACKOWSKI
DRAWN	T.LACKOWSKI
CHECKED	
APPROVED	
SUBMITTED	

FERMI NATIONAL ACCELERATOR LABORATORY

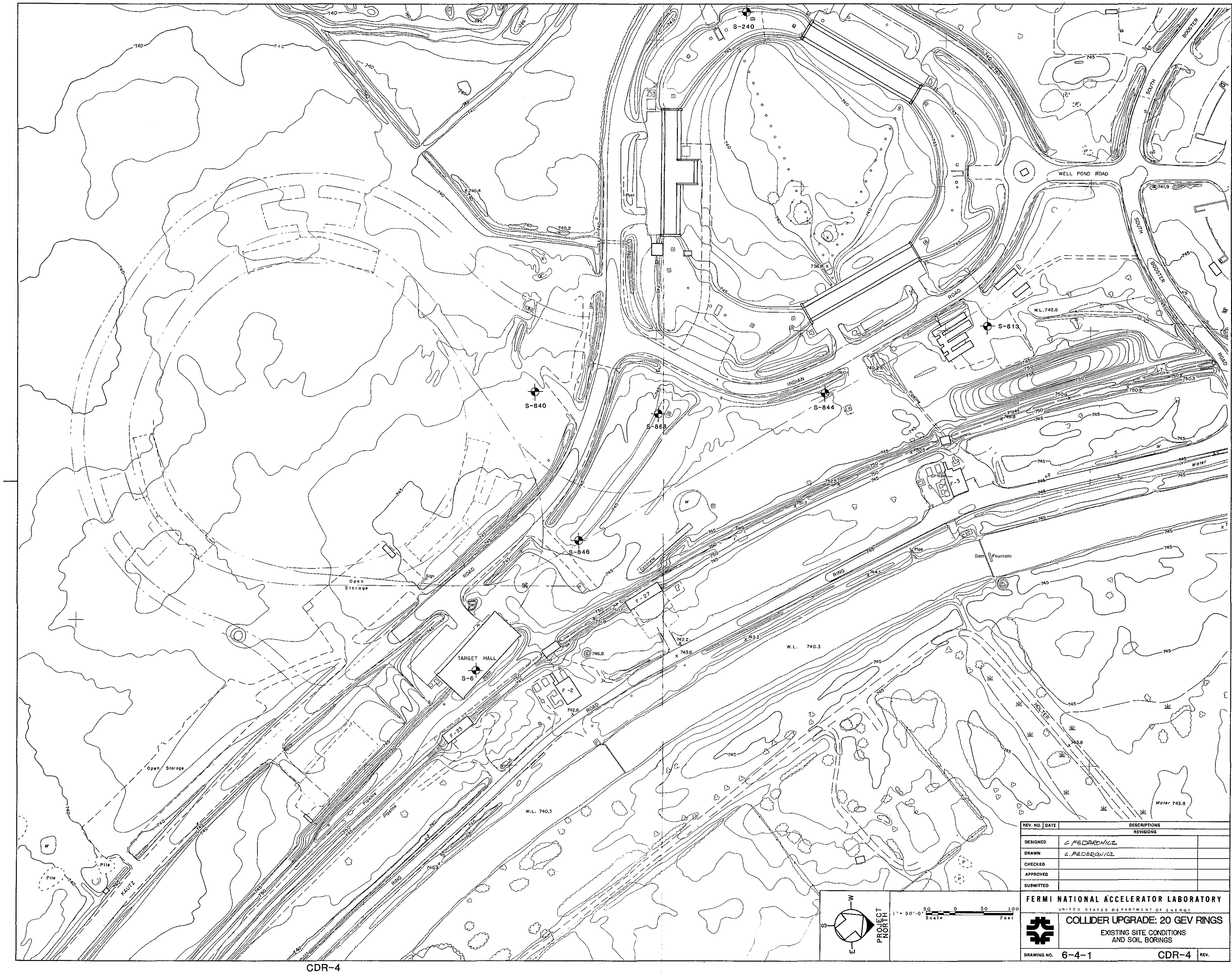
UNITED STATES DEPARTMENT OF ENERGY

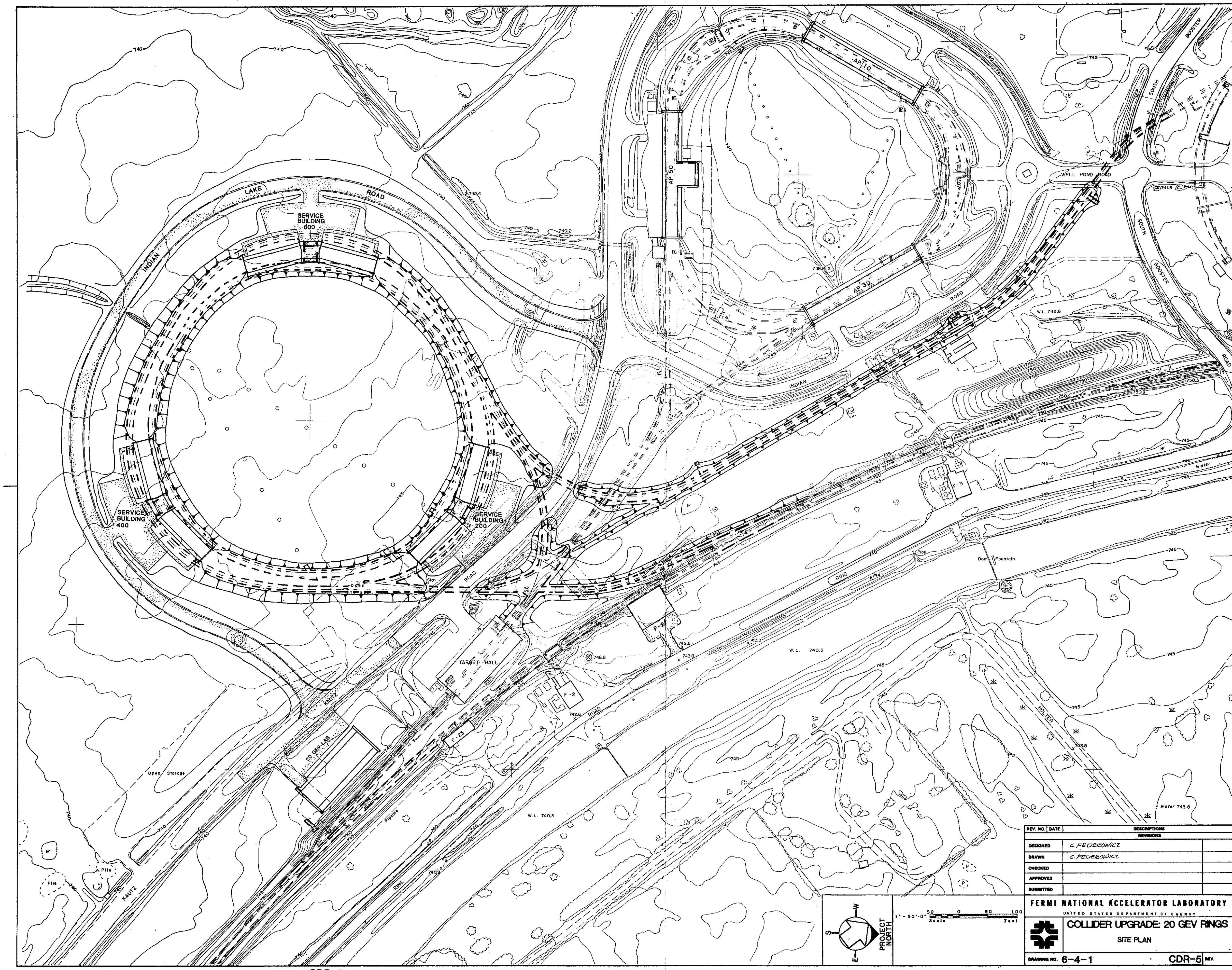
COLLIDER UPGRADE : 20 GEV RINGS

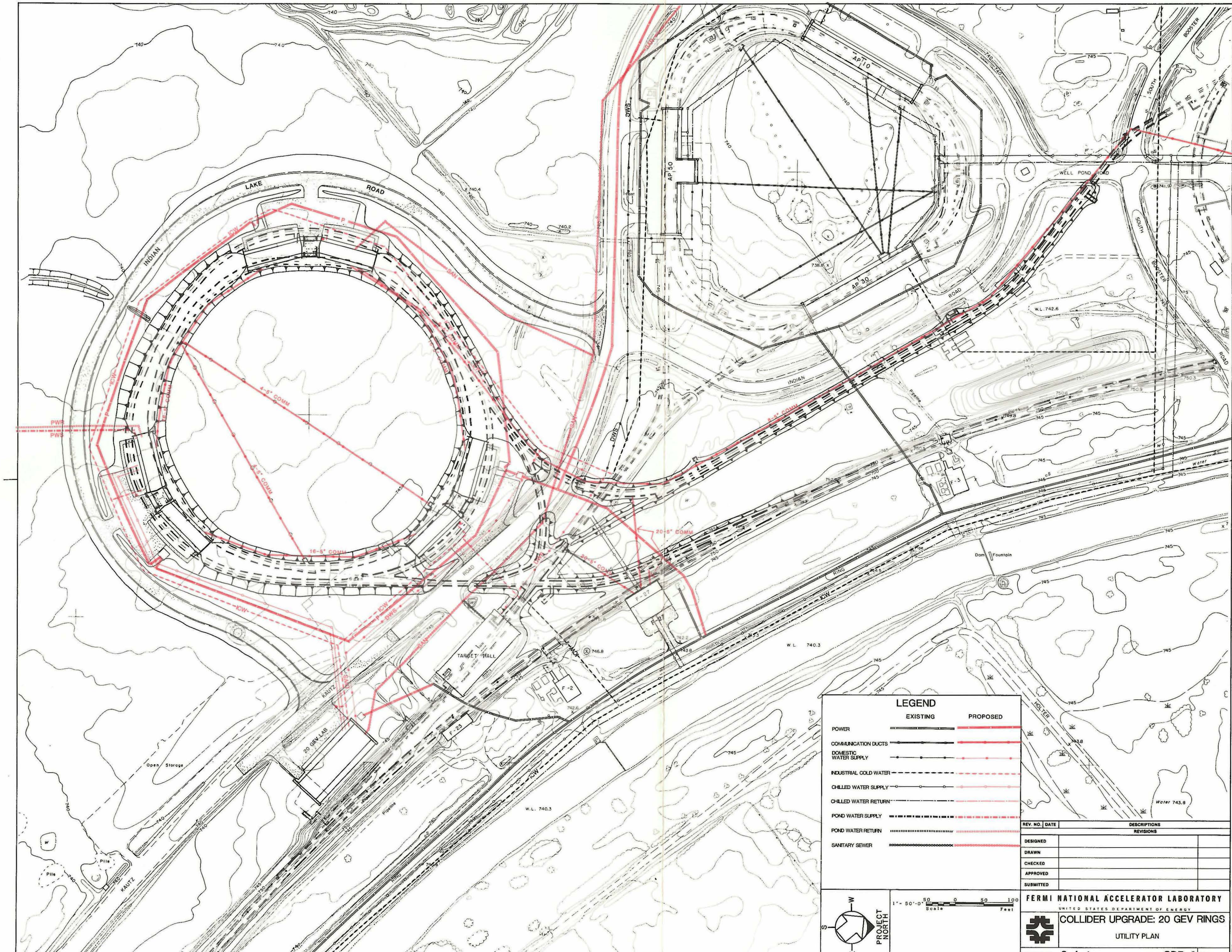
BEAM LINE GEOMETRICS

DRAWING NO. 6-4-1 CDR-3 REV.

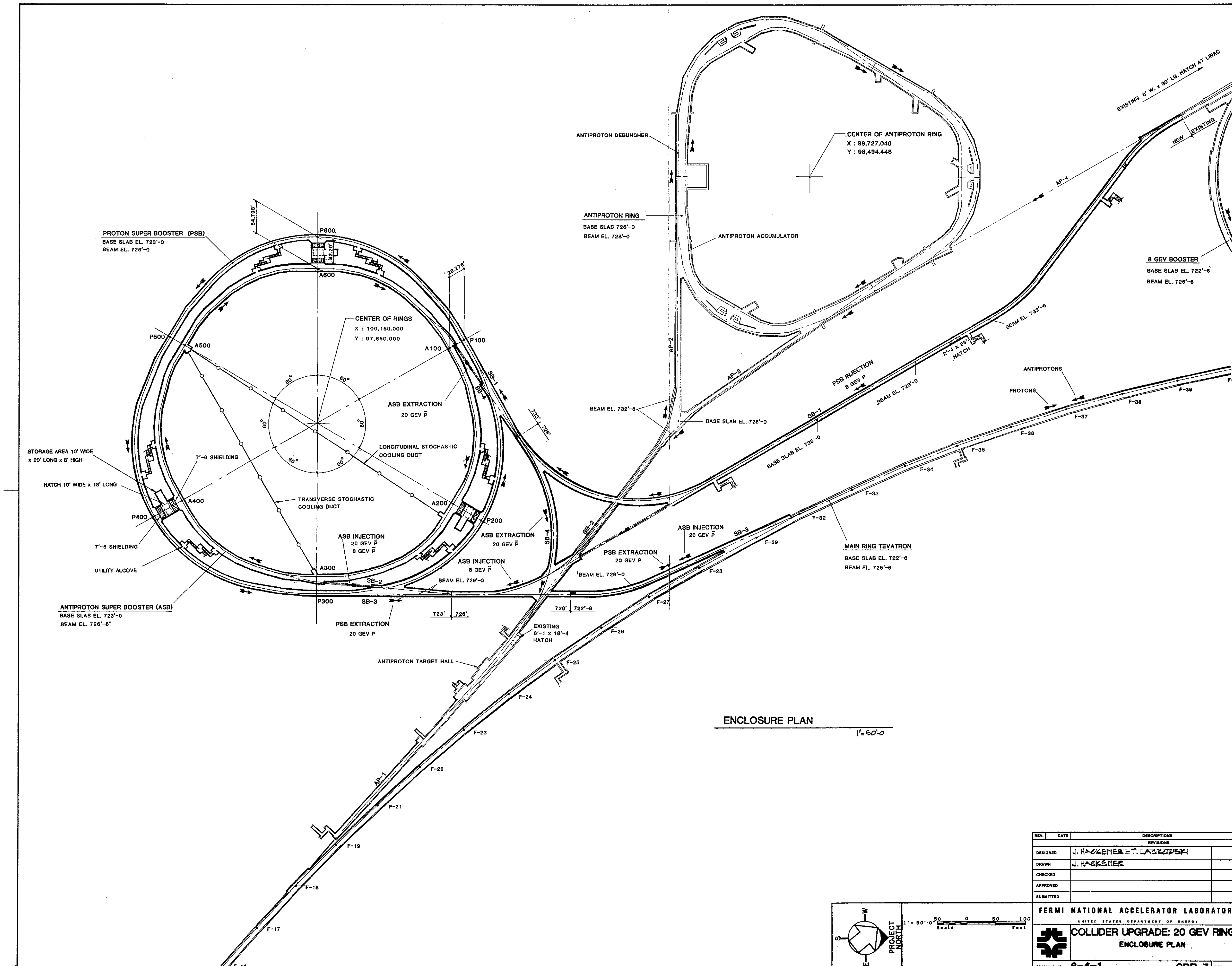
APRIL 1988


S-240
S-813
S-840
S-868
S-844
S-846
S-6
TARGET HALL
F-2
F-3
F-23
F-27
WELL POND ROAD
SOUTH BOOSTER ROAD
INDIAN ROAD
RINGS ROAD
KAUTZ ROAD
HOLTER ROAD
Open Storage
W.L. 740.3
W.L. 742.6
Water 743.8
Dam
Fountain
Pile
PROJECT NORTH
1" = 50'-0"
Scale
Feet
REV. NO.
DATE
DESCRIPTIONS
REVISIONS
DESIGNED
C. FEDEROWICZ
DRAWN
C. FEDEROWICZ
CHECKED
APPROVED
SUBMITTED
FERMI NATIONAL ACCELERATOR LABORATORY
UNITED STATES DEPARTMENT OF ENERGY
COLLIDER UPGRADE: 20 GEV RINGS
EXISTING SITE CONDITIONS
AND SOIL BORINGS
DRAWING NO.
6-4-1
CDR-4
REV.
APRIL 1988

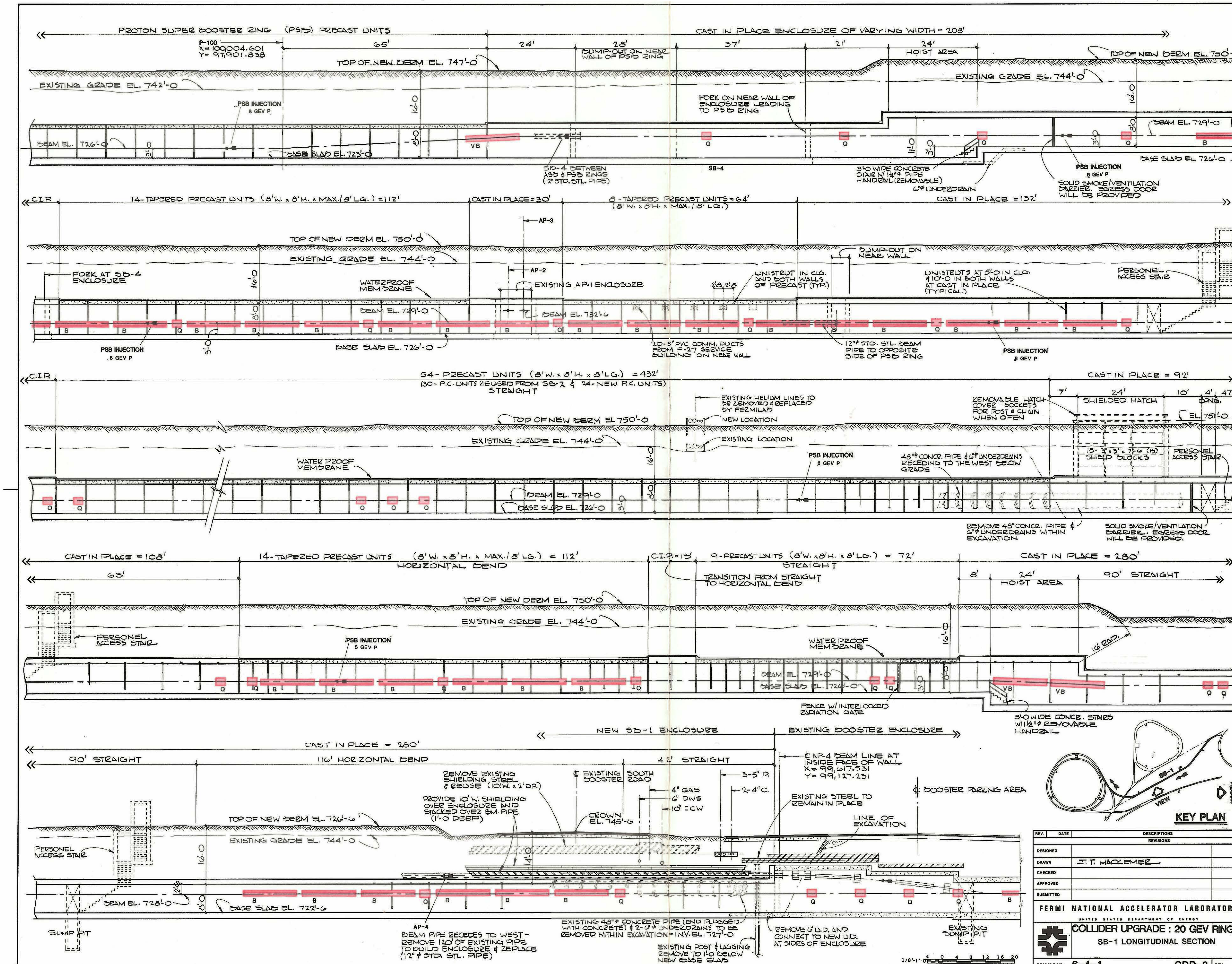

LAKE ROAD
INDIAN
SERVICE BUILDING 600
SERVICE BUILDING 400
SERVICE BUILDING 200
AP 10
AP 30
AP 50
WELL POND ROAD
SOUTH BOOSTER ROAD
INDIAN
ROAD
RING ROAD
TARGET HALL
F-2
F-23
F-27
20 GEV LAB
KAUTZ
Open Storage
Dom Fountain
HOLTER
W.L. 740.3
W.L. 742.6
Water 743.6
REV. NO.
DATE
DESCRIPTIONS
REVISIONS
DESIGNED C. FEDEROWICZ
DRAWN C. FEDEROWICZ
CHECKED
APPROVED
SUBMITTED
PROJECT NORTH
1" = 50'-0"
Scale
Feet
FERMI NATIONAL ACCELERATOR LABORATORY
UNITED STATES DEPARTMENT OF ENERGY
COLLIDER UPGRADE: 20 GEV RINGS
SITE PLAN
DRAWING NO. 6-4-1
CDR-5
REV.
APRIL 1988

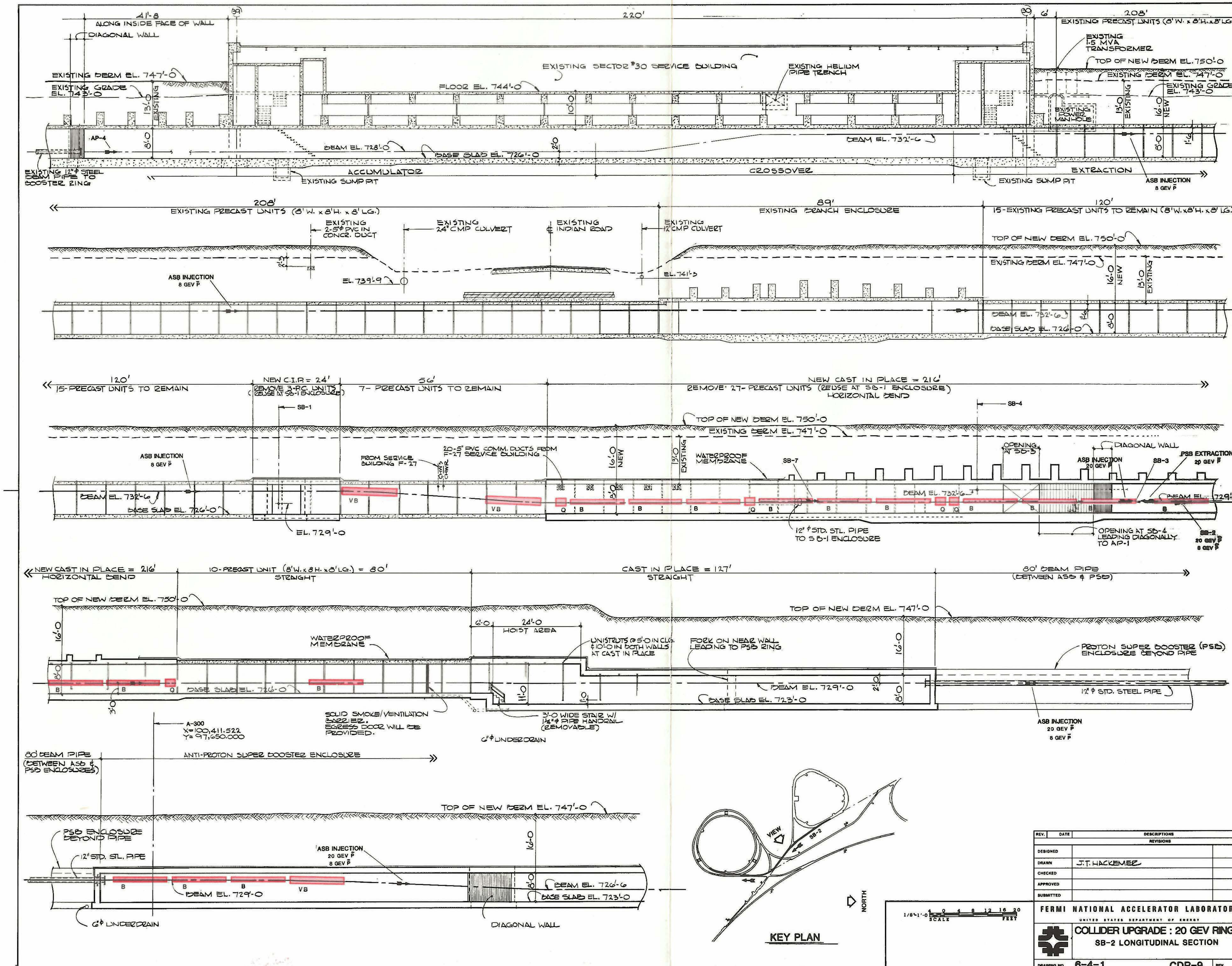

LEGEND
EXISTING
PROPOSED
POWER
COMMUNICATION DUCTS
DOMESTIC WATER SUPPLY
INDUSTRIAL COLD WATER
CHILLED WATER SUPPLY
CHILLED WATER RETURN
POND WATER SUPPLY
POND WATER RETURN
SANITARY SEWER
REV. NO.
DATE
DESCRIPTIONS
REVISIONS
DESIGNED
DRAWN
CHECKED
APPROVED
SUBMITTED
PROJECT NORTH
1" = 50'-0"
Scale
Feet
FERMI NATIONAL ACCELERATOR LABORATORY
UNITED STATES DEPARTMENT OF ENERGY
COLLIDER UPGRADE: 20 GEV RINGS
UTILITY PLAN
DRAWING NO. 6-4-1
CDR-6
REV.
APRIL 1988
INDIAN LAKE ROAD
AP 10
AP 30
AP 50
WELL POND ROAD
SOUTH BOOSTER ROAD
TARGET HALL
20 GEV LAB
KAUTZ
F-2
F-3
F-23
F-27
Open Storage
Dom. Fountain
W.L. 740.3
W.L. 742.6
Water 743.8
4-5" COMM
16-5" COMM
20-5" COMM
PWS
PWR
ICW
DWS
SAN

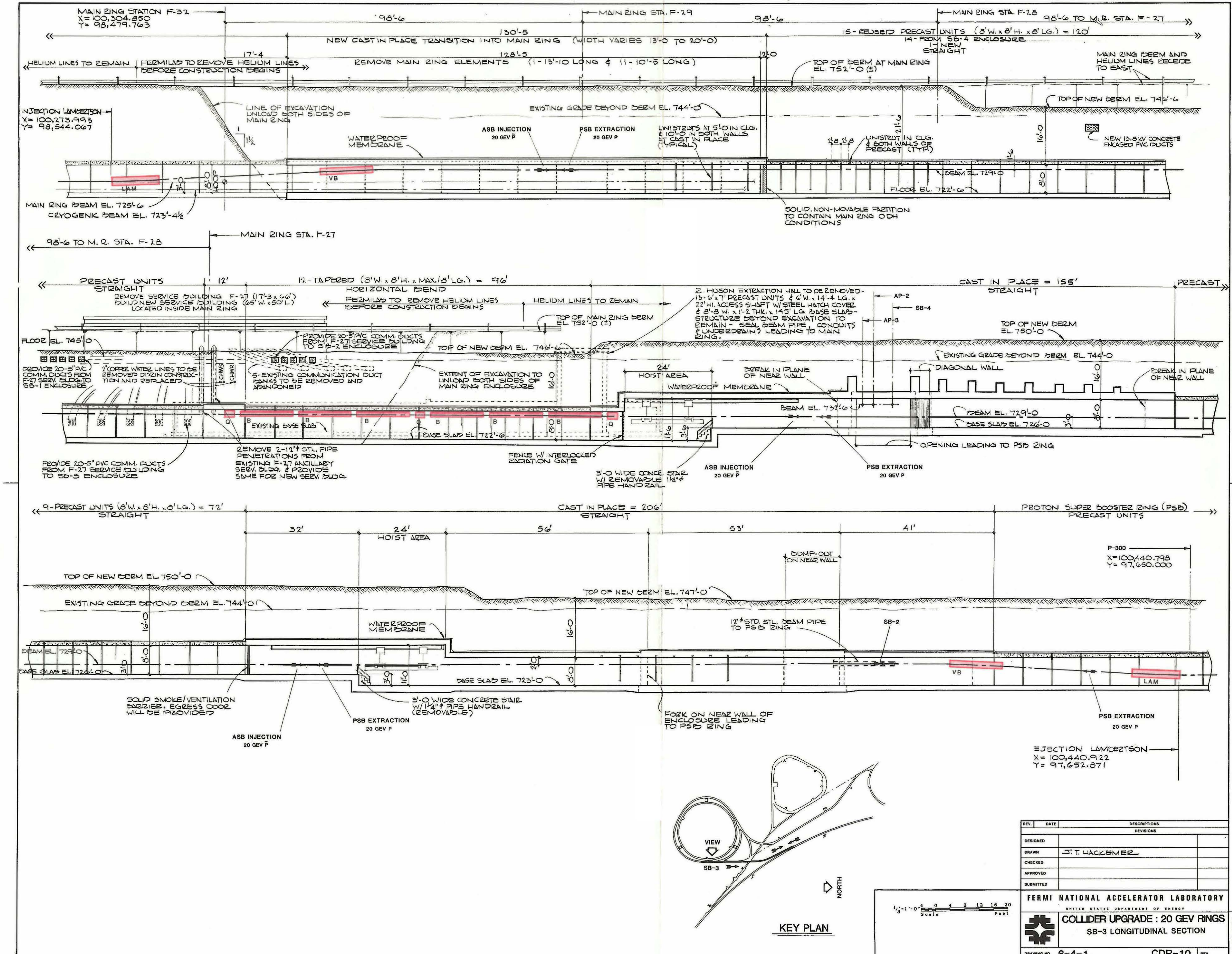
CDR-6

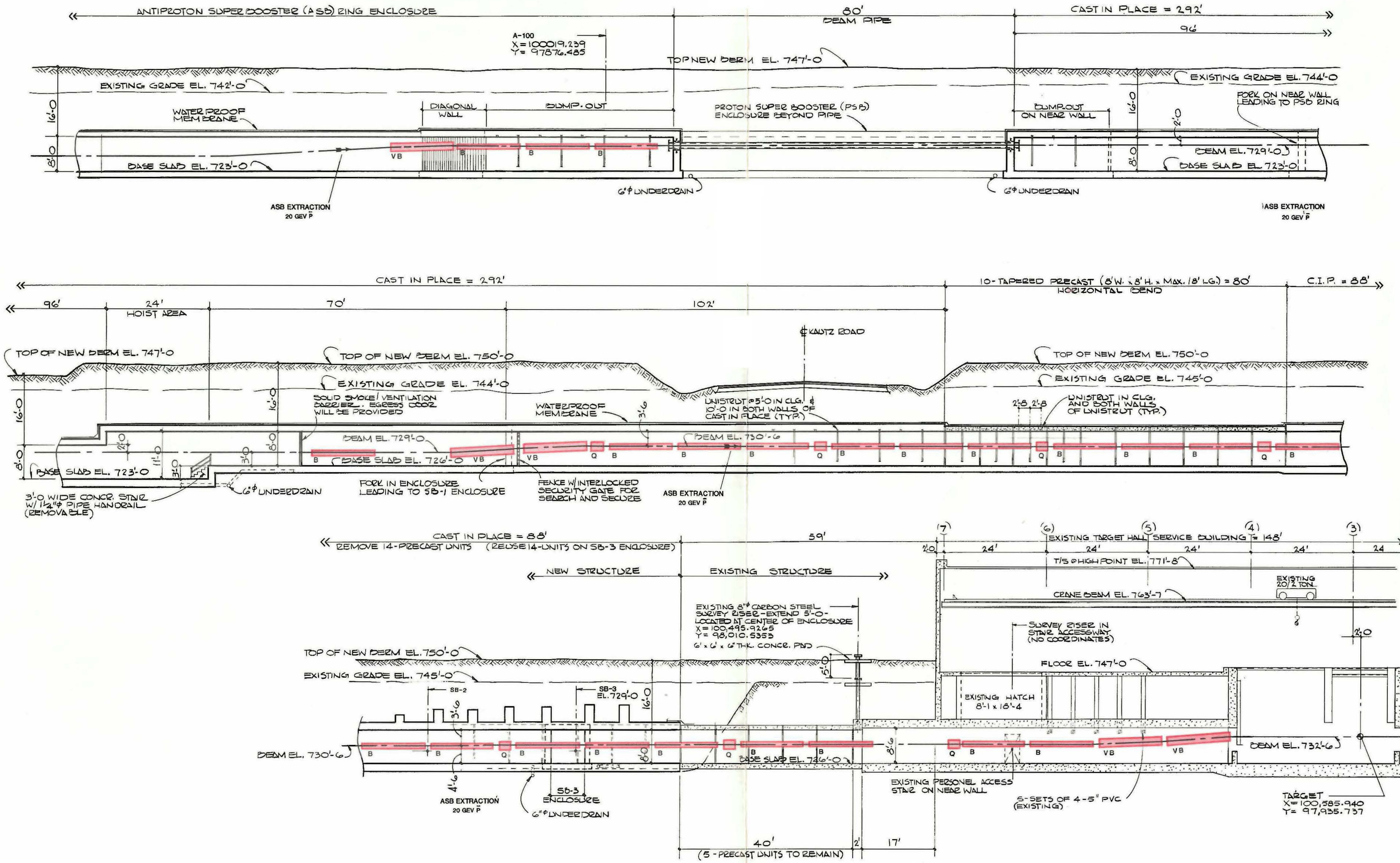

PROTON SUPER BOOSTER (PSB)
BASE SLAB EL. 723'-0
BEAM EL. 726'-0
CENTER OF RINGS
X : 100,150.000
Y : 97,650.000
ASB EXTRACTION
20 GEV P̄
LONGITUDINAL STOCHASTIC COOLING DUCT
TRANSVERSE STOCHASTIC COOLING DUCT
STORAGE AREA 10' WIDE x 20' LONG x 8' HIGH
HATCH 10' WIDE x 16' LONG
7'-6 SHIELDING
UTILITY ALCOVE
ASB INJECTION
20 GEV P̄
8 GEV P̄
ANTIPROTON SUPER BOOSTER (ASB)
BASE SLAB EL. 723'-0
BEAM EL. 726'-6"
PSB EXTRACTION
20 GEV P
BEAM EL. 729'-0
EXISTING
6'-1 x 18'-4
HATCH
ANTIPROTON TARGET HALL
CENTER OF ANTIPROTON RING
X : 99,727.040
Y : 98,494.448
ANTIPROTON DEBUNCHER
ANTIPROTON RING
BASE SLAB 726'-0
BEAM EL. 728'-0
ANTIPROTON ACCUMULATOR
BEAM EL. 732'-6
BASE SLAB EL. 726'-0
EXISTING 8' W. x 30' LG. HATCH AT LINAC
NEW
EXISTING
8 GEV BOOSTER
BASE SLAB EL. 722'-6
BEAM EL. 726'-6
PSB INJECTION
8 GEV P
2'-4 x 23' HATCH
ANTIPROTONS
PROTONS
MAIN RING TEVATRON
BASE SLAB EL. 722'-6
BEAM EL. 725'-6
ENCLOSURE PLAN
1" = 50'-0
DESIGNED J. HACKEMER - T. LACKOWSKI
DRAWN J. HACKEMER
CHECKED
APPROVED
SUBMITTED
FERMI NATIONAL ACCELERATOR LABORATORY
UNITED STATES DEPARTMENT OF ENERGY
COLLIDER UPGRADE: 20 GEV RINGS
ENCLOSURE PLAN
DRAWING NO. 6-4-1
CDR-7
APRIL 1988
PROJECT NORTH

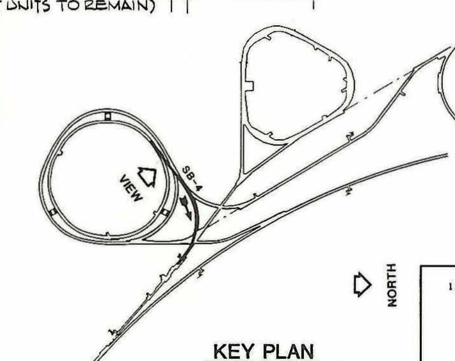
CDR-7


PROTON SUPER BOOSTER RING (PSB) PRECAST UNITS
CAST IN PLACE ENCLOSURE OF VARYING WIDTH = 208'
P-100
X= 100,004.601
Y= 97,901.838
TOP OF NEW BERM EL. 747'-0
BUMP-OUT ON NEAR WALL OF PSB RING
HOIST AREA
TOP OF NEW BERM EL. 750'-0
EXISTING GRADE EL. 744'-0
EXISTING GRADE EL. 742'-0
PSB INJECTION 8 GEV P
FORK ON NEAR WALL OF ENCLOSURE LEADING TO PSB RING
BEAM EL. 729'-0
BEAM EL. 726'-0
BASE SLAB EL. 723'-0
BASE SLAB EL. 726'-0
SB-4 BETWEEN ABS & PSB RINGS (12" STD. STL. PIPE)
SB-4
3'-0 WIDE CONCRETE STAIR W/ 1¼" ϕ PIPE HANDRAIL (REMOVABLE)
6" ϕ UNDERDRAIN
SOLID SMOKE/VENTILATION BARRIER. EGRESS DOOR WILL BE PROVIDED
C.I.P.
14-TAPERED PRECAST UNITS (8'W. x 8'H. x MAX./8' LG.) = 112'
CAST IN PLACE = 30'
8-TAPERED PRECAST UNITS = 64' (8'W. x 8'H. x MAX. / 8' LG.)
CAST IN PLACE = 132'
AP-3
AP-2
FORK AT SB-4 ENCLOSURE
WATERPROOF MEMBRANE
EXISTING AP-1 ENCLOSURE
BEAM EL. 732'-6
UNISTRUT IN CLG. AND BOTH WALLS OF PRECAST (TYP.)
BUMP-OUT ON NEAR WALL
UNISTRUTS AT 5'-0 IN CLG. & 10'-0 IN BOTH WALLS AT CAST IN PLACE (TYPICAL)
PERSONEL ACCESS STAIR
20-5" PVC COMM. DUCTS FROM F-27 SERVICE BUILDING ON NEAR WALL
12" ϕ STD. STL. BEAM PIPE TO OPPOSITE SIDE OF PSB RING
54-PRECAST UNITS (8'W. x 8'H. x 8' LG.) = 432'
(30-P.C. UNITS REUSED FROM SB-2 & 24-NEW P.C. UNITS)
STRAIGHT
CAST IN PLACE = 92'
SHIELDED HATCH
EXISTING HELIUM LINES TO BE REMOVED & REPLACED BY FERMILAB
NEW LOCATION
EXISTING LOCATION
REMOVABLE HATCH COVER - SOCKETS FOR POST & CHAIN WHEN OPEN
EL. 751'-0
48" ϕ CONCR. PIPE & 6" ϕ UNDERDRAINS RECEDING TO THE WEST BELOW GRADE
15-3'x3'x7'-6 (B) SHIELD BLOCKS
REMOVE 48" CONCR. PIPE & 6" ϕ UNDERDRAINS WITHIN EXCAVATION
CAST IN PLACE = 108'
14-TAPERED PRECAST UNITS (8'W. x 8'H. x MAX. / 8' LG.) = 112'
HORIZONTAL BEND
C.I.P.=13'
9-PRECAST UNITS (8'W. x 8'H. x 8' LG.) = 72'
CAST IN PLACE = 280'
TRANSITION FROM STRAIGHT TO HORIZONTAL BEND
90' STRAIGHT
16' RAD.
FENCE W/ INTERLOCKED RADIATION GATE
3'-0 WIDE CONC. STAIRS W/ 1¼" ϕ REMOVABLE HANDRAIL
NEW SB-1 ENCLOSURE
EXISTING BOOSTER ENCLOSURE
116' HORIZONTAL BEND
42' STRAIGHT
REMOVE EXISTING SHIELDING STEEL & REUSE (10'W. x 2' DP.)
PROVIDE 10' W. SHIELDING OVER ENCLOSURE AND STACKED OVER BM. PIPE (1'-0 DEEP)
℄ EXISTING SOUTH BOOSTER ROAD
CROWN EL. 745'-6
4" GAS
6" DWS
10" ICW
℄ AP-4 BEAM LINE AT INSIDE FACE OF WALL
X= 99,617.531
Y= 99,127.231
EXISTING STEEL TO REMAIN IN PLACE
℄ BOOSTER PARKING AREA
LINE OF EXCAVATION
TOP OF NEW BERM EL. 726'-6
EXISTING GRADE EL. 744'-0
BEAM EL. 728'-0
BASE SLAB EL. 722'-6
SUMP PIT
AP-4
BEAM PIPE RECEDES TO WEST - REMOVE 120' OF EXISTING PIPE TO BUILD ENCLOSURE & REPLACE (12" ϕ STD. STL. PIPE)
EXISTING 48" ϕ CONCRETE PIPE (END PLUGGED WITH CONCRETE) & 2-6" ϕ UNDERDRAINS TO BE REMOVED WITHIN EXCAVATION - INV. EL. 727'-0
EXISTING POST & LAGGING REMOVE TO 1'-0 BELOW NEW BASE SLAB
REMOVE 6" U.D. AND CONNECT TO NEW U.D. AT SIDES OF ENCLOSURE
EXISTING SUMP PIT
KEY PLAN
SB-1
VIEW
NORTH
1/8"=1'-0"
SCALE
FEET
REV.
DATE
DESCRIPTIONS
REVISIONS
DESIGNED
DRAWN
J. T. HACKEMER
CHECKED
APPROVED
SUBMITTED
FERMI NATIONAL ACCELERATOR LABORATORY
UNITED STATES DEPARTMENT OF ENERGY
COLLIDER UPGRADE : 20 GEV RINGS
SB-1 LONGITUDINAL SECTION
DRAWING NO. 6-4-1
CDR-8
APRIL 1988


41'-8
ALONG INSIDE FACE OF WALL
DIAGONAL WALL
220'
208'
EXISTING PRECAST UNITS (8'W. x 8'H. x 8'LG.)
EXISTING 1.5 MVA TRANSFORMER
TOP OF NEW BERM EL. 750'-0
EXISTING BERM EL. 747'-0
EXISTING GRADE EL. 743'-0
EXISTING SECTOR #30 SERVICE BUILDING
EXISTING HELIUM PIPE TRENCH
FLOOR EL. 744'-0
EXISTING POWER MANHOLE
BEAM EL. 728'-0
BASE SLAB EL. 726'-0
BEAM EL. 732'-6
EXISTING 12"φ STEEL BEAM PIPE TO BOOSTER RING
AP-4
ACCUMULATOR
CROSSOVER
EXTRACTION
EXISTING SUMP PIT
ASB INJECTION 8 GEV P̄
EXISTING PRECAST UNITS (8'W. x 8'H. x 8'LG.)
89'
EXISTING BRANCH ENCLOSURE
120'
15-EXISTING PRECAST UNITS TO REMAIN (8'W. x 8'H. x 8'LG.)
EXISTING 2-5"φ PVC IN CONCR. DUCT
EXISTING 24"CMP CULVERT
EXISTING ℄ INDIAN ROAD
EXISTING 12"CMP CULVERT
EL. 739'-9
EL. 741'-3
15-PRECAST UNITS TO REMAIN
NEW C.I.P. = 24'
REMOVE 3-P.C. UNITS (REUSE AT SB-1 ENCLOSURE)
56'
7- PRECAST UNITS TO REMAIN
NEW CAST IN PLACE = 216'
REMOVE 27- PRECAST UNITS (REUSE AT SB-1 ENCLOSURE)
HORIZONTAL BEND
SB-1
SB-4
SB-7
SB-3
FROM SERVICE BUILDING F-27
20-5" PVC COMM. DUCTS FROM F-27 SERVICE BUILDING
WATERPROOF MEMBRANE
OPENING AT SB-3
PSB EXTRACTION 20 GEV P̄
ASB INJECTION 20 GEV P̄
EL. 729'-0
12"φ STD. STL. PIPE TO SB-1 ENCLOSURE
OPENING AT SB-4 LEADING DIAGONALLY TO AP-1
SB-2 20 GEV P̄ 8 GEV P̄
NEW CAST IN PLACE = 216' HORIZONTAL BEND
10-PRECAST UNIT (8'W. x 8'H. x 8'LG.) = 80' STRAIGHT
CAST IN PLACE = 127' STRAIGHT
80' BEAM PIPE (BETWEEN ASB & PSB)
TOP OF NEW BERM EL. 747'-0
HOIST AREA
UNISTRUTS @ 5'-0 IN CLG. & 10'-0 IN BOTH WALLS AT CAST IN PLACE
FORK ON NEAR WALL LEADING TO PSB RING
PROTON SUPER BOOSTER (PSB) ENCLOSURE BEYOND PIPE
BEAM EL. 729'-0
BASE SLAB EL. 723'-0
12"φ STD. STEEL PIPE
SOLID SMOKE/VENTILATION BARRIER. EGRESS DOOR WILL BE PROVIDED.
3'-0 WIDE STAIR W/ 1½"φ PIPE HANDRAIL (REMOVABLE)
6"φ UNDERDRAIN
A-300 X=100,411.522 Y=97,650.000
80' BEAM PIPE (BETWEEN ASB & PSB ENCLOSURES)
ANTI-PROTON SUPER BOOSTER ENCLOSURE
PSB ENCLOSURE BEYOND PIPE
12"φ STD. STL. PIPE
BEAM EL. 726'-6
BASE SLAB EL. 723'-0
DIAGONAL WALL
VIEW
NORTH
KEY PLAN
1/8"=1'-0 SCALE FEET
DESIGNED
DRAWN J.T. HACKEMER
CHECKED
APPROVED
SUBMITTED
FERMI NATIONAL ACCELERATOR LABORATORY
UNITED STATES DEPARTMENT OF ENERGY
COLLIDER UPGRADE : 20 GEV RINGS
SB-2 LONGITUDINAL SECTION
DRAWING NO. 6-4-1
CDR-9
APRIL 1988


MAIN RING STATION F-32
X= 100,304.850
Y= 98,479.763
98'-6
MAIN RING STA. F-29
98'-6
MAIN RING STA. F-28
98'-6 TO M.R. STA. F-27
130'-5
NEW CAST IN PLACE TRANSITION INTO MAIN RING (WIDTH VARIES 13'-0 TO 20'-0)
15-REUSED PRECAST UNITS (8'W. x 8'H. x 8'LG.) = 120'
14-FROM SB-4 ENCLOSURE
1-NEW
STRAIGHT
17'-4
128'-5
HELIUM LINES TO REMAIN
FERMILAB TO REMOVE HELIUM LINES BEFORE CONSTRUCTION BEGINS
REMOVE MAIN RING ELEMENTS (1-13'-10 LONG & 11-10'-5 LONG)
TOP OF BERM AT MAIN RING EL. 752'-0 (±)
MAIN RING BERM AND HELIUM LINES RECEDE TO EAST
TOP OF NEW BERM EL. 746'-6
INJECTION LAMBERTSON
X= 100,273.993
Y= 98,544.067
LINE OF EXCAVATION UNLOAD BOTH SIDES OF MAIN RING
EXISTING GRADE BEYOND BERM EL. 744'-0
ASB INJECTION
20 GEV P̄
PSB EXTRACTION
20 GEV P
UNISTRUTS AT 5'-0 IN CLG. & 10'-0 IN BOTH WALLS AT CAST IN PLACE (TYPICAL)
UNISTRUT IN CLG. & BOTH WALLS OF PRECAST (TYP.)
NEW 13.8 KV CONCRETE ENCASED PVC DUCTS
WATERPROOF MEMBRANE
LAM
VB
BEAM EL. 729'-0
FLOOR EL. 722'-6
MAIN RING BEAM EL. 725'-6
CRYOGENIC BEAM EL. 723'-4½
SOLID, NON-MOVABLE PARTITION TO CONTAIN MAIN RING ODH CONDITIONS
98'-6 TO M.R. STA. F-28
MAIN RING STA. F-27
PRECAST UNITS
STRAIGHT
12'
12-TAPERED (8'W. x 8'H. x MAX. 8'LG.) = 96'
HORIZONTAL BEND
CAST IN PLACE = 155'
STRAIGHT
PRECAST
REMOVE SERVICE BUILDING F-27 (17'-3 x 66')
BUILD NEW SERVICE BUILDING (65'W. x 50'L.) LOCATED INSIDE MAIN RING
FERMILAB TO REMOVE HELIUM LINES BEFORE CONSTRUCTION BEGINS
HELIUM LINES TO REMAIN
TOP OF MAIN RING BERM EL. 752'-0 (±)
2. HUSON EXTRACTION HALL TO BE REMOVED - 13 - 6'x7' PRECAST UNITS & 6'W. x 14'-4 LG. x 22' HI. ACCESS SHAFT W/ STEEL HATCH COVER & 8'-8 W. x 1'-2 THK. x 145' LG. BASE SLAB - STRUCTURE BEYOND EXCAVATION TO REMAIN - SEAL BEAM PIPE, CONDUITS & UNDERDRAINS LEADING TO MAIN RING.
AP-2
SB-4
AP-3
TOP OF NEW BERM EL. 750'-0
FLOOR EL. 745'-0
PROVIDE 20-5" PVC COMM. DUCTS FROM F-27 SERVICE BUILDING TO SP-2 ENCLOSURE
TOP OF NEW BERM EL. 746'-6
EXISTING GRADE BEYOND BERM EL. 744'-0
DIAGONAL WALL
PROVIDE 20-5" PVC COMM. DUCTS FROM F-27 SERV. BLDG. TO SB-1 ENCLOSURE
2" COPPER WATER LINES TO BE REMOVED DURING CONSTRUCTION AND REPLACED
5-EXISTING COMMUNICATION DUCT BANKS TO BE REMOVED AND ABANDONED
EXTENT OF EXCAVATION TO UNLOAD BOTH SIDES OF MAIN RING ENCLOSURE
24'
HOIST AREA
WATERPROOF MEMBRANE
BREAK IN PLANE OF NEAR WALL
BEAM EL. 732'-6
BEAM EL. 729'-0
BASE SLAB EL. 726'-0
EXISTING BASE SLAB
BASE SLAB EL. 722'-6
OPENING LEADING TO PSB RING
REMOVE 2-12"ϕ STL. PIPE PENETRATIONS FROM EXISTING F-27 ANCILLARY SERV. BLDG. & PROVIDE SAME FOR NEW SERV. BLDG.
FENCE W/ INTERLOCKED RADIATION GATE
PROVIDE 20-5" PVC COMM. DUCTS FROM F-27 SERVICE BUILDING TO SB-3 ENCLOSURE
3'-0 WIDE CONC. STAIR W/ REMOVABLE 1½"ϕ PIPE HANDRAIL
ASB INJECTION
20 GEV P̄
PSB EXTRACTION
20 GEV P
9-PRECAST UNITS (8'W. x 8'H. x 8'LG.) = 72'
STRAIGHT
CAST IN PLACE = 206'
STRAIGHT
PROTON SUPER BOOSTER RING (PSB)
PRECAST UNITS
32'
24'
HOIST AREA
56'
53'
41'
BUMP-OUT ON NEAR WALL
P-300
X=100,440.798
Y= 97,650.000
TOP OF NEW BERM EL. 750'-0
TOP OF NEW BERM EL. 747'-0
EXISTING GRADE BEYOND BERM EL. 744'-0
WATERPROOF MEMBRANE
12"ϕ STD. STL. BEAM PIPE TO PSB RING
SB-2
BEAM EL. 729'-0
BASE SLAB EL. 726'-0
BASE SLAB EL. 723'-0
VB
LAM
SOLID SMOKE/VENTILATION BARRIER. EGRESS DOOR WILL BE PROVIDED
3'-0 WIDE CONCRETE STAIR W/ 1½"ϕ PIPE HANDRAIL (REMOVABLE)
FORK ON NEAR WALL OF ENCLOSURE LEADING TO PSB RING
PSB EXTRACTION
20 GEV P
ASB INJECTION
20 GEV P̄
PSB EXTRACTION
20 GEV P
EJECTION LAMBERTSON
X= 100,440.922
Y= 97,652.871
VIEW
SB-3
NORTH
KEY PLAN
REV. DATE DESCRIPTIONS
REVISIONS
DESIGNED
DRAWN J. T. HACKEMER
CHECKED
APPROVED
SUBMITTED
1/8"=1'-0" 0 4 8 12 16 20
Scale Feet
FERMI NATIONAL ACCELERATOR LABORATORY
UNITED STATES DEPARTMENT OF ENERGY
COLLIDER UPGRADE : 20 GEV RINGS
SB-3 LONGITUDINAL SECTION
DRAWING NO. 6-4-1
CDR-10
REV.
APRIL 1988





KEY PLAN

NORTH

1/8"=1'-0" SCALE FEET

REV.	DATE	DESCRIPTIONS
		REVISIONS

DESIGNED	
DRAWN	J.T. HACKEMER
CHECKED	
APPROVED	
SUBMITTED	

FERMI NATIONAL ACCELERATOR LABORATORY

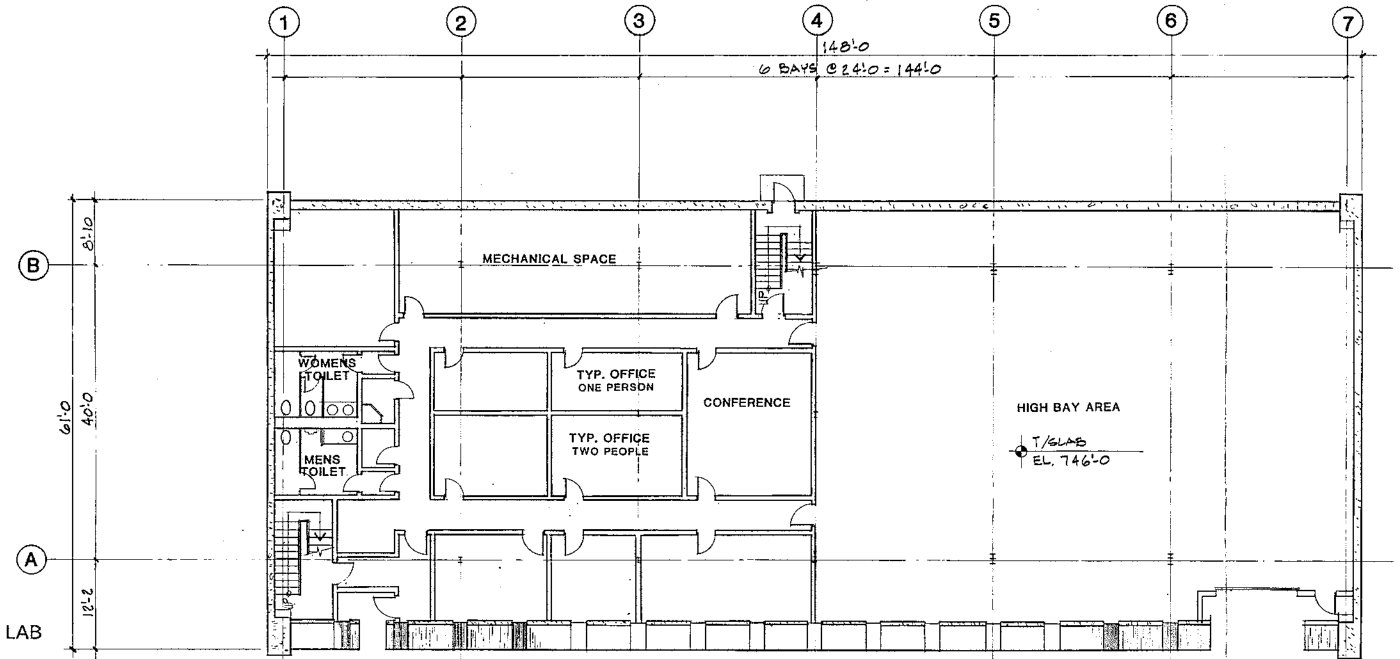
UNITED STATES DEPARTMENT OF ENERGY

COLLIDER UPGRADE 20 GEV RINGS

SB-4 LONGITUDINAL SECTION

APRIL 1988

DRAWING NO. 6-4-1 CDR-11 REV.

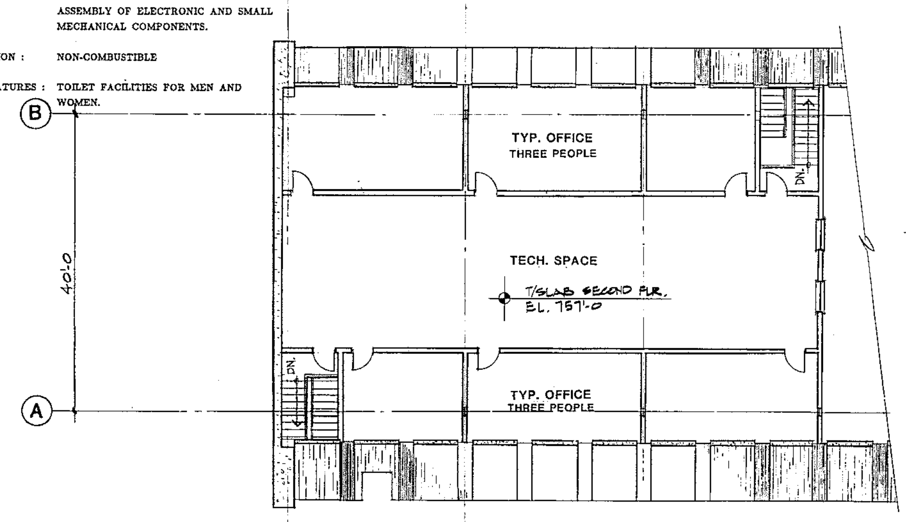


FIRST FLOOR PLAN

1/8" = 1'-0

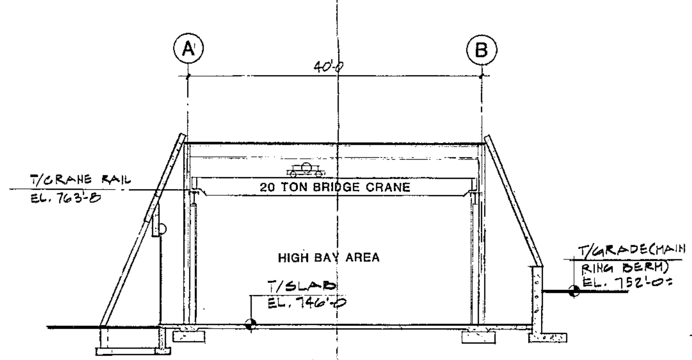
20 GEV LAB

MAIN FUNCTION :	HIGH BAY AREA WITH 20 TON CRANE COVERAGE WILL FUNCTION AS AN ASSEMBLY, TESTING AND REPAIR AREA FOR MAGNET COMPONENTS AND OTHER SCIENTIFIC EQUIPMENT. OFFICE AND CONFERENCE AREAS PROVIDED FOR THIRTY PERSONS. TECH. AREAS PROVIDED FOR ASSEMBLY OF ELECTRONIC AND SMALL MECHANICAL COMPONENTS.
CONSTRUCTION :	NON-COMBUSTIBLE
SPECIAL FEATURES :	TOILET FACILITIES FOR MEN AND WOMEN.



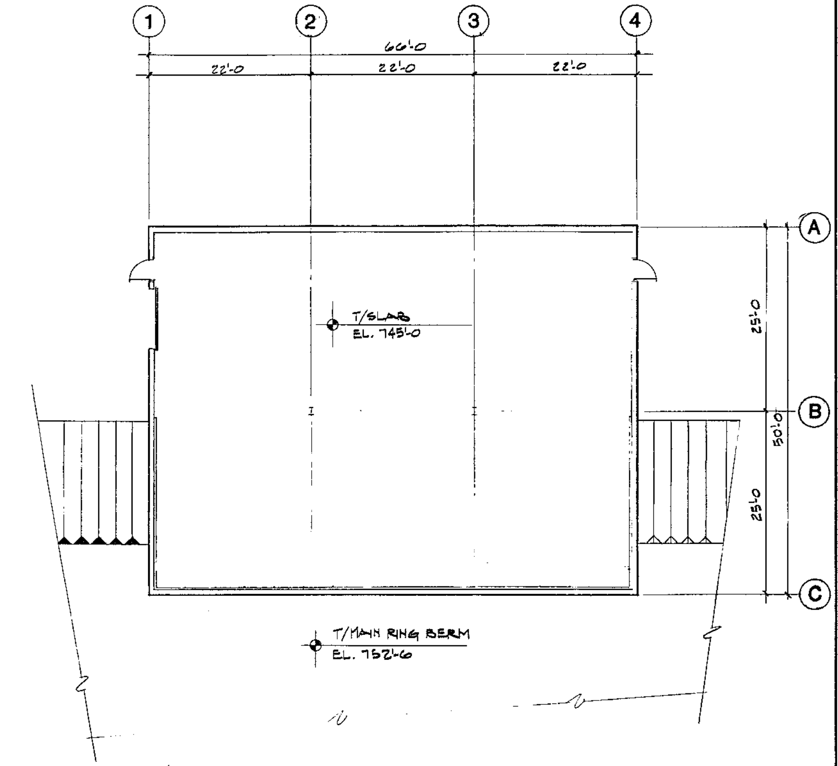
SECOND FLOOR PLAN

1/8" = 1'-0



SECTION

1/8" = 1'-0

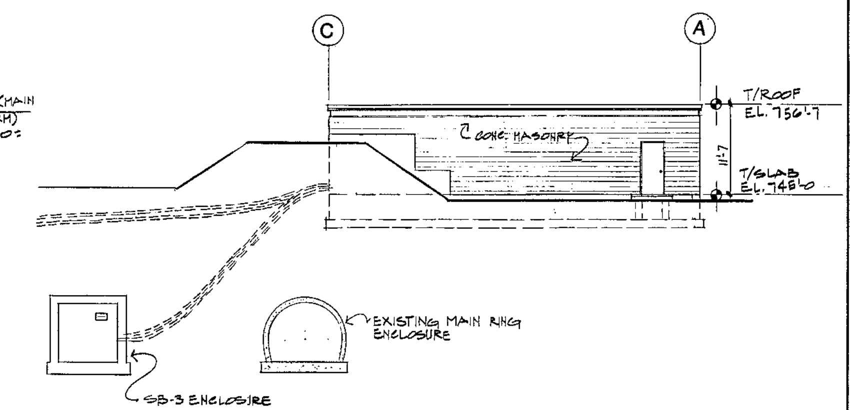


PLAN

1/8" = 1'-0

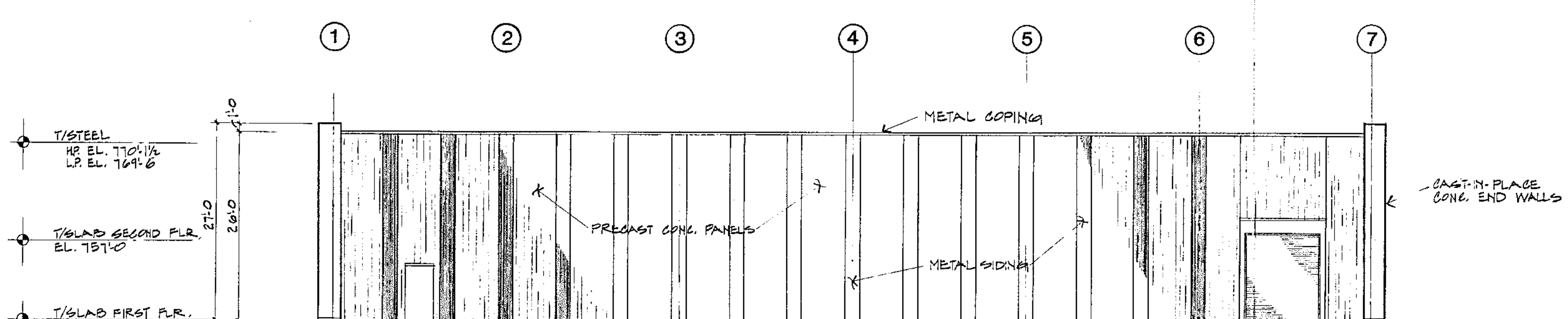
F-27 SERVICE BUILDING

MAIN FUNCTION :	HOUSE POWER SUPPLIES FOR NEW BEAM LINES(SB-1; SB-4)AND EXISTING ANTIPROTON TRANSPORT BEAMLINE.
CONSTRUCTION :	NON-COMBUSTIBLE



SOUTH ELEVATION

1/8" = 1'-0



FRONT ELEVATION

1/8" = 1'-0

NEW F-27 SERVICE BUILDING

20 GEV LAB

REV.	DATE	DESCRIPTIONS
		REVISIONS
DESIGNED		
DRAWN		
CHECKED		
APPROVED		
SUBMITTED		

PROJECT NORTH — E S W

1/8" = 1'-0" Scale 4 0 4 8 12 16 20 Feet

FERMI NATIONAL ACCELERATOR LABORATORY

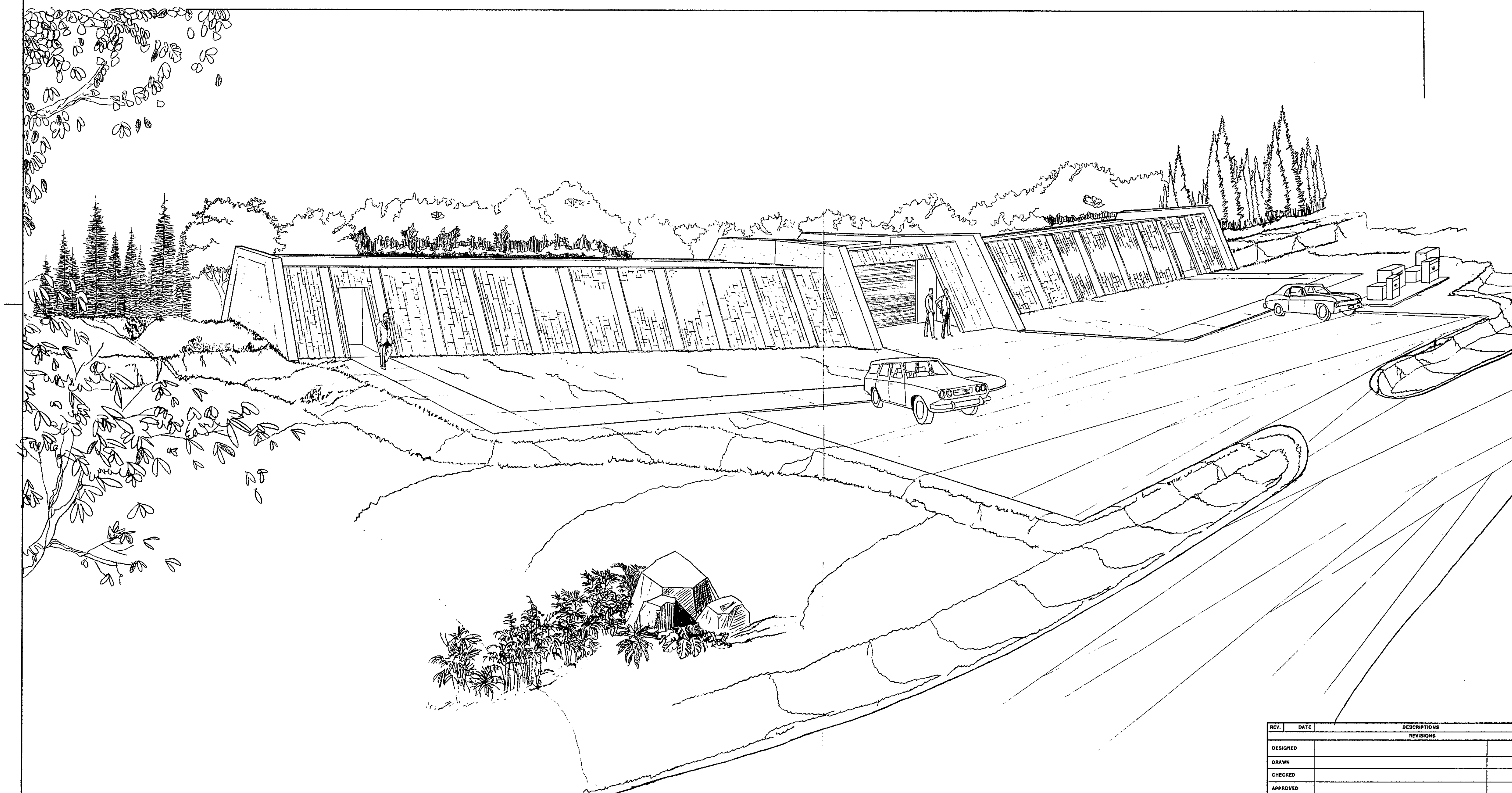
UNITED STATES DEPARTMENT OF ENERGY

COLLIDER UPGRADE: 20 GEV RINGS

LABORATORY BUILDING AND SERVICE BUILDING F-27

DRAWING NO. 6-4-1 CDR-12 REV.

APRIL 1988



REV.	DATE	DESCRIPTIONS
REVISIONS		
DESIGNED		
DRAWN		
CHECKED		
APPROVED		
SUBMITTED		

FERMI NATIONAL ACCELERATOR LABORATORY

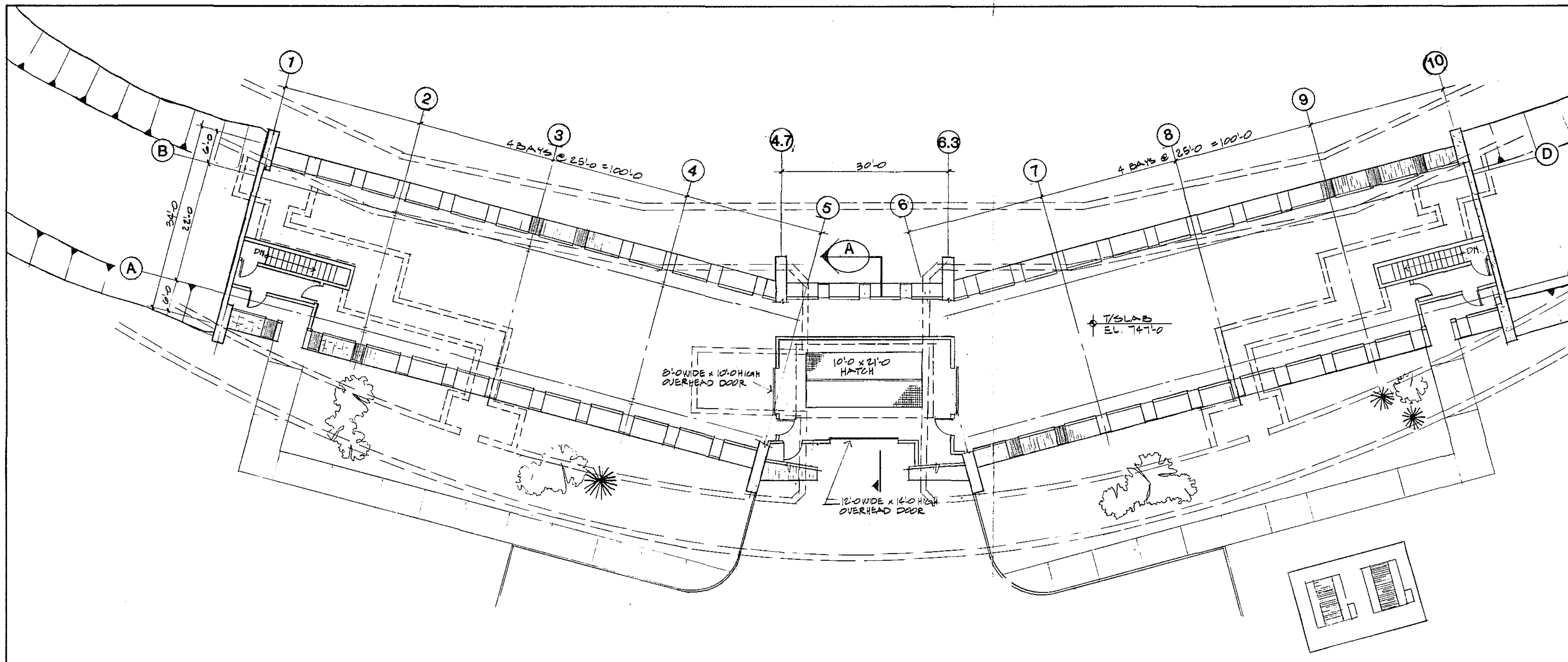
UNITED STATES DEPARTMENT OF ENERGY

COLLIDER UPGRADE: 20 GEV RINGS

TYPICAL SERVICE BUILDING PERSPECTIVE

APRIL 1988

DRAWING NO. 6-4-1 CDR-13 REV.



PLAN
1/8" = 1'-0

SERVICE BUILDING 200

MAIN FUNCTION : HOUSE POWER SUPPLIES AND OTHER SCIENTIFIC EQUIPMENT

OCCUPANCY : 10 TO 20 PERSONS DURING EQUIPMENT INSTALLATION; UNOCCUPIED DURING NORMAL BEAM ON CONDITIONS.

CONSTRUCTION : NON-COMBUSTIBLE

SPECIAL FEATURES: 7-1/2 TON BRIDGE CRANE WITH CRANE COVERAGE OVER HATCH

SERVICE BUILDING 400

MAIN FUNCTIONS : -HOUSE POWER SUPPLIES AND OTHER SCIENTIFIC EQUIPMENT.
-WEST 1/2 OF BUILDING WILL CONTAIN PROCESS WATER SYSTEMS

OCCUPANCY : 10 TO 20 PERSONS DURING EQUIPMENT INSTALLATION; UNOCCUPIED DURING NORMAL BEAM ON CONDITIONS.

CONSTRUCTION : NON-COMBUSTIBLE

SPECIAL FEATURES : 7-1/2 TON BRIDGE CRANE WITH COVERAGE OVER HATCH.

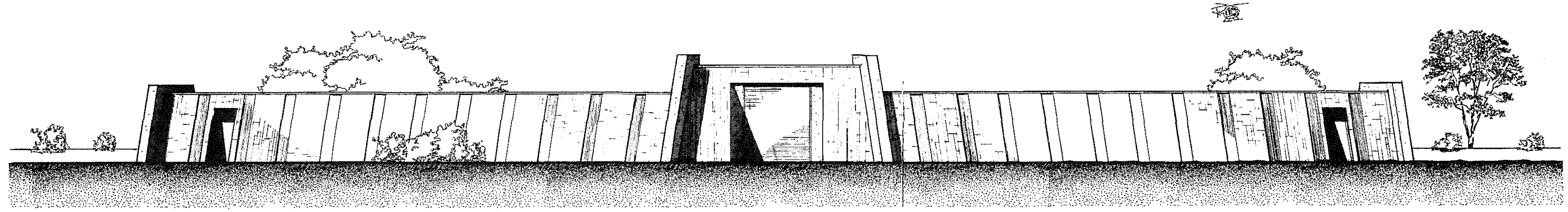
SERVICE BUILDING 600

MAIN FUNCTIONS : APPROX. 1/3 OF BUILDING WILL BE USED TO HOUSE THE CONTROL FACILITY FOR THE 20 GEV RINGS; THE REMAINDER OF THE BUILDING WILL HOUSE POWER SUPPLIES AND OTHER SCIENTIFIC EQUIPMENT.

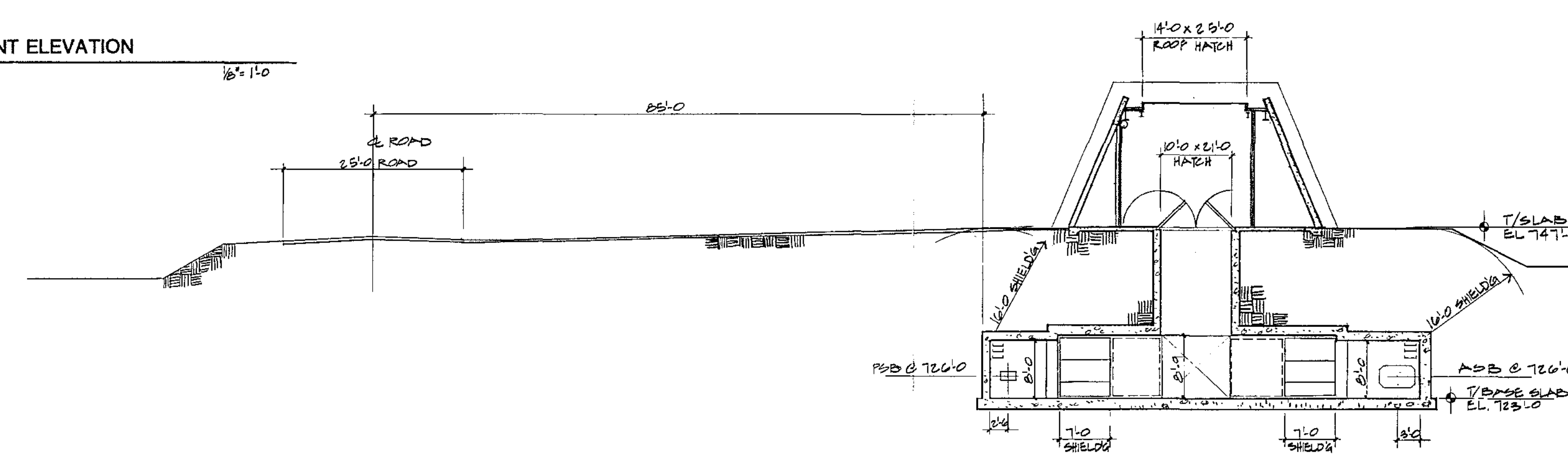
OCCUPANCY : 10 TO 30 PERSONS DURING EQUIPMENT INSTALLATIONS; 5 TO 10 PERSONS DURING BEAM OPERATIONS-3 SHIFTS PER DAY.

CONSTRUCTION : NON-COMBUSTIBLE

SPECIAL FEATURES : 7-1/2 TON BRIDGE CRANE WITH COVERAGE OVER HATCH.
18" HIGH RAISED ACCESS FLOOR UNDER CONTROL ROOM AREA.
TOILET FACILITY



FRONT ELEVATION
1/8" = 1'-0



SECTION (A)
1/8" = 1'-0

1/8"=1'-0 4 0 4 8 12 16 20 SCALE FEET

REV.	DATE	DESCRIPTIONS
		REVISIONS

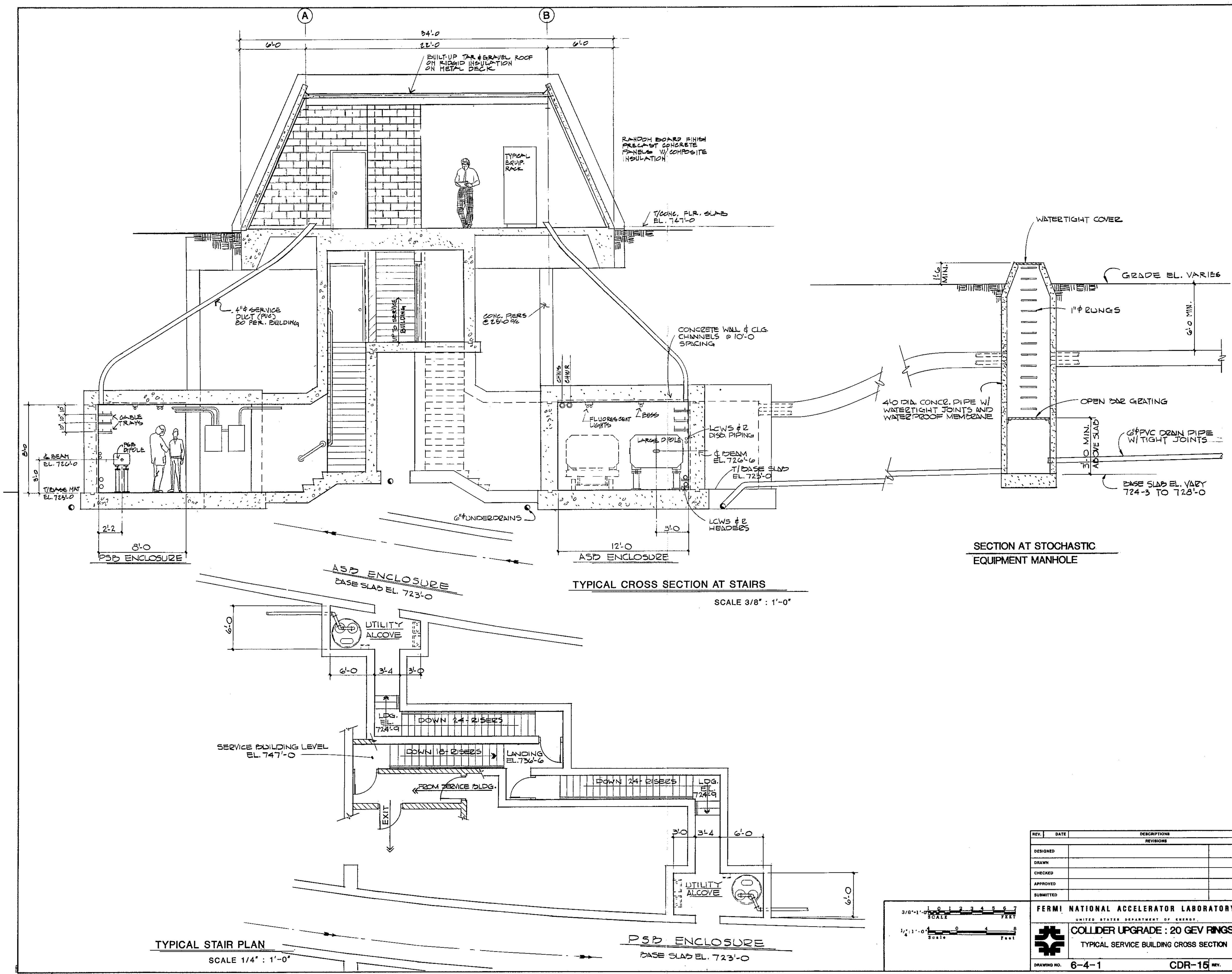
DESIGNED	T. LACKOWSKI	
DRAWN	T. LACKOWSKI	
CHECKED		
APPROVED		
SUBMITTED		

FERMI NATIONAL ACCELERATOR LABORATORY
UNITED STATES DEPARTMENT OF ENERGY

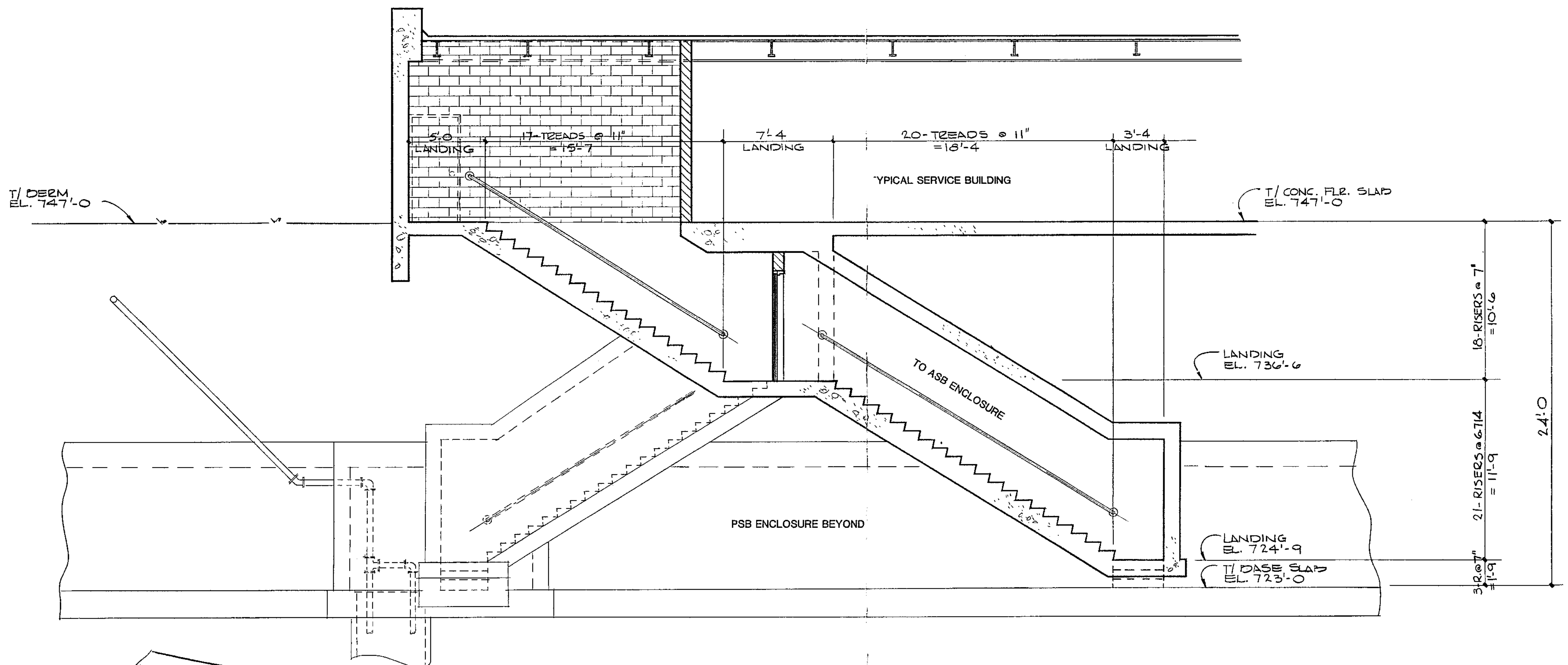
COLLIDER UPGRADE: 20 GEV RINGS
TYPICAL SERVICE BUILDING PLAN AND ELEVATION

APRIL 1988

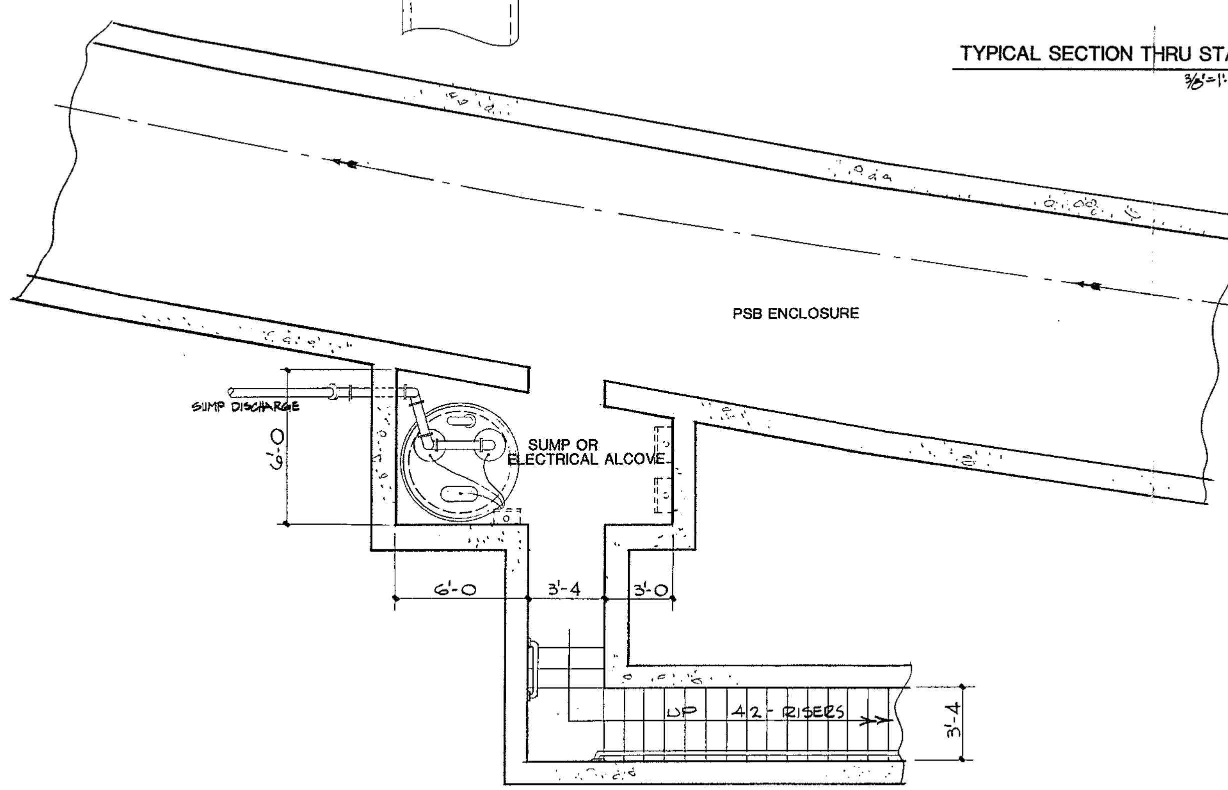
DRAWING NO. 6-4-1 CDR-14 REV.



34'-0
6'-0
22'-0
6'-0
BUILT-UP TAR & GRAVEL ROOF ON RIGID INSULATION ON METAL DECK
RANDOM BOARD FINISH PRECAST CONCRETE PANELS W/ COMPOSITE INSULATION
TYPICAL EQUIP. RACK
T/CONC. FLR. SLAB EL. 747'-0
4"ϕ SERVICE DUCT (PVC) 80 PER. BUILDING
UP TO SERVICE BUILDING
CONC. PIERS @ 25'-0 o/c
CONCRETE WALL & CLG. CHANNELS @ 10'-0 SPACING
CABLE TRAYS
PSB DIPOLE
℄ BEAM EL. 726'-0
T/BASE MAT EL. 723'-0
FLUORESCENT LIGHTS
BUSS
LCWS & R DIST. PIPING
LARGE DIPOLE
℄ BEAM EL. 726'-6
T/BASE SLAB EL. 723'-0
6" UNDERDRAINS
LCWS & R HEADERS
2'-2
8'-0
PSB ENCLOSURE
12'-0
3'-0
ASB ENCLOSURE
WATERTIGHT COVER
GRADE EL. VARIES
1" ϕ RUNGS
6'-0 MIN.
4'-0 DIA. CONC. PIPE W/ WATERTIGHT JOINTS AND WATERPROOF MEMBRANE
OPEN BAR GRATING
6" ϕ PVC DRAIN PIPE W/ TIGHT JOINTS
3'-0 MIN. ABOVE SLAB
BASE SLAB EL. VARY 724-3 TO 728'-0
SECTION AT STOCHASTIC EQUIPMENT MANHOLE
TYPICAL CROSS SECTION AT STAIRS
SCALE 3/8" : 1'-0"
ASB ENCLOSURE
BASE SLAB EL. 723'-0
UTILITY ALCOVE
6'-0
3'-4
3'-0
LDG. EL. 724'-9
DOWN 24 RISERS
SERVICE BUILDING LEVEL EL. 747'-0
DOWN 18 RISERS
LANDING EL. 736'-6
FROM SERVICE BLDG.
EXIT
DOWN 24 RISERS
LDG. EL. 724'-9
3'-0
3'-4
6'-0
UTILITY ALCOVE
6'-0
TYPICAL STAIR PLAN
SCALE 1/4" : 1'-0"
PSB ENCLOSURE
BASE SLAB EL. 723'-0
REV. DATE DESCRIPTIONS
REVISIONS
DESIGNED
DRAWN
CHECKED
APPROVED
SUBMITTED
3/8"=1'-0" SCALE FEET
1/4"=1'-0" Scale Feet
FERMI NATIONAL ACCELERATOR LABORATORY
UNITED STATES DEPARTMENT OF ENERGY
COLLIDER UPGRADE : 20 GEV RINGS
TYPICAL SERVICE BUILDING CROSS SECTION
APRIL 1985
DRAWING NO. 6-4-1
CDR-15 REV.



TYPICAL SECTION THRU STAIR
3/8"=1'-0



PLAN DETAIL AT UTILITY ALCOVE
3/8"=1'-0

REV.	DATE	DESCRIPTIONS
		REVISIONS

DESIGNED		
DRAWN	JTH	2/19/88
CHECKED		
APPROVED		
SUBMITTED		

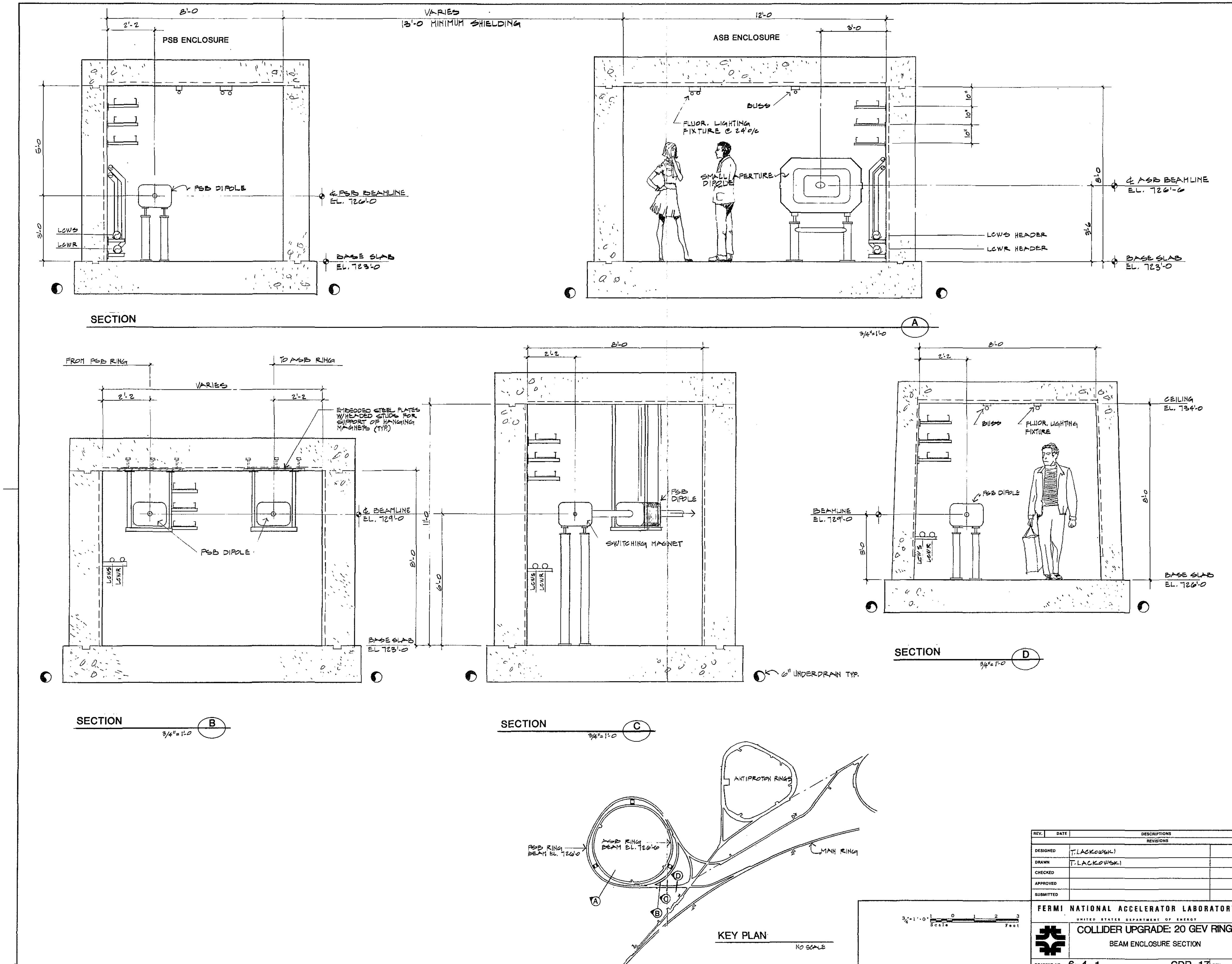
3/8"=1'-0" 1 0 1 2 3 4 5 6 7 Scale Feet

FERMI NATIONAL ACCELERATOR LABORATORY
UNITED STATES DEPARTMENT OF ENERGY

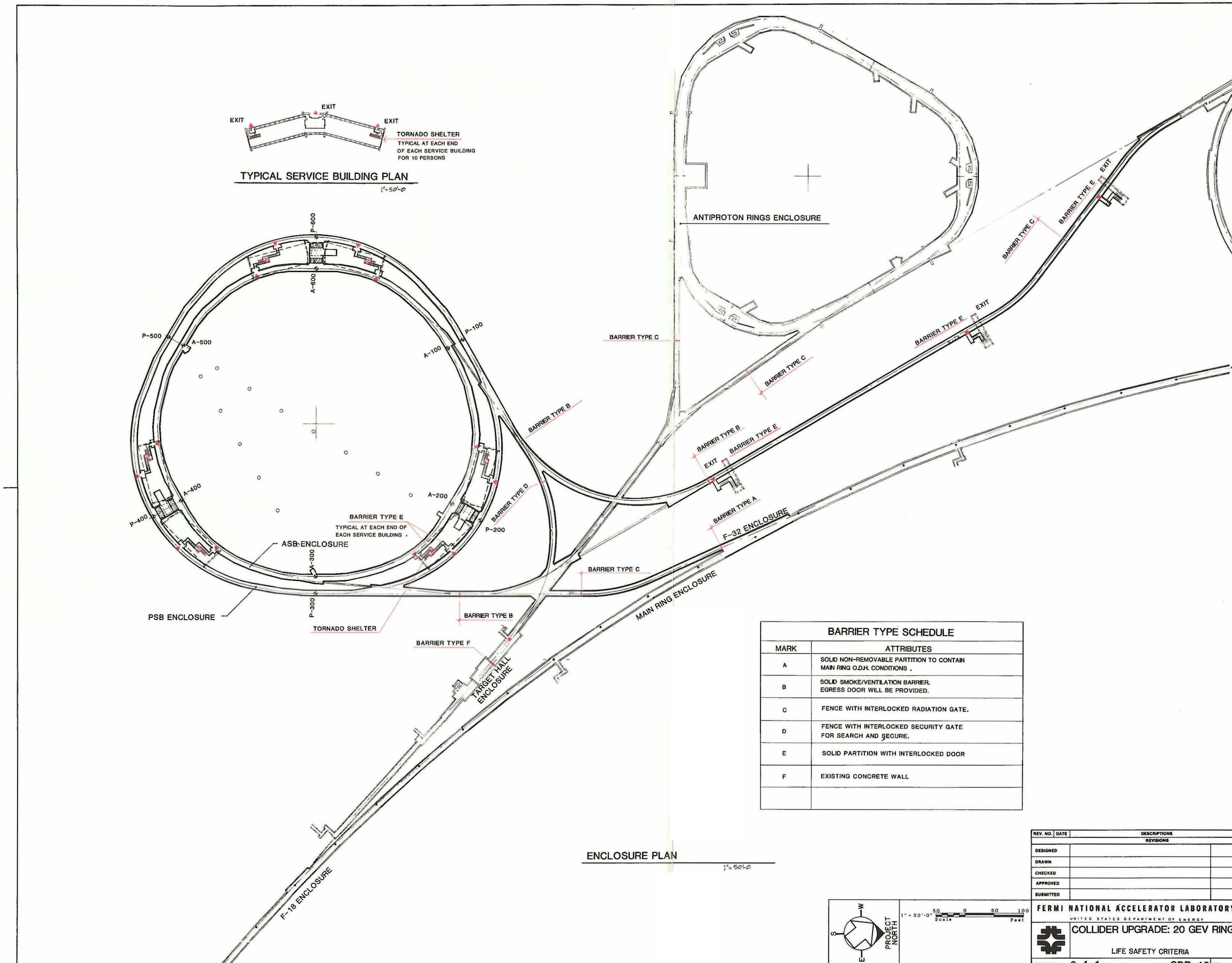
COLLIDER UPGRADE: 20 GEV RINGS
TYPICAL SERVICE BUILDING STAIR SECTION

DRAWING NO. 6-4-1 CDR-16 REV.

APRIL 1988



PSB ENCLOSURE
ASB ENCLOSURE
VARIES
13'-0 MINIMUM SHIELDING
PSB DIPOLE
℄ PSB BEAMLINE EL. 726'-0
BASE SLAB EL. 723'-0
LCWS
LCWR
FLUOR. LIGHTING FIXTURE @ 24' o/c
BUSS
SMALL APERTURE DIPOLE
℄ ASB BEAMLINE EL. 726'-6
LCWS HEADER
LCWR HEADER
SECTION A 3/4"=1'-0
FROM PSB RING
TO ASB RING
EMBEDDED STEEL PLATES W/HEADED STUDS FOR SUPPORT OF HANGING MAGNETS (TYP.)
℄ BEAMLINE EL. 729'-0
SWITCHING MAGNET
6" UNDERDRAIN TYP.
CEILING EL. 734'-0
FLUOR. LIGHTING FIXTURE
BEAMLINE EL. 729'-0
BASE SLAB EL. 726'-0
SECTION B 3/4"=1'-0
SECTION C 3/4"=1'-0
SECTION D 3/4"=1'-0
ANTIPROTON RINGS
PSB RING BEAM EL. 726'-0
ASB RING BEAM EL. 726'-6
MAIN RING
KEY PLAN
NO SCALE
DESIGNED T. LACKOWSKI
DRAWN T. LACKOWSKI
CHECKED
APPROVED
SUBMITTED
FERMI NATIONAL ACCELERATOR LABORATORY
UNITED STATES DEPARTMENT OF ENERGY
COLLIDER UPGRADE: 20 GEV RINGS
BEAM ENCLOSURE SECTION
DRAWING NO. 6-4-1
CDR-17
APRIL 1988



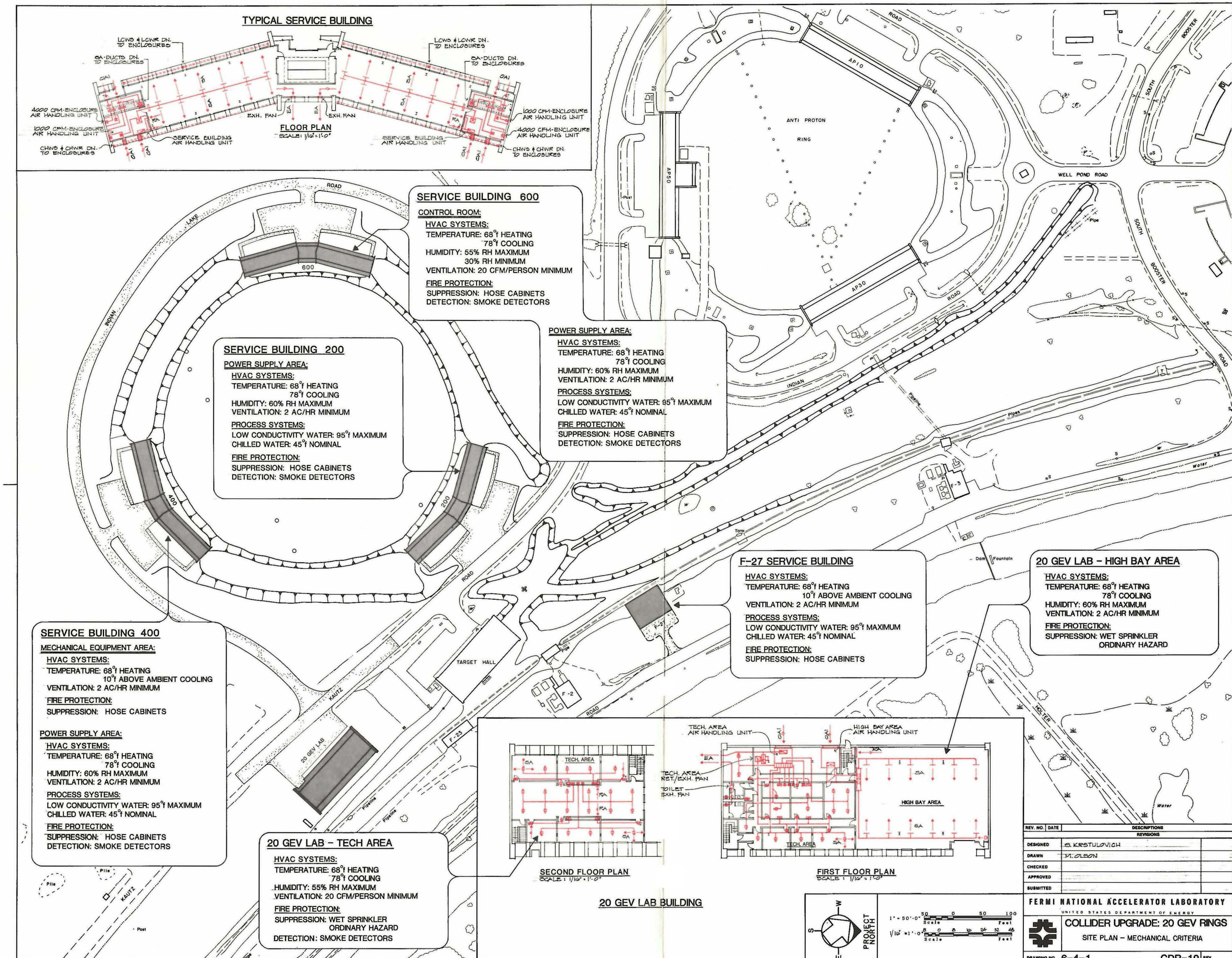
BARRIER TYPE SCHEDULE

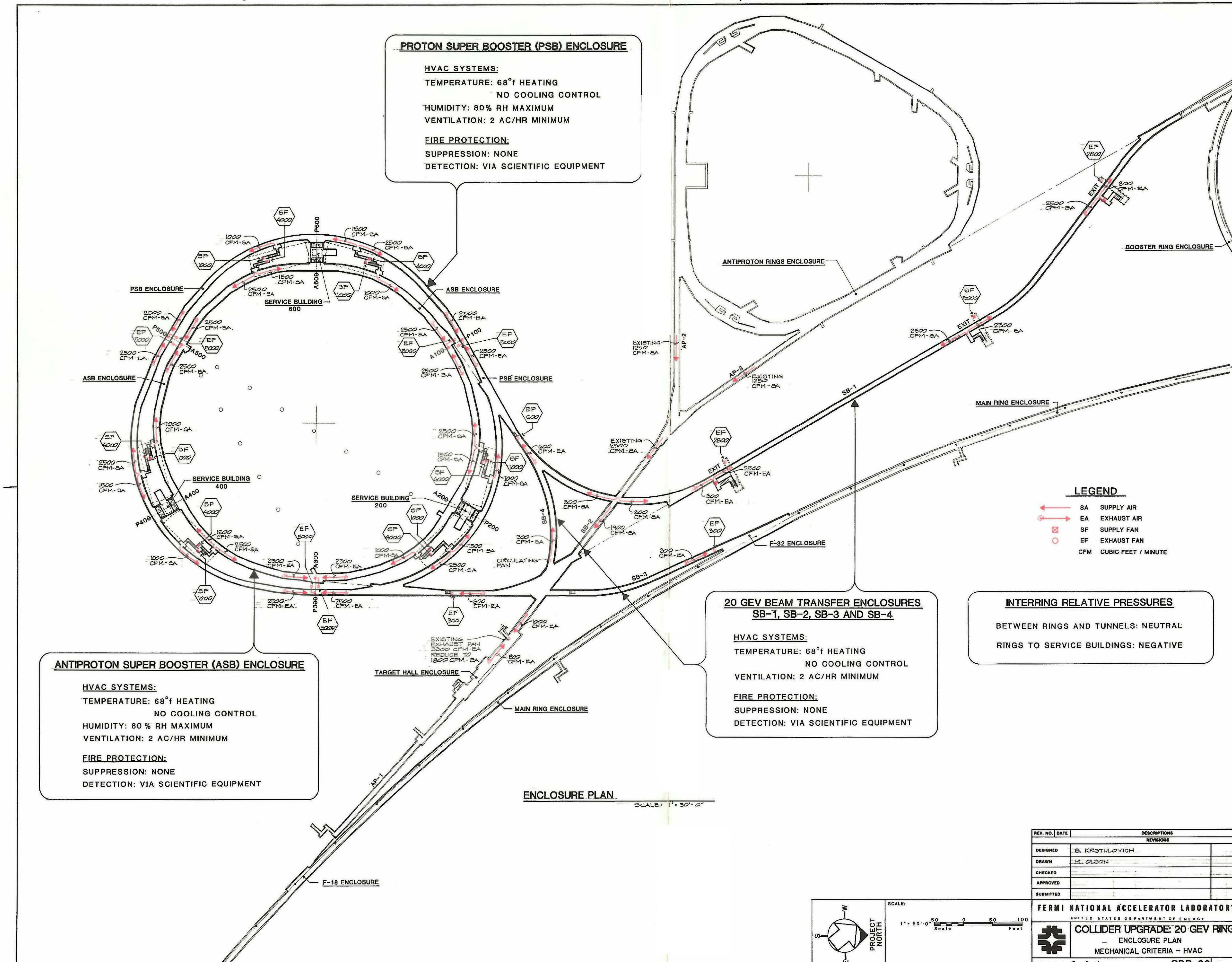
MARK	ATTRIBUTES
A	SOLID NON-REMOVABLE PARTITION TO CONTAIN MAIN RING O.D.H. CONDITIONS .
B	SOLID SMOKE/VENTILATION BARRIER. EGRESS DOOR WILL BE PROVIDED.
C	FENCE WITH INTERLOCKED RADIATION GATE.
D	FENCE WITH INTERLOCKED SECURITY GATE FOR SEARCH AND SECURE.
E	SOLID PARTITION WITH INTERLOCKED DOOR
F	EXISTING CONCRETE WALL

REV. NO.	DATE	DESCRIPTIONS
		REVISIONS

DESIGNED
DRAWN
CHECKED
APPROVED
SUBMITTED

FERMI NATIONAL ACCELERATOR LABORATORY
UNITED STATES DEPARTMENT OF ENERGY
COLLIDER UPGRADE: 20 GEV RINGS
LIFE SAFETY CRITERIA
DRAWING NO. 6-4-1 CDR-18 REV.
APRIL 1988


TYPICAL SERVICE BUILDING
FLOOR PLAN
SCALE: 1/16"=1'-0"
ANTI PROTON RING
AP10
AP30
AP50
WELL POND ROAD
SOUTH BOOSTER
INDIAN
LAKE
ROAD
KAUTZ
TARGET HALL
20 GEV LAB
600
400
200
F-27
F-23
F-2
F-3
SERVICE BUILDING 600
CONTROL ROOM:
HVAC SYSTEMS:
TEMPERATURE: 68°f HEATING
78°f COOLING
HUMIDITY: 55% RH MAXIMUM
30% RH MINIMUM
VENTILATION: 20 CFM/PERSON MINIMUM
FIRE PROTECTION:
SUPPRESSION: HOSE CABINETS
DETECTION: SMOKE DETECTORS
POWER SUPPLY AREA:
HVAC SYSTEMS:
TEMPERATURE: 68°f HEATING
78°f COOLING
HUMIDITY: 60% RH MAXIMUM
VENTILATION: 2 AC/HR MINIMUM
PROCESS SYSTEMS:
LOW CONDUCTIVITY WATER: 95°f MAXIMUM
CHILLED WATER: 45°f NOMINAL
FIRE PROTECTION:
SUPPRESSION: HOSE CABINETS
DETECTION: SMOKE DETECTORS
SERVICE BUILDING 200
POWER SUPPLY AREA:
HVAC SYSTEMS:
TEMPERATURE: 68°f HEATING
78°f COOLING
HUMIDITY: 60% RH MAXIMUM
VENTILATION: 2 AC/HR MINIMUM
PROCESS SYSTEMS:
LOW CONDUCTIVITY WATER: 95°f MAXIMUM
CHILLED WATER: 45°f NOMINAL
FIRE PROTECTION:
SUPPRESSION: HOSE CABINETS
DETECTION: SMOKE DETECTORS
F-27 SERVICE BUILDING
HVAC SYSTEMS:
TEMPERATURE: 68°f HEATING
10°f ABOVE AMBIENT COOLING
VENTILATION: 2 AC/HR MINIMUM
PROCESS SYSTEMS:
LOW CONDUCTIVITY WATER: 95°f MAXIMUM
CHILLED WATER: 45°f NOMINAL
FIRE PROTECTION:
SUPPRESSION: HOSE CABINETS
20 GEV LAB - HIGH BAY AREA
HVAC SYSTEMS:
TEMPERATURE: 68°f HEATING
78°f COOLING
HUMIDITY: 60% RH MAXIMUM
VENTILATION: 2 AC/HR MINIMUM
FIRE PROTECTION:
SUPPRESSION: WET SPRINKLER
ORDINARY HAZARD
SERVICE BUILDING 400
MECHANICAL EQUIPMENT AREA:
HVAC SYSTEMS:
TEMPERATURE: 68°f HEATING
10°f ABOVE AMBIENT COOLING
VENTILATION: 2 AC/HR MINIMUM
FIRE PROTECTION:
SUPPRESSION: HOSE CABINETS
POWER SUPPLY AREA:
HVAC SYSTEMS:
TEMPERATURE: 68°f HEATING
78°f COOLING
HUMIDITY: 60% RH MAXIMUM
VENTILATION: 2 AC/HR MINIMUM
PROCESS SYSTEMS:
LOW CONDUCTIVITY WATER: 95°f MAXIMUM
CHILLED WATER: 45°f NOMINAL
FIRE PROTECTION:
SUPPRESSION: HOSE CABINETS
DETECTION: SMOKE DETECTORS
20 GEV LAB - TECH AREA
HVAC SYSTEMS:
TEMPERATURE: 68°f HEATING
78°f COOLING
HUMIDITY: 55% RH MAXIMUM
VENTILATION: 20 CFM/PERSON MINIMUM
FIRE PROTECTION:
SUPPRESSION: WET SPRINKLER
ORDINARY HAZARD
DETECTION: SMOKE DETECTORS
TECH. AREA AIR HANDLING UNIT
HIGH BAY AREA AIR HANDLING UNIT
TECH. AREA RET./EXH. FAN
TOILET EXH. FAN
HIGH BAY AREA
TECH AREA
SECOND FLOOR PLAN
FIRST FLOOR PLAN
20 GEV LAB BUILDING
PROJECT NORTH
REV. NO.
DATE
DESCRIPTIONS
REVISIONS
DESIGNED
DRAWN
CHECKED
APPROVED
SUBMITTED
FERMI NATIONAL ACCELERATOR LABORATORY
UNITED STATES DEPARTMENT OF ENERGY
COLLIDER UPGRADE: 20 GEV RINGS
SITE PLAN - MECHANICAL CRITERIA
DRAWING NO. 6-4-1
CDR-19
APRIL 1988



PROTON SUPER BOOSTER (PSB) ENCLOSURE

HVAC SYSTEMS:

TEMPERATURE: 68°f HEATING
NO COOLING CONTROL

HUMIDITY: 80% RH MAXIMUM

VENTILATION: 2 AC/HR MINIMUM

FIRE PROTECTION:

SUPPRESSION: NONE

DETECTION: VIA SCIENTIFIC EQUIPMENT

ANTIPROTON SUPER BOOSTER (ASB) ENCLOSURE

HVAC SYSTEMS:

TEMPERATURE: 68°f HEATING
NO COOLING CONTROL

HUMIDITY: 80 % RH MAXIMUM

VENTILATION: 2 AC/HR MINIMUM

FIRE PROTECTION:

SUPPRESSION: NONE

DETECTION: VIA SCIENTIFIC EQUIPMENT

20 GEV BEAM TRANSFER ENCLOSURES SB-1, SB-2, SB-3 AND SB-4

HVAC SYSTEMS:

TEMPERATURE: 68°f HEATING
NO COOLING CONTROL

VENTILATION: 2 AC/HR MINIMUM

FIRE PROTECTION:

SUPPRESSION: NONE

DETECTION: VIA SCIENTIFIC EQUIPMENT

INTERRING RELATIVE PRESSURES

BETWEEN RINGS AND TUNNELS: NEUTRAL

RINGS TO SERVICE BUILDINGS: NEGATIVE

REV. NO.	DATE	DESCRIPTIONS / REVISIONS

DESIGNED: B. KRSTULOVICH
DRAWN: M. OLSON
CHECKED:
APPROVED:
SUBMITTED:

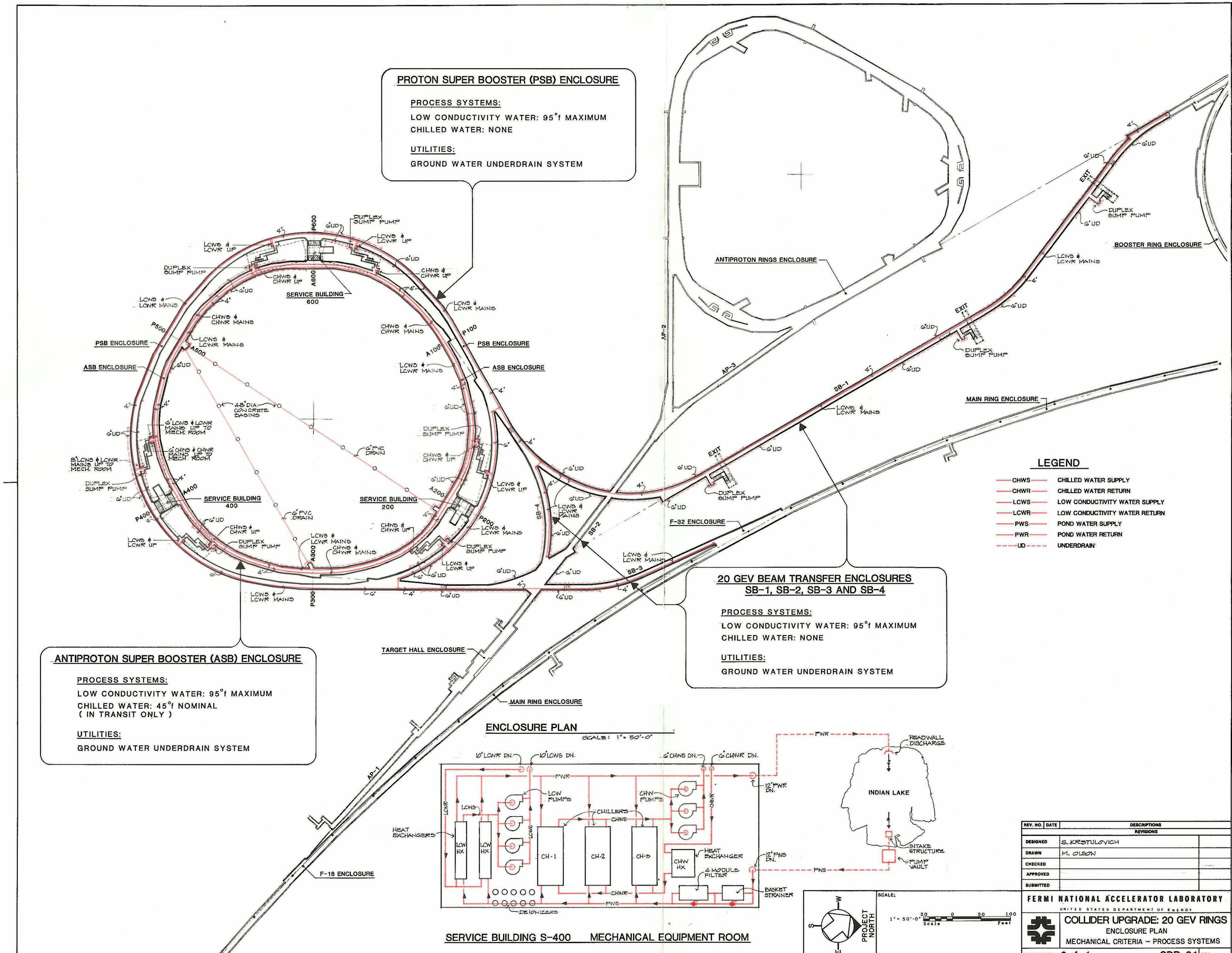
FERMI NATIONAL ACCELERATOR LABORATORY
UNITED STATES DEPARTMENT OF ENERGY

COLLIDER UPGRADE: 20 GEV RINGS
ENCLOSURE PLAN
MECHANICAL CRITERIA – HVAC

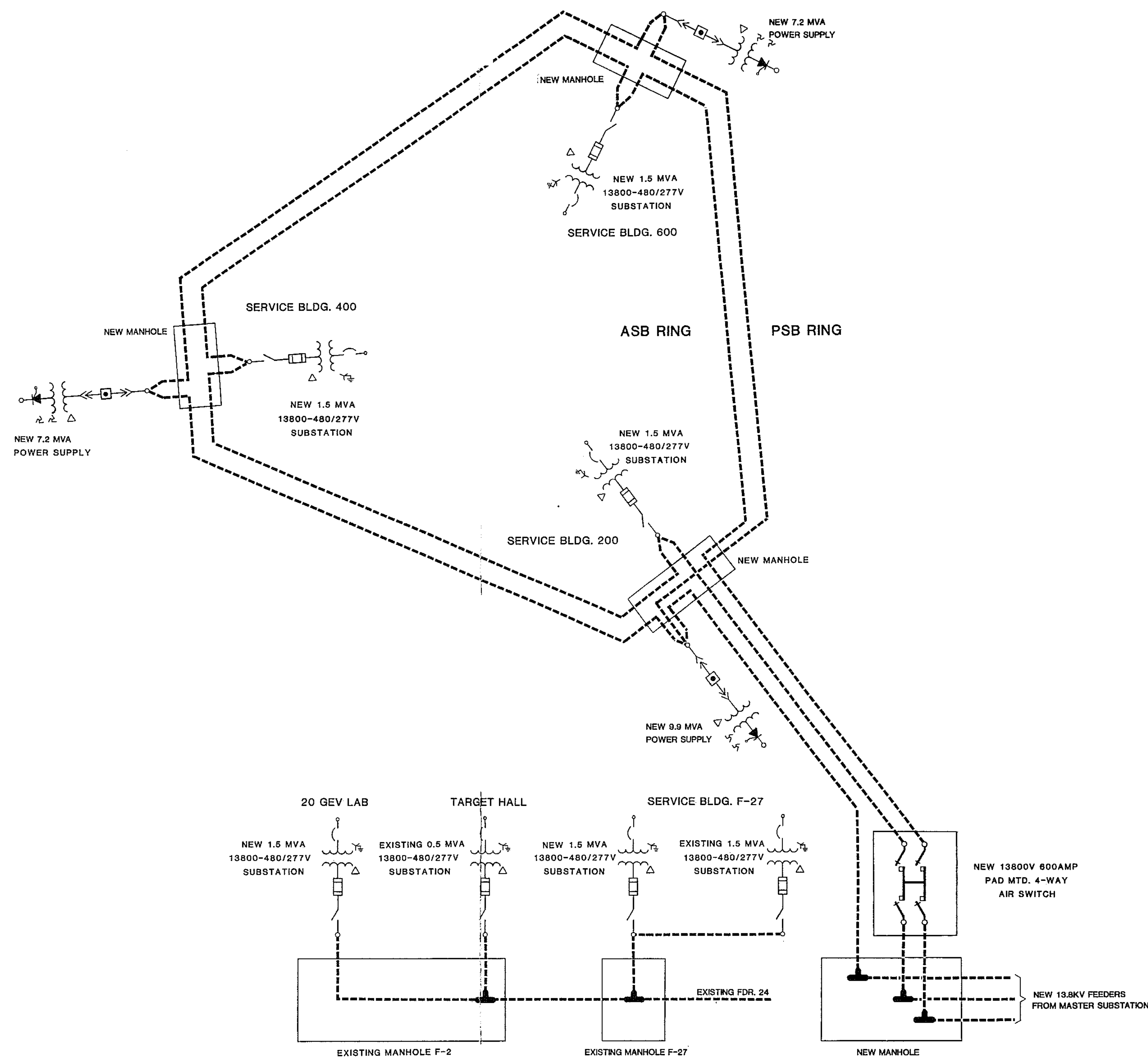
SCALE: 1" = 50'-0"

APRIL 1988

DRAWING NO. 6-4-1   CDR-20   REV.



PROTON SUPER BOOSTER (PSB) ENCLOSURE
PROCESS SYSTEMS:
LOW CONDUCTIVITY WATER: 95°f MAXIMUM
CHILLED WATER: NONE
UTILITIES:
GROUND WATER UNDERDRAIN SYSTEM
ANTIPROTON SUPER BOOSTER (ASB) ENCLOSURE
PROCESS SYSTEMS:
LOW CONDUCTIVITY WATER: 95°f MAXIMUM
CHILLED WATER: 45°f NOMINAL
(IN TRANSIT ONLY)
UTILITIES:
GROUND WATER UNDERDRAIN SYSTEM
20 GEV BEAM TRANSFER ENCLOSURES
SB-1, SB-2, SB-3 AND SB-4
PROCESS SYSTEMS:
LOW CONDUCTIVITY WATER: 95°f MAXIMUM
CHILLED WATER: NONE
UTILITIES:
GROUND WATER UNDERDRAIN SYSTEM
SERVICE BUILDING 600
SERVICE BUILDING 400
SERVICE BUILDING 200
PSB ENCLOSURE
ASB ENCLOSURE
ANTIPROTON RINGS ENCLOSURE
BOOSTER RING ENCLOSURE
MAIN RING ENCLOSURE
F-32 ENCLOSURE
TARGET HALL ENCLOSURE
F-18 ENCLOSURE
AP-1
AP-2
AP-3
SB-1
SB-2
SB-3
SB-4
48" DIA. CONCRETE BASINS
DUPLEX SUMP PUMP
LCWS & LCWR MAINS
CHWS & CHWR MAINS
EXIT
LEGEND
CHWS — CHILLED WATER SUPPLY
CHWR — CHILLED WATER RETURN
LCWS — LOW CONDUCTIVITY WATER SUPPLY
LCWR — LOW CONDUCTIVITY WATER RETURN
PWS — POND WATER SUPPLY
PWR — POND WATER RETURN
UD — UNDERDRAIN
ENCLOSURE PLAN
SCALE: 1" = 50'-0"
HEAT EXCHANGERS
LCW PUMPS
CHW PUMPS
CHILLERS
CH-1
CH-2
CH-3
CHW HX
HEAT EXCHANGER
4 MODULE FILTER
BASKET STRAINER
DEIONIZERS
INDIAN LAKE
HEADWALL DISCHARGE
INTAKE STRUCTURE
PUMP VAULT
SERVICE BUILDING S-400 MECHANICAL EQUIPMENT ROOM
PROJECT NORTH
SCALE: 1" = 50'-0"
Feet
REV. NO. | DATE | DESCRIPTIONS
REVISIONS
DESIGNED S. KRSTULOVICH
DRAWN M. OLSON
CHECKED
APPROVED
SUBMITTED
FERMI NATIONAL ACCELERATOR LABORATORY
UNITED STATES DEPARTMENT OF ENERGY
COLLIDER UPGRADE: 20 GEV RINGS
ENCLOSURE PLAN
MECHANICAL CRITERIA – PROCESS SYSTEMS
DRAWING NO. 6-4-1 CDR-21 REV.
APRIL 1988



REV.	DATE	DESCRIPTIONS
		REVISIONS

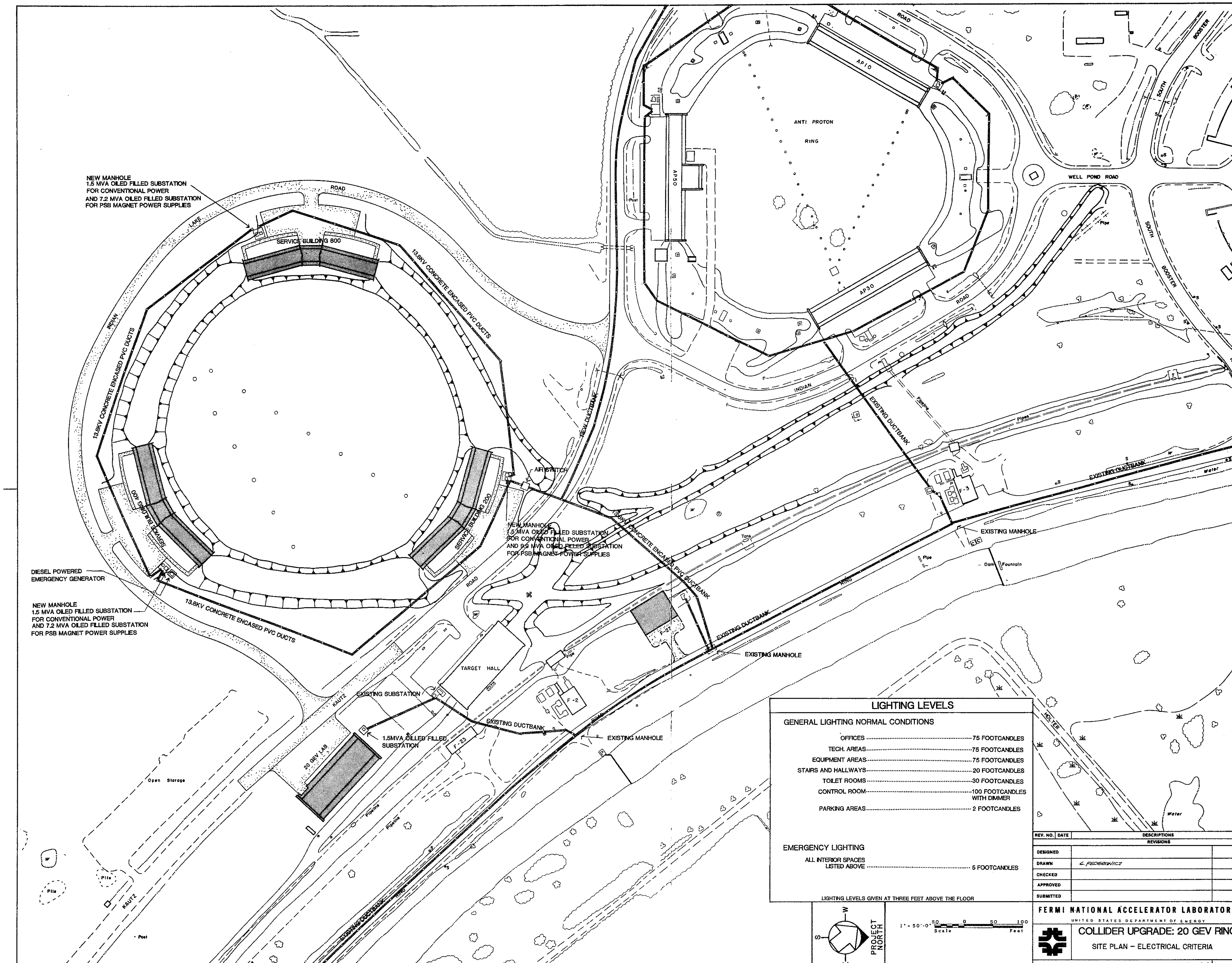
DESIGNED	E.VALDES
DRAWN	E.VALDES /A.R.FLOWERS
CHECKED	
APPROVED	
SUBMITTED	

FERMI NATIONAL ACCELERATOR LABORATORY
UNITED STATES DEPARTMENT OF ENERGY

COLLIDER UPGRADE : 20 GEV RINGS
RINGS SINGLE LINE POWER DIAGRAM

APRIL 1988

DRAWING NO. 6-4-1 CDR-22 REV.



LIGHTING LEVELS

GENERAL LIGHTING NORMAL CONDITIONS

OFFICES	75 FOOTCANDLES
TECH. AREAS	75 FOOTCANDLES
EQUIPMENT AREAS	75 FOOTCANDLES
STAIRS AND HALLWAYS	20 FOOTCANDLES
TOILET ROOMS	30 FOOTCANDLES
CONTROL ROOM	100 FOOTCANDLES WITH DIMMER
PARKING AREAS	2 FOOTCANDLES

EMERGENCY LIGHTING

ALL INTERIOR SPACES LISTED ABOVE	5 FOOTCANDLES

LIGHTING LEVELS GIVEN AT THREE FEET ABOVE THE FLOOR

REV. NO.	DATE	DESCRIPTIONS
		REVISIONS

DESIGNED	
DRAWN	C. FEDEROWICZ
CHECKED	
APPROVED	
SUBMITTED	

PROJECT NORTH

1" = 50'-0" Scale 50 0 50 100 Feet

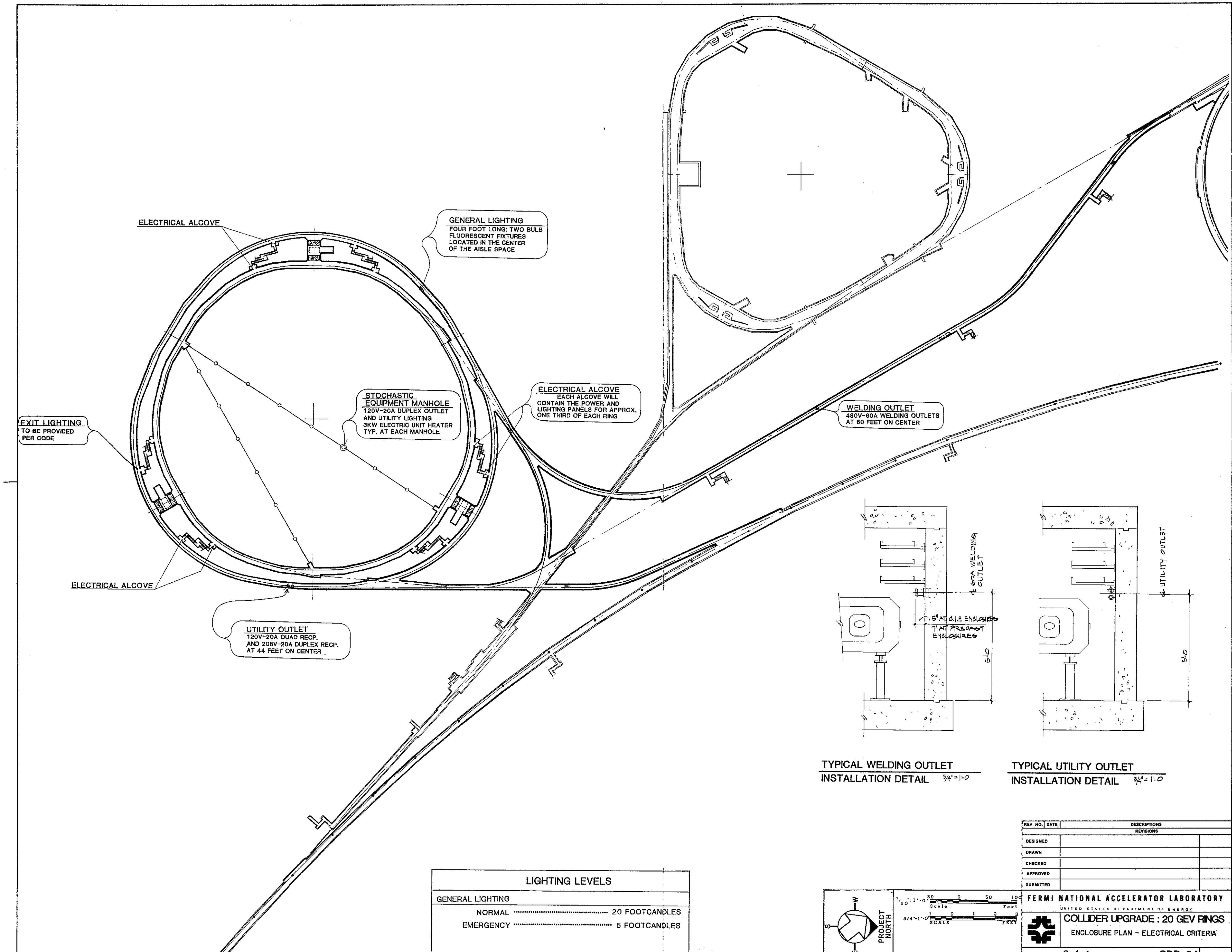
FERMI NATIONAL ACCELERATOR LABORATORY
UNITED STATES DEPARTMENT OF ENERGY

COLLIDER UPGRADE: 20 GEV RINGS

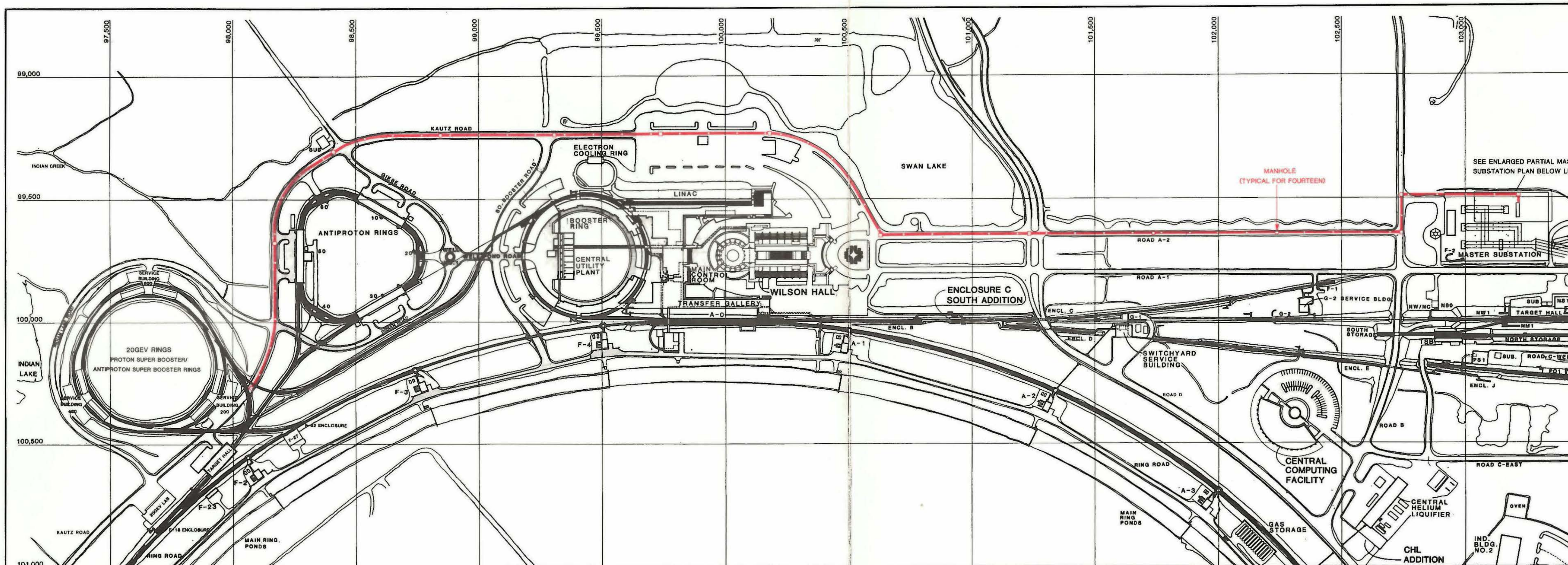
SITE PLAN – ELECTRICAL CRITERIA

DRAWING NO. 6-4-1 CDR-23 REV.

APRIL 1988

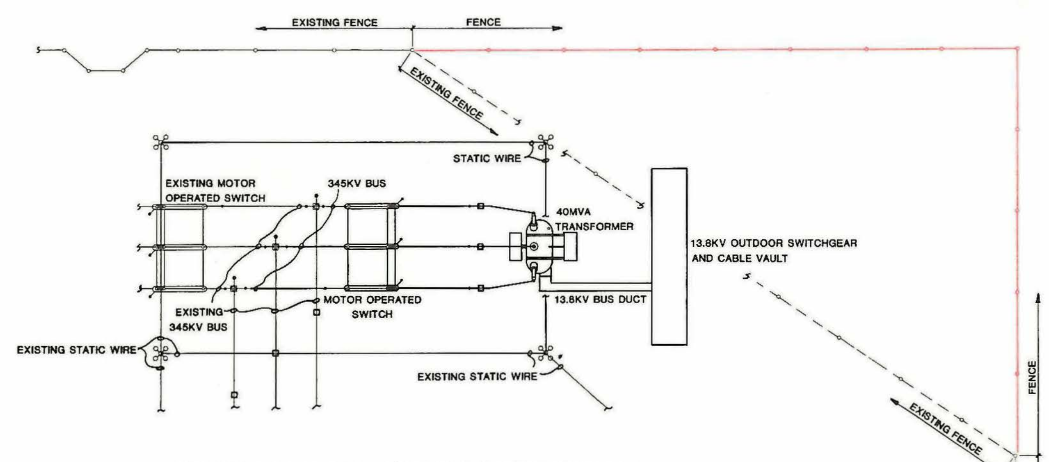


ELECTRICAL ALCOVE
GENERAL LIGHTING
FOUR FOOT LONG: TWO BULB FLUORESCENT FIXTURES LOCATED IN THE CENTER OF THE AISLE SPACE
STOCHASTIC EQUIPMENT MANHOLE
120V-20A DUPLEX OUTLET AND UTILITY LIGHTING 3KW ELECTRIC UNIT HEATER TYP. AT EACH MANHOLE
ELECTRICAL ALCOVE
EACH ALCOVE WILL CONTAIN THE POWER AND LIGHTING PANELS FOR APPROX. ONE THIRD OF EACH RING
EXIT LIGHTING
TO BE PROVIDED PER CODE
WELDING OUTLET
480V-60A WELDING OUTLETS AT 60 FEET ON CENTER
ELECTRICAL ALCOVE
UTILITY OUTLET
120V-20A QUAD RECP. AND 208V-20A DUPLEX RECP. AT 44 FEET ON CENTER
℄ 60A WELDING OUTLET
5" AT C.I.P. ENCLOSURES
7" AT PRECAST ENCLOSURES
5'-0
℄ UTILITY OUTLET
5'-0
TYPICAL WELDING OUTLET INSTALLATION DETAIL 3/4"=1'-0
TYPICAL UTILITY OUTLET INSTALLATION DETAIL 3/4"=1'-0
LIGHTING LEVELS
GENERAL LIGHTING
NORMAL .... 20 FOOTCANDLES
EMERGENCY .... 5 FOOTCANDLES
W
S
E
PROJECT NORTH
1/50":1'-0" 50 0 50 100 Scale Feet
3/4"=1'-0" 1 0 1 2 3 SCALE FEET
REV. NO.
DATE
DESCRIPTIONS
REVISIONS
DESIGNED
DRAWN
CHECKED
APPROVED
SUBMITTED
FERMI NATIONAL ACCELERATOR LABORATORY
UNITED STATES DEPARTMENT OF ENERGY
COLLIDER UPGRADE : 20 GEV RINGS
ENCLOSURE PLAN – ELECTRICAL CRITERIA
DRAWING NO. 6-4-1
CDR-24
REV.
APRIL 1988



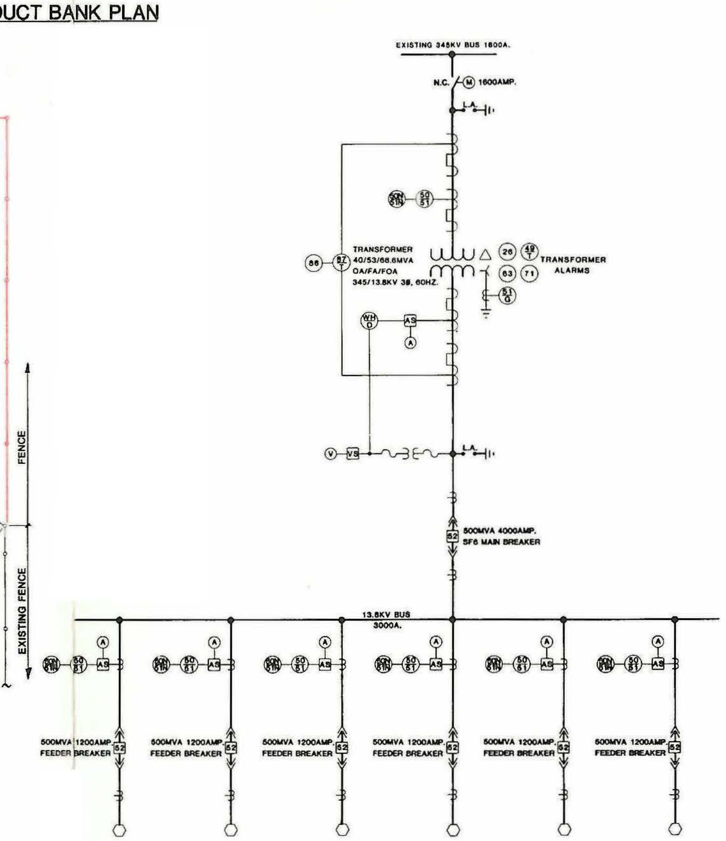
13.8KV FEEDER DUCT BANK PLAN

SCALE: NONE



ENLARGED PARTIAL MASTER SUBSTATION PLAN

SCALE: 1" = 20'-0"



345-13.8KV SINGLE LINE DIAGRAM

LEGEND

- DISCONNECT SWITCH
- L.A. LIGHTNING ARRESTER
- CURRENT TRANSFORMER-BUSHING TYPE
- 52 CIRCUIT BREAKER
- M MOTOR OPERATED DISCONNECT SWITCH
- TRANSFORMER
- THERMAL ELEMENT
- POTENTIAL TRANSFORMER
- CURRENT TRANSFORMER-STATION TYPE-WYE CONNECTED
- 52 SWITCHGEAR CIRCUIT BREAKER
- A AMMETER
- AS AMMETER SWITCH
- V VOLTMETER
- VS VOLTMETER SWITCH
- 24 BUS TIE BREAKER
- WH/D WATTHOUR DEMAND METER
- 26 OIL TEMPERATURE DEVICE
- 49/T WINDING TEMPERATURE RELAY
- 50 INSTANTANEOUS OVERCURRENT RELAY
- 51 TIME OVERCURRENT RELAY
- 63 PRESSURE RATE OF RISE RELAY
- 71 TRANSFORMER OIL LEVEL
- 86 LOCKING OUT RELAY
- 87/T TRANSFORMER DIFFERENTIAL RELAY
- FEEDER NUMBER
- N.C. NORMALLY CLOSED
- N.O. NORMALLY OPEN

REV.	DATE	DESCRIPTIONS
		REVISIONS

DESIGNED	E.VALDES	
DRAWN	A.R.FLOWERS	
CHECKED		
APPROVED		
SUBMITTED		

W S E PROJECT NORTH

1" = 20'-0" 20 0 20 40 Scale Feet

FERMI NATIONAL ACCELERATOR LABORATORY

UNITED STATES DEPARTMENT OF ENERGY

COLLIDER UPGRADE: 20 GEV RINGS

13.8KV FEEDER DUCT BANK UPGRADE

APRIL 1988

DRAWING NO. 6-4-1 PRELIMINARY CDR-25 REV.

APPENDIX IV - PROTON SUPER BOOSTER POWER SUPPLIES OPTIONS

Introduction

Initial cost estimates for a 20 GeV Proton Super Booster Power Supply System were driven primarily by expediency. The time period allowed for creating the estimate prohibited a search for an optimal design in terms of cost and reliability. For this reason, a ramped system, with similarities to the Main Ring and Tevatron power supplies, was used as the basis for the estimate. Even so, at the time, it was recognized that a resonant power supply system akin to that used by the Booster[1] might provide a cost saving and an increase in reliability over the first configuration. This note is a first attempt at addressing the issues associated with a resonant Proton Super Booster power supply.

Described in the remainder of this paper are the ramped power supply as originally estimated along with two possible resonant systems. Two different resonant systems are presented in order to illustrate methods for optimizing such a system. While not claiming this to be "the" optimal design for resonant power supplies, I believe that an optimal design will not be significantly different from what is described here.

Design Criteria

A ramped magnet system operating at 5Hz implies the need for low inductance magnets to minimize power supply voltage and voltage to ground. However, a low inductance magnet means high current which consequently dictates a magnet with low resistance. These two restraints resulted in an eight turn magnet being designed with large cross section conductors. In order to do a comparison of ramp versus resonant systems the same magnet was assumed to be used in designing the first resonant system. A twenty turn magnet was assumed for the second resonant system to illustrate some of the advantages/disadvantages of different resonant systems designs. It was assumed that changes in conductor length and cross section offset the reduction in magnet current so that the power dissipation in the magnets remained constant in both resonant systems. This means that the magnet design would remain essentially the same with the exception of number of turns in the coil.

Since there is a requirement for the Proton Super Booster calling for extended flattops, (1 second) both resonant systems must have a way for accommodating a flattop. While a ramped power supply is able to do longer flattops in a natural way, a resonant system capable of this is more complicated. There are a couple of ways this can be done with a resonant machine[2] but they greatly alter the cost of the system. It is assumed here that long flattops are not interspersed with the normal 5 Hz operation of the Post Booster but instead are somewhat infrequently required and a short change over time of operating modes is not unacceptable.

The assumptions made in calculating costs of the various components in each system are detailed later. It should be noted that even though the absolute cost may not be as accurate as one might like, since the same assumptions on cost estimates have been carried throughout, the relative cost differences between systems should still be indicative of design differences.

The Ramped Power Supply System

Table I lists magnet parameters and power supply parameters resulting from this load. The advantages of this system are in its flexibility for running varying modes of operation. Everything from 5 Hz operation to long flattops at low repetition rates are supported in a natural way and different cycles may be interspersed in any desired fashion. In addition, the power costs are duty cycle dependent and would have the lowest operating costs of any of the systems discussed. Even at 5 Hz, the power costs can be considerably lower than either resonant system described here. Further, power cost savings can be achieved by lowering the magnet bus resistance. However, doing this necessitates a larger expenditure on the power supplies since higher voltage units will be necessary during invert to maintain the desired repetition rate.

Three power supplies are specified owing to the symmetry of the civil construction (3 service buildings). The units would be placed symmetrically with respect to the load due to voltage to ground considerations. Each P.S. would be balanced with respect to ground further lowering the voltage to ground. It would probably also be possible to have a six power supply configuration at only modestly increased cost. The price per kilowatt of output for power supplies tends to level out in the range in which these supplies operate. Also, there may be price advantages to ordering a larger number of lower powered units. This might need investigation if the ramped power supply scenario is selected. There may also be an additional advantage in reliability and redundancy with 6 power supplies.

Two of the supplies specified are rated for the RMS current at 5 Hz operation and would be bypassed during long flattops. The third supply is sufficient for maintaining the flattop current when operating in the long flattop mode. All supplies have passive filtering on their output and are operated off the 13.8KV line. Transformers and switchgear are included in the cost estimates. The supplies are 6 phase, 12 pulse SCR type bridge rectifiers with bypass SCR's.

Certainly one problem with this system will be in making the regulation work. A learning regulator as used in Main Ring and Tevatron will be necessary due to the rapid cycling required. With virtually no flattop or dwell time at a 5 Hz repetition rate a feed forward/learning system is a must. Ensuring the quadrupole busses track the dipole bus should follow naturally with this regulation scheme.

<u>Resonant Power Supply System I</u>

Table II lists load and power supply parameters for this resonant system. Figure 1A shows what one load cell in this system looks like along with the AC and DC impedances of the cell. There are 12 magnets per load cell. Six cells in series with a single power supply make up the system. The injection and extraction current are also identical to the previous system. The current waveform is a DC biased sine wave at 5 Hz where the stored energy is alternately transferred from the magnets to the choke/capacitor combination and back to the magnets. For ramped operation with longer flattops a bypass switch of some kind is required to shunt current around the capacitor/choke combination. The same power supply would be able to ramp the magnets giving approximately a four to five second cycle time for a 1 second flattop. Separate current regulators would be required for each operational mode. If a 1000 volt power supply was used instead of 800 volts the cycle time for ramping could be brought down to under 3 seconds.

Choice of choke inductance and cell capacitance value are based primarily on cost. If the cost minimum is broad, however, there are several good reasons for keeping the inductance high if practical. The physical volume of the capacitors for a given stored energy will be considerably larger than the choke volume. Also, as choke inductance goes down the choke current increases and consequently the power dissipated in the choke rises. The reduction in cost caused by reducing the inductance can be offset due to the higher choke current. Finally, the parallel resonance of the choke/capacitor combination approaches the series resonant frequency of the system as the choke inductance decreases. This requires more power supply voltage to drive the load at a given current. The solution presented here is probably not an optimum. I believe with some work the cost might be further reduced by about 10% or so. In any case, the comparisons remain valid.

The value for the choke inductance chosen was approximately twice the value of the magnet inductance per cell. This is the same ratio used in the Booster. By setting the magnet and choke inductance, this defines the capacitance necessary for the resonance condition.

Resonant System #2

Table III lists the load and power supply parameters for this system. Figure 1B shows what one load cell in this system looks like along with the AC and DC impedances of the cell. Since there 20 turns in the magnet now, there are only 2 magnets per cell. Thirty-six cells in series makes up the resonant circuit. Since the current in this configuration is reduced by a factor of 2.5 while the power remains the same, the power supply voltage is now 2.5 times greater than before. It is likely that we would use two power supplies supplies to operate this ring to keep the voltage to ground reasonable. They would be placed symmetrically with respect to the load.

The current waveform is again a DC biased sine wave but with different minimum and maximum currents. We would also need bypass switches on the chokes and capacitors to accommodate ramped operation and the regulator, as mentioned for the first resonant system, would be used. Cycle time for ramped operation with the same power supply would be in the 3-4 second range for a 1 second flattop. This would be slightly faster than the first resonant system because the resistive voltage would be lower in this case and consequently more of the supply voltage can be used for di/dt.

The values of the choke inductance and capacitance are chosen as before.

Power System

The power supplies for the ramped scenario will run off a dedicated feeder. No other loads are likely to tolerate the line disturbances generated at 5 Hz by these power supplies except possibly other PSB power supplies. The peak power in the ramped system make it comparable to the present Main Ring system in power if not in extent. Also, the large reactive power make some form of power factor correction desirable. A static power factor correction was estimated for the preliminary design report based on the installation of the harmonic filters for Main Ring and Tevatron. A resonant system would have less need for the power factor correction than the ramped system. Cost estimates for a feeder system along with attendant transformer, switchgear and substation modifications are addressed later. It is possible that the resonant system could share its distribution feeders with other loads. A rough estimate indicates that problems associated with 5 Hz operation would be 3 to 10 times less of a problem than the 15 Hz line disturbances generated by Booster. This is primarily due to the lower frequency of the disturbance and the improved ability of power supply regulator to reject the lower frequency line variations.

Cost Estimates

Tables IV through VI contain the cost estimates for each of three systems described as indicated. Since the magnets for the ramped system and resonant system I are the same no entry is included for magnet cost. Resonant system II has a slightly different magnet and the estimate indicates the additional cost to this system. Because the same total amount of copper is to be used in this magnet there are no additional material costs. The cost difference is due to the extra labor required in fabricating a 20 turn coil instead of an 8 turn coil.

The estimates for all costs are based on recent expenditures for similar equipment and then scaled to 1988 prices by the inflation factors used for the Conceptual Design Report draft. The power supply estimates are extrapolations from data provided by Dan Wolff on power supplies purchased for the TEV 1 project. The power factor correction estimate is also derived from information provided by Dan Wolff. The capacitor costs are based on the recent replacement of the Booster girder capacitors. Where necessary the cost has been scaled according to the stored energy in the capacitors. Material cost and labor hours for the chokes came from data on TEV1 dipole magnets. Labor hours were scaled as appropriate according to magnet length, copper length and number of turns in the coil. Labor hours have been broken down into categories so anyone who wishes to take exception may do so. In addition, a contingency of 10% for the number of hours required has been added by me on general principle. No effort has been made at this time to estimate installation costs for either resonant system. Power system costs were provided by Jan Ryk.

Details of the choke design are contained in an appendix. Peak field in the gap was limited to 1.5T while peak fields in the iron is limited to 1.8T. Secondary windings in the chokes for monitoring purposes have not been included. The bypass switch for ramping the resonant system is pretty much a wild guess. The exact nature of the switch could be anything from SCR's to knife switches and consequently this estimate should be viewed with some skepticism.

Operating costs depend heavily on the mode of operating and for the ramped supply, on duty cycle. The figures presented are based on a 48 week year for all systems and a 20% duty cycle for the ramped system. The estimate is for 5Hz operation only.

Comparisons: Resonant vs Ramped

From the cost comparison of Tables IV and I, it can be seen that resonant system I is cheaper in terms of equipment costs. This is primarily due to elimination of 2 power supplies and the power factor correction equipment. Also the regulator for the resonant system is less expensive. However, there are some costs for either resonant system that are not included in this breakdown. These include capacitor and choke installation costs; choke costs for monitor winding; additional "balance" protection equipment for each resonant cell and perhaps additional costs related to insuring quad power supply tracking of the bend field. All these additions, while reducing the cost margin of resonant system I over the ramped system, are not likely to total the cost difference of the ramped versus resonant system.

There are other considerations, aside from the cost that need to be addressed as well, in choosing the final system. First, the flexibility associated with the ramped system is more attractive. Longer flattop ramps can be achieved without any change in operational mode. However regulation at 5Hz may be considerably more difficult. Reliability of a ramped system may be less than that of a resonant system if a comparison of Booster power supply downtime versus Main Ring power supply downtime is a valid indication. The appendix contains some downtime information on both systems. Disturbances generated on the power system may cause problems with either scenario. Is a large pulsed load more disruptive to other systems than a smaller but continuous 5Hz load? The resonant system also requires more cooling water than the ramped system.

Installation of the 13.8kv power system costs have been estimated at $4 million for the entire 20 Gev complex. This cost also covers upgrades to the entire site power distribution system. Due to space limitations in the present master substation a new transmission line and substation would be added. A sketch of this plan is included as an appendix. Cost difference for the ramped versus resonant power supplies is shown in Tables IV though IV. Obtaining a valid estimate for differences in the power system is difficult at this time.

The factors associated with implementing a general site power upgrade influence attempts at making a reasonable estimate for either power supply. The $4 million figure quoted includes two 40 MVA transformers. With a ramped system one of these would be devoted to this supply alone. It is not clear that this is necessary for the resonant system. It is also likely with a new transmission line and substation that power factor correction and harmonic filtering needs some rethinking. As a consequence the ramped system shows a transformer cost of $600K and the resonant system shows nothing for either a transformer or power factor correction. Any of these items may or may not be valid depending on the actual site power upgrade scheme. In fact adding any cost to either system related to power distribution may be an invalid point of view.

The final "fly in the ointment" is operating costs. The balance this time tips in favor of the ramped system. If the duty cycle of the ramped system approaches 100% the operating costs are still under those of the resonant system. In fact the numbers presented do not indicate the total operating cost savings possible for two reasons. First the resonant system power costs have not included losses in the magnet bus while the ramped system does. Secondly the losses in the ramped system are somewhat higher than necessary due to the fairly large bus impedance used in the calculations. If a high duty cycle ramped system were expected,the power cost could be reduced by 10-20% at the expense of raising the power supply and bus costs. The 20% duty cycle figure given assumes fixed target operation with a study cycle about every two seconds during a 60 second cycle.

Resonant I vs Resonant II

Clearly the most cost effective way in which to build a resonant machine with the PSB requirements is to minimize the number of resonant cells as much as possible while keeping the voltage across the chokes and capacitors as reasonable as possible. Even without considering the additional magnet, power supply and bypass switch costs, the cost of the chokes and capacitors for resonant system II is nearly double that of resonant system I. Resonant system II would also have significantly higher installation costs due six times the number of chokes and capacitance. The added complexity of the system, including an extra power supply, would likely make it more prone to failures as well.

About the only advantage resonant system II has over system I is one that has not been addressed in the cost estimates; namely power dissipation in the magnet bus for a given bus resistance (ie cross section) System I has 2.5 times the RMS current of system II. This disadvantage can be overcome by spending more on the bus for system I and still not approach the cost of system II.

Conclusions

From reliability and initial cost considerations a resonant system is the obvious choice. From the stand point of operating costs the ramped system is best choice for the PSB. Because operating costs are so dependent on the duty cycle in this situation a good assessment of how the PSB will be run is probably necessary prior to making a final decision. In the long run I suspect we should choose the system with the lowest operating costs because, over the lifetime of the machine, any additional initial costs will be paid back.

TABLE I
POWER SUPPLY AND LOAD PARAMETERS FOR A RAMPED SYSTEM

Magnet Inductance	1.4mH
Magnet Resistance	1.1mΩ
Ring Inductance	101.0mH
Ring Resistance	.12Ω
Number of Magnets	72.
Magnet Peak Field	13.12 Kgauss
Magnet Coil Turns	8.
Peak Magnet Current	6600A
Injection Magnet Current	2937A
Ramp DI/DT	36.6K Amps/Sec
RMS Current @ 5Hz	4800 Amps
Rise Time	100 msec
Fall Time	70 msec
Flattop Time	10 msec
Dwell Time	20 msec
RMS Power @ 5Hz	2.76MW
Peak Power	29.7MW
Total Power Supply Voltage	4500. Volts
Number of Power Supplies (1500 V)	3

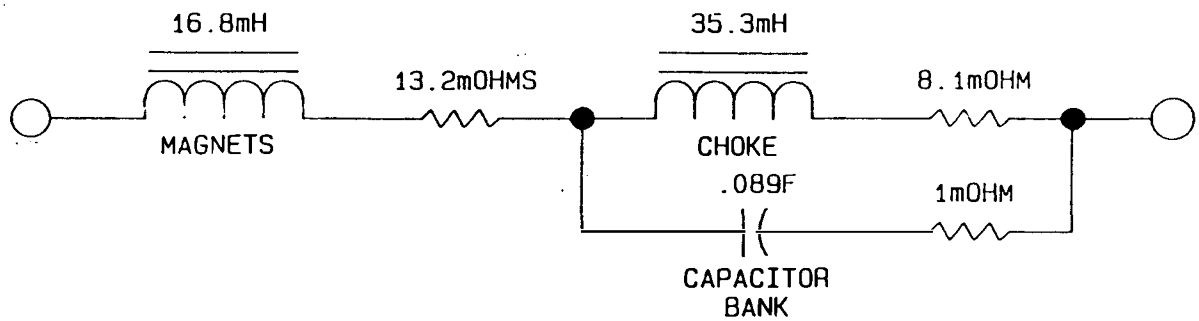
TABLE II
RESONANT POWER SUPPLY SYSTEM I

Magnet Inductance	1.4mH
Magnet Resistance	1.1mΩ
Number of Magnets per Cell	12
Magnet Inductance per Cell	16.8mH
Magnet Resistance per Cell	13.2mΩ
Peak Magnetic Field	13.12 KGauss
Peak Magnet Current	6600. Amps
Injection Current	2937. Amps
Magnet Coil Turns	8
RMS Magnet Current	4940. Amps
Number of Cells	6
Choke Inductance	35.3 mH
Choke Resistance	8.1 mΩ
Number Chokes per Cell	1
Peak Field in Gap	15. KGauss
Peak Field in Iron	18. KGauss
Peak Choke Current	5640. A
Minimum Choke Current	3895. A
RMS Choke Current	4807. A
Peak Choke Voltage (AC)	965. Volts
Number of Coil Turns	80.
Capacitance per Cell	.089 F
Peak Capacitor Voltage	965. Volts
Peak Capacitor Current	2700. Amps
RMS Capacitor Current	1908. Amps
Total Ring Capacitance	.534 F
Dissipation Factor	.1%
Total RMS Power @ 5Hz	3.08 MW
Peak Power	5.27 MW
Power Supply Peak Current	6600. Amps
Power Supply Peak Voltage	800. Volts
Number of Power Supplies	1

TABLE III
RESONANT POWER SUPPLY SYSTEM II

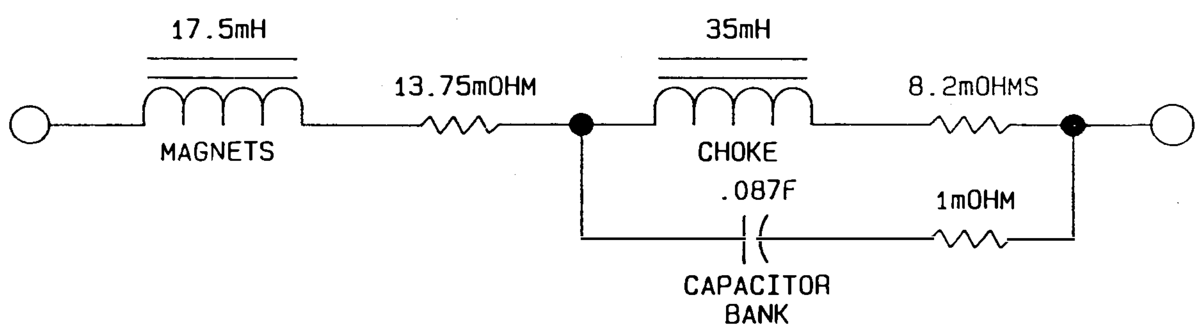
Magnet Inductance	8.75 mH
Magnet Resistance	6.88 mΩ
Number Magnets per Cell	2
Magnet Inductance per Cell	17.5 mH
Magnet Resistance per Cell	13.75 mΩ
Peak Magnetic Field	13.12 KGauss
Peak Magnet Current	2640. Amps
Injection Current	1175. Amps
Magnet Coil Turns	20.
RMS Magnet Current	1976. Amps
Number of Cells	36
Choke Inductance	35. mH
Choke Resistance	8.2 mΩ
Number Chokes per Cell	1
Peak Field in Gap	15. KGauss
Peak Field in Iron	18. KGauss
Peak Choke Current	2273. Amps
Minimum Choke Cucrrent	1542. Amps
RMS Choke Current	1924. Amps
Peak Choke Voltage (AC)	402. Volts
Number of Coil Turns	80
Capacitance per Cell	.087 F
Peak Capacitor Voltage	402. Volts
Peak Capacitor Current	1100. Amps
RMS Capacitor Current	777. Amps
Total Ring Capacitance	3.132 F
Dissipation Factor	.1%
Total RMS Power @ 5Hz	3.05 MW
Peak Power	5.28 MW
Power Supply Peak Current	2640. Amps
Power Supply Peak Voltage (Total)	2000. Volts
Number of Power Supplies (1000 V)	2

FIGURE 1
RESONANT SYSTEM LOAD CELLS



12 MAGNETS/CELL; 1 CHOKE/CELL; 6 CELLS TOTAL
AC IMPEDANCE @ 5HZ = 13.2E-3 + j.528 + 4.02E-3 - j.528 OHMS
DC IMPEDANCE 13.2E-3 + 8.1E-3 OHMS

1a. RESONANT SYSTEM 1 LOAD CELL



2 MAGNETS/CELL; 1 CHOKE/CELL; 36 CELLS TOTAL
AC INPEDANCE @ 5HZ = 13.75E-3 + j.549 + 4.29E-3 - j.549 OHMS
DC IMPEDANCE = 13.75E-3 + 8.2E-3 OHMS

1b. RESONANT SYSTEM 2 LOAD CELL

TABLE IV
RAMPED POWER SUPPLY SYSTEM COSTS

2 4800A/1500V Power Supply	$800.K
1 6600A/1500V Power Supply	$550.K
30 MVAR Power Factor Correction	$520.K
Power Supply Installation & Checkout	$71.K
Miscellaneous material	$60.K
Regulator	$50.K
Software for Regulator	$17.K
TOTAL	**$2.068 M**

Power System Costs	
Transformer	$600 K
Operating Cost ($.055/KW-HR)	
5Hz 20% Duty Cycle (fixed target with study cycles)	$.248 M
5Hz Continuous	$1.242 M

TABLE V
RESONANT SYSTEM I COSTS

1 6600 A/800 V Power Supply	$294. K
Power Supply Installation & Checkout	$24. K
Miscellaneous materials	$20. K
Regulator	$25. K
6 Chokes	$659. K
Capacitors	$385. K
6 Bypass Switches	$60. K
TOTAL	**$1.467 M**
Power System Costs	
Transformer	?
Operating Cost ($.055/KW-HR)	
5Hz Operation	$1.375 M

TABLE VI
RESONANT SYSTEM II COSTS

2 2640 M/1000 V POWER SUPPLY	\$425. K
Power Supply Installation & Checkout	\$48. K
Miscellaneous Material	\$40. K
Regulator	\$25. K
36 Chokes	\$1678. K
Capacitors	\$391. K
36 Bypass Switches	\$180. K
Additional Magnet Costs (280 Hours extra @ \$25/Hr X 72)	\$504. K
TOTAL	**\$3.291 M**
Power System Costs Transformer	?
Operating Costs (\$.055/KW-HR)	\$1.353 M

REFERENCES

1) Gradient Magnet Power Supply for the Fermilab 8-GeV Proton Synchrotron; Jan Ryk; Fermilab Publication 74/85 0323.000; 1974

2) A Multi-Function Ring Magnet Power Supply for Rapid Cycling Synchrotrons; W. F. Praeg; 1EEE Transactions on Nuclear Science, Vol. NS-32, No. 5; 1985

Los Almos National laboratory Lampf II Project - Preconceptual Design of Main Ring Magnet Pulsed Power System - Frequency 3.3Hz, 6.6Hz & 10 Hz; G. Karady et al; Los Almos National Labs; 1985

APPENDIX

Choke I Cost Breakdown

Materials	
Copper	$24,186
Iron	26,202
Insulation	3,913
End Pack	1,678
Miscellaneous	4,470
TOTAL	**$60,449**
Labor	**Hours**
Meetings	26
Supervision	360
Coil Winding	550
Dekeystone Coil	100
Sandblast Coil	100
Insulation	220
Cure	50
Manifold	50
End Pack	100
Core	150
Assembly	90
Contingency	180
TOTAL	**1,976 HOURS**
Labor Costs @ $25/Hour	$49,400
Total Cost/Choke Labor	$49,400
Material	$60,449
	$109,849

APPENDIX

Choke II Cost Breakdown

Materials	
Copper	$6,870
Iron	8,948
Insulation	1,118
End Pack	1,118
Miscellaneous	3,018
TOTAL	**$21,072**

Labor (Hours)	
Meetings	26
Supervision	160
Coil Winding	240
Coil Dekeystone	53
Coil Sandblast	53
Insulation	116
Cure	26
Manifold	50
End Pack	100
Core	65
Assembly	40
Contrigency	93
TOTAL	**1022**

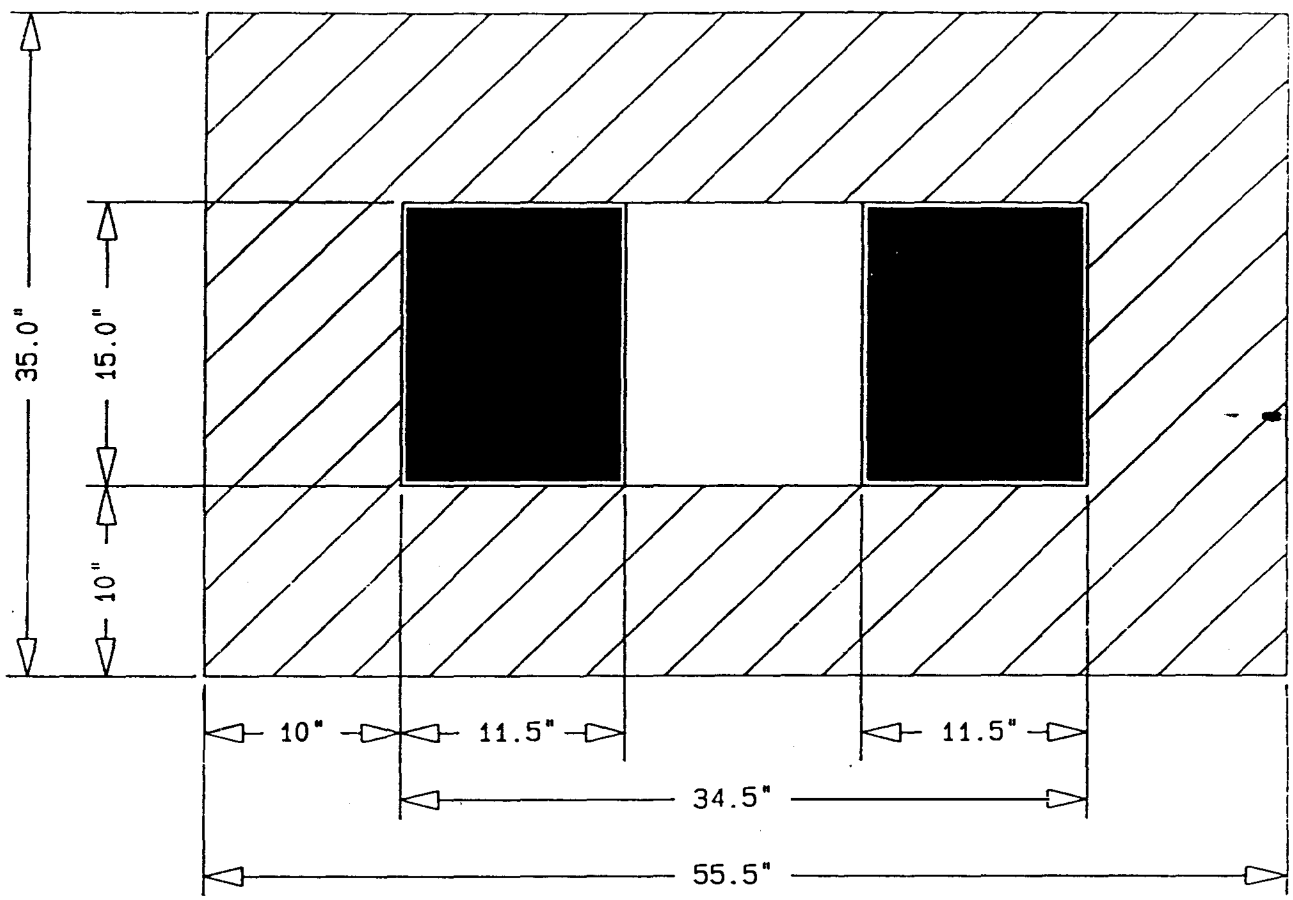
Labor Cost @ $25/Hour		**$25550**
Total Cost/Choke	**Labor**	**$25550**
	Material	**$21072**
	Total	**$46622**

RESONANT SYSTEM 1

CAPACITOR/CHOKE PARAMETERS

COST OF CAPACITORS = $.72/UF FOR 1000V CAPCITORS

CHOKE CROSS SECTION



GAP = 15"; WINDOW WIDTH = 34.5"; COIL WIDTH = 11.5"; CHOKE LENGTH = 108"
COIL = 10 TURNS X 8 TURNS

COPPER CROSS SECTION = 1.375 SQ. IN.; COOLING CHANNEL DIA. = .5";
COPPER AREA = 1.69 SQ. IN.; COPPER LENGTH = 22,500"

WEIGHT OF COPPER = 6.15 TONS; WEIGHT OF IRON = 21.7 TONS
TOTAL WEIGHT = 27.85 TONS

PEAK FIELD GAP = 15KGAUSS; PEAK FIELD IRON = 18KGAUSS

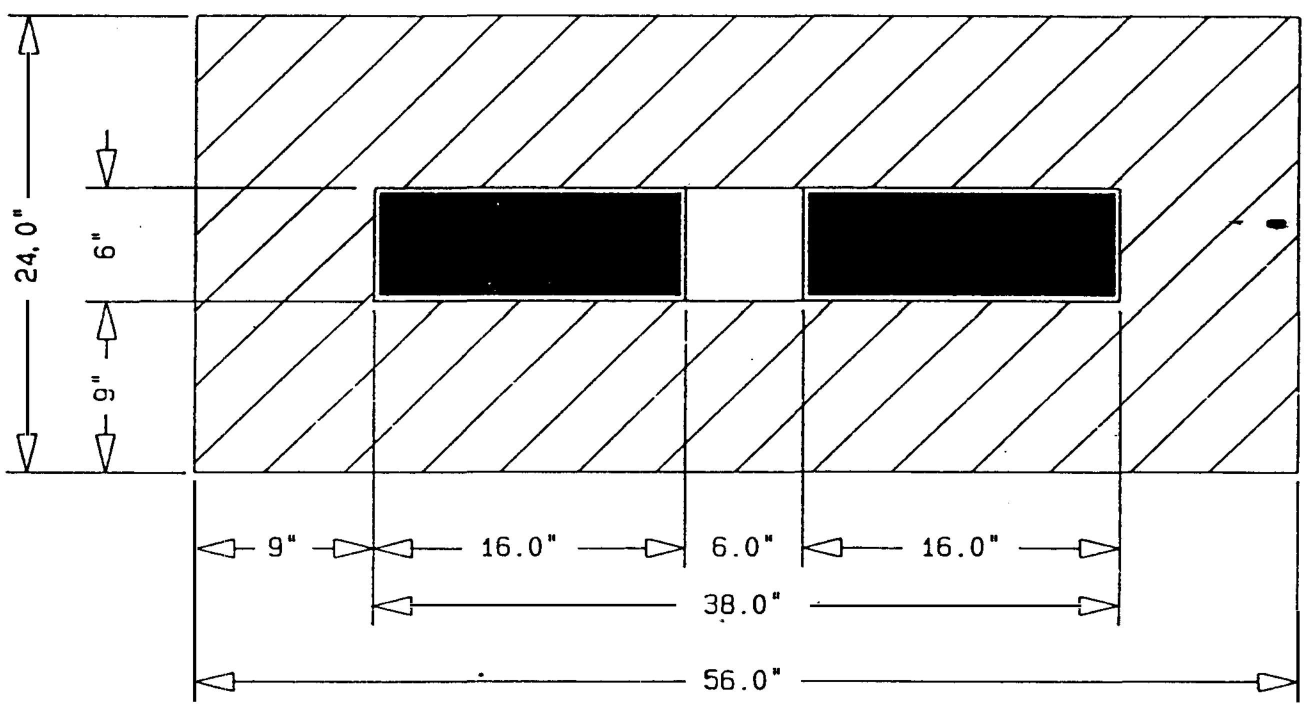
CHOKE RESISTANCE = 8.1 mOHMS; POWER DISSIPATION = 187.2 KW
COOLING FOR DELTA T = 20 DEG.C = 34.6 GAL/MIN

RESONANT SYSTEM 2

CAPACITOR/CHOKE PARAMETERS

COST OF CAPACITORS = $.125/UF FOR 400V CAPACITORS

CHOKE CROSS SECTION



GAP = 6"; WINDOW WIDTH = 38"; COIL WIDTH = 16"; CHOKE LENGTH = 46.6";
COIL = 5 TURNS X 16 TURNS

COPPER CROSS SECTION = 1 SQ. IN.; COOLING CHANNEL DIA. = .375";
COPPER AREA = .89 SQ. IN.; COPPER LENGTH = 12,000"

WEIGHT OF COPPER = 1.75 TONS; WEIGHT OF IRON = 7.41 TONS;
TOTAL WEIGHT = 9.16 TONS

CHOKE RESISTANCE = 8.2 OHMS; POWER DISSIPATION = 30.4 KW;
COOLING FOR A DELTA T = 20 DEG.C = 5.6 GAL/MIN

DOWNTIME SYSTEM TALLY

	SYS_DT	ENTRIES	MAX_DT	AVG_DT	STD_DEV	ACT%	CALNDR%	% OF TOT
ACCPS	31.300	8	17.950	3.913	6.199	0.320	100.000	0.611
DEBPS	22.144	19	3.367	1.165	1.044	0.227	100.000	0.432
ACCRF	3.433	8	2.000	0.429	0.679	0.035	100.000	0.067
DEBRF	29.100	7	9.333	4.157	3.325	0.298	100.000	0.568
ACOOL	20.216	58	4.000	0.349	0.734	0.207	100.000	0.395
DCOOL	2.517	9	1.033	0.280	0.381	0.026	100.000	0.049
PBTRGT	36.599	34	7.167	1.076	1.603	0.374	100.000	0.714
PBDIAG	1.500	1	1.500	1.500	0.000	0.015	100.000	0.029
PBCOR	0.617	2	0.450	0.308	0.200	0.006	100.000	0.012
PBMISC	79.944	17	38.450	4.703	9.591	0.818	100.000	1.560
PBCON	1.683	5	0.617	0.337	0.241	0.017	100.000	0.033
EXPAR	31.510	119	4.039	0.265	0.537	0.322	100.000	0.615
NTF	0.317	2	0.283	0.158	0.177	0.003	100.000	0.006
MISC	77.060	45	8.833	1.712	2.182	0.788	100.000	1.504

SYSTEM TOTALS

	SYS_DT	ENTRIES	MAX_DT	AVG_DT	STD_DEV	ACT%	CALNDR%	% OF TOT
LINAC	120.250	821	2.683	0.146	0.318	1.230	100.000	2.347
BOOSTER	220.114	487	13.500	0.452	1.238	2.252	100.000	4.296
PBAR	305.419	200	38.450	1.527	4.253	3.124	100.000	5.961
MAIN RING	464.543	645	16.167	0.720	1.587	4.752	100.000	9.067
TEVATRON	3320.613	999	1440.061	3.324	46.802	33.967	100.000	64.811
SY	174.299	277	13.267	0.629	1.290	1.783	100.000	3.402
UTILITIES	173.527	75	35.167	2.314	4.829	1.775	100.000	3.387
CONTROLS	220.314	511	7.933	0.431	0.810	2.254	100.000	4.300
MISC	53.812	148	4.039	0.364	0.622	0.550	100.000	1.050

LINAC -- PACC,LRF,LQUAD,LVAC

BOOSTER -- 2MISC,2PS,BVAC,BCOR,BMAG,BLLRF,BMISC,BGMPS

PBAR -- APVAC,ACCVAC,DEBVAC,APPS,ACCPS,DEBPS,ACCRF,DEBRF,ACOOL,DCOOL,PBTRGT,PBDIAG,PBCOR,PBMISC,PBCON

MR -- 8VAC,8PS,8MAG,8MISC,MRVAC,MRPS,MRREG,MRRF,MRMAG,MRCOR,MRMISC,MRWATR

TEV -- TCOR,TVAC,TPS,TMAG,TCRYO,TQPM,TRF,TINJ,TMISC,TQUEN,UCHL

SY -- SYVAC,SYPS,SYMAG,SYLOS,SYMISC,SYCRYO,SYQUEN,SYQPM

CONTROLS -- LCON,BCON,MRCON,SYCON,TCON,CMISC

MISC -- EXPAR, NTF, SAFETY

UTILITY -- UPOWER,UWATER,UMISC

TOT DT IN HRS = 5123.509 CALENDAR% DT = 52.409 ACTUAL% DT = 100.000

LARGEST DT = 1439.208 CALENDAR TIME = 9776.000 ACTUAL UP TIME = 0.000

EFFICIENCY = ACTUAL TIME / CALENDAR TIME(100) = 0.000

From 01-jan-87 0000 to 12-feb-88 0800

DOWNTIME SYSTEM TALLY

	SYS_DT	ENTRIES	MAX_DT	AVG_DT	STD_DEV	ACT%	CALNDR%	% OF TOT
PACC	13.316	137	1.345	0.097	0.211	0.136	100.000	0.260
LRF	92.614	596	2.683	0.155	0.347	0.947	100.000	1.808
LQUAD	7.201	41	0.786	0.176	0.190	0.074	100.000	0.141
LVAC	0.745	8	0.217	0.093	0.077	0.008	100.000	0.015
LMISC	6.373	39	1.283	0.163	0.283	0.065	100.000	0.124
2MISC	0.892	2	0.767	0.446	0.454	0.009	100.000	0.017
2PS	48.929	80	13.500	0.612	1.819	0.500	100.000	0.955
2VAC	0.810	3	0.633	0.270	0.315	0.008	100.000	0.016
2MAG	0.000	0	0.000	0.000	0.000	0.000	100.000	0.000
BVAC	34.062	76	12.433	0.448	1.627	0.348	100.000	0.665
BMAG	7.467	3	7.000	2.489	3.913	0.076	100.000	0.146
BCOR	12.193	18	5.317	0.677	1.353	0.125	100.000	0.238
BLLRF	20.486	11	5.000	1.862	1.682	0.210	100.000	0.400
BRF	36.183	136	2.750	0.266	0.481	0.370	100.000	0.706
BMISC	36.103	69	7.250	0.523	1.146	0.369	100.000	0.705
BGMPS	22.991	89	3.983	0.258	0.562	0.235	100.000	0.449
8VAC	11.350	4	7.333	2.838	3.350	0.116	100.000	0.222
8PS	18.845	47	2.500	0.401	0.555	0.193	100.000	0.368
8MAG	0.000	0	0.000	0.000	0.000	0.000	100.000	0.000
8MISC	5.400	4	2.750	1.350	0.996	0.055	100.000	0.105
MRVAC	14.546	30	3.467	0.485	0.845	0.149	100.000	0.284
MRPS	93.118	163	4.767	0.571	0.826	0.953	100.000	1.817
MRMAG	114.107	19	16.167	6.006	4.864	1.167	100.000	2.227
MRCOR	27.378	53	2.000	0.517	0.591	0.280	100.000	0.534
MRWATR	8.900	4	6.900	2.225	3.155	0.091	100.000	0.174
MRRF	36.984	142	6.167	0.260	0.611	0.378	100.000	0.722
MRMISC	81.342	95	8.783	0.856	1.363	0.832	100.000	1.588
MRREG	52.574	84	10.750	0.626	1.277	0.538	100.000	1.026
SYVAC	9.600	4	6.283	2.400	2.977	0.098	100.000	0.187
SYPS	48.438	97	5.750	0.499	0.954	0.495	100.000	0.945
SYMAG	27.394	15	13.267	1.826	3.284	0.280	100.000	0.535
SYLOS	3.825	14	1.667	0.273	0.440	0.039	100.000	0.075
SYMISC	20.558	61	4.500	0.337	0.636	0.210	100.000	0.401
SYCRYO	10.041	31	1.596	0.324	0.435	0.103	100.000	0.196
SYQUEN	45.506	30	9.483	1.517	1.743	0.465	100.000	0.888
SYQPM	4.732	13	1.017	0.364	0.359	0.048	100.000	0.092
CMISC	124.079	351	7.933	0.354	0.759	1.269	100.000	2.422
LCON	2.389	9	1.217	0.265	0.376	0.024	100.000	0.047
BCON	4.474	16	2.167	0.280	0.556	0.046	100.000	0.087
MRCON	29.216	41	6.050	0.713	1.104	0.299	100.000	0.570
SYCON	4.206	12	1.000	0.351	0.312	0.043	100.000	0.082
TCON	54.267	77	5.417	0.705	0.929	0.555	100.000	1.059
UPOWER	103.840	32	35.167	3.245	6.655	1.062	100.000	2.027
UWATER	40.446	20	17.167	2.022	3.694	0.414	100.000	0.789
UMISC	29.241	23	5.450	1.271	1.330	0.299	100.000	0.571
UCHL	7.644	14	3.000	0.546	0.779	0.078	100.000	0.149
SAFETY	21.986	27	2.350	0.814	0.787	0.225	100.000	0.429
TCOR	75.728	75	12.400	1.010	2.054	0.775	100.000	1.478
TVAC	46.269	41	9.250	1.129	2.249	0.473	100.000	0.903
TPS	115.669	81	6.600	1.428	1.463	1.183	100.000	2.258
TMAG	2443.189	27	1439.558	90.489	275.404	24.992	100.000	47.686
TCRYO	146.337	193	6.233	0.758	1.068	1.497	100.000	2.856
TQPM	45.986	43	4.250	1.069	0.914	0.470	100.000	0.898
TRF	28.411	97	3.500	0.293	0.561	0.291	100.000	0.555
TIN[illegible]	38.161	53	5.500	0.720	1.402	0.390	100.000	0.745
TMI[illegible]	[illegible].896	[illegible]6	4[illegible]	[illegible]92	0.9[illegible]	0[illegible]	1[illegible]00	[illegible].99
[illegible]	[illegible]	[illegible]	8.783	1.114	1.256	3.292	100.000	6.281

STD_DEV = (SUM OF (DT-MEAN)**2)**1/2

ACT% = (SYS_TOT / ACTUAL UP TIME)*100

CAL% = (SYS_TOT / CALENDAR TIME)*100

% OF TOT = (SYS_TOT / TOT_DT)*100