Title I Design Report

Fermilab Main Injector

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Technical Componets

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1. INTRODUCTION

This report contains a description of the preliminary design, cost estimate, and construction schedule of the Fermilab Main Injector (FMI) Project. The technical, cost, and schedule baselines for the FMI Project have already been established and may be found in the Fermilab Main Injector Conceptual Design Report, Revision 3.1, (CDR3.1) issued in April 1992. In this report the design and schedule for construction of all subsystem components and associated civil construction are described at a level of detail beyond that found in the April 1992 CDR. The facilities described have been designed in conformance with DOE 6430.1A, "United States Department of Energy General Design Criteria."

The purpose of the Fermilab Main Injector Project is to construct a new 150 GeV accelerator, and all required interconnections and interfaces to the existing accelerator complex, on the Fermilab site in support of the Fermilab High Energy Physics (HEP) research program. The construction of this accelerator will result simultaneously in significant enhancements to both the Fermilab collider and fixed target programs. The FMI is to be located south of the Antiproton Source and tangent to the Tevatron ring at the F0 straight section, as shown in Figure 1-1. The FMI will perform all duties currently required of the existing Main Ring. Thus, operation of the Main Ring will cease following commissioning of the FMI, with a concurrent reduction in the background rates seen in the colliding beam detectors. The performance of the FMI, as measured in terms of protons per second delivered to the antiproton production target or total protons delivered to the Tevatron, is expected to exceed that of the Main Ring by a factor of two to three. In addition the FMI will provide high duty factor 120 GeV beam to the experimental areas during collider operation, a capability which does not presently exist in the Main Ring.

The location, operating energy, and mode of construction of the FMI are chosen to minimize operational impacts on Fermilab's ongoing High Energy Physics program. The area in which the FMI is to be situated is devoid of any underground utilities which might be disturbed during construction, while the separation between the FMI and Tevatron is sufficient to allow construction concurrent with Tevatron operations. The energy capability of the FMI is chosen to match the antiproton production and Tevatron injection energies presently used in the Fermilab complex. The FMI will be built from newly constructed dipole magnets allowing a large portion of the installation process to proceed independent of Tevatron operations. The use of newly designed dipoles is also desirable from the standpoint of enhanced performance and reliability, and results in a reduction of the operating costs by 33% relative to what would be obtained by recycling existing Main Ring magnets.

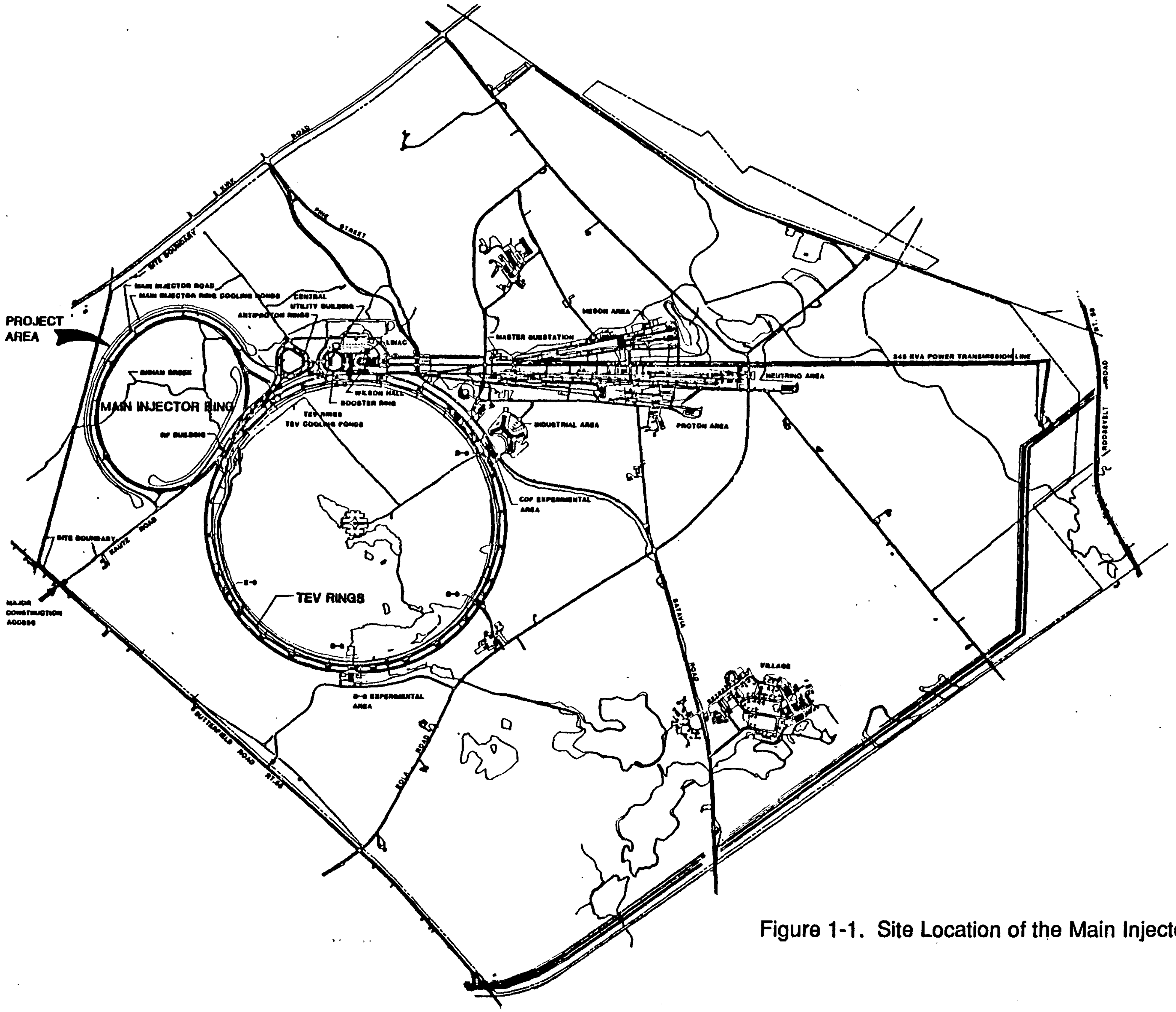

Figure 1-1. Site Location of the Main Injector.

The Total Project Cost (TPC) of the FMI is estimated to be $246,600,000 including a Total Estimated Construction Cost (TECC) of $217,450,000 and $29,150,000 in associated R&D, pre-operating, capital equipment, conceptual design, and spares costs. Included within the scope of the project are all technical and civil construction components associated with the ring itself, with beamlines needed to tie the ring into the existing accelerator complex, and with modifications to the Tevatron and switchyard required to accommodate the relocated injections. The project involves the construction of 15,000 ft of tunnel enclosures, 11 service buildings, and a new 345 kV substation. The FMI ring and all beamline interconnections to existing facilities are shown schematically in Figure 1-2. It is proposed to complete construction over a five year period starting on March 1, 1992. Design of civil construction will be done by an outside Architectural Engineering (AE) firm with support from the Fermilab Engineering Support Section. Design of technical components will be done by Accelerator Division and Technical Support Section personnel. It is anticipated that construction and operation of the new FMI will not require any expansion of the Fermilab permanent staff.

1.1. ROLE IN THE FERMILAB III PROGRAM

The Fermilab Main Injector is the centerpiece of Fermilab's initiative for the 1990s, known as Fermilab III. Some of the more important goals of Fermilab III are to discover and illuminate the properties of the top quark, the last unobserved fundamental building block of matter in our current understanding of the strong interactions, to provide a factor of two increase in the mass scales characterizing possible extensions to the Standard Model, and to support new initiatives in neutral kaon physics and neutrino oscillation investigations. In order to attain these goals Fermilab is planning to attain by mid-decade a luminosity in excess of $5x10^{31}$ cm^2sec^{-1} in the Tevatron $\bar{p}$-p collider.

Several projects currently underway will result in a factor of 6 improvement in luminosity over the current performance of $1.6x10^{30}$ $cm^{-2}sec^{-1}$ by 1993. These include upgrades to the Antiproton Source to improve the yield by a factor of 3, development of new low-ß systems which have allowed the implementation of a second high luminosity interaction region, development of separators to allow multibunch operation, and the installation of cold compressors to raise the Tevatron energy. On October 1, 1989 work was initiated to raise the Linac energy from 200 MeV to 400 MeV for the purpose of increasing the antiproton production rate by 75% and reducing proton beam emittances by 40%. As a result of these enhancements it is expected that the luminosity of the collider will gradually increase to $1x10^{31}cm^{-2}sec^{-1}$ by 1993. It is also anticipated that these developments will increase the number of protons delivered from the Tevatron for fixed target physics up to $3x10^{13}$ per minute.

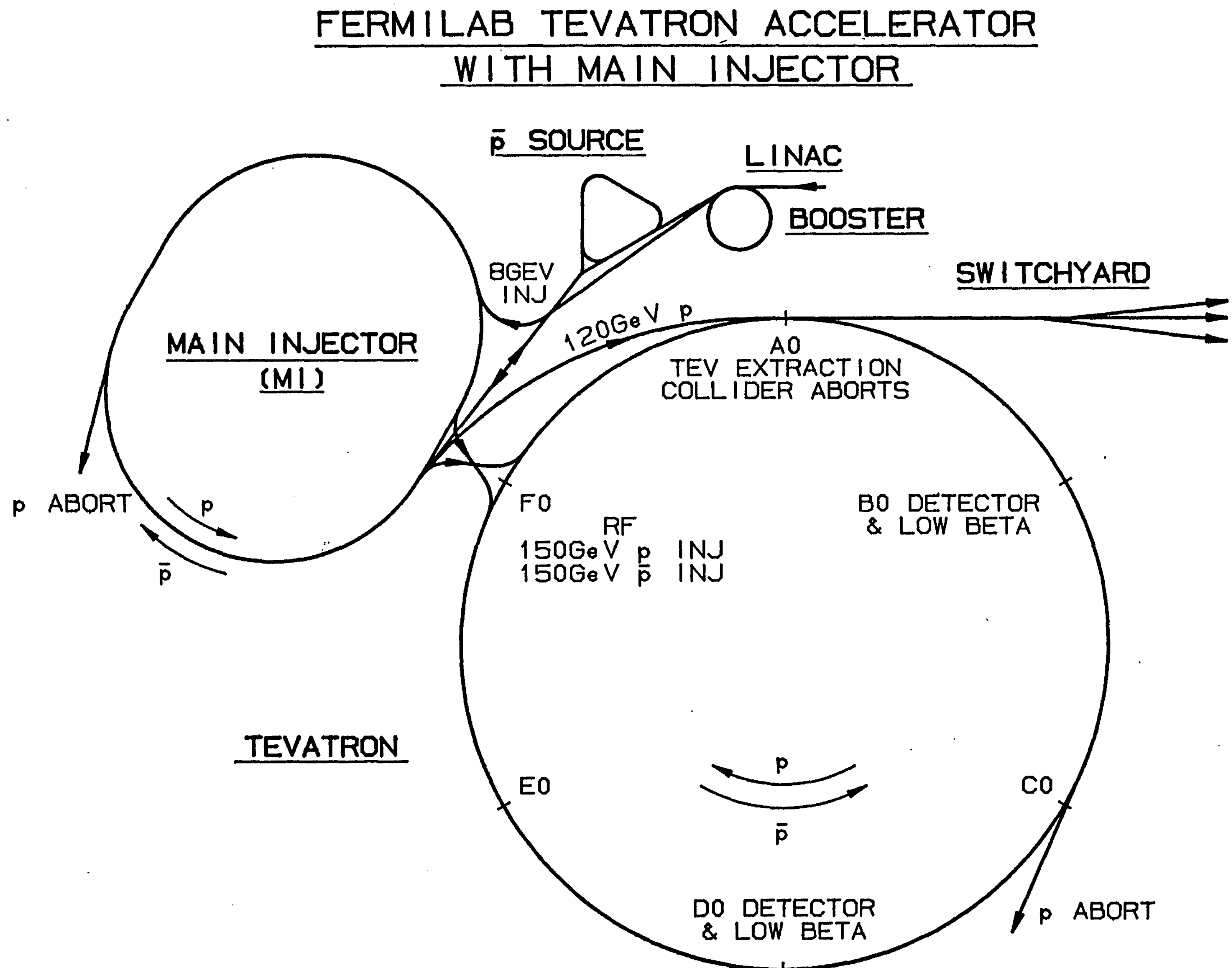

Figure 1-2. Schematic View of the Main Injector Connections to the Booster, Antiproton Source, Tevatron and Switchyard.

Further improvements to performance require the construction of the FMI. The present bottleneck in the production of antiprotons and in the delivery of intense beams to the Tevatron is the Main Ring. The Main Ring is not capable of accelerating the quantity of protons which can be provided at injection by the 8 GeV Booster. This is for the simple reason that the aperture of the Main Ring (12π mm-mr) is about half the size of the Booster aperture (20π mm-mr). (All emittances in this report are quoted as 95% normalized values.) As a result the Booster is typically run at about two-thirds of its capability during normal operations. Additionally, the Main Ring is not capable of accelerating antiprotons delivered from large stacks in the Antiproton Source due to the larger emittances associated with larger stacks. As a result the Source is limited to stacks containing 6×10^{11} antiprotons (about two-thirds of its present capability) during collider operations. The restricted aperture in the Main Ring is due to perturbations to the ring which have been required for the integration of overpasses and new injection and extraction systems related to operations with antiprotons. With the 400 MeV Linac upgrade the Booster aperture at injection will be increased to 30π mm-mr due to increased adiabatic damping within the new linac, and the ability to produce larger antiproton stacks will be increased. However, the mismatches between Booster/Antiproton Source and Main Ring capabilities will become even more acute. Only with the construction of the FMI will these mismatches be removed, and the full benefit to the collider and fixed target programs of the upgrade projects currently underway be realized.

The construction of the FMI will also provide beams of up to 3×10^{13} protons at 120 GeV to the experimental areas during collider runs. Such beams are envisioned as being used for detector development, for the debugging and shakedown of fixed target experiments prior to commencement of 1 TeV fixed target runs, and for supporting certain specialized rare K decay and neutrino experiments which can benefit from the high average intensity deliverable from the FMI. The Main Ring as presently configured does not support a slow spill, nor is it felt that implementation of a high intensity slow spill in the existing ring would be feasible in light of the small machine aperture and the need to minimize backgrounds in the collider experiments.

Specifically, benefits expected from the construction of the FMI include:

1. An increase in the number of protons targeted for $\bar{p}$ production from 5.0×10^{15}/hour (following the Linac upgrade) to 1.2×10^{16}/hour.

2. An increase in the total number of protons which can be delivered to the Tevatron to 6×10^{13}.

3. The ability to accelerate efficiently antiprotons originating in stacks containing $2x10^{12}$ antiprotons for injection into the Tevatron collider.

4. The ability to produce proton bunches containing up to $3x10^{11}$ protons for injection into the Tevatron collider.

5. The reduction of backgrounds and dead time at the CDF and D0 detectors through removal of the Main Ring from the Tevatron enclosure.

6. Provision for slow extracted beams at 120 GeV year-round and potential development of very high intensity, high duty factor ($1x10^{13}$ protons/sec at 120 GeV with 34% duty factor) beams for use in high sensitivity K decay and neutrino experiments.

It is expected that with the construction of the FMI and the completion of planned improvements to the Antiproton Source the antiproton production rate will exceed $1x10^{11}$ antiprotons/hour, and that a luminosity of $5x10^{31}cm^{-2}sec^{-1}$ will be supportable in the existing collider.

1.2 PERFORMANCE

The FMI parameter list is given in Table 1-1. It is anticipated that the FMI will perform at a significantly higher level than the existing Main Ring as measured either in terms of protons delivered per cycle, protons delivered per second, or transmission efficiency. For the most part expected improvements in performance are directly related to the optics of the ring. The FMI ring lies in a plane with stronger focusing per unit length than the Main Ring. This means that the maximum ß-functions are half as large and the maximum (horizontal) dispersion only a third of the Main Ring, while vertical dispersion is nonexistent. As a result physical beam sizes associated with given transverse and longitudinal emittances are significantly reduced compared to the Main Ring. The elimination of dispersion in the rf regions, raising the level of the injection field, elimination of sagitta, and improved field quality in the dipoles all have a beneficial impact on beam dynamics. The construction of new, mechanically simpler magnets is expected to yield a highly reliable machine.

The FMI is seven times the circumference of the Booster and slightly more than half the circumference of the existing Main Ring and Tevatron. Six Booster cycles will be required to fill the FMI and two FMI cycles to fill the Tevatron. The FMI is designed to have a transverse

Table 1-1: Main Injector Parameter List

Circumference	3319.419	m
Injection Momentum	8.9	GeV/c
Peak Momentum	150	GeV/c
Minimum Cycle Time (@120 GeV)	1.5	sec
Number of Protons	$3x10^{13}$	
Harmonic Number (@53 MHz)	588	
Horizontal Tune	26.4	
Vertical Tune	25.4	
Transition Gamma	20.4	
Natural Chromaticity (H)	-33.6	
Natural Chromaticity (V)	-33.9	
Number of Bunches	498	
Protons/bunch	$6x10^{10}$	
Transverse Emittance (Normalized)	20π	mm-mr
Longitudinal Emittance	0.4	eV-sec
Transverse Admittance (@ 8.9 GeV)	40π	mm-mr
Longitudinal Admittance	0.5	eV-sec
β_{max}	57	m
Maximum Dispersion	2.0	m
Number of Straight Sections	8	
Length of Standard Cell	34.6	m
Phase Advance per Cell	90	degrees
RF Frequency (Injection)	52.8	MHz
RF Frequency (Extraction)	53.1	MHz
RF Voltage	4	MV
Number of Dipoles	216/128	
Dipole Lengths	6.1/4.1	m
Dipole Field (@150 GeV)	17.2	kG
Dipole Field (@8.9 GeV)	1.0	kG
Number of Quadrupoles	128/32/48	
Quadrupole Lengths	2.1/2.5/2.9	m
Quadrupole Gradient	196	kG/m
Number of Quadrupole Busses	2	

admittance of 40π mm-mr (both planes, normalized at 8.9 GeV/c). This is 30% larger than the expected Booster aperture following the 400 MeV Linac upgrade, and a factor of 3 larger than that of the existing Main Ring. It is expected that the Linac upgrade will yield a beam intensity out of the Booster of $5\text{-}7\times10^{12}$ protons per batch with a 20-30π mm-mr transverse and a 0.4 eV-sec longitudinal emittance. A single Booster batch needs to be accelerated for antiproton production while six such batches are required to fill the FMI. The FMI should be capable of accepting and accelerating these protons without significant beam loss or degradation of beam quality. Yields out of the FMI for a full ring are expected to lie in the range $3\text{-}4\times10^{13}$ protons ($6\text{-}8\times10^{13}$ delivered to the Tevatron.) By way of contrast the existing Main Ring is capable of accelerating 1.8×10^{13} protons in 12 batches for delivery to the Tevatron.

The power supply and magnet system is designed to allow a significant increase in the number of 120 GeV acceleration cycles which can be run each hour for antiproton production, as well as to allow a 120 GeV slow spill with a 35% duty factor. The cycle time at 120 GeV can be as low as 1.5 seconds. This is believed to represent the maximum rate at which the Antiproton Source could ultimately stack antiprotons, and is to be compared to the current Main Ring capability of 2.4 seconds. The FMI dipole magnets are designed with twice the total cross section of copper and half as many turns as existing Main Ring dipoles. This keeps the total power dissipated in the dipoles during antiproton production at roughly the same level as in present operations while keeping the number of power supplies and service buildings low.

1.3 OPERATIONAL MODES

At least four distinct roles for the FMI have been identified along with four corresponding acceleration cycles. These are listed in Table 1-2. More detailed description of the acceleration cycles and power supply requirements are given in Section 2 of this report.

1) In the antiproton production mode a single Booster batch containing 5×10^{12} protons is injected into the FMI at 8.9 GeV. These protons are accelerated to 120 GeV and extracted in a single turn for delivery to the antiproton production target. As mentioned earlier, it is anticipated that with this flux of protons onto the target and expected improvements in the Antiproton Source the antiproton production rate will exceed 1×10^{11}/hour.

2) For fixed target injection the FMI is filled with six Booster batches, each containing 5×10^{12} protons at 8.9 GeV. Since the Booster cycles at 15 Hz, 0.4 seconds are required to fill the FMI. The beam is accelerated to 150 GeV, cogged, and extracted in a single turn for delivery to

Table 1-2: Main Injector Operational Modes

	Operational Mode	Energy	Cycle	Flattop	Protons
1)	Antiproton Production	120 GeV	1.5 sec	0.04 sec	$5x10^{12}$
2)	Fixed Target Injection	150	2.4	0.25	$3x10^{13}$
3)	Collider Injection	150	4.0	1.45	$5x10^{12}$
4a)	High Intensity Slow Spill	120	2.9	1.0	$3x10^{13}$
4b)	High Intensity Fast Spill	120	1.9	0.04	$3x10^{13}$

the Tevatron. The FMI is capable of cycling to 150 GeV every 2.4 seconds for short periods of time. Two FMI cycles are required to fill the Tevatron at 150 GeV at one minute intervals.

3) The FMI operates on a 4 second, 150 GeV cycle for delivery of beam to the Tevatron for collider operations. The acceleration cycle and beam manipulations are the same for both protons and antiprotons. A 1.45 second flattop is required for bunch coalescing and cogging of the beams prior to injection into the Tevatron. Under the currently envisioned filling scenario a maximum of 15 cycles of the FMI are required to load the Tevatron with protons and antiprotons. Assuming a one minute Antiproton Source cycle time, this results in a 10 minute collider fill time. It is anticipated that the collider will require filling approximately every 20 hours.

4) A much higher intensity, high duty factor (34%) beam can be delivered at 120 GeV with a 2.9 second cycle time. The average proton current delivered is about 2 mA ($3x10^{13}$ protons/2.9 seconds). Running in this mode does not put any peak power demands on the power supply system beyond those imposed by the antiproton production cycle, but it does expend 67% more average power. This cycle can also be used to provide test beams to the experimental areas during collider running. In this instance it is likely that a much lower cycle rate, accompanied by a much lower average power, would satisfy experimenters' needs. Additionally, a high intensity, low duty factor beam can be delivered at 120 GeV with a 1.9 second cycle time for the production of high flux neutrino beams.

Combinations of the above operational modes are also possible. One such example is simultaneous operation for antiproton production and high intensity slow spill. One could load the FMI with six Booster batches containing $3x10^{13}$ protons, accelerate to 120 GeV, fast extract one batch to the antiproton production target, and slow extract the remainder of the beam over a second. This would produce slightly more than half the antiproton flux into the Source and 83% of the average intensity of the dedicated scenarios listed in Table 1-2.

1.4 ORGANIZATION OF THIS REPORT

This report is organized into two volumes. Volume One contains a description of the technical component subsystems as well as overviews of the performance objectives, design specifications, cost, and schedule for the project. Discussion and descriptions of technical component subsystems are organized to follow the Work Breakdown Structure (WBS) of the project. Volume One has been prepared by Fermilab staff. Volume Two contains the project civil construction design. Volume Two has been prepared jointly by Fermilab and by the Architectural Engineering firm of Fluor Daniel.

WBS Organization

Chapter 3 is organized according to the Work Breakdown Structure (WBS) which has been adopted for the FMI project. All technical components are contained in WBS category 1.1. The third digit of the WBS describes the component type: 1 = magnet, 2 = vacuum, 3 = power supply, etc. The fourth digit indicates the location in which that component will be used: 1 = Main Injector ring, 2 = 8 GeV line, 3 = 150 GeV proton transfer line, etc. To describe a general system which is used throughout the Main Injector, or in a number of different beamlines, the fourth digit is set to 10. The fifth level provides further definition of system or component subtype. Schedules for the design, procurement, fabrication and installation of major systems are included as figures in Chapter 3.

2. THE FERMILAB MAIN INJECTOR

2.1. OVERVIEW

The FMI is a 150 GeV accelerator with a circumference 28/53 times that of the existing Main Ring. The primary design goals are to increase the admittance to 40π mm-mr and lower the cycle time to 1.5 sec. The FMI will be situated tangent to the Tevatron at the F0 straight section on the southwest side of the Fermilab site. Other possible sites have been considered, including locations inside the existing Tevatron ring, but these were deemed less desirable than the site shown in this report. The FMI, as described here, is constructed using newly designed (conventional) dipole magnets. The decision to build new magnets is based on considerations of field quality, aperture, and reliability. With the major exception of the dipoles, existing components from the Main Ring are for the most part recycled. Such components specifically include quadrupoles and the radio frequency (rf) systems. The use of all 18 existing rf cavities in a ring roughly half the size of the Main Ring will support an acceleration rate of 240 GeV/sec as compared to 120 GeV/sec in the present Main Ring. The FMI power supply systems are designed to support this rate.

Lattice

The design of the FMI is driven by a number of considerations. Given the preferred site, a maximum physical size of the ring is established by the proximity of the Fermilab site boundary. This in turn leads to a minimum needed field strength in the magnets. The number and location of the straight sections is determined by the roles the ring is required to play. In all phases of design the motivation has been to produce a lattice in which the transverse beam size is smaller than in the Main Ring over the energy range 8 to 150 GeV. The two lattice parameters which affect beam size are the beta function, ß, and the dispersion, η. In this design ß is kept small by the short distance between quadrupoles. This is a cost effective approach because the quadrupoles will be taken from the existing Main Ring. The η is kept smaller in the FMI than in the Main Ring by carefully matching dispersion around all straight section insertions. Dispersion matching ensures that the maximum dispersion in the ring is no larger than the maximum dispersion in the standard cell. The FMI will not have overpasses, in contrast to the present Main Ring, and therefore, the vertical dispersion is zero.

Lattice Design

Figure 2.1-1 shows the FMI geometric layout. The standard cell of the FMI is, like the Main Ring, a FODO design but with two dipoles between the quadrupoles as shown in Figure 2.1-2. (The Main Ring has four dipoles between quadrupoles.) The inter element spacing is the same as in the present Main Ring so that the length of the half-cell is shorter by the length of two dipoles and the short drift spaces which follow them, i.e. by about half. Because of the shorter circumference, there are fewer than half as many dipoles as in the Main Ring.

The lattice incorporates two different types of cells, the normal 17.2886-m FODO cells and the 12.9665-m FODO dispersion-suppressor cells. The dispersion-suppressor cells feature shorter dipoles, and match the horizontal dispersion to zero in the straight sections. There are 72 normal cells (54 in the arcs and 18 within the straight sections), and 32 dispersion suppressing cells. The advantages of the lattice include:

i. Zero dispersion in the straight sections. This reduces the horizontal beam size, which in turn makes beam transfers easier to accomplish.
ii. The ß-functions in the straight sections and in the dipoles surrounding the straight sections are the same as, or less than, those in the normal FODO cells, affording more clearance for the beam and tolerance in steering at transfer time.
iii. A 136-m long rf straight.
iv. A lattice which accommodates transfer lines to the Tevatron that match the vertical dispersion exactly.
v. A separation of 11.8 m between the FMI and the Tevatron, which permits phased construction of the FMI enclosure.

Having fewer dipoles than the Main Ring leads to higher fields and a larger bending angle. The resulting sagitta in a 6 m dipole is 16 mm. The new dipoles will be built with a curvature which eliminates loss of aperture due to sagitta. A 90° phase advance per cell is chosen, resulting in a maximum ß in the cells of 58 meters and a maximum η in the cells of 1.9 meters. By comparison the Main Ring has maximum ß and η of 110 m and 6.6 m, respectively. Thus the beam size due to transverse emittance is only 70% of what it is presently, and the maximum beam size due to momentum spread is down by a factor of 3 from the Main Ring. The ring is designed to have twofold rotational symmetry; Figure 2.1-3 shows the FMI lattice functions for one-half the ring. Lattice functions, as generated by the program MAD, are tabulated in Appendix A.

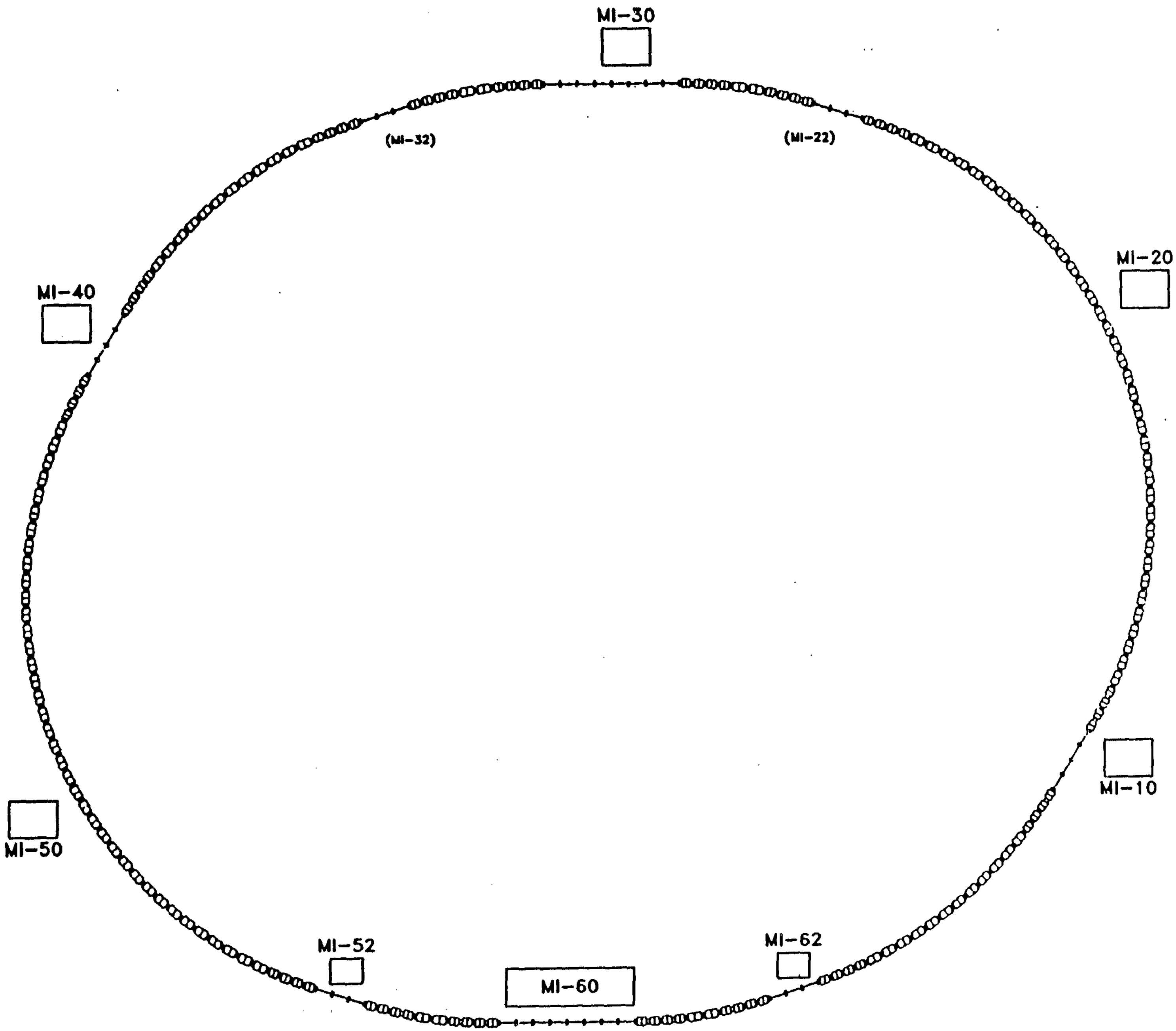

Figure 2.1-1. Main Injector Geometric Layout Showing Locations of Service Buildings and Straight Sections

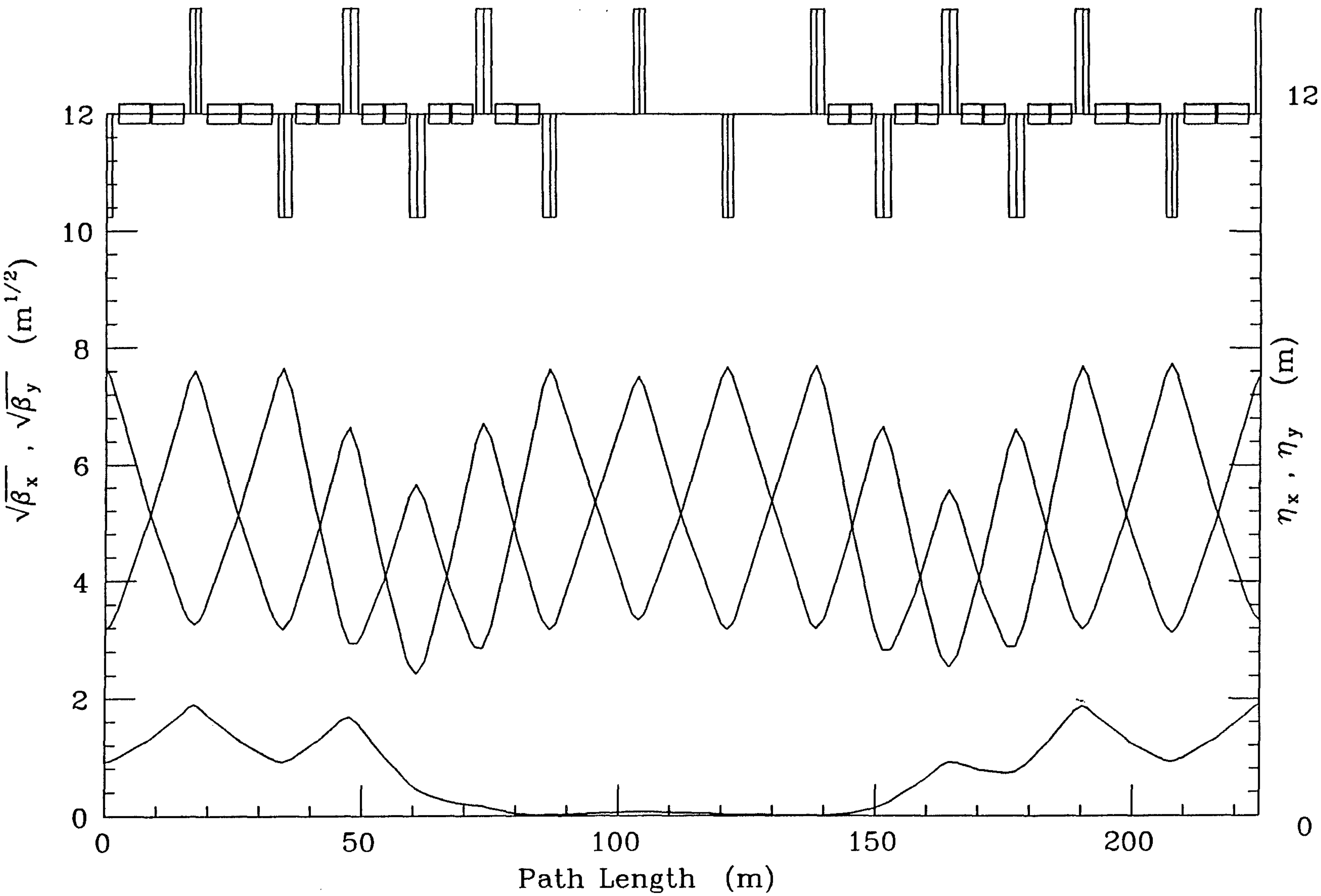

Figure 2.1-2. Main Injector FODO Lattice Showing (Left to Right) One Normal Cell, Two Dispersion-Suppressor Cells, Three Straight-Section Half-Cells, Two Dispersion-Suppressor Cells, and One Normal Cell

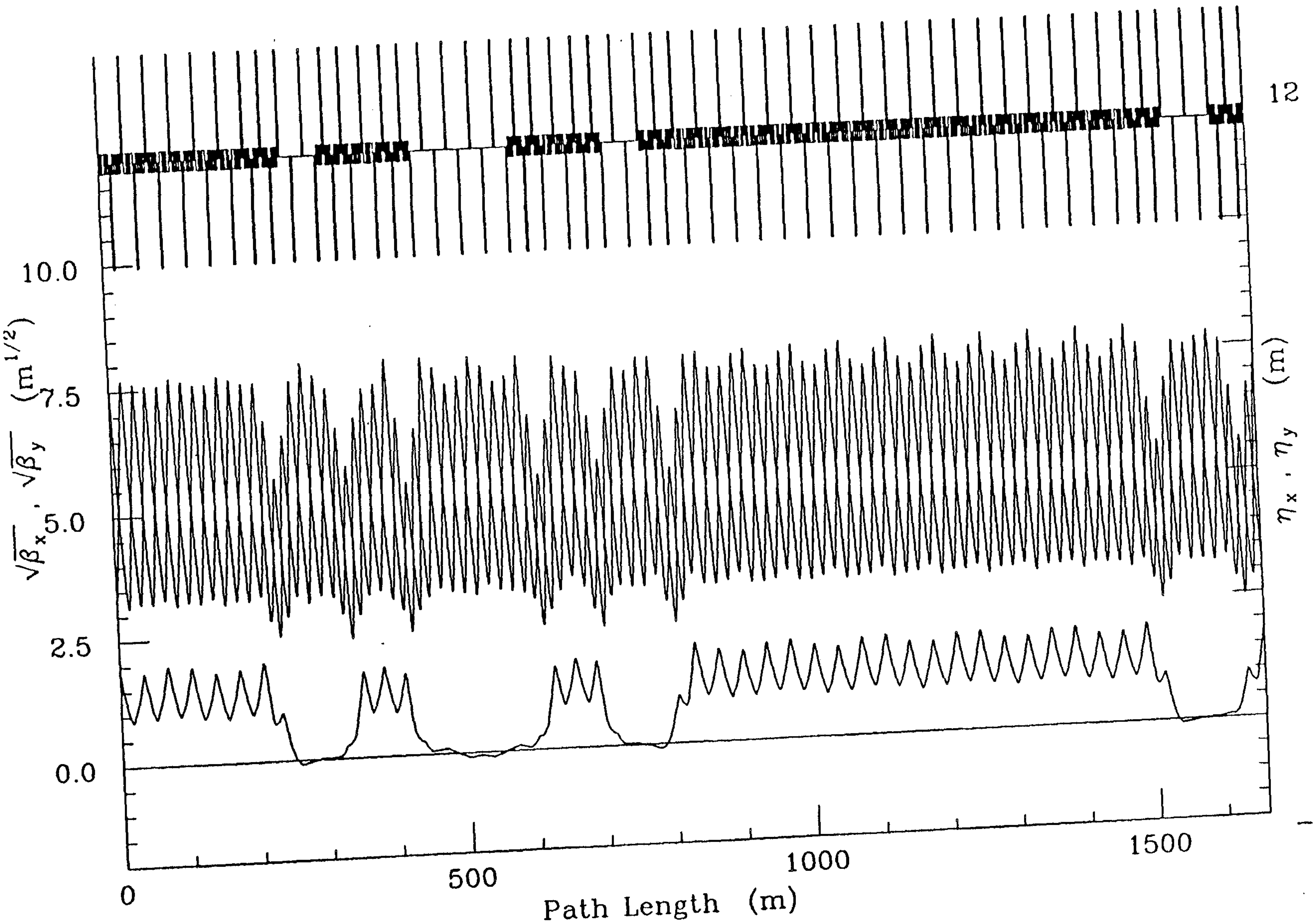

Figure 2.1-3. Main Injector Lattice Functions for One-Half the Ring

The 344 dipoles are excited by 12 power supplies located in six service buildings; the locations of these service buildings are used as the basis for numbering locations in the FMI ring.

The FMI contains eight straight sections. Their locations are shown in Figure 2.1-1, and a detail of the layout of the MI-52 straight-section is shown in Figure 2.1-4. Their numbering and their functions are as follows:

MI-10 - 8 GeV proton injection
MI-22 - (unused)
MI-30 - (unused)
MI-32 - (unused)
MI-40 - proton abort
MI-52 - 150/120 GeV proton extraction; 8 GeV antiproton injection
MI-60 - FMI rf section
MI-62 - 150 GeV antiproton extraction

All straight sections are obtained by omitting dipoles while retaining the standard 17.29-m quadrupole spacing. There are three different lengths of straight sections. Straight sections MI-10 and MI-40 are 69 m long (two cells), straight sections MI-22, -32, -52, and -62 are 52 m long (one and one half cells), and straight sections MI-30 and MI-60 are 138 m long (four cells). Straight section MI-60 is used for the rf; its length will allow flexible spacing of the rf cavities and provide generous free space for diagnostic beam pickups.

Three different quadrupole lengths are required: 2.13-m quadrupoles for the normal cells, 2.95-m quadrupoles for the dispersion-suppressor cells, and 2.54-m quadrupoles at the boundary between the two types of cells. The lengths are such that all quadrupoles are powered off two main quadrupoles busses. All straight section insertions are dispersion matched to the cells. With at least 135° of phase advance in each straight section, there is space within the long straight for kickers and septa, a situation not provided for in the present Main Ring lattice.

The long straight sections are capable of beam extraction at the highest FMI energy. Due to the fact the ring lies 11 meters from the Tevatron, two of these (MI-52, MI-62) are required to provide injection into the Tevatron, one each for protons and antiprotons. On the opposite side of the ring two straight sections (MI-22, MI-32) are added for symmetry. MI-10 is necessary for injection of protons from the Booster, and MI-40 is placed symmetrically for the proton abort.

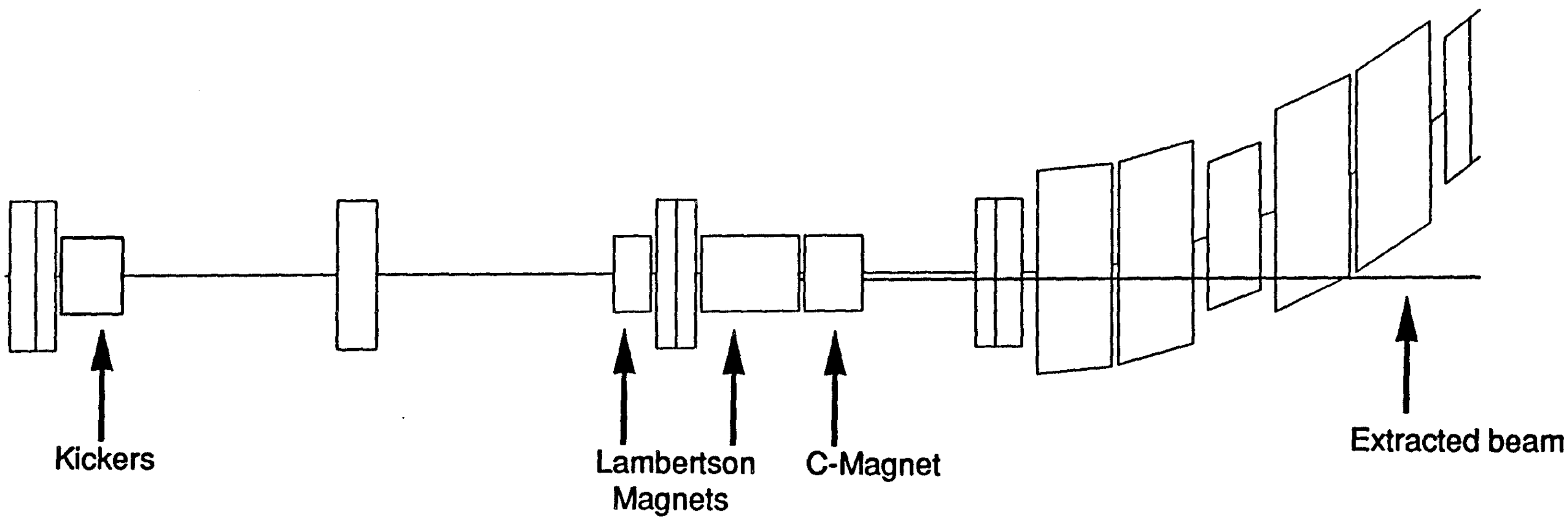

Figure 2.1-4. Detail (Plan View) of MI-52 Straight Section
Used for 8 GeV Antiproton Injection and 120/150 GeV Proton Extraction

The FMI is situated in the southwest corner of the Fermilab site. The details of its location are determined by requirements for transfers of both protons and antiprotons into the Tevatron. The MI-60

straight section is parallel to the Tevatron F0 straight section, separated from it by 11.823 m (38' 9.5") horizontally and 2.3253 m (7' 7.5") vertically. The reference point defining the plane containing the Main Injector design orbit lies at the intersection of a line from the center of the Tevatron ring and passing near F0 normal to the F0 straight section, and a line parallel to the MI-60 straight section and equidistant from the MI-60 and MI-30 straight sections. Gravity at this point defines the normal to the plane. The plane containing the Main Injector orbit dips at an angle of 0.231 milliradians (47.65") toward the southwest corner (project coordinates) of the site.

The nominal elevation of the FMI was specified in earlier design reports to be 2.332 m below the Tevatron beam. To account for the relative tilt of the Tevatron and the FMI, it is now specified that MI-52 and MI-62 are placed at this elevation. The line from MI-52 to MI-62 is offset 28.789277 m from the MI-60 straight section and parallel to it. The tilt of the FMI then places the MI-60 straight section 2.3253 m below the Tevatron beamline.

The FMI is designed to be a planar machine, but because the ring is eccentric, the elevation varies around the ring. The minimum elevation is in the MI-30 and MI-60 straight sections and is about 11.6 mm below the maximum which occurs in the 100 arc near Q123 (northwest). A second elevation maximum, about 6.0 mm above the minimum, occurs in the 400 arc near Q425 (southeast). The variation in beam elevation, relative to a surface which follows the curvature of the earth, is shown in Figure 2.1-5. The elevation of the MI-60 and MI-30 straight sections is 715' 8.953", 2.3253 m below the elevation of the Tevatron (723' 4.5"). The center of the MI-60 straight section lies directly opposite the transfer point into the Tevatron, which is 13.222 m (43'4.6") downstream of the center of the F0 straight section. For reference, the FMI tunnel floor is at a constant (locally-defined) elevation of 713'6", and the MR/Tevatron tunnel floor is at 722'6".

2.2. ACCELERATION CYCLES

There are four basic acceleration cycles, shown in Figure 2.2-1, serving each of the four operational modes of the FMI:

1. The antiproton production cycle: 1.5 second cycle, single Booster batch (5×10^{12} protons) accelerated to a peak energy of 120 GeV and extracted in a single turn.

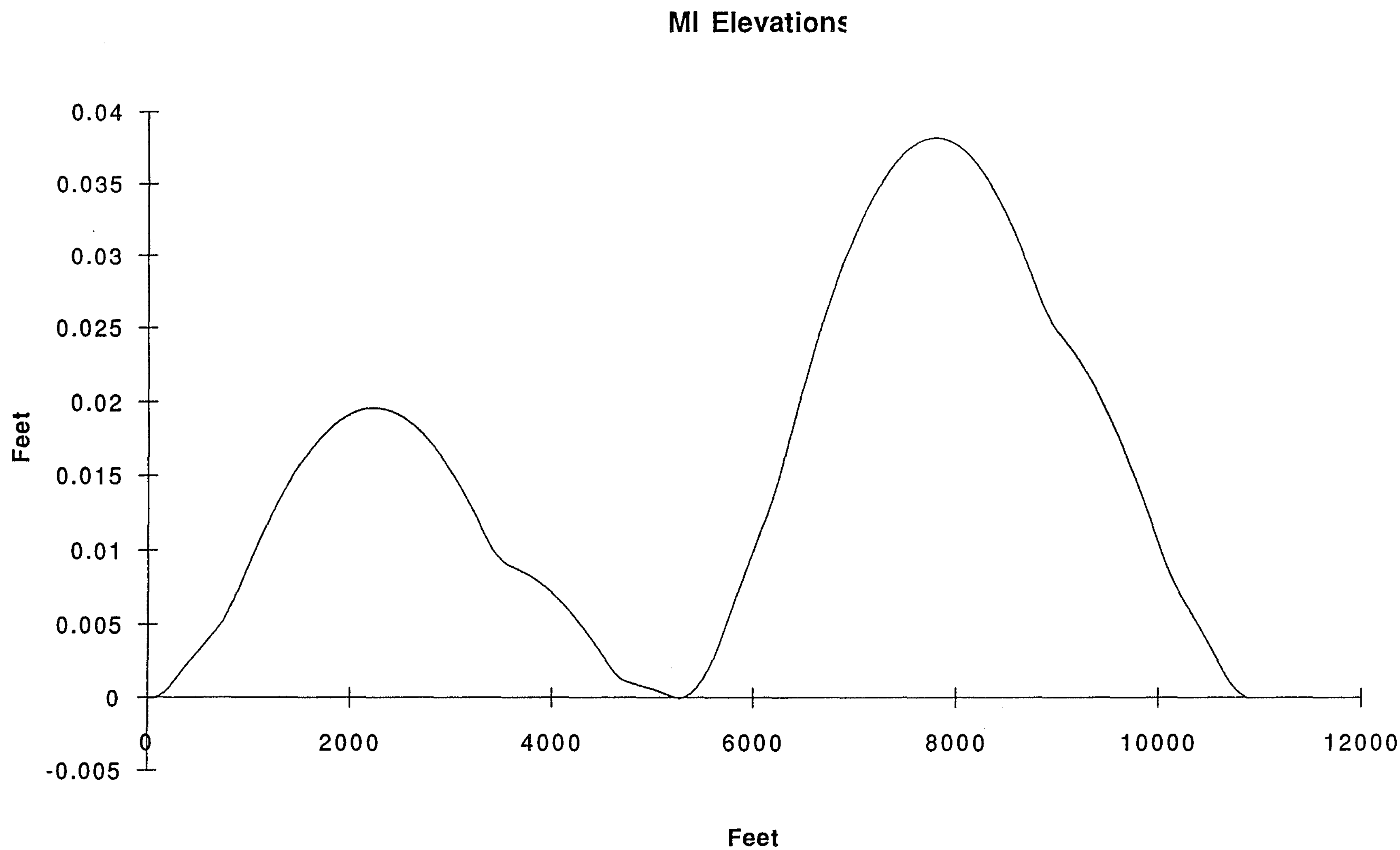

Figure 2.1-5. Variation of Main Injector Beam Height vs. Position

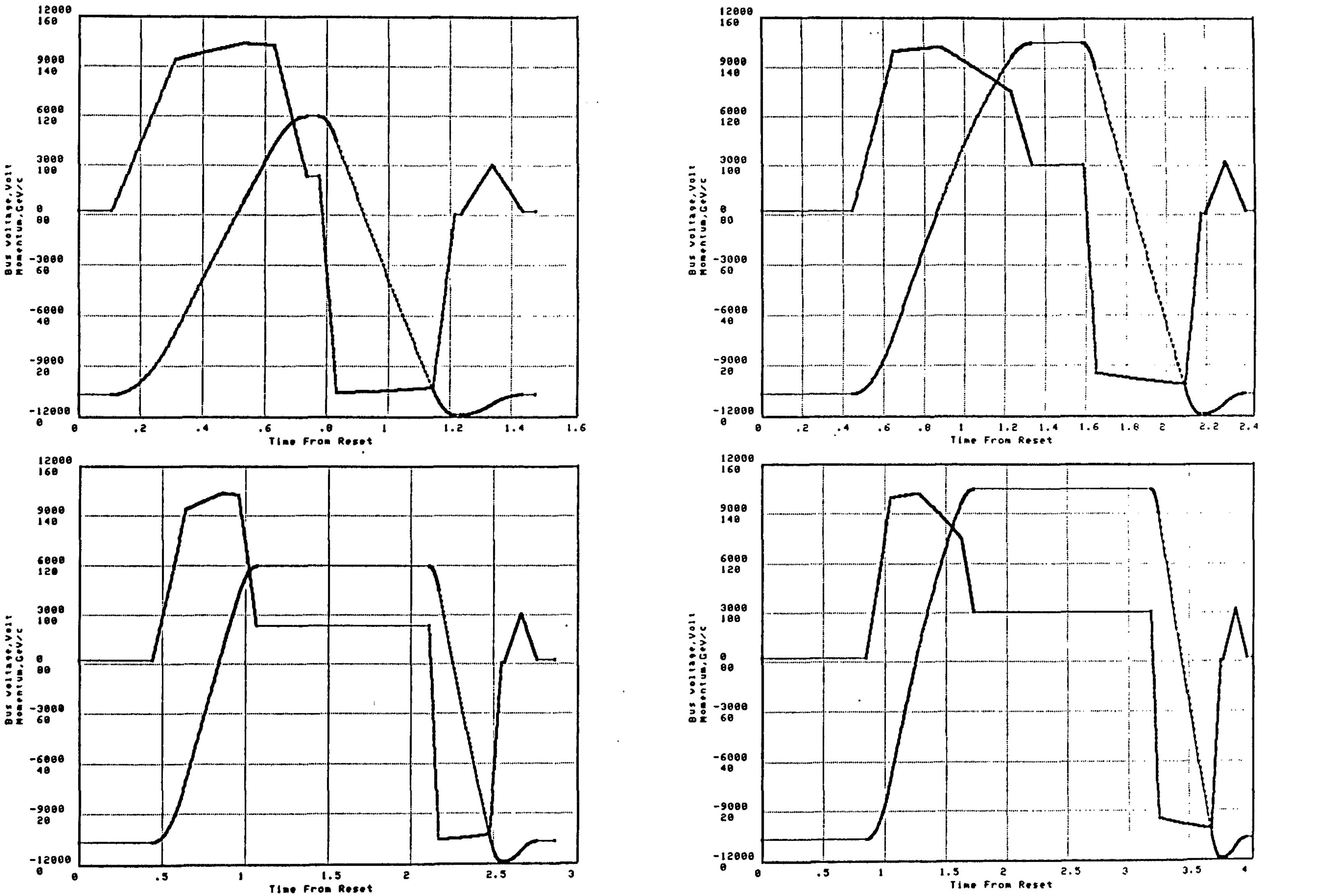

Figure 2.2-1. Acceleration Cycles

a. 120 GeV Antiproton Production

b. 120 GeV Slow Spill

c. 150 GeV Fixed Target Injection

d. 150 GeV Collider Injection

2. The 120 GeV slow spill cycle: 2.9 second cycle with a one second slow spill at 120 GeV to the fixed target area; a variant of this cycle, for fast resonant extraction , requires only a short flattop (1.9 second cycle). Both cycles would normally accelerate six Booster batches (3 x 10^{13} protons). Another variation, which is extremely attractive for fulfilling the demand for protons per hour, is a combination of antiproton production and slow spill. In this case, referred to as "mixed mode", the sixth Booster batch is injected into the center of the 3.2 μsec gap that exists after the first five batches are injected. The beam is accelerated to 120 GeV, the sixth batch is extracted in a single turn to the antiproton production target, and then the remaining beam is extracted by resonant extraction to Switchyard. Compared to running only slow spill or only antiproton production, the mixed mode results in a 17% decrease in protons per hour delivered for slow spill, or a factor of two reduction in protons per hour delivered onto the production target. Interleaving cycles that are dedicated to one or the other does much worse. For example, if the two are interleaved in equal numbers, i.e. one slow spill cycle and one antiproton production cycle, then the slow spill gets only 66% of its maximum, and the production only 34% of its maximum.

3. The Tevatron fixed target injection cycle: 2.4 second cycle for Tevatron injection; six Booster batches accelerated to 150 GeV; two Main Injector cycles are required to fill the Tevatron.

4. The Tevatron collider injection cycle: 4.0 second cycle with a 1.4 second flattop at 150 GeV for coalescing. Three Main Injector cycles are required to fill the Tevatron. Each Main Injector cycle requires the Booster to inject beam as follows. Each Booster cycle injects a small number of bunches, typically 11 bunches; the remaining bunches from the Booster go to the Booster dump. Successive injections place the subsequent bunches 21 rf-buckets apart (center-to-center) for 36-on-36 operation in the Tevatron. Twelve Booster cycles are required to inject the proper number of proton bunches, which fill approximately one-half of the Main Injector circumference. The bunches are then accelerated to 150 GeV, coalesced, and injected into the Tevatron in a single turn. The cycle for injecting antiprotons into the Tevatron will have an identical power supply program. On each cycle, one transfer from the Antiproton Source injects four groups of 11 bunches, the groups being spaced 21 rf-buckets apart (center-to-center), which are accelerated to 150 GeV, coalesced, and injected into the Tevatron in a single turn. Nine Main Injector cycles are required to load the 36 antiproton bunches.

The operational limits for the power supply and rf cavities systems are discussed in Sections 3.3 and 3.4, respectively. The 18 existing Main Ring cavities in their current running mode are adequate for all of the above cycles.

2.3. TRACKING STUDIES

Introduction

This section describes the simulations to study the performance of the Main Injector at the injection energy of 8.9 GeV. These studies of the Main Injector lattice include closed orbit errors, betatron function errors, tune versus amplitude, and dynamic aperture. The tracking calculations include the magnetic field errors, both systematic and random, and misalignment errors. The tracking conditions as well as the errors are described. The thin element tracking program TEAPOT* was used for these simulations.

Tracking Conditions and Errors

The Main Injector lattice has two different types of dipole magnets, with magnetic lengths of 6.096 and 4.064 meters at 120 GeV. The magnetic length of these dipoles decreases with energy due to the saturation of ends, and at 8.9 GeV their length is 2.5 mm larger than the nominal value at 120 GeV. This change in length introduces a non-zero dipole multipole at each end of the magnet, and is represented in TEAPOT by a horizontal kick given by

$$H_{kick} = (\Delta L/2L_{ref}) \times (2\pi/904/3) \quad \text{radians}$$

where ΔL is 2.5 mm. The additional bending is corrected by decreasing the dipole excitation. (The number 904/3 = 301.333... represents the equivalent number of 6-m dipoles in the ring, i.e. 216, the number of actual 6-m dipoles, plus 2/3 times 128, the number of 4-m dipoles. Or, put another way, $2\pi/(904/3)$ is the bend produced by each 6-m dipole.) Table 2.3-1 summarizes all of the multipoles as used in the input file to TEAPOT. Multipole field errors are quoted in units of 10^{-4} at a displacement of one inch.

The ends of the magnet have different magnetic multipoles than the body of the magnet. Further the two ends of the dipole are slightly different due to the presence or absence of nearby bus work, leading to the labels "BUS END" or "NO BUS END" in Table 2.3-1. For the tracking

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* L. Schachinger and R. Talman, Particle Accl. 22, 35(1987).

Table 2.3-1 Magnetic errors used in the 8.9 GeV simulation.

	Multipole	Normal		Skew	
	Order	<bn>	σ_{b_n}	<an>	σ_{a_n}
Dipole Body	dipole	-4.68	10.0	-	-
	quadrupole	-0.13	0.45	-	-
	sextupole	0.43	0.61	-0.04	0.22
	8	0.09	0.13	0.00	0.41
	10	0.18	0.32	0.03	0.15
	12	-0.03	0.10	0.00	0.19
	14	-0.01	0.23	-0.05	0.08
Dipole End BUS	Dipole	2.05	-	0.00	-
	quadrupole	0.03	-	-	-
	sextupole	0.92	-	0.03	-
	8	-0.02	-	0.02	-
	10	-0.09	-	0.04	-
	12	0.04	-	-0.03	-
	14	-0.07	-	0.00	-
Dipole End No BUS	Dipole	2.05	-	0.00	-
	quadrupole	0.03	-	-	-
	sextupole	0.99	-	-0.07	-
	8	-0.08	-	-0.02	-
	10	-0.11	-	-0.05	-
	12	-0.06	-	0.03	-
	14	-0.09	-	0.00	-
Recycled New	quadrupole	-	24.0	-	-
Main Ring	sextupole	0.50	2.73	0.12	1.85
Quadrupole	8	5.85	1.02	-1.16	2.38
	10	-0.10	1.12	0.42	0.47
	12	-1.82	0.63	0.40	0.70
	14	0.21	0.64	-0.55	0.44
	16	1.41	0.64	-	-
	18	-0.03	0.12	0.14	0.16
	20	-0.80	0.06	0.02	0.07
Newly Built	quadrupole	-	24.0	-	-
MI Quads	sextupole	-	2.73	-	-
	8	-0.39	1.02	-	-
	10	-	1.12	-	-
	12	-1.39	0.63	-	-
	14	-	0.64	-	-
	16	1.29	0.64	-	-
	18	-	0.12	-	-
	20	-0.73	0.06	-	-

calculation the two ends and the body are treated as separate magnets. The end multipoles, both normal and skew, are calculated from magnetic measurements of the prototype dipoles, discussed in Chapter 3.1. Multipole error values quoted for the dipole ends are obtained by dividing the integrated multipole moments by eight, (the length of a long dipole magnet 240" divided by 30"), so that their values can be compared directly with the dipole body multipole errors. The random errors of the body multipoles are calculated from measurements of B2 dipoles at 210 A.

The values of the systematic and random errors of the quadrupoles are calculated using the Main Ring quadrupole measurements. There are a very limited number of measurements available for MR quads. Normal multipoles are calculated by using the 195 A measurements, whereas the skew multipoles are calculated using the measurements at 1575 A. The variation of the octupole strength and random errors with current are small.

Skew quadrupole field errors are ignored in the simulation, since these linear coupling effects can be removed by using a coupling compensation scheme.

Misalignments of all the magnetic elements and beam position monitors are included in this calculation. The one-sigma deviation of the alignment error with respect to the closed orbit is 0.25 mm in both horizontal and vertical directions. In addition dipole magnets have a roll angle deviation of 0.5 mr sigma.

Base tunes of $(Q_x, Q_y) = (26.425, 25.415)$ are used in all the simulations. These tunes are different than the values (26.407, 25.409) used in previous Main Injector calculations. These changes in tunes increase the dynamic aperture, with all magnetic and misalignment errors turned on, in the presence of synchrotron oscillations, and with chromaticity adjusted to -5,-5. In the lattice there are 18 rf cavities, each operating at $V_{rf} = 0.0218$ MV. The rf frequency is set to 53 MHz corresponding to a harmonic number of 588.

Closed Orbit Errors and Corrector Strength

In the Main Injector lattice there are 208 quadrupoles. Located inside these quadrupoles are the beam position monitors. The vertical and horizontal beam position are measured at the focusing and defocusing quadrupoles respectively. The vertical and horizontal displacement of the particles are corrected by applying corresponding kicks just after these position monitors.

A typical uncorrected closed orbit in both the horizontal and vertical plane is shown in Figure 2.3-1. The average rms closed orbit deviation before correction is 7.2 mm horizontal and 5.2 mm vertical for the selected seed. After three iterations of the orbit corrections the average rms closed orbit deviation is reduced to 0.12 mm (H) and 8×10^{-3} mm (V).

The contribution from each magnetic error and of the displacement error to the average rms closed orbit deviation for this seed has been studied. The total error is not a simple combination of all of these errors. There are some cancellations between errors. The results are summarized in Table 2.3-2. Most of the orbit deviation is due to random errors. Figure 2.3-2 shows the distribution of uncorrected horizontal and vertical rms closed orbit errors for 20 different seeds. The average rms deviation of each seed is 7 mm and 6 mm in the horizontal and vertical planes respectively. The maximum corrector strength required to correct these orbit deviations is 150 μr in both planes. The Main Injector is provided with new dipole correctors which can provide 2000 μr and 1300 μr of horizontal and vertical correction at 8 GeV.

Table 2.3-2. Closed orbit errors (in mm) for one seed.

Error(s)	H	V
All	5.8	6.7
Dipole Systematic (including ΔL)	3.2	0.0
Dipole Random	5.72	0.0
Quad Systematic	0.0	0.0
Quad Random	0.0	0.0
Displacement and Rotational Error	5.1	5.8
Change of Effective Length	3.2	small

Betatron Function Errors

Figure 2.3-3(a) shows a plot of the square roots of the horizontal and vertical ß functions of the Main Injector without any errors. In all of these figures the solid line represents β_x and the dashed line β_y. The root ß calculated without including any errors with TEAPOT is the same as calculated previously for the FMI using MAD. Figure 2.3-3(b) is a plot of $\Delta\beta/\beta$ with all errors included. Further studies have shown that the asymmetry between the left and right half of the figure is due to random errors. When plots like Figure 2.3-3(b) are done for different seeds, the σ of the deviations is about 10%. Figures 2.3-4(a) through 2.3-4(f) show the percentage change in ß function due to (a) dipole systematic errors which includes the effect of change in the effective length of the dipole magnets, (b) only the change in effective length of dipole magnets, (c) dipole random errors, (d) quadrupole systematic errors, (e) quadrupole random errors, and (f) magnet alignment errors, respectively. The seed which generated Figure 2.3-3(b) was selected for these figures. It is clear from these figures that most of the ß function variations are due to dipole and

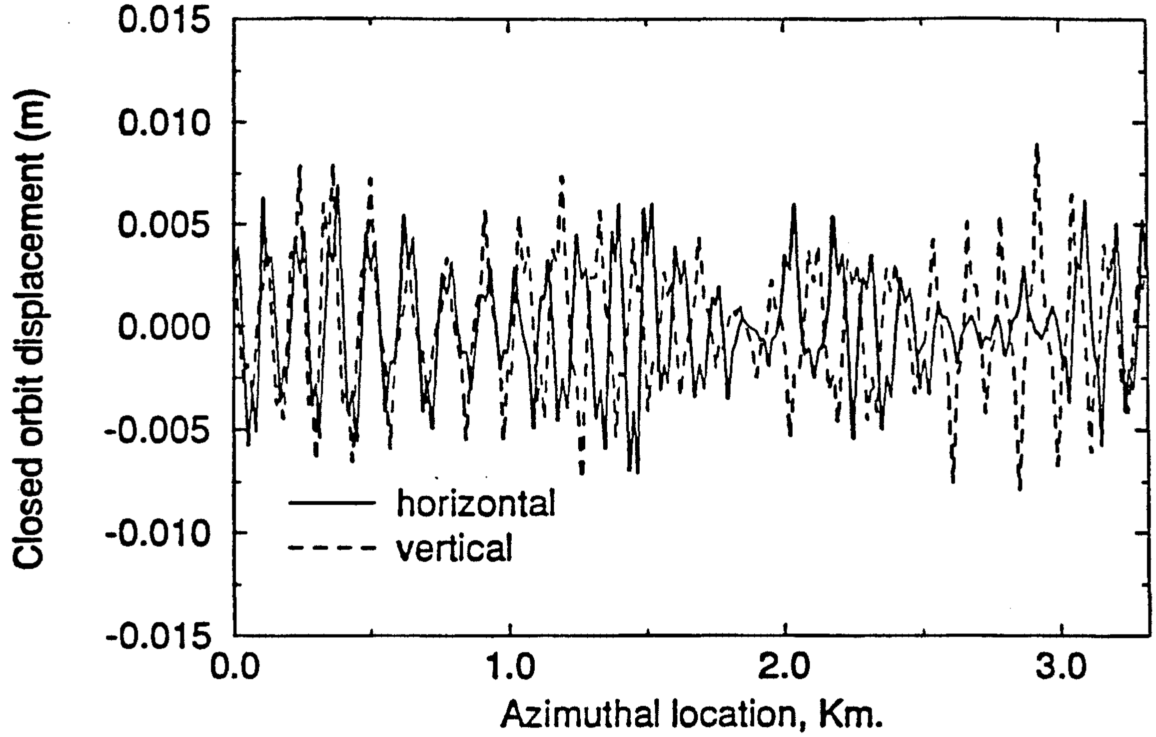

Figure 2.3-1. Closed Orbit Errors Before Correction

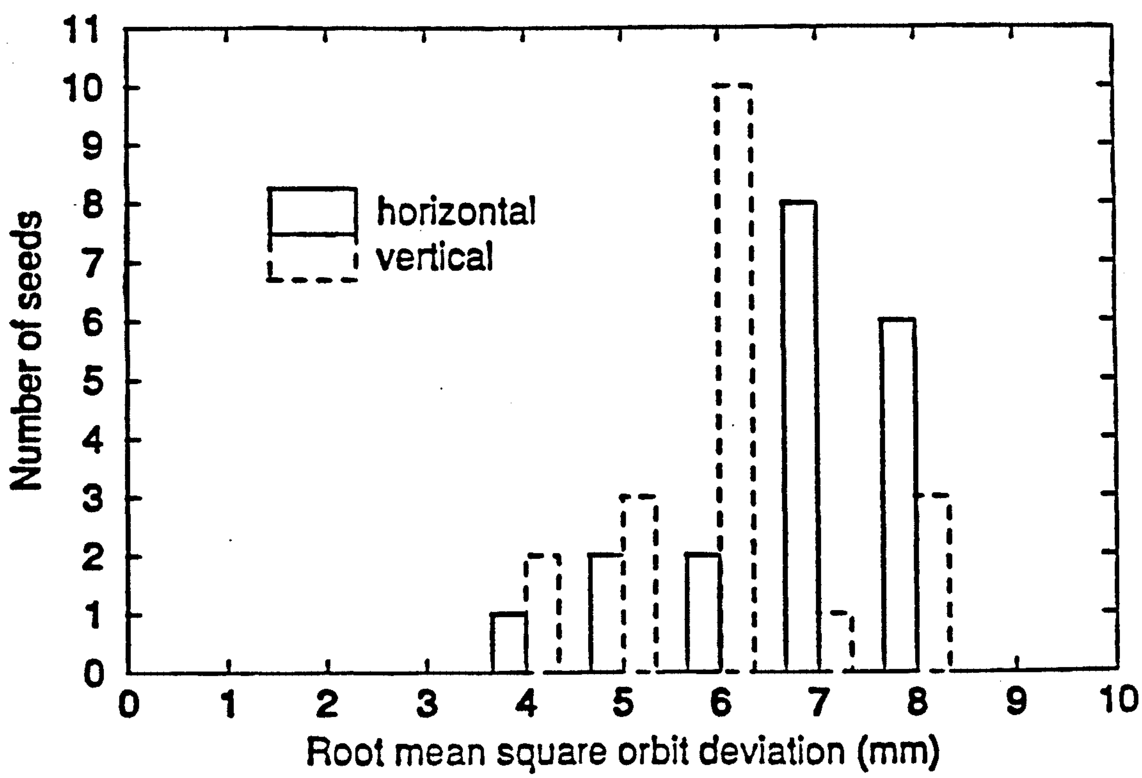

Figure 2.3-2. Histogram of Closed Orbit Errors Before Correction

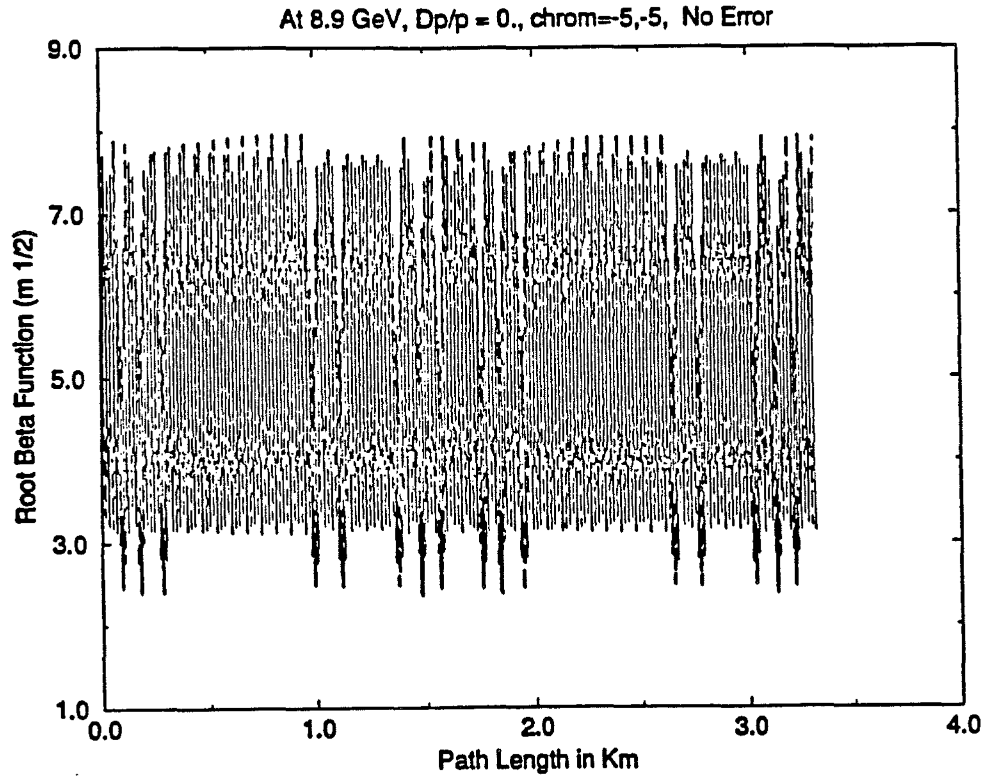

Figure 2.3-3(a). Beta Function with No Errors

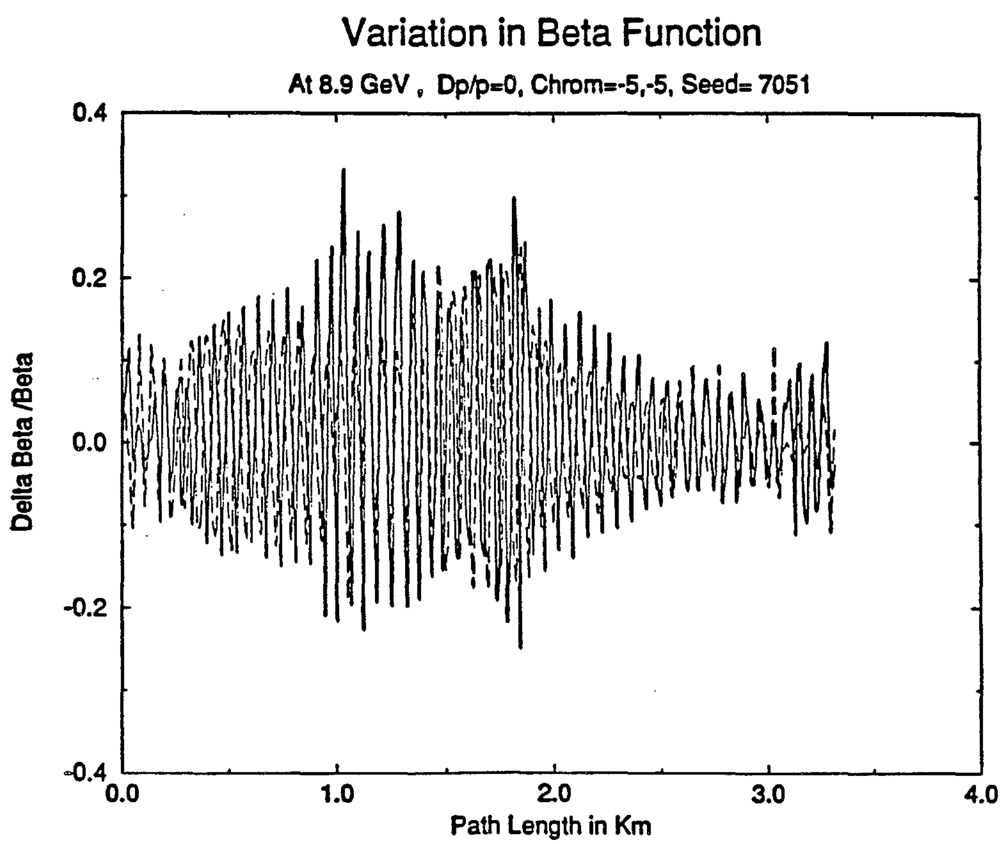

Figure 2.3-3(b). Variation in Beta Function with Errors Turned On

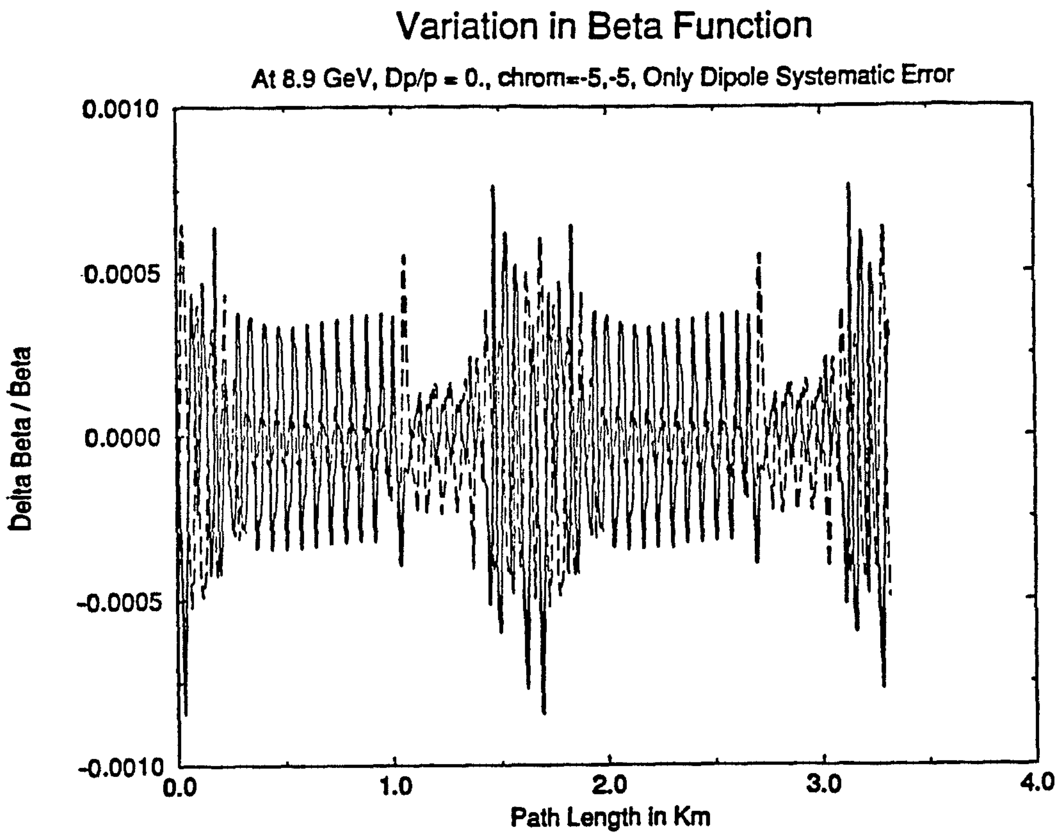

Figure 2.3-4(a). Variation in Beta Function with Dipole Systematic Errors

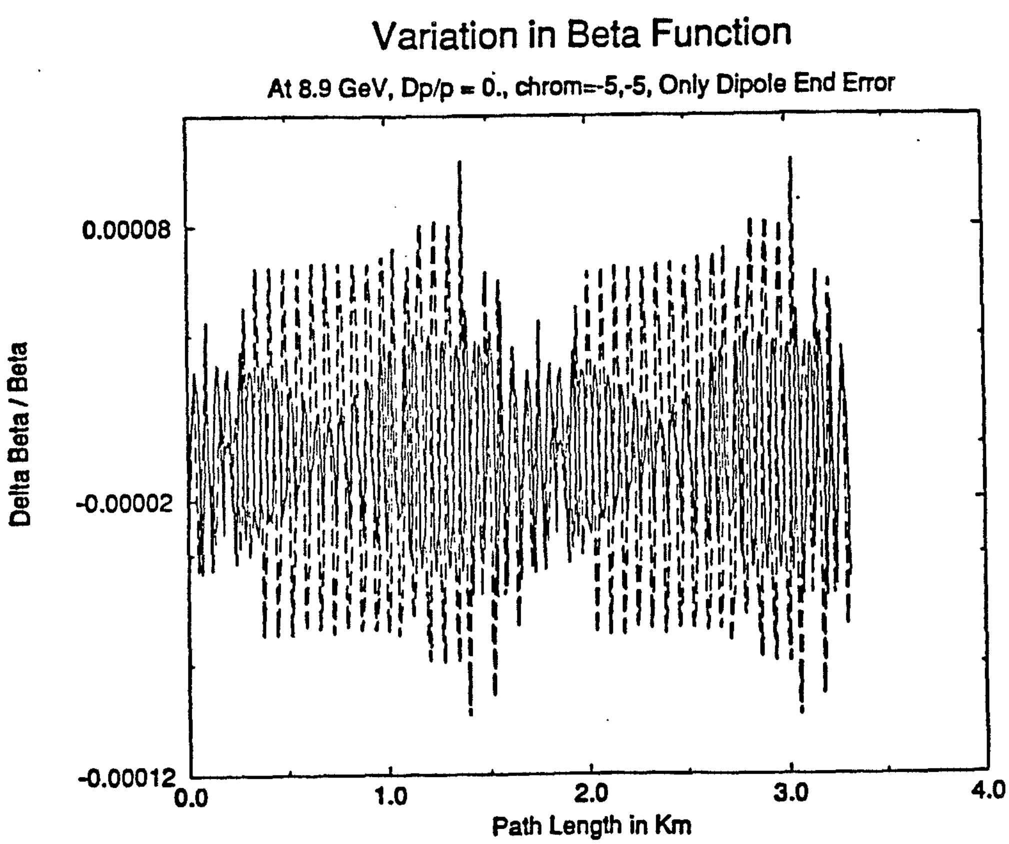

Figure 2.3-4(b). Variation in Beta Function with Dipole End Errors

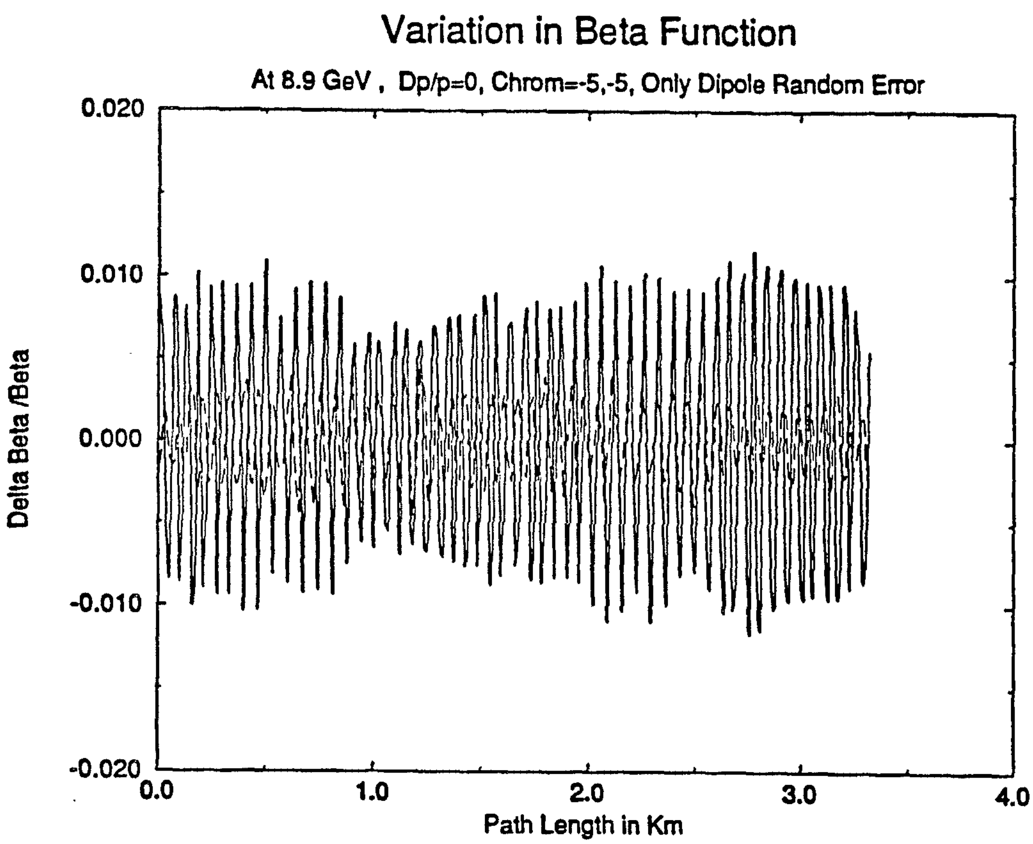

Figure 2.3-4(c). Variation in Beta Function with Dipole Random Errors

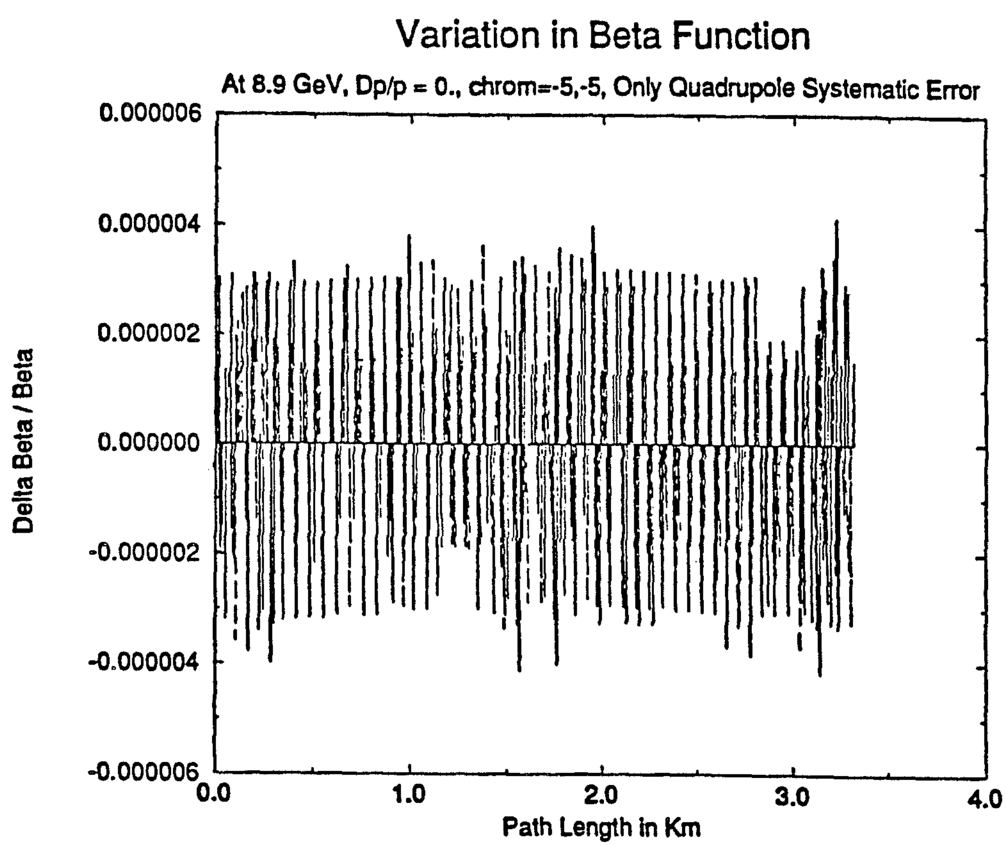

Figure 2.3-4(d). Variation in Beta Function with Quadrupole Systematic Errors

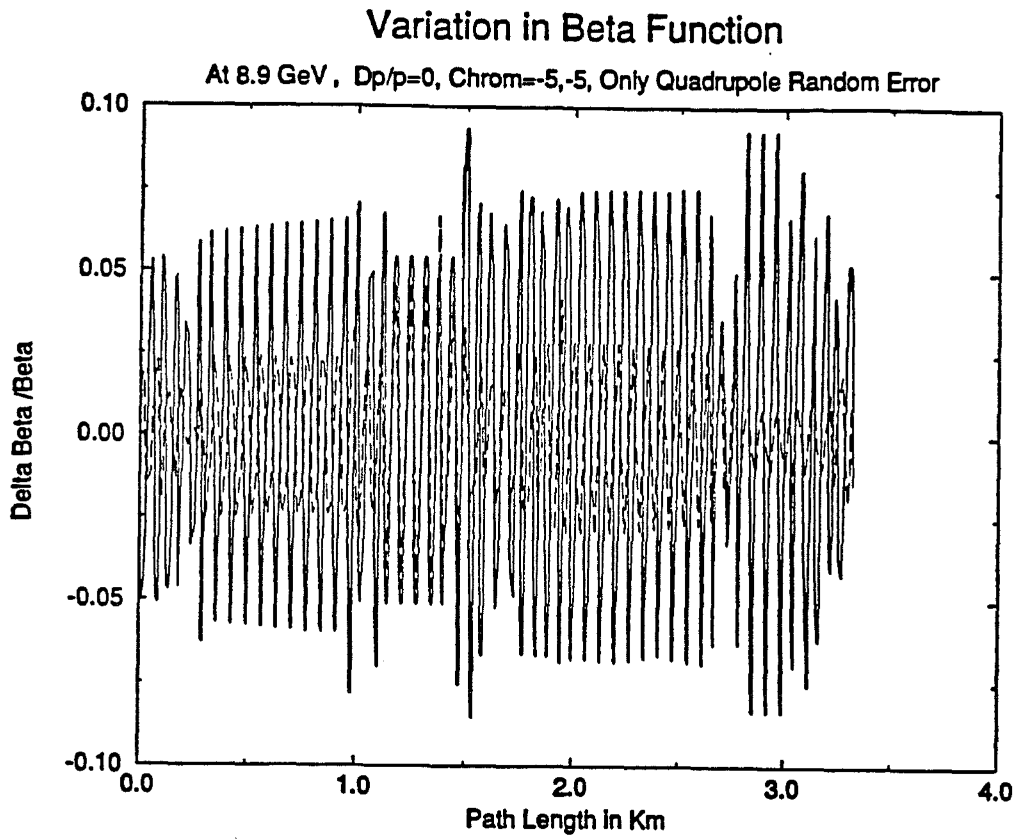

Figure 2.3-4(e). Variation in Beta Function with Quadrupole Random Errors

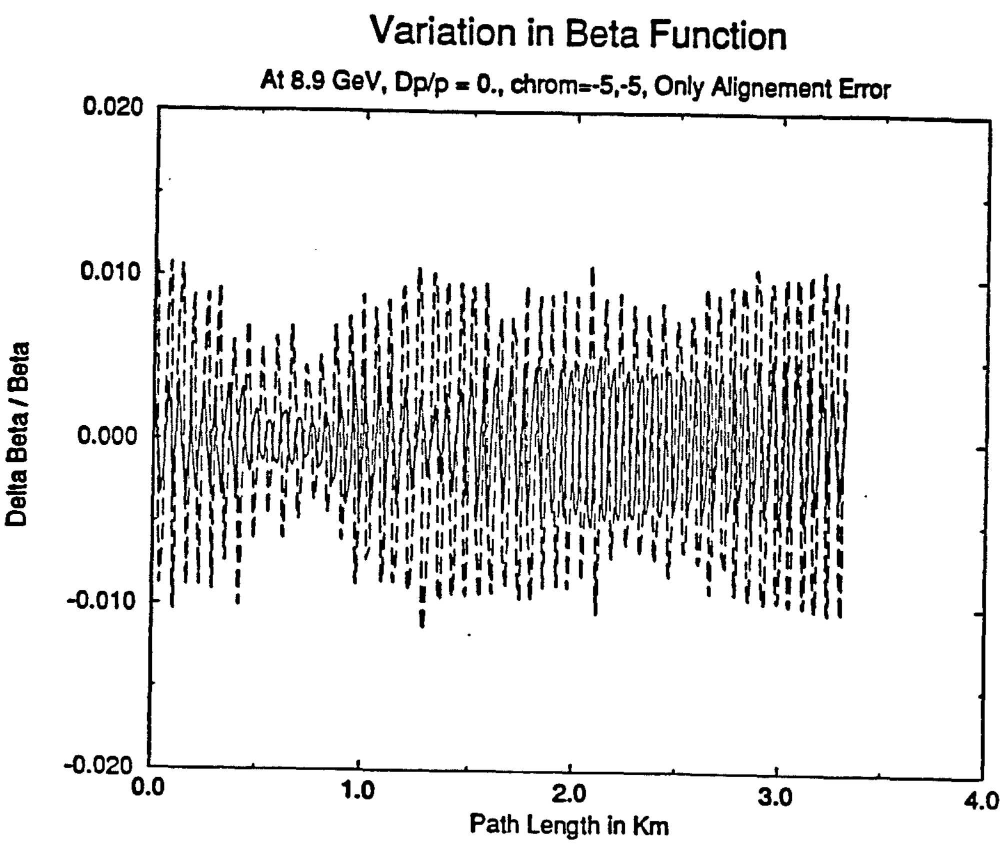

Figure 2.3-4(f). Variation in Beta Function with Alignment Errors

quadrupole random errors and magnet alignment errors. The randomness of these errors leads to an asymmetry between the two halves of the FMI which is a result of some kind of cancellation between these errors. A shuffling scheme for the placement of the quadrupoles is being developed.

Tune Versus Amplitude and Dynamical Aperture Results

The survival of particles launched at different amplitudes in the Main Injector at the injection energy has been studied. A single particle executes up to 35,000 turns at the injection energy of 8 GeV during any operation that involves filling the ring with six Booster batches. A particle is launched with a maximum horizontal displacement equal to "A" at a location where the horizontal ß function is at its maximum of 80 meters. The maximum vertical displacement of the same particle is 0.4A (x/y=2.5) also at ß of 80 meters. Synchrotron oscillation are included in the simulation by launching all particles with an amplitude of $\delta_{max} = (\Delta p/p)_{max} = .002$

Figure 2.3-5 shows the variation of horizontal and vertical tunes as the amplitudes of the motion is increased. The numbers on the tune plot correspond to the initial amplitude "A" of a test particle, in millimeters. Points on the plot lie on a straight line up to an amplitude of about 17 mm, with the spacing between points increasing linearly. Both the horizontal and vertical tunes depend quadratically on amplitude, for moderate amplitudes. This octupolar detuning is dominated by a combination of the systematic octupole error in the recycled Main Ring quadrupoles, and second order sextupole effects. Particles were launched from 1 mm to 25 mm amplitude. Particles with an amplitude above 19 mm did not survive for the full 35000 turns of the simulation, for this particular seed. Similar simulations were performed for five different seeds. Figure 2.3-6 is a survival plot, displaying how many turns a particle survives in the Main Injector, as a function of initial amplitude. If the dynamical aperture of the machine is defined as the smallest amplitude particle that did not survive for 35,000 turns, then the dynamical aperture for the Main Injector at the injection energy is predicted to be 22 ± 1.4 mm, corresponding to a normalized emittance of 59.2 ± 10.2π mm-mr.

To study the detuning effects the octupole strength of the Main Ring quadrupole and sextupole strength of the Main Injector dipole ends were varied. Reducing the end sextupole to half the nominal value has no significant effect on the quadratic detuning. Also there is no change to the dynamic aperture of the machine. When the octupole (b_3) component of the quadrupole is set to zero, the detuning is very small. Figure 2.3-7 is a tune-tune plot for different initial amplitudes with half nominal sextupole strength of the dipole ends and $b_3 = 0$ for the MR quads. This study was done for only one seed. For this seed, and with the nominal octupole-

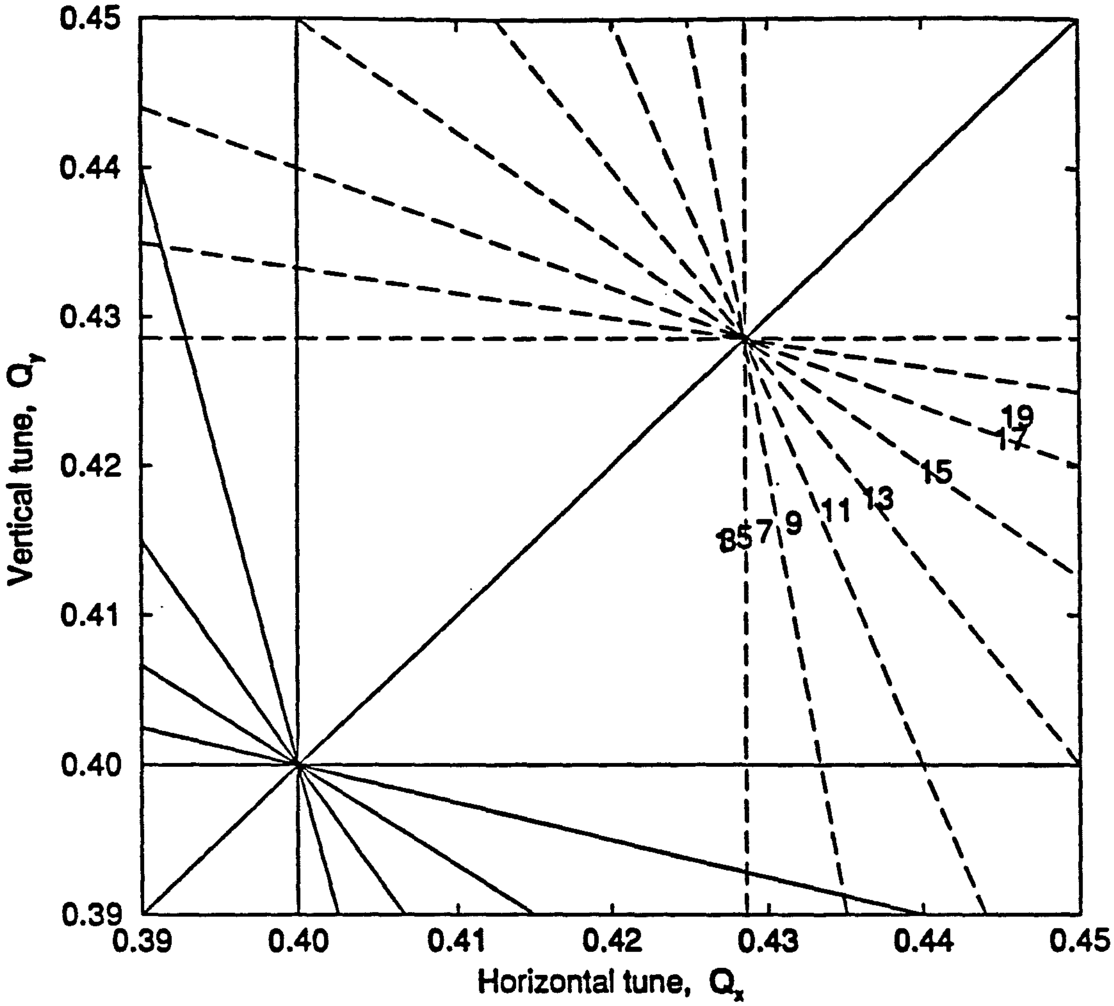

Figure 2.3-5.Tune-Tune Plot.
Numbers 1 to 19 are Initial Amplitude of the Launched Particle

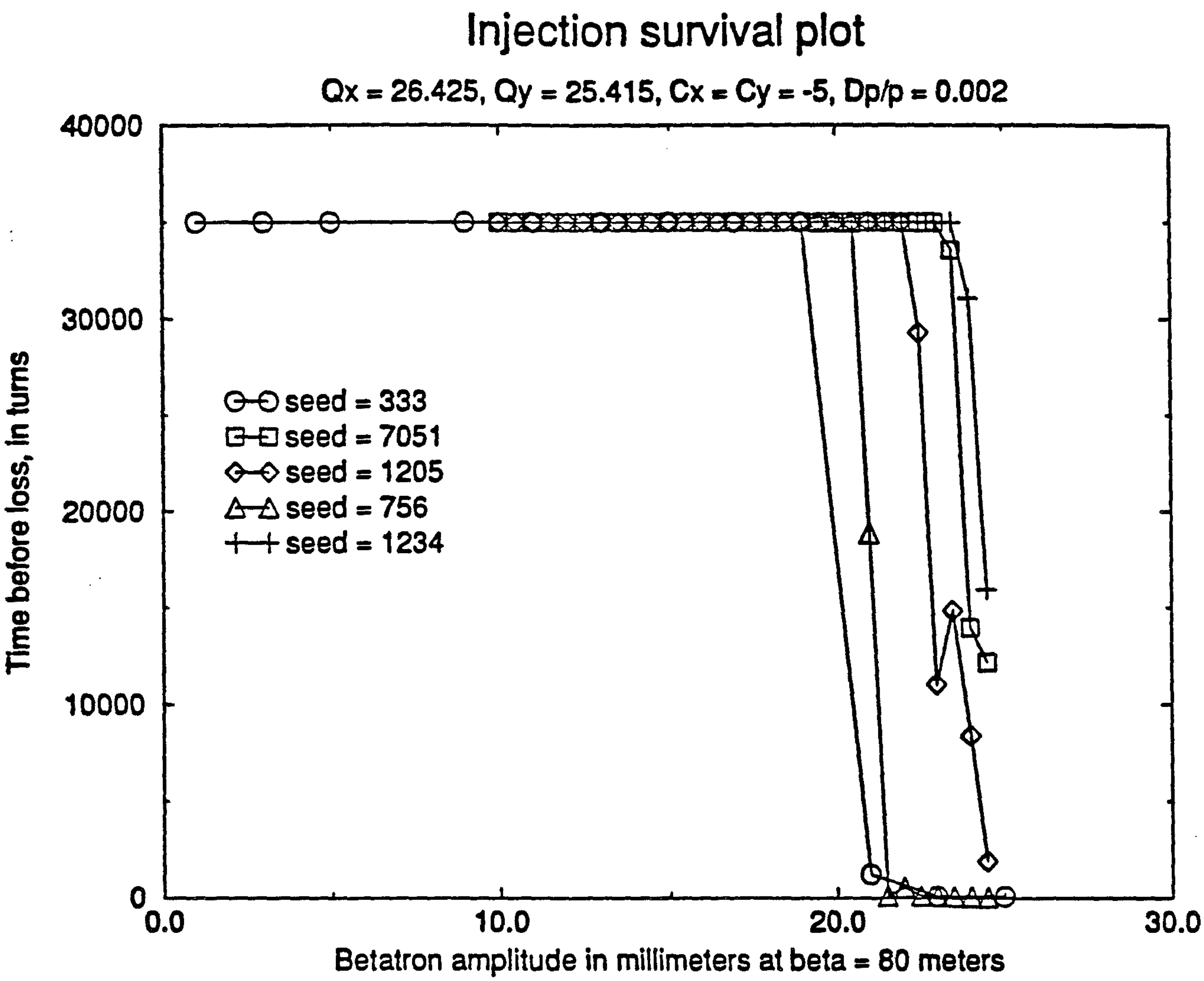

Figure 2.3-6. Injection Survival Plot for Five Seeds

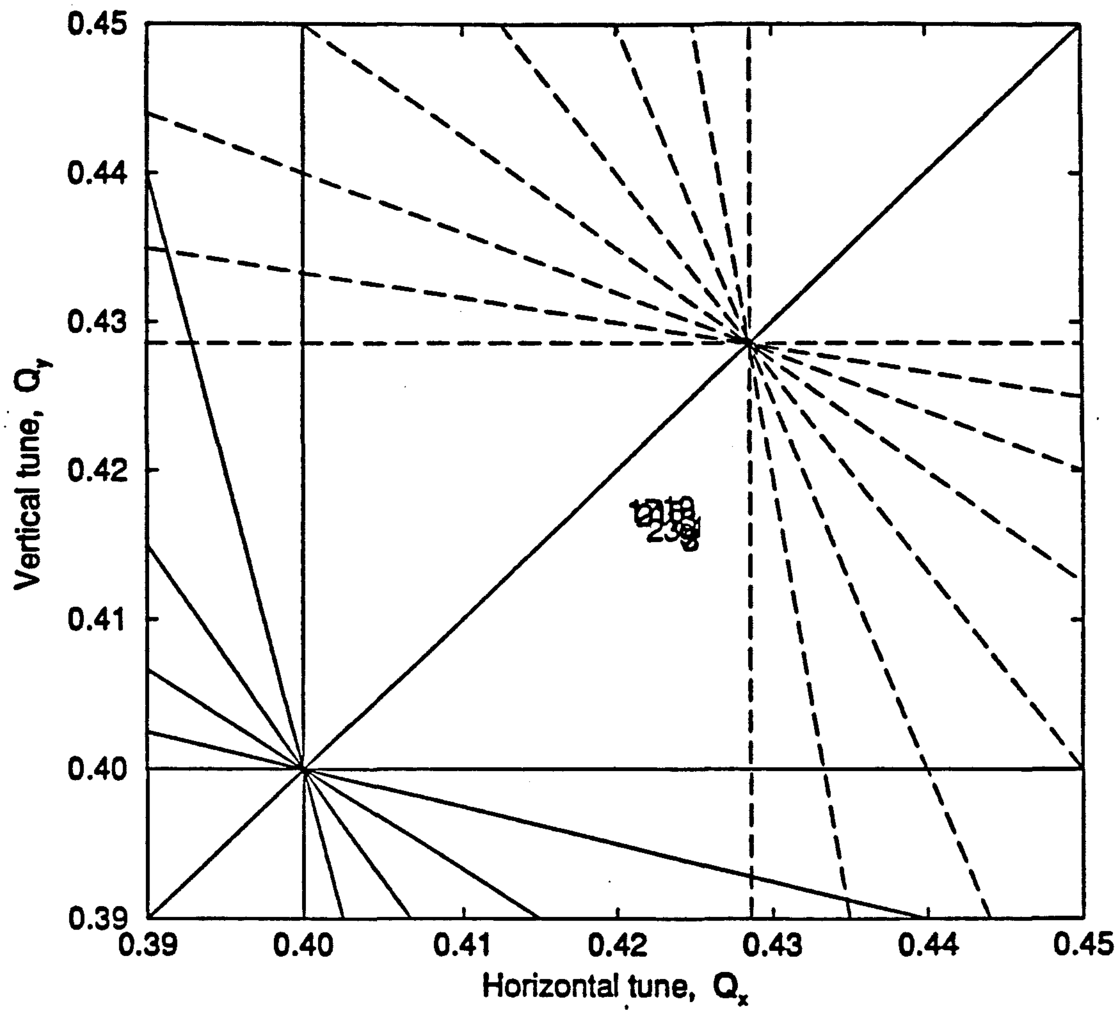

Figure 2.3-7.Tune-Tune Plot with No Octupole Component in Quadrupoles and One-Half the Sextupole Component in the Dipole Ends

component of the MR quadrupoles, particles with amplitude larger than 19 mm did not survive. Particles with amplitude larger than 24 mm did not survive when $b_3 = 0$ for the MR quads. A correction scheme, using the octupole correctors placed in the ring for 120 GeV slow extraction, is being developed to cancel or reduce the total octupole of the ring at 8.9 GeV. This will improve the dynamic aperture of the FMI.

2.4. BEAMLINES AND BEAM TRANSFERS

Five new beamlines with a combined length of about 1,425 m are required to integrate the FMI into the existing Fermilab accelerator complex. The notation in brackets following each item refers to the engineering drawings which provide details of the beamline magnetic elements and enclosures. Lattice descriptions of each of these may be found in the Appendices.

1. A 760 m beamline for transporting the 8.9 GeV/c protons from Booster straight section L3 to the FMI injection point in straight section MI-10. [AS-9 through AS-16]

2. A 260 m beamline to transport 150 GeV/c antiprotons from the MI-62 straight section in the FMI to the Tevatron F0 straight section. [AS-3, AS-5, AS-6]

3. A 260 m Tevatron injection beamline which transports 150 GeV/c protons from the MI-52 straight section to the Tevatron F0 straight section. [AS-3, AS-5, AS-6]

4. A 15 m magnet section to match between the Tevatron injection Lambertsons and Main Ring station F11. [AS-3]

To connect the Main Injector complex with the Antiproton Source and Switchyard most of the existing magnets and power supplies in F-Sector (from F0 to A0) of the Main Ring and in the AP-1 beamline remain in place. The 150 GeV/c line from MI-52 also provides the link between the Injector and the F-Sector magnet string of the Main Ring. This dual functionality of the 150 GeV/c line is made possible by using the Tevatron injection Lambertsons as a magnetic switch for selecting either the Tevatron or Main Ring F-Sector. Figure 2.4-1 shows an elevation view of the Tevatron F0 straight section.

The 120 GeV protons used for antiproton production are transferred at Main Ring station F17 into the existing AP-1 beamline. This section of beamline is also used to transfer 8.9 GeV/c antiprotons from the Antiproton Source to MI-52 for injection into the FMI. The 120 GeV/c protons used for test beams are transported through the entire F-Sector to A0 where the fifth beamline is installed.

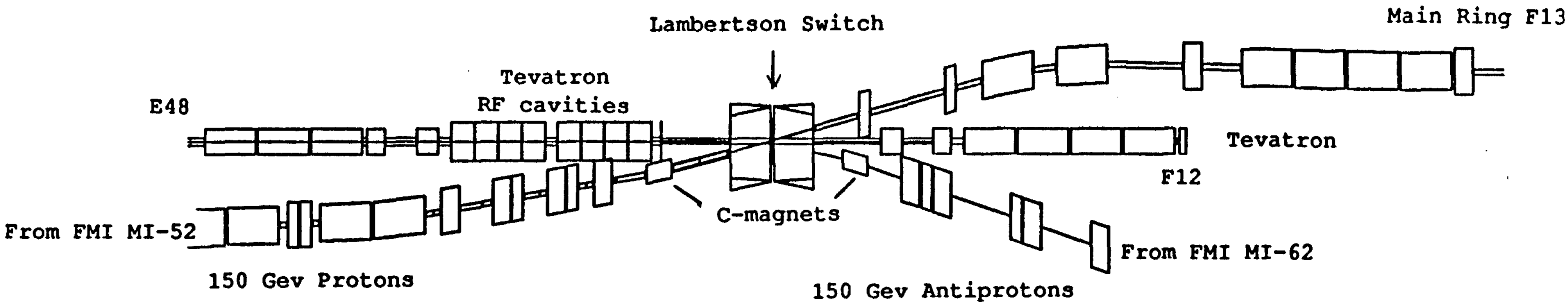

Figure 2.4-1. Elevation View of the Tevatron F0 Straight Section

5. A 130 m section which connects F49 to the upstream end of the Switchyard.

Finally, a sixth beamline is required to transport beam to the abort dump.

6. A 140 m beamline transport beam out of the FMI enclose at the MI-40 straight section. The last 30 m are simply a drift from the enclosure to the dump itself. This beamline must be capable of transporting beam at any energy between 8 GeV and 150 GeV. [AS-4]

The layout of the beamlines and site coordinates of all beamline elements have been determined. Optical designs exist for the 8.9 GeV/c Booster to FMI line, the two 150 GeV/c FMI to Tevatron beamlines, and the FMI to Main Ring F11 beamlines. With a few exceptions, that are discussed in a subsequent section, all beamline dipoles and quadrupoles are recycled from the Main Ring and existing 8.9 GeV/c beamline. Every quadrupole focusing center has associated with it a beam position monitor and correction dipole recycled from the Main Ring.

2.4.1. The 8 GeV Line

Protons extracted from the Booster are transported 760 m for injection into the FMI. The 8 GeV transport line is comprised of four major sections: a matching section between the Booster and the main body of the beamline; descent from the Booster to Main Injector elevation; a long section of periodic FODO cells; and a final matching section into the FMI. Design of the 8 GeV line is driven by the desire to optimize utilization of recycled Main Ring magnets consistent with minimizing the impact of the line on existing roads and structures.

Protons are extracted horizontally from the Booster at straight section L3. Two Main Ring EPB dipoles centered 10.6 m downstream of the extraction point provide 9.37° of horizontal bend to steer the beam into the existing AP-4 enclosure. A third EPB, centered 18.2 m further downstream, bends the beam through 4.64° to put it on a line parallel to, and 2'6" away from, the wall of the enclosure. The line extends another 34.4 m to the end of the existing enclosure. Two SDB dipoles, separated by 26.7 m, then provide 11.0° of bend each to steer the beam sharply away from the existing AP-4 line trajectory. This completes the Booster matching section.

Immediately following this matching section a Main Ring B3 dipole pitches the beam downwards by 3.0°. Once the 10'9" corresponding to the Booster-FMI elevation difference is obtained, another Main Ring B3 cancels the beam's downward slope.

One hundred and twelve degrees (112°) of horizontal bend are achieved in the next 555 m of the line by 51 Main Ring B2/B3 dipoles embedded in a regular FODO lattice. The trajectory of the line through this section takes the protons 10'9" below the existing AP2/AP3 enclosure, or 16'9" below the AP2/AP3 beamlines. The closest distance of approach of the 8 GeV line to the Tevatron is approximately 100'. The final 2° of horizontal bend from the recycled A0 Lambertson places the protons on the horizontal closed orbit of the FMI. The 8 GeV proton line terminates at the defocusing quadrupole (quad #101) situated 17 m upstream of the MI-10 straight section center.

Optics

Lattice functions for the 8 GeV line are illustrated in Figure 2.4-2(a). The corresponding 40π mm-mr beam envelopes and magnet apertures are shown in Figure 2.4-2(b) The Booster matching section employs 6 SQA quadrupoles, powered individually, to obtain the optical match between lattice functions of the Booster and the standard values of the beamline. The transverse beam size reaches its maximum in this section of the line. With ß~90 m in the vertical plane and a normalized transverse emittance of 40π mm-mr, the maximum beam size is ±20 mm; much less than the 3.5" pole-tip diameter of the SQA quadrupole. The vertical drop to the FMI elevation is achieved in a special insertion section. Five SQA quads, four of which are powered in series, produce the 360° of betatron phase advance that ensures the vertical drop is achromatic. Vertical dispersion does not exceed 0.70 m, and ß is less than 65 m. The 555 m of 90° FODO cells is constructed from units of regular cells containing 4 dipoles per cell interfaced with dispersion suppressing cells with 2 dipoles per cell. This produces locations of zero horizontal dispersion and minimizes dispersion through the arcs. The lattice functions at the interface of the cells is shown in Figure 2.4-3. Horizontal dispersion does not exceed 3.12 m and, with the choice of 51.0 m for the maximum ß, the transverse beam size is less than ±16 mm for a 40π mm-mr emittance and $\Delta p/p$ of 0.002. With each dipole producing a bend of 2.20° the sagitta is only 1.15", which is perfectly acceptable. The FODO section contains 34 SQA quads, all powered in series, and 51 B2 dipoles powered in series. The final six SQA quads in the line are run on separate supplies, and perform the optical match to the FMI.

Correction Elements

Every quadrupole in the 8 GeV line has both a BPM and recycled Main Ring correction dipole associated with it. For 8.9 GeV/c protons the angular correction produced by Main Ring shimmed horizontal (2"x5" aperture) and vertical (2"x4" aperture) dipoles is θ = 445 µr and 335 µr, respectively, at 5 A. These provide the ability to correct for central trajectory errors induced, predominantly, by dipole field errors and magnet misalignments. Sensitive steering capability becomes particularly important in the FODO region of the beamline, where individual current adjustment to the 51 dipoles is not available.

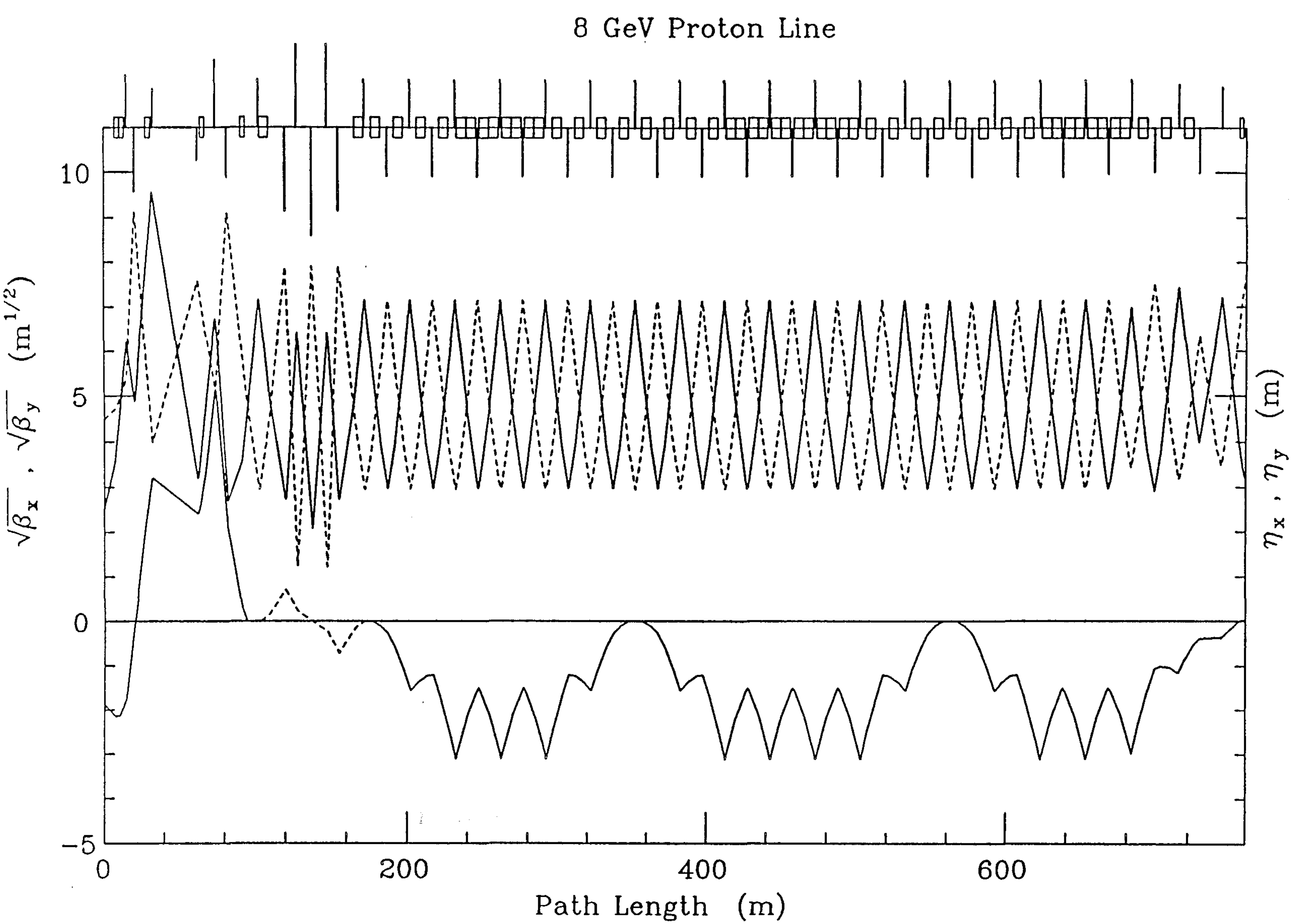

Figure 2.4-2(a). 8 GeV Line Lattice Functions.

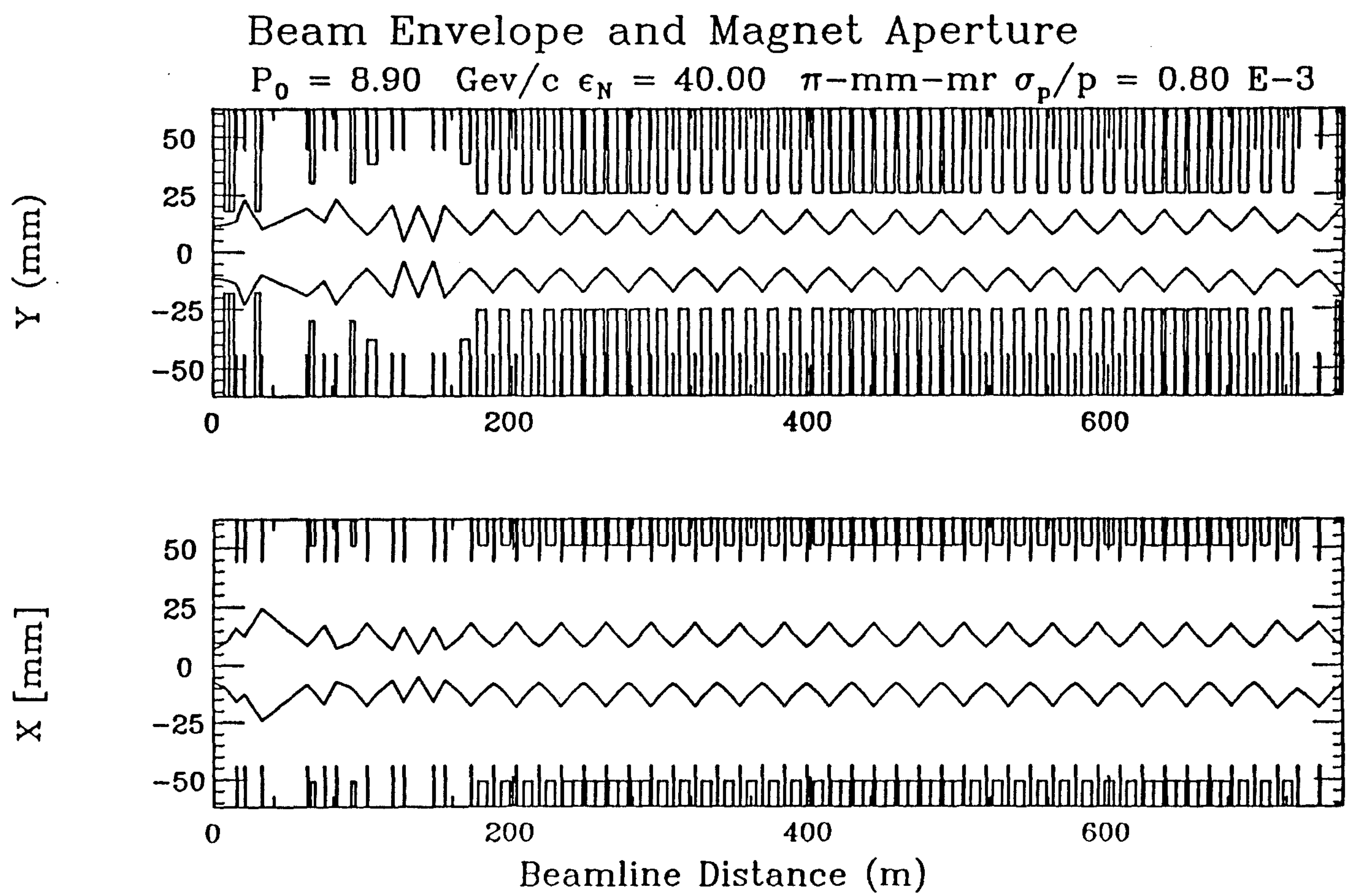

Figure 2.4-2(b). 8 GeV Line Beam Envelope and Magnet Apertures.

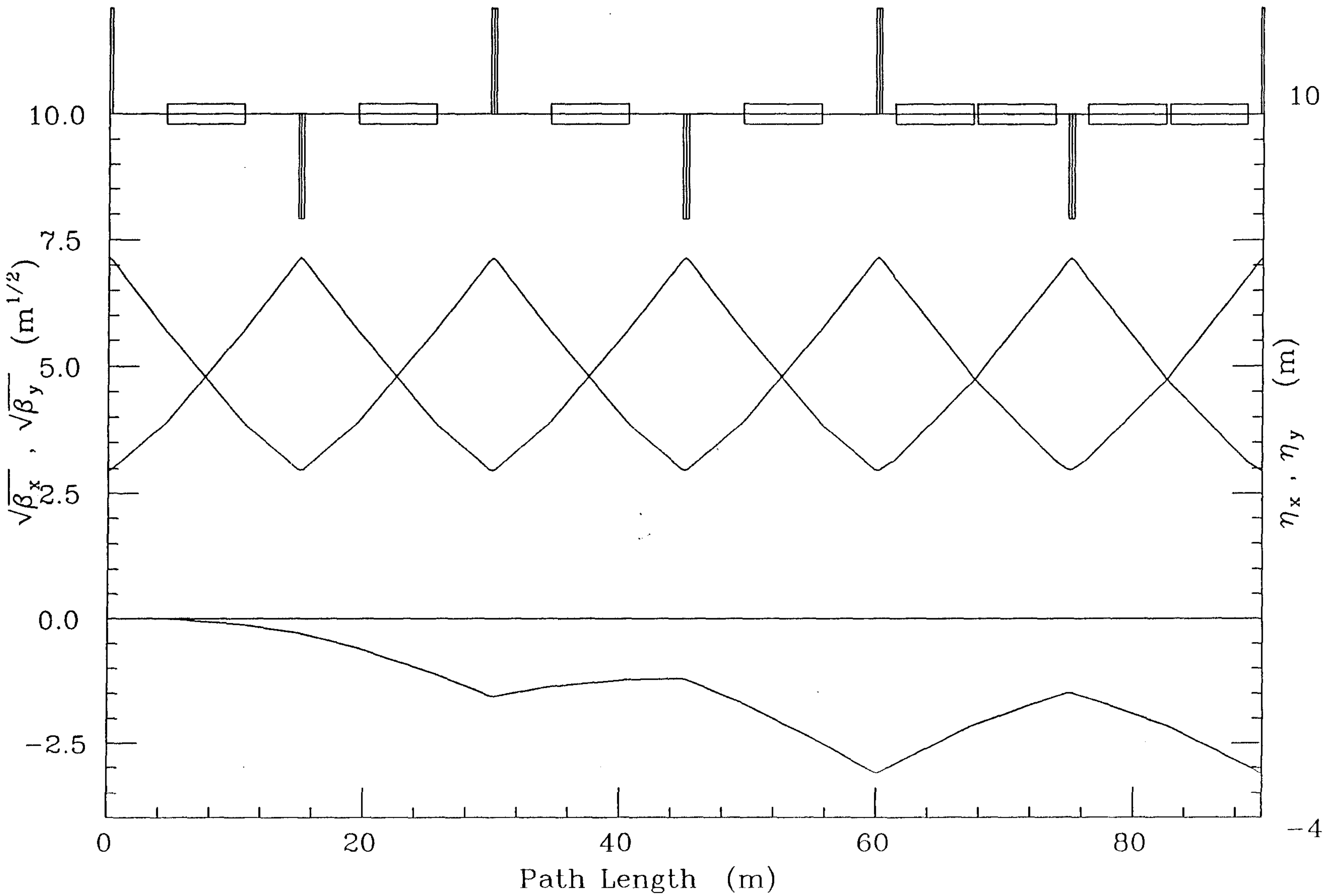

Figure 2.4-3. 8 GeV Line Lattice Functions at Interface Between Regular and Dispersion-Suppressor Cells

The effect of random magnet errors on the trajectory, and the consequent dipole strengths required for correction, have been investigated in simulations. The alignment errors assumed in the simulation, $\sigma_x = \sigma_y = 0.25$ mm and $\sigma_{roll} = 0.50$ mr, are consistent with the accuracy expected from conventional alignment techniques. The dipole error of $\sigma(\Delta B/B) = 0.25\%$ is determined from measurements of the Main Ring B2 magnets. Since some selection among the recycled B2 magnets for the beamlines is possible, this error includes a safety factor.

Figure 2.4-4(a) illustrates possible deviations of the central trajectory from the ideal orbit in the long FODO section due to random dipole errors and misalignments. The 20 curves represented in the figure are the composite results from 20 different random generator seeds. The maximum excursions of the trajectories are $\Delta x \sim \pm 42$ mm and $\Delta y \sim \pm 12$ mm. The 'worst-case' trajectory is shown in Figure 2.4-4(b) before and after it has been corrected based on the BPM readings. The deviations of the trajectory are reduced to $\Delta x(\max) = 1.15$ mm, $\Delta x(\text{rms}) = 0.39$ mm, and $\Delta y(\max) = 0.28$ mm, $\Delta y(\text{rms}) = 0.14$ mm. The maximum dipole strengths required are only $\theta_H = 386$ μr and $\theta_V = 86$ μr; well within the limits of Main Ring corrector capabilities.

FMI Injection

Injection of 8.9 GeV/c protons is accomplished in the FMI straight section MI-10. The straight section is approximately 69 m long and has to accommodate the horizontal injection Lambertson and vertical kickers. The recycled A0 Lambertson is located at the FMI defocusing quad 17 m upstream of the straight section center; this quadrupole must be rotated by 90° to provide adequate vertical aperture for the injected beam. The beam trajectory in the horizontal plane at the entrance to the Lambertson is displaced 38.9 mm from center with a 34 mr angle. Vertically, the beam is 40 mm above the center of the aperture; the FMI circulating beam is displaced 10 mm downwards. The beam is steered through the Lambertson with a small vertical pitch of ~165 μr to cancel the off-axis dipole kick it receives from the downstream FMI quadrupole. The Lambertson removes the 34 mr angle to bring the beam onto the horizontal closed orbit of the FMI. Figure 2.4-5 shows the Lambertson and quadrupole magnet apertures and 40π mm-mr beam profiles at 8 GeV and 150 GeV.

Three MK-90 kicker modules located 90° downstream of the Lambertson provide the 0.95 mr of vertical kick necessary to cancel the 50 mm vertical offset present at the Lambertson. This places the injected protons onto the vertical closed orbit of the Main Injector.

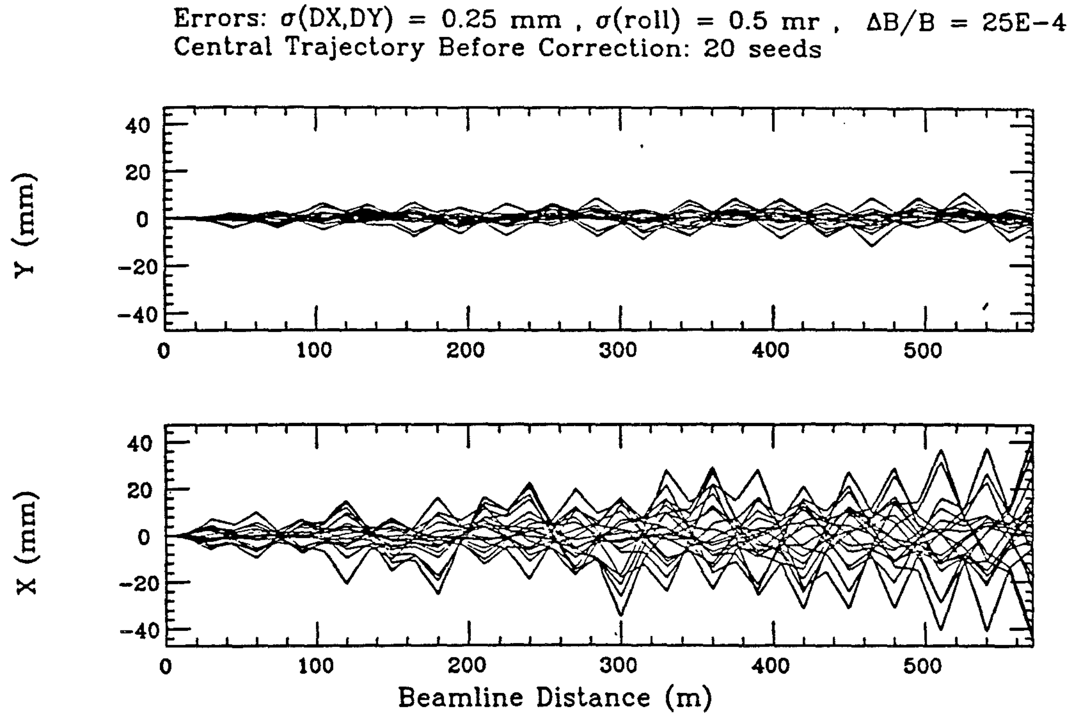

Figure 2.4-4(a). Uncorrected Orbit Errors in the 8 GeV Line

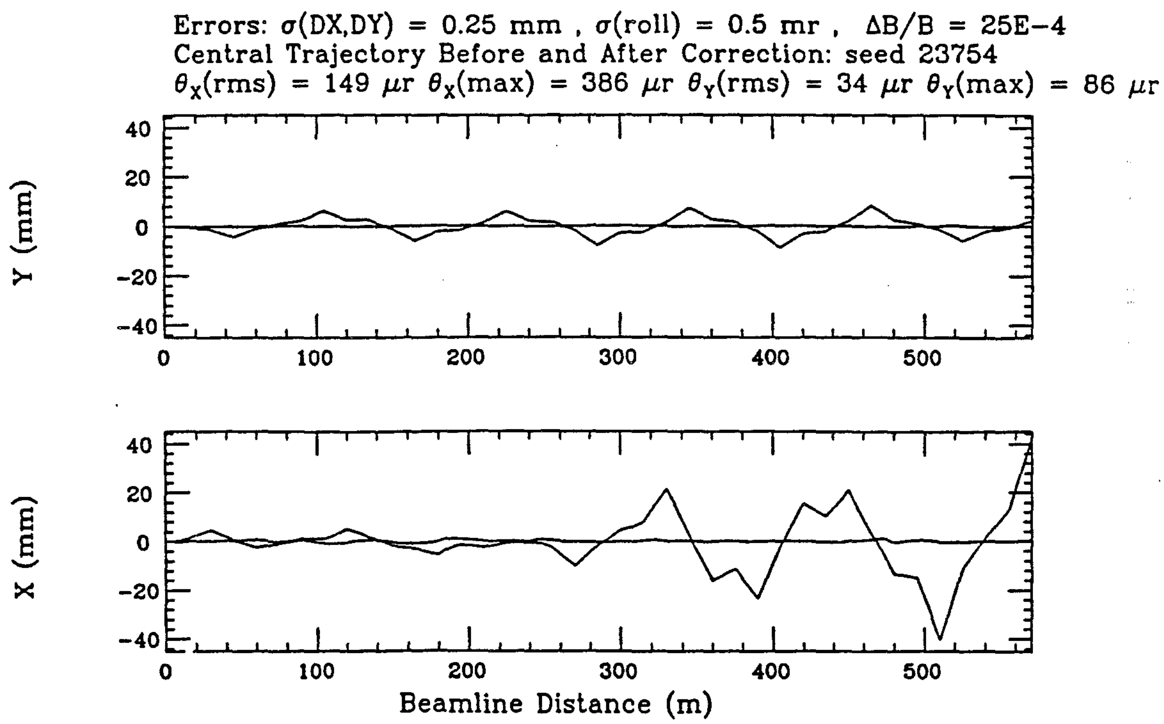

Figure 2.4-4(b). Worst-Case Uncorrected Orbit in the 8 GeV Line and Corrected Orbit

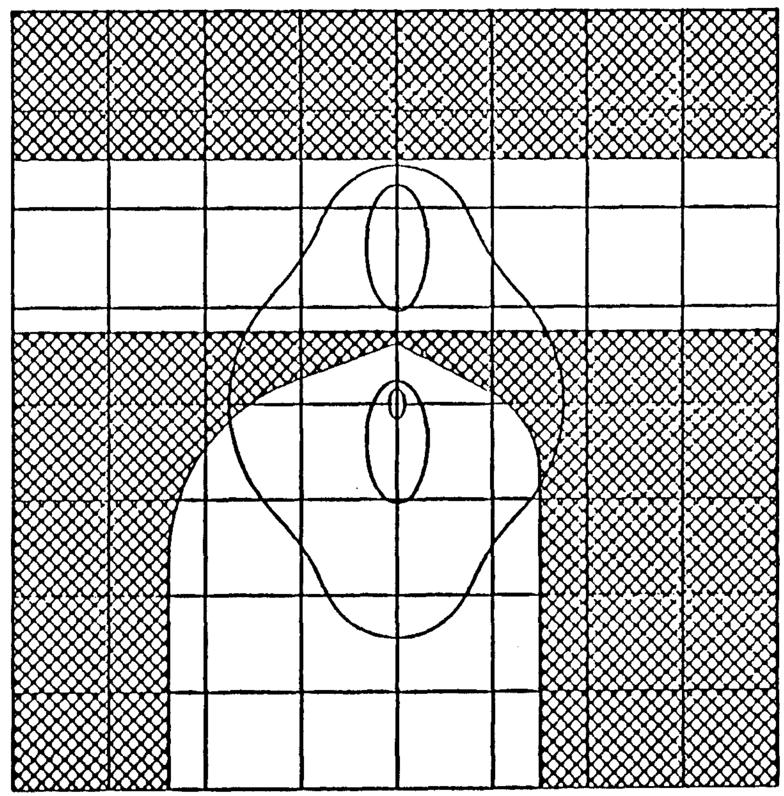

Figure 2.4-5. Injection Lambertson Magnet Apertures and Beam Profiles

2.4.2. The 150 GeV Lines

Two beamlines connect the FMI to the Tevatron. One of these transports the 150 GeV/c antiprotons. The other, in addition to its role of delivering 150 GeV/c protons to the Tevatron, is also required to transport 120 GeV/c protons destined for the antiproton production target or Switchyard, plus transport 8.9 GeV/c antiprotons to the FMI for injection. In this section, only the two optically similar beamlines which transport 150 GeV/c particles from the FMI to the Tevatron are described. The supplementary transport commitments of the 150 GeV/c proton line are discussed in subsequent sections. Small differences exist between the proton and antiproton transfer lines, originating in the slight optical asymmetry of the Tevatron injection point with respect to the two species of particles.

The Main Injector lies 2.332 m lower in elevation than the Tevatron. Extraction of protons (antiprotons) is initiated by kicker magnets located at the extreme upstream end of MI-52 (MI-62) straight section. These provide the 525 μr of kick necessary to deflect the beam across the septa of the vertically bending Lambertson magnets. The Lambertsons straddle the F quad located 90° in betatron phase downstream of the kickers. A C-magnet (current septum magnet) follows the second Lambertson. The Lambertson and C-magnet deflect the beam upward by 24 mr; this is the minimum angle that provides clearance from the FMI quad at the downstream end of the straight section. Three vertical C-magnets then reduce the vertical pitch to 3 mr. The horizontal dipoles are rolled to produce the desired horizontal and vertical trajectory for vertical injection into the Tevatron.

The total length of each of the 150 GeV/c beamlines is 260 meters. Each line includes 15 recycled 6 m Main Ring B2 dipoles and 17 recycled Main Ring quads, grouped into 14 quadrupole focusing centers. Design of the five vertical C-magnets and the three Lambertson septum magnets is based on a current Fermilab pattern.

Optics

The lattice functions for the 150 GeV/c Tevatron injection lines for protons and antiprotons are shown in Figures 2.4-6 and 2.4-7. All eight lattice functions are well matched to the Tevatron optics. The two transport lines have essentially identical designs. Minor differences in the locations and gradients of the last four quadrupoles are necessary to accommodate the match into the optically asymmetric Tevatron F0 straight section. Basically, the lines continue the FMI lattice cell structure up to a pair of quadrupole doublets, which then achieve the final optical match to the Tevatron. Vertical dispersion generated by the FMI vertical extraction components is almost canceled by the Tevatron vertical injection magnets. To complete the

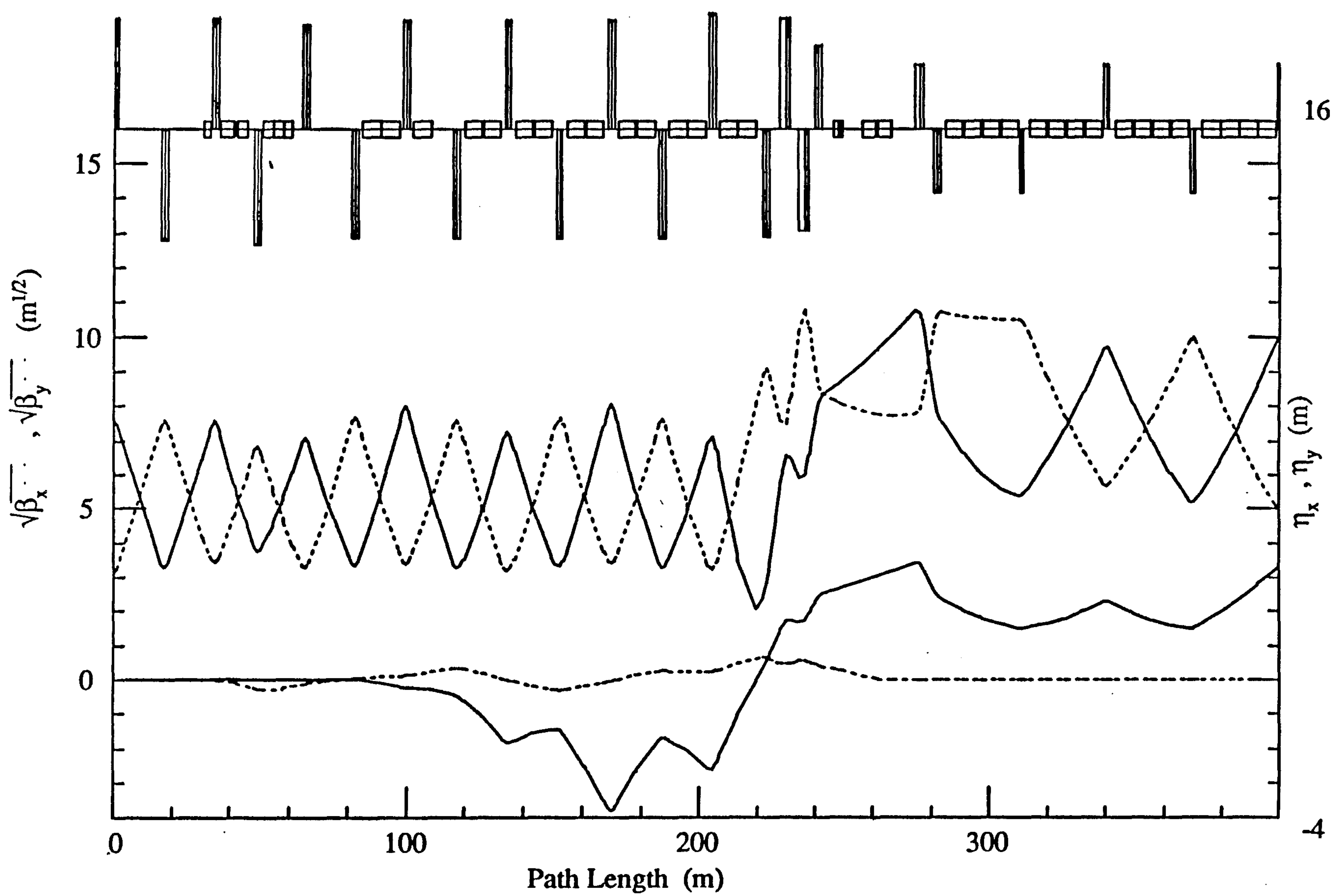

Figure 2.4-6. 150 GeV Proton Line Lattice Functions

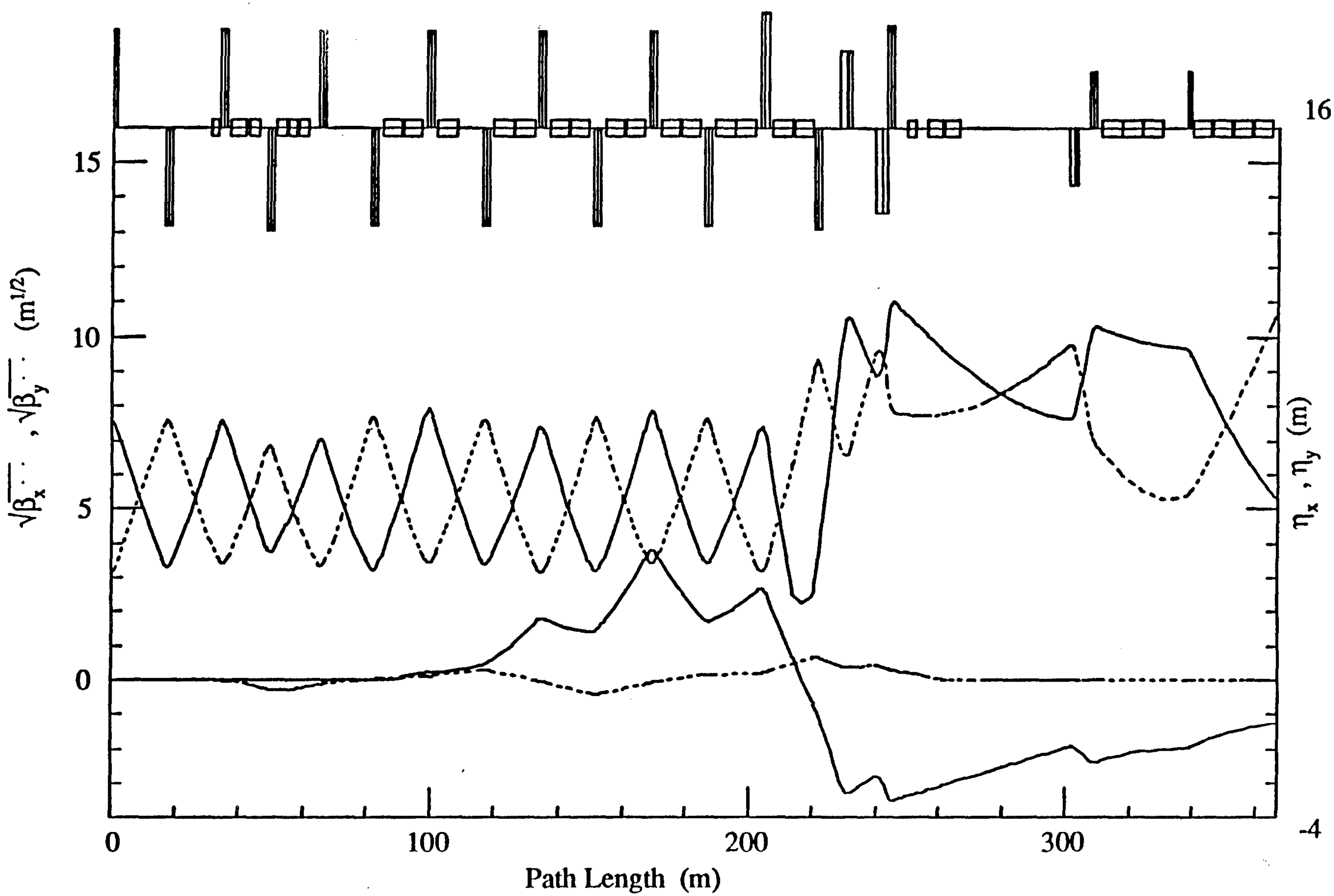

Figure 2.4-7. 150 GeV Antiproton Line Lattice Functions

cancellation, and satisfy the extremely tight geometric constraints, four families of rolled dipoles are utilized.

Correction Elements

Main Ring correction dipoles and BPMs are associated with each of the 14 quadrupole focusing centers in the 150 GeV/c lines. The operational mode in which 8.9 GeV/c antiprotons are transported dictates that fine trajectory control is essential for steering through the restricted aperture presented by the rolled dipoles. At 150 GeV/c steering tolerances through the line are not as stringent due to the smaller beam size.

Correction of central trajectory errors has been simulated with random magnet misalignments and dipole field errors assigned to the beamline elements. As discussed in connection with the 8 GeV proton line, suitable error values are: $\sigma_x = \sigma_y = 0.25$ mm, $\sigma_{roll} = 0.5$ mr, and; $\Delta B/B = 0.25\%$. Figure 2.4-8(a) illustrates deviations of the uncorrected central trajectory for 20 random error seeds. The consistently larger Δx values reflects the (approximate) absence of $\Delta B/B$ errors in the vertical plane. The maximum offsets at the end of the 260 m lines are $\Delta x \sim\pm 14$ mm and $\Delta y \sim\pm 6$ mm. Figure 2.4-8(b) shows the worst case trajectory, before and after correction. Maximum deviations in the line are reduced to ~ 1 mm, and the beam position and angle have been tuned at the injection point to $\Delta x = \Delta y = 0$ mm, and $\Delta x' = \Delta y' = 0$ mr. The maximum corrector strengths required are $\theta_H = 97$ μr, and $\theta_V = 40$ μr. At 150 GeV/c this horizontal strength is too large to be accommodated by the standard horizontal Main Ring correctors and the required vertical strength is over 80% of existing Main Ring vertical correctors. Therefore, Main Ring double-strength horizontal correctors will be required at each of the 7 focussing quad locations and 2 vertical correctors at each of the 7 defocussing quad locations to ensure orbit correction at 150 GeV.

FMI Extraction

Extraction from the FMI takes place at three straight sections: MI-52 for 8.9, 120 and 150 GeV/c proton extraction, plus 8.9 GeV/c antiproton injection; MI-62 for 150 GeV/c antiproton extraction, and; MI-40 for proton abort. Each extraction region contains a kicker located ~90° in betatron phase upstream of a pair of Lambertsons and a C-magnet. Figure 2.4-9(a) and (b) show the 40π mm-mr (dots) and 30π mm-mr (solid) beam envelopes through the MI-52 straight section at 8.9 GeV/c and 150 GeV/c, respectively. The FMI closed orbit and extraction central trajectories are indicated by dashed lines. The magnet apertures of the quadrupoles and extraction devices are shown for the central orbit. Figure 2.4-9(a) shows the dc closed orbit bump, required at injection energy, to keep the circulating beam away from the slow extraction septa wires and

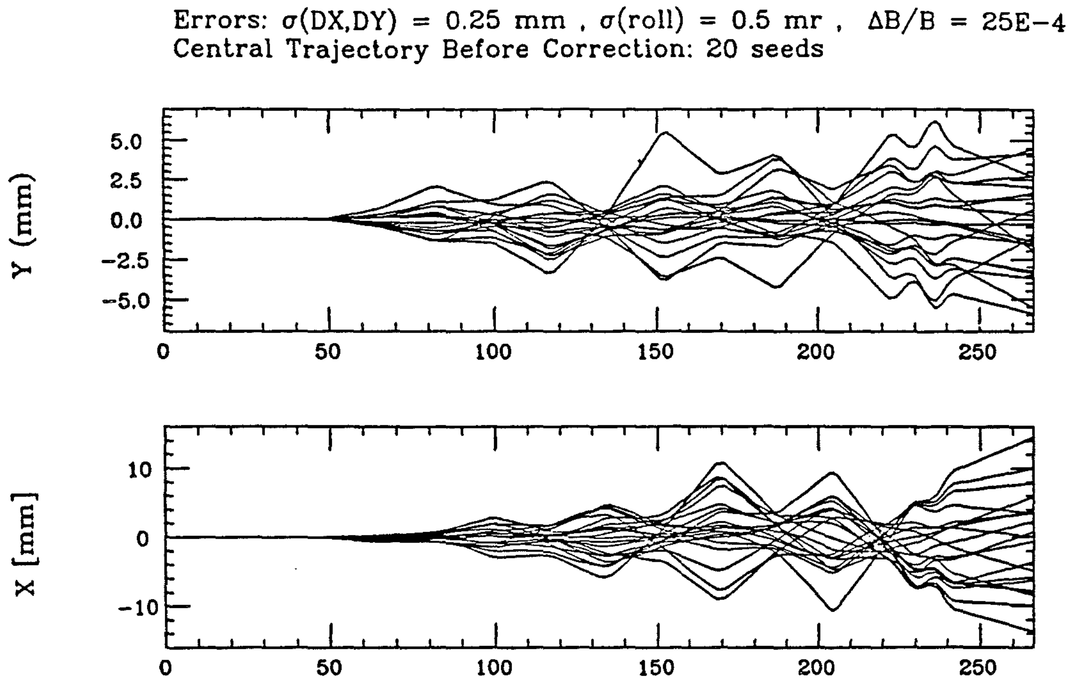

Figure 2.4-8(a). Uncorrected Orbit Errors in the 150 GeV Line

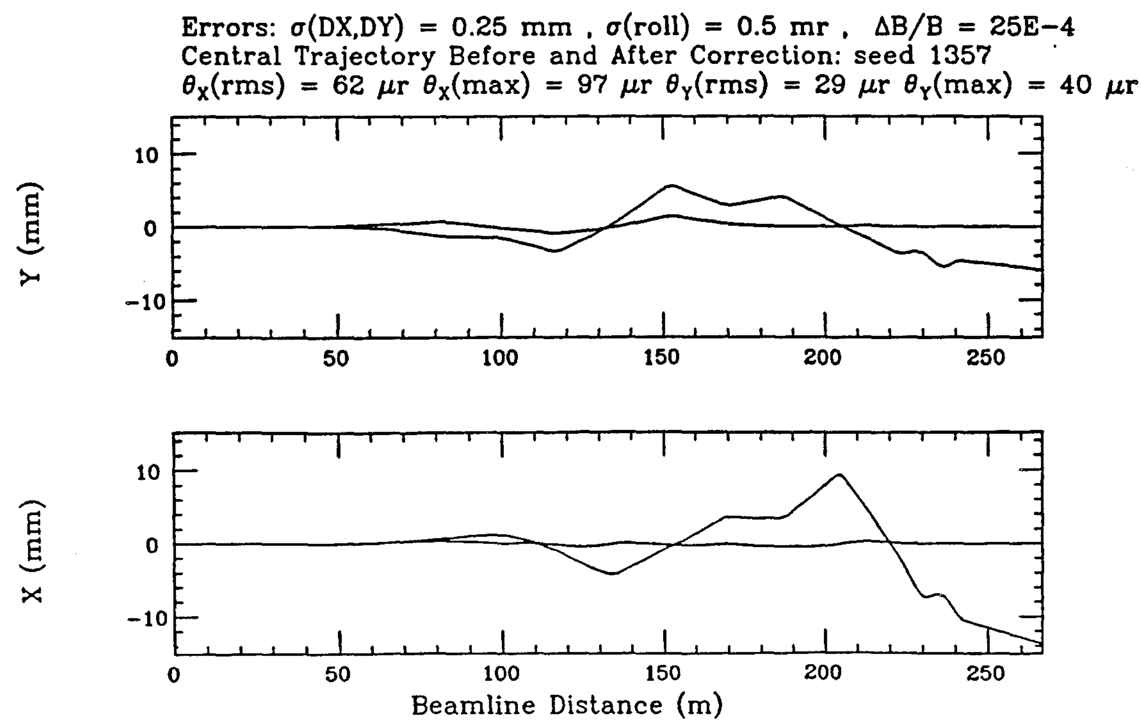

Figure 2.4-8(b). Worst-Case Uncorrected Orbit in the 150 GeV Line and Corrected Orbit

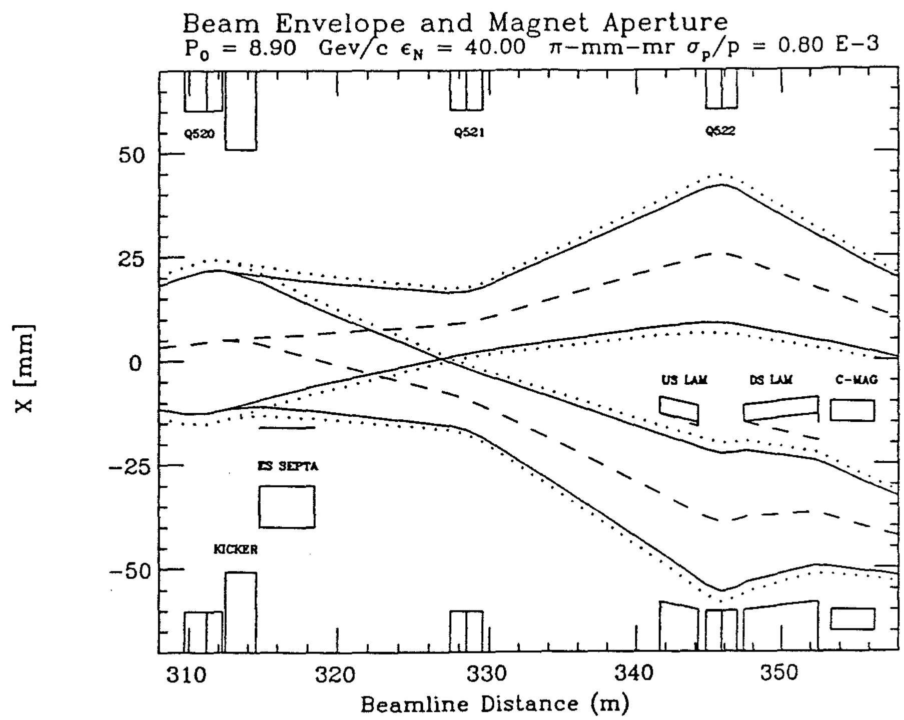

Figure 2.4-9(a). 8 GeV Closed Orbit and Extracted Beam Trajectories in the MI-52 Straight Section.

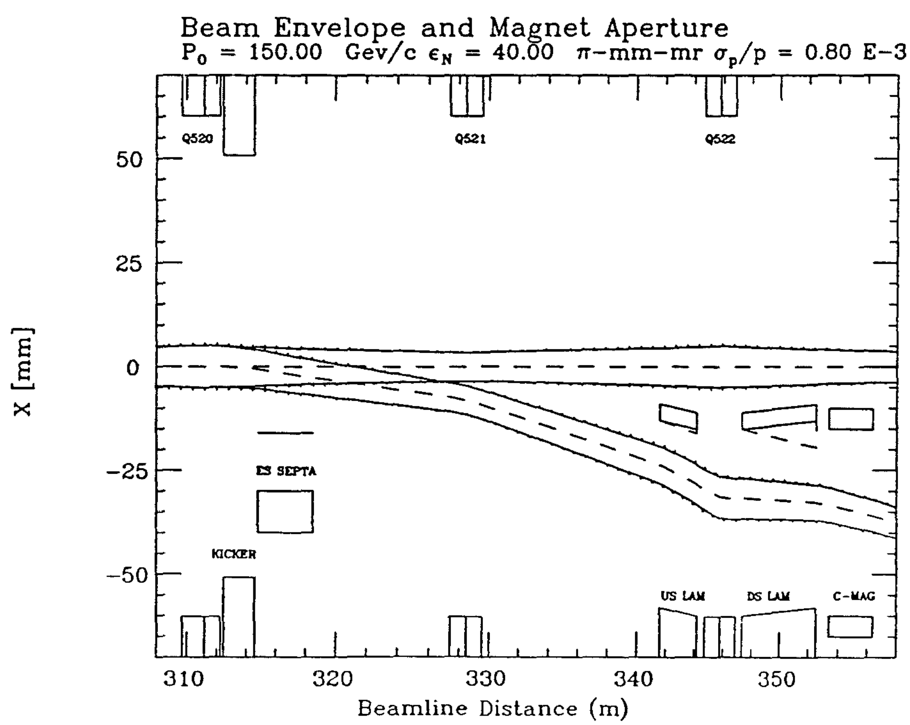

Figure 2.4-9(b). 150 GeV Closed Orbit and Extracted Beam Trajectories in the MI-52 Straight Section.

Lambertson septa. The effect of this bump on the circulating beam vanishes by 150 GeV/c, as can be seen in Figure 2.4-9(b).

The aperture of the extraction Lambertson is dictated by its use as the injection Lambertson for 8.9 GeV/c antiprotons. Consequently, a F-17 style Lambertson magnet is used, which is the design currently used for injection of 8.9 GeV/c antiprotons into the Main Ring. The location of the Lambertson septa in the FMI aperture is dictated by the 150 GeV/c closed orbit on the inside and quadrupole aperture to the outside. To increase the aperture for the 8.9 GeV/c antiprotons, both upstream and downstream Lambertsons are tilted by ±2 mm with respect to the central 150 GeV/c closed orbit. Additionally, both Lambertsons are rolled (12.3° and 4.6°) away from the closed orbit to compensate for the quadrupole steering. In Figures 2.4-9(a) and (b) the dashed lines associated with the Lambertson septa indicate the reduction in aperture at the exit of the Lambertsons due to these rolls. Figure 2.4-9(c) shows the Lambertson and quadrupole apertures and 40π mm-mr beam profiles at 8.9 GeV/c and 150 GeV/c at the entrance (solid line) and exit (dashed line) of each device. The dashed lines in the field region of each Lambertson shows the aperture at the exit of the Lambertson due to the ±2 mm tilt. The dotted aperture outlines the device immediately downstream.

Tevatron Injection

Injection into the Tevatron is moved from its present location in the E0 straight section to the F0 straight section. This move leaves the E0 straight section completely free for possible use as an interaction region or for other purposes.

The F0 region continues to be used to accommodate the Tevatron rf systems. By rearranging the accelerating cavities in the upstream end (proton beam direction) of the straight section, the proton and antiproton injection lines converge toward a common set of injection septum magnets located at the downstream end of the straight section. This reduces the number of such elements needed for injection into the Tevatron. In the present Tevatron configuration, the accelerating cavities are arranged in a manner that ensures proper phasing between the proton and antiproton systems and minimizes the effects of cavity trips. Thus, a new layout of the cavities is necessary and its consequences are being investigated.

The incoming beam approaches the Tevatron vertically for injection, with the last vertical bend produced by a pair of Lambertsons common to both proton and antiproton injection lines. Closure onto the horizontal orbit is accomplished by a kicker magnet downstream of the injection point. The nearest points on either side of the long straight section where kickers can be placed are the F17 medium straight section (for clockwise proton injection) and the E48 short

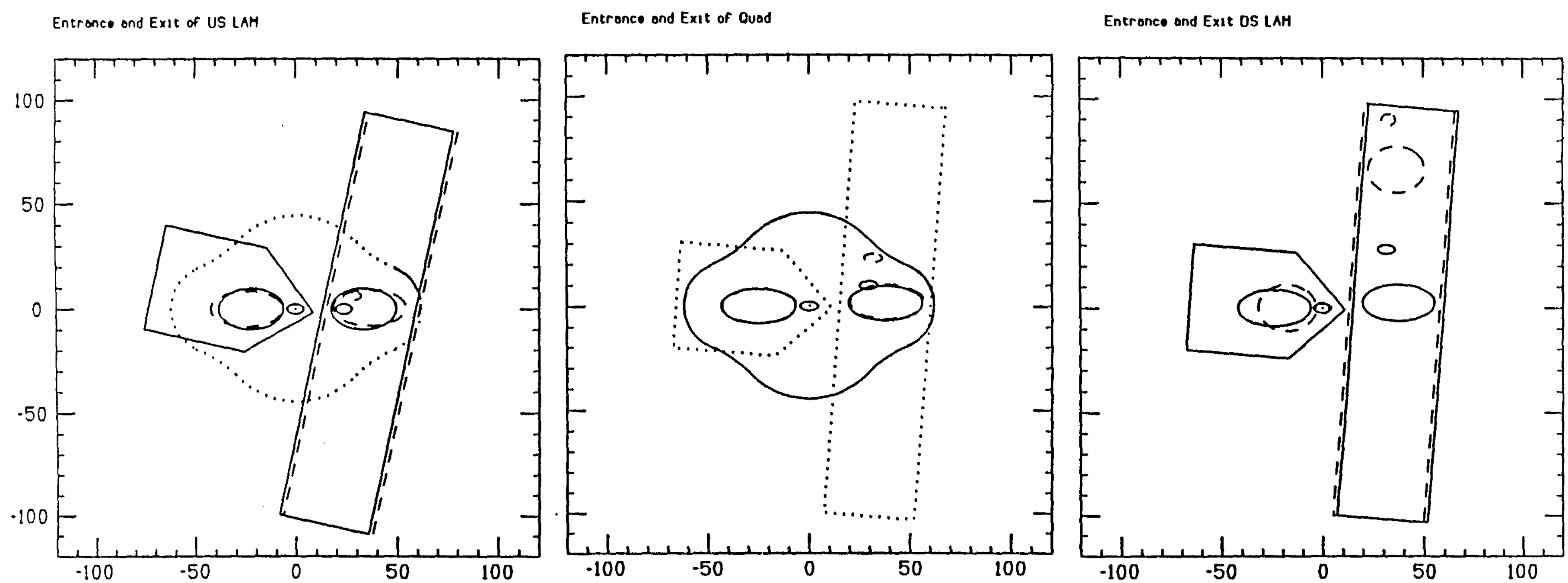

Figure 2.4-9(c). Extraction Lambertson and Quadrupole Magnet Apertures and Beam Profiles.

straight section (for counterclockwise antiproton injection). The present Tevatron antiproton injection kicker will be recycled; a new proton kicker will be required.

Injection System Layout

The Tevatron rf system occupies roughly 26 m of the 52 m straight section. In the remaining 26 m, two Lambertson magnetic septa are placed symmetrically about a point 13 m upstream (proton direction) of the end of the straight section. Both the proton and antiproton beams pass through the field region of these magnets upon injection. With the Lambertson off, the 120 GeV/c proton and the 8.9 GeV/c antiprotons pass through the same field region (de-energized) to get to and from the Main Ring remnant. To accommodate the 120 GeV/c proton and 8.9 GeV/c antiproton trajectories, a Lambertson is being designed with a larger field region. This design is based on the present Fermilab F17 Lambertson design. The same Lambertson design is used for FMI extraction (proton, antiproton, and abort), as discussed previously. To provide more clearance at the ends of the free space, each of the injection lines incorporates one C-style magnet just in front of the Lambertsons. An elevation view of the F0 region is shown in Figure 2.4-1.

2.4.3. 120 GeV Antiproton Production

The existing AP-1 beamline, which is used to target 120 GeV/c protons for antiproton production and transport 8.9 GeV/c antiprotons back to the Main Ring, remains intact. The Main Ring magnets used from F11 to F17 also remain in place, with only minor modifications to the bus and power supplies. The 120 GeV/c protons utilize the Tevatron proton injection line from the FMI (MI-52) to the Tevatron injection Lambertsons. With the Lambertsons off, the protons enter the Main Ring remnant at Main Ring station F11 for transport to Main Ring station F17. A vertically bending Main Ring B3 dipole, located immediately downstream of the Main Ring F17 quad, when energized, deflects the beam into the existing AP-1 beamline. De-energized, this magnet allows the 120 GeV/c slow spill to be transported to the Switchyard. Figure 2.4-10(a) shows the retune of the Tevatron proton injection line for matching into the Main Ring remnant. The 40π mm-mr 8.9 GeV/c antiproton beam envelopes and magnet apertures are shown in Figure 2.4-10(b).

Modifications to Main Ring F11 to F17 Magnet String

This section of magnets remains in its current location. Only minor modifications to the magnet bus are required to power the dipole and quadrupole circuits. The B1 magnets (1.5"x5" beam pipe) are replaced with B2 magnets (2"x4" beam pipe) to increase the acceptance for antiproton transfers. It may also be determined advantageous to replace the six B2 magnets at the

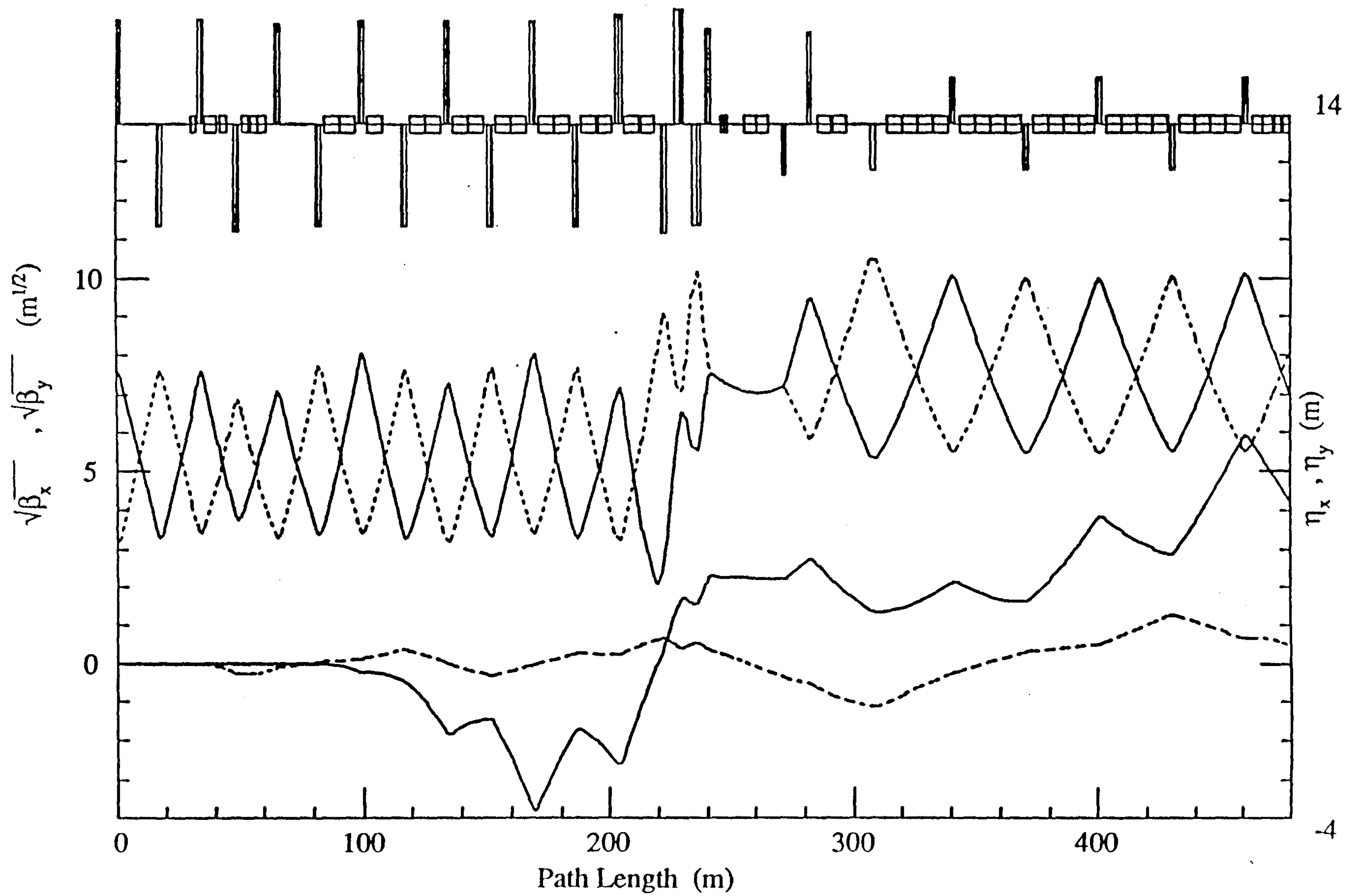

Figure 2.4-10(a). Lattice Functions for 8/120 GeV Transfers to Main Ring Remnant.

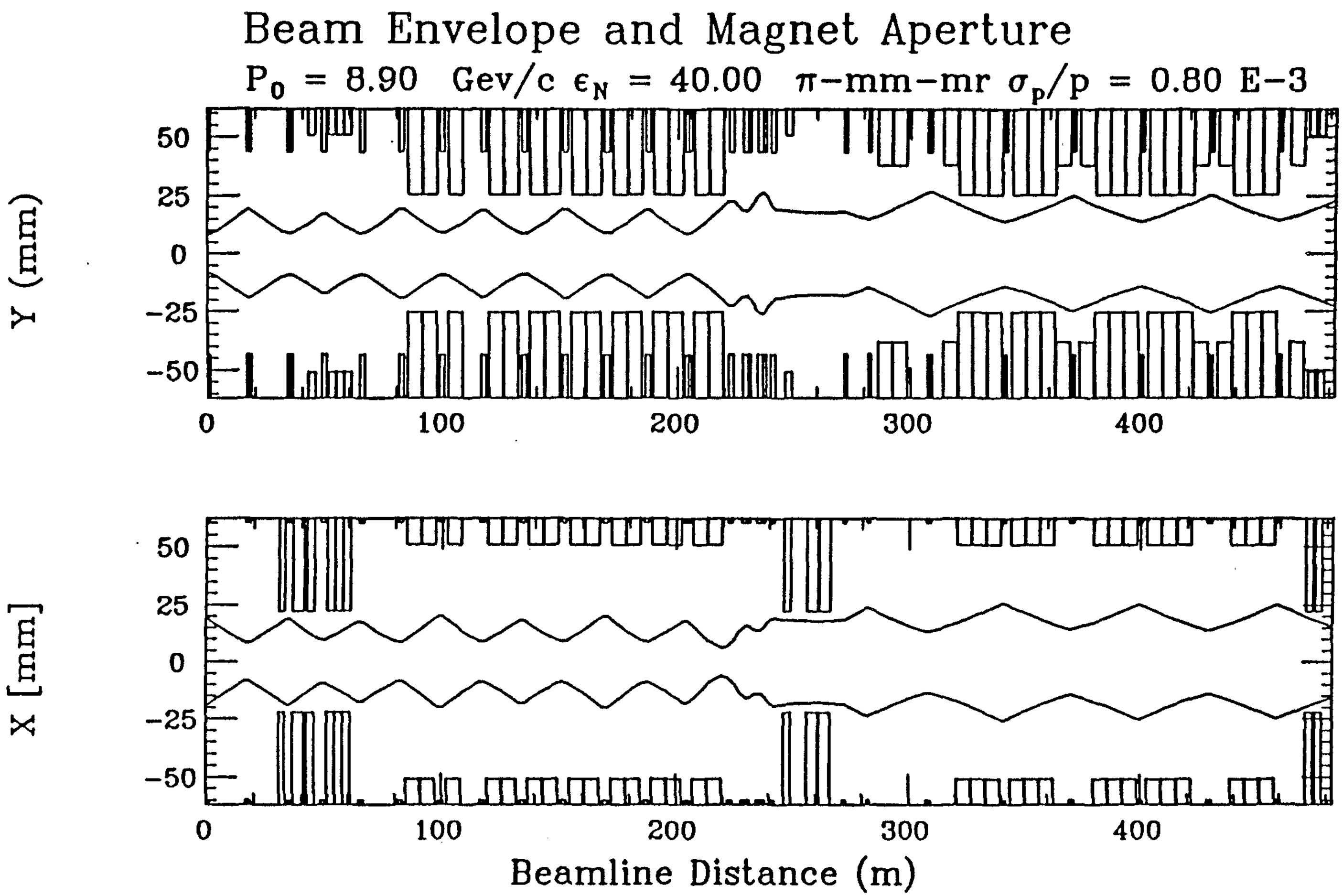

Figure 2.4-10(b). 8 GeV Antiproton Beam Envelope and Magnet Apertures.

locations of largest vertical ß-function with B3 magnets (3"x5" beam pipe). The quadrupoles at F11 are modified to produce a doublet that matches into the Main Ring FODO lattice at Main Ring F13. The four Main Ring F11 dipoles are replaced by two B3 dipoles running at twice the field of a standard B2 dipole and rolled by about 40°. The Main Ring F12 dipoles are also rolled (with the first dipole being replaced by a B3 at twice the field) to produce the required horizontal and vertical trajectory for the present Main Ring trajectory at F13. A Main Ring power supply located at F1 powers the bending magnets in this section. The focusing and defocusing quadrupole busses are powered in series by a new supply. The dipole correction elements remain in this section for use in smoothing the orbit of 8.9 GeV/c antiprotons.

Connection with the Existing AP-1 Beamline

In the current Tevatron configuration, a kicker at E17 supplies the necessary orbit distortion to place the beam in the field region of the Lambertson magnet at F17. In the FMI era this Lambertson is replaced by a vertically bending B3 which deflects the beam upwards sufficiently to miss the first downstream Main Ring dipole and enter the AP-1 line. The match between the Main Ring F17 and the AP-1 line is not altered. Use of a B3 has the advantage that it provides a larger aperture for the 8.9 GeV/c antiprotons. The B3 is turned off during slow spill to Switchyard. Since the B3 is individually powered (in series with the two C-magnets at the beginning of the AP-1 line) this configuration is consistent with the FMI acceleration cycle in which antiproton production and slow spill are mixed on a common flattop.

2.4.4. The 120 GeV Slow Spill Line

The 120 GeV slow spill beamline transports both slow and fast extracted beam from the FMI to the experimental areas for a variety of purposes during collider and fixed-target runs. This beamline uses four beamline sections: MI-52 to F11; F11-F17 magnet string; F18-A0 magnet string, and the new section of beamline between F48 and Switchyard. The first two segments were described previously.

Modifications to F18-A0 Magnet String

The magnet string remains in its current location. The fourth Main Ring F47 B2 dipole is replaced with a rolled (~4.4°) B3 dipole at twice the field, and the three Main Ring F48 dipoles are removed. These modifications produce a trajectory approximately 3' west of the entrance into the Switchyard with a downward pitch. Minor bus work is needed to connect the four power supplies required to ramp the bending magnets in this section. One Main Ring power supply at F3 is used to power two quad busses in series. The quadrupoles at F48 and F49 plus an additional recycled Main Ring quad are powered individually to produce the required optical match into the

Switchyard. A savings in operating cost could be realized by replacing the B2 magnets in this section with B1 magnets, which have a lower impedance.

F49 to Switchyard

A pair of recycled Main Ring B2 horizontal bending dipoles located 60 m downstream of F49 are powered individually to produce a trajectory which intercepts the Switchyard beamline approximately 40 meters downstream of the present Switchyard channel. The final closure onto the horizontal and vertical Switchyard trajectory is produced by a rolled (~17°) B3 dipole powered by the F-Sector bus. Figures 2.4-11(a) and 2.4-11(b) show plane and elevation views of the magnets, in distorted scale, in this beamline. Figure 2.4-12(a) shows the lattice functions and Figure 2.4-12(b) shows the beam envelopes and magnet apertures

Modifications to Switchyard

Minor modifications to the upstream end of the Switchyard are required. The first horizontal dipole and quad along with five of the seven proton electrostatic splitting septa modules (PSEPs) are moved upstream. The last two PSEP modules are shifted downstream to provide space for the rolled B3 magnet that provides the matching into Switchyard. The two PSEP modules downstream of the B3 are required to provide test beams to all areas.

2.4.5. The Abort Line

Aborted beam is extracted from FMI straight section MI-40. Two kicker modules at the upstream end of the straight section provide sufficient displacement (38 mm at 8.9 GeV/c and 28 mm at 150 GeV/c) 90° in phase downstream for the beam to enter the extraction channel. Two vertically bending F17-style Lambertsons straddle the focusing quad situated at the straight section midpoint. The Lambertsons plus a C-magnet deflect the beam down by 24 mr to clear the next downstream FMI quad. The aborted beam is then leveled off and deflected outwards by two B2 dipole magnets rolled at a 40° angle. In addition, three 3Q52 quadrupoles are placed in the abort line to maintain a suitable beam size for transport to the beam dump. The optics of this line are designed such that all of these elements are powered in series with the FMI quadrupole bus, eliminating the need for an additional power supply. Main Ring correctors are used for fine adjustment of the beam position at the dump. Sufficient free space exists in the downstream portion of the abort line for other magnetic elements which could be used to deflect the beam around the beam dump to future experimental areas. Figure 2.4-13 shows the layout of the magnets in the abort line.

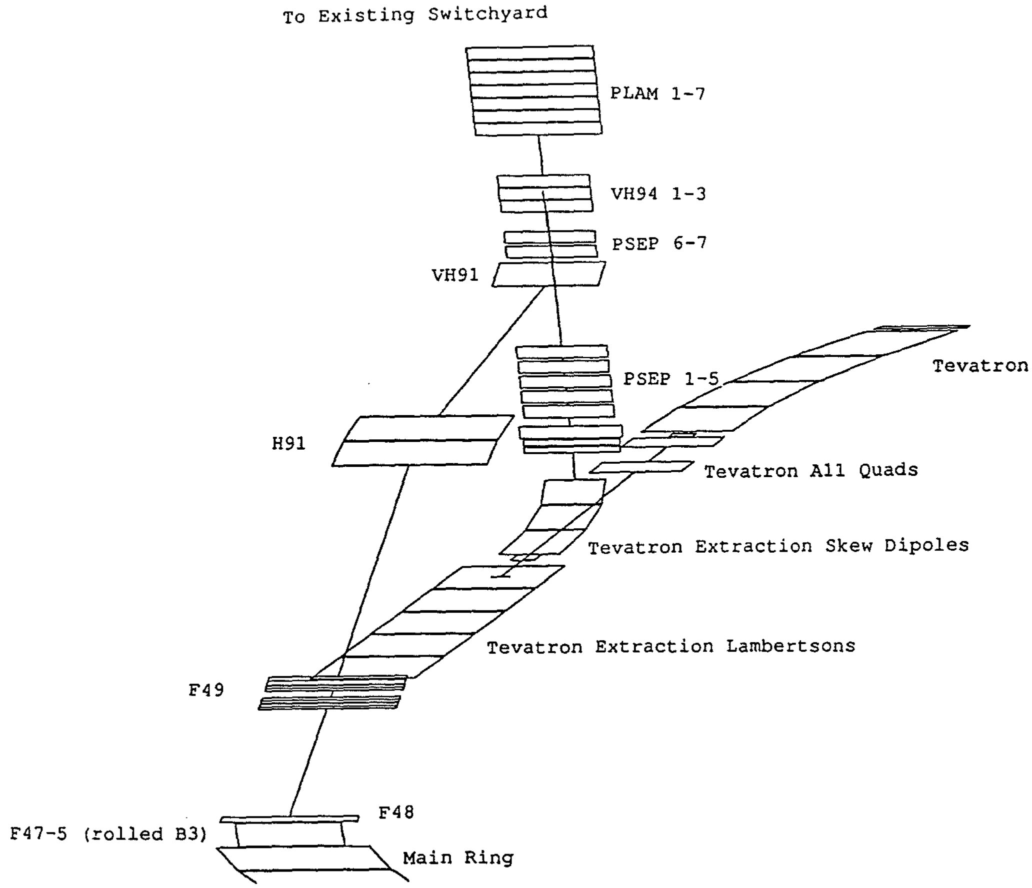

Figure 2.4-11(a). Plan View of 120 GeV Slow Spill Line Connection to Switchyard

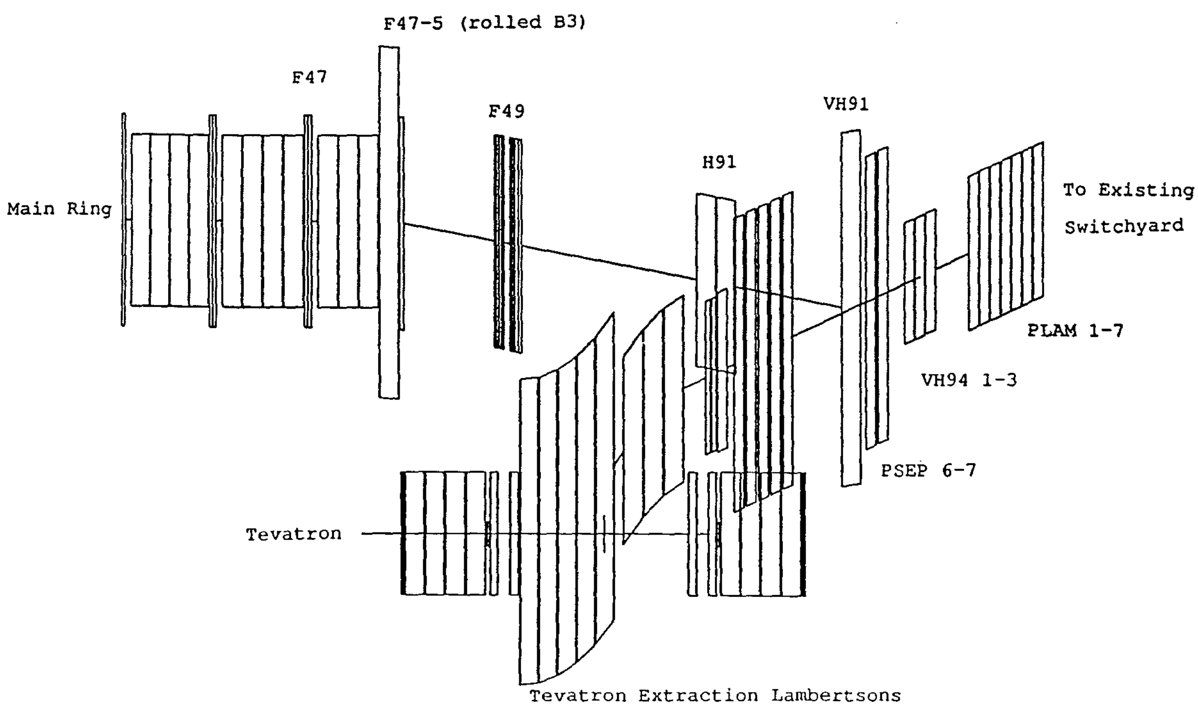

Figure 2.4-11(b). Elevation View of 120 GeV Slow Spill Line Connection to Switchyard

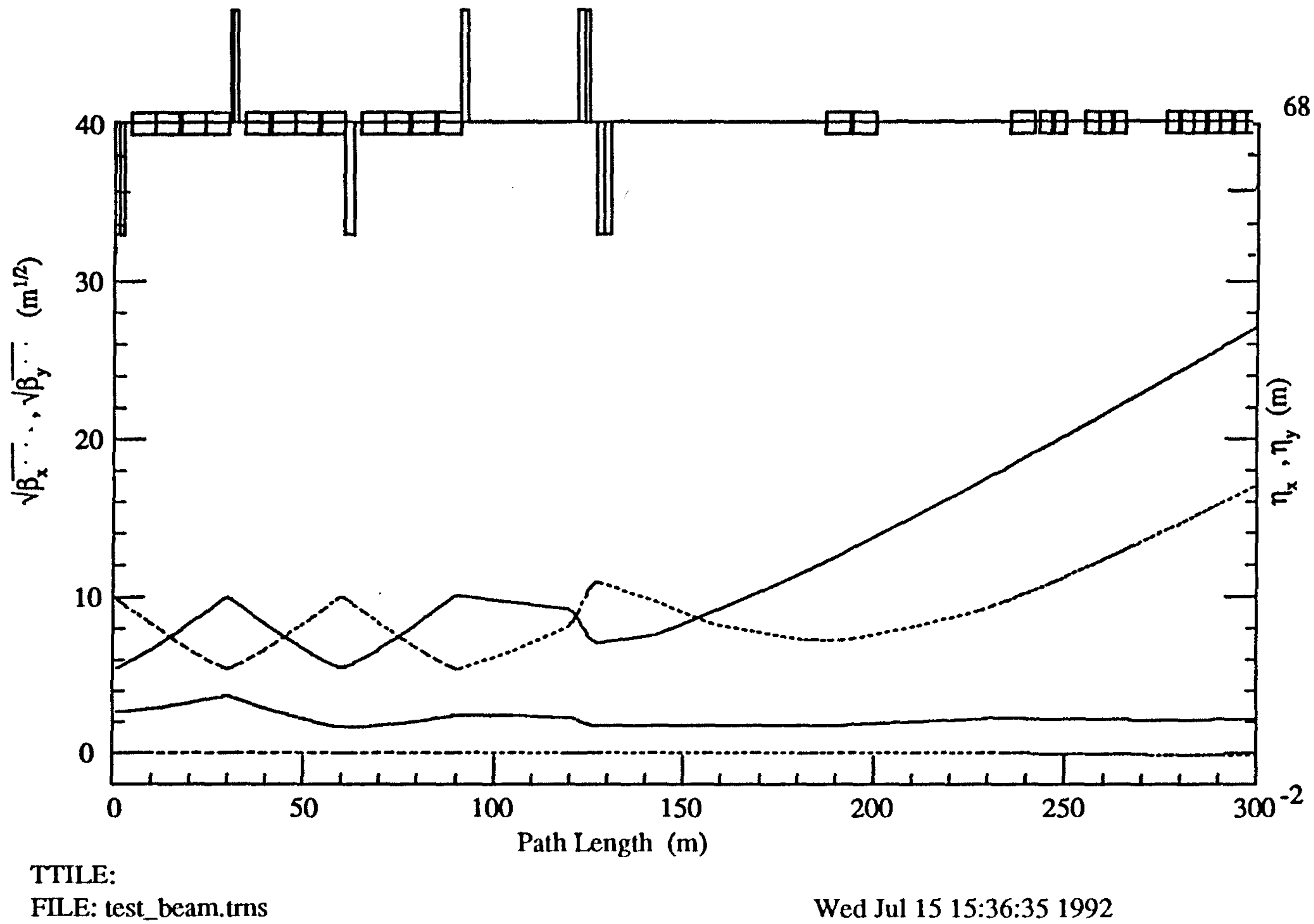

Figure 2.4-12(a). Lattice Functions for the 120 GeV Slow Spill Line Connection to Switchyard

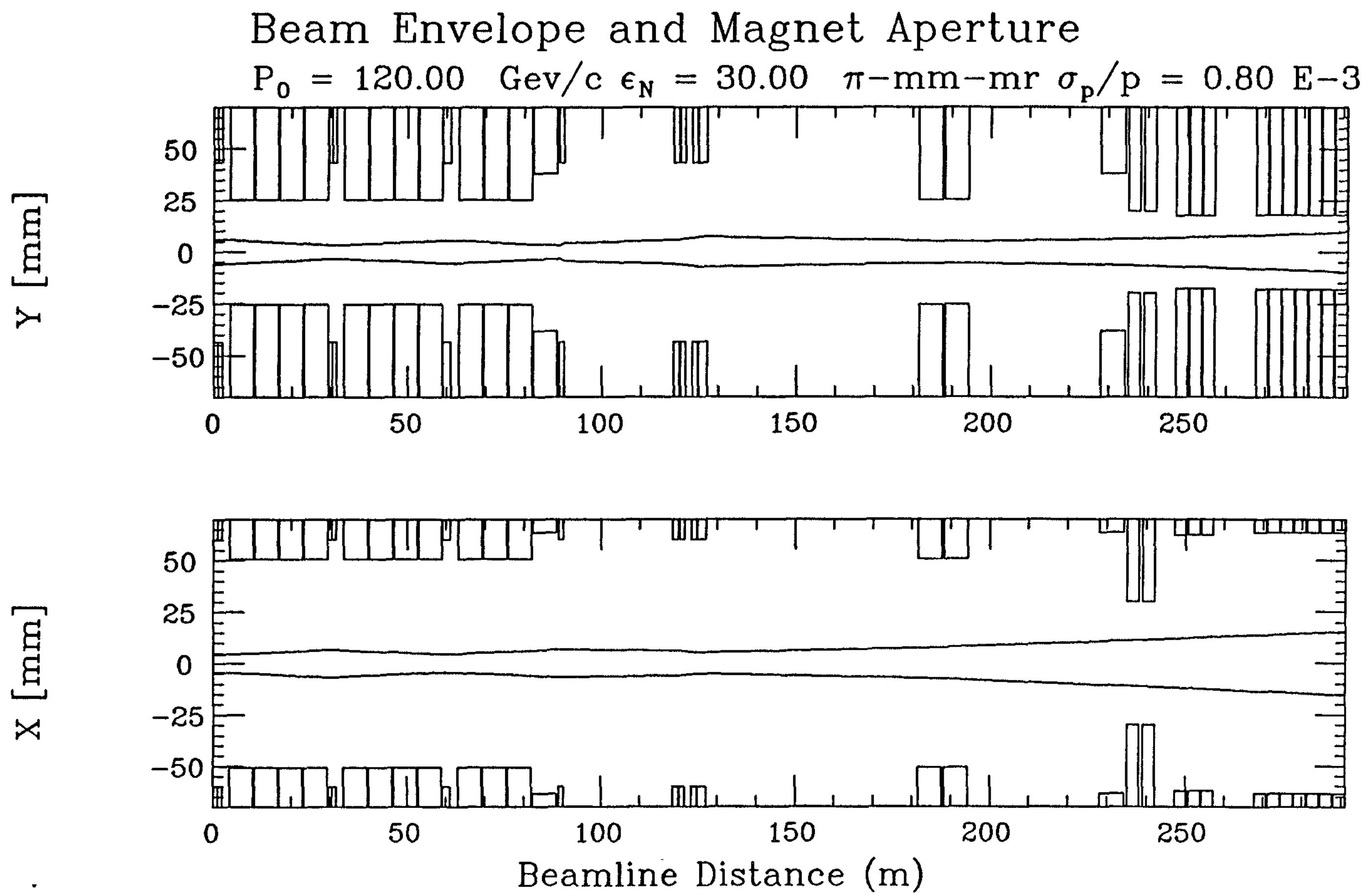

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Figure 2.4-12(b). Beam Envelopes and Magnet Apertures in the
120 GeV Slow Spill Line Connection to Switchyard

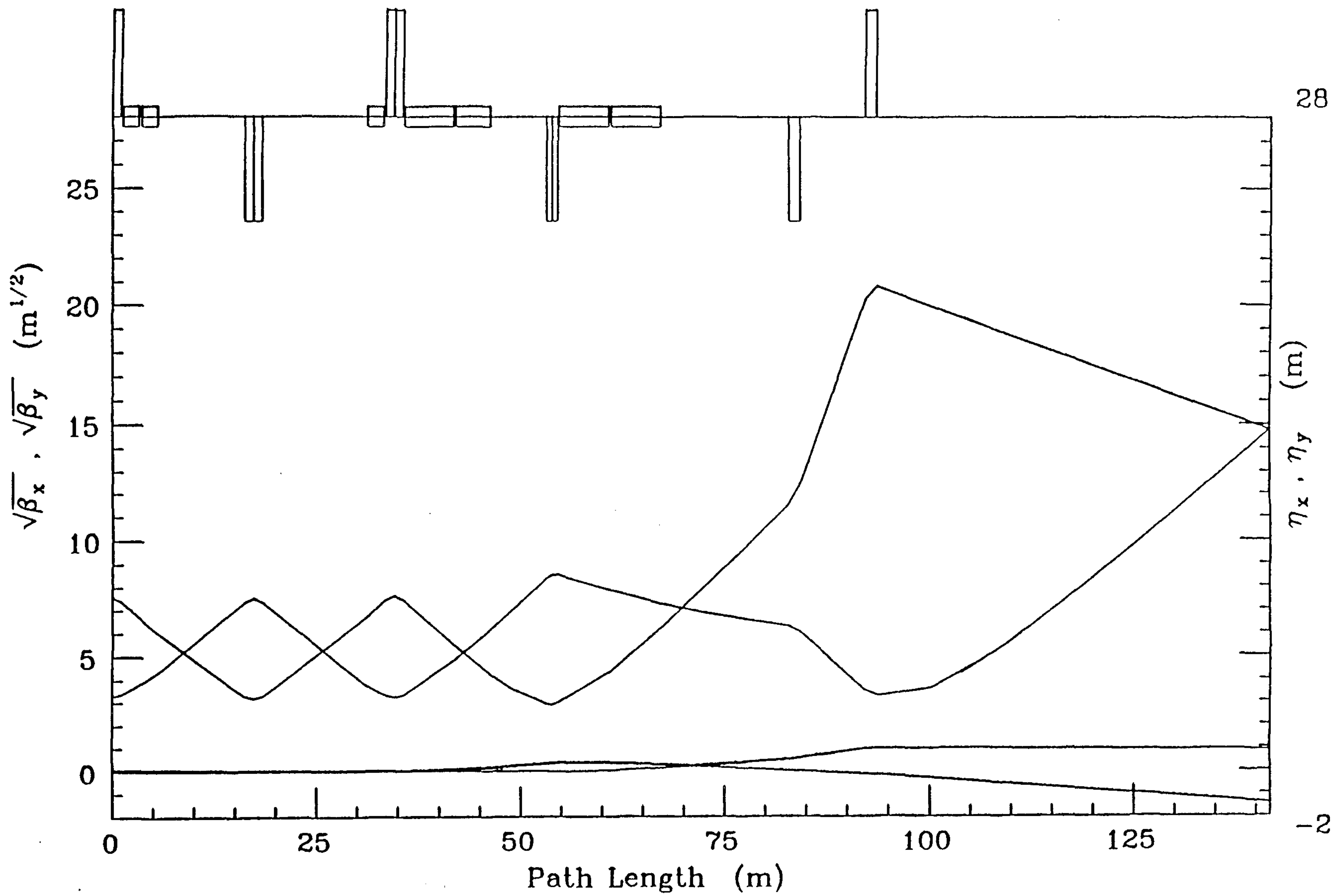


Figure 2.4-13. Abort Line Lattice Functions

2.4.6. Beamline Magnets and Power Supplies

Magnet Requirements

Magnet requirements for all beamlines are summarized in Table 2.4-1. Decommissioning the Main Ring and the 8 GeV line will provide a major source of magnets for the beamlines.

The new 8 GeV line utilizes 51 recycled Main Ring B2 magnets for all the required bends with a few exceptions. All exceptions are located in the upstream end of the beamline. The necessity for the exceptions are generally due to tight spatial constraints (EPBs), required small bend radii (TEV I style SDB dipoles), or large aperture (Main Ring B3s). All quadrupoles in the 8 GeV line are of the SQA type. Seventeen of the 51 required will be recycled from the current 8 GeV line. The remainder will be newly constructed. The Lambertson magnet and power supply currently being used for 8.9 GeV/c proton injection into the Main Ring will be used without any major modifications. The existing injection kickers and power supplies will be modified, and a third system will be required.

All dipole magnets required for the two Tevatron injection lines, the F0-F17 magnet string and the F18-SY magnet string are recycled from the Main Ring. The only new magnets required are the F17 style Lambertsons and C-magnets required at the FMI extraction and Tevatron injection straight sections.

All quadrupoles in the beamlines, except for the 8 GeV line, are recycled 3Q84s and 3Q52s from the Main Ring.

Power Supply Requirements

The power supply requirements for all beamlines are summarized in Table 2.4-2. The power supplies will be located in the existing Booster Gallery, new North Hatch Building, new MI-10 Service Building, new extension to Main Ring F0, existing Main Ring F1 through F4, and the existing A0 Transfer Hall. All major dipole and quadrupole supplies for the 120 GeV and 150 GeV beamlines will be ramped to minimize the average power consumed. The 8 GeV line will run dc. Approximately 30% of the major dipole and quadrupole supplies will be reused from the present transfer lines. The kicker supplies will be located in the buildings at MI-10,-40,-52,-62, F0 (for E48), and F17.

Table 2.4-1: Beamline Magnet Requirements

	Number	Magnet Style	Status
150 GeV (both)			
Lambertson	6	F17 type	New
C-magnet	10	F17 type	New
Dipoles	30	B2	Exist
Quadrupoles	26	3Q84	Exist
	8	3Q52	Exist
Trims (H)	14	MR trim	Exist
Trims (V)	28	MR trim	Exist
F0/F17 Magnet String			
Dipoles	15	B1/B2	Exist
	8	B3	Exist
Quadrupoles	6	3Q84	Exist
	2	3Q52	Exist
C-magnet	2	F17 type	Exist
Trims (H)	4	MR trim	Exist
Trims (V)	4	MR trim	Exist
F18/SY Magnet String			
Dipoles	101	B1/B2	Exist
	2	B3	Exist
	1	2xB2	Exist
Quadrupoles	27	3Q84	Exist
	4	3Q52	Exist
Trims (H)	14	MR trim	Exist
Trims (V)	14	MR trim	Exist
Abort			
Lambertson	2	F17 type	New
C-magnet	1	F17 type	New
Dipoles	2	B2	Exist
Quadrupoles	3	3Q52	Exist
Trims (H)	2	MR trim	Exist
Trims (V)	2	MR trim	Exist
8 GeV			
Dipoles	51	B2	Exist
	2	B3	Exist
	2	SDB	New
	3	EPB	New
Quadrupoles	17	SQA	Exist
	34	SQA	New
Trims (H)	25	MR trim	Exist
Trims (V)	25	MR trim	Exist
Lambertson	1	A0	Exist

Table 2.4-2 Beamline Power Supply Requirements

		Number of Circuits	Peak Load Current (kA)	Load RMS Power (kW)	Required PS Rating V/I/PWR
8 Gev					
Dipole	B1	1	0.895	47.9	60/1.0kA/65kW
	B2	1	1.293	90.8	80/1.5kA/120kW
	B3	1	0.679	25.7	45/800/36kW
	B4	1	0.499	109.8	250/600/150kW
	B5	1	0.930	25.0	30/1.2kA/36kW
Quad	Q1	1	0.147	33.5	275/175/48kW
	Q2	1	0.200	6.2	36/250/9kW
	Q3	1	0.255	13.6	60/300/18kW
	Q4	1	0.332	12.3	45/400/18kW
Trims	Bend	51	0.006	0.4	60/6/360
	Quad	17	0.025	0.3	10/25/250
150 Gev Proton/150 Gev P-Bar					
Dipole	B1	1	3.80	102.8	110/2.5kA/275kW
	B2	1	3.24	127.3	160/2.2kA/350kW
	B3	1	4.90	838.9	1,265/3.3kA/4200kW
	B4	1	1.48	18.1	55/1.0kA/55kW
	B5	1	3.45	35.5	45/2.3kA/105kW
	B6	1	3.60	64.1	80/2.4kA/192kW
Quad	Q1	1	4.00	88.0	85/2.7kA/230kW
	Q2	1	4.00	84.4	80/2.7kA/216kW
	Q3	1	4.00	233.0	230/2.7kA/621kW
	Q4,Q6,Q7	1 ea.	4.00	62.2	65/2.7kA/175kW
	Q5	1	4.00	48.9	50/2.7kA/135kW
	Q8	1	4.00	44.8	45/2.7kA/122kW
Trims		28	0.1	5.0	50/100/5kW
F0-to-F17					
Dipole	B1	1	1.36	284.4	1,200/1.1kA/1300kW
	B2	1	2.84	303.0	480/2.4kA/1200kW
Quad	Q1	1	1.77	16.8	25/1.5kA/38kW
	Q2	1	2.63	37.2	40/2.2kA/88kW
	Q3	1	1.30	11.7	25/1.1kA/28kW
	Q4	1	1.29	34.6	75/1.1kA/83kW
Trims		8	0.1	5.0	50/100/5kW
F18-to-A0					
Dipole	B1	1	1.36	783.6	3,000/1.1kA/3300kW
	B2	1	0.65	5.6	35/600/21kW
Quad	Q1	1	1.36	174.6	350/1.1kA/385kW
	Q2	1	4.00	64.9	45/3.3kA/150kW
	Q3,Q4,Q5	1 ea.	4.00	92.3	65/3.3kA/215kW
Trims		28	0.1	5.0	50/100/5kW

CHAPTER 3.1. MAGNETS

WBS 1.1.1. MAGNETS

WBS 1.1.1 includes all DC and ramped magnets. Pulsed magnets (kickers and septum magnets) are included in 1.1.6. The fourth level WBS under magnets indicates the area in which they are used. Table 3.1-1 lists these areas. The fifth level of the WBS indicates the class of magnet. The sixth level indicates the specific magnet design. Table 3.1-2 lists the classes and individual magnet designs. Where there are multiple sources for a specific design, they are indicated by a seventh level in the WBS. Some gaps exist in the WBS numbers due to deletion or movement of items from previous versions. The total count of magnets of each type in each area is given in Table 3.1-3.

The rapid cycle rate of the FMI dictates using conventional steel and copper magnets rather than superconducting magnets. Where possible existing magnets from the Main Ring are reused. Where reusing magnets is not practical, new magnets are built, either to existing designs or to new designs.

WBS 1.1.1.1. MAIN INJECTOR RING MAGNETS

WBS 1.1.1.1.1. RING DIPOLES

The FMI ring uses newly designed dipole magnets of two lengths, 6.096 meters and 4.064 meters, as described in Section 2.1. To facilitate the electrical connections in the tunnel, two styles of each length magnet are used, having the jumper between top and bottom coils at opposite ends of the magnet. The 6-m dipoles are designated type A and type B and are referred to as IDA and IDB magnets. The 4-m dipoles are types C and D and are referred to as IDC and IDD magnets. The configuration of two 6-m dipoles together in one half-cell is shown in Figure 3.1-1.

<u>Dipole Design</u>

A new dipole design for the FMI ring is needed for several reasons. First, the existing Main Ring magnets are straight. Reusing these magnets in the FMI would result in a loss of about 16 mm of aperture due to the sagitta of the beam path. This aperture is recovered by constructing curved magnets. Second, the existing magnets suffer from reliability problems. Most of the failures in the existing magnets occur at conductor joints within the coil. The number of such joints per magnet is reduced in the new magnet and at the same time the reliability of the joints is increased through improved construction techniques. Third, higher

TABLE 3.1-1: Fermilab Main Injector Areas for Magnet WBS 1.1.1

1.1.1.1	FMI ring
1.1.1.2	8 GeV line from the Booster to the FMI ring
1.1.1.3	150 GeV proton line from the FMI ring to the Tevatron (also carries 120 GeV proton from the FMI ring to the Main Ring Remnant and 8 GeV anti-protons from the Remnant to the FMI ring)
1.1.1.4	150 GeV antiproton line from FMI ring to the Tevatron
1.1.1.5	120 GeV proton line, Main Ring Remnant from F0 to F17
1.1.1.6	Slow spill line, 120 GeV protons in Main Ring Remnant from F17 to Switchyard
1.1.1.8	Abort line
1.1.1.10	Magnet tooling

TABLE 3.1-2: Fermilab Main Injector Magnets by Type

1.1.1.x.1 Main Dipoles

1.1.1.x.1.1	IDA dipole 240"	[new design]
1.1.1.x.1.2	IDB dipole 240"	[new design]
1.1.1.x.1.3	IDC dipole 160"	[new design]
1.1.1.x.1.4	IDC dipole 160"	[new design]
1.1.1.x.1.5	SDB (120")	[more existing]
1.1.1.x.1.7	BDM (240" B2)	[rework old]
1.1.1.x.1.10	2XB2 (240")	[left in place]
1.1.1.x.1.12	EPB 5-1.5-120	[more existing]
1.1.1.x.1.13	ODM (240" B3)	[rework old]
1.1.1.x.1.14	BDM (240" B1/B2)	[left in place]

1.1.1.x.2 Quadrupoles

1.1.1.x.2.3	IQC (100.13" MI)	[new design]
1.1.1.x.2.4	IQD (116.26" MI)	[new design]
1.1.1.x.2.5	BQB (84" MR)	[rework old]
1.1.1.x.2.6	BQA (52" MR)	[rework old]
1.1.1.x.2.7	SQA (17" P-Bar)	[rework old]
1.1.1.x.2.8	SQA (17" P-Bar)	[more existing]
1.1.1.x.2.9	BQB, rolled	[rework old]
1.1.1.x.2.10	BQB (in place)	[left in place]
1.1.1.x.2.11	BQA (in place)	[left in place]

1.1.1.x.3 High Order Correction Elements

1.1.1.x.3.1	ISA (sextupoles)	[new design]
1.1.1.x.3.2	MR trim quads	[rework old]
1.1.1.x.3.3	MR skew quads	[rework old]
1.1.1.x.3.4	MR skew sext	[rework old]
1.1.1.x.3.5	MR trim sext	[rework old]
1.1.1.x.3.6	MR octupoles	[rework old]

1.1.1.x.4 Dipoles Trim Steering Magnets

1.1.1.x.4.1	HDC MR horz trim	[rework old]
1.1.1.x.4.2	IDH MI horz trim	[new design]
1.1.1.x.4.3	VDC MR vert trim	[rework old]
1.1.1.x.4.4	IDV MI vert trim	[new design

1.1.1.x.5 Injection and Extraction Lamberston and C Magnets

1.1.1.x.5.1	Lambertson, A0	[rework old]
1.1.1.x.5.2	Lambertson,MI, 94"	[new design]
1.1.1.x.5.3	Lambertson,MI, 189"	[new design]
1.1.1.x.5.5	C-magnet, MI, 118"	[new design]

Table 3.1-3: Main Injector Magnet Count

	Ring	8-GeV	150p	150ap	120p	Slow	Abort	Total	Spare
IDA dipole 240"	108	-	-	-	-	-	-	108	5
IDB dipole 240"	108	-	-	-	-	-	-	108	5
IDC dipole 160"	64	-	-	-	-	-	-	64	4
IDC dipole 160"	64	-	-	-	-	-	-	64	4
SDB (120")	-	2	-	-	-	-	-	2	1
BDM (240" B2)	-	51	15	15	-	-	2	83	5
2XB2 (240")	-	-	-	-	-	1	-	1	1
EPB 5-1.5-120	-	3	-	-	-	-	-	3	1
ODM (240" B3)	-	2	-	-	8	2	-	12	2
BDM (240" B1/B2)	-	-	-	-	15	101	-	116	6
IQC (100.13" MI)	32	-	-	-	-	-	-	32	3
IQD (116.26" MI)	48	-	-	-	-	-	-	48	4
BQB (84" MR)	127	-	13	13	-	1	-	154	7
BQA (52" MR)	-	-	4	4	2	-	3	13	2
SQA (17" P-Bar)	-	17	-	-	-	-	-	17	
SQA (17" P-Bar)	-	34	-	-	-	-	-	34	4
BQB, rolled	1	-	-	-	-	-	-	1	1
BQB (in place)	-	-	-	-	6	26	-	32	3
BQA (in place)	-	-	-	-	-	4	-	4	1
ISA (sextupoles)	108	-	-	-	-	-	-	108	5
MR trim quads	24	-	-	-	-	-	-	24	3
MR skew quads	18	-	-	-	-	-	-	18	2
MR skew sext	12	-	-	-	-	-	-	12	2
MR trim sext	28	-	-	-	-	-	-	28	3
MR octupoles	20	-	-	-	-	-	-	20	3
HDC MR horz trim	-	25	7	7	4	14	2	59	4
IDH MI horz trim	104	-	-	-	-	-	-	104	5
VDC MR vert trim	-	25	14	14	4	14	2	73	5
IDV MI vert trim	104	-	-	-	-	-	-	104	5
Lambertson, A0	-	1	-	-	-	-	-	1	1
Lambertson, MI, 94"	-	-	1	1	-	-	1	3	1
Lambertson, MI,189"	-	-	2	2	-	-	1	5	1
C-magnet, F17,118"	-	-	-	-	2	-	-	2	1
C-magnet, MI, 118"	-	-	5	5	-	-	1	11	2
Totals:	970	160	61	61	41	163	12	1468	102

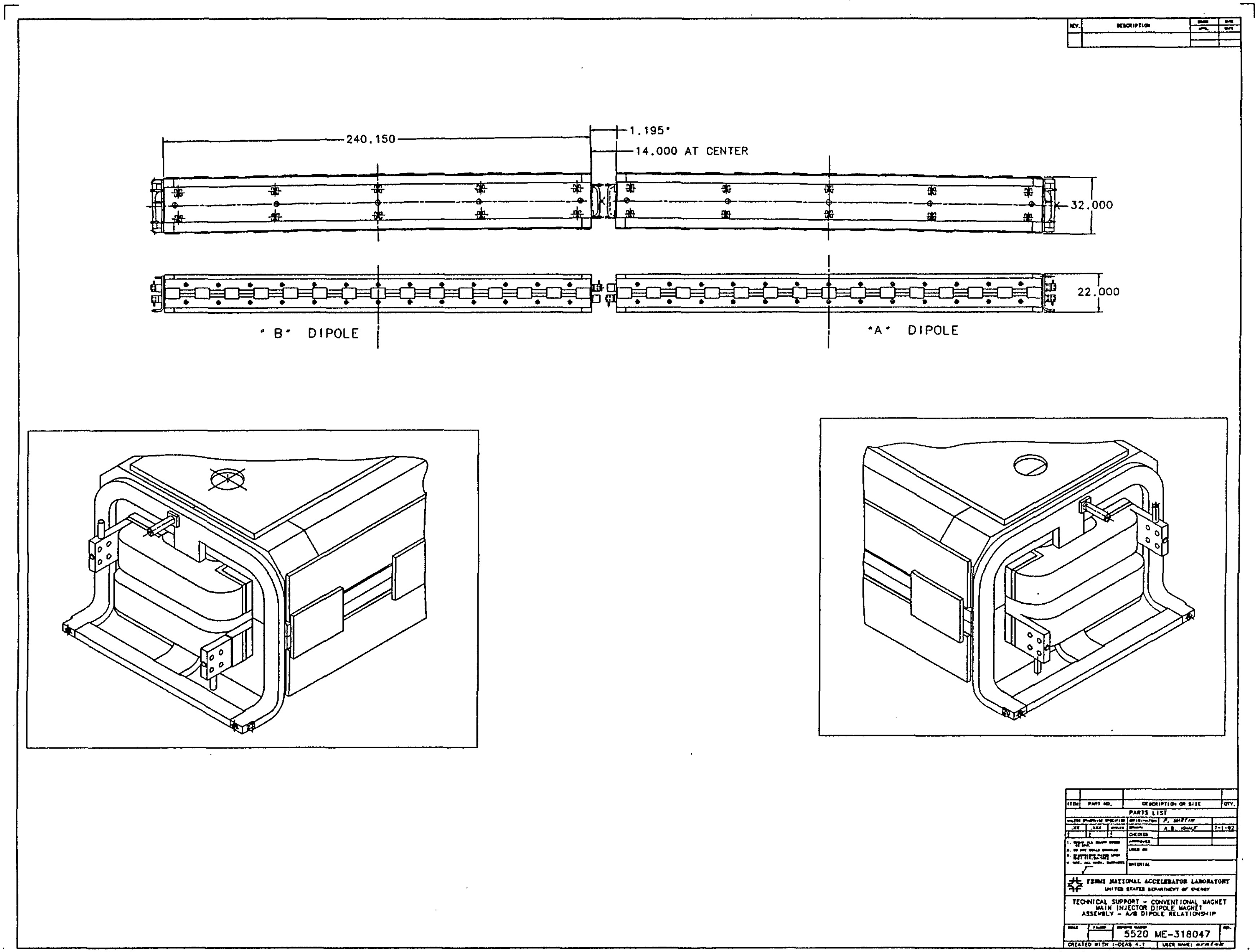


Figure 3.1-1. Layout of "A" and "B" Dipoles Together in a Half-Cell

field quality can be achieved in a newly constructed magnet, so that the dynamic aperture is only limited by the magnet physical aperture - a situation not achieved in the existing Main Ring.

A cost optimization has been performed to minimize the sum of construction plus operating costs over five years. The result is a magnet with twice as much conductor and half as many turns as the existing Main Ring B2 magnet. The dipole magnet cross section is shown in Figure 3.1-2. The basic parameters of the dipoles are listed in Table 3.1-4. The core is constructed from 1.52 mm (0.0598") thick laminations which are split on the magnet midplane. The coil consists of four turns per pole of a 25.4 mm x 101.6 mm (1"x4") copper conductor. Since no conductor is contained in the median plane of the magnet, the coil can be wound as two "pancakes" with no bends along the long dimension of the conductor. This conductor is available in 6-m (20-ft) lengths, so each coil can be made with only eight joints. The joints will be of a type with demonstrated reliability in which conductors are brazed together with a ferrule inserted between the conductor water holes. Induction brazing of the joint will assure uniformly high quality. The water hole is 12.7 mm (0.5") in diameter. A single water circuit in each pancake (two circuits per magnet) provides sufficient cooling.

A four terminal design has been chosen for the dipole magnet. In a magnet of this design, the role of return bus is filled by one of the conductor turns within the magnet. This has the advantage of removing the need for approximately 3600 m (12,000 ft) of 2580 square mm (4 square inch) copper bus (@ $130/m, $40/ft) in the FMI enclosure. The price paid for this benefit is the requirement that the insulation be sufficient to withstand 2,000 volts between conductors within the coil and 1,000 volts to ground.

Prototype Dipoles

The body field of two prototype dipoles has been measured using four systems: a narrow loop moved across the aperture ("flat coil"); a rotating coil positioned at three locations across the aperture; a Hall probe; and an NMR probe. From each measurement the field $B_y(x)$ has been reconstructed. The field has been modeled using the programs Poisson and PE2D. Figure 3.1-3 shows the relative variation from the central field of the first prototype at the injection energy as calculated by PE2D, as measured with flat coil, and as measured with the rotating coil. Agreement is quite good.

The effects of the remnant field are minimized by: the reasonably high injection field of 1 kG; the use of high quality steel with coercivity < 1 Oe; and the lamination design. Figure 3.1-4 shows the measured field shape for 8 GeV, 120 GeV, and 150 GeV. Both flat coil data and fields reconstructed from the harmonics data are plotted, again demonstrating good agreement between

MAIN INJECTOR RING DIPOLE

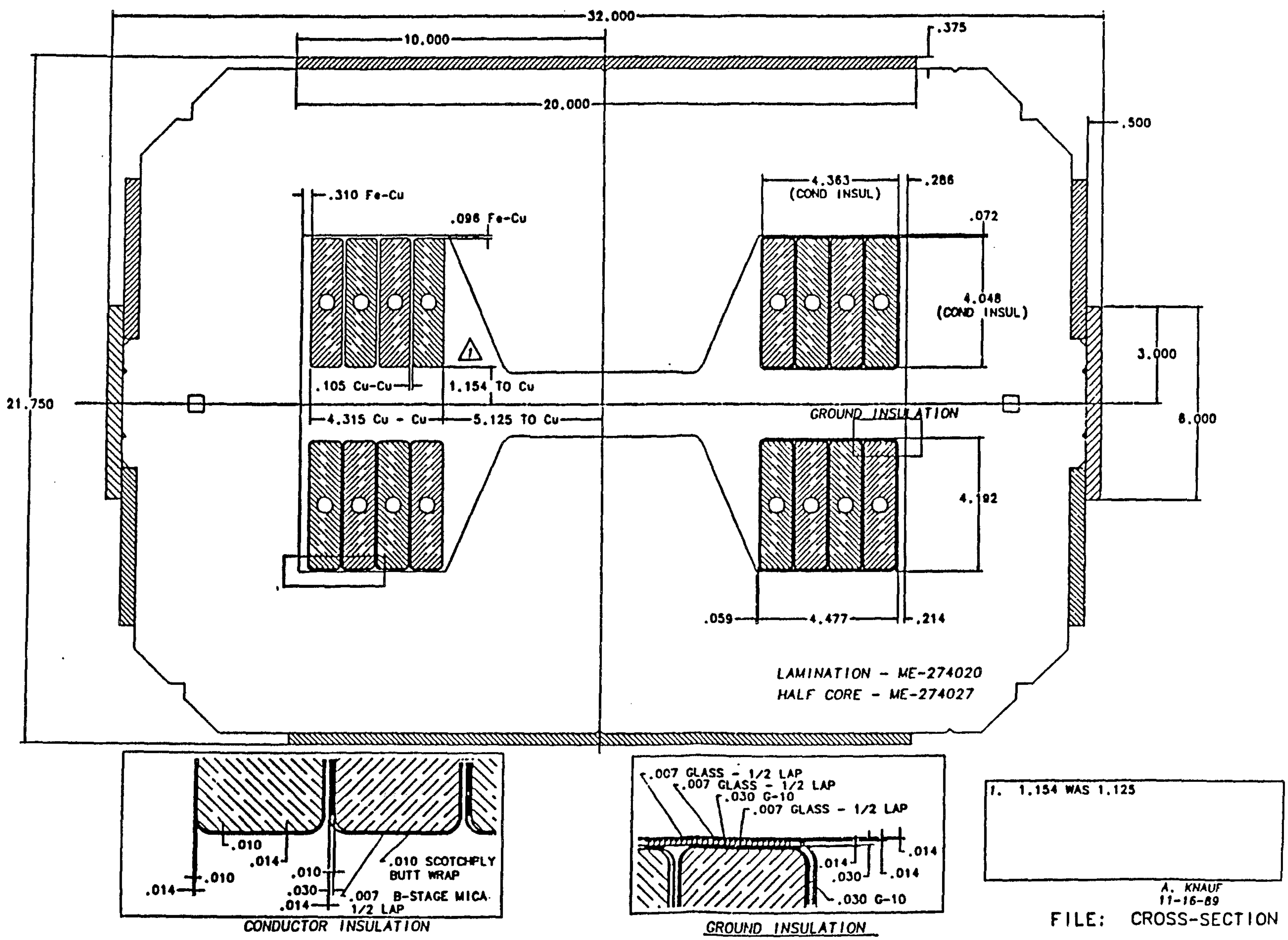


Figure 3.1-2. Cross-Section of the Main Injector Dipole Magnet

Table 3.1-4 Properties of Dipoles in the Main Injector Project

	IDA/IDB	IDC/IDD	SDB	2XB2	BDM (B2)	_BDM_ (B2)	_BDM_ (B2)	EPB 1.5-5-120	ODM (B3)	_ODM_ (B3)
Where used	FMI	FMI	8 GeV	Slow	8 GeV	120 GeV	150 GeV	8 GeV	8 GeV	120 GeV
Length (meters)	6.096	4.064	3.048	6.071	6.071	6.071	6.071	3.048	6.071	6.071
Strength (Tesla)	1.72	1.72	1.85	1.08	0.20	.54	1.89	0.92	0.28	1.08
Gap (mm)	50.8	50.8	60.3	50.8	50.8	50.8	50.8	38.1	76.2	76.2
Turns/pole	4	4	36	16	8	8	8	14	12	12
Peak Current (A)	9375	9375	1294	1356	498	1356	4900	895	679	1356
RMS Current (A)	4987	4987	1294	721	498	721	2600	895	679	721
Coil Resistance (mΩ)	0.8	0.6	14.1	30	7.2	7.2	7.2	17.5	11.4	45.6
Coil Inductance (mH)	2.0	1.3	109.2	32	8.0	8.0	8.0	30.0	15.0	60.1
Peak Power (kW)	69.8	53.0	23.6	55.2	2.0	13.2	172.9	14.0	5.2	83.8
RMS Power (kW)	19.8	15.0	23.6	15.6	2.0	3.7	48.6	14.0	5.2	23.7
Number Used	216	128	2	1	51	116	32	3	2	10*
Weight (kG)	17000	12000	17857	11455	11455	11455	11455	2558	13454	13454
Sagitta	16	7	63.5	0	0	0	0	0	0	0

* 3 B3 dipoles run at twice strength, with the parameters shown, and 7 run at single strength, or half the field and one-fourth the power.

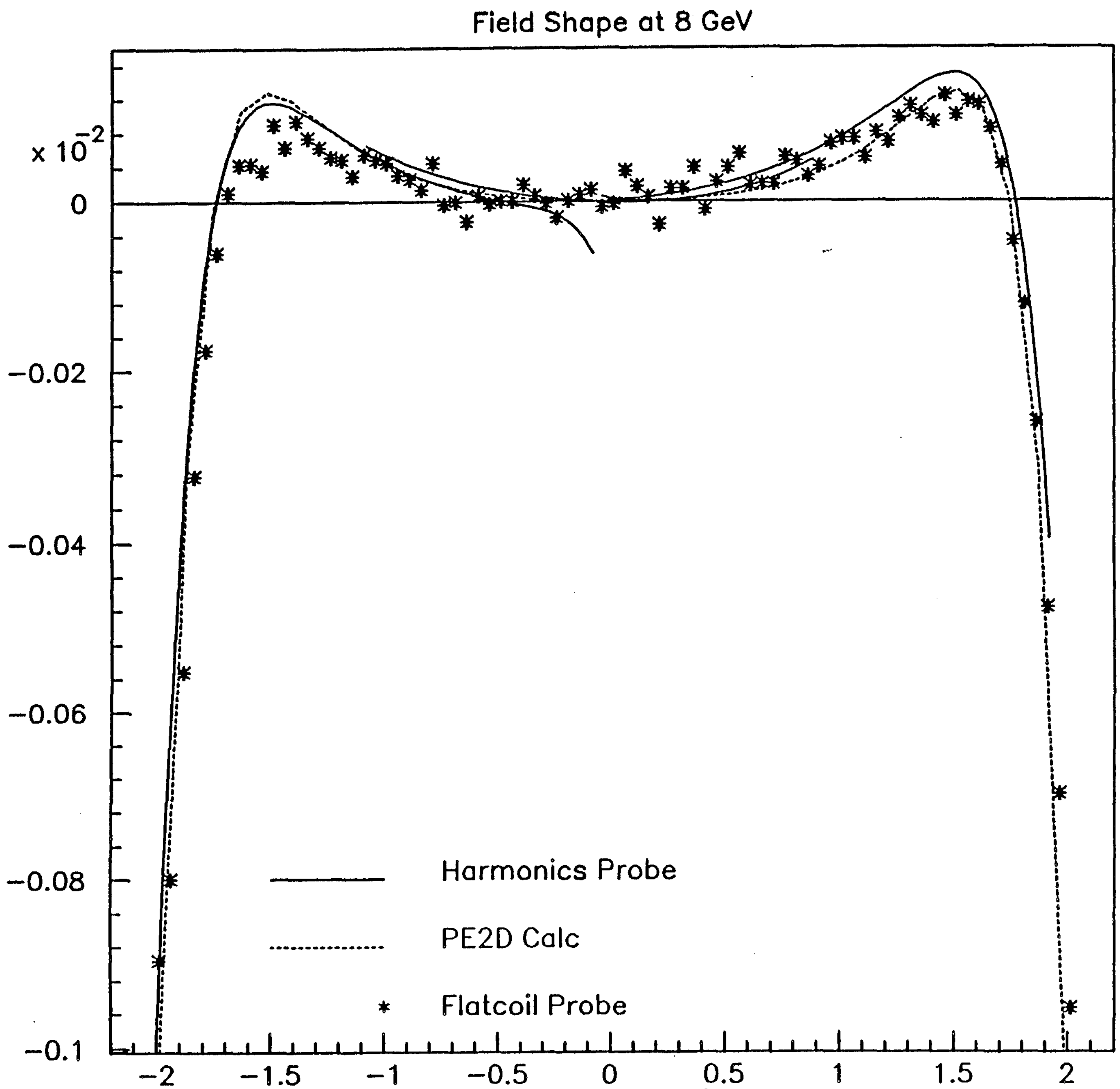


Figure 3.1-3. Comparison of Calculated and Measured Field Shape at Injection

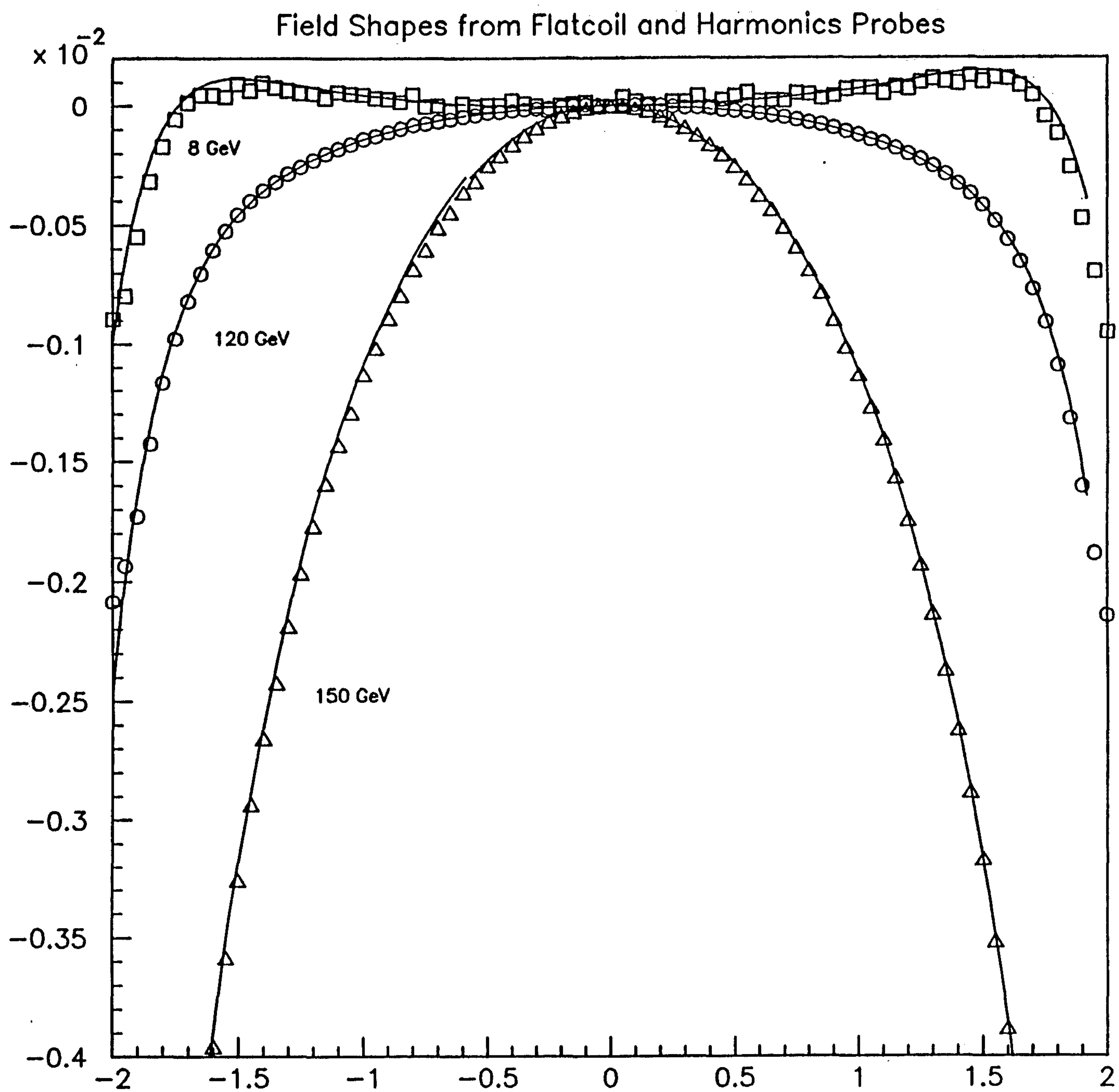


Figure 3.1-4. Measured field Shape at Injection, 120 and 150 GeV.

the measurements. The multipole composition of the field shape is shown in Figure 3.1-5 as a function of current. The deviations in field shape are predominantly a sextupole field. This means that the horizontal chromaticity-correcting sextupoles can completely correct for these deviations.

At injection energy the field shape is dominated by the lamination shape. The lamination shape is designed to provide a field at the injection energy which varies by no more than $1x10^{-4}$ over the range -44 mm < x < +44 mm. The beam will cover a region of -22 mm < x < +22 mm. The additional good field will allow steering to optimize the injection efficiency.

At transition the field shape from the magnet is still dominated by the lamination shape. Although the required good field region grows to -34 mm < x < +34 mm at transition, the steel shape continues to provide a good field over -44 mm < x < +44 mm.

At the 120 GeV energy used for antiproton production and slow spill some saturation has started to set in on the edges of the pole face. The $1x10^{-4}$ tolerance still holds over the beam size -23 mm < x < +23 mm.

The beam size at 150 GeV has shrunk to 10 mm (95% full width), so the shrinkage of the $1x10^{-4}$ region to -8 mm < x < +8 mm is acceptable. The required strength of the sextupoles is dominated by the the desire to control the chromaticity at full energy.

<u>End Field</u>

Nominal operation of the FMI requires that the ratio of integrated strength of the 6-meter dipoles to the 4-meter dipoles be 3:2. The "effective length" is the integral of the field through the whole magnet divided by the average field in the body. The original end pack was designed when all the magnets in the design lattice were the same length. That design produces a field that varies with current differently from the body of the magnet, and that variation produced a variation in the effective length of the magnet of 5 mm over the operating range. The closed orbit error caused by the variation can be corrected by the dipole trim magnets, but it would use up a significant fraction of their range which would be better kept available for unexpected needs. Work is in progress to design, build, and test an end pack that will reduce the effect. The transverse profile of the end packs of the magnets will also be tailored to reduce its sextupole component at injection energy.

<u>Eddy Current Effects</u>

The ramping magnetic field induces eddy currents in the stainless steel beam pipe described in Chapter 3.2. These eddy currents produce magnetic fields that affect the beam.

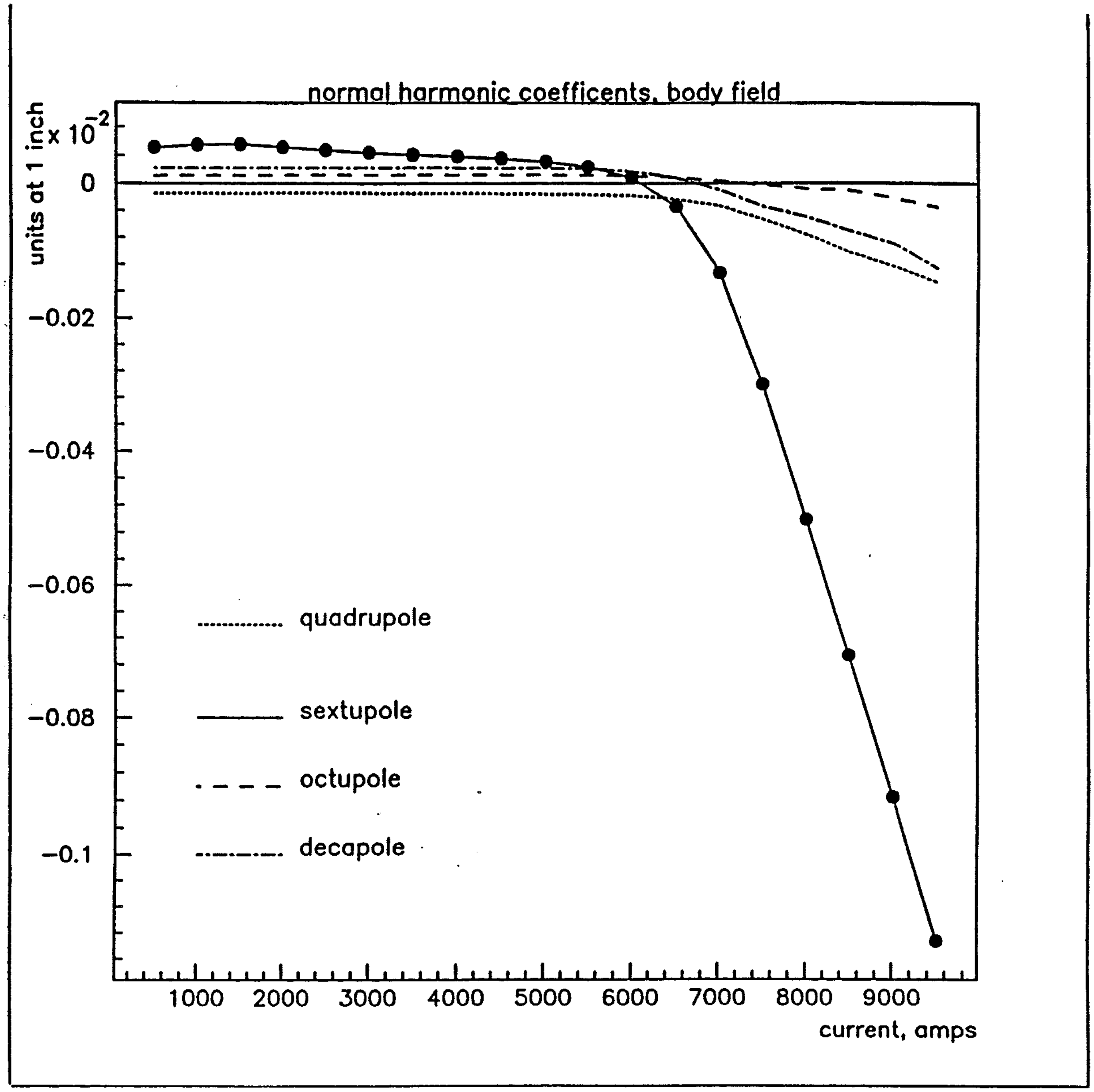


Figure 3.1-5. Multipole Composition of Field Shape vs. Current

Symmetry allows only even terms in a multipole expansion: dipole, sextupole, decapole. The dipole term, predominantly from current flowing in the side walls of the beam pipe, merely requires a greater current to produce the desired magnetic field. The sextupole field, which is produced by infinite parallel plates, is troublesome. The decapole and higher fields are too small to be measurable or of significant effect.

The eddy current fields have been calculated. The sextupole field has been measured for three ramp rates and two stainless steel alloys. Figure 3.1-6 shows the sextupole field as a function of time during a simplified, abbreviated ramp cycle for three conditions: no beam pipe, 330 beam pipe, and 316L beam pipe. The linear rise with current of the geometrical sextupole can be seen for the curve without beam pipe. The additional sextupole field, proportional to dB/dt, is seen adding to the geometrical term during the ramp for each of the cases with beam pipe. The eddy currents and the resulting field are smaller with the 330 stainless steel than with the 316L stainless due to the higher resistivity of 330. The measurements and calculations agree to within 10%.

The lower fields produced by the 330 stainless steel are attractive, but the higher cost and worries about mating it to other vacuum components of a dissimilar stainless steel led to the choice of 316L for the beam pipe.

Procurement

An advanced procurement plan for the Main Injector Ring dipoles has been prepared, endorsed by the Business Strategy Group, and accepted by DOE. Major sub-assemblies will be constructed by industrial subcontractors. Fermilab will do the final assembly of the components on-site.

Fermilab will acquire the lamination steel. One subcontractor will stamp the steel into laminations. Another subcontractor will stack the laminations and weld them together into half-cores. One subcontractor will manufacture the bare coils, acquiring the copper, then bending and brazing it; another subcontractor will insulate the coils. The vacuum pipe assemblies will be fabricated by a subcontractor (with the beam pipe itself and the bellows acquired by Fermilab). Fermilab will also purchase the material used in the final assembly. The final assembly labor, approximately 4% of the total cost, will be provided by Fermilab.

To improve the chances for success, twelve dipoles will be constructed in a research and development project with industry participation. Bare coils will be fabricated by a subcontrator chosen in a competitive process. Six coil sets will be insulated by Fermilab and three each by two subcontractors selected through a competitive process. Vendors will have the opportunity to

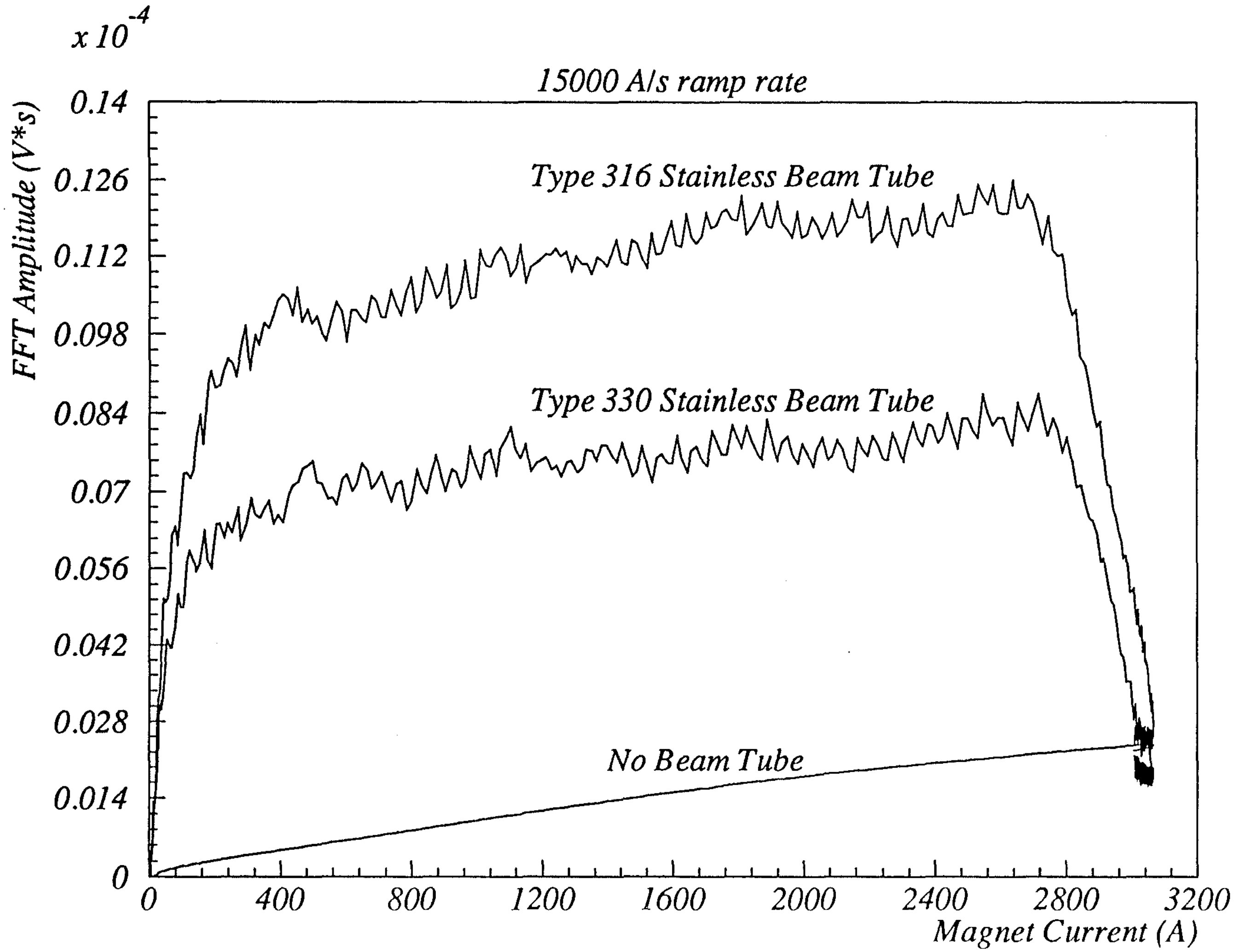


Figure 3.1-6. Sextupole Field for No Beam Pipe and for Beam Pipes made of 316L and 330 Stainless Steel

observe the insulation process at Fermilab during their contract. The subcontractor for the production run of insulation will be chosen in a limited competition between the two R&D subcontractors. Similarly, six sets of half-cores will be constructed by Fermilab and three each by two subcontractors. The subcontractor for the production run will be chosen in a limited competition between the two R&D subcontractors. Fermilab will do the final assembly of the R&D dipoles, as it will for the production run.

The subassemblies will be received, inspected, and stored at Industrial Building 4. The final assembly will be done in Fermilab's Industrial Building 2. The building has adequate floor space, crane capacity, and vehicular access for staging the subassemblies and doing the final assembly. The complete magnets will be moved to the adjacent Magnet Test Facility (MTF) for final testing. Storage is expected to be available in the Main Injector service buildings and tunnels at the time that it is needed.

The procurement schedule is shown in Figure 3.1-7. The acquisition will require multi-year funding. This will be achieved by writing contracts with options which can be exercised in the out years. The ability to exercise those options in a timely fashion is imperative.

Testing

Every dipole will be thoroughly tested promptly after assembly. This will ensure that every magnet installed meets the magnetic requirements of the project. Subtle manufacturing problems can be identified early and corrected. It will be possible to trim each magnet to meet tolerances in the unlikely event that the manufacturing process cannot hold the tolerances required. Additional improvement of the accelerator performance can be achieved by assigning magnets to locations in the ring based on their magnetic properties. Finally, measurements on every magnet will allow improved accelerator modeling.

It is believed that all necessary measurements on the production dipoles can be performed in about one-and-a-half eight-hour shifts, including installation and removal from the test stand. This comfortably provides a testing rate of twenty magnets a month, well above the production rate of fifteen or sixteen magnets per month.

The integrated strength and the strength as a function of position will be measured by two methods each to provide continuous cross-calibration and some redundancy in the case of failures. The primary measurement system will be a long narrow coil of wire, rigidly formed to the trajectory of a particle through the magnet. Both strength and field shape can be measured with this. NMR and Hall probes traveling through the magnet will measure the field at many

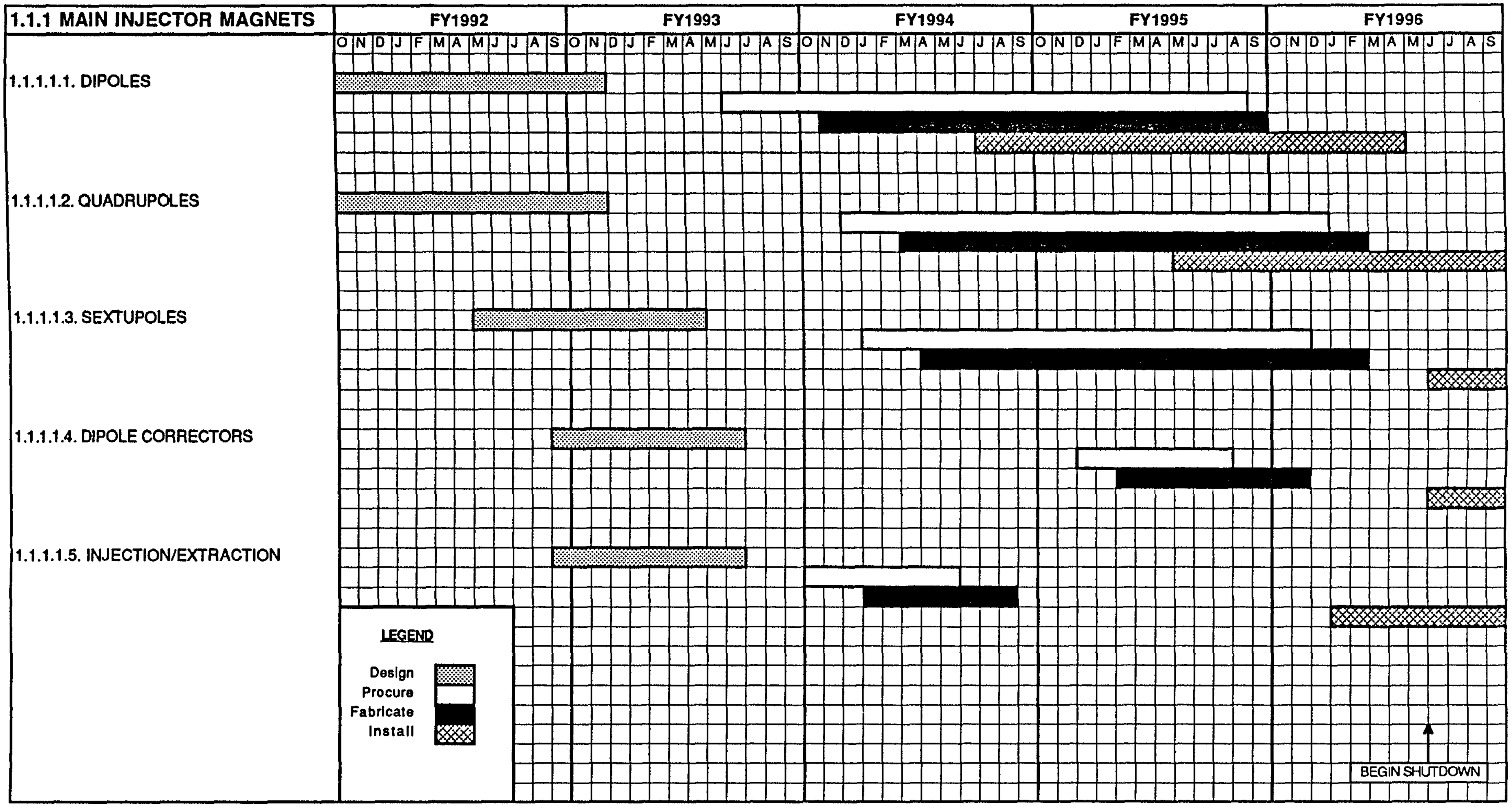


Figure 3.1-7. Main Injector Magnet Schedule.

points, giving a longitudinal profile and the central field integral. The alternate shape determination may be done with a long or a short rotating coil.

WBS 1.1.1.1.2 RING QUADRUPOLES

The majority of the quadrupole magnets in the project are reused Main Ring quadrupoles. Since the beam travels straight through them, they do not suffer the trouble with sagitta that the dipoles do. They have been somewhat more reliable than the dipoles. To complement the existing quadrupoles, additional quadrupoles are built to essentially the same design but in different lengths. Figure 3.1-8 shows a cross-section of the quadrupole magnet.

New Main Injector Quadrupoles

These quadrupoles use the same lamination shape as the original Main Ring quadrupoles. See Table 3.1-5 for the quadrupole parameters. A new design for the insulation should improve reliability over the Main Ring insulation. Also, the hole in the conductor for cooling water has been expanded compared to the Main Ring quadrupole conductor to provide adequate water flow through the longer coils.

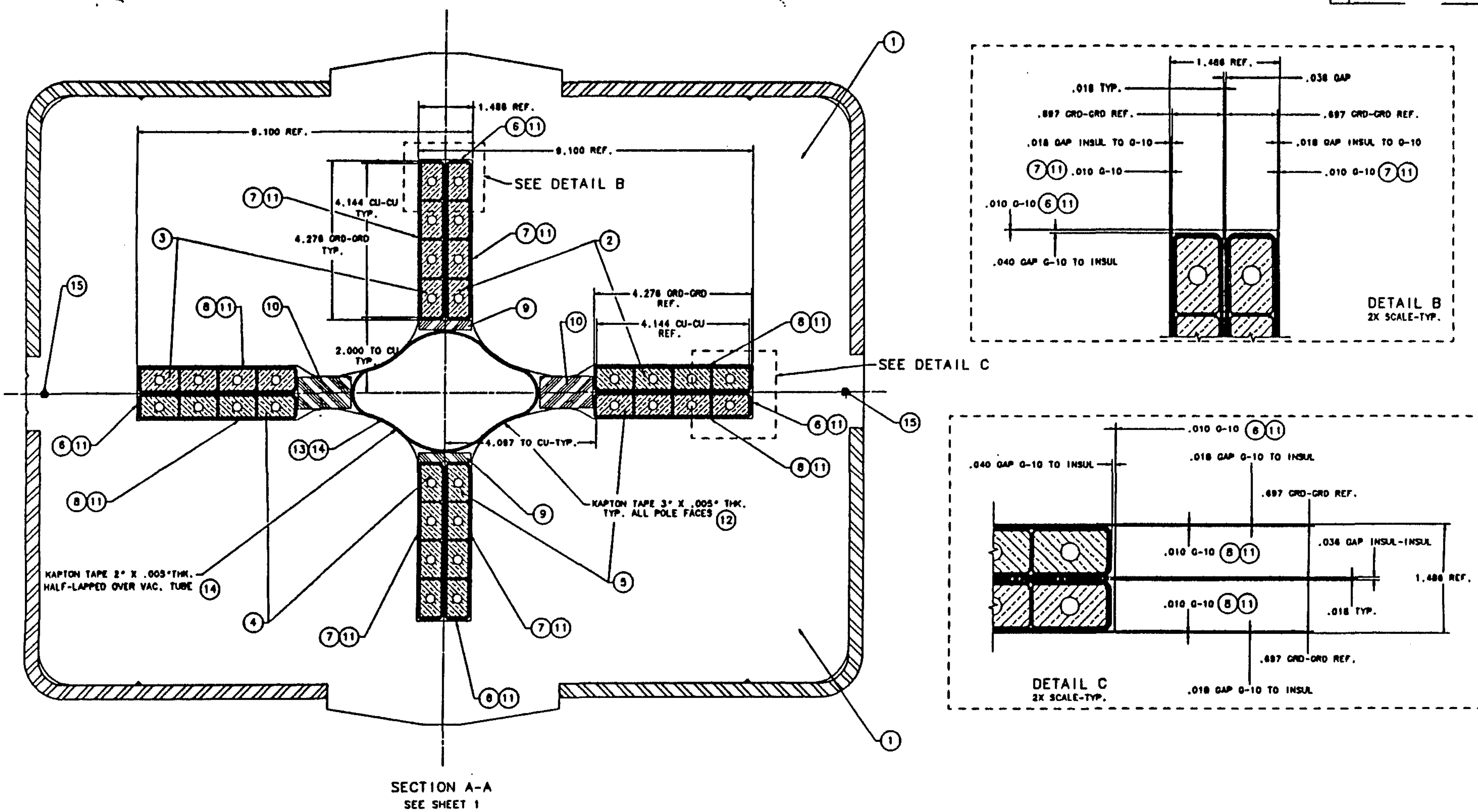
A trim coil is added to the winding, allowing adjustment of the gradient over a range of ±1 % from the nominal full field. This will allow more precise matching of the lattice between the arcs and the zero-dispersion straight sections. A trim coil is chosen rather than adding a comparable power supply to each quad in parallel. First, floating the power supplies significantly away from ground is more troublesome than not having to worry about it. Second, an independent coil allows bussing the trims of several quads together for grouped control.

The original Main Ring lamination was designed to be essentially free from octupole contamination. Most Main Ring quadrupoles have been modified to include a substantial octupole component. Magnetic modeling and measurements on unmodified Main Ring quadrupoles indicate that the field quality is excellent.

One prototype of each length is expected to be completed early in fiscal 1993. Fermilab will build the quadrupoles on the schedule shown in Figure 3.1-8. All of the quadrupoles will be tested at the Fermilab Magnet Test Facility.

2.13-Meter Main Ring Quadrupoles

Most of the quadrupoles in the FMI ring arcs are reused 2.13-m (84") Main Ring quadrupoles. The 2.13-m quads in the Main Ring are of two styles, "old" and "new". The old style has a very small octupole component. The newly built quadrupoles match that shape. The



NOTES:

2. THIS DRAWING SHOWS THE MAGNET CROSS SECTION.
SEE SHEET 1 FOR PARTS LISTING.
SEE SHEETS 3 & 4 FOR THE COIL, CORE AND VACUUM TUBE ASSEMBLY DETAILS AND PROCEDURES.
SEE SHEETS 5 & 6 FOR THE MANIFOLDING AND POTTING DETAILS AND PROCEDURES.
SEE SHEET 7 FOR FINAL ASSEMBLY AND PAINTING.

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FERMI NATIONAL ACCELERATOR LABORATORY
UNITED STATES DEPARTMENT OF ENERGY

CONVENTIONAL MAGNET FACILITY
MAIN INJECTOR QUADRUPOLE MAGNET
CROSS SECTION-116" QUAD. ASSY.

FULL 5520-ME-274651

Figure 3.1-8. Cross-Section of the Quadrupole Magnet .

Table 3.1-5 Properties of Quadrupoles in the Main Injector Project

Where used	IQD FMI	IQC FMI	BQB FMI	_BQB_ 120 GeV	_BQB_ 150 GeV	BQA 150 GeV Abort	SQA 8 GeV (Typ.)	SQA 8 GeV (Max.)
Length (m)	2.945	2.539	2.134	2.134	2.134	1.321	0.432	0.432
Strength (T/m)	19.6	19.6	19.6	7.3	20.5	20.5	6.2	14.0
Integrated strength (T-m/m)	57.79	49.83	41.87	15.62	43.74	27.08	2.67	6.03
Pole radius (in)	1.643	1.643	1.643	1.643	1.643	1.643	1.750	1.750
Pole radius (mm)	41.74	41.74	41.74	41.74	41.74	41.74	44.45	44.45
Turns/pole	4	4	4	4	4	4	33	33
Peak Current (A)	3630	3630	3630	1356	3800	3800	147	234
RMS Current (A)	2095	2095	2095	783	3000	3000	147	234
Coil resistance (mΩ)	6.1	5.2	4.5	4.5	4.5	2.6	32.3	32.3
Coil inductance (mH)	1.8	1.5	1.3	1.3	1.3	0.8	43	43
Peak power (kW)	80.4	68.5	59.3	8.3	65.0	37.6	.70	3.5
RMS power (kW)	25.4	21.6	18.7	2.8	40.5	23.4	.70	3.5
Number used	48	32	128	32	26	13	--	51 --
Weight (kG)	5852	5046	4082	4082	4082	2722	1330	1330

needed for resonant extraction, only new-style quads are reused in the FMI ring. The basic "new" style quads have about 0.25 mm milled from the backleg of the top half-core, resulting in a significant octupole component. For the sake of uniformity and to help provide the octupole properties are shown in Table 3.1-5

The Main Ring quadrupoles used in the FMI ring require two major modifications: The support structure and the vacuum system need to be changed. In the Main Ring many of the quadrupoles are held by a long cradle welded to the magnet to provide a support structure for correction elements. For the FMI, these cradles will be cut off and replaced by a new support fixture. The vacuum system must also be modified to match the FMI system. The end connections will be cut off flush and a new vacuum pipe inserted into the magnet. The new pipe is the same shape and dimensions as that used in the dipoles, reducing the impedance seen by the beam at shape transitions. The beam pipe carries the beam position monitor pickups in the quadrupoles. One of the quadrupoles needs to be mounted with an orientation rolled 90 degrees from usual to increase the vertical aperture for the beam just downstream of the injection Lambertson magnet. Magnets with this rolled configuration exist in the present Main Ring.

Removing, testing, modifying, retesting, and reinstalling these quadrupoles will be one of the major challenges of the installation period between shutting down the Main Ring and commissioning the FMI. The removal of the quads can be done quite rapidly. These magnets will have been running immediately before the shutdown period and will thus be known to be in good shape electrically. Each one will be visually inspected for potential problems before being moved. Each magnet will undergo a cursory measurement at the MTF, designed to coarsely characterize its properties at a limited number of critical excitations. Two test stands will run in parallel, two shifts a day, five days a week. The suite of measurements will be chosen to take five hours per magnet, including mounting and removal (three magnets/stand/day). Thirty magnets/week can be measured in the selection pass. The modifications detailed above are estimated to take 60 worker-hours/magnet. With 30 workers at 40 hours/week, 20 magnets/week will be processed. The magnets to rework are selected, probably on a very weak selection criterion, from the total set of magnets tested.

WBS 1.1.1.1.3. HARMONIC CORRECTORS

Wherever possible existing components are reused from the Main Ring, with minimal modifications. The sextupoles require more strength than is available from the Main Ring sextupoles, so a new design is required.

Chromaticity Sextupoles

The chromaticity sextupole magnets for the FMI are a new design, tailored to the geometrical, optical, and electrical requirements of the Main Injector. The natural chromaticities of the FMI are -33.65 horizontally and -32.87 vertically. The lattice has been designed to have low ß and η (58 m and 1.9 m are the maximum values). Thus, very strong sextupoles are needed to cancel the natural chromaticity. The configuration chosen places an F(D) sextupole at each F(D) main quadrupole in the arcs where η is large. There are also large sextupole components in the dipole magnet induced by saturation of the steel as the beam energy approaches 150 GeV and by eddy currents in the beam pipe, as shown in Figure 3.1-9(a). These effects produce inherent chromaticities of -77 horizontally (at 150 GeV) and -55 vertically (near 20 GeV). The correction sextupole magnets must be capable of compensating for all these effects.

Based on a requirement that the sextupoles be capable of producing a corrected chromaticity of +10 in each plane through the entire ramp, the sextupoles need to have a maximum field strength of 55 T-m/m^2. The required sextupole strengths as a function of time in the cycle are shown in Figure 3.1-9(b). Geometric considerations lead to a steel length of 0.46 meters (18 "), implying a field strength of 120 T/m^2. The cross section of a preliminary design is shown in Figure 3.1-10. To reduce the resistance and inductance of the magnet the design is not six-fold symmetric, but rather matches the beam pipe with top and bottom poles that are closer to the axis than are the side poles. The number of turns on the top and bottom poles is correspondingly smaller. The properties are summarized in Table 3.1-6. The sextupoles will be built at Fermilab on the schedule shown in Figure 3.1-7. The strength of sextupole magnets will be measured as the final quality control check and to characterize the performance.

Other Multipole Correctors

The main quadrupoles of the FMI will run on two separate busses and will be used for most operating tune adjustments. The need for the trim quadrupoles is obviated by the trim windings on the new Main Injector quadrupoles, but the old Main Ring trim quadrupoles are available. Trim quadrupoles are needed for harmonic generation or cancellation. A sufficient number of Main Ring trim quadrupoles will be installed around the ring to cancel half-integer stopbands, if they are significant. In addition, slow extraction will require sixteen trim quadrupoles for excitation of the half-integer resonance.

The twelve skew quads recovered from the Main Ring are necessary to adjust the betatron coupling. Additionally, four quadrupoles from the old Fermilab Electron Cooling Ring are used as skew quads in the Main Injector.

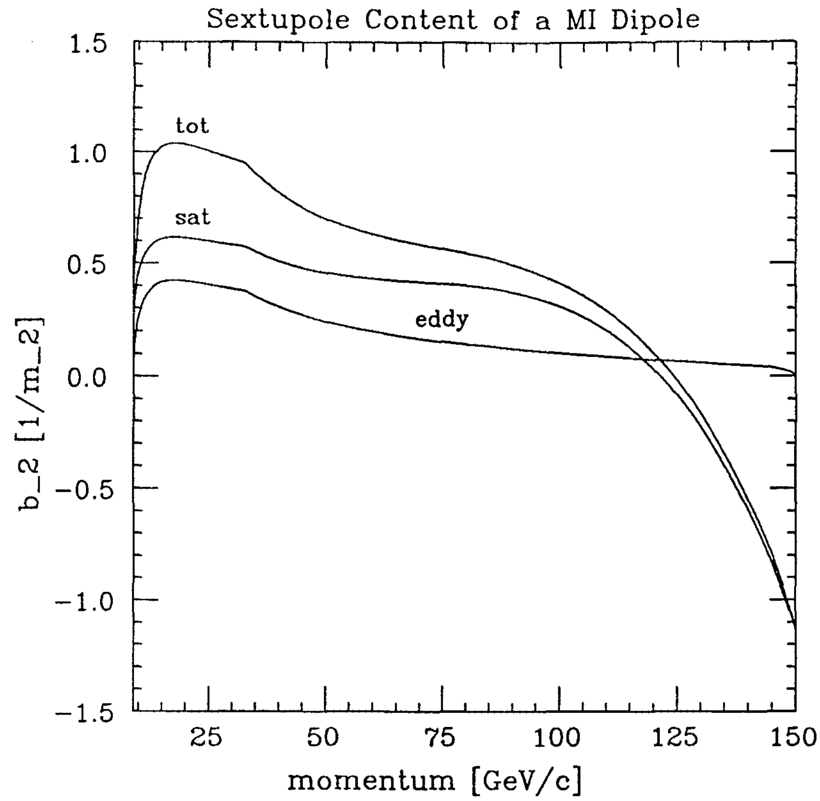

Figure 3.1-9(a) Dipole Magnet Contribution to Sextupole Strength Requirements.

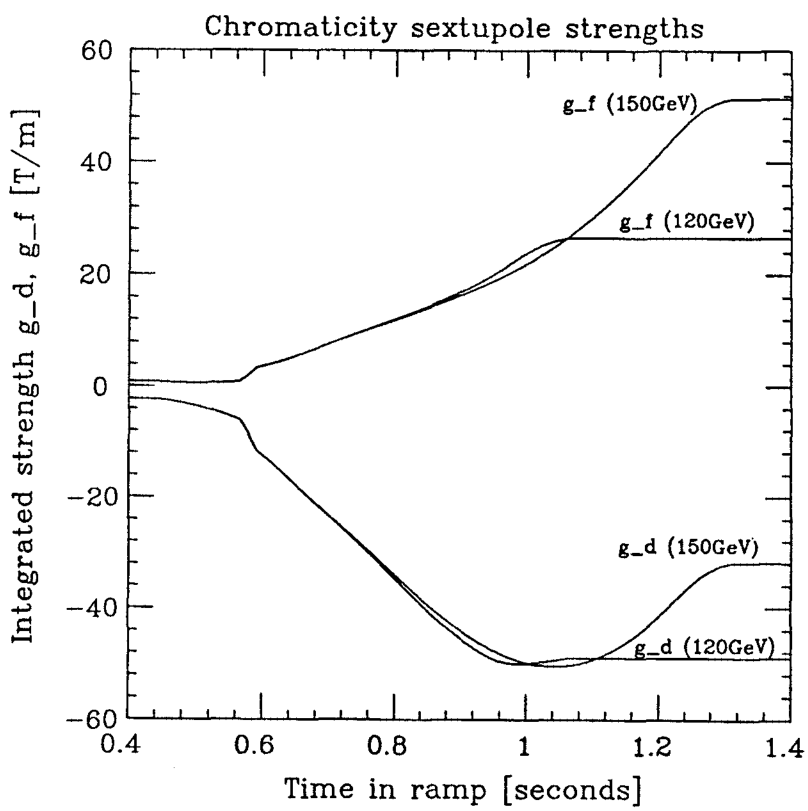

Figure 3.1-9(b). Sextupole Strength Requirements vs. Energy.

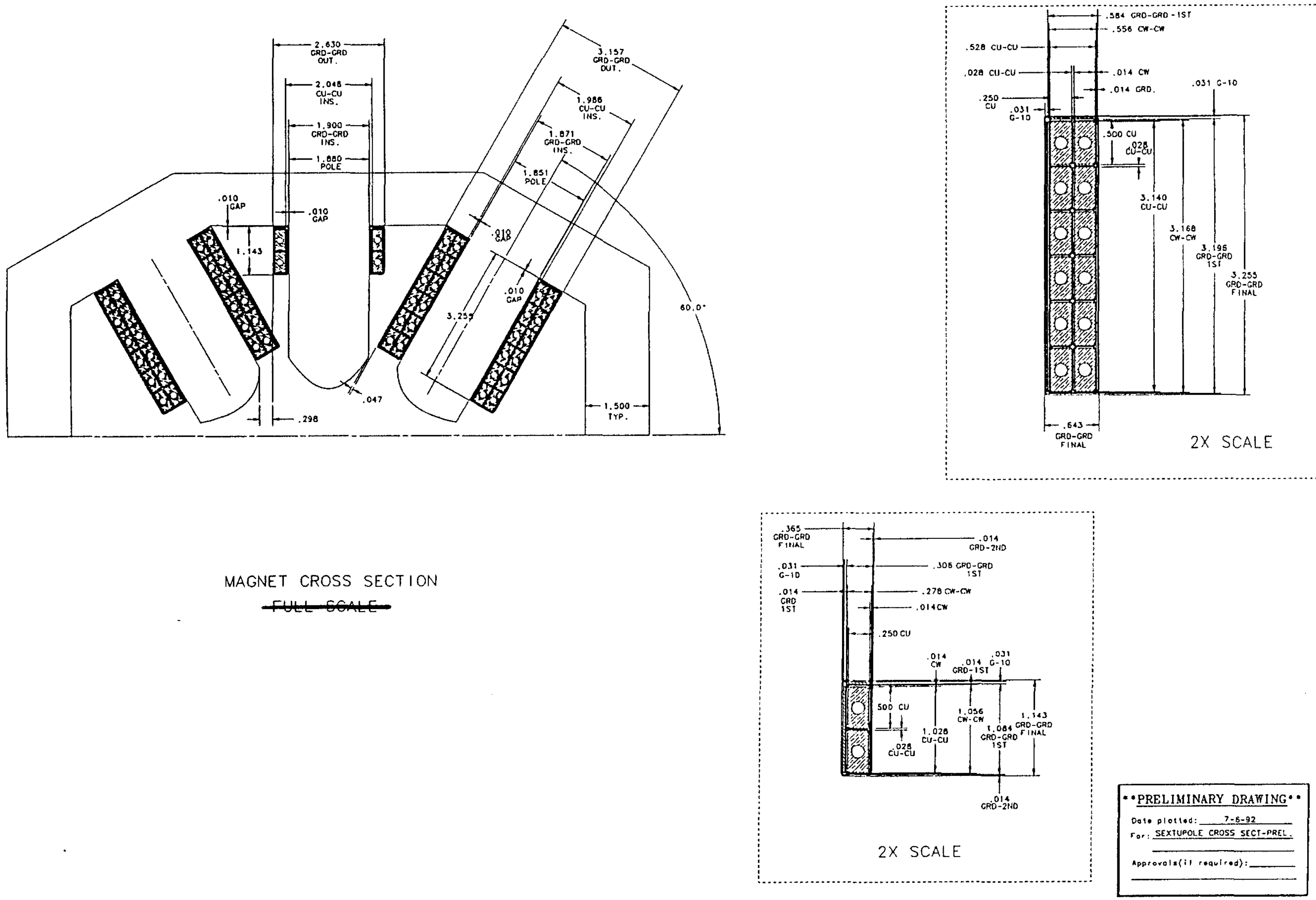

Figure 3.1-10. Cross-Section of the Sextupole Magnet.

Table 3.1-6 Properties of the Main Injector Sextupoles

		Side pole	Top/bottom poles
Steel length (meters)	0.457		
Length Steel (inches)	18.0		
Strength (T/m^2)	120		
Integrated strength ($T\text{-}m/m^2$)	55.0		
Distance to pole (inch)		1.890	1.040
Distance to pole (mm)		48.0	26.4
Turns/pole		12	2
Current (Ampere)		588	588
Number used	108		

With the strong sextupoles required in this ring there is some concern that the dynamic aperture of the machine might be adversely affected. Tracking studies completed to date indicate that there is no loss of dynamic aperture due to the sextupole correction system. However, we will

still distribute eight individually powered sextupoles in the straight sections for control of third order resonant driving terms. The Main Ring trim sextupoles are reused here. The Main Ring skew sextupoles are also available.

The Main Ring octupoles are used to compensate at injection for the octupole component in the Main Ring quads and to control the slow extraction.

WBS 1.1.1.1.4 RING CORRECTION DIPOLES

The steering dipoles correct the closed orbit. The primary sources of orbit distortion are quadrupole placement errors, dipole strength errors, and dipole rotations. These errors cause orbit distortions proportional to ß, which, if uncorrected, would yield rms errors on the order of 6 mm. Although the present Main Ring trims have adequate strength for correcting these errors at low field, the effort of shimming and recentering them and engineering a new mounting scheme is nontrivial. Therefore, new trim dipoles for the FMI ring will be fabricated, with strengths a factor of two greater than the present Main Ring correctors, allowing correction of errors up to 4 mm horizontally (3 mm vertically) at 150 GeV. A horizontal (vertical) trim dipole will be placed next to every focussing (defocussing) quadrupole in the ring.

The Main Injector trim dipoles are a new design to provide the needed steering strength within the geometrical constraints. Parameters for the conceptual design of the horizontal and vertical trim dipoles are shown in Table 3.1-7. The conceptual lamination shapes are shown in Figures 3.1-11 and 3.1-12. Fermilab will build the trim dipoles following the schedule shown in Figure 3.1-7.

WBS 1.1.1.2. 8 GEV LINE MAGNETS

WBS 1.1.1.2.1 8-GEV LINE DIPOLES

The basic properties of all of the dipoles are listed in Table 3.1-4.

SDB Dipole

There are two 10-foot dipoles near the start of the 8 GeV line whose exact identity is not yet settled. An SDB dipole, the 10-foot "small" aperture dipole used in the Fermilab Accumulator ring would work. We are looking for a substitute that would be less expensive to build and have a smaller cross-section to make installation easier. The best possibility we have found to date is to use the laminations for the FMI ring dipoles with a different coil configuration to produce the needed magnetic field at a lower current.

Table 3.1-7 Design Criteria of Main Injector Trim Dipoles

	Horizontal	Vertical
Integrated strength (T-m)	0.06	0.04
Slot length (m))	<0.42	<0.42
Gap (m)	0.053	0.121
Peak Current (A)	<12	<12
RMS Current 9A)	5	5

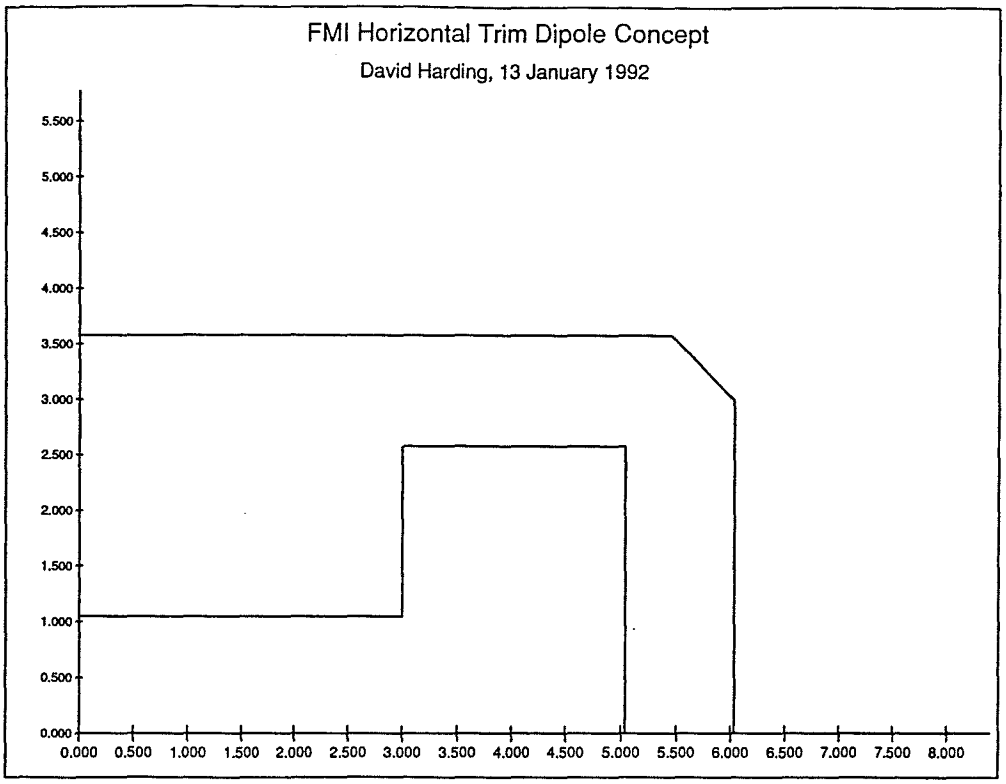

Figure 3.1-11. Horizontal Trim Dipole Lamination Shape.

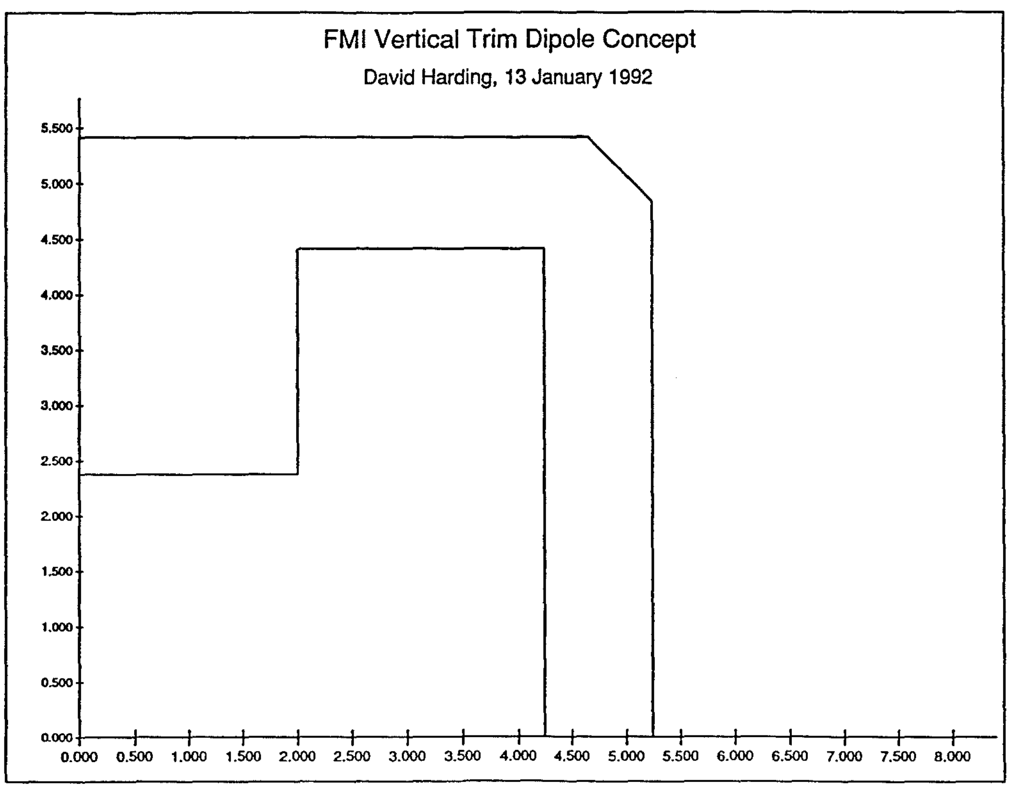

Figure 3.1-12. Vertical Trim Dipole Lamination Shape.

Reused Main Ring B2 Dipoles

The main horizontal bend of the 8 GeV line is composed of B2 magnets recovered from the Main Ring. These magnets will have been running immediately before the shutdown period and will thus be known to be in good shape. Each one will be visually inspected for potential problems before being moved to its new location. Extensive reworking of these magnets is not expected.

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The tight geometry of the existing Booster enclosure and the need for a wide aperture suggested the use of these dipoles. The design has been used in external beamlines for many years. The magnets seem to have been built primarily by an outside vendor. No tooling, or even tooling drawings, seem to exist at Fermilab. Identifying available spare magnets from the external beamlines seems important to using this magnet.

Reused Main Ring B3 Dipoles

The vertical bends required to drop the beam 3.3 meters between Booster and the Main Injector ring heights is provided by two B3 magnets recovered from the Main Ring. The magnets are presently used as vertical bends for the Main Ring overpasses. Extensive reworking of these magnets is not expected. These magnets will have been running immediately before the shutdown period and will thus be known to be in good shape. Each one will be visually inspected for potential problems before being moved to its new location.

WBS 1.1.1.2.2. QUADRUPOLES

SQA

The SQA quadrupoles were designed for the Anti-Proton Source. The basic properties of the quadrupoles are included in Table 3.1-5. SQAs were also used in 1986 when the 8 GeV beamline from Booster to Main Ring was rebuilt. All of the SQAs downstream of the dump in that old 8 GeV line are reused in the Booster to FMI line, along with newly constructed ones. The reused magnets do not require remeasurement, but a visual and electrical inspection will be conducted. The newly constructed magnets will be measured at MTF.

WBS 1.1.1.2.4. DIPOLE CORRECTION MAGNETS

Main Ring correctors will be used in the beamlines, providing either horizontal or vertical correction at every quadrupole. The Main Ring trim dipoles will be modified as needed to fit around the appropriate beam pipes.

WBS 1.1.1.2.5. INJECTION LAMBERTSON MAGNET

The injection Lambertson for the 8 GeV line is the magnet from the old 8 GeV line. Only minor changes to the support structure and vacuum connections are required.

WBS 1.1.1.3. 150 GEV PROTON LINE

Except for the extraction and injection elements at the ends, all of the magnets in the 150 GeV Proton Line are reused Main Ring magnets. The magnets will be in good shape, having just been removed from a working accelerator. Nonetheless, a visual and electrical inspection will be conducted in the tunnel before selecting the magnets to be reused.

WBS 1.1.1.3.1. DIPOLES

The bending dipoles are B2s recovered from the Main Ring. The B2s that are rolled to provide vertical as well as horizontal bends in the same magnet may require a change in their support structure. The vacuum connections should remain the same. Magnetic measurements are not necessary for these magnets.

WBS 1.1.1.3.2. QUADRUPOLES

The quadrupoles are 2.13-m (84") quads and 1.32-m (52") quads reused from the Main Ring. These will require new support structures. The vacuum connections will not need to be changed. We expect to have made magnetic measurements on them as part of the selection process of quadrupoles to be used in the ring.

WBS 1.1.1.3.4. TRIM DIPOLES

Trim dipoles, horizontal and vertical, will be recovered from the Main Ring as well. These may also require a change in their support structure. Magnetic measurements are not necessary for these magnets.

WBS 1.1.1.3.5. INJECTION AND EXTRACTION ELEMENTS

The combination of aperture and strength considerations require a new Lambertson design for the transfers between the FMI and the Tevatron. One each of two lengths, 2.4 meters and 4.8 meters are used for Main Injector extraction. Two 4.8-meter Lambertsons of the same design are required for injection into the Tevatron. These are shared between the 150 GeV Proton Line and the 150 GeV Antiproton Line, with one being counted in each line's WBS.

Aperture and strength requirements also demand a new 3.0-meter C-magnet design for the FMI to Tevatron transfer.

WBS 1.1.1.4 150 GEV ANTIPROTON LINE

The 150 GeV Antiproton Line uses exactly the same combination of magnets as the 150 GeV Proton Line. Not having to deal with large 8 GeV beam relaxes the constraints on the line somewhat, but for the sake of uniformity the elements are kept identical. There are slight differences in the tune of the line.

Except for the extraction and injection elements at the ends, all of the magnets in the 150 GeV Antiproton Line are reused Main Ring magnets. The magnets will be in good shape, having just been removed from a working accelerator. Nonetheless, a visual and electrical inspection will be conducted in the tunnel before selecting the magnets to be reused.

WBS 1.1.1.4.1. DIPOLES

The bending dipoles are B2s recovered from the Main Ring. Those B2s that are rolled to provide vertical as well as horizontal bends in the same magnet may require a change in their support structure. The vacuum connections should remain the same. Magnetic measurements are not necessary for these magnets.

WBS 1.1.1.4.2. QUADRUPOLES

The quadrupoles are 2.13-m (84") quads and 1.32-m (52") quads reused from the Main Ring. These will require new support structures. The vacuum connections will not need to be changed. We expect to have made magnetic measurements on them as part of the selection process of quadrupoles to be used in the ring.

WBS 1.1.1.4.4. TRIM DIPOLES

Trim dipoles, horizontal and vertical will be recovered from the Main Ring as well. These may also require a change in their support structure. Magnetic measurements are not necessary for these magnets.

WBS 1.1.1.4.5. INJECTION AND EXTRACTION ELEMENTS

The combination of aperture and strength considerations require a new Lambertson design for the transfers between the FMI and the Tevatron. One each of two lengths, 2.4 meters and 4.8 meters are used for Main Injector extraction. Two 4.8-meter Lambertsons of the same design are required for injection into the Tevatron. These are shared between the 150 GeV Proton Line and the 150 GeV Antiproton Line, with one being counted in each line's WBS. Aperture and strength requirements also demand a new 3.0-meter C-magnet design for the FMI to Tevatron transfer.

WBS 1.1.1.5. 120 GEV PROTON LINE

The 120 GeV Line is composed mainly of the Main Ring Remnant from F0 to F17. A new section joins the 150 Proton Line to the remnant. Also, the Lambertson magnets previously used to extract beam from the Main Ring to the AP1 line are replaced with B3 dipoles which need only be turned on or off to switch beam to AP1 or the slow spill line.

WBS 1.1.1.5.1. DIPOLES

B3 Dipoles

The larger aperture (compared to the B2) of the Main Ring B3 dipoles is required in a few places. Each magnet will be visually inspected for potential problems before being moved to its new location. Extensive reworking of these magnets is not expected.

B1 And B2 Dipoles Left In Place

The existing B1 and B2 dipoles that remain in place through the Main Ring remnant require no work except changes to the bussing and power supplies. They will be visually inspected for indications of problems.

WBS 1.1.1.5.2. MAIN RING QUADRUPOLES

Main Ring quadrupoles used in the Main Ring Remnant will not require modification. Most quads (2.13-m quads) will not even require movement, though we may choose to replace some with more highly activated magnets from elsewhere in the ring so that we do not have to remove them from the tunnel. Depending on the rate of progress during the shut-down, we may choose to remove and measure some 2.13-m quads, giving a broader selection from which to choose the magnets being used in the Main Injector Ring. Two 1.32-m quads are used to match from the 150 GeV Line to the 120 GeV Line.

WBS 1.1.1.6. SLOW SPILL (F18-A0) MAGNETS

Most of the Slow Spill line is Main Ring remnant. The match to Switchyard requires a new configuration. Any magnets that do not simply remain in place will have been recovered from elsewhere in the Main Ring.

WBS 1.1.1.6.1. DIPOLES

The Slow Spill line will be composed primarily of B1 and B2 magnets presently in place in the Main Ring. In addition, there is one B2 dipole magnet modified to have twice as many turns as the standard B2. These magnets will remain in place with no modification.

WBS 1.1.1.6.2. QUADRUPOLES

2.13-m Main Ring Quadrupoles

Twenty-seven of the 2.13-m Main Ring quadrupoles will be required for the Slow Spill line. These magnets will be used in essentially the same manner (and current levels) as they are at present. Most will, however, be removed from the Main Ring for magnetic measurements, so that the best magnetic-property magnets can be placed in the Main Injector ring. The lesser-quality magnets will be reinstalled in the Slow Spill line without rework except to correct significant deficiencies.

1.32-m Main Ring Quadrupoles

Four of the 1.32-meter Main Ring quadrupoles will be reused in the Slow Spill line without rework except to correct significant deficiencies.

WBS 1.1.1.6.4. CORRECTION DIPOLES

The Main Ring correction dipole magnets will be used in the Slow Spill line, providing correction at every quadrupole, which requires 28 of the existing correctors. The Main Ring trim dipoles will be reinstalled on the quadrupole cradle without modification.

WBS 1.1.1.8 ABORT LINE MAGNETS

WBS 1.1.1.8.1. DIPOLES

The Abort line bending will be composed solely of two B2 magnets recovered from the Main Ring. These magnets are rolled at approximately 45 degrees to level off the aborted beam and deflect it away from the circulating beamline to provide faster separation. These magnets will be powered in series with one of the Main Injector quadrupole busses.

WBS 1.1.1.8.2. QUADRUPOLES

Three Main Ring 1.32-m quadrupole magnets will be used in the Abort line to preserve a reasonable beam size ahead of the abort dump. These magnets will be powered in series with one of the Main Injector quadrupole busses.

WBS 1.1.1.8.4. CORRECTION DIPOLES

Main Ring correction dipole magnets will be used in the Abort line, providing correction of angle and position in both planes as the beam enters the drift space before the abort dump. This requires 4 of the existing correctors. The Main Ring trim dipoles will be shimmed as needed to fit around the appropriate beam pipes, and a new mounting scheme will be designed.

WBS 1.1.1.8.5. EXTRACTION MAGNETS

The combination of aperture and strength considerations require a new Lambertson design for the Abort. Two lengths, 2.4 meters and 4.8 meters are used. Aperture and strength also require a new 3-meter C-magnet design for the FMI to Tevatron transfer. These magnets will be identical in design to those used in the 150 GeV proton and antiproton lines.

CHAPTER 3.2 VACUUM

WBS 1.1.2 MAIN INJECTOR VACUUM

WBS 1.1.2.1. MAIN INJECTOR RING VACUUM

The Main Injector vacuum system design incorporates the most useful features of both the Main Ring and the Tevatron. As shown in Fig. 3.2-1, the ring is divided into 29 vacuum sections by 29 pneumatic, automatic (fails closed) sector valves. Each sector valve is located between a pair of gauge trees, each consisting of 2 convectron gauges and a cold cathode gauge. One cable is pulled to service a pair of convectron gauges providing a backup gauge in the event of a convectron failure. The arc section gauge trees are connected to the vacuum system at "B" style dipole vacuum chambers by means of a Conflat (copper gasket) flange. Spacing for the arc sector valves is somewhat less than that in the Main Ring, approximately 500 ft. as opposed to 800 ft. in the Main Ring. Additionally, each arc vacuum sector is provided with three 1-1/2" all metal hand valves which provide ample ports for pumpdown and leak detection. All permanently installed vacuum components are connected by metal seals, thereby limiting the Main Injector ring elastomers to the 29 clapper seals, one per sector valve. Sector rough down is accomplished by attaching an oil free, cold trapped, and self protected turbomolecular pump to the system through a flex hose and a 1-1/2" "O"-ring valve attached to a 1-1/2" all metal hand valve roughing port. No permanently installed roughing stations are installed, thus permitting the 10 costed pumps to be utilized most effectively during initial installation and maintenance situations. Vacuum component specifications are incorporated in Table 3.2-1.

Main Injector dipole beam tubes are depicted in Figs. 3.2-2 ("A" style dipole) and 3.2-3 ("B" style dipole). The beam tube material is 16 gauge 316L stainless steel which is formed, seam welded, electropolished, chemically cleaned, and vacuum baked at 400°C. The beam tube cross section is chosen such that it can be inserted through the existing Main Ring quadrupole tubes and be captured by the Main Injector dipole pole tips. Its section is shown in Fig. 3.2-4. Attached to the tube are bellows, flanges, and access ports for gauging and ion pumps. Bellows are 10 convolutions each and are the edge welded type made of 316L stainless steel. This configuration allows maximum longitudinal motion in the restricted space available. In order to minimize image current effects, the convolutes are 1/2" greater in radius than the beam tube. The access ports are provided with machined or laser cut slits which allow both pumping and conduction of the image current along the longitudinal direction of the tube. The flanges are designed to meet three fundamental requirements, these being minimization of image current

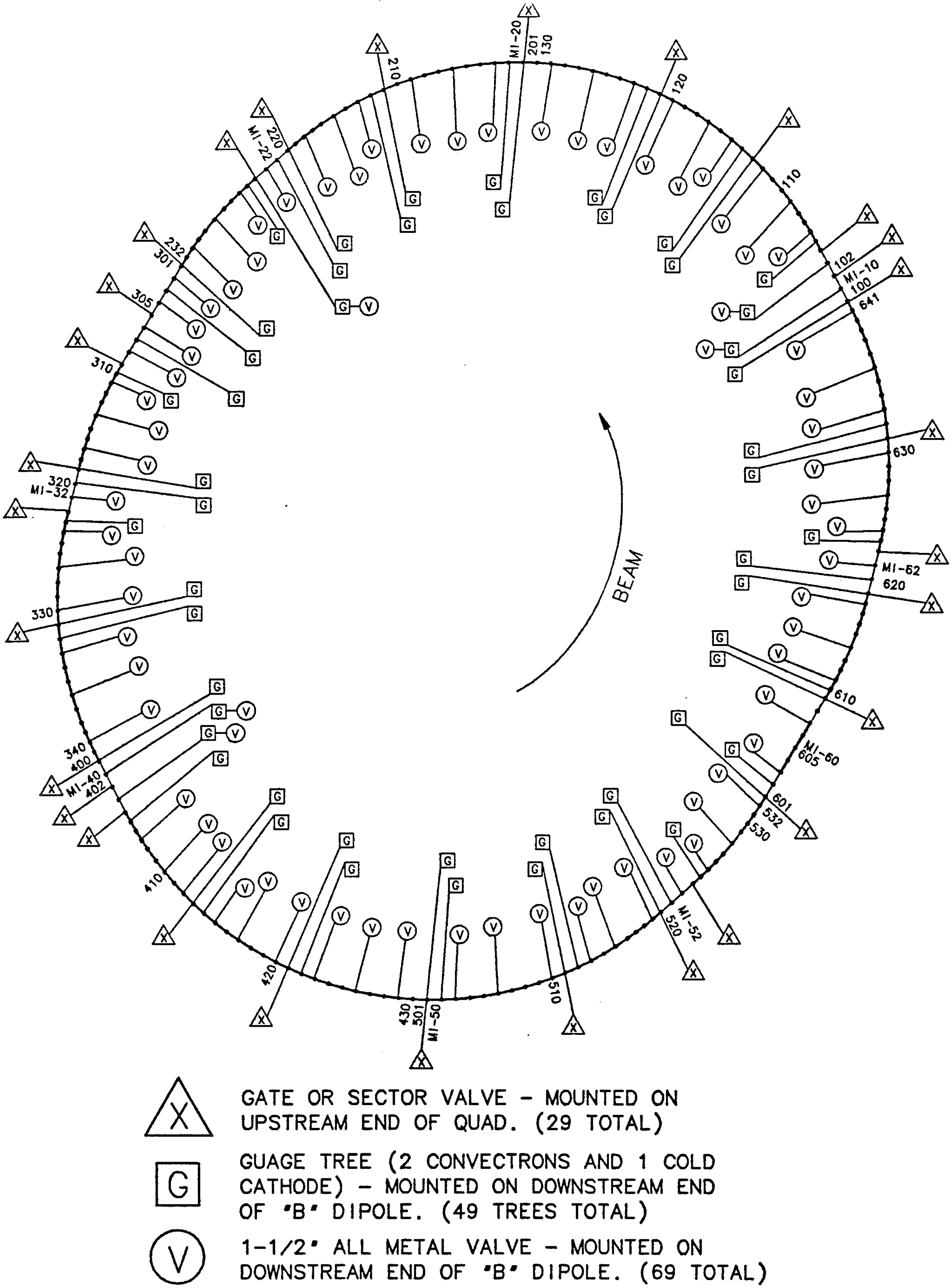


Figure 3.2-1. Main Injector Vacuum Valves and Instrumentation Layout

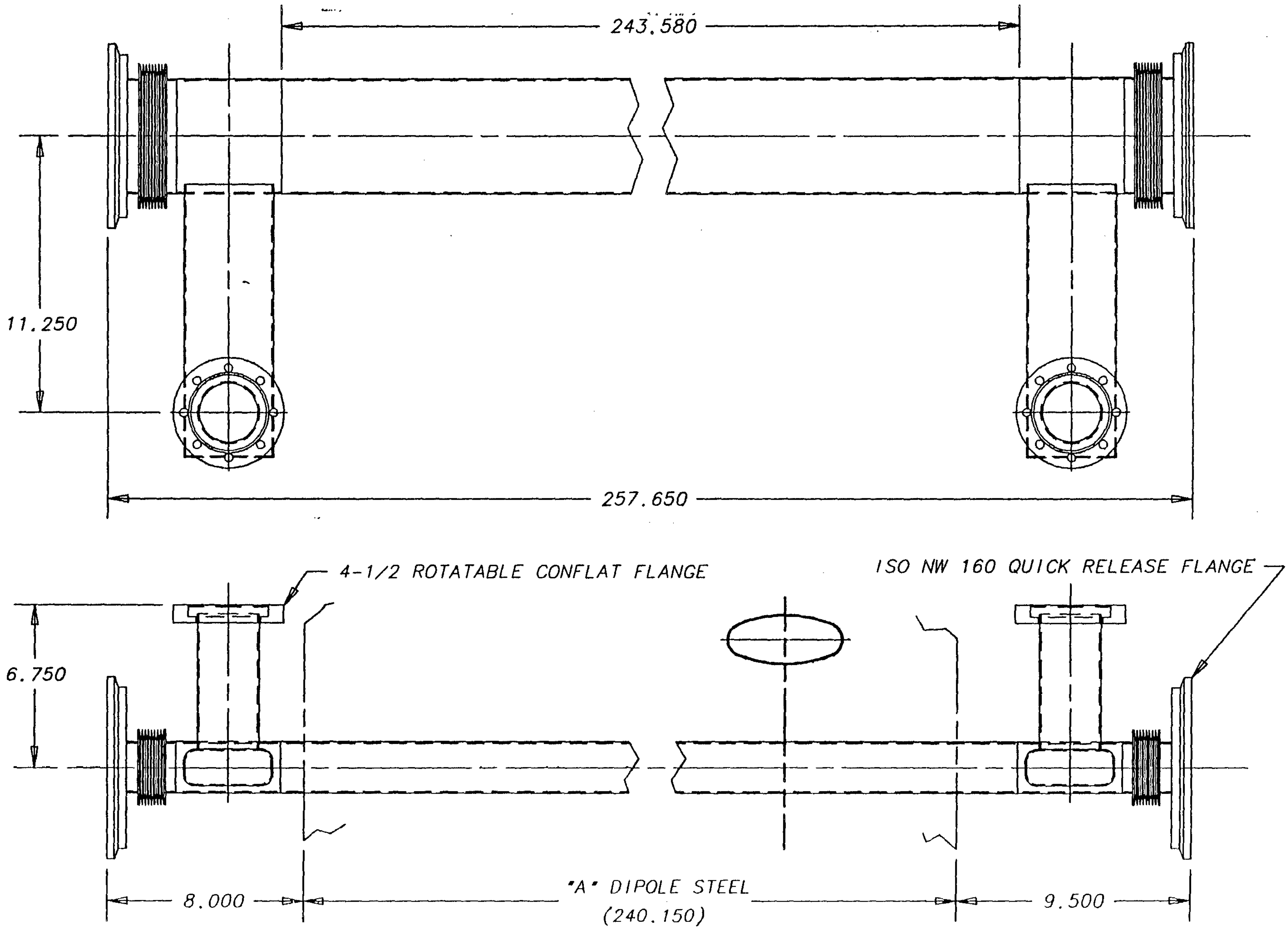


Figure 3.2-2. Beam Pipe for the "A" Dipole

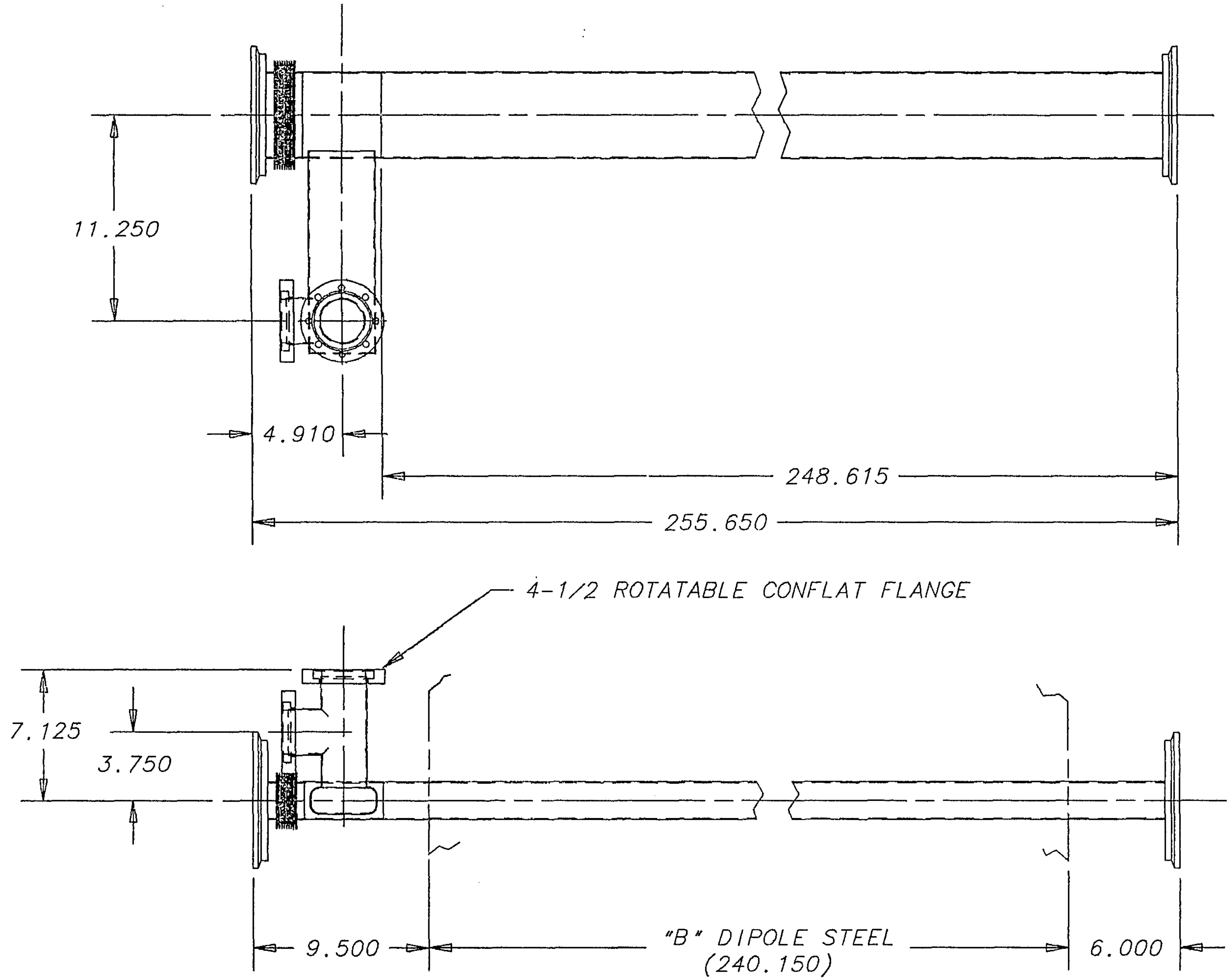


Figure 3.2-3. Beam Pipe for the "B" Dipole.

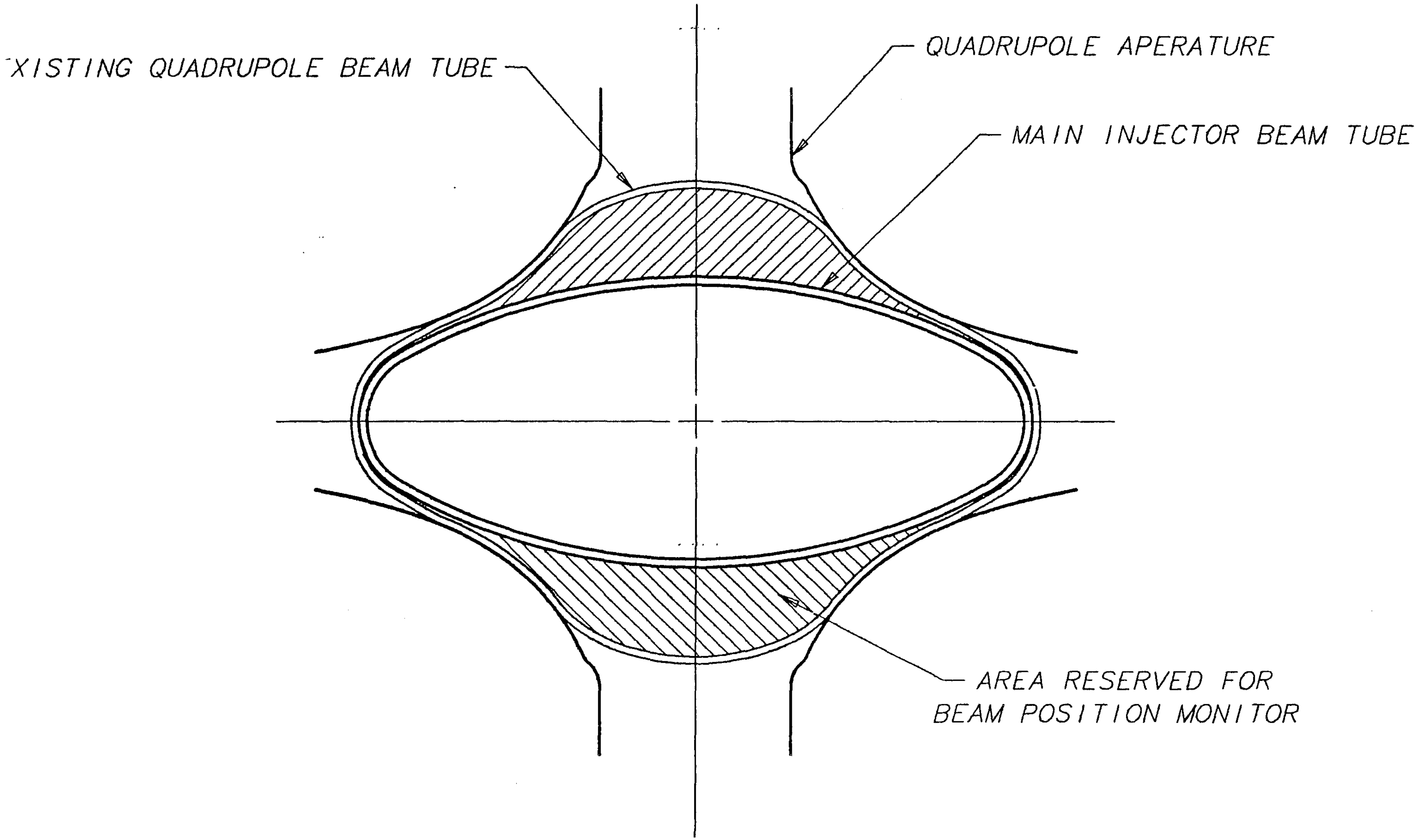


Figure 3.2-4. Beam Pipe Cross-Section
(Shown Inserted Inside Quadrupole "Star-Shaped" Beam Pipe)

effects, high vacuum, and reliable/repeatable performance. A typical flange pair is shown in Fig. 3.2-5. The beam tube configuration allows for three 30 l/s ion pumps per 1/2 cell which equates to a pump density roughly 1.3 times that of the Main Ring. Combining the effects of increased pump density, careful beam tube processing, increased molecular conductance, and minimization of elastomers the average pressure of the Main Injector ring should be less than 1×10^{-8} Torr. Ion pumps are recycled Main Ring pumps which meet specific outgassing and leakage current criteria and are attached to the dipole ion pump access ports using Conflat seals.

Vacuum controls are provided by new CIA crates located in each of 6 service buildings. The ion pump supplies are new and drive 8 to 10 pumps simultaneously. These supplies are internally interlocked and are directly interfaced to the CIA crate, thus eliminating the digital readout box required in the Main Ring. This configuration uses 2/3 the relay rack space compared to Main Ring and, unlike the Main Ring, provides overheating protection for the ion pumps. The valve control logic is similar to the Tevatron in that ion pump readings are considered for sector valve operating permits. Space is provided for future controls expansion for those straight sections not containing a valve dividing the straight section in two.

Table 3.2-1 Vacuum Component Specifications

Component	Item	Description
<u>Sector Valve</u>		
leak rate	-body	$<5 \times 10^{-10}$ mbar l/s
	-seat	$<1 \times 10^{-10}$ mbar l/s
differential pressure on gate		1 bar in either direction
max. diff. press. at opening		30 mbar
cycles until 1st service		50,000
bake out temp-valve		250°C open, 200°C closed
	-pneumatic actuator	50°C
		200°C without solenoid
heat/cool rate		80°C/hr
material	-body	304 stainless
	-mechanism	316L stainless
	-bellows	316L stainless
seal	-bonnet	metal
	-gate	Viton
solenoid	-supply voltage	115V, 60 Hz
	-power required	2.5 W
position indicator: contact rating		5A/250 VAC
flange/seal		6" conflat
lubricants		none
feedthrough		bellows

1.5" all metal hand valve

leak rate:	body/seat	<5x10^{-10} mbar l/s
pressure range		UHV to 10 bar
Δp on plate		10 bar in either direction
max. Δp at opening		10 bar in either direction
cycles until 1st service		10,000
bake out temperature		
	-valve	450°C
	-manual actuator	300°C
heat/cool rate		60°C/hr
material	-body and mechanism	304L stainless
	-bellows	316L stainless
seal: bonnet, plate		metal
system port		1.5" conflat
access port		1.5" ISO-KF, Viton
actuator		hexagon head

1.5" "O" ring hand valve

leak rate: body/seat		<1x10^{-9} mbar l/s
pressure range:		
open and closed in closing direction		1x10^{-8} mbar to 5 bar
Δp on plate		2 bar
max. Δp at opening		1 bar in either direction
cycles to 1st service		100,000
bake out temperature	-valve	150°C
	-actuator	100°C
material	-body	aluminum
	-plate	304 stainless
	-bellows	316L stainless
seal		Viton
flanges		ISO-KF

Convectron Gauge

range	1x10^{-3} to 10^3 mbar
temp. range	4°C to 50°C
mounting position	horizontal
construction	stainless steel
fitting	1/8 NPT
connector	self aligning
sensor	gold plated tungsten

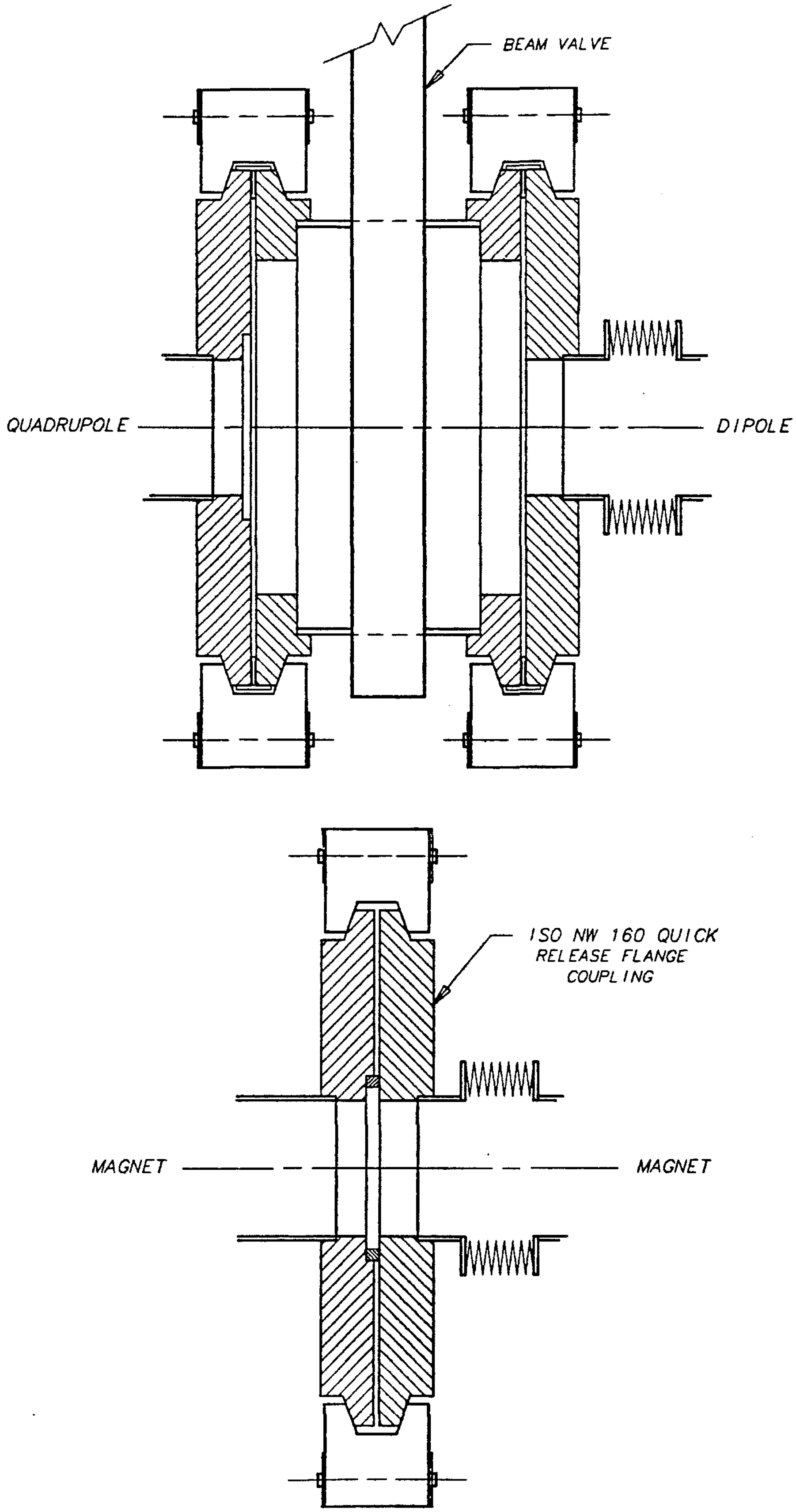


Figure 3.2-5. Beam Valve and Beam Pipe Flanges

WBS 1.1.2.10. BEAMLINE VACUUM

8 GeV Line

The 8 GeV beamline vacuum system is divided by 6" automatic, pneumatic gate valves into 5 vacuum sections, each approximately 500 ft. long. Each section is provided with 2 gauge trees (identical to those described in the "Main Injector Vacuum System") and pump out ports consisting of 1-1/2" "O" ring hand valves. The hand valves provide ample access to the vacuum system for pump down and leak check functions. No permanently installed roughing stations are provided as the pumps are attached on an as needed basis, as in the Main Injector. Permanent pumping is provided by recycled 30 l/s ion pumps mounted to recycled Main Ring dipoles. In the portions of the beamline where the dipole density is low, additional ion pumps are connected to the drift tubes by pumping tees and Conflat flanges. The ion pump density averages 1 per 10 meters. A thin titanium window separates the Booster and 8 GeV beamline vacuum systems at the upstream end of the 8 GeV beam line. Because the duty cycle of the 8 GeV magnets is low compared to the Main Ring, the vacuum system is all welded. The vacuum system is designed to achieve an average pressure of $5x10^{-7}$ Torr and is shown schematically in Figure 3.2-6. Vacuum component specifications are included in Table 3.2-1. Vacuum controls are identical to those described in the "Main Injector Vacuum System" and are housed in the North Hatch Building.

150 GeV Beamline Vacuum System

The 150 GeV beamline vacuum is isolated from the Tevatron vacuum system by 2 thin titanium windows centered about the MI-60 Lambertson magnets. Although the Main Injector circulating beam tube vacuum chamber and the 150 GeV vacuum chamber are, in practice, common at their intersections, effective isolation (in the operating mode) is maintained by differential pumping throughout the kicker and Lambertson areas. Each kicker is pumped by a pair of 60 l/s ion pumps, one at each end. All Lambertson magnets have distributed pumping in the form of 30 l/s ion pumps spaced 1 meter apart along the length. Additionally each Lambertson is provided with heating blankets and controls for in situ vacuum baking as necessary. The 3 Lambertson pairs are situated between a pair of automatic, pneumatic gate valves. As shown in Figure 3.2-7, ample "O" ring or all metal hand valves are installed for pump down and leak checking. Pump down is accomplished by the use of portable turbomolecular pumping stations as in the Main Injector. Recycled 30 l/s ion pumps attached to recycled Main Ring dipoles provide permanent pumping capability along with additional pumps installed in the drift spaces between quads. The average spacing between ion pumps is approximately 8 meters, rendering the beamline virtually identical to the Main Ring. Therefore the attainable average pressure is $5x10^{-7}$ Torr. Vacuum controls are identical to those described in the "Main

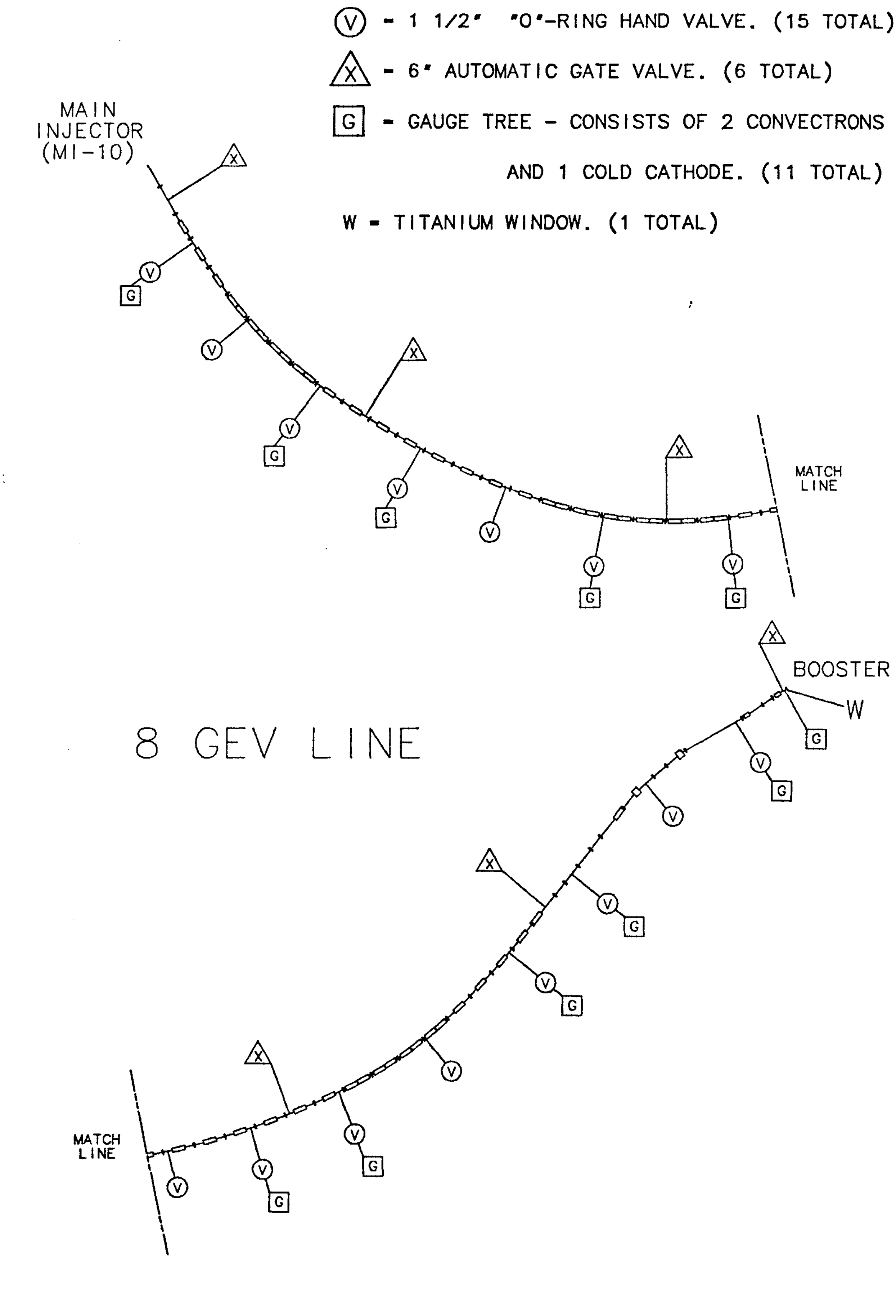


Figure 3.2-6. 8 GeV Line Vacuum Valves and Instrumentation Layout

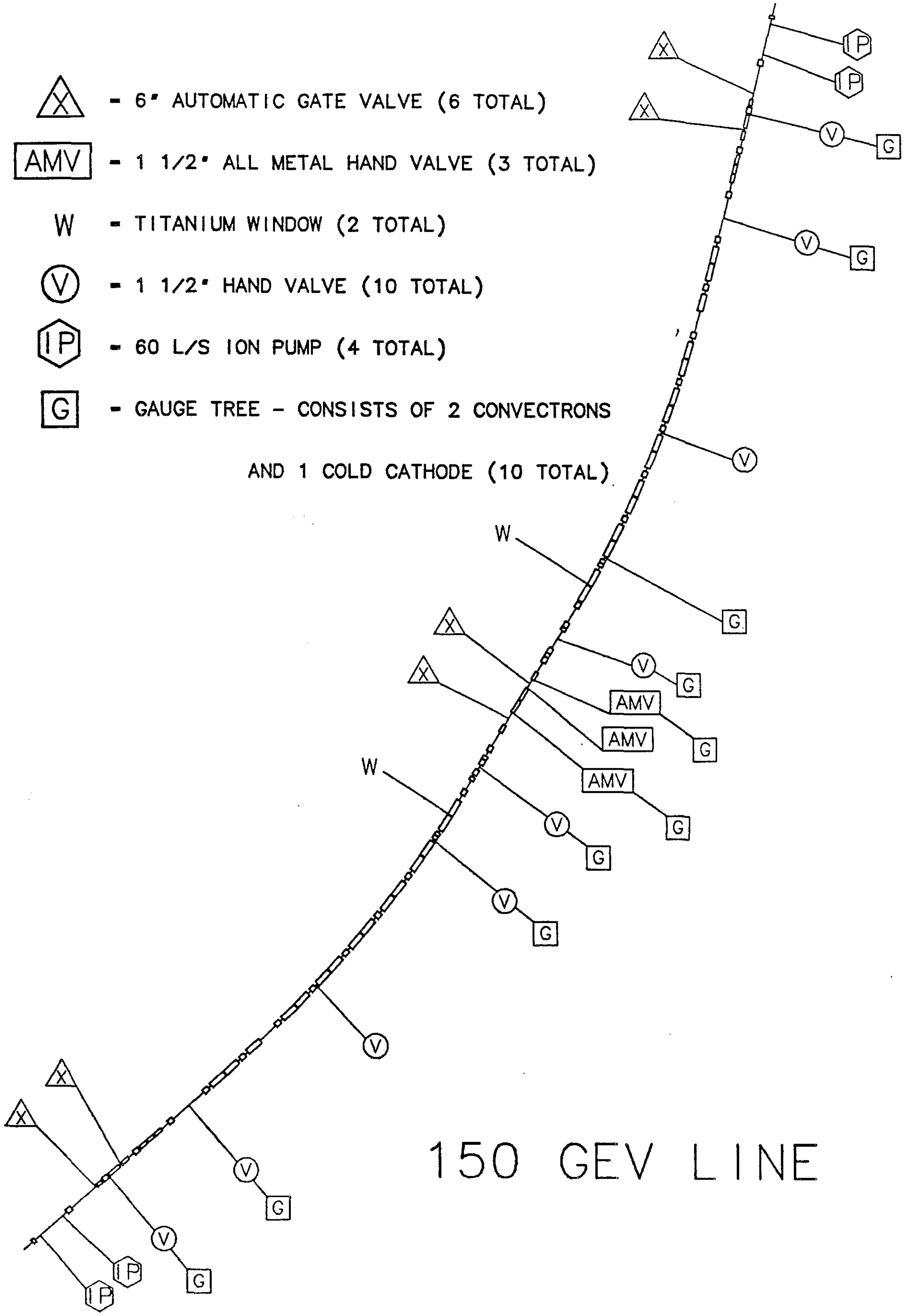


Figure 3.2-7. 150 GeV Line Vacuum Valves and Instrumentation Layout

Injector Vacuum System" and are housed in the MI-60 Building. Vacuum components are described in Table 3.2-1.

Abort Vacuum System

The Main Injector abort vacuum system is designed to achieve 1×10^{-8} Torr pressure in the portion common with the Main Injector and several microns in the remaining section. A pair of thin titanium windows downstream of the quadrupole pair separates MI vacuum from the rough vacuum leading to the dump. Located in the air gap between windows is the necessary beam-profile instrumentation. Downstream of the windows a roughing pump can be connected through a 1-1/2" "O" ring hand valve and pressure is monitored by a convectron. The Lambertson-quadrupole-Lambertson trio can be isolated by a pair of 6" automatic gate valves. Lambertsons are provided with heating blankets and controls for in situ baking as required. They also support 30 l/s ion pumps spaced every meter along their length. A pair of all metal hand valves and a gauge tree are also located between the gate valves for pump down and pressure monitoring. Near MI quad 400, the kicker pair is permanently pumped by 3 60 l/s ion pumps equally spaced about the kicker. Roughing valves and vacuum instrumentation are provide by the MI vacuum system in the region between the kickers and the upstream Lambertson. An "O" ring hand valve and a convectron are located between the downstream Lambertson and the upstream window. No permanent roughing stations are provided in the system.

Schedule

Figure 3.2-8 shows the schedule for the Main Injector vacuum systems.

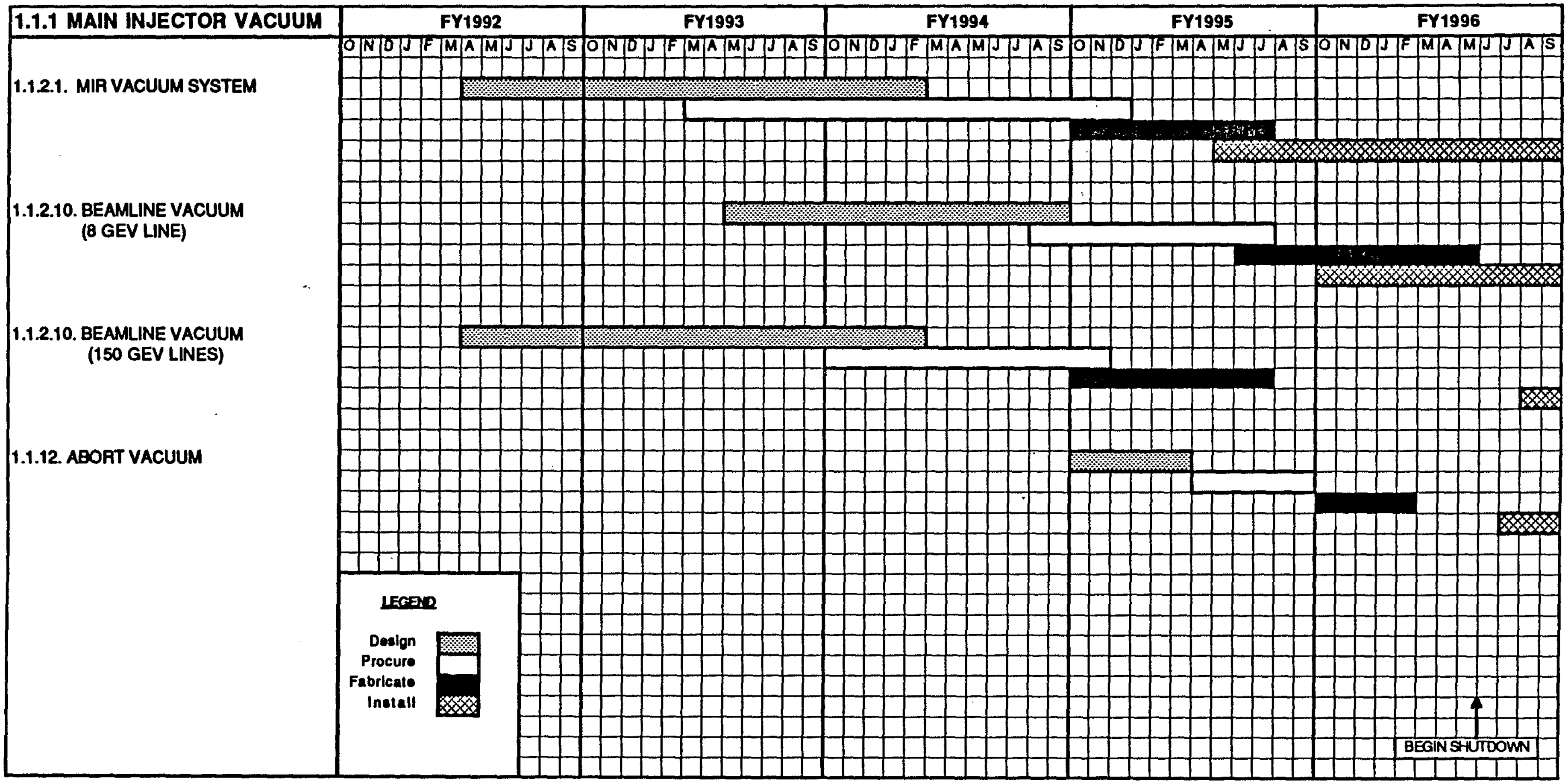


Figure 3.2-8. Main Injector Vacuum System Schedule

CHAPTER 3.3 POWER SUPPLIES

WBS 1.1.3. POWER SUPPLIES

Introduction

The FMI power supply system has been designed to ramp the magnet system from an injection level of 8.9 to 120 or 150 GeV/c excitation at a repetition rate adequate to meet requirements for Antiproton Source stacking, Tevatron injection, and slow spill operations. The power system consists of 12 new rectifier power supplies for the bend bus, reuse of existing equipment on the quadrupole bus including six main bus supplies, a new power feeder system for all the supplies, a new harmonic correction system, and the reuse of many smaller items from the present Main Ring. A summary of the FMI power supply requirements is given in Table 3.3-1.

Table 3.3-1: Power Supply Summary for the FMI System

Power Supplies		Voltage	Maximum Current
Bend	12 new	1,000 V	9,375 A
Quad F	3 old	850 V	3,630 A
Quad D	3 old	850 V	3,630 A
Other Equipment Needed:			
Quad regulator	2 new	300 volts	500 A
Regulation			
Transductors	2 new		10,000 A
Transductors	2 new		5,000 A
Computer link	1 new		
Harmonic filter	1 new		

Power supply spacing for minimum voltage-to-ground requires an equal impedance between power supplies on the dipole bus. The proposed system will have six service buildings with two dipole supplies per building, one on each of two busses, and one quadrupole supply. The buildings are spaced so that there are 25 6-m dipole magnets (or an equivalent mixture of 4-m and 6-m dipoles) between each supply, with the magnets on a folded bus loop. The third supply in each of the six buildings is configured such that three are in series with the focussing quadrupole magnet bus; three are similarly used with the defocussing quadrupole bus.

Criteria for Ramps and Constraints on Power Supply Layout

The overriding design criterion was to design a combined magnet and power supply system that would be cost effective during operation. A system was chosen to have low power consumption and a safe power supply voltage without being unduly expensive to construct and unwieldy in physical size. Two new 40 MVA power distribution transformers located at the new Kautz Road Substation will be used in the new installation with an operational limit set at 120 MVA peak and an RMS value of 60 MVA. There will be a 13.8 kV feeder cable system installed in a triple loop around the FMI ring. The rms current rating of the entire system is 2,700 amps.

The maximum rate of rise will be set by the use of the existing Main Ring rf system, which has at present an operational limit of about 240 GeV/sec. The maximum ramp repetition rate is set by the 2,700 amp feeder current limit and a chosen RMS dipole bus current of 5,000 amps.

The dipole configuration is two busses internal to the new magnets with a fold at MI-60 allowing for six upper bus supplies and six lower bus supplies. The impedance of the magnet load in the FMI dipole bus is 0.6 H and, with the use of 4 square-inch cross section copper for the magnets and power supply bus, will have a dc resistance of 0.32 Ω. The required peak power supply voltage is 12 kV for the bend bus.

The quadrupole configuration is two separate busses in continuous loops around the injector with current flowing in opposite directions, one focussing and one defocussing, each having three supplies for ramping and a transistor regulator supply for injection current regulation. Each quadrupole magnet loop impedance is 0.15 H, and with the use of 2 square-inch power distribution bus, will have a dc resistance of 0.3 Ω. Thus the required peak power supply voltage is 1500 volts for each quadrupole bus.

Ramp Details

The ramp details are determined by a number of limitations which enter at various points in the ramp: rf voltage; power supply voltage; feeder currents; etc. For antiproton stacking, the voltage and number of power supplies are chosen to provide a repetition rate of 1.5 seconds with a maximum rate of rise of 240 GeV/sec. Figure 2.2-1 and Table 3.3-2 give details on the five modes of operation. The fixed target injection ramp requires only a short flattop. The collider injection ramp will need a longer flattop, but is only run at a low repetition rate. The fixed target injection ramp is intended to be run twice in succession, once a minute, with 120 GeV cycles the remainder

Table 3.3-2: Main Injector Ramp Parameters

Ramp	Fixed Target	Collider Injection	Antiproton Production	Slow Spill	Fast Spill	
Peak Energy	150	150	120	120	120	GeV
Cycle time	2.40	4.0	1.4667	2.8667	1.8667	sec
Time (Booster cycles)	36	60	22	43	28	
Injection Dwell	.441	.841	.108	.441	.441	sec
Flattop	.250	1.45	.040	1.04	.04	sec
DIPOLE BUS						
Max. Current	9375	9375	7100	7100	7100	A
RMS Current	5412	6631	3763	4987	3346	A
Power	9.4	14.1	4.5	8.0	3.6	MW
RMS Feeder Current	1902	1739	1797	1319	1594	A
Peak Feeder Volt-Amps	95	95	82	82	82	MVA
Average Feeder Volt-Amps	34	32	32	23	25	MVA
QUAD BUSSES						
Max. Current	3630	3630	2904	2904	2904	A
RMS Current	2095	2568	1539	2040	1369	A
The following numbers are the sum of both busses:						
Power	4.8	7.1	2.5	4.4	2.0	MW
RMS Feeder Current	418	542	260	327	231	A
Peak Feeder Volt-Amps	20	20	15	15	15	MVA
Average Feeder Volt-Amps	7	10	4	6	4	MVA

of the time. The transformers for the FMI are being sized for a current (average between peak and rms) of 6500 A. If the fixed target injection ramp is run repetitively (e.g. for studies) the repetition rate must be slowed to reduce the rms current to ~3600 A (~5.4 sec rep rate).

With 12 kV maximum power supply voltage, the ramp rate will need to decrease above 80 GeV from 240 GeV/sec to 225 GeV/sec at 108 GeV. This is required due to the lack of power supply voltage to maintain high inductive voltage and high resistive voltage at the same time. The lower rate of rise slightly increases the RMS current in the magnets and feeders.

Feeder current limitations require the ramp rate to decrease more dramatically above 120 GeV, to 120 GeV/sec at 144 GeV. The result of this restriction is that as one approaches the parabola coming into flattop, no more than nine power supplies can be turned on. Ramp regulation which puts supplies into bypass is required. While this lowers the peak feeder currents, it raises the peak voltage-to-ground and bus-to-bus voltage that the magnets experience.

Power Supply Control

The power supplies are assumed to be controlled differently on different cycles. For the fast cycling 120 GeV cycles (with very short flattop) one power supply is used at 8 GeV, but as the ramp begins, the remaining power supplies are turned on simultaneously. For the 150 GeV cycle, the supplies are turned on and off as required by voltage demands, with either 1,4,8,10 or 12 supplies on at once. For the 120 GeV slow spill cycle, 1,3 or 12 supplies are energized. This sequential turn-on is required to minimize voltage-to-ground distributions and RMS feeder currents.

Studies on the Main Ring supplies indicate that the regulation will not be degraded in going to a ramp rate of 240 GeV/sec, twice that of the Main Ring, with no changes in the power supply control. The regulation of the FMI power supply system will be further improved by providing two 24-pulse power supplies, one of which will be used as the regulating power supply and the other as a spare. The remaining ten supplies will remain 12-pulse.

Power Feeder Loading

The main 13.8 kV power feeders have an operating limit of 2,700 A RMS. The power supplies around the ring will be supplied in a three feeder loop to ensure proper current sharing. More details are given in Chapter 3.10.

The use of rectifier power supplies on this system draws current pulses from the feeders which then drive harmonic resonances, causing higher voltages at the resonant frequencies to be imposed on the power equipment. The present Main Ring has an harmonic filter to limit the peak voltages of higher frequencies superimposed on the 60 Hz line voltage. The FMI will run with 12 power supplies at 120 MVA peak versus 70 MVA for the Main Ring, requiring the filter to damp more harmonic power. Therefore, in the FMI a new filter needs to be designed to correct for the higher harmonic driving force of the system. This new filter will be installed at the switch in the feeder system where the feeders change from direct feed to loop feed (near the MI-50 service building), and will consist of a new section in parallel with the Main Ring filter.

WBS 1.1.3.1. MAIN INJECTOR RING POWER SUPPLIES

WBS 1.1.3.1.1. DIPOLE POWER SUPPLY

The dipole bus requires twelve 1000 V, 5000 A rms 12 pulse voltage regulated and filtered ramping supplies connected in series. There will be two dipole supplies and one quadrupole supply in each of the six service buildings. The dipole magnet power supplies will power the 344 main bending magnets, which are configured in a folded-loop circuit, as shown in Figure 3.3-1. The fold is at the MI-60 straight section. The dipole supplies will be braced for continuous pulsed operation to 9400 A. Each power supply consist of two 500 V, 3 phase full wave bridges connected in series. The two bridges are shifted in phase by 30 degrees using one delta-delta and delta-wye transformer; see Figure 3.3-2. In order to improve the power factor on the 13.8 kVAC power lines, the output of the supply can be bypassed using an SCR switch, thus removing the transformer from the bus current. Each transformer is a 13.8 kVAC to 410 VAC, 3.6 MVA 3 phase source. The transformers are mineral oil filled exterior equipment. A Vacuum Circuit Breaker (VCB) and manual disconnect are provided for isolating each supply from the 13.8 kVAC line; knife switches provide isolation from the high-current bus and magnets. Each of the service buildings will have a fused line cubical as back up to the three vacuum breakers for overcurrent and fault protection. All of the 13.8 kVAC switch gear is commercial medium voltage equipment, while the transformers are custom designed. Figure 3.3-3 shows the schedule for the dipole power supplies.

WBS 1.1.3.1.2. QUADRUPOLE POWER SUPPLY

The quadrupole magnets will be installed on two busses with the current flowing in opposite directions, as shown in Figure 3.3-4. Each power supply loop will require relocation of three Main Ring Power Supplies. Each power supply is a voltage regulated and filtered 12 pulse supply rated at 850 V and 2.8 MVA rms. There are 16 decommissioned power supplies in the Main Ring which are available for the Main Injector. The full wave bridge, cabinet, VCB, filter

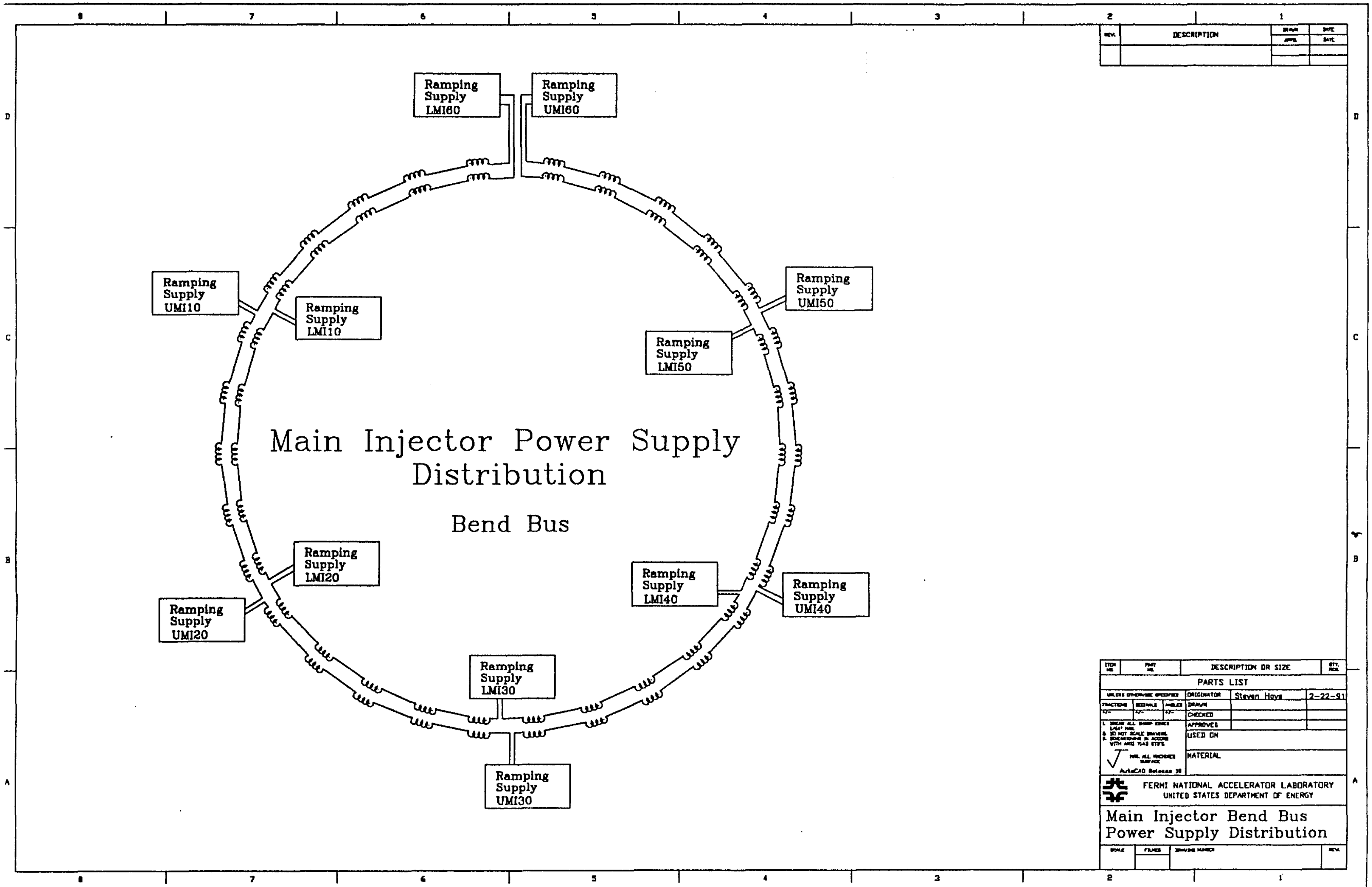


Figure 3.3-1. Main Injector Dipole Bus Configuration

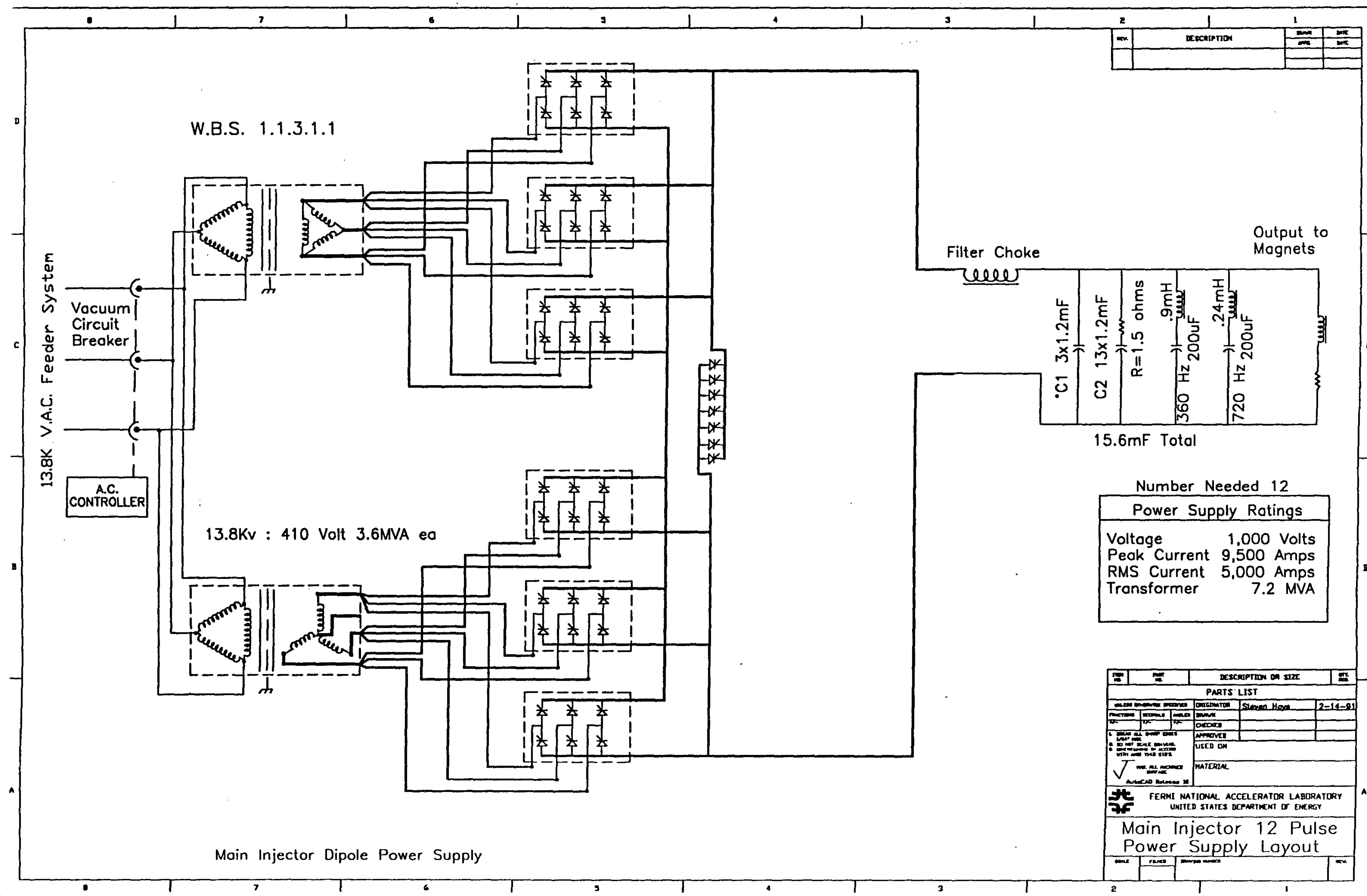


Figure 3.3-2. Main Injector Dipole Power Supply Layout

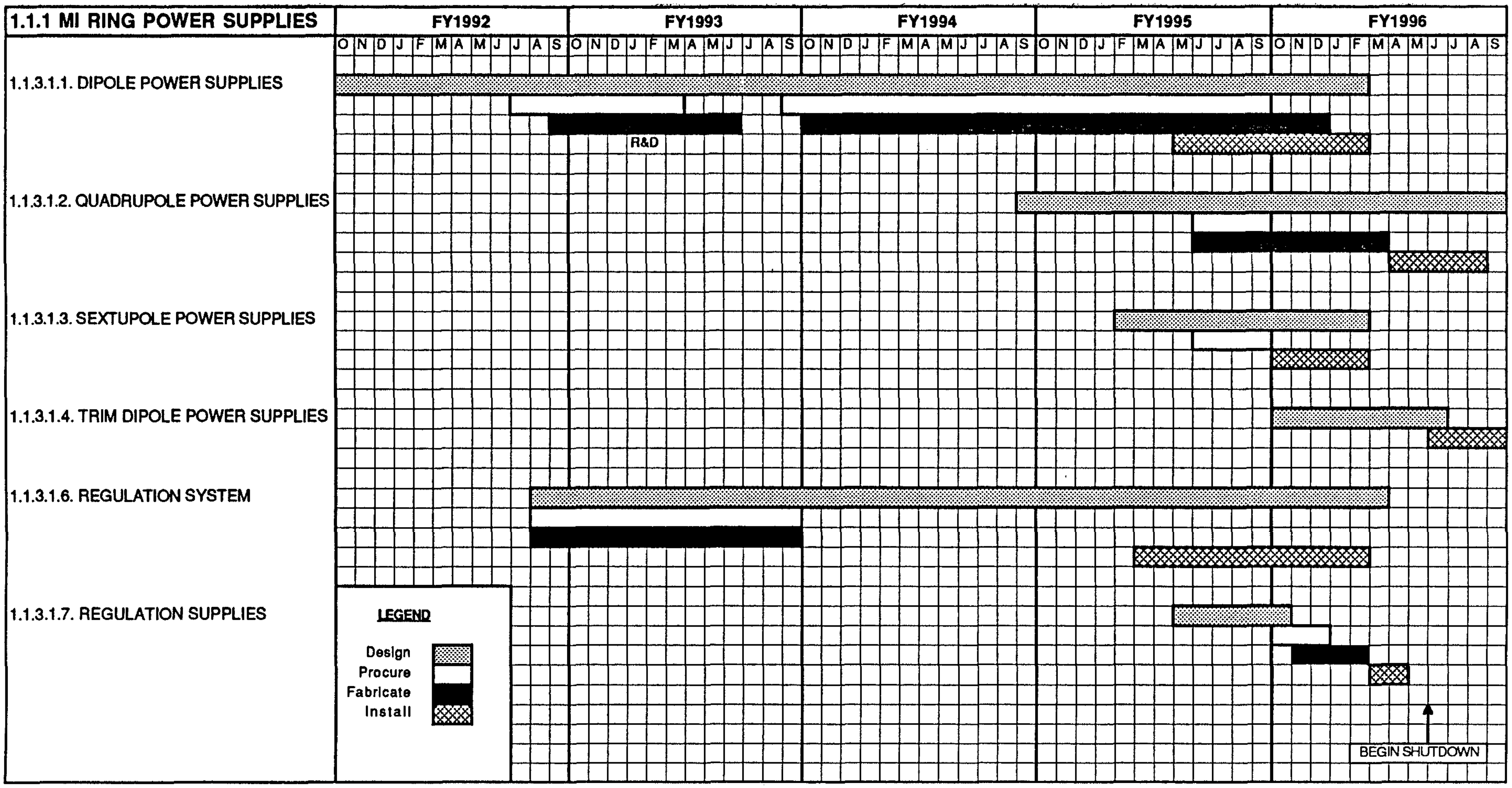


Figure 3.3-3. Main Injector Power Supply Schedule

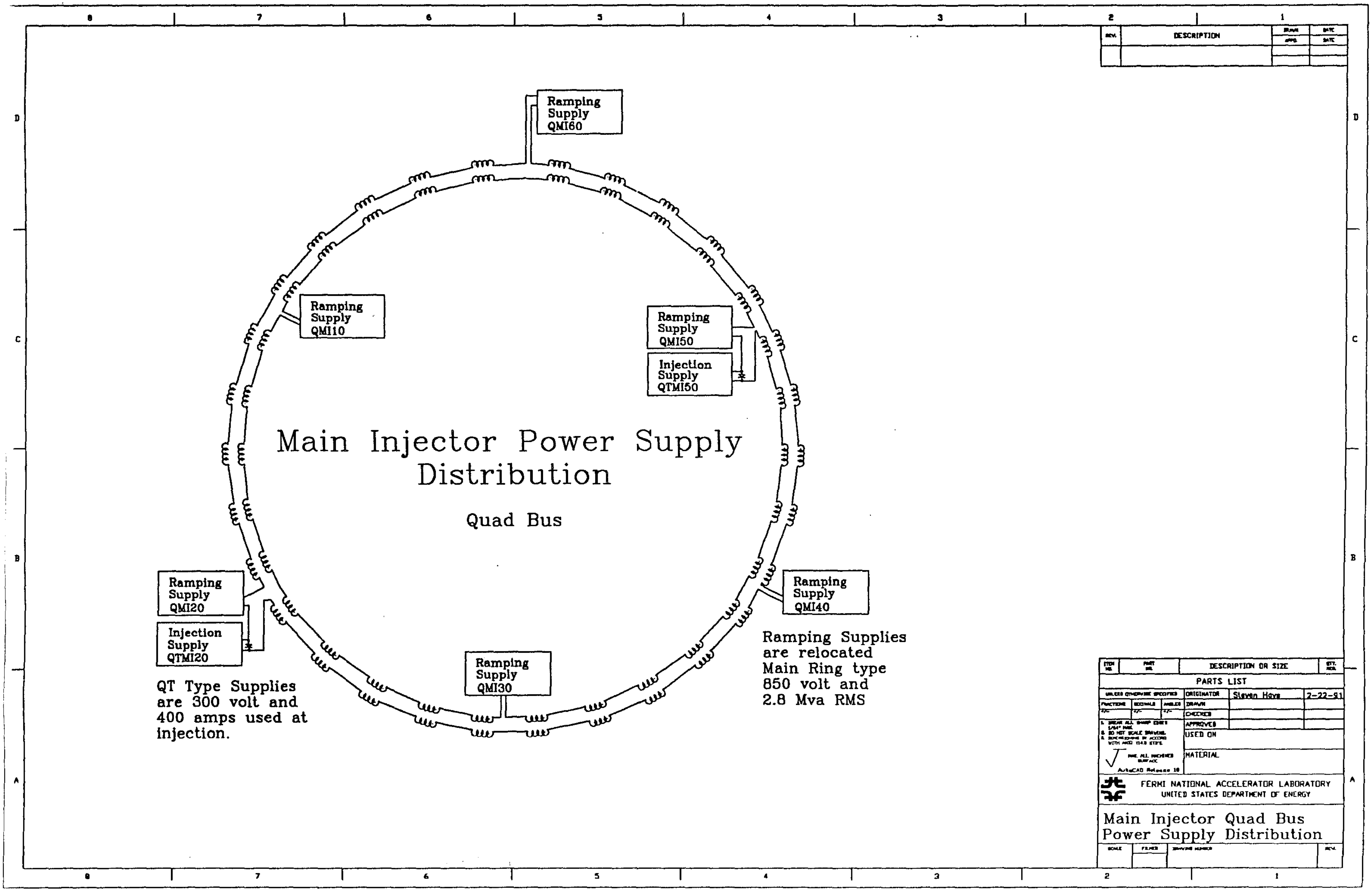


Figure 3.3-4. Main Injector Quadrupole Bus Configuration

choke and controls can be removed from Main Ring for relocation to the Main Injector once beneficial occupancy of the service buildings is granted. The relocation of the transformers for these supplies will need to be done during the shut down because the units which will be moved are operational. The transformers which will be moved are non-PCB type determined by independent testing. Non-PCB is defined as oil with <10 ppm contamination. The following transformers will be relocated into the Main Injector ring: A4-1, D1-1, B2-1, A1-1, D2-2, and F3-2.

In addition to the six main ramping supplies there will be two new transistor regulated supplies (one on each bus). These supplies are used during injection up through the first parabola and have a higher bandwidth and lower ripple than the main supplies. Each supply will be rated at 200 V, 200 A rms, but needs to pulse to 350 V. Figure 3.3-3 shows the schedule for the quadrupole power supplies.

WBS 1.1.3.1.3. SEXTUPOLE POWER SUPPLY

The magnet load specification calls for two magnet loops with 54 elements in each loop. The inductance of each magnet is 3 mH and the d.c. resistance is 15.2 mΩ. Each load cable will be a folded loop 6.64 km long using 300 MCM cable at 137 μΩ/m for a total cable resistance of .91 Ω. The inductance of the cable will be .5 μH/m for a total of 1.7 mH. The total load impedance for each loop will be 1.7 Ω and .164 H. The maximum dI/dt occurs at a low current and does not set the peak voltage needed but does help to set the maximum voltage slew rate and therefore the bandwidth of the supply. The maximum dI/dt is 768 A/sec and the dI/dt at the peak of the ramp is 572 A/sec. The inductive voltage step required for a 768 A/sec ramp into each load is 126 V. A reasonable step input to a filtered 360 Hz power supply is 15% of its maximum output voltage. The maximum voltage for each loop would occur just before flattop with a dI/dt of 572 A/sec at 295 A which will require 596 V. Each loop will require a 650 V, 200 A, rms, 3 phase SCR type power supply, braced for 300 A peak pulse operation. This will allow for a maximum of 46 kV/sec dV/dt for stable operation. In order to avoid over powering the load and supply an rms current limiter will need to be installed. These limiters are presently used in the Main Ring sextupole loops and can be moved to the Main Injector. The sextupole power supply specifications are listed in Table 3.3-3.

WBS 1.1.3.1.4. CORRECTION ELEMENT POWER SUPPLIES

These supplies will be recycled from the Main Ring. The Main Ring Correction Element Magnet Power Supply system consist of two 5 kW bulk power supplies and a power op-amp channel for each magnet. These channels are grouped six per chassis with two chassis grouped

Table 3.3-3 Sextupole Power Supply Specifications

Number of loops	2
Number of magnets per loop	54
Magnet inductance	3 mH
Magnet dc resistance	15.2 mΩ
Cable dc resistance	.91 Ω
Cable inductance	1.7 mH
Total load impedance	.164 H
	1.7 Ω
Power supply voltage	650 V
Power supply current	300 A peak
	200 A rms
Power supply rated power	130 kW
Maximum dI/dt	775 A/sec
Current regulation	100 ppm pulse to pulse

with a pair of ±80 V bulk power supplies; thus, twelve channels form one system at present. The Main Injector will require 36 channels per service building in five locations, and 48 channels in MI-60. The op-amps are water cooled so installation requires 95° F water connections. Each channel is designed to operate at ±12 A with an rms current limit of 6 A and a bandwidth of 1 kHz. One channel per chassis can be configured for 160 V output voltage if needed for larger impedance magnets; 18 of the 48 chassis are presently configured that way. The correction element power supply specifications are listed in Table 3.3-4.

There are 24 sets of 12 channel correction power supplies which will be relocated to the Main Injector ring and beam lines. The C453 CAMAC control card will be relocated along with the supplies. The load resistance is set to 6 ohms for all standard channels and 12 ohms in the twice voltage channels in order to control the power in the amplifiers. This resistance is adjusted by installing extra resistance at the magnet.

Table 3.3-4 Correction Element Power Supply Specifications

Correction Element Power Supplies	
Output Voltage Standard Channel	± 80 V
Output Voltage Dual	± 160 V
Output Current all Channels	± 12A peak
Average RMS Over One Minute	6 A rms
Ramping Limits: Current to Peak Value	50 A/sec
Bandwidth	1 kHz
Total Bulk Power Supply Current	80 or 100 A

The channels are grouped in sets of 12 per bulk supply. The total current draw must be less than the above number in any one direction.

Magnet Loads	
Horizontal and Vertical Dipole	300 mH
TeV 1 trim Dipole	300 mH
Quadrupole	80 mH
Sextupole	100 mH
Skew Sextupole	35 mH

WBS 1.1.3.1.6. POWER SUPPLY CONTROLLERS

The current regulation will be controlled by the existing ramping computer. It consists of a VME based computer and a dedicated control link. New current monitoring equipment is required due to the higher bus current and will consist of 10 ppm DCCT type transductors. The link cards are CAMAC (C269) based and seven (two in MI-60, one in each of the remaining power supply service buildings) will be relocated to the Main Injector. New voltage regulation controllers will be constructed for the dipole supplies and will be compatible with the existing power supply link interface. The power supply link interface electronics controls both the dipole and quadrupole supplies and will be relocated along with the existing support electronics from the Main Ring. The relocated support equipment consist of small rack supplies, voltage monitors, battery back up system and low level interlock equipment.

WBS 1.1.3.2-1.1.3.6. BEAMLINE POWER SUPPLIES

WBS 1.1.3.2. 8 GEV LINE POWER SUPPLIES

Dipole Power Supplies

The 8 GeV line dipoles will be powered by a combination of new and recycled power supplies. The line is made up of five bends, each of which will be powered by its own supply operated dc.

- Bend Circuit #1 will consist of three EPB dipoles powered from the West Booster Gallery at a current of 895 A. The supply will be a TRANSREX, Model ISR2220, 200 V/1,200 A supply reused from the present 8 GeV line (ILAMB).
- Bend Circuit #2 will consist of two SDB dipoles powered from the North Hatch Building at a current of 1,293 A. The supply will be new, 80 V/1500 A.
- Bend Circuit #3 will consist of two B3 dipoles powered from the North Hatch Building at a current of 680 A. The supply will be new, 45 V/800 A.
- Bend Circuit #4 will consist of 51 B2 dipoles powered from the North Hatch Building at a current of 499 A. The supply will be a TRANSREX, Model ISR2220, 400 V/600 A supply reused from the present 8 GeV line (VB812).
- Bend Circuit #5 will be the Injection Lambertson in the MI-10 straight section and be powered from MI-10 service building at 930 A. The supply will be a DYNAPOWER, 60 V/1,200 A supply reused from the present 8 GeV line (HB83).

Quadrupole Power Supplies

The 8 GeV line quadrupoles will be powered by a combination of new and recycled power supplies. The line will contain 51 SQA quads that are an existing Fermilab design. Magnets requiring a similar current will be bussed in series with an individual quad trim supply across each magnet that will require a current different than the common dc buss current. The magnets naturally divide into four circuits.

- Quad Circuit #1 will consist of one SQA quad powered from the North Hatch Building at 332 A. No trim supplies will be involved with this circuit. The supply will be a DYNAPOWER, Model PPS-65-350, 65 V/350 A supply reused from the present 8 GeV line (QCELL).

- Quad Circuit #2 will consist of four SQA quads powered from the North Hatch Building at 255 A. Each quad will have a trim supply to modify the quad current. The supply will be a DYNAPOWER, Model PPS-65-350, 65 V/350 A supply reused from the present 8 GeV line (QCELL spare).

- Quad Circuit #3 will consist of two SQA quads powered from the North Hatch Building at 200 A. Each quad will have a trim supply to modify the quad current. The supply will be a HEWLETT PACKARD, Model HP6469C, 36 V/300 A supply reused from the present 8 GeV line (VBMP).

- Quad Circuit #4 will consist of 44 SQA quads powered from the North Hatch Building at 147 A. Trim supplies will be included on 11 of the magnets in the circuit to modify the quad current. The supply will be new, 300 V/175 A.

The 17 quadrupole trim supplies will be new. Their design will be such that 25 A will be added to or diverted around the individual quad.

Correction Element Power Supplies

The 8 GeV line dipole corrector magnets will be recycled Main Ring elements with new small dc supplies. The line will contain 51 trim magnets generally located adjacent to each quadrupole. The supplies will be 60 V/6 A.

Lambertson Power Supply

The Lambertson magnet power supply is discussed under the dipole power supplies.

WBS 1.1.3.3-1.1.3.4. 150 GEV PROTON/PBAR BEAM LINE POWER SUPPLIES

The 150 GeV Proton line and the 150 GeV Pbar line are very similar in design. The 150 GeV Proton line will serve three main functions:

- Transfer 150 GeV protons to the Tevatron,

- Transfer 120 GeV protons to the Main Ring remnants, and

- Transfer 8 GeV protons to and Antiprotons from the Antiproton Source.

The 150 GeV Pbar line will serve one function:

- Transfer 150 GeV Pbars to and protons from the Tevatron.

The four very different functions require matching to lattice functions in each machine. Various magnets will be powered at different values for each function. The lines will use common supplies switched between equivalent magnet loads of the two lines. A result of these requirements is that quadrupole magnets will in general be individually powered at each end of the beamlines.

Dipole Power Supplies

Six magnet circuits have been identified and each circuit will be powered by a power supply that will be ramped. Each supply will be located in the F0 extension with cables from the 2-pole transfer switch running to the magnet load in the proton or pbar lines. For each circuit, currents will be given in the order 150p/120p/8p/150pbar. Since the supplies will be ramped both the peak current and the rms current will be given for the proposed supply.

- Bend Circuit #1 will consist of two extraction Lambertson magnets powered at currents of 3800 A/3000 A/450 A/3800 A. For this circuit the transfer switch between the proton and pbar line will be 3-pole with the third pole going to the center of the two magnets allowing you to power only the second magnet for 8 GeV operation. The supply will be a TRANSREX, Model ISR2126, 100 V/5000 A peak/5000 A rms supply reused from the MR to TEV transfer lines. This bend circuit is pictorially given in Figure 3.3-5.

- Bend Circuit #2 will consist of four C-magnets powered at currents of 3235 A/2588 A/192 A/3235 A. As in the case of bend circuit #1 above the circuit will use a 3-pole transfer switch to allow bypassing the first C-magnet of the string for 8 GeV proton operation. The supply will be new, 150 V/4000 A peak/2700 A rms.

- Bend Circuit #3 will consist of 14 B2 magnets powered at currents of 4900 A/3726 A/276 A/4810 A. The supply used to power the string will be two FNAL MR supplies, 835 V/6800 A peak/3350 A rms each, run in series to drive the bus both plus and minus with respect to ground. This bend circuit is pictorially given in Figure 3.3-6.

- Bend Circuit #4 will consist of one B2 magnet powered at currents of 1409 A/1126 A/83 A/1483 A. The supply will be new, 50 V/1600 A peak/1100 A rms.

- Bend Circuit #5 will consist of one C-magnet powered at currents of 3453 A/2764 A/206 A/2985 A. The supply will be new, 45 V/4000 A peak/2700 A rms.

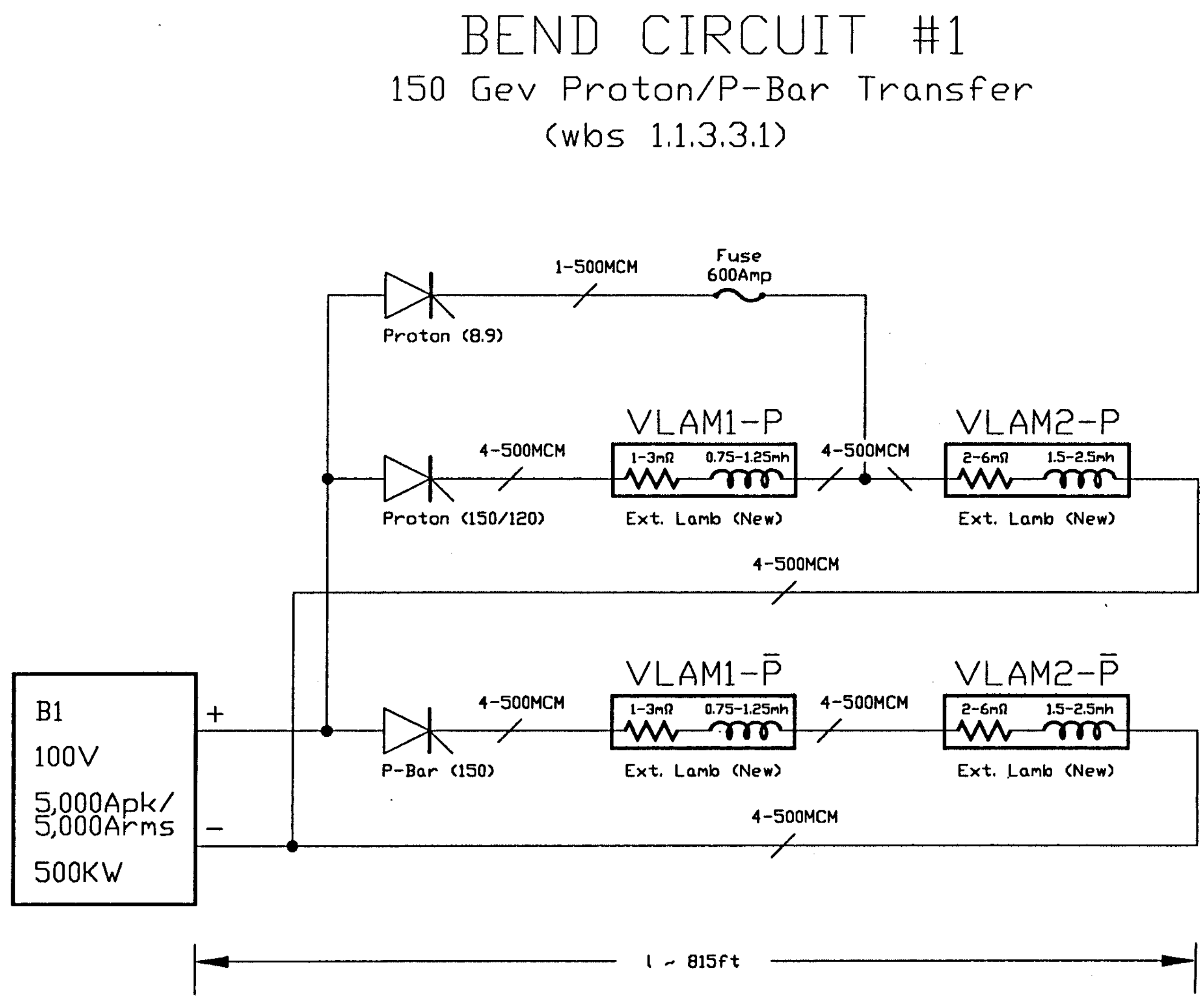


Figure 3.3-5. 150 GeV Line Lambertson Magnet Power Supply Configuration

BEND CIRCUIT #3

150 Gev Proton/P-Bar Transfer

(wbs 1.1.3.3.1)

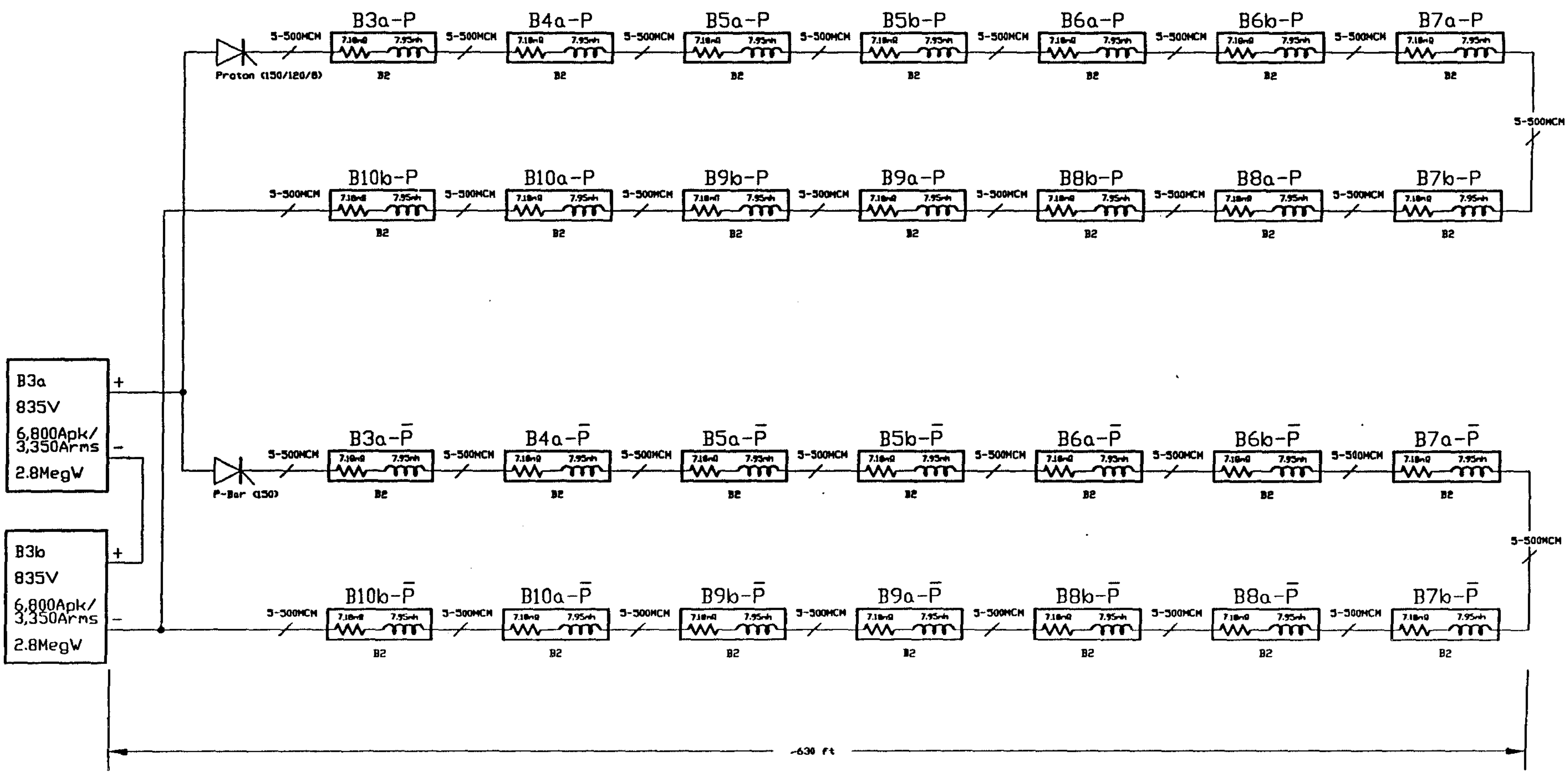


Figure 3.3-6. 150 GeV Line Main Dipole Magnet Power Supply Configuration

- Bend Circuit #6 will consist of two Tevatron injection Lambertson magnets powered at currents of 3600 A/0/0/3600 A. A transfer switch will not be used for this circuit since the magnets are common to both the 150 GeV proton and pbar lines. For 120 GeV or 8 GeV, the supply will be off allowing the beam to enter the MR remnants for transfer to or from the Antiproton Source or transfer to the Switchyard. The supply will be a TRANSREX, Model ISR2126, 100 V/5000 A peak/5000 A rms supply reused from the MR to TEV transfer lines.

Quadrupole Power Supplies

Quads at either end of the lines will be individually powered with the seven middle quads powered in series from a single supply. Eight magnet circuits have been identified. Again for each circuit currents will be given in the order 150p/120p/8p/150pbar. Peak and rms supply currents will be given for each supply.

- Quad Circuit #1 will consist of one 3Q84 MR quad powered at currents of 3833 A/3032 A/225 A/3716 A. The supply will be new, 75 V/4000 A peak/2700 A rms.

- Quad Circuit #2 will consist of one 3Q84 MR quad powered at currents of 3488 A/2787 A/207 A/3551 A. The supply will be new, 75 V/4000 A peak/2700 A rms.

- Quad Circuit #3 will consist of seven 3Q84 MR quads powered at currents of 3695 A/2930 A/218 A/3660 A. The supply used to power the string will be a FNAL MR supply, 417 V/6800 A peak/3350 A rms. This supply will be configured with the output bridges in parallel giving one-half the normal output voltage.

- Quad Circuit #4 will consist of two 3Q52 MR quads powered at currents of 3809 A/2737 A/203 A/4000 A. The supply will be new, 50 V/4000 A peak/2700 A rms.

- Quad Circuit #5 will consist of one 3Q84 MR quad powered at currents of 3450 A/2380 A/176 A/4000 A. The supply will be new, 40 V/4000 A peak/2700 A rms.

- Quad Circuit #6 will consist of one 3Q84 and one 3Q52 MR quad powered at currents of 3551 A/2517 A/187 A/4000 A. The supply will be new, 50 V/4000 A peak/2700 A rms.

- Quad Circuit #7 will consist of one 3Q84 and one 3Q52 MR quad powered at currents of 3308 A/3080 A/228 A/4000 A. The supply will be new, 50 V/4000 A peak/2700 A rms.

- Quad Circuit #8 will consist of one 3Q84 MR quad powered at currents of 2631 A/3462 A/258 A/4000 A. The supply will be new, 40 V/4000 A peak/2700 A rms.

Correction Element Power Supplies

Dipole corrector magnets will be recycled Main Ring elements with new small dc supplies. Each of the lines will have 12 of these trim magnets generally located at each quad location. The supplies will be 60 V/10 A with an rms current limit of 6 A.

Lambertson Power Supplies

The Lambertson magnet power supplies are discussed under the dipole power supplies.

WBS 1.1.3.5. 120 GEV (F0-F17) POWER SUPPLIES

The F0-to-A0 Beam line is generally referred to as the Main Ring remnant; the first section, F0-to-F17, will be used to perform three functions.

- Transfer of 120 GeV protons to the AP-1 line and on to the target for antiproton production.
- Transfer of 8 GeV pbars from the AP-3 line and on to the MI.
- Transfer of 120 GeV protons to F18 and on to the rest of the MR remnants for delivery of slow spill beam to the switchyard.

Power supplies for this line will be ramped to minimize power consumption.

Dipole Power supplies

The dipoles that are included in this section will be a combination of B2s, B3s and the existing F17 C-magnets. Two bend circuits have been identified. Currents for each circuit will be given in the order 120p/8pbar.

- Bend Circuit #1 will consist of 15 B2 magnets, 4 B3 magnets configured with their coils in parallel (such that when run with B2 current the B3 will have the same bend) and 3 B3 magnets configured with their coils in series (such that when run with B2 current the B3 will have twice the bend). This string will be run at currents of 1356 A/98 A. The supply used to power the string will be two FNAL MR supplies, 835 V/6800 A peak/3350 A rms. These two supplies will be located at F1 in their normal location.

- Bend Circuit #2 will consist of one B3 magnet configured with its coils in parallel and two F17-C magnets powered at currents of 2838 A/211 A. The supply will be a FNAL MR supply, 417 V/6800 A peak/3350 A rms. This supply will be located at F2. The only change to this bend circuit from what is installed today is the substitution of the B3 for the extraction Lambertson.

Quadrupole Power Supplies

The quads at the front end of this line will be individually controlled to aid in the matching from the 150 GeV proton line lattice to the original Main Ring lattice. Four quad circuits have been identified for this line. The supplies for these four circuits will be located in the F0 service building.

- Quad Circuit #1 will consist of one 3Q52 magnet powered at a current of 1770A/310A. The supply will be new, 25 V/2000 A peak/1500 A rms.

- Quad Circuit #2 will consist of one 3Q52 magnet powered at a current of 2633A/195A. The supply will be new, 40 V/3000 A peak/2142 A rms.

- Quad Circuit #3 will consist of one 3Q84 magnet powered at a current of 1297A/96A. The supply will be new, 25 V/1500 A peak/1070 A rms.

- Quad Circuit #4 will consist of five 3Q84 magnets powered at a current of 1289A/96A. The supply will be new, 75 V/1500 A peak/1070 A rms.

Correction Element Power Supplies

Dipole corrector magnets will be recycled Main Ring elements with new small dc supplies. The line will have 8 of these trim magnets generally located at each quad location. The supplies will be 60 V/10 A with an rms current limit of 6 A.

WBS 1.1.3.6. SLOW SPILL (F18-A0) POWER SUPPLIES

This line is the remainder of the MR remnant that will be used to transport 120 GeV protons to the Switchyard for delivery to the fixed target experimental areas. The line will in general remain unchanged from its operation at this time. Several dipole and quad magnet changes at A0 will be the only element changes. Quad currents will be different around the A0 section to facilitate matching into the Switchyard lattice.

Dipole Power Supplies

Two bend circuits have been identified for this line. The first will encompass most of the line and except for a few magnet changes will be what is installed at this time. The second will be new elements located at A0.

- Bend Circuit #1 will consist of 49 B1s, 52 B2s, one 2XB2 and two B3s configured with their coils in series powered at a current of 1356 A This string of magnets will be powered from four FNAL MR supplies, 835 V/6800 A peak/3350 A rms. These supplies will be located at F2 and F4 in normal slots for MR supplies.

- Bend Circuit #2 will consist of two B2 magnets powered at a current of 650 A. The supply will be new, 35 V/750 A peak/500 A rms.

Quadrupole Power Supplies

Five quad circuits have been identified for this line. The first will encompass most of the line. The last four will be used to match the Main Ring lattice into the present switchyard.

- Quad Circuit #1 will consist of 25 3Q84 MR quads powered at a current of 1356 A. The supply will be a FNAL MR supply, 417 V/6800 A peak/3350 A rms. The supply will be located at F3 in a normal location.

- Quad Circuit #2 will consist of one 3Q52 MR quad powered at a current of 4000 A. The supply will be new, 45 V/4000 A peak/2856 A rms. The supply will be located in the A0 transfer hall.

- Quad Circuit #3 will consist of two 3Q52 MR quads powered at a current of 4000 A. The supply will be new, 60 V/4000 A peak/2856 A rms. The supply will be located in the A0 transfer hall.

- Quad Circuit #4 will consist of one 3Q52 and one 3Q84 MR quads powered at a current of 4000 A. The supply will be new, 60 V/4000 A peak/2856 A rms. The supply will be located in the A0 transfer hall.

- Quad Circuit #5 will consist of two 3Q52 MR quads powered at a current of 4000 A. The supply will be new, 60 V/4000 A peak/2856 A rms. The supply will be located in the A0 transfer hall.

Correction Element Power Supplies

Dipole corrector magnets will be recycled Main Ring elements with new small dc supplies. The line will have 28 of these trim magnets generally located at each quad location. The supplies will be 60 V/10 A with an rms current limit of 6 A.

Schedule

Figure 3.3-7 shows the schedule for the beamline power supplies.

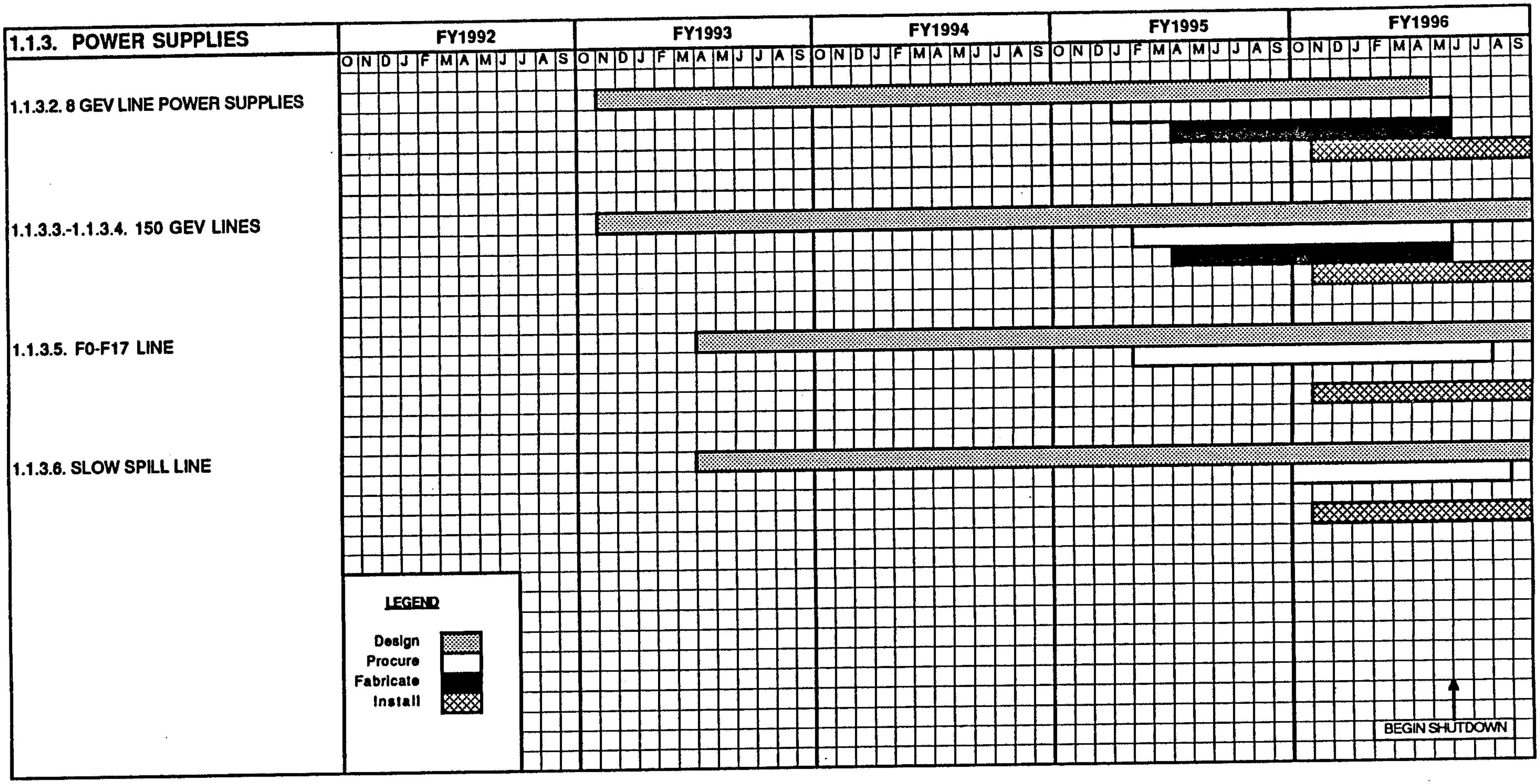


Figure 3.3-7. Beamline Power Supply Schedule

CHAPTER 3.4 RF SYSTEMS

WBS 1.1.4. RF SYSTEMS

WBS 1.1.4.1.1. MAIN INJECTOR 53 MHZ RF SYSTEM

h=588 cavities

The 18 existing 53 MHz Main Ring rf cavities will be installed in straight section MI-60 and operated at harmonic number 588. The operating levels below transition are determined by an interplay between cycle time, bucket area, and synchrotron frequency. A bucket area of at least 0.5 eV-sec is required to accept beam out of the Booster. Historically, it has been necessary to keep the synchrotron frequency in the Main Ring below 720 Hz to avoid resonance with power supply ripple at the sixth harmonic of the line frequency. Figure 3.4-1 shows the rf voltage, bucket area, synchrotron frequency, and synchronous phase through the 120 GeV antiproton production cycle. A bucket area of 0.5 eV-sec is maintained, but with the synchrotron frequency rising above 720 Hz. The ramp would have to be slowed down to avoid this. The momentum spread in the beam, $\delta p/p$ (95% half width), is ±0.2% at injection, increasing to about ±1.0% near transition, and decreasing to ±0.1% at extraction.

Since the FMI must accelerate antiprotons as well as protons, a degree of simplicity and system flexibility can be achieved by placing the cavities at spacings that are multiples of one-half the rf wavelength. This will simplify the fan-out/fan-back system as well as standardizing systems for greater flexibility during coalesing. Easier maintenance, better personnel understanding and greater system reliability are expected as a result of the new spacing. A schematic of the rf cavity is shown in Figure 3.4-2.

The rf system has the capability of generating enough voltage at injection to produce a 1.0 eV-sec bucket area at injection. In this mode the synchrotron frequency lies well above 720 Hz at injection and descends rapidly, crossing 720 Hz when the beam energy is about 15 GeV. Operational experience will dictate the exact ramp scenario that is used.

One limitation of the existing Main Ring rf system is the power that it can deliver. The present requirements are 55 kW per cavity, which will grow to 70 kW after the Linac upgrade provides increased beam intensity. The FMI will require 112 kW for accelerating the full intensity at 240 GeV/sec, which is slighty above a reliable rf amplifier capability. To overcome this limitation, new 200 kW power amplifiers and 30 kV series tube modulators will be required. The new 200 kW amplifiers will be a cathode-driven, grounded-grid design with the operating point efficiently regulated with a dc bias voltage. The design will retain much of the existing Main Ring

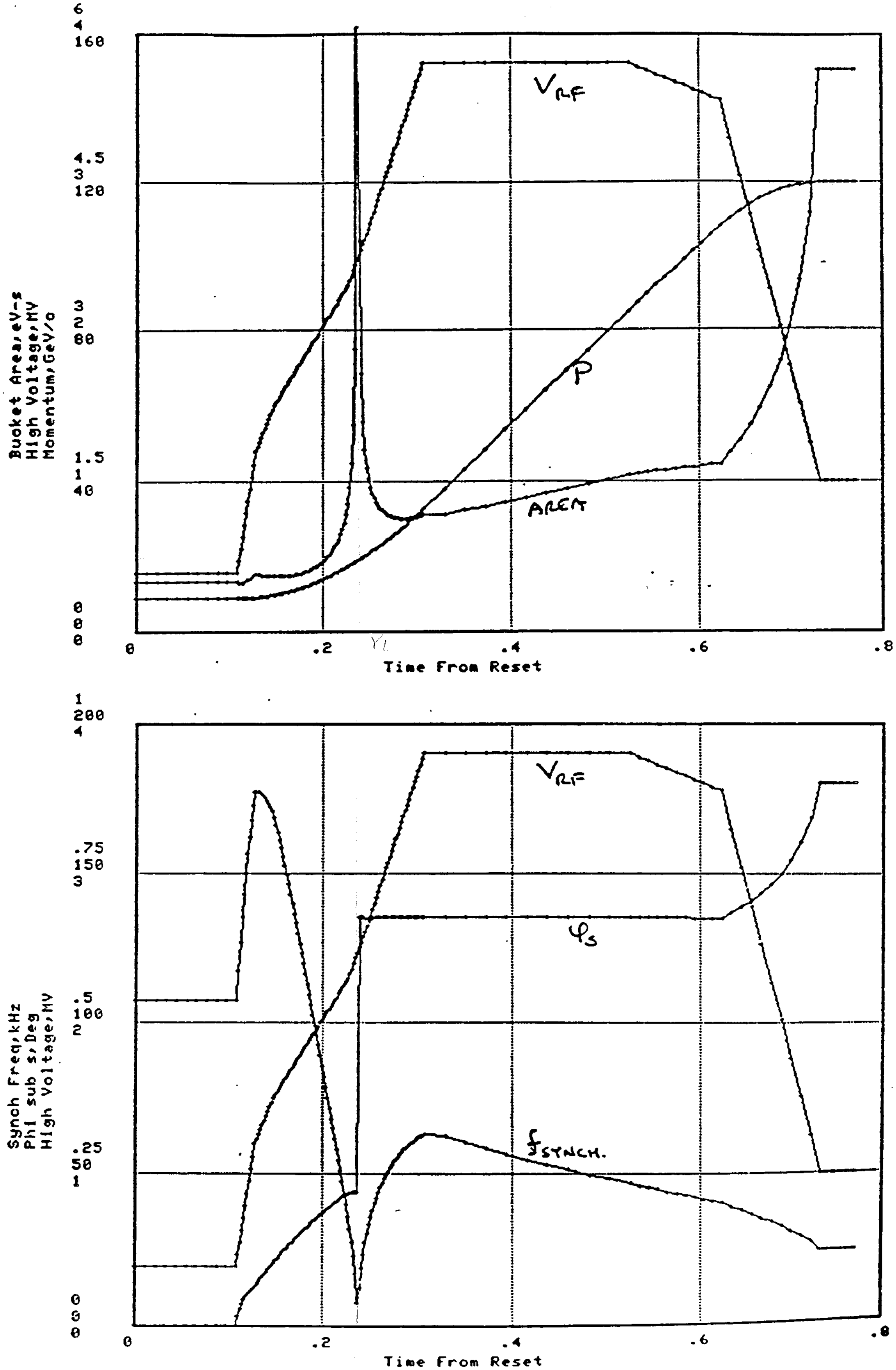


Figure 3.4-1. RF Parameters for the 120 GeV Antiproton Production Cycle

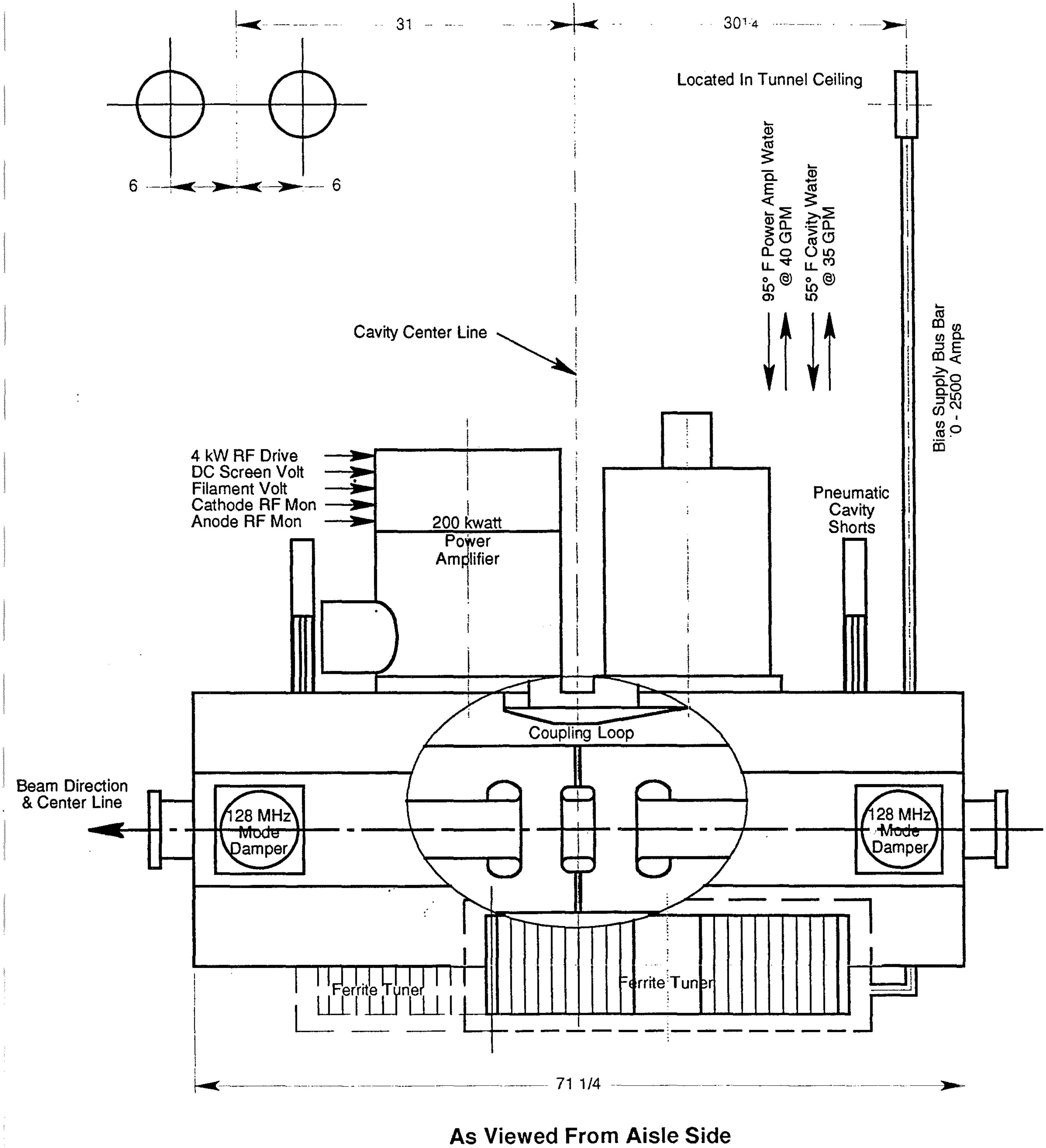


Figure 3.4-2. Main Injector RF Cavity

final PA tube module. A new 500 volt programmable supply will be required for DC biasing. RF drive will be provided by a solid state 4 kW rf driver transformer coupled to the final tube cathode. A Tevatron style power amplifer (grid biased to -230 volt) has already produced more than 200 kW of output power with the final tube cathode driven by 4 kW of rf drive power. This demonstrates the feasibility of the new design and is also a possible alternative to the biased cathode design.

The transient beam loading from 6×10^{10} protons per bunch will require about 1.25 amp delivered to the cavities, supplied by 15 A (12:1 cavity step-up ratio) of rf current generated by the power amplifier. A 200 kW rf power amplifier operated at a dc plate voltage of 20 kV will produce a peak rf current of approximately 21 A. The 40% surplus initial current capability will insure adequate operating lifetime as the power tube ages.

In the present Main Accelerator rf systems two 30 kV anode power supplies provide dc power to 18 rf stations. Nine stations are powered by each anode supply. Using 200 kW amplifiers only six stations can be powered by a MR anode supply. One additional anode supply will be provided. The two present MR anode supplies will be rebuilt at the MI-60 location when the present main ring is decommissioned. Design improvements proven to increase reliability in a similar supply used in the Tevatron rf systems will be implemented. This will make the Main Injector anode supplies similar to the Tevatron supply. Uniformity of the systems will improve both maintainability and provide consistent safety requirements in the two systems. A schedule for the Main Injector rf system is shown in Figure 3.4-3.

Transition Crossing

Concerns over emittance dilution (Johnsen and Umstätter effects) during transition crossing have led to a prosposal for a higher harmonic cavity which will avoid the rf-focussing effects which contribute to the dilution. Results from simulations of transition crossing in the presence of a second harmonic rf voltage for the FMI are very encouraging. Presently the Main Ring longitudinal emittance is about 2.5 times smaller than that for the FMI, and a third harmonic rf cavity should be enough to reduce the emittance blow-up during transition crossing. Therefore, an experiment to study transition crossing in the Main Ring using a third harmonic rf cavity was proposed and is underway. For this purpose, a single-cell 200 MHz copper rf cavity has been acquired from CERN and modified to resonate at 159.09 MHz. The cavity is required to operate in the frequency range of 159.059 MHz to 159.123 MHz during the transition crossing. This frequency swing is about a factor of 4 larger than the natural resonance width of the cavity. To tune the cavity in this frequency range a low loss orthogonally biased tuner using Trans-tech G510 ferrite has been built and tested. Also, a power amplifier which is capable of delivering

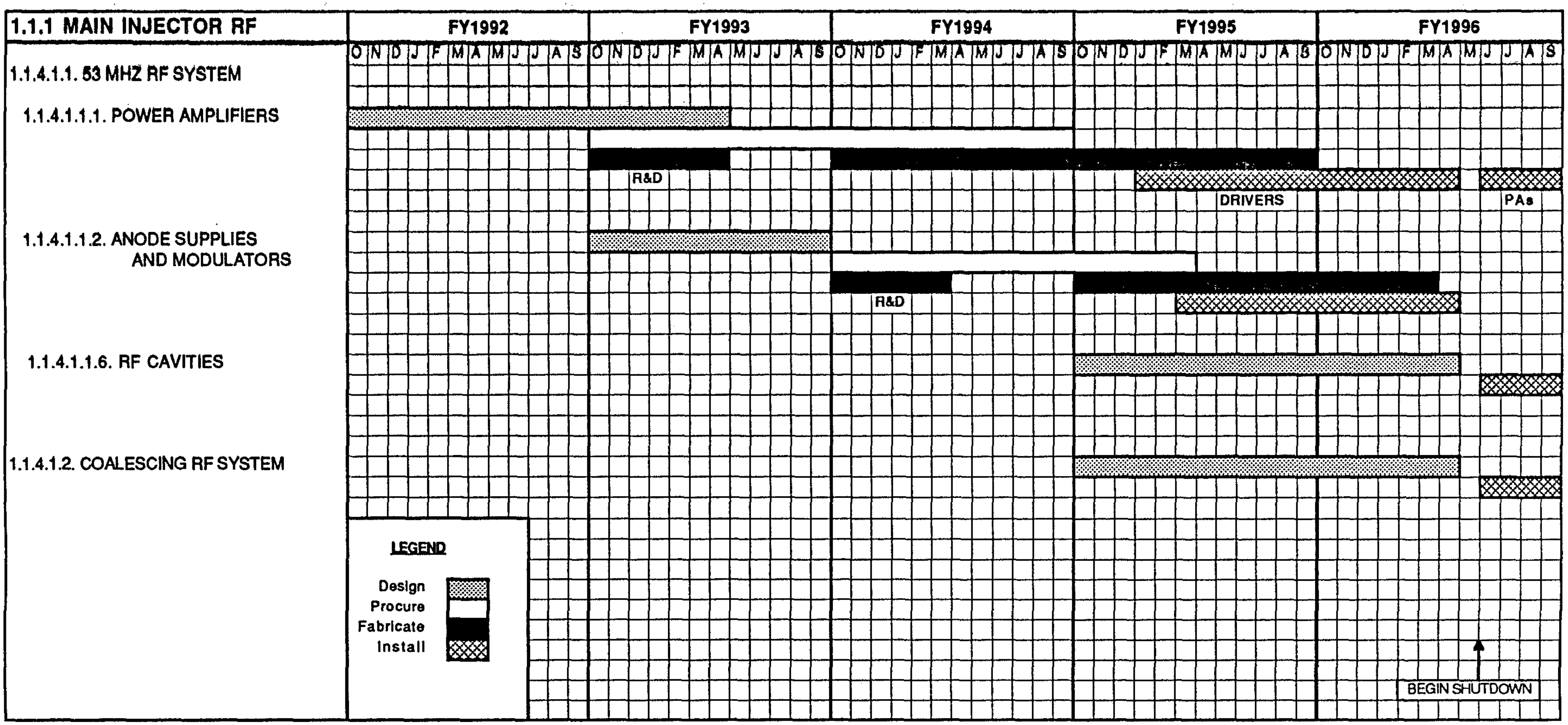


Figure 3.4-3. Main Injector RF Schedule

sufficient third harmonic current to excite the cavity to full amplitude of 280 kV has been built. This cavity has been installed in the Main Ring and will be tested during the next collider run. If such studies successfully demonstrate the ability to transmit the beam through transition without blow-up, then construction of a dedicated second harmonic cavity for the FMI will be undertaken.

WBS 1.1.4.1.2. COALESCING RF SYSTEM

Coalescing Cavities

The Main Ring coalescing rf cavities (2.5 MHz and 5 MHz) will also be employed in the FMI for use during collider loading. The change in harmonic number, coupled with the change in γ_t, results in the coalescing cavity bucket height increasing by a factor of 1.5 relative to the Main Ring. This should improve the coalescing efficiency, enhancing the ability to make bunches of the desired intensity for delivery to the Tevatron collider. Alternatively, if the need arose the voltage in these cavities could be reduced keeping the coalescing bucket height the same as currently used in the Main Ring.

Coalescing Performance

The luminosity goal for the Fermilab III program is 5×10^{31} $cm^{-2}sec^{-1}$ to be obtained by colliding 36 bunches of 3×10^{11} protons with 36 bunches of 6×10^{10} antiprotons. At the design longitudinal phasespace density of 1.5×10^{11} per eVs for both species, the longitudinal emittance in the Main Injector will be 2 eVs for protons and 0.4 eVs for antiprotons. The former substantially exceeds the design acceptance of 0.5 eVs, and the latter exceeds the performance of the Main Ring at its record intensity by a factor of two in both intensity and emittance before transition. In the Main Injector, as in the existing Main Ring, this limitation will be circumvented by coalescing several (up to 13) smaller bunches at 150 GeV to produce the required bunches for the collider. This manipulation will be accomplished with an rf system consisting of four accelerating gaps with 2.5 MHz (h=28) and three with 5.0 MHz (h=56). These cavities will be taken from the Main Ring to the Main Injector without significant change.

Coalescing RF Parameters

Frequency for coalescing bucket (h=28)	2.5 MHz
Second harmonic frequency - linearization (h=56)	5.0 MHz
2.5 MHz voltage for coalescing	500 V
2.5 MHz voltage for bunch rotation	22.5 kV
5.0 MHz voltage to linearize rotation	3 - 5 kV
Coalescing time	~0.5 s
Rotation time	0.083 s

The coalescing process consists of first debunching a train of a few h=588 bunches to as low a momentum spread as practicable. This debunching is carried out over about a half second to preserve the longitudinal emittance. If the process can be carried sufficiently far without instability or premature losses from the buckets, it is best done with a low voltage of about 500 V present on the h=28 system. The resulting distribution is then rotated to minimum phase spread in a linearized h=28 bucket produced by 22.5 kV of 2.5 MHz and about 4 kV of 5.0 MHz rf. At the time of minimum bunch length the ensemble is recaptured into a h=588 bucket by the main rf system.

At sufficiently low intensity it should be possible to carry out the entire process with little emittance dilution. However, at intensities of interest, the voltage produced by the beam image current in rf cavities and other sources of longitudinal impedance create both practical problems and a fundamental limit to attaining low momentum spread. Coalescing without full debunching leads to emittance dilution which reduces the efficiency of the final 53 MHz capture. In Main Ring operation the coalescing efficiency has been seen to drop below 50% in making bunches of 3×10^{11} protons. The performance limitation at this level is not fully understood, but, qualitatively, a broad resonance at roughly 1 MHz with R_{sh} of 1.2 kΩ and $Q \sim 2$ accounts for observed premature loss of protons from the later bunches. This R_{sh} is an order of magnitude larger than the 10-20 Ω $Z_{\|}/n$ which is believed to represent the broadband impedance of the Main Ring. To permit the Main Injector to produce bunches of 3×10^{11} at good efficiency, with little of the undesirable beam in the adjacent buckets, the vacuum chamber contours will be kept as smooth as possible; a $Z_{\|}/n$ of about 5 Ω is expected. With such a broadband longitudinal impedance and significant reduction from the Main Ring level for low frequency impedance, there will be some freedom to optimize coalescing efficiency by adjustment of the number of bunches in the train, bunch emittance and intensity, and rf voltages. It is clear that the nominal high intensity proton bunches of 6×10^{10} at 0.4 eVs are not optimum for preparing collider bunches.

In Figures 3.4-4 through 3.4-7, the steps in the coalescing process are illustrated neglecting beam current effects. The first shows a debunched ensemble of nine 0.2 eVs bunches; the next shows this ensemble being rotated in the h=28 bucket. The third figure shows the capture of this ensemble in a single h=588 bucket. Here the process is nearly ideal and efficiency practically 100 %. For comparison, the final capture of 3×10^{11} protons in the presence of a broadband $Z_{\|}/n$ of 5 Ω is shown in Figure 3.4-8. The nine initial bunches in this case each have 3.3×10^{10} protons in 0.3 eVs. This example may not illustrate the optimum choice for the number of bunches to coalesce, but it indicates that it should be possible to obtain acceptable coalescing efficiency to produce bunches of 3×10^{11} protons.

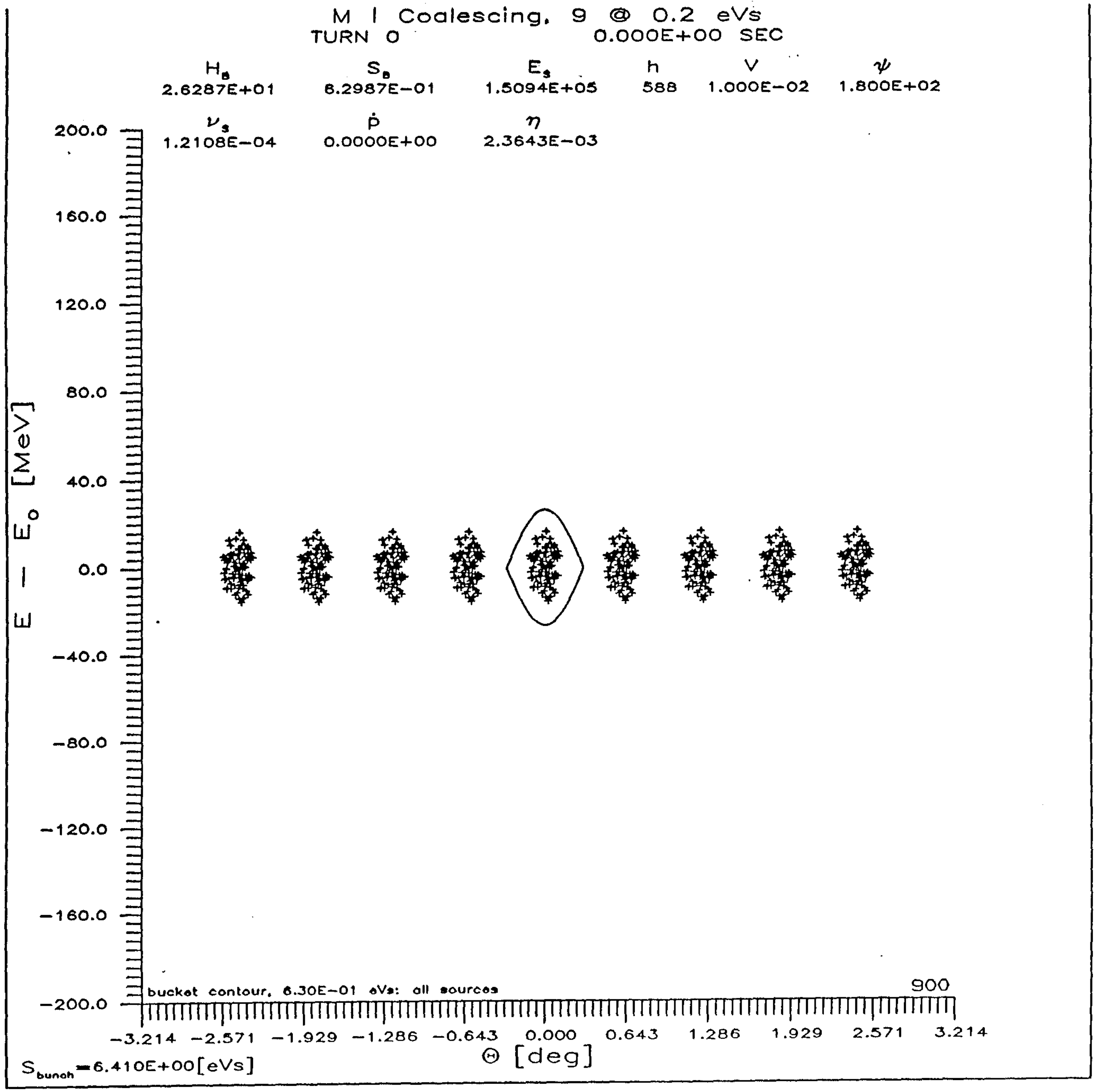


Figure 3.4-4. Coalescing Simulation: Nine h=588 Bunches During Debunching

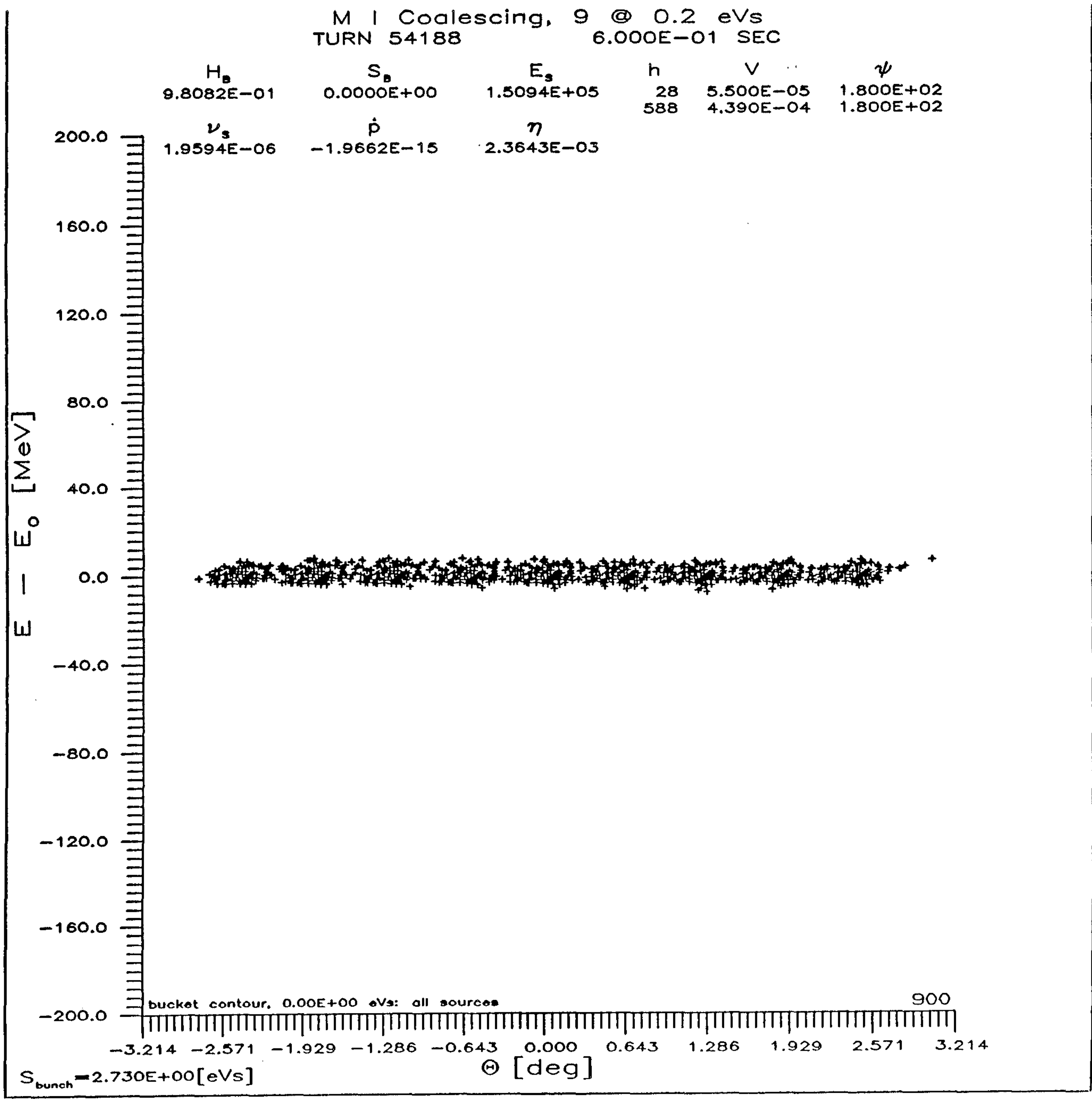


Figure 3.4-5. Coalescing Simulation: Fully Debunched

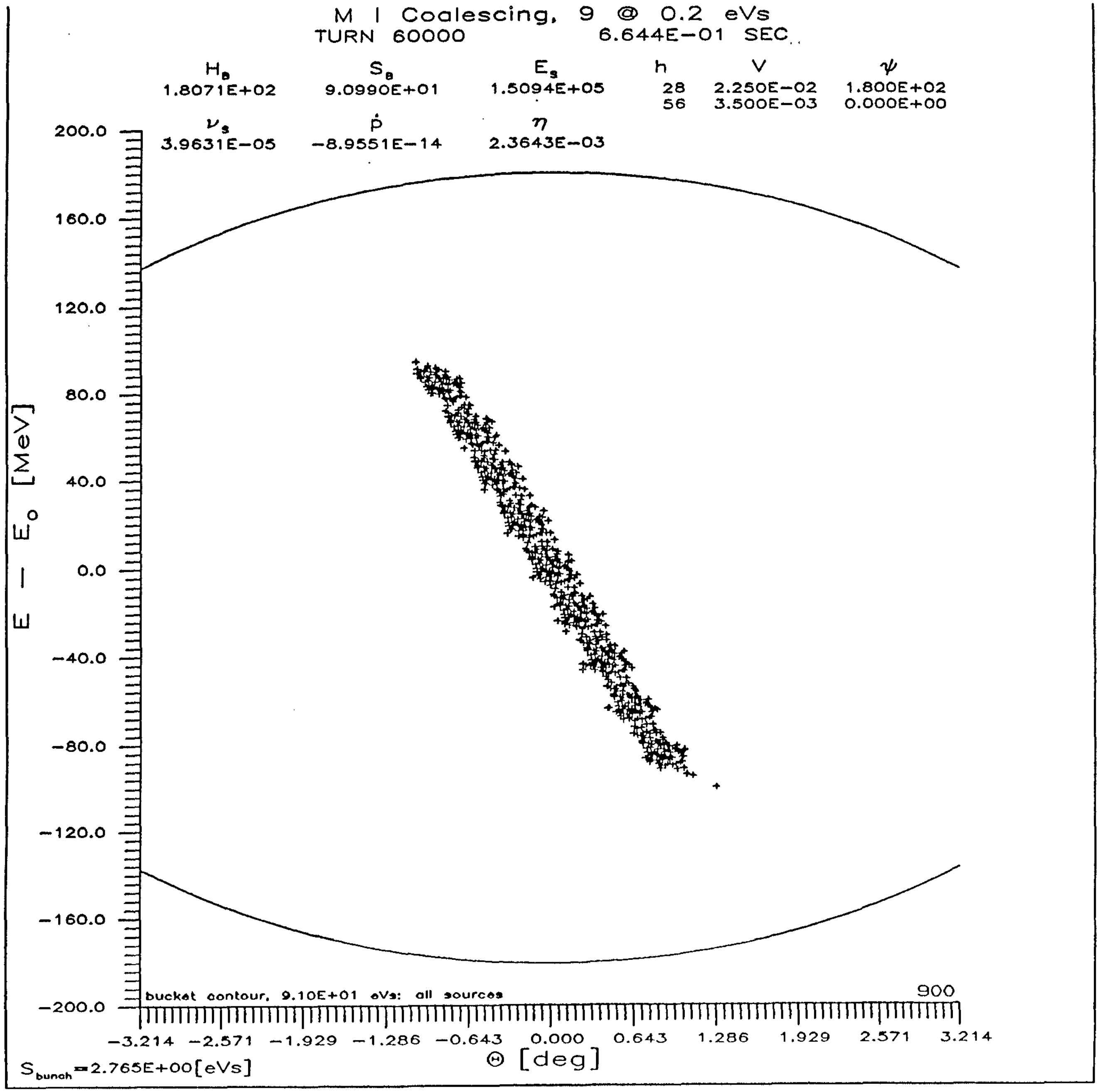


Figure 3.4-6. Coalescing Simulation: During Rotation in h=28 Bucket

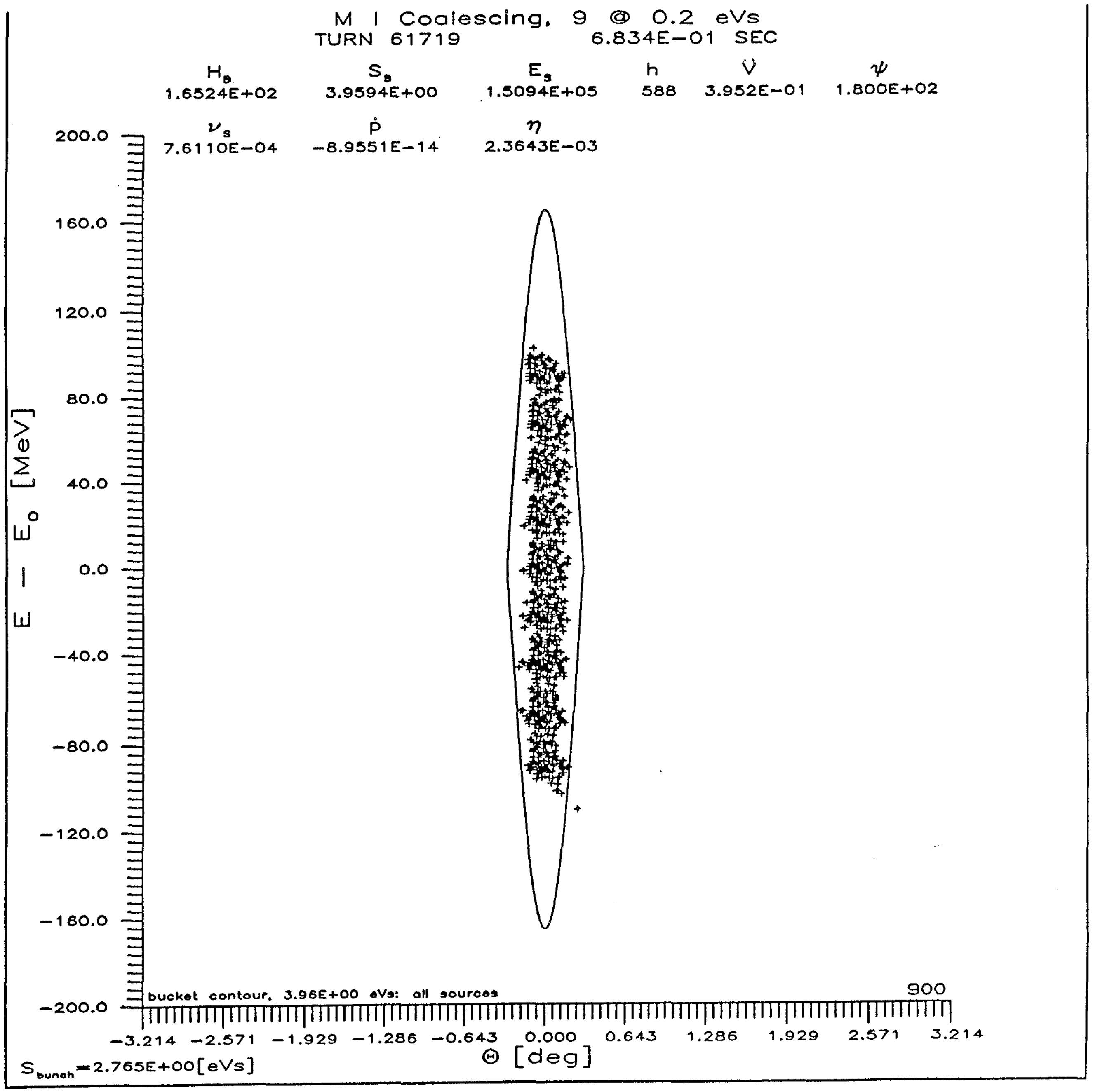


Figure 3.4-7. Coalescing Simulation: Recapture in h=588 Bucket

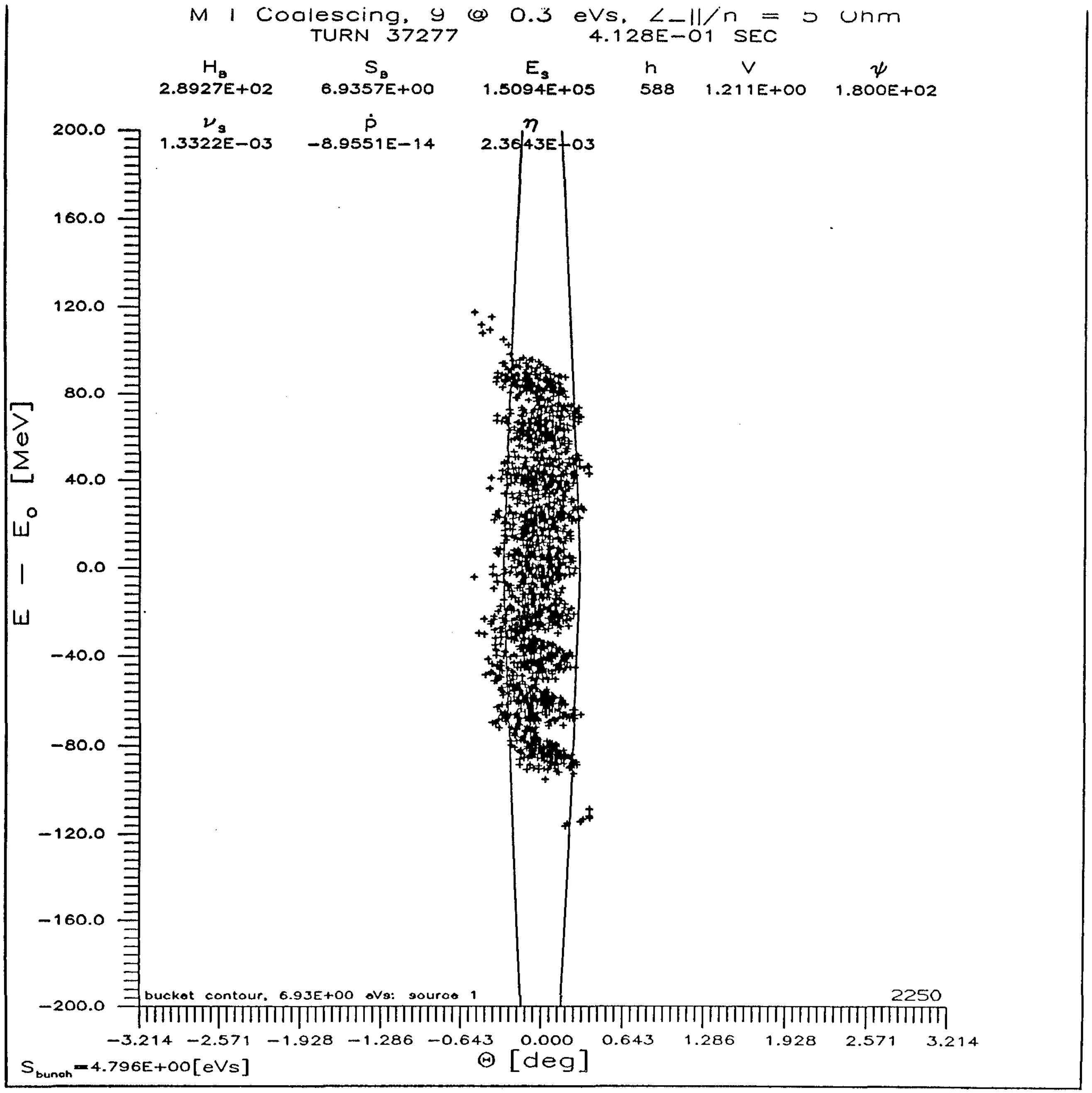


Figure 3.4-8. Coalescing Simulation: Recapture Following Debunching with $Z_{||}/n$ = 5 Ohm

CHAPTER 3.5 KICKERS AND SLOW EXTRACTION

WBS 1.1.6. KICKERS AND SLOW EXTRACTION

WBS 1.1.6.1.1. PROTON INJECTION KICKER

Six batches of 8 GeV beam will be injected into the MIR from the Booster as described in Chapter 2.4. The trajectory of the beam must be bent 1.05 mr to place it on the equilibrium orbit. Fast rise and fall times are required to insure that the circulating beam is not disturbed by the transition field at the beginning and end of the pulse.

Requirements		
	Beam aperture	101.6 mm (H) x 50.8 mm (V)
	Kick angle	1.05 mr vertical
	$\int Bdl$	.309 kG-m
	Field rise time	<50 nsec
	Field fall time	<150 nsec
	Field flattop	1.60 msec
	Field flatness ($\Delta B/B$)	±1%
Location		
	Magnet	Upstream of Q103
	Power supply	MI-10 Service Building
Magnet parameters		
	Peak current	1200 A
	Field at peak current	.136 kG
	Impedance	25 Ω
	Gap height	111.1 mm
	Gap width	63.5 mm
	Magnetic length	.758 m
	Field rise time	22 nsec
	Number required	3
Power supply		
	Peak output voltage	30 kV
	Peak output current	1200 A
	Impedance	25 Ω
	Pulse length	1.60 msec
	Flatness	±1%
	Repetition rate	15 Hz
	Number required	3

Design approach

The system will use the present MK90 Main Ring proton injection kickers for two of the three systems. A new charging supply will be required to enable these power supplies to meet the rise time requirements; see Figure 3.5-1. The magnets, shown in Figure 3.5-2, will also require modification to meet the new field rise time demands. A single new kicker system will be required which will be a copy of the modified existing design.

WBS 1.1.6.1.2. P-BAR INJECTION/PROTON EXTRACTION KICKER

Purpose

This kicker functions for five distinct operating modes, any (and only) one of which might be required on a particular cycle. In Mixed Mode operation, 5 batches of Booster beam are injected tightly spaced with the sixth batch centered in the remaining gap. The sixth batch is extracted at 120 GeV using this kicker while the remaining 5 batches are extracted at 120 GeV using slow extraction techniques. In the Fixed Target mode, 6 batches of Booster beam are injected tightly spaced. They are all extracted at 150 GeV by this kicker. The Collider Mode requires 12 Booster cycles, each of which injects a group of eleven bunches. Consecutive groups are spaced at 21-bucket intervals; these are accelerated to 150 GeV, and then coalesced into 12 bunches and extracted by this kicker. The coalesced bunches span 11 x 21 = 231 buckets, or 4.4 μsec. The 8 GeV Extraction Mode is used to extract a single batch of Booster beam into the antiproton injection line for injection line tuneup. The 8 GeV Injection Mode simply kicks a single batch of antiprotons onto the MIR equilibrium orbit.

Requirements:

Beam aperture 85.7 mm (H) x 38.1 mm (V)

Field flatness (ΔB/B) ±1%

Mode:	(units)	Mixed	Fixed Targ.	Collider	8 GeV Ext.	P-Bar Inj
Kick angle	mr	.525 (H)	.525 (H)	.525 (H)	1.25 (H)	1.25 (H)
∫Bdl	kG-m	2.10	2.625	2.625	.37	.37
Field rise	μsec	<.70	<1.48	<6.76	<9.6	NA
Field ftop	μsec	1.6	9.8	>4.4	1.6	1.6
Field fall	μsec	<700	NA	NA	NA	<9.6
Duty cycle	sec^{-1}	1/2.9	1/2.4	1/4	1/1	1/20

Location

Magnet Downstream of Q520

Power supply MI-52 Service Building

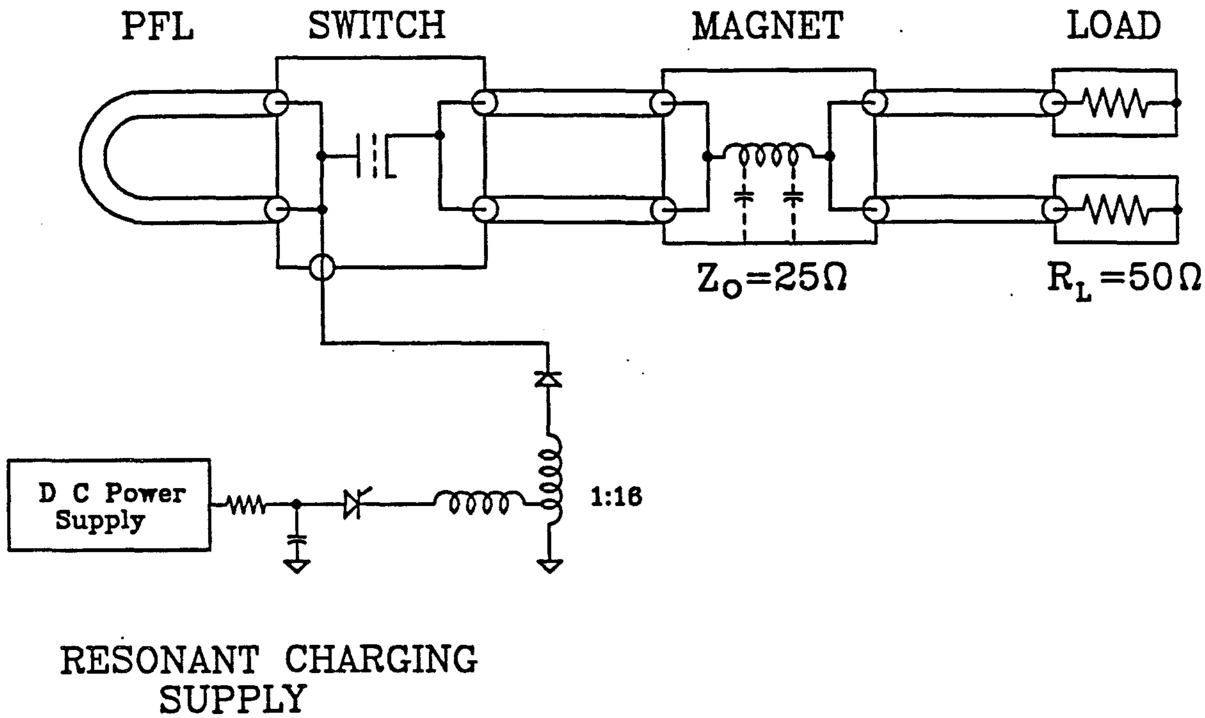


Figure 3.5-1. 8 GeV Proton Injection Kicker System

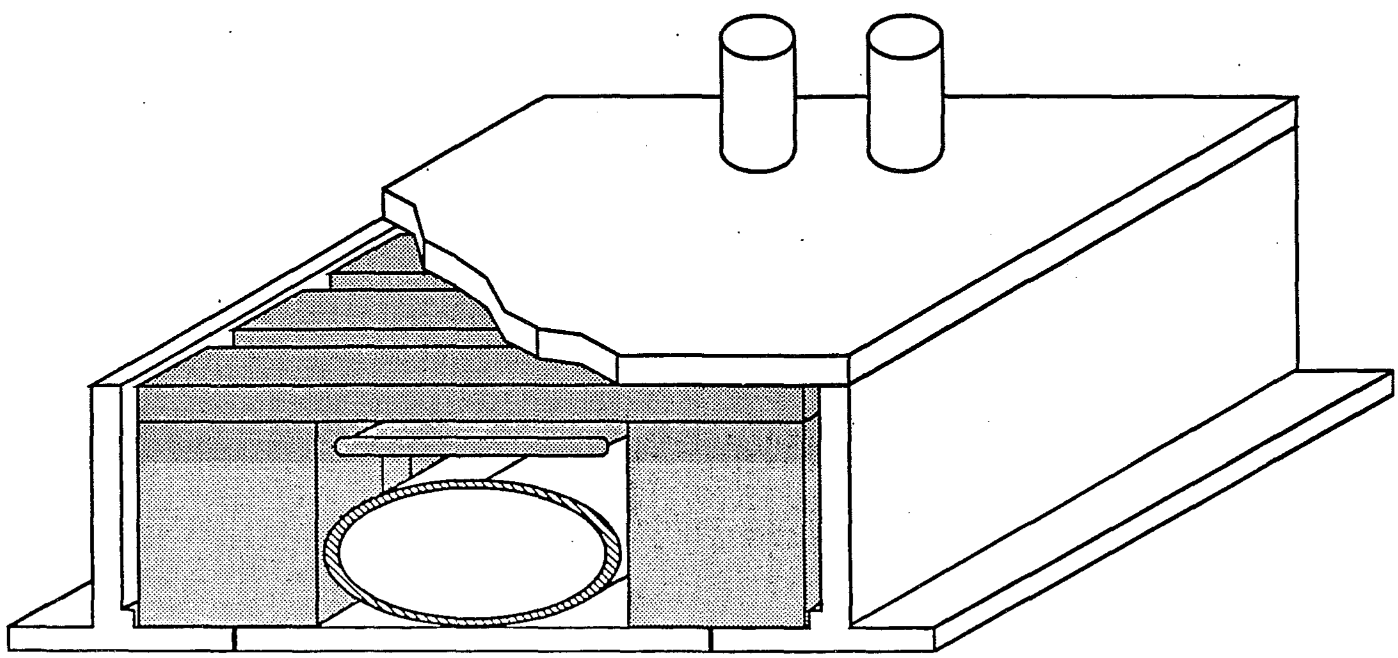


Figure 3.5-2. 8 GeV Proton Injection Kicker Magnet

Magnet parameters

Peak current	3000 A
Field at peak current	.742 kG
Impedance	10 Ω
Gap height	50.8 mm
Gap width	108 mm
Magnetic length	.177 m
Field rise time	480 nsec
Number required	2

Power supply

Impedance	5 Ω
Flatness	±1%
Number required	1

Mode:	(units)	Mixed	Fixed Targ.	Collider	8 GeV Ext.	P-Bar Inj
Peak voltage	kV	24	30	30	4.23	4.23
Peak current	kA	2.4	3	3	.423	.423
Duty cycle	sec^{-1}	1/2.9	1/2.4	1/4	1/1	1/20
Pulse length	μsec	1.6	9.8	9.8	1.6	1.6

Design approach

The magnets for this kicker will be ferrite loaded transmission line C-magnets, as shown in Figure 3.5-3. Capacitors will be distributed along the center conductor to achieve an impedance of 10 Ω. The power supply shown in Figure 3.5-4 will consist of two separate pulsers tied to a common output. A cable PFL will generate the 1.6 μsec wide pulse while the 9.8 μsec pulse will come from a lumped constant PFN.

WBS 1.1.6.1.4. 150 GEV PBAR EXTRACTION KICKER

Purpose

This kicker deflects the group of four coalesced antiproton bunches in a horizontal direction from the MIR equilibrium orbit at 150 GeV into the pbar extraction line. For tune-up, this kicker also places 150 GeV protons from the Tevatron onto the FMI closed orbit.

Requirements

Beam aperture	85.7 mm (H) x 38.1 mm (V)
Kick angle	.525 mr (H)
∫Bdl	2.625 kG-m
Field rise time	<9.6 μsec

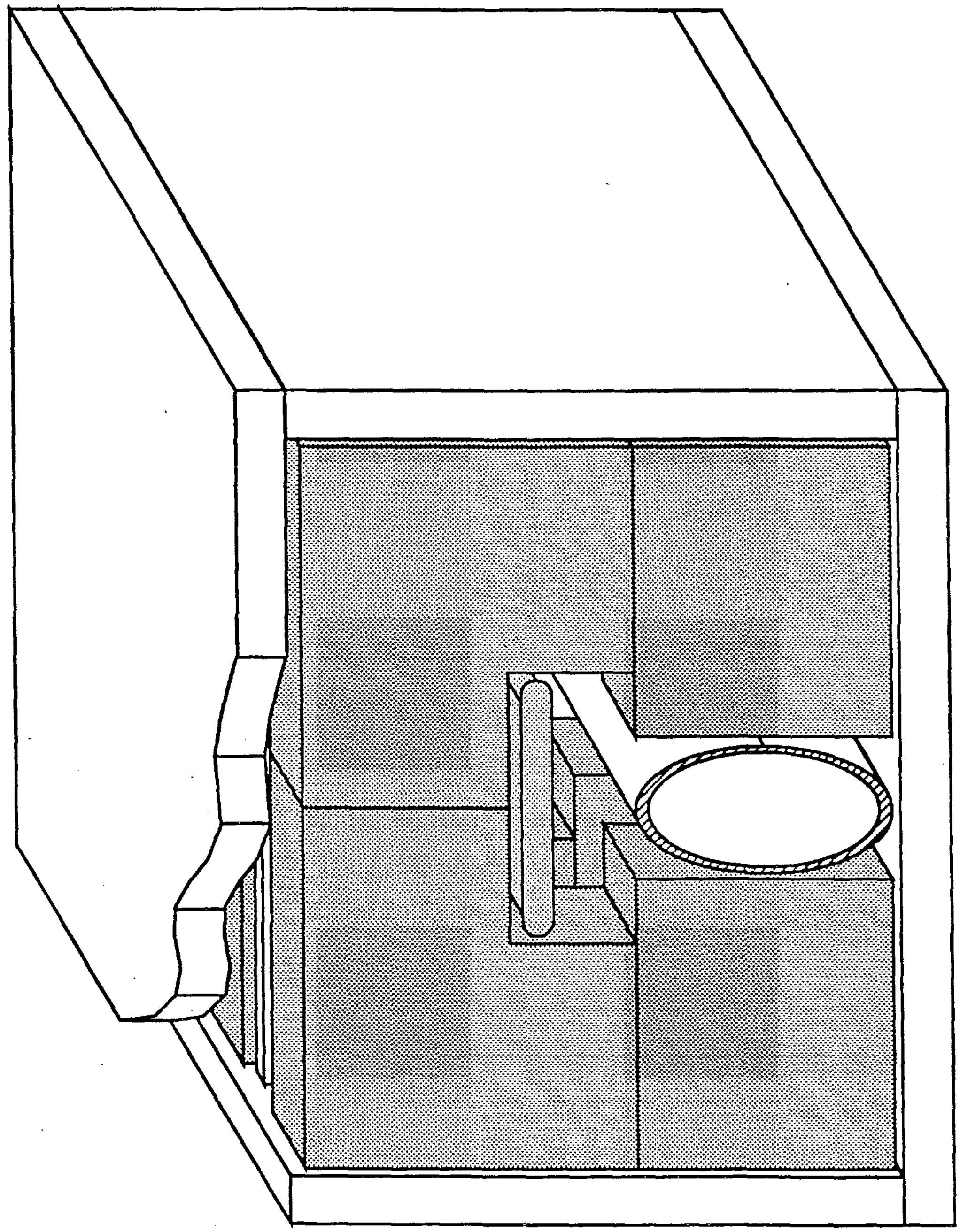


Figure 3.5-3. 8 GeV Antiproton Injection, 120/150 GeV Extraction Kicker Magnet

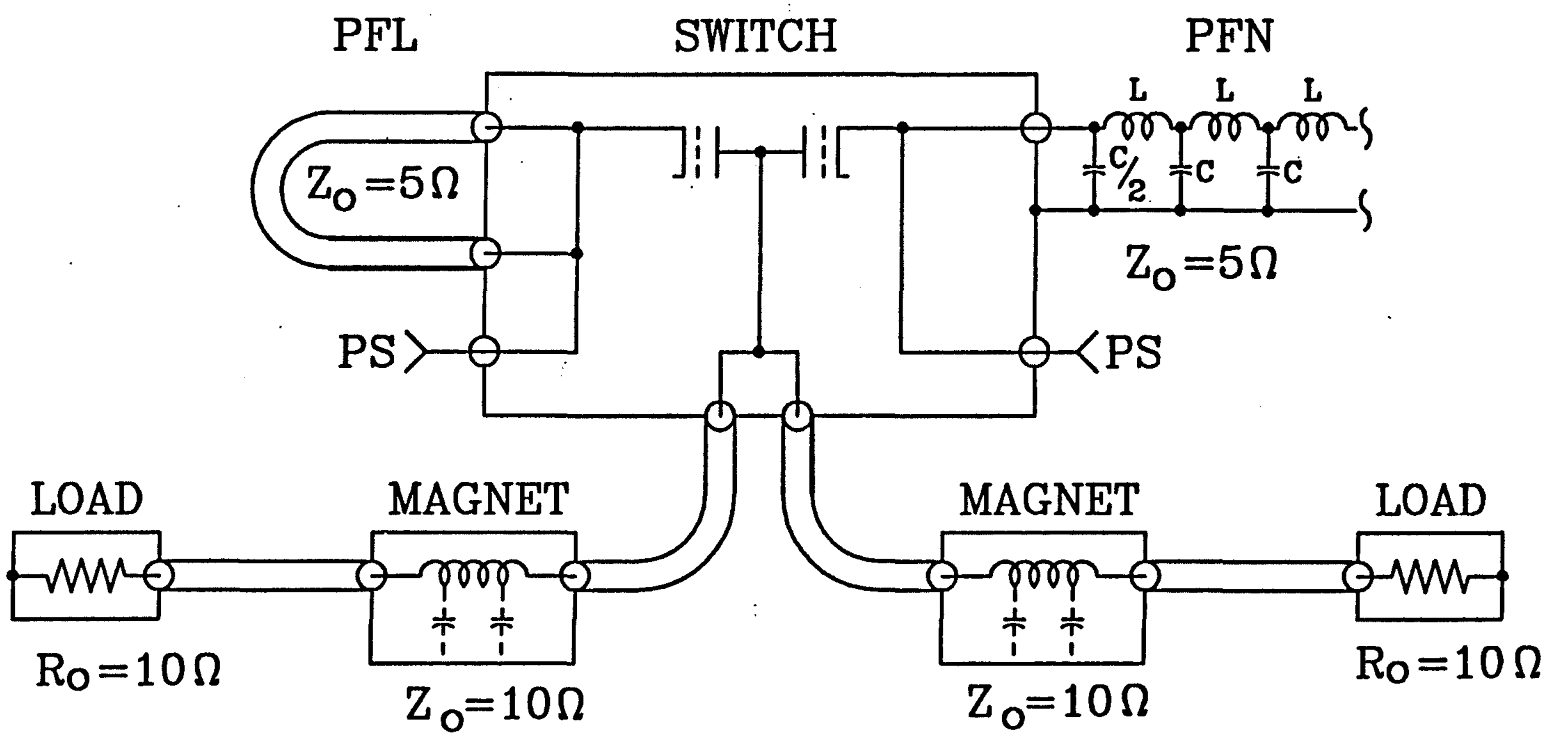


Figure 3.5-4. 8 GeV Antiproton Injection, 120/150 GeV Extraction Kicker System

Field fall time	<9.6 μsec
Field flattop	1.6 μsec
Field flatness (ΔB/B)	±1%

<u>Location</u>

Magnet	Upstream (proton direction) of Q622
Power supply	MI-62 Service Building

<u>Magnet parameters</u>

Peak current	2800 A
Field at peak current	.691 kG
Inductance	5.37 μH
Gap height	50.8 mm
Gap width	114.3 mm
Magnetic length	1.9 m
Number required	2

<u>Power supply</u>

Peak output current	5600 A
Peak output voltage	4750 V
Current rise/fall time	9.6 μsec
Current flattop (±1%)	1.6 μsec
Number required	1

<u>Design approach</u>

Two existing Main Ring abort kickers will be used for the magnets in this system. The power supply will be a half sinewave pulse with a small amount of third harmonic coupled in to flatten the peak of the fundamental as seen in Figure 3.5-5. The power supply will contain two pulse generator channels with a common power and timing source. This can be seen in Figure 3.5-6.

WBS 1.1.6.1.5. PROTON ABORT KICKER

<u>Purpose</u>

The Proton Abort kicker deflects the proton beam into a beam dump in the event of an anomaly in the MI during acceleration. The kick is synchronized with a 700 nsec gap in the circulating beam. The magnitude of the kicker field is proportional to the energy to keep the deflection angle constant since the kicker must be capable of being fired anytime during the cycle.

<u>Requirements</u>

Beam aperture	85.7 mm (H) x 38.1 mm (V)
Kick angle (Horizontal)	1.254 mr (8 GeV) to .501 mr (150 GeV)

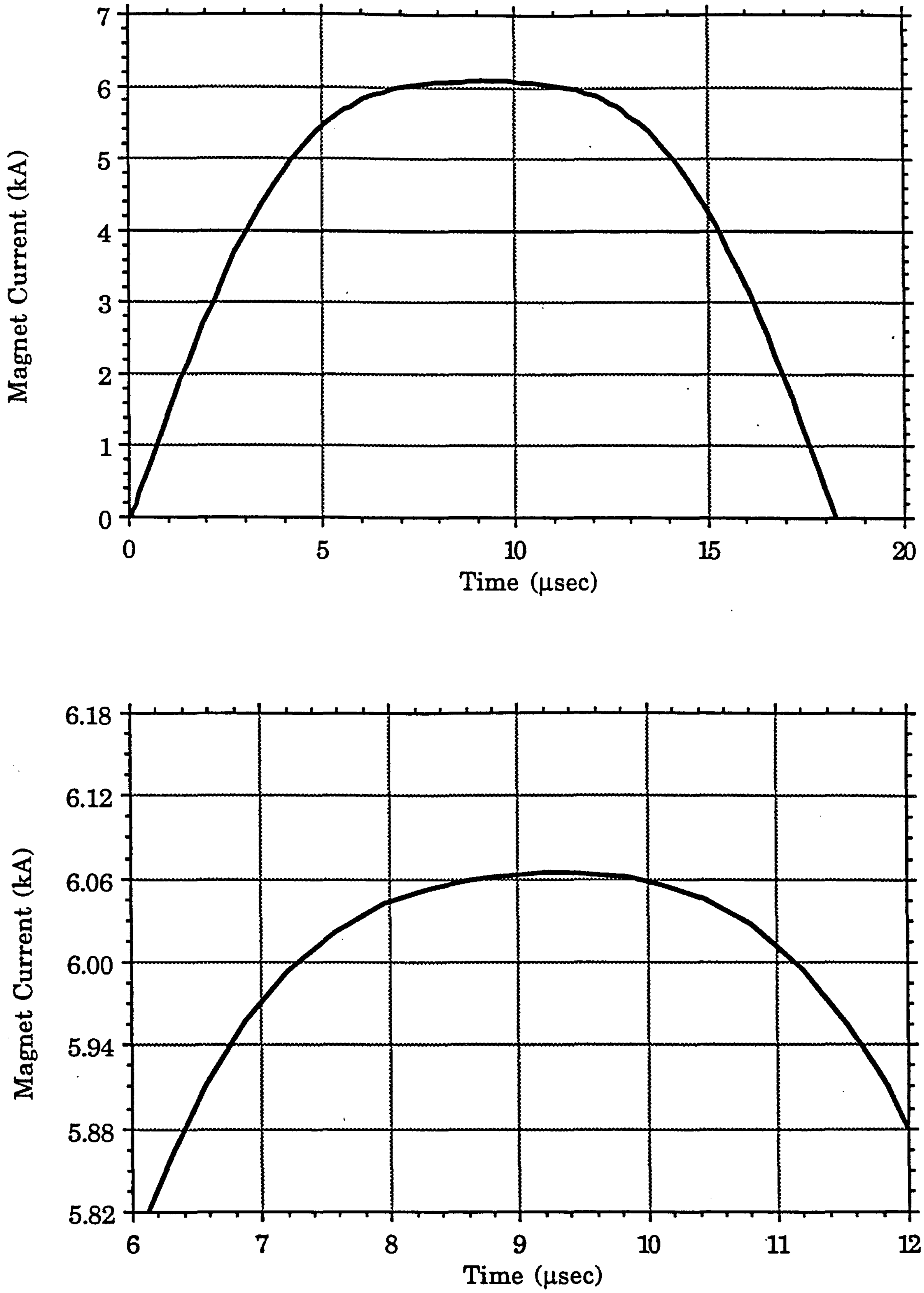


Figure 3.5-5. 150 GeV Antiproton Extraction Kicker Magnet Current Waveform

∫Bdl	.371kG-m (8 GeV)
	2.51kG-m (150 GeV)
Field rise time (10-70%)	700nsec
(10-90%)	1 μsec
Field fall time	NA
Field flattop	>9.8 μsec
Field flatness (ΔB/B)	±10%
<u>Location</u>	
Magnet	Downstream of Q400
Power supply	MI-40 Service Building
<u>Magnet parameters</u>	
Peak current (150 GeV)	2.67 kA
Field at peak current	.66 kG
Inductance	5.37 μH
Gap height	50.8 mm
Gap width	114.3 mm
Magnetic length	1.9 m
Number required	2
<u>Power supply</u>	
Peak output voltage	33.5 kV
Peak output current	2.67KkA
Impedance	12.5 Ω
Pulse length	10 μsec
Flatness	±10%
Repetition rate	1/2.4 sec
Number required	2

<u>Design approach</u>

The magnets used for this system will be existing Main Ring abort kicker magnets. Some minor modification will be required to accommodate the cable termination resistors on the input cables. Two power supplies using a new design approach will be required, each made up of a 14 cell PFN matched to the load with a step-up transformer as shown in Figure 3.5-7.

WBS 1.1.6.3.1. TEV PROTON INJECTION KICKER

<u>Purpose</u>

This kicker will operate in two modes, each requiring .381 mr of kick to place the injected beam onto the Tevatron closed orbit. The Collider mode requires rise and fall times of 2.6 μsec with a flattop of 4.4 μsec to accommodate 12 coalesced bunches spaced by 21 buckets. The Fixed Target mode has a much more stringent rise and fall time requirement of < 800 nsec each, with a

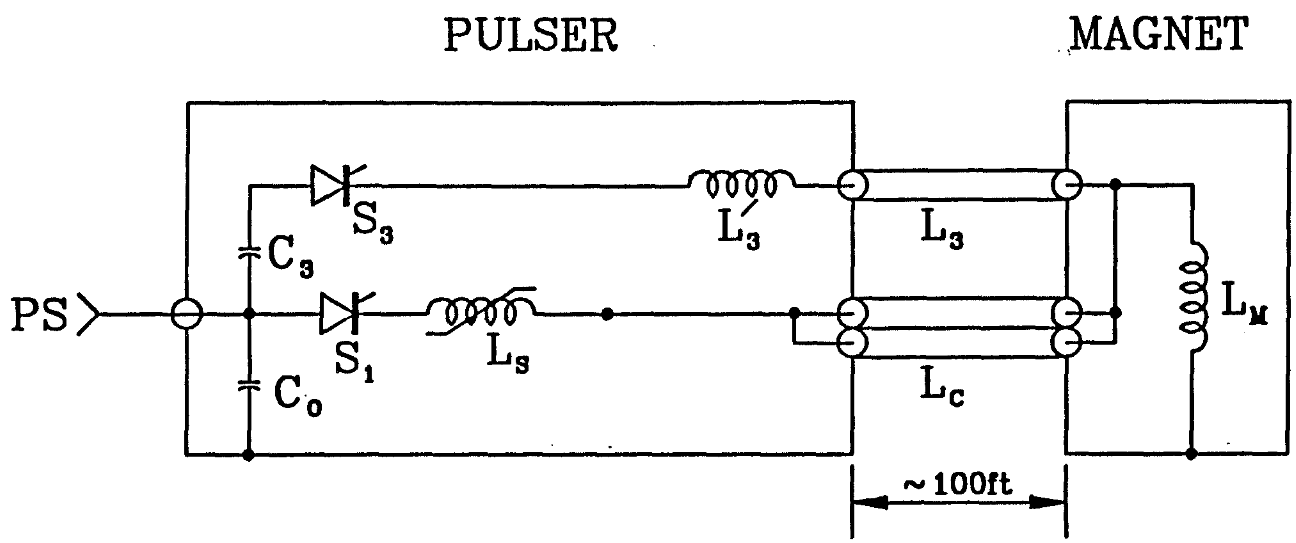


Figure 3.5-6. 150 GeV Antiproton Extraction Kicker System

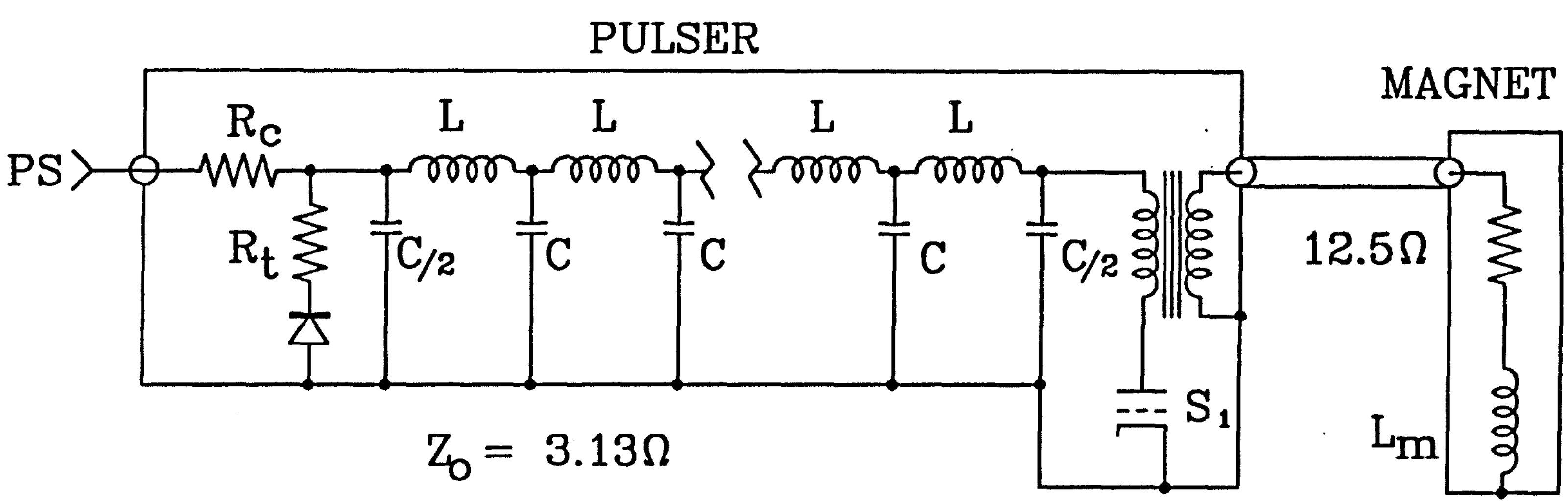


Figure 3.5-7. Abort Kicker System

flattop of 9.6 μsec. In this mode, two MI cycles of six batches each are required to load 12 batches into the Tevatron.

Requirements		
	Beam aperture	85.7 mm (H) x 38.1 mm (V)
	Kick angle	.381 mr
	∫Bdl	1.906 kG-m
	Field rise time	<800 nsec
	Field fall time	<800 nsec
	Field flattop	4.4 or 9.8 μsec
	Field flatness (ΔB/B)	±1%
Location		
	Magnet	TEV F17 Medium Straight Section
	Power supply	F17 Kicker Buidling
Magnet parameters		
	Peak current	1.93 kA
	Field at peak current	.477 kG
	Impedance	12.5 Ω
	Gap height	50.8 mm
	Gap width	108 mm
	Magnetic length	2 m
	Field rise time	<550nsec
	Number required	2
Power supply		
	Peak output voltage	50 kV
	Peak output current	4 kA
	Impedance	6.25 Ω
	Pulse length	10.35 μsec
	Flatness	±1%
	Repetition rate	1/2.4 sec
	Number required	1

Design approach:

Measurements on the present E17 kicker magnet indicate that its rise and fall times are far too long for the Fixed Target mode. The ferrite cores and perhaps the beam tube can be recycled into an upgraded design similar to the MI Pbar Injection/Proton Extraction magnet. The existing power supply would be moved to a new service building at F17. The present interlock and control hardware would be upgraded at this time.

WBS 1.1.6.3.2. TEV PBAR INJECTION KICKER

Purpose

Four coalesced bunches spaced at 21 buckets (total of 1.6 µsec) will be injected horizontally into the Tevatron from the MI. A horizontal kick of .35 mr is required to place the beam on the proper horizontal trajectory. Fast rise and fall times are required to insure that the circulating beam is not disturbed by the transition field at the beginning and end of the pulse.

Requirements		
	Beam aperture	85.7 mm (H) x 38.1 mm (V)
	Kick angle	.35 mr
	∫Bdl	1.75 kG-m
	Field rise time	<395 nsec
	Field fall time	<395 nsec
	Field flattop	1.6 µsec
	Field flatness ($\Delta B/B$)	±1%
Location:		
	Magnet	TEV E48 Short Straight Section
	Power supply	F0 Service Building
Magnet parameters:		
	Peak current	3.3 kA
	Field at peak current	.724 kG
	Impedance	6.25 Ω
	Gap height	57.2 mm
	Gap width	79.4 mm
	Magnetic length	.241 m
	Field rise time	336 nsec
	Number required	1
Power supply		
	Peak output current	3.3 kA
	Peak output voltage	20.6 kV
	Impedance	6.25 Ω
	Pulse length	2.0 µsec
	Flatness	±1%
	Repetition rate	1/4 sec
	Number required	1

Design approach

One of the existing two D48 kickers will be moved to E48 since only half the present kick is required. Since this is a new system, no upgrades are required.

Schedule

Figure 3.5-8 shows the schedule for the kicker systems.

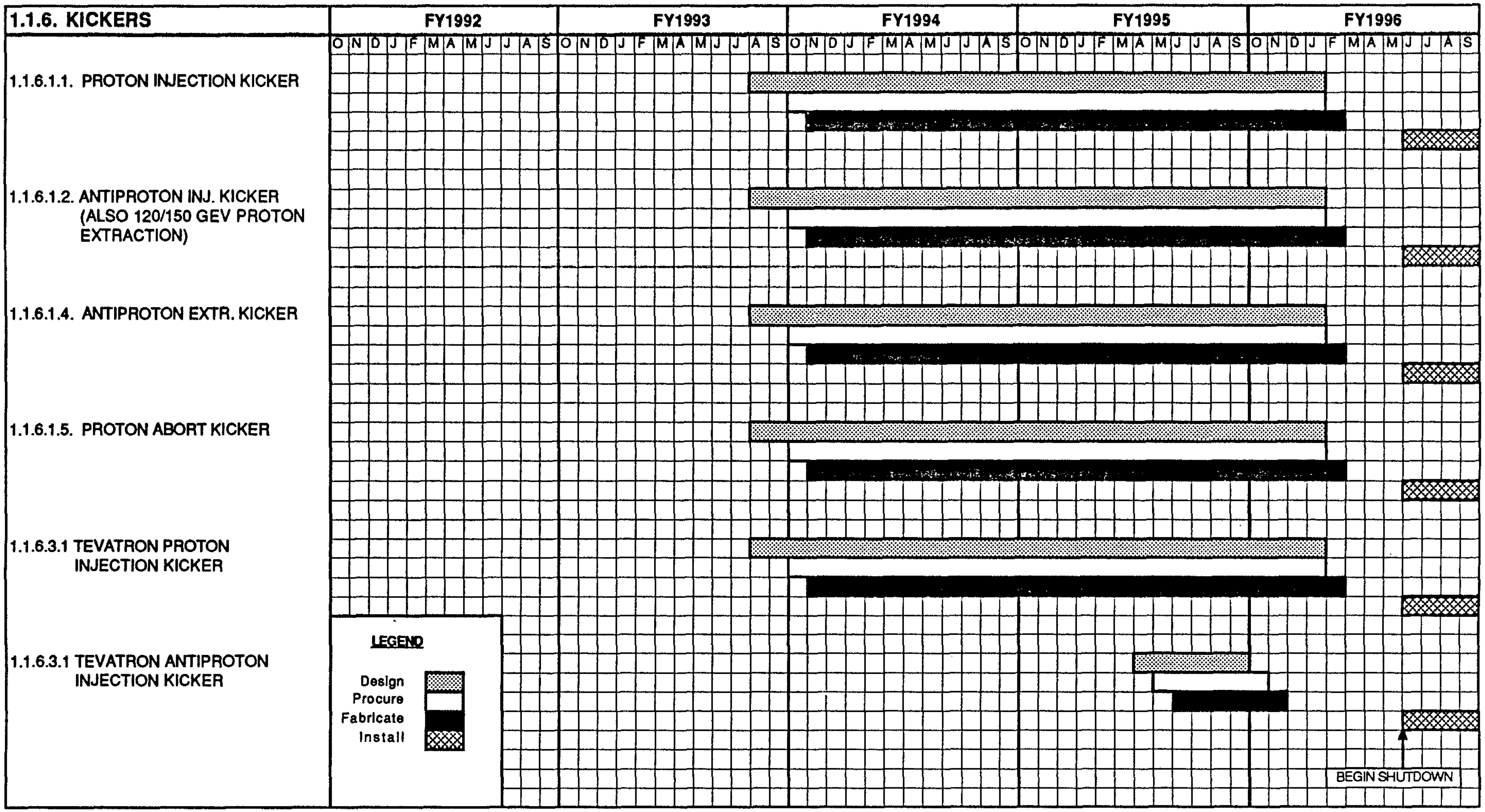


Figure 3.5-8. Kicker Magnet and Power Supply Schedule.

WBS 1.1.6.2 SLOW EXTRACTION

Introduction

The aim of the Main Injector slow extraction system is to provide the capability for year-round high efficiency, uniform spills of 120 GeV protons over periods on the order of 1 second. Half-integer resonant extraction is considered to be most suitable for realizing this goal. The half-integer resonance is a linear resonance and can be induced solely by a quadrupole field: the beam in this case is either entirely stable or entirely unstable. With the addition of a (non-linear) octupole field the phase-space splits into the stable and unstable regions essential for controlling the extraction rate. In contradistinction to third-integer resonances, which have zero stop-band width, the finite width of the half-integer stop-band ensures that all of the beam can be extracted from the machine. This finite width is particularly important in the event that there is significant current ripple in the main quadrupole supplies. Recycled Main Ring trim quads and octupoles are used to provide the appropriate harmonics for extraction.

Slow extraction from the Main Injector proceeds as follows. The horizontal tune is raised towards the half-integer from the nominal operating value of 26.425 to 26.485 using the main quadrupole circuits. The desired orientation of the phase-space is obtained by energizing appropriate 53rd-harmonic quadrupole circuits. Simultaneously, a 0th-harmonic octupole circuit is turned on. The octupole field produces an amplitude-dependent tune shift $\Delta u \ \mu \ x^2$ and consequently produces a tune spread in the beam: particles with a large betatron amplitude have a higher tune and are closer to the half-integer than those with a small amplitude. The strength of the octupoles is chosen so that the stable phase-space area just encompasses the emittance of the circulating beam.

Extraction begins by ramping the harmonic quadrupoles to increase the width of the half-integer stop-band and start the stop-band moving through the beam. Small amplitude (smaller tune) particles remain stable, with their phase-space motion on subsequent turns oscillating between the 'fixed' points. As the stable phase-space area shrinks, the larger amplitude particles enter the stop-band and become unstable, with their amplitude then growing exponentially from turn to turn. The unstable particles stream out along the separatrix until they ultimately jump across (or hit) the wires of an electrostatic septum and enter the extraction channel. The kick supplied by the electrostatic septum provides sufficient separation between the extracted and circulating beams that magnetic septa can be used for the final extraction from the machine.

Septa

The extraction septa are located in straight section MI-52. This region must accomodate extraction of 120 GeV slow spill protons, single-turn extraction of 120 GeV and 150 GeV protons, and 8.9 GeV antiproton injection. The Lambertson magnetic septa and C-magnets are common to all three beam transfers. There is sufficient phase advance in the straight section that both the extraction kicker magnets and electrostatic septum can be placed at the upstream end of the straight section. The septum is located downstream of the kicker magnets to avoid radiation damage to the kickers resulting from small beam losses on the septum wires. There is 82.9∞ of phase advance from the septum to the entrance of the Lambertson.

The electrostatic septum is modeled after existing Tevatron extraction septum modules. The overall length of the septum is 3.6576 m (12') with the anode consisting of 0.1 mm tungsten-rhenium wires spaced at 2.5 mm. The high-voltage gap is 14 mm and is designed to operate at gradients up to 75 kV/cm. It is desirable to have a separation of at least 6 mm at the magnetic septa between the circulating and extracted beams. A 149 mr kick from the electrostatic septum achieves this with an applied voltage gradient of 49 kV/cm.

Harmonic Elements

The minimum number of harmonic quads necessary is determined by the condition that there be sufficient strength to raise the fractional horizontal tune from 0.485 to 0.500 at 120 GeV. With ß ~ 50 m at the quadrupole locations, the total strength required is ~15 kG-m/m. For Main Ring trim quads, this translates into 8 quadrupoles operating at ~7 A. In the Main Injector 16 harmonic quadrupoles are utilized. These are distributed around the ring, separated into two orthogonal families (cosine and sine) of eight quads each. Within each family, equal numbers of F and D quads guarantees that the 0th-harmonic contribution cancels. The 53rd-harmonic term is retained by separating opposite polarity quads by odd multiples of 90∞ in betatron phase. The orthogonality of the families provides the capability both to cancel the natural half-integer stopband of the machine and to manipulate the orientation of the phase-space at the electrostatic septum for extraction. Ideally, one family is situated to provide the desired phase-space and alone needs to be activated for slow extraction.

The 0th-harmonic octupole circuit is required to serve two functions. During resonant extraction it is augmented by the (large) octupole component of the 128 Main Ring quadrupoles to produce appropriate stable and unstable phase-space regions. At injection, however, the octupole field of the Main Ring quads has a degrading effect on dynamic aperture, as discussed in Section 2.3. The harmonic octupoles in this case are used to cancel this detuning influence. It is primarily this latter function that determines the number of octupoles needed in the Main Injector.

At 8.9 GeV the integrated octupole strength of a single MR quad is ~28 kG-m/m^3. The effect of the 64 F quads in the ring can be cancelled by 32 recycled MR trim octupoles operating at ~2 A. In the Main Injector the 32 octupoles are distributed around the ring in a single family. All octupoles have the same polarity, producing a 0th-harmonic contribution. Higher harmonics are cancelled by spacing the octupoles equidistant in phase around the ring.

Phase Space

Simulations of the extraction process from the Main Injector with ~1000 particles tracked over ~1000 - 1500 turns (~10 msec/turn) are performed in reasonable computer time without introducing approximations. Within this framework the discussion that follows applies, strictly, only to 'fast' resonant extraction, wherein the beam is fully extracted in periods of a few milliseconds. The extension to extraction over time spans on the order of 100,000 turns (~1 sec), however, is straightforward and presents no additional physics issues. In the simulations, initial particle positions, transverse momenta, and momentum offsets are selected randomly from uncoupled, Gaussian-distributed phase-spaces. There is provision to assign random dipole and quadrupole field errors. Typical phase-space distributions obtained at the electrostatic and magnetic septa are displayed in Figure 3.5-9. To produce these plots 1000 particles are tracked over 1000 turns, with the displayed phase-space corresponding to mid-way through the extraction process; i.e., 500 particles remain from the initial 1000.

With only 53rd-harmonic quadrupole and 0th-harmonic octupole circuits the central stable region is described by the overlap of two circles in the phase-space. Unstable particles follow the separatrices (arcs of circles) to the wires of the electrostatic septum. The angular kick supplied to the extracted beam by the electrostatic septum translates into a 6 mm separation between circulating and extracted beams at the Lambertson. The electrostatic septum wire array is positioned 16 mm from the center of the circulating beam. This represents an unavoidable compromise between high extraction efficiency and considerations of magnet aperture. For larger separations both the step-size at the wires and maximum particle amplitude increase. A larger step-size means fewer particles are lost on the wires, while a larger amplitude implies that particles circulate further into the poor field region of the magnets. For the extracted phase space shown, the emittance is 6π mm-mr with an extraction inefficiency of 2%.

The phase-space orientation shown in Figure 3.5-9 is produced by just one of the two families of harmonic quadrupoles. Figure 3.5-10 demonstrates how, by varying the relative contribution from the cosine and sine harmonic circuits, any desired orientation of the phase-space can be obtained. This control makes it possible to cancel the natural half-integer stop-band of the machine, and to manipulate the phase-space at extraction if necessary.

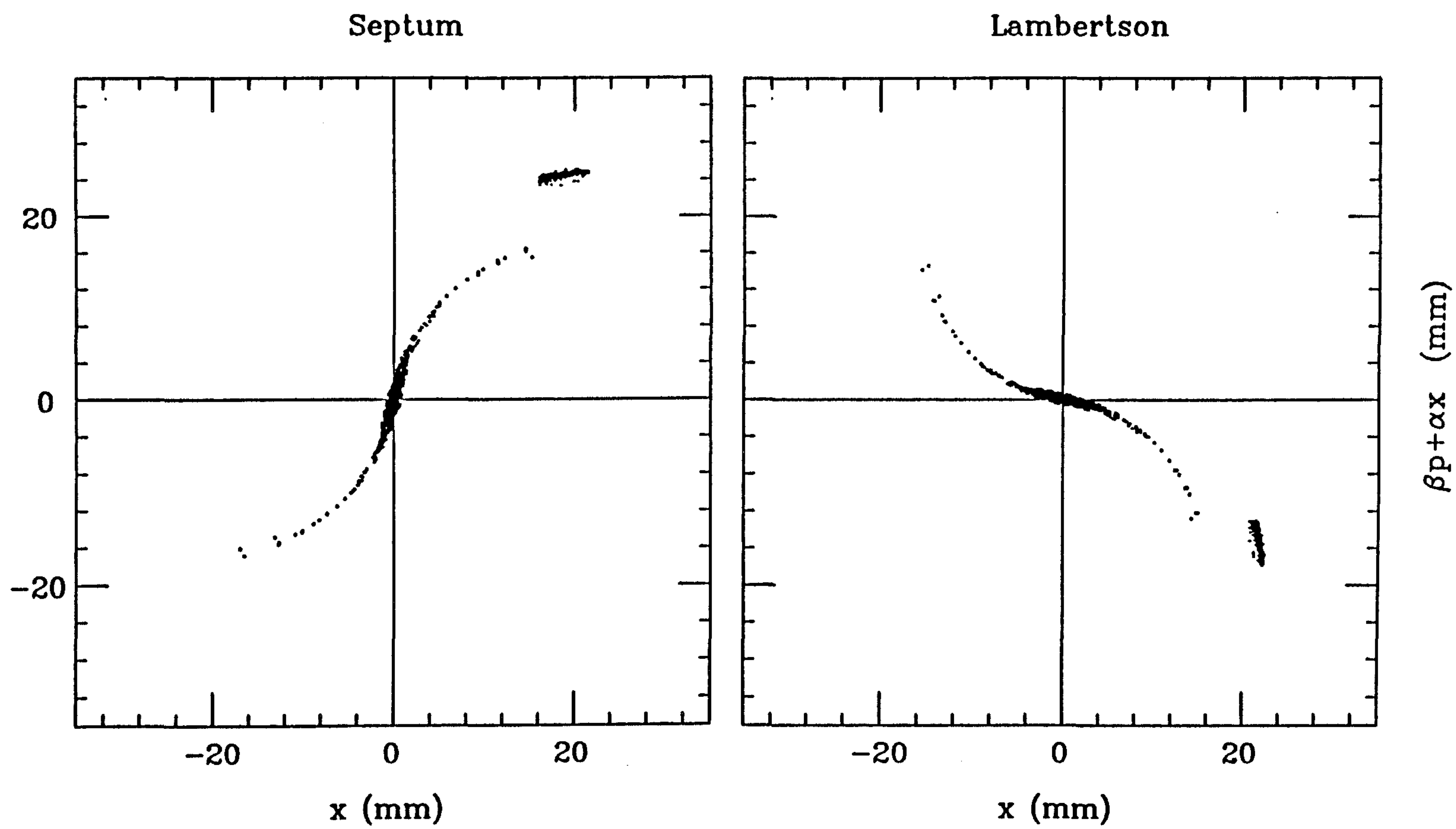


Figure 3.5-9. Phase-Space Plots of the Beam at the Electrostatic and Magnetic Septa.

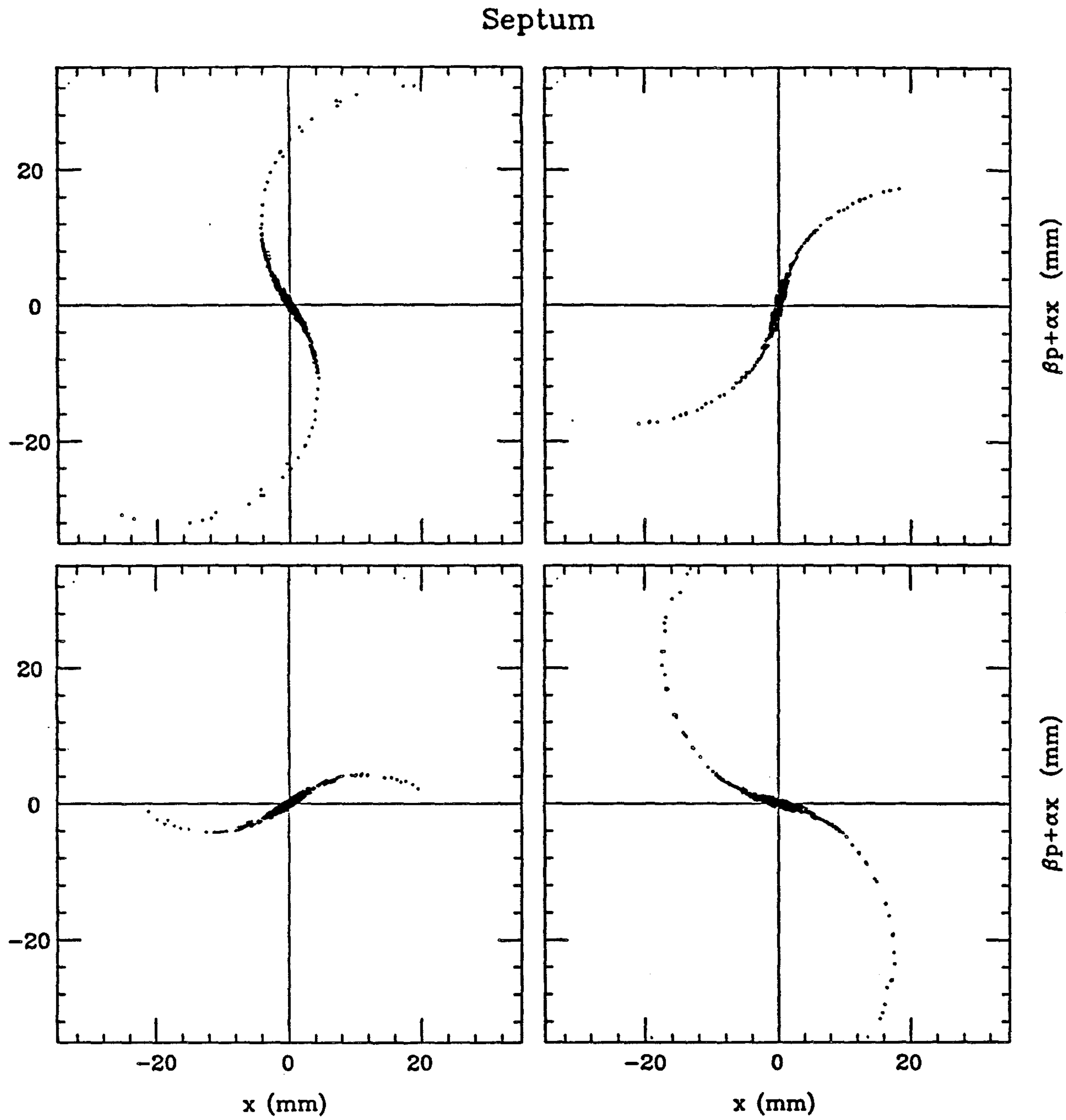


Figure 3.5-10. Phase-Space Plots of the Beam at the Electrostatic Septa for Different Excitations of the 53rd Harmonic Quadrupole Circuits.

Quadrupole Extraction Regulator System (QXR)

The goal of the slow extraction system is to provide a constant rate of extraction during the slow spill. This is accomplished by moving the stopband smoothly through the beam using the quadrupole extraction regular system (QXR). There are two parts to this system, distinguished by strength and bandwidth. The stronger, lower bandwidth components ard tied to a normal beam intensity monitor which is insensitive to fast fluctuations. After the signal is sampled during the spill and compared to an ideal signal, the resultant smoothed error signal is used to modify the power supply output. This system is the base from which the weaker, faster responding system works. Monitoring is based on a fast reacting detector in the extracted beamline itself. Power supply ripple up to 360 Hz can be compensated by this system.

CHAPTER 3.6 INSTRUMENTATION

WBS 1.1.8. INSTRUMENTATION

WBS 1.1.8.1. MAIN INJECTOR RING INSTRUMENTATION

Beam Position Detector (BPM)

The beam position system for the FMI is patterned after the existing Main Ring system. At each F(D) main quadrupole there will be a horizontal (vertical) pickup. Twenty quadrupole locations in the vicinity of beam transfer points will have both horizontal and vertical pickups. New BPMs will be built for the FMI. The processing electronics are 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.

Beam Loss Monitors (BLM)

The loss monitor system will utilize the recently constructed Main Ring ion chambers at each quadrupole in the ring and be of the same type as the present Tevatron system.

Other Special FMI Diagnostics

The FMI will employ a second harmonic dc current transducer. This will enable accurate acceleration efficiency measurements and will also be used for dc storage studies.

In order to analyze longitudinal and transverse instabilities, the FMI will be equipped with a broadband longitudinal pickup and two broadband 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 FMI will also be equipped with three flying wires to allow dynamic emittance and momentum spread measurements during acceleration.

Dampers and Scrapers

The FMI damper systems 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 FMI 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.

WBS 1.1.8.10. BEAMLINE INSTRUMENTATION

Beam Diagnostics in the 8 GeV beam line from Booster to MI

The purpose of the beam diagnostic system is two fold. First it should aid in the investigation of the problems associated with beam transport in the beam line and help establish the beam. For this a number of beam position and beam loss monitors will be installed in this beam line. Secondly, the beam diagnostic system should provide a reliable method for quick measurements of beam parameters like transverse emittances and emittance dilutions on batch by batch basis for the beam coming from the Booster. In case of any mismatch during the bucket-to-bucket measurements will help correct it. We find the multiwire systems of the type presently being used in 8 GeV beam line from Booster to Main Ring are quite adequate. Also each of these multwire systems is capable of measuring both horizontal as well as vertical beam profiles at the same location in the lattice.

The emittance dilution in a beam line can arise from various types of errors like fluctuations and higher ordered components in field, misalignment- and/or roll-errors in the beam line elements . Calculations carried out using the program MAD shows that a 1% field error (random as well as systematic) in all beam line magnets (quadrupoles and bending magnets) gives a maximum of 10% emittance dilution from the amplitude functions and a maximum of 5% emittance dilution from the dispersion functions. But major contribution arises from the position errors which we propose to correct by using correction dipoles downstream of each quadrupole.

To determine the beam emittances and establish matching of the bunches during operation we propose to use three groups of multiwire systems. The first set containing three multiwire chambers will be installed in the long straight section. Two of these will be at zero dispersion points and one will be placed in non zero dispersion point in the lattice to measure the momentum spread. A second set of four multiwire chambers will be installed MI matching section to measure beam parameters before injection into the MI. The third set of four chambers are going to be placed in the MI ring down stream of the injection Lambertson. The details of the lattice function and the locations of all the multiwire chambers in the beam line are summarized in Table 3.6-1.

Schedule

Figure 3.6-1 shows the schedule for the instrumentation.

Table 3.6-1. Positions of the Multiwire Chambers in the 8 GeV Beamline

Position Between (m)	Available Space (m)	Beta Function (m) x	Beta Function (m) y	Dispersion Function (m) x	Dispersion Function (m) y
Zero Dispersion section					
SQ_A(25) & B2_MAG(17)	4.242	50.503 to 32.496	8.829 to 15.046	0.0	0.0
SQ_A(39) & B2_MAG(37)	4.242	50.504 to 32.496	8.828 to 15.046	0.0	0.0
SQ_A(439 & B2_MAG(37)	4.242	50.504 to 32.496	8.828 to 15.046	3.103 2.947	0.0
MI Matching Section					
SQ_A(46) & B2_MAG(47)	1.054	8.903 to 9.882	50.471 to 46.148	1.503 1.569	0.0
SQ_A(47) & B2_MAG(49)	4.242	47.932 to 30.724	11.879 to 19.334	2.970 2.350	0.0
SQ_A(48) & B2_MAG(50)	3.971	8.544 to 14.146	56.200 to 38.654	1.067 1.006	0.0
SQ_A(50) & B2_MAG(51)	11.529	15.919 to 51.483	39.640 to 12.058	0.400 0.368	0.0

MI Ring

QUAD100 & QUAD101 (1)	11.907	54.533 to 19.138	11.588 to 47.371	0.073 0.035	0.0
QUAD101 & QUAD102 (1)	14.587	10.616 to 53.426	57.331 to 11.686	0.020 0.0	0.0
QUAD102 & QUAD103 (1)	12.087	55.290 to 18.802	11.048 to 44.985	-.004 -.018	0.0
QUAD103 & QUAD104 (2)	14.587	10.808 to 52.743	53.771 to 11.818	-0.026 -0.072	0.0
QUAD301 & QUAD309 (3)	14.587	~55 to ~11	~11 to ~55	~0	0

(1) Multiwire will be near the first quad.
(2) One multiwire near the first quad and one near the second.
(3) A total of eight multiwires will be installed in the MI-30 straight section, one just downstream of each of the first eight quads. Lattice functions vary slightly at each F or D location.

150 GeV Beamlines and Slow Spill Line

Beam position monitors and beam loss monitors wil be provided at each quadrupole location. Multiwires will be placed at a few locations (to be determined) to provide profile information to assure that the lattice functions are matched between the beamlines and the Main Injector and Tevatron.

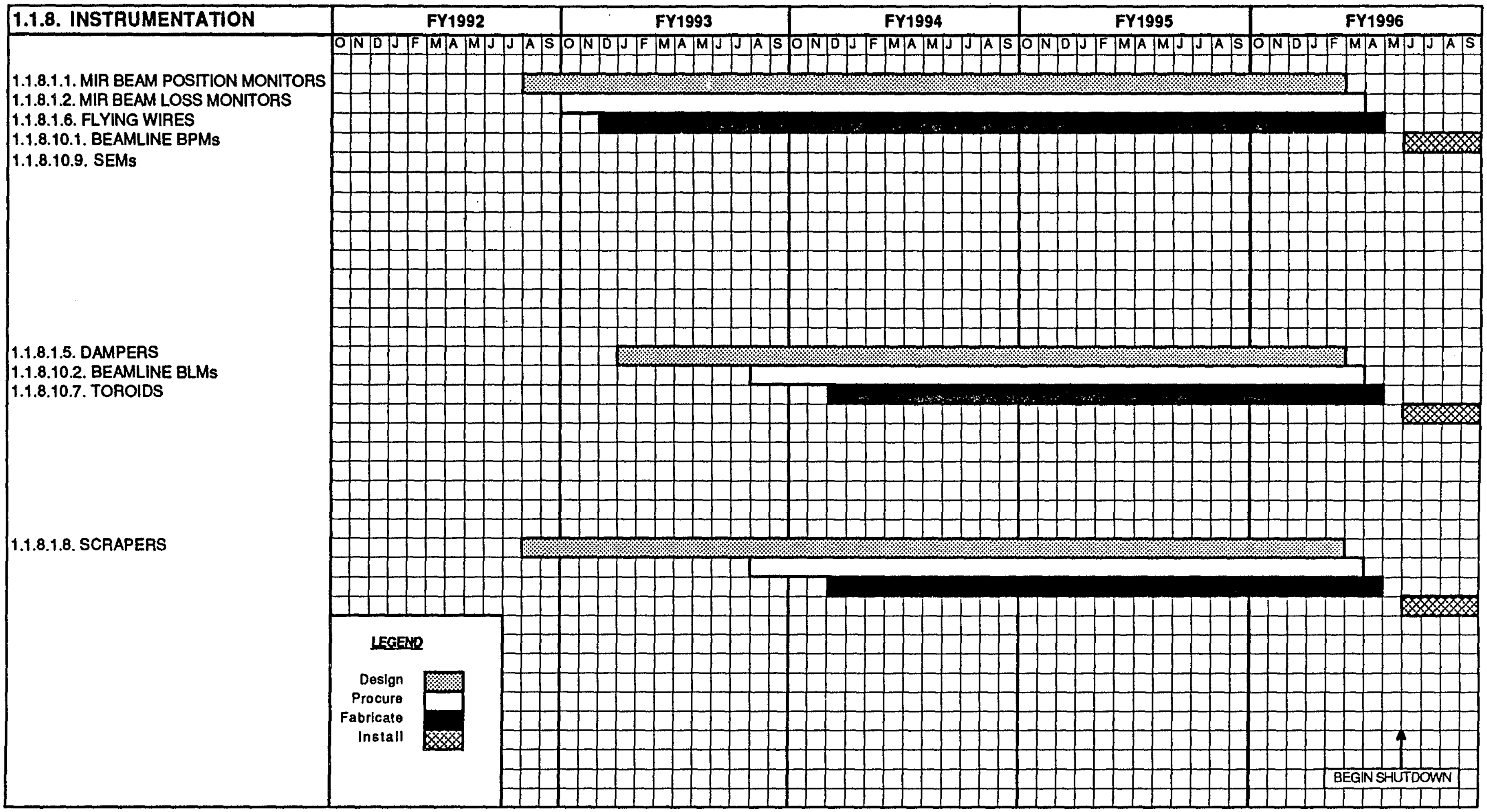


Figure 3.6-1. Instrumentation Schedule

CHAPTER 3.7 CONTROLS

WBS 1.1.9. CONTROLS

GENERAL SYSTEM INTRODUCTION

Structure

All of the Fermilab accelerators are operated through a uniform control system known as ACNET (Accelerator Controls Network); machines from the Linac to the Tevatron and Antiproton Source are connected through this system. The controls for the CDF detector and some of those for D-Zero are similarly included. A diagram of the computers and networks of this control system is presented in Figure 3.7-1. Since ACNET, as can be seen, is modular at the hardware level but generic at the user interface, it is a straightforward matter to attach a new major system such as FMI to it.

Front ends and alternatives

There are three major means in which accelerator hardware is connected to ACNET.

• Intelligent subsystems. These are the most modern interfaces. They consist of computer backplane bus crates with single board computers and direct connection to our backbone Token Ring network. At present, these systems are connected only to the Tevatron but not to the Main Ring. However by the time the FMI becomes operational, certain of its subsystems will be connected in this manner.

• CAMAC. The Tevatron control system was built utilizing this standard, and in the period since the Tevatron's construction most of the older equipment has been reconfigured utilizing it. The most recent of these conversions has been that of the bulk of the equipment in the Main Ring. Thus Main Ring equipment, and the software to control it, are quite up to date and useful as they stand for the FMI.

• Older equipment based on MAC computers. Before the construction of the Tevatron most connection to hardware was effected through Lockheed MAC-16 computers and Fermilab constructed MIUs (Module Interface Units). Main Ring (and Booster) RF is still controlled in this manner. Additionally the Main Ring guide field ramp is generated by two Digital Equipment Corporation PDP-11/55 computers which are made to look like MACs to the rest of the control system.

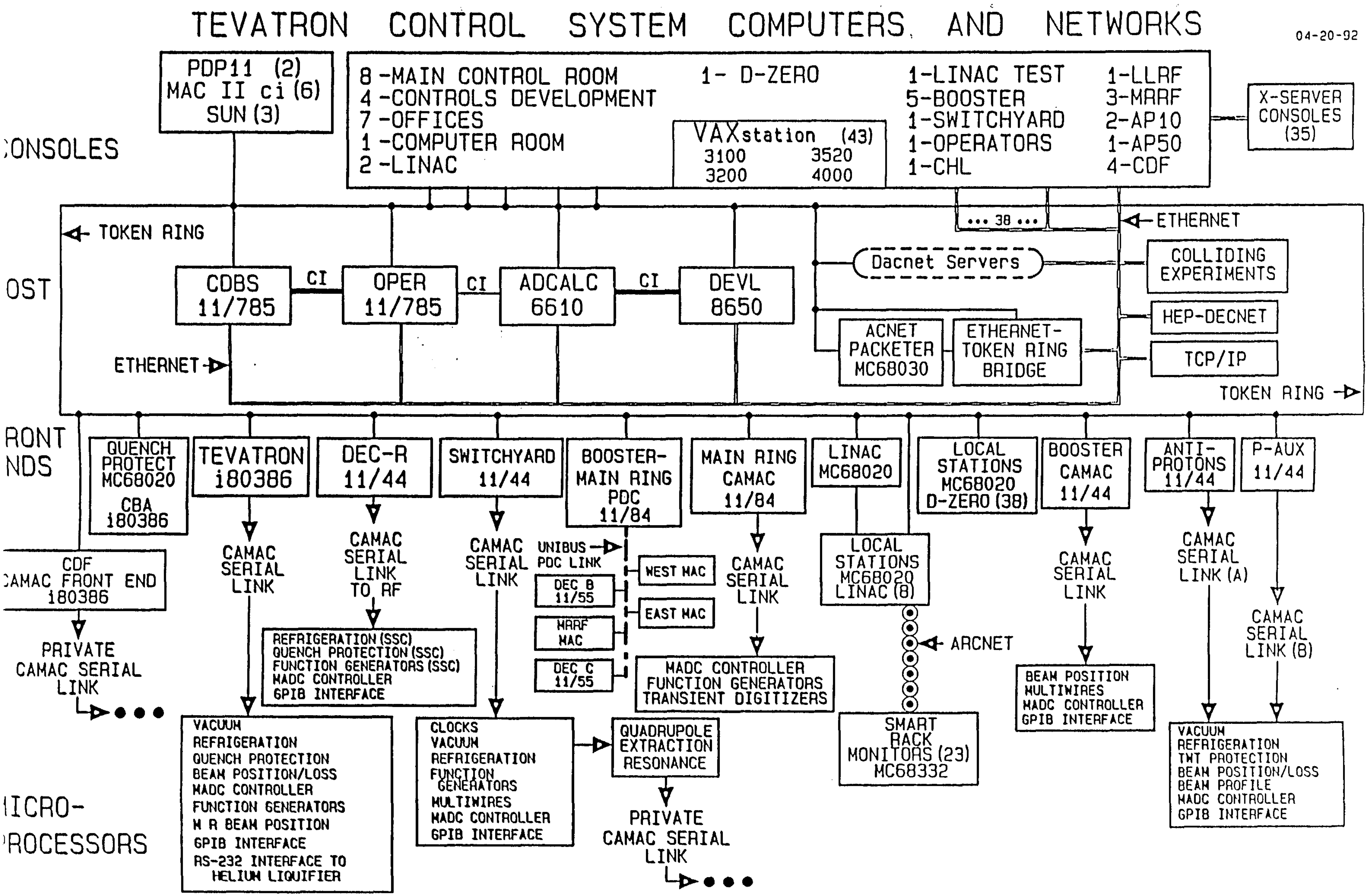


Figure 3.7-1. Schematic of Fermilab ACNET Computers and Control System

Host

The central Host system consists of a number of DEC-VAX computers. It is used for software development and archiving by programmers of the control system and for a variety of real time tasks. The most important single task is operation of database software. The ACNET database contains addressing and scaling information for all of the attached hardware. In addition the Host runs the software modules for central file sharing and alarm distribution. The control software will be made aware of the replacement of the Main Ring with the FMI by modifying this database appropriately.

Consoles

Most consoles are DEC VAXstations running the Motif windowing system, with X-terminals, Macintoshes, and a few Unix workstations also utilized. As all consoles are either connected or bridged to the backbone network, each is able to monitor and control the operation of any of the accelerators. Furthermore, as the network is site-wide they may be placed at locations remote from any control room. In particular they will be made available at FMI service buildings to aid in commissioning.

Current efforts related to Main Ring

There are currently three active projects involving upgrades to the controls for the Main Ring. These are being carried out as part of a continuous process of improving and modernizing the control system. This work will all be completed well before the commissioning of the FMI, but will help assure that controls are state of the art at the time of that commissioning.

MECAR

Work is in progress replacethe PDP-11/55 dipole ramp computers mentioned above. The replacement will be a VME-based microprocessor subsystem. Like other modern parts of the control system, this chassis will have a direct connection to the Token Ring backbone network. The advantages of this upgrade are the removal of old computers where maintenance and reliability are serious concerns and the creation of a software structure which is understood by a healthy cross-section of the Accelerator Division's software staff.

MRRF

Preliminary discussions are underway regarding an appropriate replacement for the MAC-MIU system which is used to operate Main Ring RF. At present it appears some of the needed work can be handled by passive modules such as digitizers, timers, and DACs. There is also the possibility of considerably improving the functionality of these controls by introduction of a flexibly programmable smart subsystem.

NFE-M

All of the PDP-11 front end computers are to be replaced in the next several months by NFEs (New Front Ends), which are parallel arrays of i80386 microprocessors housed in Multibus II and with direct Token Ring connection. At present the Tevatron front end (DEC-T) is in the process of being converted; upon completion of this work, a similar conversion of MR CAMAC will be a reasonably straightforward process. As in other conversion efforts, the result will be software which is adaptable for FMI commissioning work.

WBS 1.1.9.1 CONTROLS FOR MAIN INJECTOR RING

Hardware work in Main Injector

As a general rule, the recycling of Main Ring equipment into the FMI works well for controls. As was discussed above, all of this hardware is either reasonably up to date, or is in the process of being modernized. The equipment to be recycled includes CAMAC crates and power supplies, a large number of CAMAC modules, multiplexed ADCs, the MECAR ramp generation system, and whatever is developed in the coming months for RF control. Detailed below are those pieces of hardware for which simple recycling is not appropriate.

WBS 1.9.1.1.1 COMPUTERS AND LINKS

Links and repeaters

The controls signals in the Main Ring/Tevatron complex are carried on a combination of copper heliax and fiber optic cables. It is unrealistic that these be removed to a new location, and thus those currently serving Main Ring will be left in place to take care of future expansion of needs for Tevatron or the collider detectors. A bundle of 24 optic fibers will be installed, with half connected and the rest reserved for future expansion. The work involved is construction and installation of electro-optic repeaters, pulling of the bundle, and termination of the fibers.

Beam sync clock

For both the Main Ring and the Tevatron there is a clock whose signals are synchronized with the arrival of beam. This feature is required for triggering kickers and beam detecting instrumentation. A similar clock is to be designed for the FMI.

WBS 1.1.9.1.2 CRATES, CARDS , RELAY RACKS AND CABLING

Controls has taken the responsibility for all service building relay racks. As a given rack is often shared by the equipment of different groups, it is not realistic for separate entities to estimate their needs separately. Thus the number required is based on those present in the Main Ring with an extrapolation of the amount of similar equipment in FMI. Most controls equipment will be, as noted above, recycled from the Main Ring. However a small number of multiplexed

ADCs and CAMAC cards, nominally part of the Main Ring system, have some channels connected to Tevatron equipment, and thus must remain. A typical FMI service building has space for 21 racks allocated, providing adequate space for all anticipated control modules with additional space for expansion. The layout of the controls racks is shown in Figure 3.7-2. Assignment of racks for other systems is in progress.

WBS 1.1.9.1.3 CATV SYSTEM

It is traditional at Fermilab to include television systems under accelerator controls. Several channels of CATV will be run around the ring and connected to the various control rooms. Some channels will convey beam diagnostic signals such as scope traces and fluorescent screens, and others will provide live observation of remote locations for security purposes.

WBS 1.1.9.1.4 FIRUS SYSTEM

The Fermilab Fire, Utility and Security alarm system (FIRUS) also falls under the province of controls. All new buildings and the new tunnel will have connection to the labwide system for fire alarms and, where appropriate, for security alarms as well. There will also be one or more FIRUS display consoles installed in the new buildings.

WBS 1.1.9.10 BEAMLINE CONTROLS

All of the topics which pertain to the hardware in the FMI ring pertain as well to the associated beamlines. However there is one major difference between the two, dealing with the fraction of CAMAC hardware which can be recycled. In the case of the ring, there is enough equipment of the proper types being decommissioned in Main Ring to cover virtually all the needs. However the new beamlines are longer and more complex than the current ones which they are replacing, and there is not sufficient controls equipment to service them. In particular a significant number of power supply and beam position monitor controllers will need to be constructed.

WBS 1.1.13.1.5 RING INSTALLATION

WBS 1.1.13.10.5 BEAMLINE INSTALLATION

The major installation task for the control system is the physical act of putting in place the various pieces of CAMAC equipment. As noted above, in the ring most of this equipment will be recycled, while in the beamlines a larger fraction will represent new construction. In both cases a relay rack must first be installed and powered; then CAMAC crates and MADC units put in place followed by CAMAC module insertion and cabling of the various system elements. In the case of the recycled components the above steps (with exception of the relay rack work) must first be un-

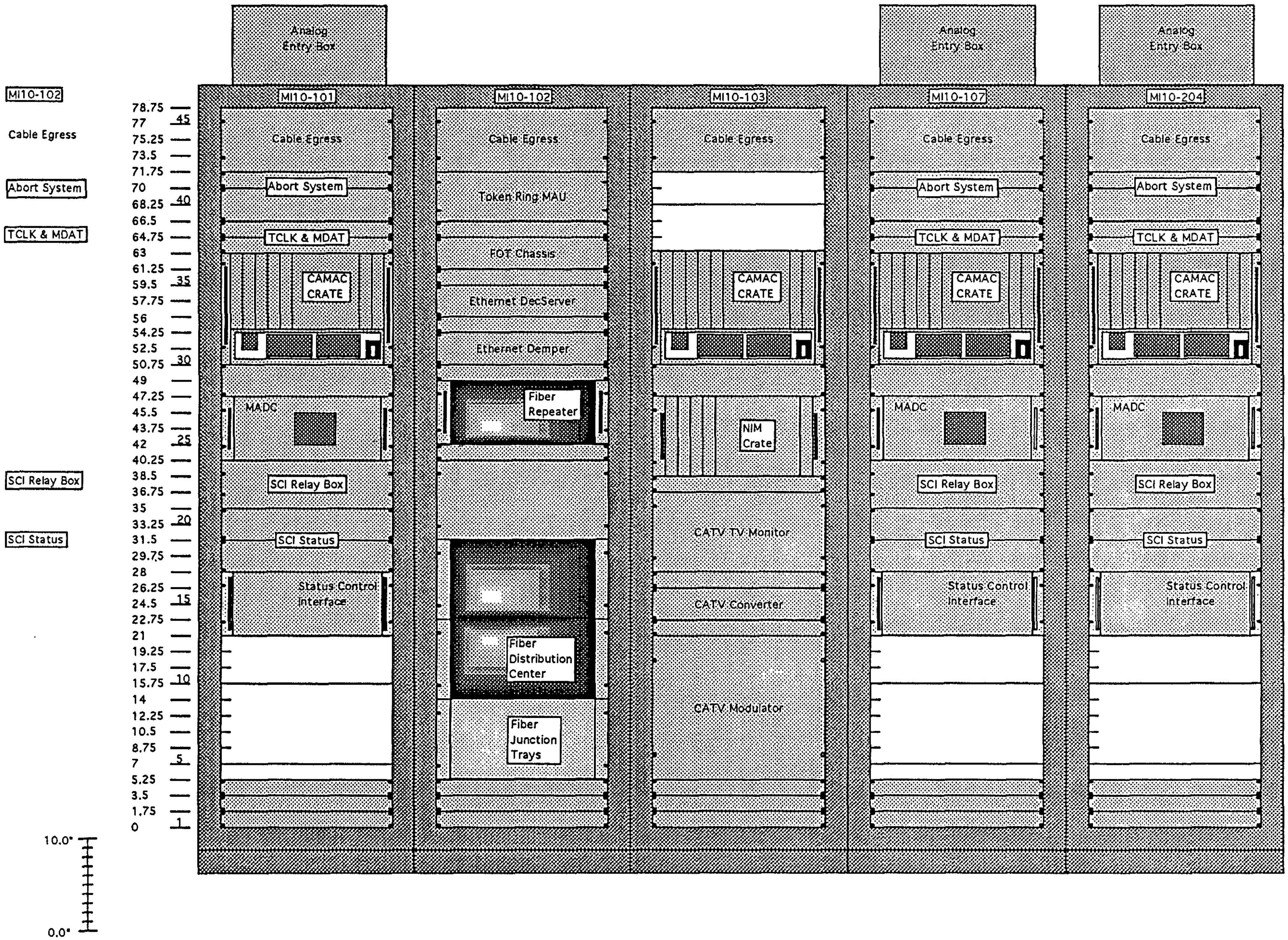


Figure 3.7-2. Layout of Controls Racks in a Typical Service Building

K. C. Seino, 7/16/92

done in the old location. The other major installation efforts concern the optic cable and the reconfiguration of RF controls after completion of construction.

WBS 4.1.8. SOFTWARE

The question of the amount of software effort required for this project has been the subject of serious discussion in the past. Since the controls hardware is precisely that of the Main Ring (or in the case of the beamlines copies of existing modules) new software support is by and large not required. A change in the database indicating the location of the module and the name of the hardware signal to which it is attached is generally sufficient. Described below are those areas where changes or additions are known to be required.

Far front ends

Those microprocessor crates which are attached directly to the backbone network, without benefit of an intervening front end computer, are sometimes referred to as far front ends. Those under construction for the Main Ring include the ramp generator and any intelligent RF controller which might emerge. Additionally a new universal BPM system is being proposed which will encompass the Main Ring and will utilize the far front end principle. Some changes of a significant nature will be required in the ramp generator, due to the higher ramp rate and different power supply configuration. However that software is being developed with such future changes in mind. Similarly some changes related to voltage levels and ramp rate are envisioned in a smart RF controller.

Front ends

The major functions of a CAMAC front end, such as that serving the Main Ring or FMI, are database driven. Since there has been no hardware proposed which does not already have support, a database change is in principle sufficient. In practice there are a number of tables required in a front end detailing the configuration of CAMAC crates, MADCs, and certain modules which are addressed in a "wild card" or ringwide manner. Parameters arise in all accelerators which in practice can only be supported by a small piece of unique code in the front end. It is anticipated that this will happen for FMI as well.

Database

As has been frequently noted above, a database entry detailing the changes (in location, function, scale factors) pertaining to any particular piece of controls hardware is all that is required to have the system adapt. A systematic naming convention for FMI devices will have to be developed by the operations crew, and careful records kept by personnel who move the hardware. When these things are done the modification effort will be minimal.

An active project at this time is a change from our current in-house developed database to a commercial one. One of the features that such a system will be required to have is the ability to prepare reports on entries satisfying a variety of conditions. Such a feature should be particularly valuable when large numbers of changes, such as those envisioned here, are being made.

Console applications

There are 84 application entries on the Main Ring index of ACNET software. Some of these programs will require significant changes, particularly those dealing with machine physics (WBS 1.3.2). Those which display all data from a particular subsystem in a ringwide fashion, or in general deal with global information, will require changes to the user interface and data acquisition to deal with the smaller ring. Many of the Main Ring programs are copies of the generic Parameter Page which is widely used for reading and setting any quantities in the database. Since certain combinations of parameters often need to be studied or set together, permanent subpages containing the lists are established and entered on the index as separate programs. Many of these pages will require reconfiguration; however no new software needs to be written for this to happen.

Schedule

Figure 3.7-3 shows the schedule for the controls systems for the ring and beamlines.

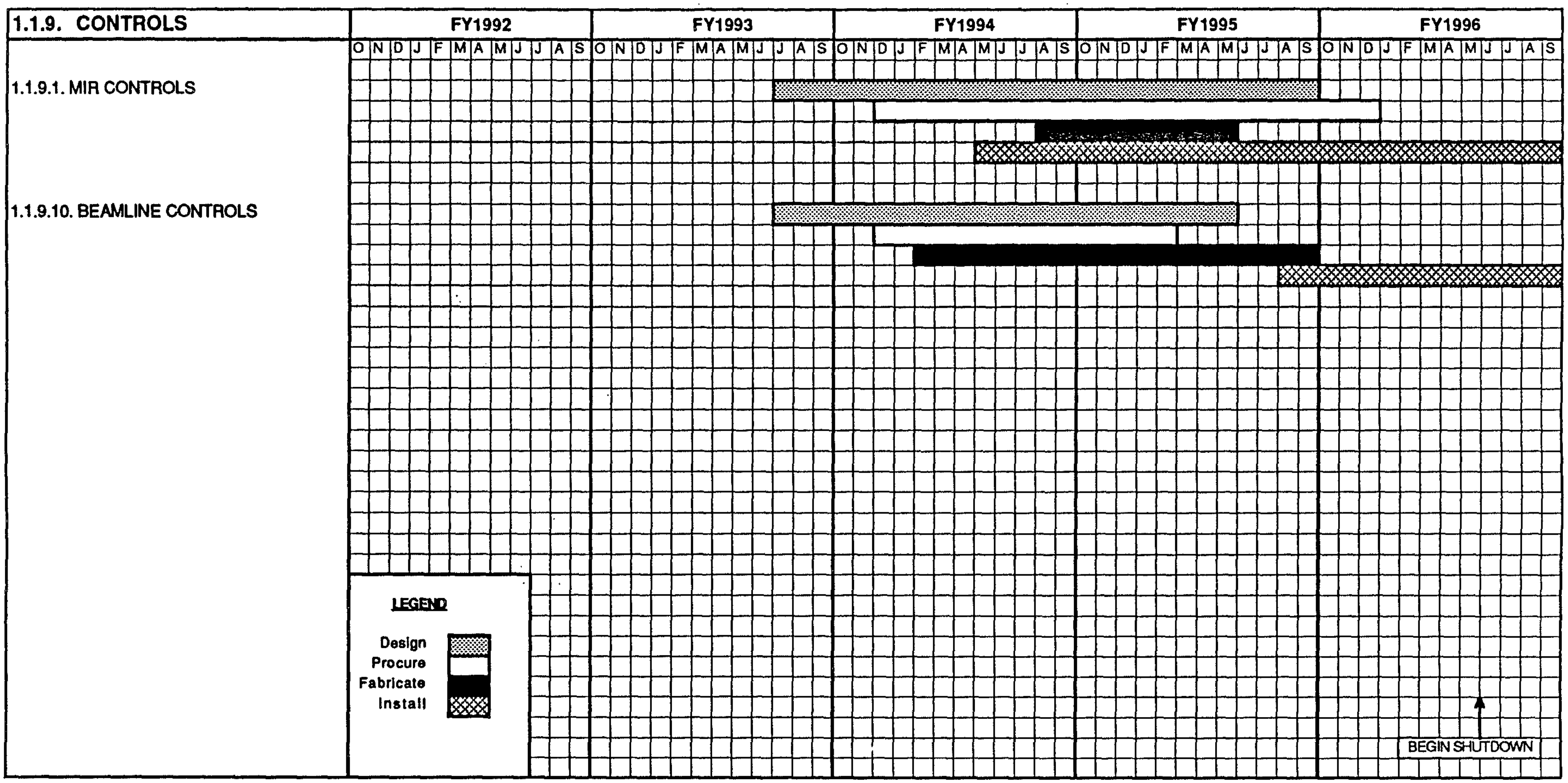


Figure 3.7-3. Control System Schedule

CHAPTER 3.8 SAFETY SYSTEM
WBS 1.1.10. SAFETY SYSTEM

A number of safety interlock systems have been developed to protect personnel, and in some situations equipment, from potential hazards which may be present when the various accelerators at Fermilab are operated. There are two principal safety systems the Main Injector are concerned with:

1. radiation safety, and
2. electrical safety.

Radiation-interlock systems have been in use at the existing Fermilab accelerator complex and external experimental areas from the beginning of Fermilab 200-GeV operations more than fifteen years ago. These systems have proven to be exceptionally reliable and little training on the use of the new systems for the Main Injector will be needed.

Inherent in each of these systems is the idea of "fail-safe" circuits. All circuits are designed in such a way that if a circuit fails, the failure would result in a safe condition. Another key characteristic used in designing all safety systems is the concept of "redundancy". All hardware has been designed in such a way that no single failure will result in the loss of protection. To accomplish this, two separate circuits are used to detect specific conditions.

Similarly, the electrical-safety interlock systems which have been in use in the accelerator complex for many years will need relatively straightforward additions to accommodate FMI operations. The electrical safety systems will also utilize fail-safe and redundant techniques.

Perhaps the most important part of the radiation and electrical safety systems is the searching and securing of an area to insure that it is not occupied. Before beam or power supplies are enabled for an area, a search is performed by authorized operators. The securing of an area requires that a minimum of two qualified persons thoroughly search an area in a predefined sequence.

The Main Injector will need one new radiation safety system and three new electrical safety systems to support the different modes of operation. The existing Tevatron radiation safety system will need minor modifications due to the new operational modes available.

The Main Injector enclosure will be divided into four sections, the rf section, the 150 GeV antiproton (A1) line, the 150 GeV proton (P1) line, and the remaining Main Injector enclosure;

refer to Figure 3.8-1. The rf section will contain only the central section of the MI-60 straight section in which the rf cavities are situated. The A1 injection/extraction line will extend from MI-62 to the existing Tevatron enclosure, but will incorporate the portion of the MI enclosure between MI-62 and the rf section of MI-60. The P1 injection / extraction line will extend from MI-52 to the existing Tevatron enclosure, including the section between MI-52 and MI-60. The remaining Main Injector enclosure extends from MI-52 around the west side of the ring to MI-62. This subdivision of the enclosure is being done to allow personnel to access the rf section and the majority of the Main Injector enclosure while colliding beams studies are in progress. Additional radiation shielding studies will need to be completed to insure these boundaries will provide adequate shielding from beam accident conditions.

The Main Injector radiation safety system will be used to control proton injection, extraction, and pbar injection, extraction in the Main Injector; refer to Figure 3.8-2. The radiation safety system will be comprised of the 8 GeV beam line, the Main Injector enclosure (rf section, the 150 GeV antiproton (A1) line, the 150 GeV proton (P1) line, and the remaining MI enclosure), the PBar Transport enclosure, the Tevatron enclosure sectors E3-E4, F0 sector, transfer hall, A1-A2, and Enclosure B of switchyard. The critical devices for Booster extraction into the 8 GeV beam line will be 1EPB and P8B2. The critical devices to control the extraction of protons or p-bars from the P-Bar source are IB1, EB5-6, BSC700, and BSC925. The Tevatron devices to prevent protons or p-bars from reentering the Main Injector are the E48 and F17 kickers and the F0 lambertson.

The two electrical safety system needed for the Main Injector will be the Main Injector ESS and the 8 Gev ESS; refer to Figure 3.8-3. The existing Tevatron electrical safety system will be split into two sections to allow for fixed target slow and fast spill operations while the CDF and D0 Collision Halls are in an access mode; refer to Figure 3.8-4.

The electrical safety system for each area controls all the power supplies in that area as well as various extraction supplies via a power supply interlock module in each of the service buildings. The units have come to be called "to-from" interlock units due to the repeating nature in which they work. The electrical safety system sends out a signal to the first service building which actuates the "to-from" unit. From there, the unit sends out a duplicate signal to the next building. Each of these "to-from" units is capable of interlocking 11 supplies. A schedule for the safety system is shown in Figure 3.8-5.

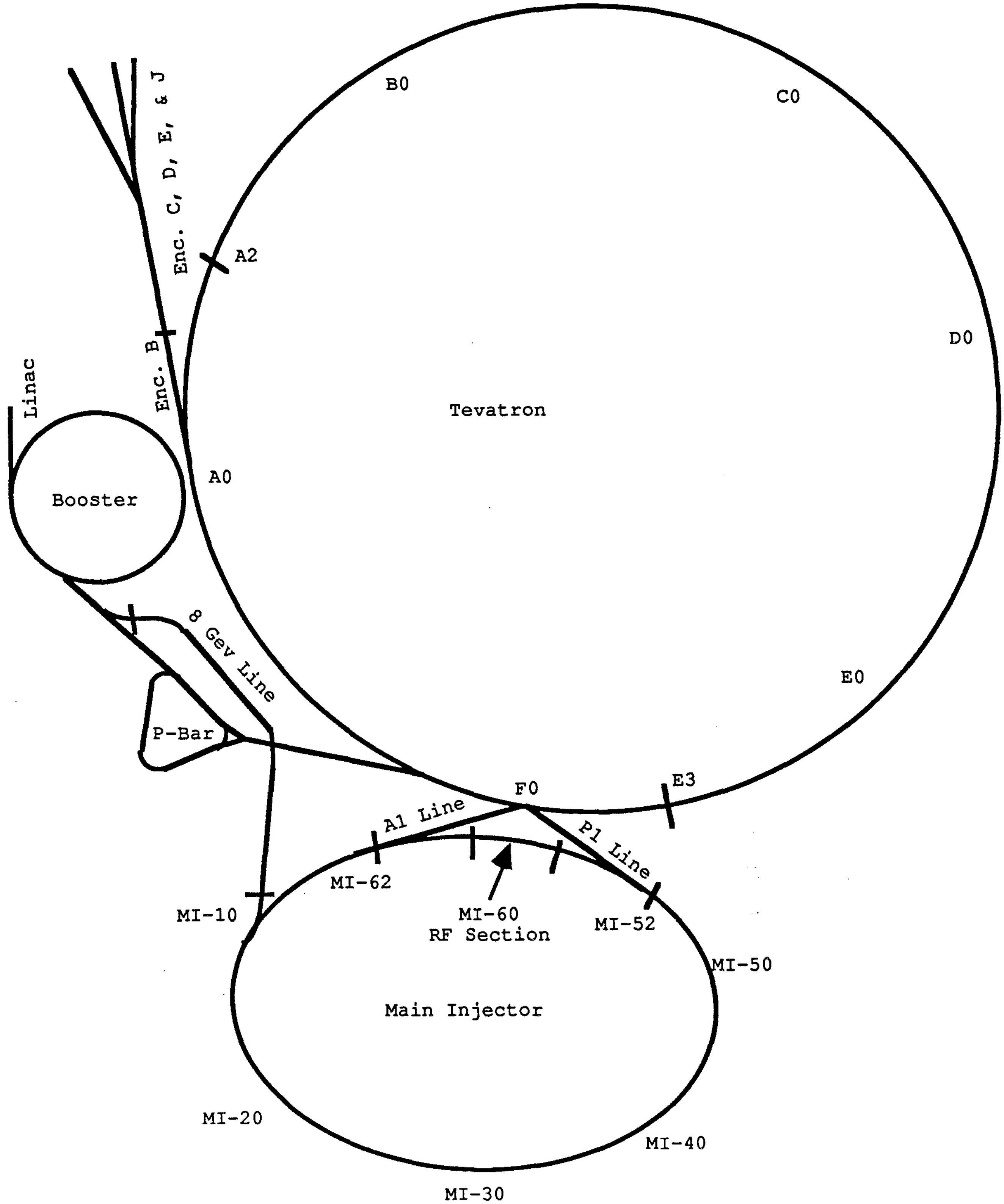
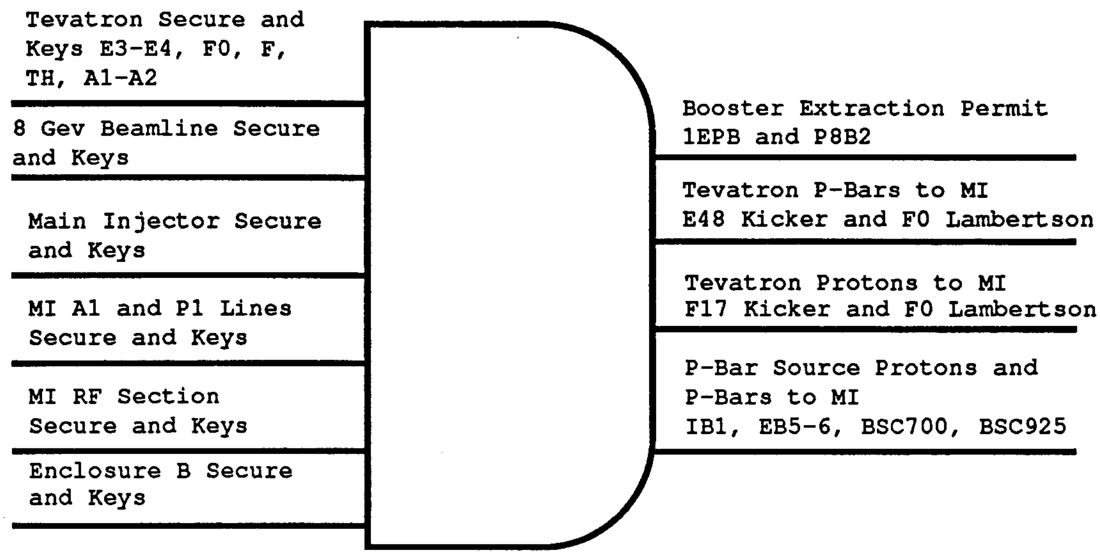


Figure 3.8-1. Radiation Safety System Sections for the Main Injector

Main Injector RSS



Tevatron RSS

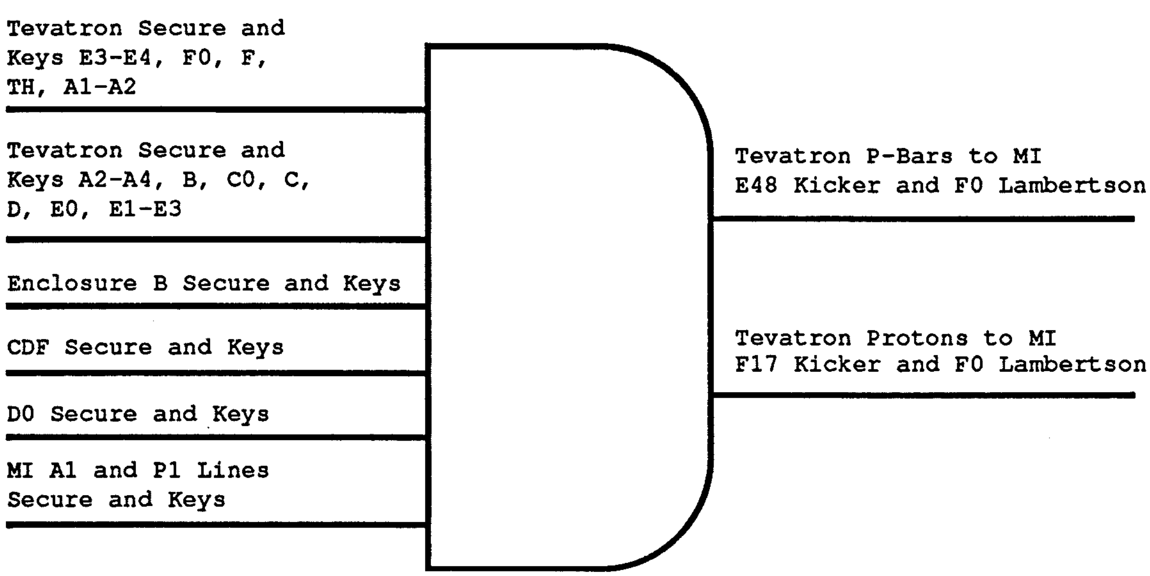
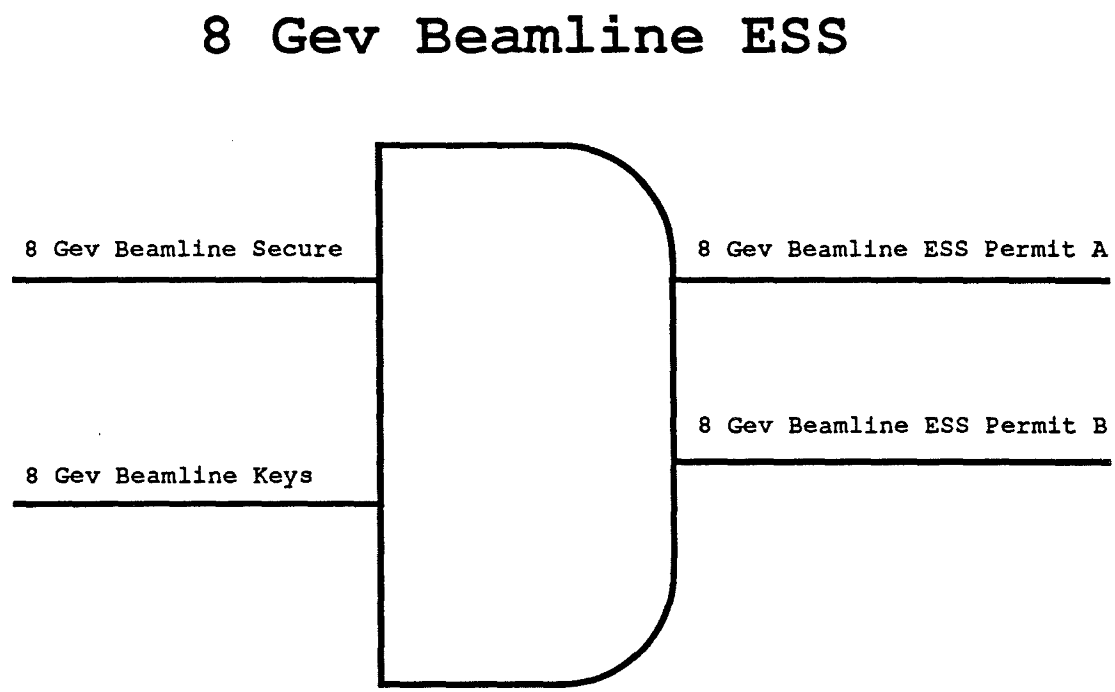


Figure 3.8-2. Logic Diagram for Main Injector
and Tevatron Radiation Safety Systems



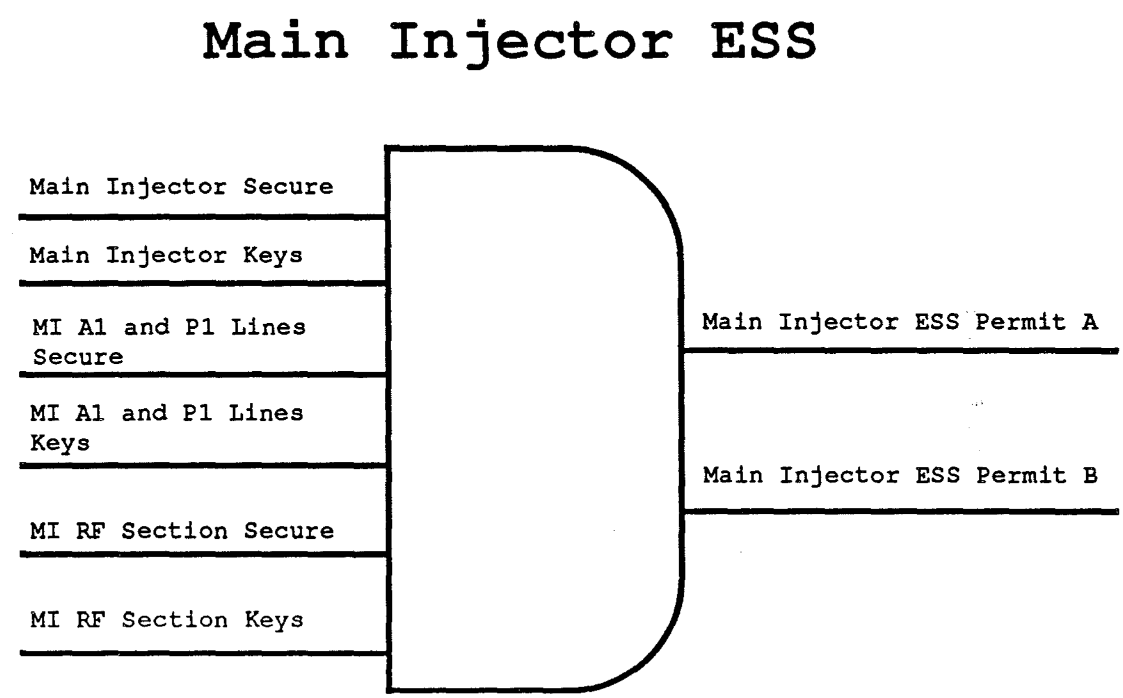


Figure 3.8-3. Logic Diagram for 8 GeV Line and Main Injector Electrical Safety Systems

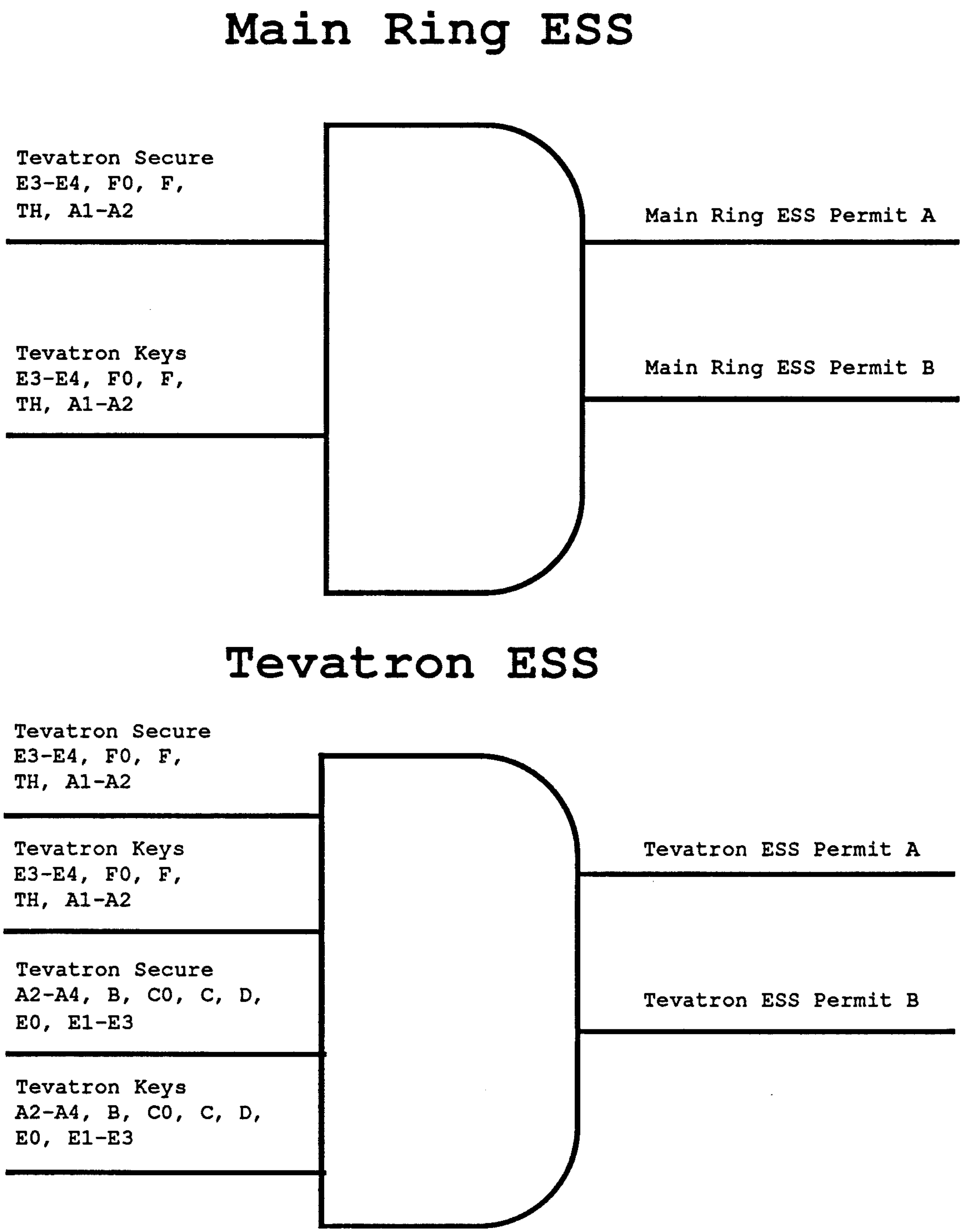


Figure 3.8-4. Logic Diagram for Main Ring and Tevatron Electrical Safety Systems

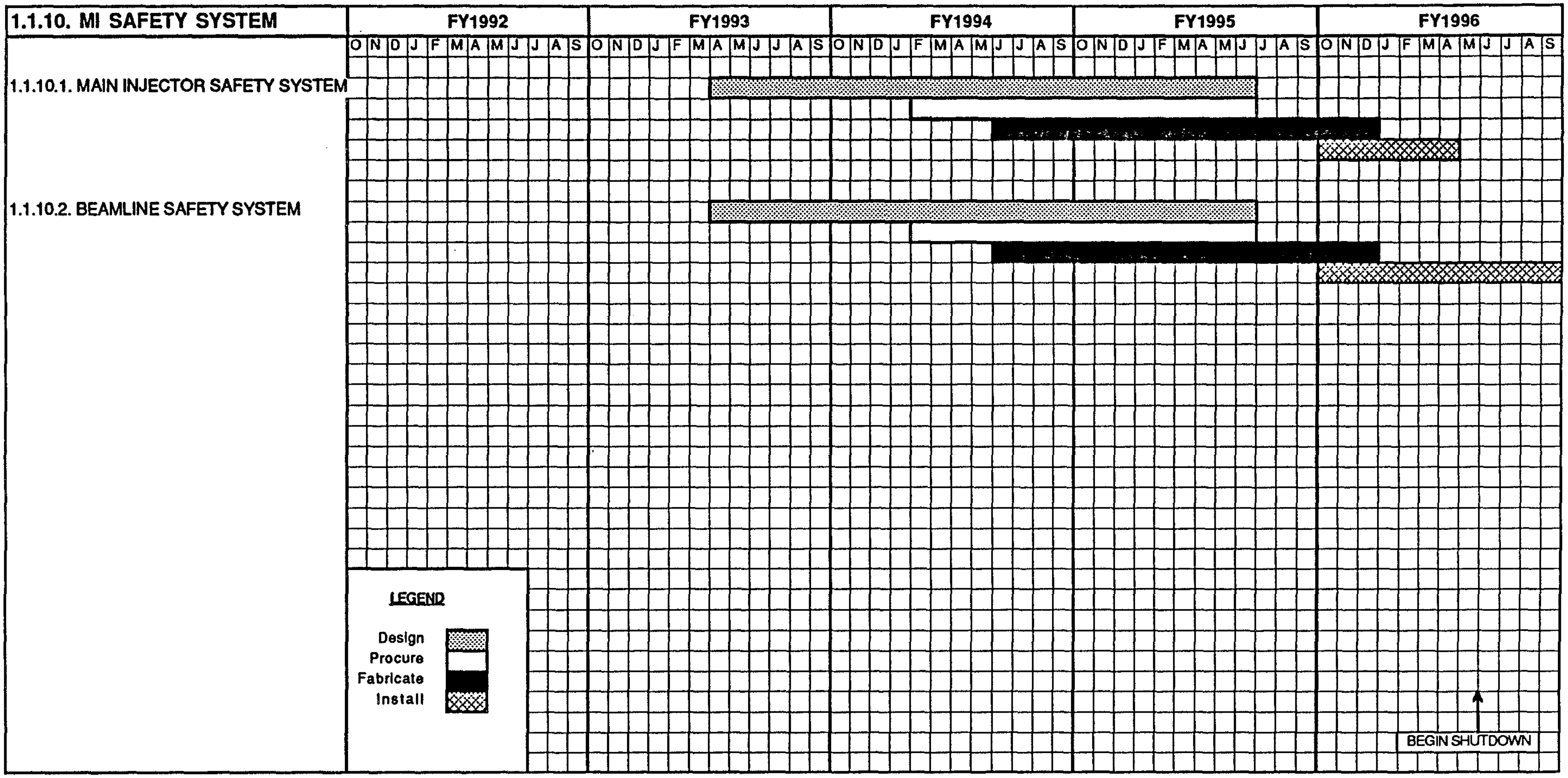


Figure 3.8-5. Safety System Schedule

CHAPTER 3.9 UTILITIES AND ABORT

WBS 1.1.12. UTILITIES AND ABORT

WBS 1.1.12.1.1. MAIN INJECTOR RING WATER SYSTEM and

WBS 1.1.12.1.10. BEAMLINE WATER SYSTEM

FMI Low Conductivity Water System and Magnet Bus Connections

The proposed system for connecting the power and water to the FMI is similar to the Main Ring. This system requires minimum maintenance. Stainless steel headers supply low conductivity water (LCW) to copper bus which conduct both power and cooling water to the magnets. Ceramic feedthroughs, with flexible metal braid hoses, electrically insulate the piping from the copper bus system.

The FMI components and associated utilities are grouped together at the outside wall of the tunnel leaving most of the enclosure space for servicing, as shown in Figure 3.9-1. All connections to the magnets are designed so they are accessible from the inner space of the enclosure. The new dipole magnets have bolted electrical connections with flexible copper jumpers. Separate compression fittings are used for the water connections. Figure 3.9-2. shows a schematic representation of the cooling for the dipole magnets. Each pair of dipole magnets has four water circuits in parallel designed to minimized thermal stresses and the number of electrical insulators. At the LCW manifolds connection to the bus, two ceramic insulators connected in series are used. This design has shown to minimize the copper ion deposits inside the insulators. The quadrupoles connections are the same as the Main Ring where the brazed copper joint carries the water and the power to the magnet. There will be six utility buildings uniformly spaced along the perimeter of the FMI. These are labeled MI-10, -20, -30, -40, -50, and -60. Each utility building will supply power and cooling water to about 1,815 feet of circumference in the FMI.

A total of 30 water pumps will be installed around the ring with 5 pumps in each service building. Each pump has a 50 hp motor, and delivers 300 gpm of LCW with a pressure head of 162 psi (375 TDH). Figures 3.9-3. to 3.9-8. show the required LCW from each service building. All the components are connected in parallel; and with the proper hydraulic impedance for each magnet, the local water distribution will be balanced in between service buildings. The centrifugal pumps, also connected in parallel with the magnets, will share the flow and will balance the pressure head to match the impedance across the LCW manifolds. This LCW system has shown to work well in the Main Ring. The 150 GeV antiproton line has a low rms power cooling requirement. A branch from the enclosure served by the MI-60 building will be used. The abort line will be cooled from the area served by the MI-40 building. The heat from the magnets and

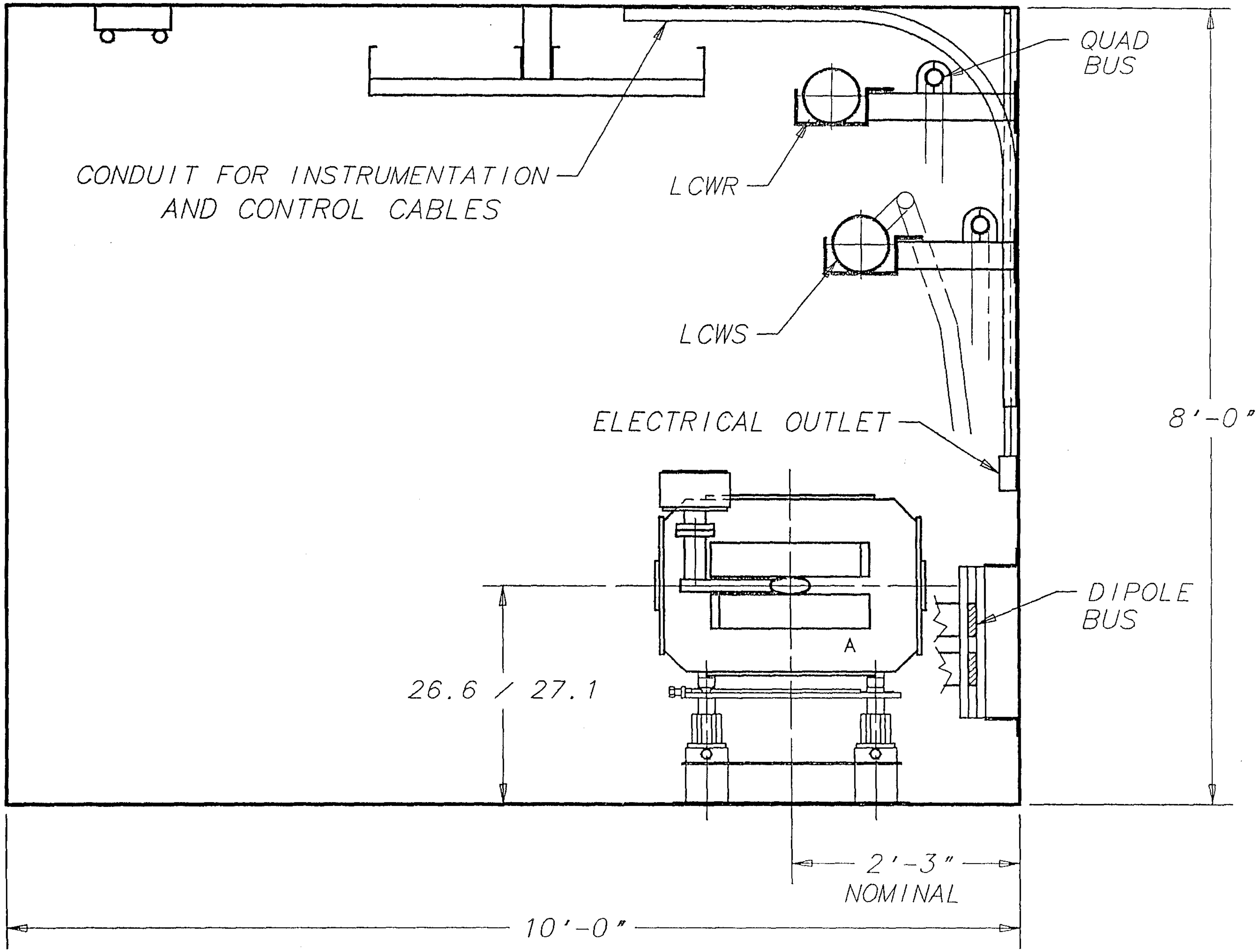


Figure 3.9-1. Cross Section of Main Injector Tunnel

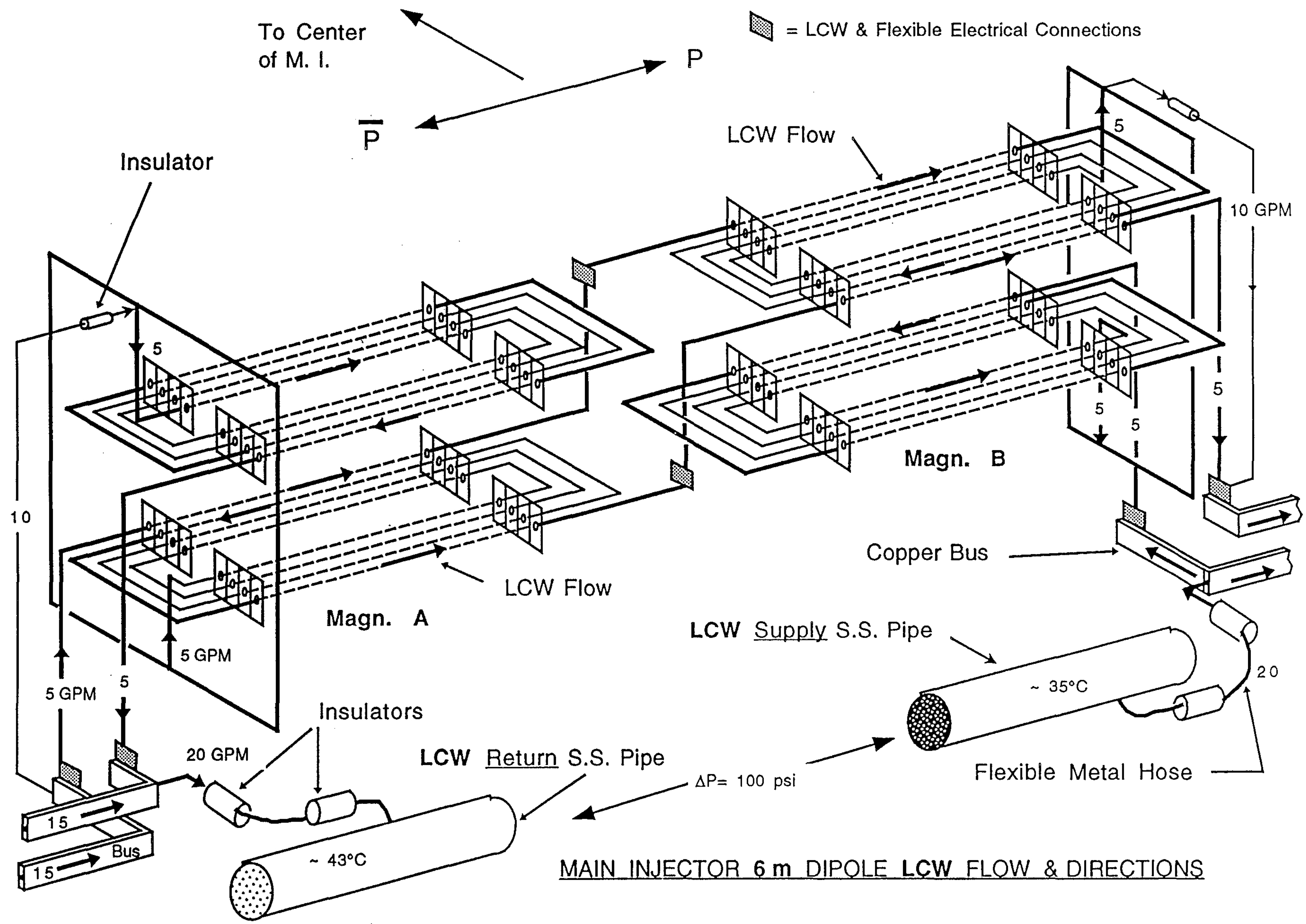
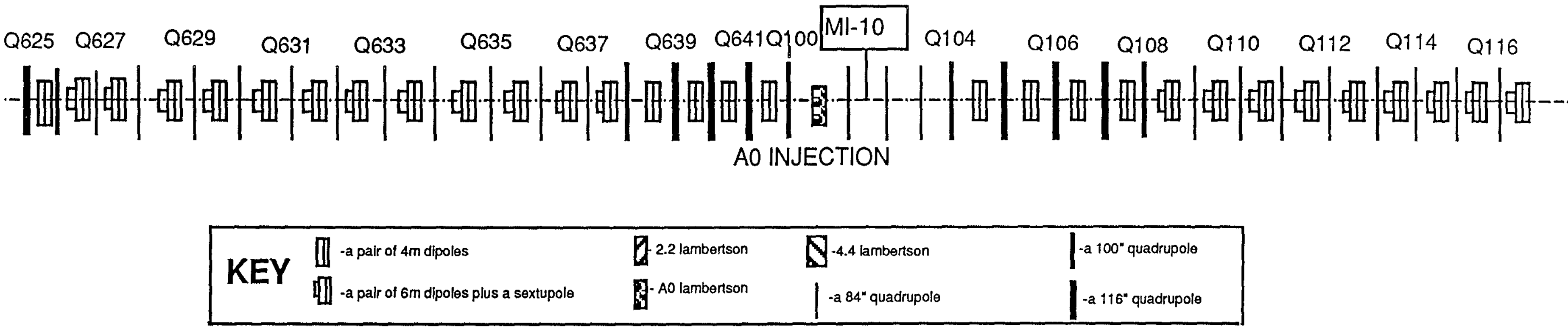
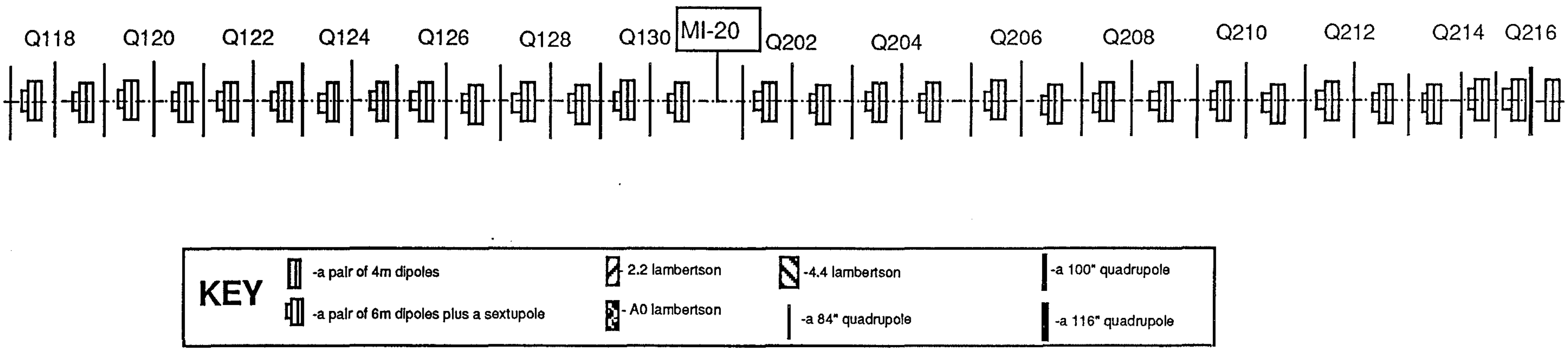


Figure 3.9-2. Schematic of LCW Circuits for a Pair of Dipole Magnets



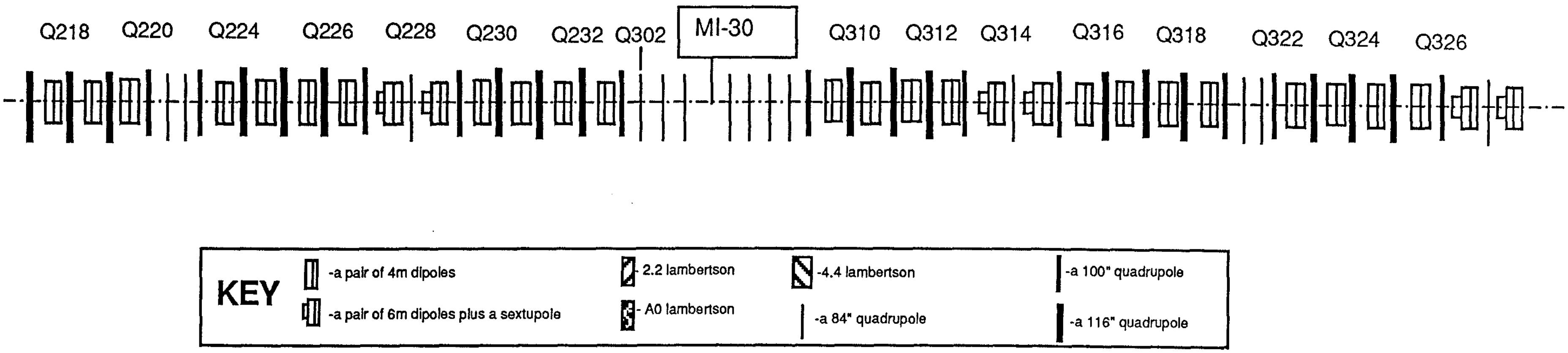
Quanitity	Magnet type	Each magnet Power [kW]	requires Flow [Gal./min.]	Water temp. rise [C]	Total flow [Gal./min.]	
18	4m dipoles	16	8	~8	144	
42	6m dipoles	21.6	10	~8	420	
22	84" quads	18	10	~7	220	
5	100" quads	21.4	12	~7	60	
7	116" quads	24.9	12	~8	84	
21	Sextupoles		1	~6	21	
1	A0 Injection		25		25	
1	Service Bld.					
	Power supply		(70+70+35+14+4)		193	
5	Water pumps		18		90	
1	LCW Polishing		40		40	
				Sum	1297	
				Avaliable flow	1500	
				Extra GPM	203	13.53%

Figure 3.9-3. LCW Requirements for Service Building MI-10



Quanitity	Magnet type	Each magnet Power [kW]	requires Flow [Gal./min.]	Water temp. rise [C]	Total flow [Gal./min.]	
2	4m dipoles	16	8	~8	16	
58	6m dipoles	21.6	10	~8	580	
29	84" quads	18	10	~7	290	
1	100" quads	21.4	12	~7	12	
29	Sextupoles		1	~6	29	
1	Service Bld.					
	Power supply		(70+70+35+14)		189	
5	Water pumps		18		90	
1	LCW Polishing		40		40	
				Sum	1246	
				Avaliable flow	1500	
				Extra GPM	254	16.93%

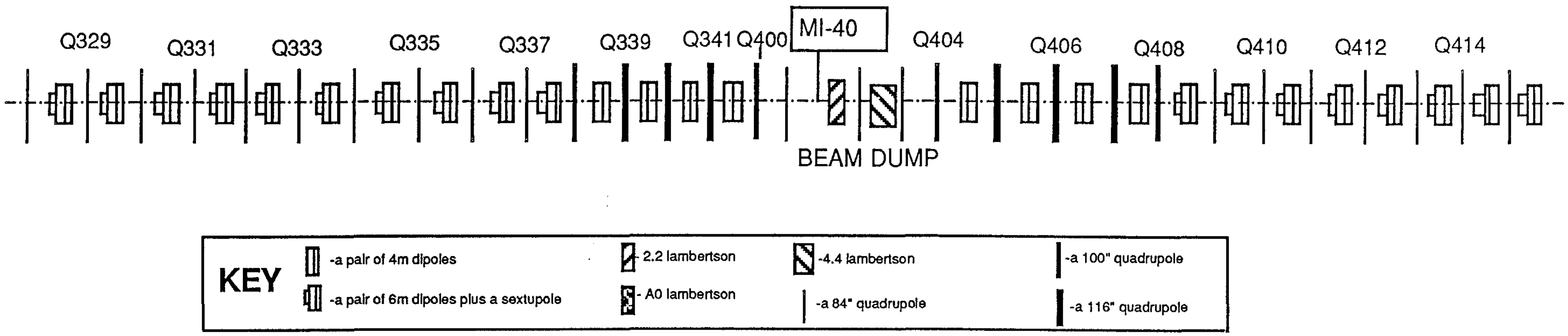
Figure 3.9-4. LCW Requirements for Service Building MI-20



Quanitity	Magnet type	Each magnet Power [kW]	requires Flow [Gal./min.]	Water temp. rise [C]	Total flow [Gal./min.]
46	4m dipoles	16	8	~8	368
12	6m dipoles	21.6	10	~8	120
14	84" quads	18	10	~7	140
11	100" quads	21.4	12	~7	132
18	116" quads	24.9	12	~8	216
6	Sextupoles		1	~6	6
1	Service Bld.				
	Power supply		(70+70+35+14)		189
5	Water pumps		18		90
1	LCW Polishing		40		40
				Sum	1301
				Avaliable flow	1500
				Extra GPM	109

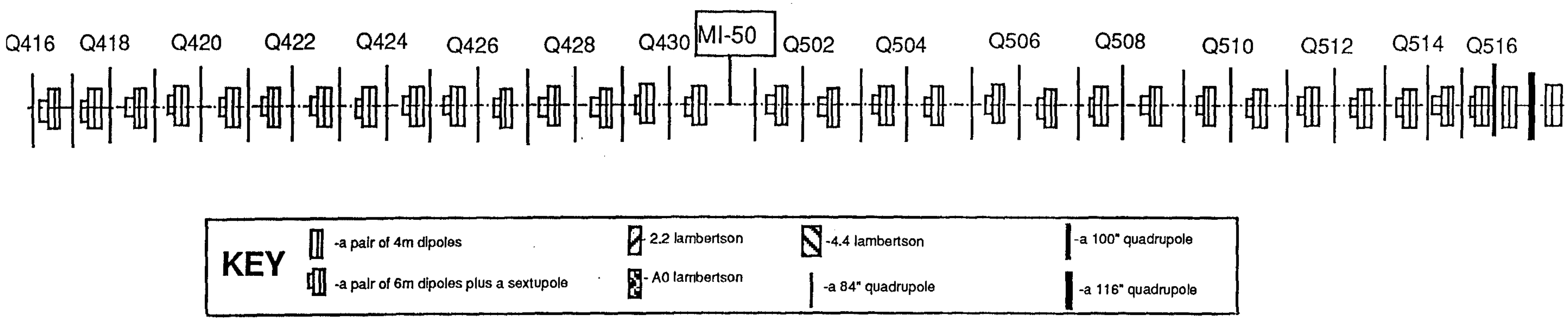
13.27%

Figure 3.9-5. LCW Requirements for Service Building MI-30



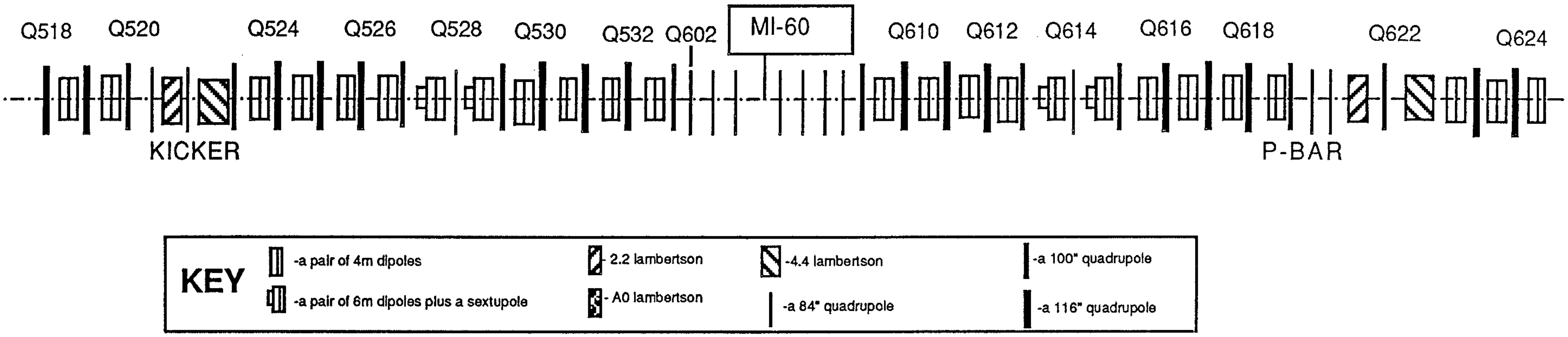
Quanitity	Magnet type	Each magnet requires Power [kW]	Flow [Gal./min.]	Water temp. rise [C]	Total flow [Gal./min.]	
16	4m dipoles	16	8	~8	128	
36	6m dipoles	21.6	10	~8	360	
20	84" quads	18	10	~7	200	
4	100" quads	21.4	12	~7	48	
6	116" quads	24.9	12	~8	72	
18	Sextupoles		1	~6	18	
1	2.2 Lambertson	32	15		15	
1	4.8 Lambertson	52	25		25	
1	Beam dump		150		150	
1	Service Bld.					
	Power supply	(70+	70+35+14+4+5)		198	
5	Water pumps		18		90	
1	LCW Polishing		40		40	
				Sum	1344	
				Avaliable flow	1500	
				Extra GPM	156	10.40%

Figure 3.9-6. LCW Requirements for Service Building MI-40



Quanitity	Magnet type	Each magnet Power [kW]	requires Flow [Gal./min.]	Water temp. rise [C]	Total flow [Gal./min.]	
4	4m dipoles	16	8	~8	32	
60	6m dipoles	21.6	10	~8	600	
30	84" quads	18	10	~7	300	
1	100" quads	21.4	12	~7	12	
1	116" quads	24.9	12	~8	12	
30	Sextupoles		1	~6	30	
1	Service Bld.					
	Power supply		(70+70+35+14)		189	
5	Water pumps		18		90	
1	LCW Polishing		40		40	
				Sum	1305	
				Avaliable flow	1500	
				Extra GPM	195	16.25%

Figure 3.9-7. LCW Requirements for Service Building MI-50



Quanitity	Magnet type	Each magnet Power [kW]	requires Flow [Gal./min.]	Water temp. rise [C]	Total flow [Gal./min.]
42	4m dipoles	16	8	~8	336
8	6m dipoles	21.6	10	~8	80
13	84" quads	18	10	~7	130
10	100" quads	21.4	12	~7	120
16	116" quads	24.9	12	~8	192
4	Sextupoles		1	~6	4
1	2.2 Lambertson	32	15		15
1	4.8 Lambertson	52	25		25
1	MI-52 Kicker	84	5		5
1	Service Bld.				
	Power supply		(70+70+35+14)		189
5	Water pumps		18		90
1	LCW Polishing		40		40
1	150 Gev P-bar	70	60		60
				Sum	1286
				Avaliable flow	1500
				Extra GPM	214	14.27%

Figure 3.9-8. LCW Requirements for Service Building MI-60

other electrical components is transferred to the LCW and dissipated in the tube and shell heat exchangers. Pond water is circulated in the tube side of the heat exchanger to remove the heat by evaporation.

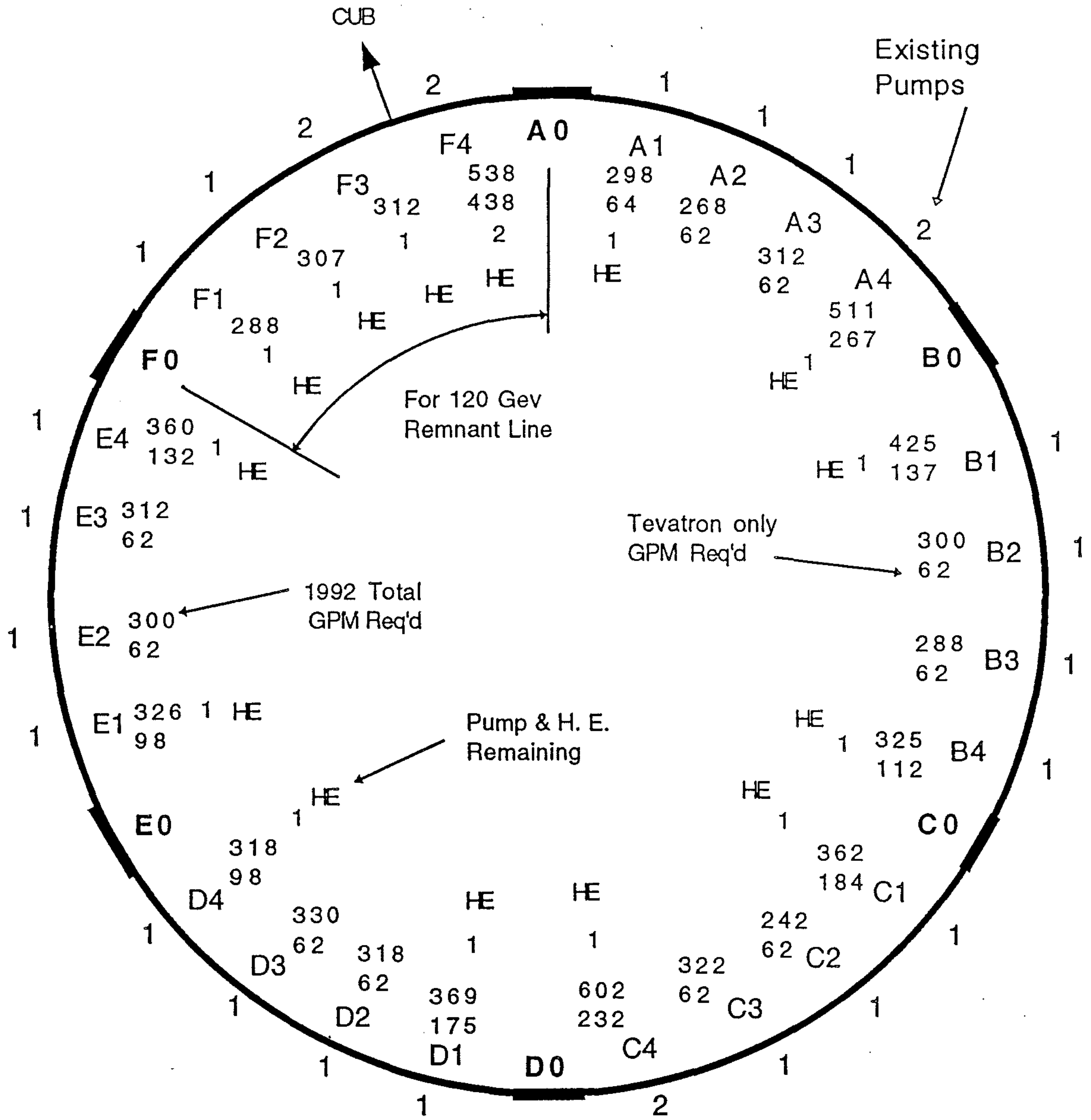
Figure 3.9-9. shows the required LCW at each service building in the Main Ring at present and after the installation of the Main Injector. From the existing LCW system in the Main Ring, 13 pumps with starters and controllers, and 10 heat exchangers will be reused for the FMI. Four existing spare pumps will also be used. The remaining water cooling equipment in the Main Ring will be required for the Tevatron, and the Main Ring Remnant Line. New extra strong copper bus (with 4 square inches in cross section for the dipoles, and 2 square inches in cross section for the quadrupoles) will be used for the FMI. The old copper bus from the Main Ring (1.625" o.d. by 0.187" wall) with the porcelain clamps will be reused for some of the beamlines.

Four and six inch stainless steel pipe headers will be installed over the magnets along the 10,891-ft circumference of the FMI. Eight inch headers will be used to connect the pumps from the service buildings to the manifolds in the enclosure. Two heat exchangers per service building are required to provide cooling for the LCW flow at 8°C temperature gradient. With the existing heat exchangers, the maximum cooling capacity is limited by the allowable LCW velocity in the shell side . The heat load removing capacity per building will be about 3.2 MW using 2 of the old Main Ring heat exchangers connected in parallel. Approximate 8,000 gpm of LCW will be required to cool magnets, bus, and power supplies in the Main Injector enclosure and service buildings. The 30 centrifugal pumps are capable of delivering approximately 9,000 gpm at the designed head.

At each utility entrance, as well as at locations half-way in-between, the enclosure will have a ceiling one foot higher than the regular tunnel. The purpose of this extra space is to make room for expansion joints for the stainless steel pipes. At this position the enlarged enclosure allows the pipes to cross over the cable trays without obstructing the regular tunnel clearance for the magnet moving vehicle.

A net counterclockwise flow in the ring will be accomplished with restricting valves at each of the entrances. In each service building around the ring, portable mixed-bed deionizer bottles will be installed. A continuous polishing flow of about 40 gpm per service building will be required to keep low conductivity in the water. The bottles are only used for polishing action. An average of 9 MΩ-cm resistivity of the LCW will be maintained in the ring. LCW fills will be done from the Central Utility Building (CUB) via the 8 GeV line. The CUB has large industrial deionizer columns within the appropriate EPA guidelines for the effluent discharge system. The

Main Ring and Tevatron LCW Required



1992 LCW Required for M. R. & Tev .....8333 GPM .....28 Pumps (8400 gpm)
Required for Tevatron & F0/A0............ 3564 GPM ....15 Pumps (4500 gpm)
Pumps Reusable for FMI...13 Pumps
M. R. Reusable Spare Pumps (7-3) ....4 Pumps
Heat Exchangers Reusable for FMI ....10 H.E.
} For FMI

Figure 3.9-9. Present and Future LCW Requirements for Main Ring and Tevatron portable deionizer bottles will be regenerated in the CUB with the existing regeneration system. In service building MI-60, a 3000 gallon combination storage and expansion tank will be installed for emergency LCW make-up. The FMI will require an estimated 27,000 gallons of LCW to fill the pipes, tanks, bus, and magnets. A schematic of the LCW system processing is shown in Figure 3.9-10; a schedule for the LCW systems is shown in Figure 3.9-11.

WBS 1.1.12.1.2. CABLES AND CABLE TRAYS

Each of the 208 quadrupole locations in the Main Injector Ring has a variety of control devices. These include the diagnositc devices discussed in Chapter 3.8, various individually- or series-powered correction magnetic elements discussed in Chapter 3.1. In addition, there are the vacuum pumps and gauges discussed in Chapter 3.2. All of these elements require cables running to/from the nearest service building. Two, 18" wide by 4" deep cable trays are provided for carrying these cables; one of these trays will in general be filled with coaxial signal cables. The other tray will be divided into two sections, one part for high voltage coaxial cables for the ion pumps, the other part for cables for powering the magnetic elements, either #10 or 250 MCM cable.

Each service building must provide control for up to 36 channels of beam position monitors and beam loss monitors, 36 dipolecorrectors, 16 other correction elements, and 96 vacuum ion pumps. The service buildings are placed according to the dipole bus requirements to reduce voltage to ground stress on the magnets. Consequently, the "servicing" of quadrupole locations by a particular service building is not necessarily evenly distributed upstream and downstream of the building. In the worst situation, 56% of the cables run one direction, and 44% run the other direction. Table 3.9-1. lists the various cable types and quantities that are anticipated. These quantities will only fill about one fourth of the tray depth at the location nearest the service building, with the amount of cables dropping off as one moves away from the building. The schedule for cable and cable tray installation is shown in Figure 3.9-11. Installation of both the water systems and cable trays begins with the beneficial occupancy of the MI-60 service building.

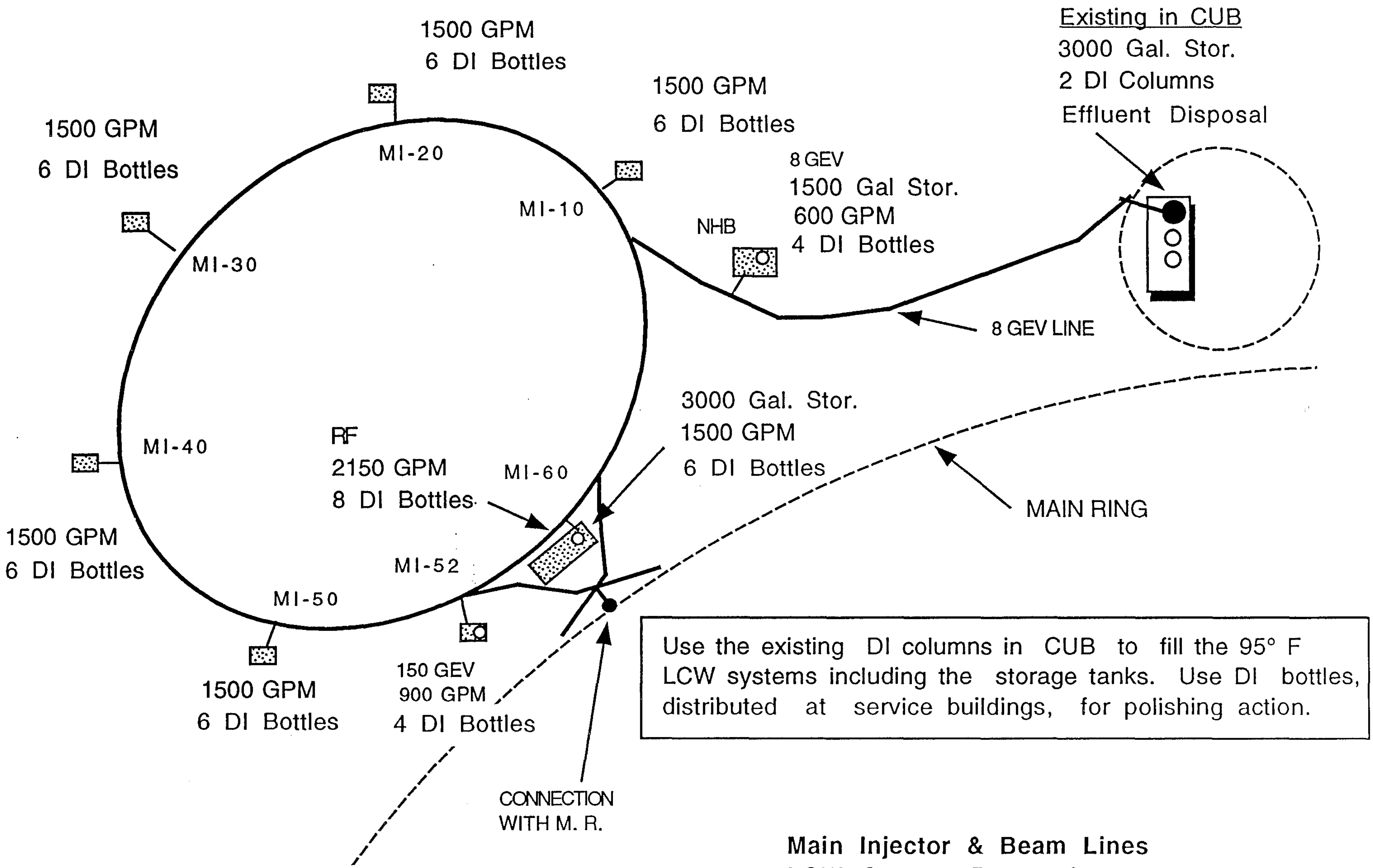


Figure 3.9-10. LCW System Processing

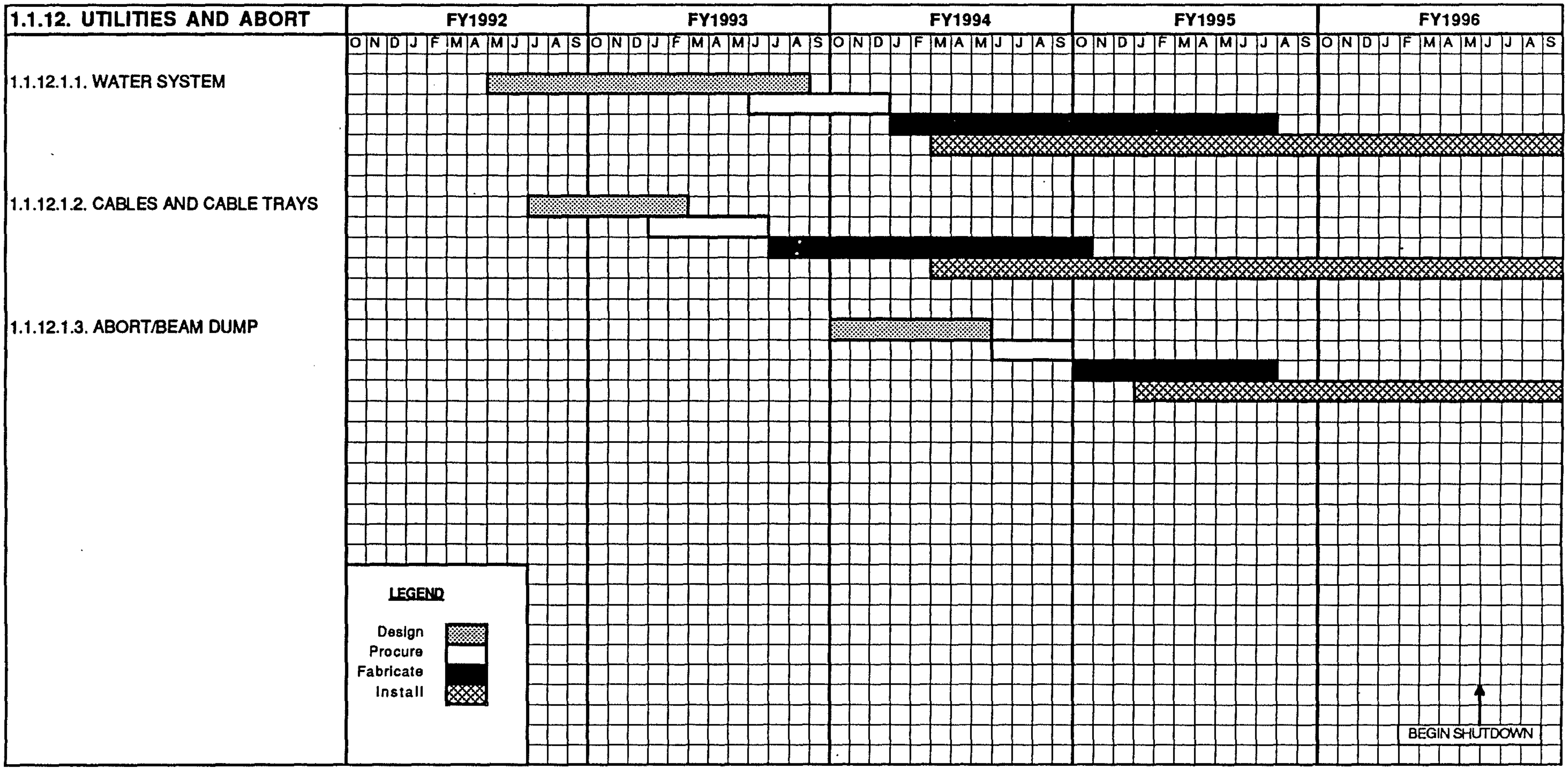


Figure 3.9-11. Utilities and Abort Schedule

Table 3.9-1. Cable Count for Typical Service Building

Item	Number Weight (lb./ft.)	Cable Cables	Total Type	Total Area (sq. in.)
"Signal" Tray				
BPMs:	72	RG-8	12	12
BLMs:	36	RG-58	2	2
Safety System	4	Multicon.	1	1
Misc.		16	Various	4
	4			
Total				19
	19			
Total x .56			11	11
"Power" Tray				
Dipole CE:	72	#10	2	2
Misc. & other CE:	16	#10	2	2
Ion Pumps:	96	RG-58	4	4
ξ Sext.	4	250 MCM	1	3
Total				9
	11			
Total x .56			5	6

Cable properties: (R at 35°C. Area & weight = copper only for non-coax)

Cable Type	Diameter	Area	R/1000'	#/1000'	
250 MCM	.500 in	.196 sq in	.044 Ω	755 lbs.	
#10		.102	.030	1.06	31
RG-8		.405	.129	-	120
RG-58	.195	.030	-	29	
Multiconductor	.530	.221	-	220	

WBS 1.1.12.1.3. ABORT SYSTEM

The proposed proton abort system for the new FMI relies heavily on the technology and design utilized in the existing Main Ring abort system commissioned in 1983. This system has successfully provided clean single-turn abort capability for all subsequent Main Ring proton beam operation. The abort system for the new FMI reuses much of the hardware of the present Main Ring system, with the exception of the beam dump. Because of the low intensities transported, there is no pbar abort.

The system will track the energy of the FMI ring, and be capable of aborting the beam at any point in the 8.9 - 150 GeV/c range, within 50 μsec (5 turns) of the abort command. A 1.5 μsec abort kicker risetime matched to a corresponding minimum gap in the circulating beam allows abort efficiency approaching 100%.

Two 2.2-m long kicker magnets are located at the upstream end of long straight section MI-40. The peak kicker field required is 1.9 kG with the 90° phase advance between the kicker location and the Lambertson magnets at the center of the long straight section. The first of these will be located upstream of the quadrupole in the middle of the straight section. A horizontal displacement of the aborted beam of 28 mm (at 150 GeV) to 38 mm (at 8 GeV) at the first Lambertson magnet positions the beam appropriately for the abort channel.

The two Lambertsons and one C-magnet, with peak fields of 11 kG, deflect the aborted beam vertically downward at an angle of 24 mr so as to clear the quadrupole at the downstream end of straight section MI-40 and exit the FMI tunnel toward the abort beam dump. The geometry of the MI-40 straight section is similar to that of MI-52, shown in Figure 2.1-4. The aborted beam will pass through a short quadrupole and through two B2 magnets rolled at a 40 degree angle. The rolled B2s level the beam off and deflect it outwards, so that the abort beamline remains above the floor level and diverges from the circulating beam more quickly, simplifying the civil construction of the straight section. Two additional quadrupoles further downstream maintain a reasonable beam size up to the beam dump. The Lambertson, C-magnet, B2 and abort quadrupole magnets must track the FMI ramp in order to abort the beam at any energy. This will be accomplished by tailoring the design of the abort line so that all these elements are powered in series with one of the quadrupole busses. Steering adjustments will be made using the separately powered trim coil windings in the Lambertson and C-magnets, and with separate trim dipoles reclaimed from the Main Ring. Details of the magnetic elements and civil construction associated with the abort line and dump are shown in drawing AS-4.

The beam dump will be constructed with a graphite core of length 4.4 m, similar to the existing Tevatron beam dump, which is shown in Figure 3.9-12. It will be enclosed and steel and concrete, as shown in Figures 3.9-13 and 3.9-14, to avoid groundwater contamination and to reduce radiation levels at the surface to levels which permit unlimited occupancy. Underdrains on each side of the dump connect to sumps in the Main Injector enclosure, while the sampling underdrain connects to a standpipe in the Main Injector enclosure, from which samples can be drawn for analysis. The Main Injector dump will differ from the Tevatron dump in two respects. Since the Tevatron dump also serves the Main Ring, it has two separate but adjacent graphite core stacks; only one will be required for the Main Injector. Second, because of the higher intensity and shorter cycle time, the thickness of steel will be increased to reduce the levels of groundwater activation and surface radiation.

The kicker power supplies will be located in the MI-40 service building. The beam dump will be located approximately 70 m downstream of the end of the MI-40 straight section; at this location, the beam dump will be about 6 m outside of the tunnel, in the vicinity of quad 409.

Cooling of the core will be by water and will be patterned after the existing Main Ring beam dump. One significant deviation will be the fact that new dump will be cooled by a closed loop water system incorporating a heat exchanger. This design is preferable to using a large storage tank of sufficient capacity so that activated elements can decay until acceptable radioactive levels are reached before bleeding the water into the main LCW loop.

Schedule

The schedule for the abort and beam dump is shown in Figure 3.9-11. The beam dump will be installed concurrently with the construction of the tunnel enclosure in the vicinity of the dump. The magnetic elements will be installed during the seven month shutdown.

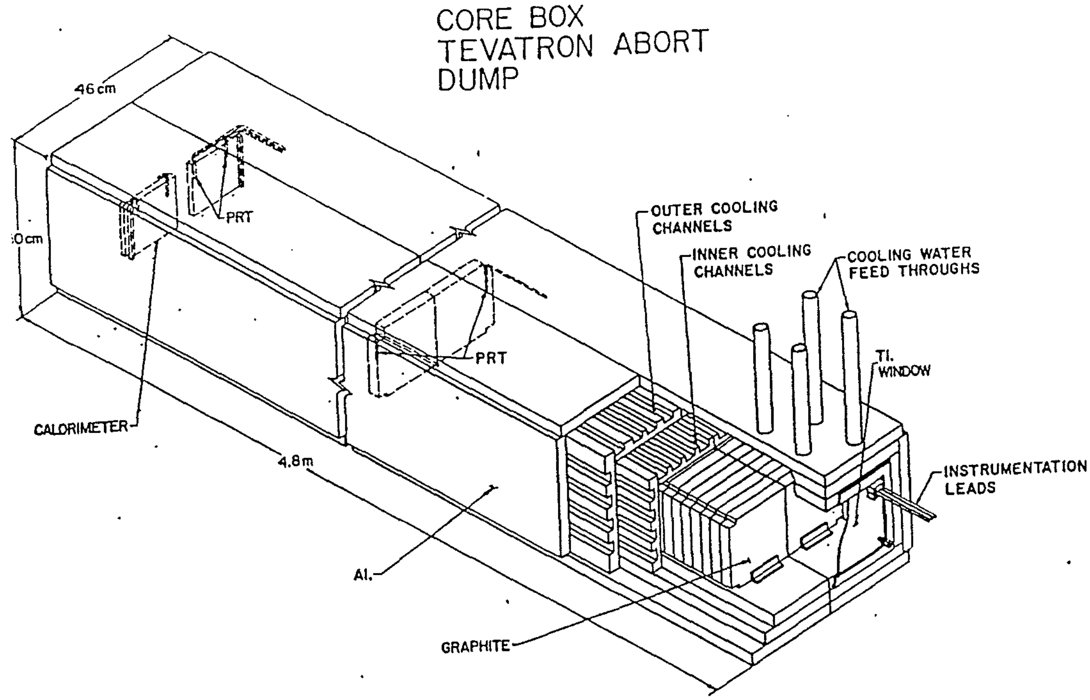


Figure 3.9-12. Tevatron Abort Dump Core Box

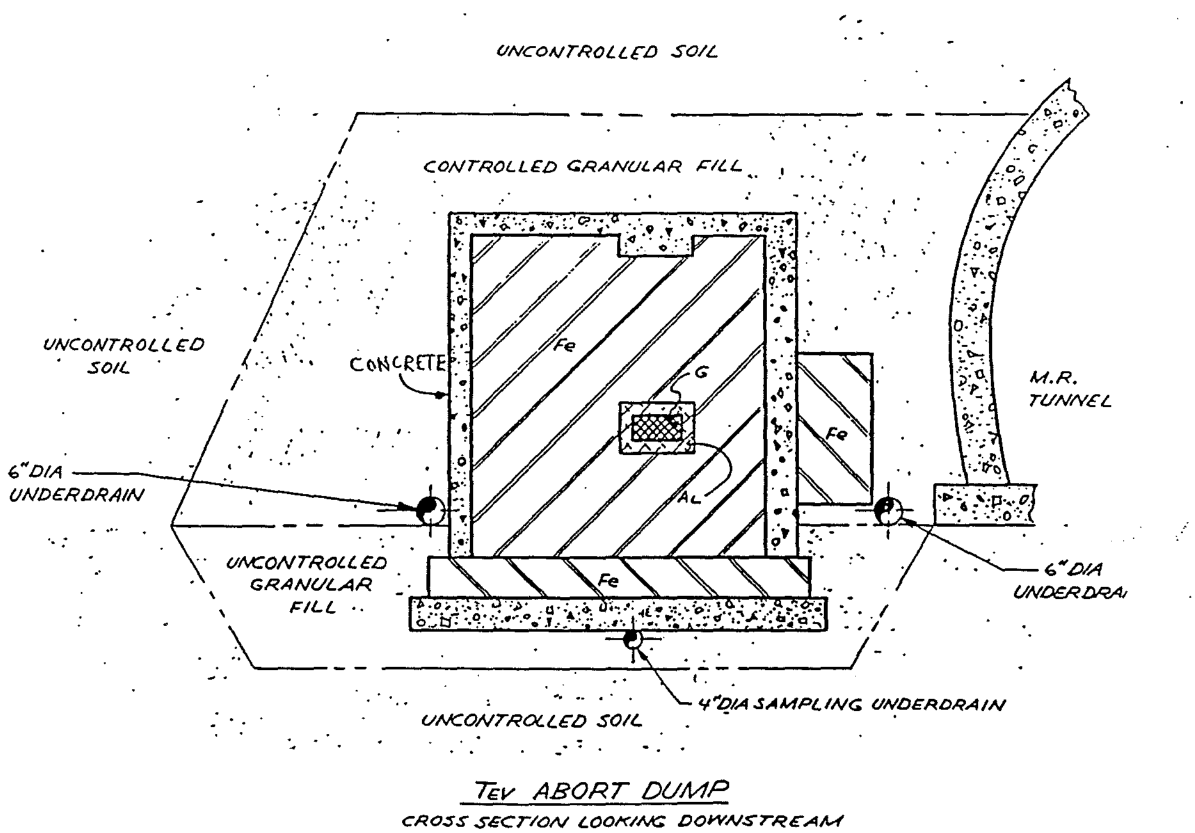


Figure 3.9-13. Cross Section of Tevatron Abort Dump

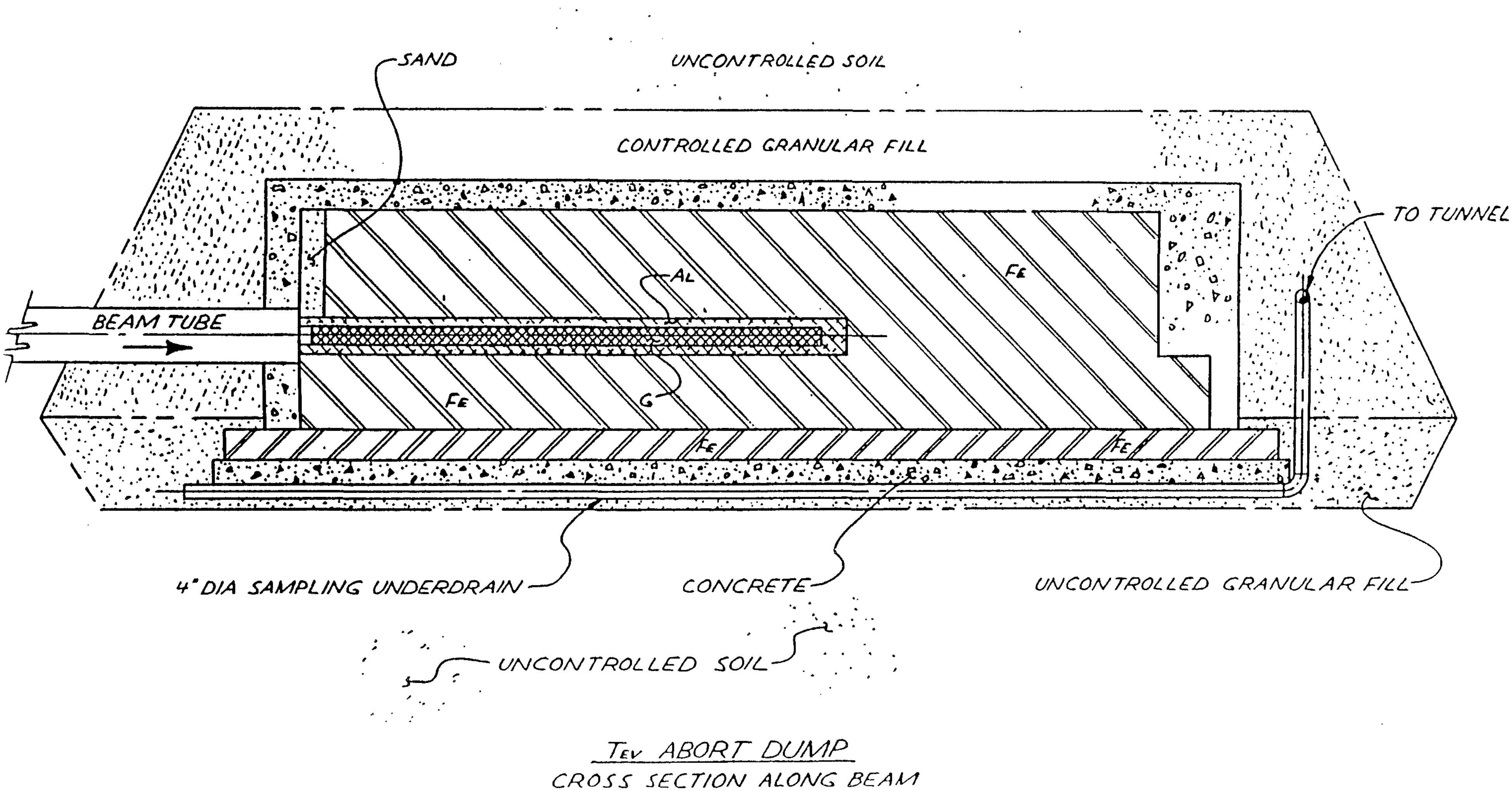


Figure 3.9-14. Longitudinal Section of Tevatron Abort Dump

CHAPTER 3.10 INSTALLATION

WBS 1.1.13. INSTALLATION

The installation WBS covers a large number of diverse tasks and requires careful coordination of the various tasks and tradesmen. Much thought has gone into the planning of these activities, how to sequence them around each other, and integrate them with the Main Ring and Tevatron shutdowns. Some of the equipment and systems that will be installed as part of this WBS will have been designed and fabricated under different WBSs and are consequently described elsewhere in this report. Supports and positioning hardware for dipole, quadrupole, correction magnets, specialty devices, and utilities will be described in this section.

In the overall scheme, certain tasks need to follow a sensible sequence. Before receiving full or partial beneficial occupancy of the enclosures, lighting will have to be installed. Alignment crews will establish reference points in finished portions of the enclosures which will guide the installation of all components that do not require very precise location. The physical support for devices other than those that lie in the beam path will come from Unistrut rails that have been strategically imbedded in the ceiling and outer wall of the enclosure. At this point, installation of LCW piping, magnet busses, and cable trays will begin. The LCW piping will start first, the bus and the cable tray installation will follow at weekly intervals.

Over the years, several schemes have been used for adjusting and supporting magnets in the existing Main and Tevatron rings, the Pbar rings, and various beam lines. The Main Injector magnets will be supported by adjusters and supports that have performed best in the past. These designs use thrust bearings so that heavy magnets (dipoles weigh over 40,000 lbs). can be adjusted up and down requiring a reasonable amount of torque; thin inserts that have a low coefficient of friction are placed between sliding steel surfaces, and bronze bearing material is used in conjunction with steel actuators to reduce friction where large forces need to be applied.

With magnets that have sufficient rigidity, a three point support scheme is used; a four point scheme is used wherever conditions make it necessary. Dipoles and quadrupoles have three axis adjustment: $\pm$0.75 inches in the transverse and longitudinal directions and $\pm$2.00 inches in the vertical direction. The large vertical travel is readily built into the stands and requires less installation time compared to other techniques, such as using shims or selectively inserting segments that have variable height. The need for the large vertical travel comes about because of the combination of three circumstances: the anticipated deviation of the tunnel floor from its nominal elevation resulting from normal construction tolerances, the eccentricity of the MI ring, and the 3.5 μr tilt of the plane of the MI ring discussed in Chapter 2.1. Figures 3.10-1 through

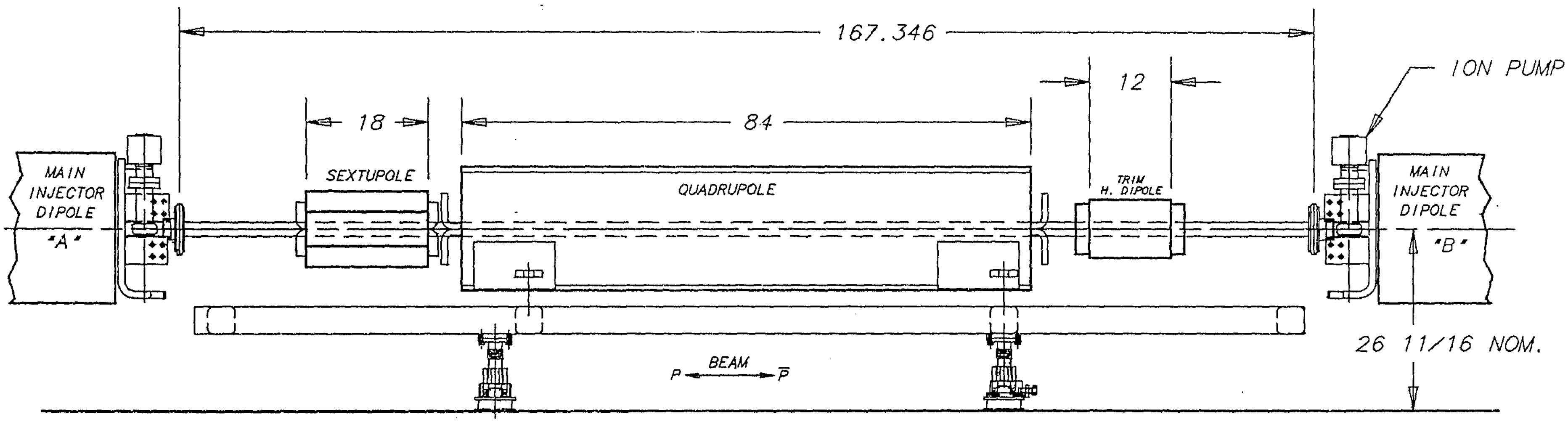


Figure 3.10-1. Layout of a Normal Cell 84"- Quadrupole and Correction Elements

Figure 3.10-7 show most of the anticipated combinations of quadrupoles, correction elements, and vacuum valves. Figure 3.10-8 shows in some detail the dipole support design.

Installation of the dipole magnet stands will take place after the LCW piping, the magnet bus, and the cable trays have been installed. Once the entire ring enclosure is available, the alignment crews will return for a second survey. The crews will establish specific reference marks on the enclosure floor for the magnet stand locations. Using these marks, an installation crew, with the aid of custom templates, will locate and install mounting studs in the floor to which the appropriate magnet stands will be bolted. When the installation of magnet stands of a common type is completed, the stands will be coarsely adjusted using a light weight, custom fixture that represents the actual magnet. It is expected that this additional step will position the magnets to within 1/4 inch of their specified locations.

The intent of these procedures is to substitute, wherever possible, low cost labor for highly skilled labor. Magnet stands will be installed by relatively inexpensive labor. By pre-adjusting the stands, again using unskilled labor, the amount of time needed by rigging crews to set the magnets will be minimized. An additional benefit should be the reduced time that an alignment crew will need to make final adjustments.

Transporting and positioning the magnets to their locations in the enclosure will again be patterned after procedures that have evolved at the Laboratory over several years. Several compact magnet moving carts will transport magnets from their staging area in the enclosure to their designated locations. At that point, a compact, hydraulically operated device will shift the magnet from the transporter to its permanent support. These devices will be custom designed and fabricated for the specific magnets used in the Main Injector. This particular technique was successfully employed during the Pbar ring magnet installation.

Since the dipoles for the Main Injector ring will be newly constructed, they will be installed during the early phases of the installation cycle. The majority of the quadrupoles will be recycled from the existing Main Ring. During the shut down period marking the end of Main Ring operation, they will be removed from the Main Ring and will undergo modifications at the magnet factory. A major operation will be the insertion of a new beam tube into the existing quadrupole tube. Another key modification will be the addition of internal beam position monitors. Once refurbished, they will be transported to the Main Injector enclosure and installed using techniques similar to those used for the dipole magnet installation. Their support stands will be new and will have been installed as described above.

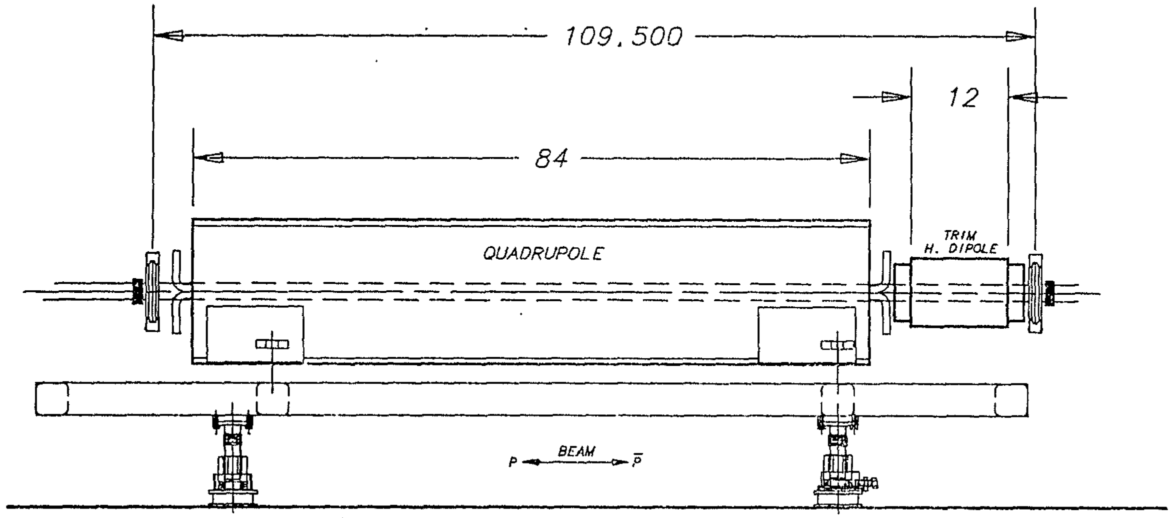


Figure 3.10-2. Layout of an 84"- Quadrupole For Use Between Lambertson Magnets

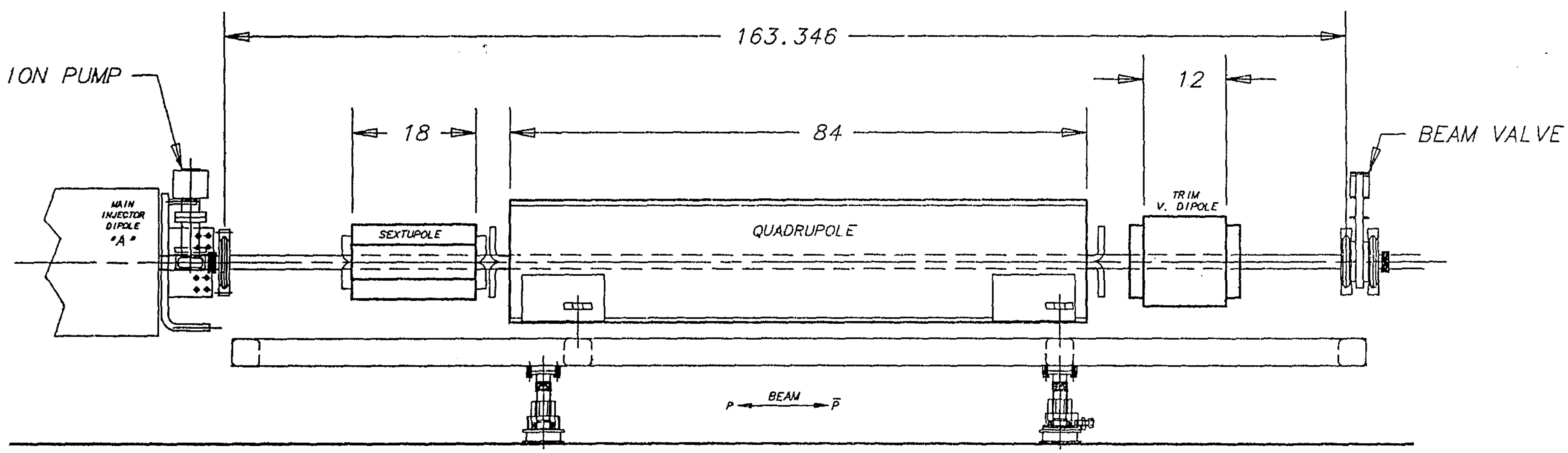


Figure 3.10-3. Layout of a Normal Cell 84"- Quadrupole with Beam Valve

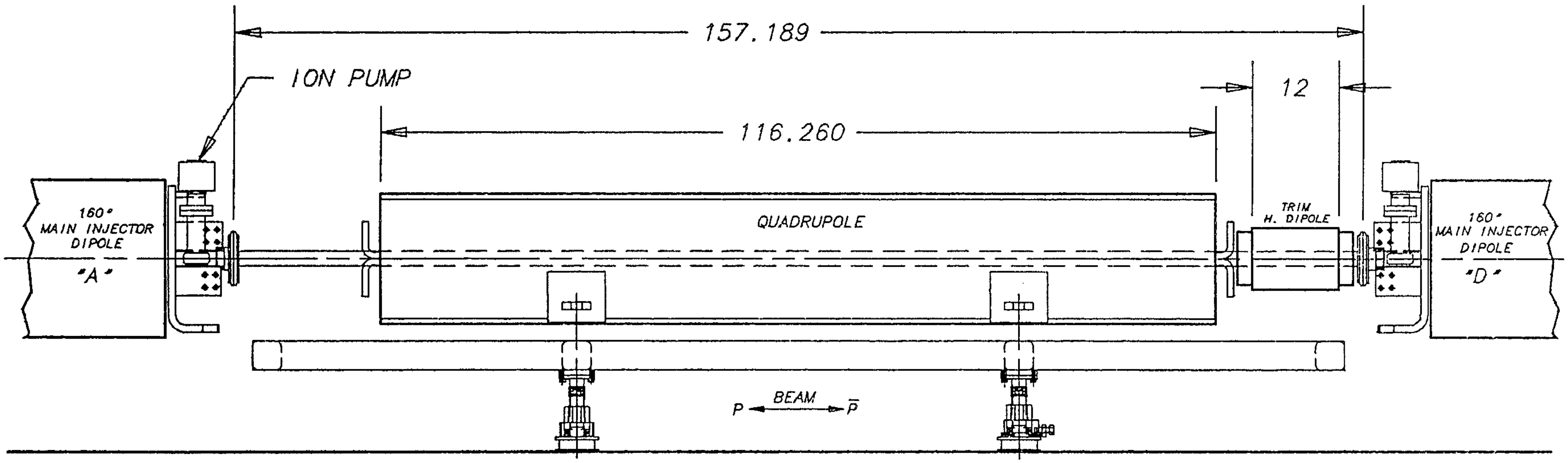


Figure 3.10-4. Layout of a Dispersion Suppression Cell 116"- Quadrupole

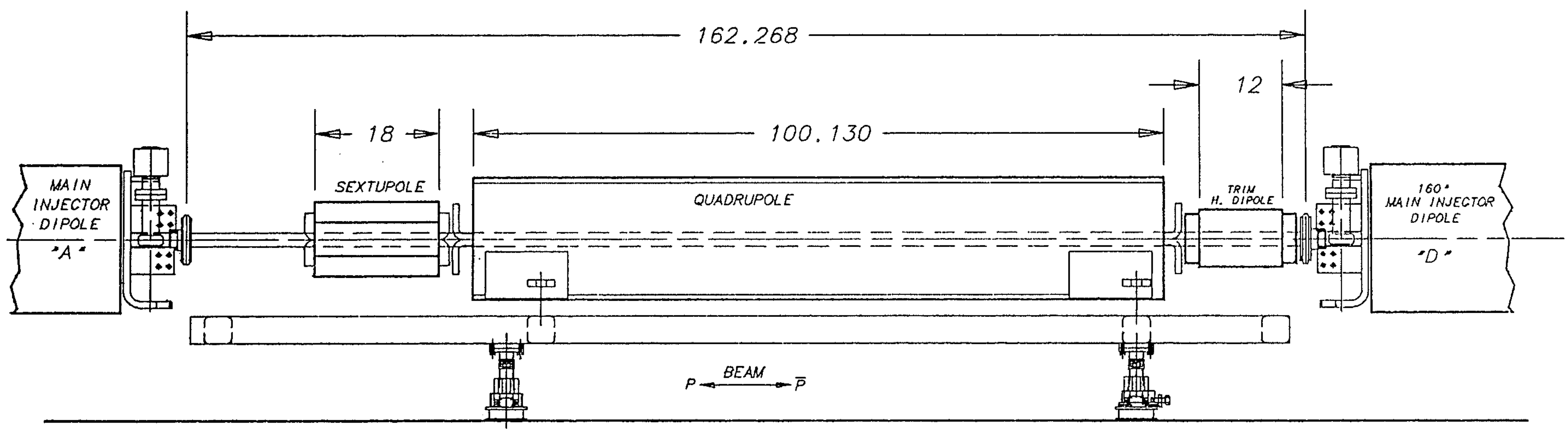


Figure 3.10-5. Layout of a 100"- Quadrupole Between Dispersion Suppression Cell and Normal Cell

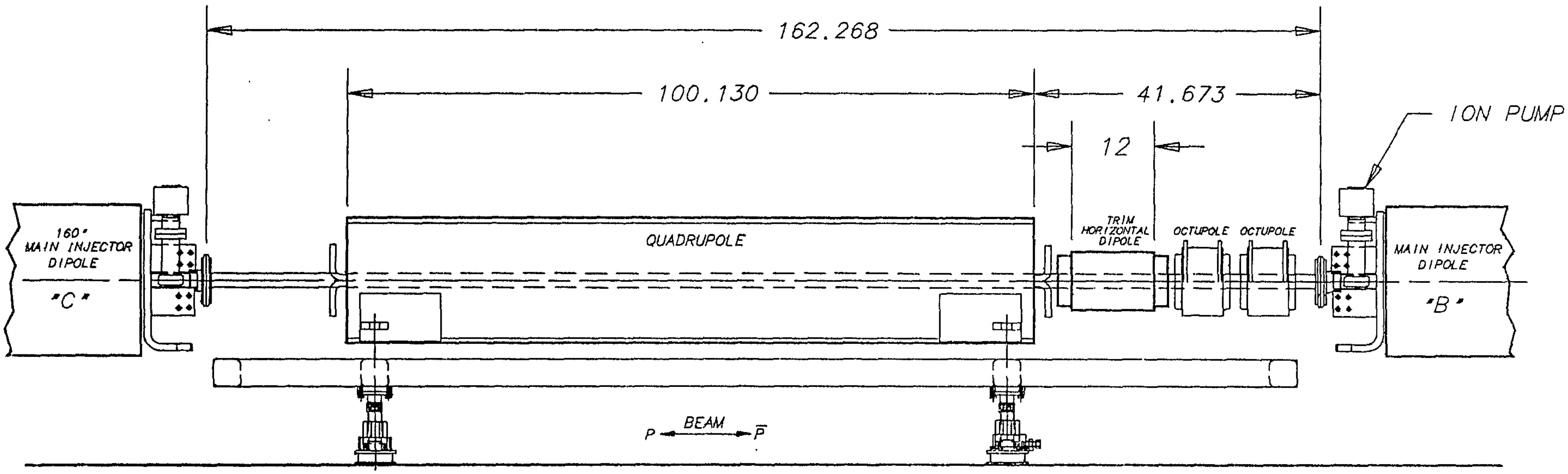


Figure 3.10-6. Layout of a 100"- Quadrupole Between Normal Cell and Dispersion Suppression Cell

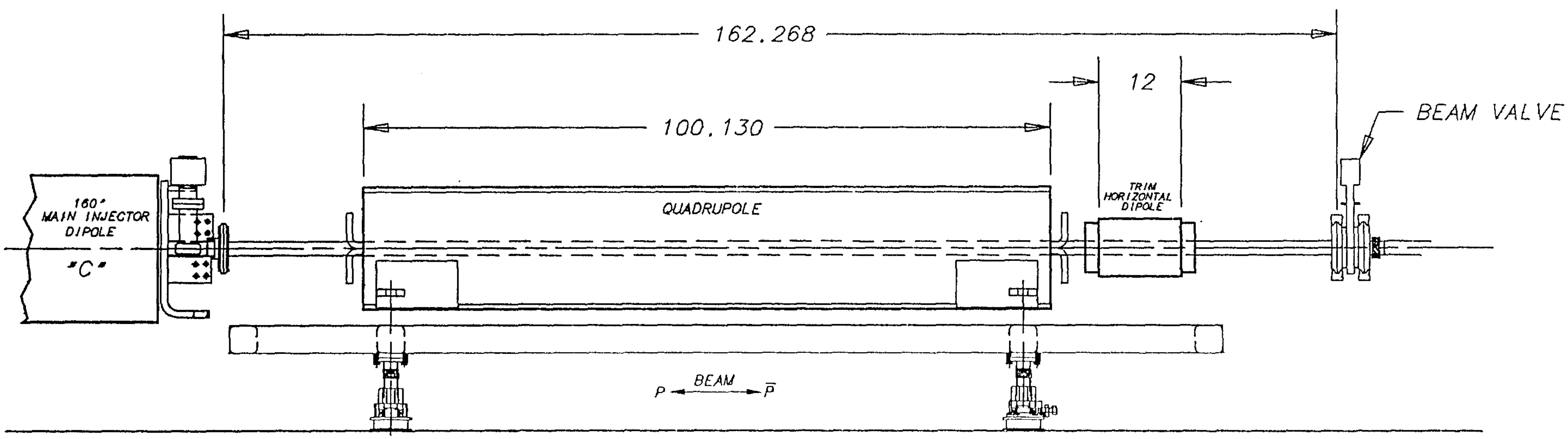


Figure 3.10-7. Layout of a 100"- Quadrupole Between Straight Section and Dispersion Suppression Cell

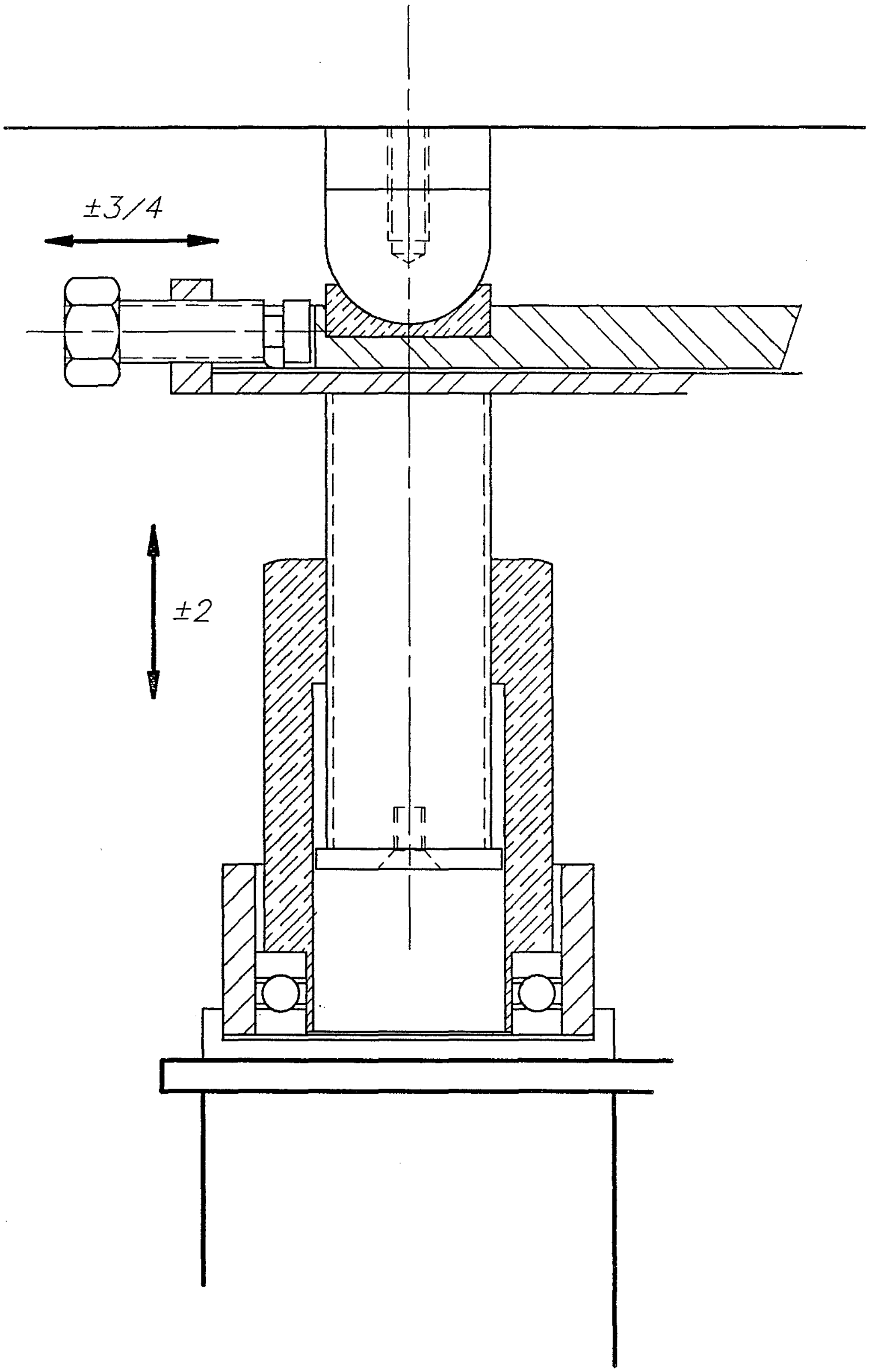


Figure 3.10-8. Dipole Magnet Support Stand (Half Scale).

The rolled magnets in the abort line and specialty devices, such as Lambertson magnets, kicker magnets, etc., follow mounting schemes that are patterned after those described earlier. Their installation, however, will be done by rigging crews using the existing Main Ring magnet mover and installer.

Many details, especially at the magnet interfaces, are complex and congested. Several full scale mockups will be used during the final design stages to verify the feasibility of the designs. One mockup will include a segment of the tunnel enclosure as well as replicas of magnets and other major component.

Magnets that have been mounted, can be surveyed and aligned. When groups of dipoles and quadrupoles have been aligned, cooling water and bus connections (Chapter 3.9) will be made and vacuum components (Chapter 3.2) will be installed.

Small correction magnets, some of which will be recycled from the Main Ring, will be mounted on either side of the quardrupoles. The beam pipe that runs through each quadrupole is one continuous piece which connects directly to the dipoles on either end. Therefore, the correction magnets need to split into halves in order to install them. With the exception of the sextupole magnet, these small magnets halves can be lifted by hand and put into their proper positions. Because of their heavier weight, a fixture will be necessary to support the sextupole halves while they are being positioned around the beam pipe. Again, the techniques used for these installations will make use of templates and mechanical aids that will permit the use of low cost labor.

As far as instrumentation is concerned, the most prevalent devices will be the beam position monitors and the beam loss monitors. Many of the beam position monitors will be incorporated into the spaces that remain when the new beam tubes are inserted into the old beam tubes of the quadrupoles as shown in Figure 3.2-4. The beam position monitors will be installed as part of the Main Ring quadrupole rework program. The beam loss monitors are the same type as the Tevatron system and will be installed at each quadrupole.

Laying out the cabling for a complex machine with a large number of diverse devices needs careful planning to prevent clutter and disorder. Wiring for the smaller devices will be brought through a conduit that runs from the cable tray to the individual devices. The conduit is mounted transversely along the ceiling and runs vertically down on the wall nearest the beam line. (See Figure 3.9-1) A generous bend radius will make wire pulling easier. With the use of a conduit at each quadrupole, wiring will be neatly collected at the cable tray and at the other end the wires will be fanned out to their respective components.

Power lines for devices requiring 120 VAC and 208 VAC will be provided via outlets on the wall closest to the beam line. Four 20 A, 120 VAC outlets will be located at each quadrupole, while two 20 A, 3-phase 208 VAC outlets will be located at each quadrupoles. However, the 208 VAC outlets at two adjacent quadrupole locations can be powered from the same circuit breaker. This provides adequate coverage for the pump-out ports and where leak checking equipment and turbopumps will be connected.

The various magnets (dipoles, quadrupoles, trim magnets, C-magnets, Lambertsons, etc.), the vacuum components, the cable trays, the LCW piping, the power bus, and the instrumentation represent most of the major physical components that will be installed in the enclosures. There are additional groups of devices and systems that will complete the installation of the key elements of the Main Injector. These are the power supplies (Chapter 3.3), the RF systems (Chapter 3.4), the control system (Chapter 3.7), the safety system (Chapter 3.8), and the abort system (Chapter 3.9). Their installation will be staggered with respect to the other installations. With careful coordination, different activities can take place simultaneously in different sections of the Main Injector complex.

Schedule

The schedules for installation of most components are shown in the schedules for design, procurement, and fabrication of these components. Figure 3.10-9 shows the schedule for fabrication and installation of the magnet stands, magnet installation and magnet alignment to the FMI ring and beamlines.

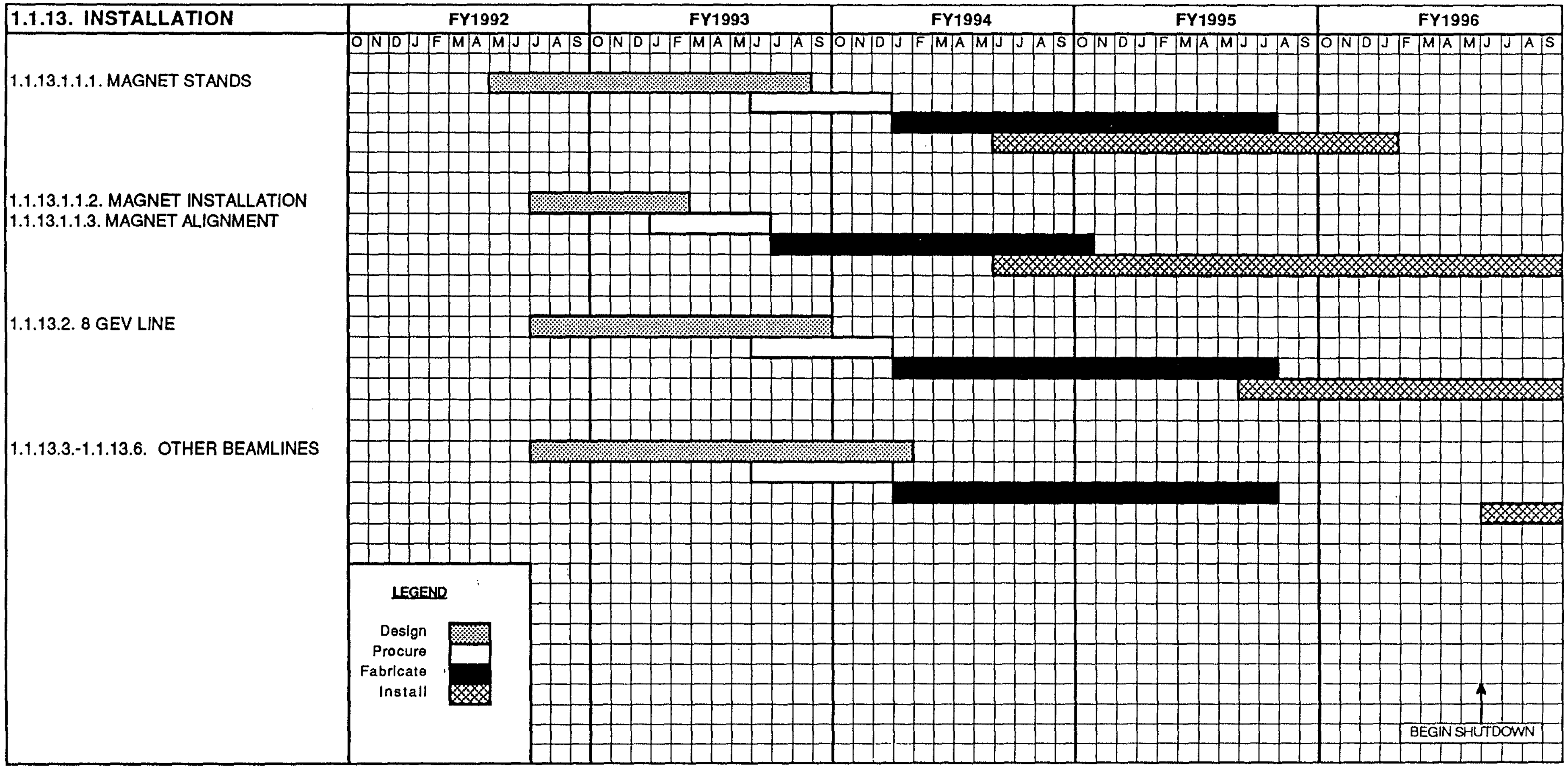


Figure 3.10-9. Installation Schedule

4. COST ESTIMATE

The TECC for construction of the FMI, associated beamlines, and required modifications to existing facilities is $217,450,000 in then-year dollars. The cost estimate is summarized in Table 4-1. An additional $29,150,000 is required in direct R&D, pre-operating, capital equipment, conceptual design, and spares costs to support the project. The cost estimate methodology is based on a Work Breakdown Structure (WBS) which has been developed for this project over the last few years. Our recent experiences with the TeV I (Antiproton Source), Main Ring overpass, and Linac Upgrade construction projects form the basis for a large fraction of the cost estimate of this project.

4.1 Methodology

A WBS is set up in order to identify all required components of the FMI project and to insure that each component is adequately specified and incorporated into the estimate. The WBS through third level is shown implicitly in Table 4-1. The actual WBS used for the cost estimate extended through the seventh level.

All components are estimated at the lowest applicable level in 1991 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 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 1991 prices using DOE inflation factors issued in February 1992. The translation of craft codes into hourly costs is based on current local labor rates and is given in Table 4-2. 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 manpower estimate is given in Table 4-3.

The cost estimate is produced in 1991 dollars. The TEC in $1991 is $190,000,000. Escalation to then year dollars is accomplished through a convolution of the cost spending profile with DOE construction project escalation rates.

Table 4-1: Main Injector Cost Estimate (Dollar amounts in thousands)

WBS		DESCRIPTION			Total
1.		MAIN INJECTOR CONSTRUCTION (TEC)			217450
1.1		Technical Components		79900	
	.1	Magnets	41652		
	.2	Vacuum	3083		
	.3	Power Supplies	10107		
	.4	RF Systems	4399		
	.6	Kickers & Slow Extract.	2142		
	.8	Instrumentation	1649		
	.9	Controls	897		
	.10	Safety Systems	583		
	.12	Utilities & Abort	6419		
	.13	Installation	8973		
1.2		Civil Construction		72000	
	.1	Phase 1	11330		
	.2	Phase 2	51065		
	.3	Phase 3	9010		
	.4	Phase 4	592		
1.3	Project Management			5920	
	.1	Project Management	3561		
	.2	Accelerator Physics	1260		
	.3	G&A	1097		
1.4		Contingency		32170	
1.5		Escalation		27460	
OTHER PROJECT COSTS (escalation included)					29160
2.		R&D		11840	
3.		Capital Equipment		1000	
4.		Pre-operating		3460	
5.		Prior years conceptual		5100	
6.		Spares		7760	
TOTAL PROJECT COST (TPC)					246600

Table 4-2: Cost Estimate Labor Codes & Rates ($/hour)

Fabrication		
Technician, Conventional Magnets	T1	29.00
Technician, Accelerator Division	T2	18.70
Technical Support	T3	29.00*
Shops, average capability	S1	33.00*
Shops, specialized/precision	S2	38.00
Installation		
Plumber, steam fitter, sheet metal	IP	41.10
Electrician	IE	38.20
Rigger, crane operator	IG	42.80
Laborer	IL	27.20
Surveyor	IA	31.10
EDIA		
Physicist	PH	33.90
Engineer	EN	32.40
Engineer, Construction Services	CE	40.00*
Designer/drafter	DC	32.00*
Drafter, Accelerator Division	DR	22.20
Programmer	PR	30.90
Project Management	PM	40.00
Architectural Engineering	AE	50.00
Administrative Support	AD	20.00

*Fermilab Service Center chargeback rates

Table 4-3: Total Labor Effort (Man-years, R&D, Pre-Op included)

Fabrication		
Technician, Conventional Magnets	T1	85
Technician, Accelerator Division	T2	61
Technical Support	T3	75
Shops, average capability	S1	4
Shops, specialized/precision	S2	1
Installation		
Plumber, steam fitter, sheet metal	IP	18
Electrician	IE	40
Rigger, crane operator	IG	9
Laborer	IL	2
Surveyor	IA	7
EDIA		
Physicist	PH	38
Engineer	EN	78
Engineer, CES	CE	29
Designer/drafter	DC	43
Drafter, Accelerator Division	DR	35
Programmer	PR	7
Program management	PM	15
Architectural Engineering	AE	45
Administrative support	AD	26
Total		618

4.2 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 $79,900,000 (1991). Engineering design and inspection (ED&I) are included in the component cost. All components are similar to components already built and installed at other locations within the Fermilab complex. The only extraordinary items are the new dipole magnets and the 10,000 A power supply. A modest R&D effort is associated with these items.

4.3 Civil Construction

The civil construction cost estimate includes the FMI ring enclosure, beamline enclosures, service buildings, modifications to the Main Ring enclosure and service building at F0, and all associated utilities including primary power and water distribution. Also included are the requisite site work and road development. Specifically provided for are new cooling ponds, environmental restoration of impacted wetlands, and the new 345 kV Kautz Road Substation.

The total civil construction is estimated at $72,000,000 (1991). Specifically included are funds targeted for environmental mitigation (accounted for in WBS 1.2.1). Costs are estimated on the basis of quantity take offs and include contractor overhead and profit. The ED&I component of the cost assumes the use of the architectural/engineering firm or Fluor-Daniel for design work on all civil components removed from the interface between the FMI ring and existing facilities.

4.4 Engineering Design Inspection & Administration (EDIA)

ED&I is incorporated into component costs at the lowest applicable WBS level and summed upwards. Project management costs are explicitly estimated under WBS 1.3. Total estimated EDIA as a fraction of the total components cost is 16.2% (including 11.8% for ED&I, 3.3% for project management, and 0.7% for G&A). The G&A rate is the established incremental overhead on construction projects at the laboratory. EDIA is estimated at $21,800,000 (1991).

4.5 Contingency

Contingency is assigned to all technical components on the basis of the cost estimating procedure. Estimates based on previous actual purchases, on vendor quotes, or on catalog prices are assigned a 15% contingency. Estimates based on undocumented engineering estimates (approximately 19% of the total materials cost estimate for the project) are assigned a 20% contingency. An across-the-board 20% contingency is applied to all labor estimates. A special allowances has been provided for unanticipated refurbishing expenses associated with the reuse of existing quadrupole power supplies ($600,000). Civil construction contingencies are assigned at the third WBS level on the basis of previous experience with similar projects.

The total contingency assigned to the FMI project is $32,200,000 (1991). This represents 20% of all construction, installation, and EDIA costs. This level of contingency is felt to be appropriate for the advanced conceptual design stage of a project with minimal technical risk.

4.6 Other Project Costs (R&D, Pre-operating, Capital Equipment, Conceptual Design, Spares)

Specific R&D required to support the FMI is limited to the areas of the dipole magnet, the 10,000 A/1,000 V power supply, the special length quadrupole magnets required at the FMI straight sections, the sextupole magnet, rf power amplifiers (PAs), and 53 MHz vernier cavities. Twelve dipole magnets, two quadrupole magnets and tooling, one sextupole magnet and tooling, two 10 MVA power supplies, three new PAs, and two low voltage, low impedence cavities will be constructed using R&D funds. Total estimated cost of this effort is $11,800K including approximately 30 man-years of ED&I and project management associated with the R&D

program. These costs are included in the TPC as is a 37% G&A surcharge, 27% contingency, and escalation.

Pre-operating costs ($3,500K) include the operation of the FMI ring and beamlines during a three month commissioning period. Capital equipment required in support of R&D is estimated at $1,000K.

Prior year costs are now reported in the TPC for this project. These costs ($5,100) include support for all conceptual design work completed through March 1992. Also newly included in the TPC are estimated costs for spares inventories which will be required at the start of operations ($7,800).

4.7 Funding Profiles

Both obligations and cost profiles have been developed based on the construction and installation schedule described in Chapter 6. The profiles are developed at WBS level 3 for all technical and civil components. The project obligations and cost profiles are given in Table 4-4.

Table 4-4: TEC Spending Profiles (Dollar Amounts in Thousands)

Fiscal Year	Obligations		Costs	
	1991	Then-year	1991	Then-year
1992	11227	11650	5718	5838
1993	28084	30000	25513	26916
1994	46708	52000	43300	47673
1995	49075	57000	50862	58543
1996	46335	56000	52241	62898
1997	8563	10800	12358	15583
Total	189991	217450	189991	217450

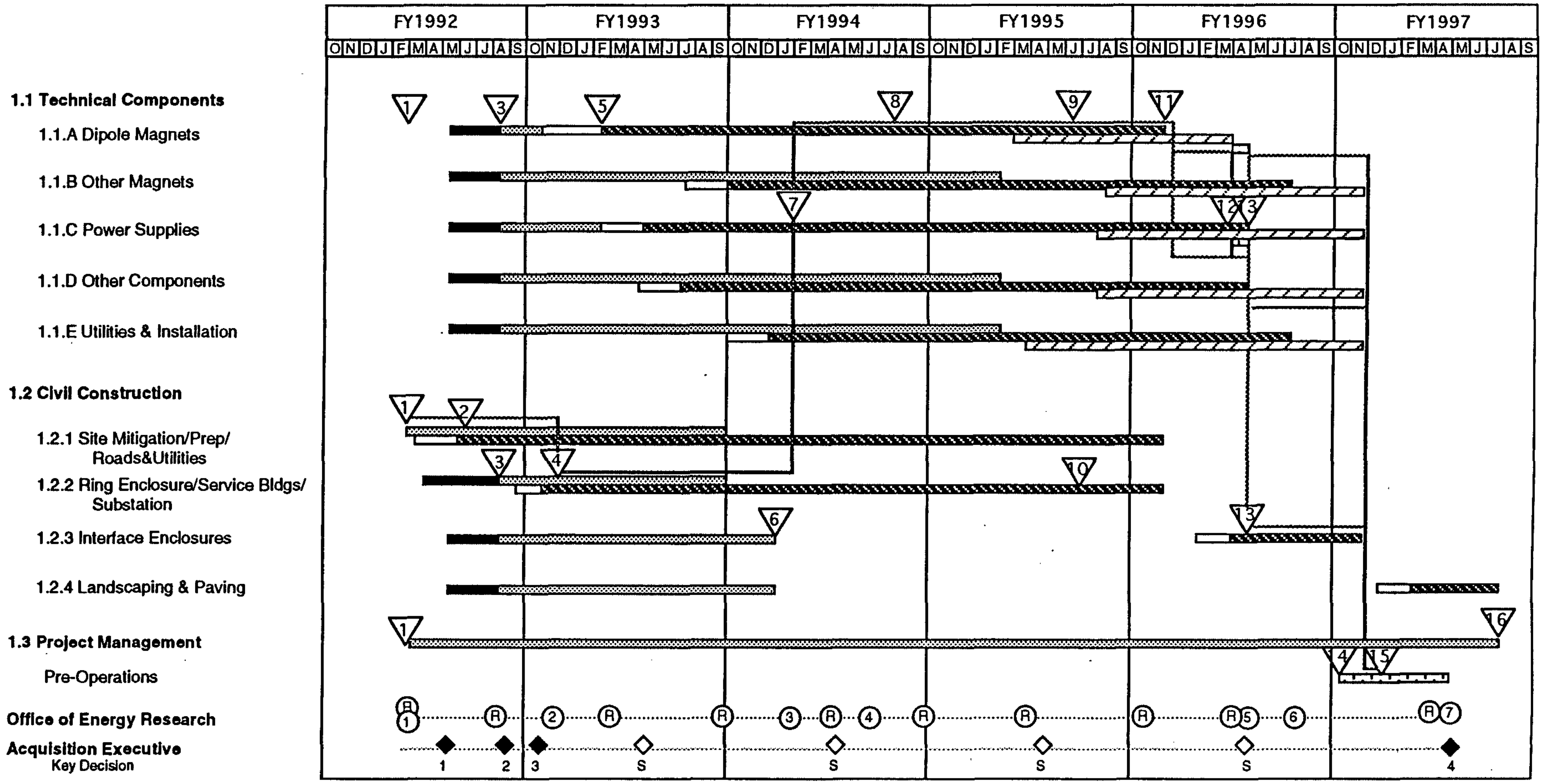
5. SCHEDULE

It is proposed that the FMI project be completed over the period March 1, 1992 through August 1, 1997. The project master schedule is shown in Figure 5-1. The period October 1, 1989 through February 29, 1992 has been devoted to preconstruction R&D and to the completion of all required environmental documentation and the securing of required permits. Preparatory engineering in support of construction began on March 1, 1992. The schedule shown reflects the funding profile given in the FY93 Construction Project Data Sheets submitted to the Congress in January 1992 and the total manpower estimate shown in Table 4-3. The schedule is funding driven with the exception of the period in which HEP operations are disrupted for construction required at the interfaces of the FMI and the existing complex. This work is anticipated to require a seven month disruption to HEP operations starting on May 1, 1996.

A set of project milestones is given in Table 5-1. As can be seen the FMI ring and 8 GeV beamline can be largely installed without disturbing Tevatron operations. The length of the HEP shutdown is tied to the civil construction in the vicinity of F0 and to the effort associated with recycling Main Ring components such as rf cavities and quadrupole magnets. Pre-operations with beam are expected to be initiated in October 1996 with Tevatron commissioning starting three months later. Tevatron operations are expected to be initiated in proton-antiproton collider mode with simultaneous slow spill from the FMI.

Fermilab Main Injector Project Schedule

Revision 3.1.6
7/16/92



Level 0 Milestones	Level 1 Milestones	Level 2 Milestones	
Acquisition Executive (◆)	Office of Energy Research (○)	DOE Project Manager (▽)	
1. Establish Project Baselines (5/92)	1. Approve Start of Project (3/92)	1. Start Project (3/92)	10. CompleteBenerficial Occupancy of Ring Enclosure/Serv. Bldgs. (7/95)
2. Start Detailed Design (9/92)	2. Conduct Radiation Safety Review (12/92)	2. Start Wetland Mitigation (6/92)	11. Last Dipole Constructed (12/95)
3. Commence Construction (11/92)	3. Beneficial Occupancy of MI-60 Serv. Bldg. (3/94)	3. Complete Title I Design (8/92)	12. Complete Dipole Power Supply Installation (4/96)
4. Approval to Begin Operation (5/97)	4. Initiate Dipole Installation (7/94)	4. Start Construction of MI-60/Enclosure (12/92)	13. Complete Dipole Power Test and Start Tevatron Shutdown (5/96)
S. Status Report	5. Tevatron Shutdown (5/96)	5. Start Dipole Procurement (2/93)	14. Initiate Pre-operations w/ Beam (10/96)
	6. Operational Readiness Review (8/96)	6. Complete Civil Constr. Title II (1/94)	15. Start Commissioning (1/97)
	7. Complete Pre-Operations (5/97)	7. First Dipole Power Supplies Delivered (2/94)	16. Full Project Completion (8/97)
	R. Semi-annual Review	8. 25% of Dipoles Completed (8/94)	
		9. 75% of Dipoles Delivered (6/95)	

Legend

- Title I
- Title II
- Bid
- Procure/Construct
- Install/Test
- Pre-operations
- Critical Path

Figure 5-1: Fermilab Main Injector Project Master Schedule

Table 5-1: Major Project Milestones

	Milestone	Date	Description
1992	1	March	Start Project
	2	June	Award Site Mitigation Contract
	3	August	Complete Title 1
	4	December	Award MI-60/Enclosure Contracts
1993	5	February	Award Magnet Fabrication Contract
1994	6	January	Complete Civil Construction Title II
	7	February	First Power Supplies Delivered
	8	August	25% of Dipoles Delivered
1995	9	June	75% of Dipoles Delivered
	10	August	Beneficial Occupancy of Ring Enclosure and all Service Buildings
	11	December	Last Dipole Delivered
1996	12	April	Complete Dipole Power Supply Installation, Start Dipole Power Test
	13	May	Complete Dipole Power Test and Start Tevatron Shutdown
	14	October	Start Pre-operations with Beam
1997	15	January	Start Tevatron Commissioning
	16	August	Project Complete

APPENDIX A

LATTICE FUNCTIONS

"MAD" Version: 8.17   Run: 22/04/92 14.44.56

Linear lattice functions for beam line: MI17   Range: #S/#E

delta(p)/p = 0.000000   symm = F

ELEMENT SEQUENCE			HORIZONTAL								VERTICAL						
element name	quad type	dist [m]	betax [m]	alfax [1]	mux [2pi]	x(co) [mm]	px(co) [.001]	Dx [m]	Dpx [1]	betay [m]	alfay [1]	muy [2pi]	y(co) [mm]	py(co) [.001]	Dy [m]	Dpy [1]
MI60		0.000	9.811	-0.026	0.000	0.000	0.000	-0.057	0.000	62.422	-0.040	0.000	0.000	0.000	0.000	0.000
Q605	D	0.000	9.811	-0.026	0.000	0.000	0.000	-0.057	0.000	62.422	-0.040	0.000	0.000	0.000	0.000	0.000
Q604	F	17.289	59.382	-0.025	0.127	0.000	0.000	-0.098	0.002	11.099	0.064	0.114	0.000	0.000	0.000	0.000
Q603	D	34.577	10.318	0.027	0.250	0.000	0.000	0.000	0.006	54.981	0.045	0.237	0.000	0.000	0.000	0.000
Q602	F	51.866	56.249	0.024	0.377	0.000	0.000	0.097	0.002	10.148	-0.060	0.368	0.000	0.000	0.000	0.000
Q601	D	69.155	9.839	-0.028	0.508	0.000	0.000	0.057	0.000	62.044	-0.049	0.489	0.000	0.000	0.000	0.000
BENDDS_1		71.394	12.335	-0.913	0.542	0.000	0.000	0.061	0.003	52.036	3.187	0.495	0.000	0.000	0.000	0.000
BENDDS_2		75.458	22.211	-1.517	0.581	0.000	0.000	0.103	0.017	29.665	2.317	0.512	0.000	0.000	0.000	0.000
BENDDS_1		75.817	23.321	-1.571	0.584	0.000	0.000	0.109	0.017	28.028	2.240	0.514	0.000	0.000	0.000	0.000
BENDDS_2		79.882	38.541	-2.175	0.605	0.000	0.000	0.207	0.031	13.364	1.368	0.547	0.000	0.000	0.000	0.000
Q532	F	82.121	45.045	0.251	0.614	0.000	0.000	0.265	0.016	9.149	0.366	0.581	0.000	0.000	0.000	0.000
BENDDS_1		84.360	36.541	2.548	0.622	0.000	0.000	0.277	0.000	9.699	-0.433	0.620	0.000	0.000	0.000	0.000
BENDDS_2		88.424	19.216	1.715	0.647	0.000	0.000	0.305	0.014	15.234	-0.929	0.674	0.000	0.000	0.000	0.000
BENDDS_1		88.784	18.010	1.641	0.650	0.000	0.000	0.310	0.014	15.918	-0.973	0.678	0.000	0.000	0.000	0.000
BENDDS_2		92.848	8.058	0.808	0.705	0.000	0.000	0.394	0.028	25.845	-1.469	0.710	0.000	0.000	0.000	0.000
Q531	D	95.087	5.985	0.018	0.758	0.000	0.000	0.474	0.053	30.415	0.078	0.722	0.000	0.000	0.000	0.000
BENDDS_1		97.327	7.883	-0.763	0.812	0.000	0.000	0.639	0.084	25.221	1.586	0.735	0.000	0.000	0.000	0.000
BENDDS_2		101.391	17.400	-1.579	0.869	0.000	0.000	1.008	0.098	14.626	1.020	0.769	0.000	0.000	0.000	0.000
BENDDS_1		101.750	18.561	-1.651	0.872	0.000	0.000	1.043	0.098	13.911	0.970	0.773	0.000	0.000	0.000	0.000
BENDDS_2		105.814	35.294	-2.467	0.897	0.000	0.000	1.468	0.112	8.328	0.403	0.834	0.000	0.000	0.000	0.000
Q530	F	108.054	43.544	-0.252	0.906	0.000	0.000	1.648	0.016	7.884	-0.360	0.880	0.000	0.000	0.000	0.000
BENDDS_1		110.293	37.301	2.092	0.915	0.000	0.000	1.536	-0.082	11.931	-1.323	0.918	0.000	0.000	0.000	0.000
BENDDS_2		114.357	22.677	1.506	0.937	0.000	0.000	1.231	-0.068	26.487	-2.259	0.955	0.000	0.000	0.000	0.000
BENDDS_1		114.717	21.613	1.454	0.940	0.000	0.000	1.207	-0.068	28.140	-2.341	0.957	0.000	0.000	0.000	0.000
BENDDS_2		118.781	12.172	0.869	0.980	0.000	0.000	0.959	-0.054	50.968	-3.275	0.974	0.000	0.000	0.000	0.000
Q529	D	121.020	9.851	-0.007	1.014	0.000	0.000	0.876	-0.002	61.508	-0.107	0.980	0.000	0.000	0.000	0.000
BEND_1		123.389	12.067	-0.709	1.049	0.000	0.000	0.939	0.035	52.969	2.251	0.987	0.000	0.000	0.000	0.000
BEND_2		129.485	25.331	-1.468	1.106	0.000	0.000	1.216	0.056	29.761	1.555	1.011	0.000	0.000	0.000	0.000
BEND_1		129.844	26.402	-1.512	1.108	0.000	0.000	1.236	0.056	28.659	1.514	1.013	0.000	0.000	0.000	0.000
BEND_2		135.940	49.464	-2.271	1.135	0.000	0.000	1.640	0.077	14.464	0.814	1.062	0.000	0.000	0.000	0.000
SF		136.864	53.765	-2.386	1.138	0.000	0.000	1.711	0.077	13.058	0.708	1.072	0.000	0.000	0.000	0.000
Q528	F	138.309	58.247	-0.021	1.142	0.000	0.000	1.781	0.001	11.794	0.044	1.091	0.000	0.000	0.000	0.000
BEND_1		140.677	49.648	2.237	1.149	0.000	0.000	1.643	-0.076	14.008	-0.708	1.121	0.000	0.000	0.000	0.000
BEND_2		146.773	26.872	1.500	1.175	0.000	0.000	1.246	-0.055	26.622	-1.360	1.172	0.000	0.000	0.000	0.000
BEND_1		147.133	25.810	1.456	1.178	0.000	0.000	1.227	-0.055	27.614	-1.399	1.174	0.000	0.000	0.000	0.000
BEND_2		153.229	12.549	0.719	1.233	0.000	0.000	0.957	-0.034	48.631	-2.048	1.201	0.000	0.000	0.000	0.000
SD		154.152	11.323	0.608	1.245	0.000	0.000	0.926	-0.034	52.505	-2.147	1.204	0.000	0.000	0.000	0.000
Q527	D	155.597	10.282	0.008	1.267	0.000	0.000	0.897	0.004	56.395	0.110	1.208	0.000	0.000	0.000	0.000
BENDDS_1		157.837	12.655	-0.885	1.299	0.000	0.000	0.986	0.057	46.698	3.006	1.215	0.000	0.000	0.000	0.000
BENDDS_2		161.901	22.174	-1.457	1.338	0.000	0.000	1.248	0.071	25.811	2.134	1.234	0.000	0.000	0.000	0.000
BENDDS_1		162.260	23.240	-1.508	1.340	0.000	0.000	1.274	0.071	24.305	2.056	1.236	0.000	0.000	0.000	0.000
BENDDS_2		166.324	37.824	-2.081	1.362	0.000	0.000	1.592	0.085	11.141	1.182	1.276	0.000	0.000	0.000	0.000
Q526	F	168.563	43.959	0.296	1.371	0.000	0.000	1.709	-0.016	7.616	0.268	1.316	0.000	0.000	0.000	0.000
BENDDS_1		170.803	35.464	2.521	1.380	0.000	0.000	1.523	-0.115	8.454	-0.497	1.362	0.000	0.000	0.000	0.000

"MAD" Version: 8.17 Run: 22/04/92 14.44.56
Range: #S/#E

Linear lattice functions for beam line: MI17

delta(p)/p = 0.000000 symm = F

ELEMENT SEQUENCE			HORIZONTAL								VERTICAL						
element name	quad type	dist [m]	betax [m]	alfax [1]	mux [2pi]	x(co) [mm]	px(co) [.001]	Dx [m]	Dpx [1]	betay [m]	alfay [1]	muy [2pi]	y(co) [mm]	py(co) [.001]	Dy [m]	Dpy [1]
BENDDS_2		174.867	18.398	1.678	1.405	0.000	0.000	1.083	-0.101	14.923	-1.095	1.421	0.000	0.000	0.000	0.000
BENDDS_1		175.226	17.218	1.604	1.408	0.000	0.000	1.046	-0.101	15.729	-1.148	1.424	0.000	0.000	0.000	0.000
BENDDS_2		179.290	7.610	0.761	1.466	0.000	0.000	0.662	-0.088	27.491	-1.746	1.456	0.000	0.000	0.000	0.000
Q525	D	181.530	5.735	-0.021	1.522	0.000	0.000	0.490	-0.056	33.199	-0.088	1.467	0.000	0.000	0.000	0.000
BENDDS_1		183.769	7.815	-0.813	1.578	0.000	0.000	0.404	-0.030	28.196	1.614	1.479	0.000	0.000	0.000	0.000
BENDDS_2		187.833	17.932	-1.677	1.634	0.000	0.000	0.312	-0.016	17.187	1.095	1.508	0.000	0.000	0.000	0.000
BENDDS_1		188.193	19.165	-1.753	1.637	0.000	0.000	0.306	-0.016	16.417	1.049	1.512	0.000	0.000	0.000	0.000
BENDDS_2		192.257	36.923	-2.617	1.661	0.000	0.000	0.270	-0.002	10.001	0.529	1.563	0.000	0.000	0.000	0.000
Q524	F	194.496	45.716	-0.295	1.670	0.000	0.000	0.254	-0.018	9.044	-0.275	1.602	0.000	0.000	0.000	0.000
BENDDS_1		196.736	39.276	2.177	1.678	0.000	0.000	0.194	-0.032	12.759	-1.233	1.636	0.000	0.000	0.000	0.000
BENDDS_2		200.800	23.993	1.583	1.699	0.000	0.000	0.093	-0.018	26.043	-2.035	1.672	0.000	0.000	0.000	0.000
BENDDS_1		201.159	22.874	1.531	1.702	0.000	0.000	0.086	-0.018	27.532	-2.106	1.674	0.000	0.000	0.000	0.000
BENDDS_2		205.223	12.845	0.937	1.740	0.000	0.000	0.042	-0.004	47.904	-2.906	1.692	0.000	0.000	0.000	0.000
Q523	D	207.463	10.269	0.033	1.772	0.000	0.000	0.035	-0.002	57.000	0.066	1.699	0.000	0.000	0.000	0.000
Q522	F	224.751	55.907	0.019	1.900	0.000	0.000	0.028	-0.002	9.929	-0.025	1.828	0.000	0.000	0.000	0.000
MI52		233.396	24.945	1.418	1.936	0.000	0.000	0.005	-0.003	26.587	-1.536	1.919	0.000	0.000	0.000	0.000
Q521	D	242.040	9.893	-0.034	2.031	0.000	0.000	-0.019	-0.003	59.897	-0.068	1.953	0.000	0.000	0.000	0.000
Q520	F	259.329	59.859	-0.017	2.157	0.000	0.000	-0.091	0.000	11.376	0.020	2.069	0.000	0.000	0.000	0.000
BENDDS_1		261.568	49.884	3.156	2.163	0.000	0.000	-0.084	0.005	13.890	-0.935	2.098	0.000	0.000	0.000	0.000
BENDDS_2		265.632	27.860	2.263	2.181	0.000	0.000	-0.036	0.019	23.719	-1.483	2.134	0.000	0.000	0.000	0.000
BENDDS_1		265.992	26.262	2.184	2.183	0.000	0.000	-0.029	0.019	24.802	-1.531	2.136	0.000	0.000	0.000	0.000
BENDDS_2		270.056	12.139	1.291	2.219	0.000	0.000	0.076	0.033	39.470	-2.078	2.157	0.000	0.000	0.000	0.000
Q519	D	272.295	8.190	0.344	2.256	0.000	0.000	0.154	0.040	45.506	0.348	2.165	0.000	0.000	0.000	0.000
BENDDS_1		274.534	8.705	-0.417	2.300	0.000	0.000	0.260	0.051	36.695	2.598	2.174	0.000	0.000	0.000	0.000
BENDDS_2		278.599	14.322	-0.965	2.359	0.000	0.000	0.495	0.065	19.061	1.741	2.198	0.000	0.000	0.000	0.000
BENDDS_1		278.958	15.033	-1.014	2.363	0.000	0.000	0.519	0.065	17.838	1.665	2.201	0.000	0.000	0.000	0.000
BENDDS_2		283.022	25.499	-1.562	2.396	0.000	0.000	0.810	0.079	7.797	0.806	2.257	0.000	0.000	0.000	0.000
Q518	F	285.261	30.489	0.002	2.409	0.000	0.000	0.947	0.024	5.755	0.008	2.313	0.000	0.000	0.000	0.000
BENDDS_1		287.501	25.482	1.565	2.421	0.000	0.000	0.916	-0.032	7.720	-0.786	2.369	0.000	0.000	0.000	0.000
BENDDS_2		291.565	14.998	1.015	2.455	0.000	0.000	0.813	-0.019	17.568	-1.637	2.426	0.000	0.000	0.000	0.000
BENDDS_1		291.924	14.286	0.966	2.459	0.000	0.000	0.806	-0.019	18.772	-1.712	2.429	0.000	0.000	0.000	0.000
BENDDS_2		295.988	8.668	0.416	2.518	0.000	0.000	0.759	-0.005	36.144	-2.562	2.454	0.000	0.000	0.000	0.000
Q517	D	298.228	8.157	-0.344	2.562	0.000	0.000	0.781	0.040	44.840	-0.347	2.462	0.000	0.000	0.000	0.000
BENDDS_1		300.467	12.103	-1.291	2.599	0.000	0.000	0.942	0.088	38.914	2.042	2.471	0.000	0.000	0.000	0.000
BENDDS_2		304.531	26.229	-2.186	2.636	0.000	0.000	1.327	0.102	24.503	1.503	2.492	0.000	0.000	0.000	0.000
BENDDS_1		304.891	27.829	-2.265	2.638	0.000	0.000	1.363	0.102	23.439	1.456	2.494	0.000	0.000	0.000	0.000
BENDDS_2		308.955	49.873	-3.160	2.655	0.000	0.000	1.805	0.116	13.802	0.915	2.530	0.000	0.000	0.000	0.000
Q516	F	311.194	59.866	0.013	2.662	0.000	0.000	1.978	-0.001	11.366	-0.035	2.560	0.000	0.000	0.000	0.000
BEND_1		313.563	50.875	2.329	2.668	0.000	0.000	1.822	-0.085	13.939	-0.792	2.590	0.000	0.000	0.000	0.000
BEND_2		319.659	27.175	1.559	2.695	0.000	0.000	1.366	-0.064	27.921	-1.501	2.640	0.000	0.000	0.000	0.000
BEND_1		320.018	26.071	1.514	2.697	0.000	0.000	1.343	-0.064	29.015	-1.543	2.642	0.000	0.000	0.000	0.000
BEND_2		326.114	12.307	0.744	2.752	0.000	0.000	1.015	-0.043	52.145	-2.250	2.667	0.000	0.000	0.000	0.000
SD		327.038	11.040	0.628	2.765	0.000	0.000	0.975	-0.043	56.400	-2.358	2.670	0.000	0.000	0.000	0.000
Q515	D	328.483	9.937	0.035	2.787	0.000	0.000	0.934	-0.004	60.725	0.070	2.674	0.000	0.000	0.000	0.000
BEND_1		330.851	11.948	-0.661	2.822	0.000	0.000	0.998	0.036	51.540	2.363	2.681	0.000	0.000	0.000	0.000

ELEMENT SEQUENCE		I	HORIZONTAL							I	VERTICAL						
element name	quad type	dist [m]	betax [m]	alfax [1]	mux [2pi]	x(co) [mm]	px(co) [.001]	Dx [m]	Dpx [1]		betay [m]	alfay [1]	muy [2pi]	y(co) [mm]	py(co) [.001]	Dy [m]	Dpy [1]
BEND_2		336.947	24.473	-1.394	2.880	0.000	0.000	1.280	0.057		27.459	1.586	2.707	0.000	0.000	0.000	0.000
BEND_1		337.307	25.491	-1.437	2.883	0.000	0.000	1.300	0.057		26.335	1.540	2.709	0.000	0.000	0.000	0.000
BEND_2		343.403	47.479	-2.170	2.911	0.000	0.000	1.710	0.078		12.308	0.760	2.764	0.000	0.000	0.000	0.000
SF		344.326	51.590	-2.281	2.914	0.000	0.000	1.781	0.078		11.013	0.642	2.776	0.000	0.000	0.000	0.000
Q514	F	345.771	55.869	-0.014	2.918	0.000	0.000	1.852	-0.002		9.881	0.040	2.799	0.000	0.000	0.000	0.000
BEND_1		348.140	47.603	2.147	2.925	0.000	0.000	1.703	-0.081		11.895	-0.664	2.834	0.000	0.000	0.000	0.000
BEND_2		354.236	25.805	1.429	2.953	0.000	0.000	1.275	-0.060		24.490	-1.401	2.892	0.000	0.000	0.000	0.000
BEND_1		354.595	24.793	1.386	2.955	0.000	0.000	1.253	-0.060		25.513	-1.445	2.895	0.000	0.000	0.000	0.000
BEND_2		360.691	12.270	0.668	3.012	0.000	0.000	0.953	-0.039		47.609	-2.179	2.923	0.000	0.000	0.000	0.000
SD		361.615	11.137	0.559	3.025	0.000	0.000	0.917	-0.039		51.737	-2.291	2.926	0.000	0.000	0.000	0.000
Q513	D	363.060	10.226	-0.034	3.046	0.000	0.000	0.881	-0.001		56.091	-0.068	2.930	0.000	0.000	0.000	0.000
BEND_1		365.428	12.622	-0.750	3.080	0.000	0.000	0.946	0.036		48.192	2.070	2.937	0.000	0.000	0.000	0.000
BEND_2		371.524	26.357	-1.504	3.135	0.000	0.000	1.228	0.057		27.012	1.403	2.964	0.000	0.000	0.000	0.000
BEND_1		371.883	27.453	-1.548	3.137	0.000	0.000	1.248	0.057		26.018	1.364	2.966	0.000	0.000	0.000	0.000
BEND_2		377.979	50.926	-2.302	3.163	0.000	0.000	1.658	0.078		13.467	0.695	3.019	0.000	0.000	0.000	0.000
SF		378.903	55.284	-2.417	3.166	0.000	0.000	1.729	0.078		12.278	0.593	3.030	0.000	0.000	0.000	0.000
Q512	F	380.348	59.782	0.016	3.170	0.000	0.000	1.800	0.001		11.312	-0.044	3.050	0.000	0.000	0.000	0.000
BEND_1		382.716	50.788	2.328	3.176	0.000	0.000	1.661	-0.076		13.925	-0.801	3.081	0.000	0.000	0.000	0.000
BEND_2		388.812	27.101	1.558	3.203	0.000	0.000	1.259	-0.055		28.065	-1.518	3.131	0.000	0.000	0.000	0.000
BEND_1		389.172	25.998	1.512	3.205	0.000	0.000	1.240	-0.055		29.171	-1.560	3.133	0.000	0.000	0.000	0.000
BEND_2		395.268	12.260	0.742	3.260	0.000	0.000	0.965	-0.035		52.552	-2.274	3.158	0.000	0.000	0.000	0.000
SD		396.191	10.998	0.625	3.273	0.000	0.000	0.933	-0.035		56.853	-2.383	3.160	0.000	0.000	0.000	0.000
Q511	D	397.636	9.902	0.033	3.295	0.000	0.000	0.904	0.004		61.231	0.065	3.164	0.000	0.000	0.000	0.000
BEND_1		400.005	11.918	-0.662	3.331	0.000	0.000	0.983	0.042		51.994	2.379	3.171	0.000	0.000	0.000	0.000
BEND_2		406.101	24.473	-1.398	3.389	0.000	0.000	1.304	0.063		27.734	1.600	3.196	0.000	0.000	0.000	0.000
BEND_1		406.460	25.493	-1.441	3.391	0.000	0.000	1.327	0.063		26.601	1.554	3.199	0.000	0.000	0.000	0.000
BEND_2		412.556	47.545	-2.177	3.419	0.000	0.000	1.775	0.084		12.419	0.772	3.253	0.000	0.000	0.000	0.000
SF		413.480	51.669	-2.288	3.422	0.000	0.000	1.852	0.084		11.103	0.653	3.266	0.000	0.000	0.000	0.000
Q510	F	414.925	55.964	-0.018	3.426	0.000	0.000	1.930	0.002		9.941	0.048	3.288	0.000	0.000	0.000	0.000
BEND_1		417.293	47.698	2.148	3.433	0.000	0.000	1.782	-0.081		11.918	-0.655	3.323	0.000	0.000	0.000	0.000
BEND_2		423.389	25.882	1.431	3.461	0.000	0.000	1.352	-0.060		24.360	-1.385	3.381	0.000	0.000	0.000	0.000
BEND_1		423.749	24.869	1.388	3.463	0.000	0.000	1.330	-0.060		25.372	-1.428	3.384	0.000	0.000	0.000	0.000
BEND_2		429.845	12.317	0.671	3.520	0.000	0.000	1.027	-0.039		47.222	-2.155	3.412	0.000	0.000	0.000	0.000
SD		430.768	11.178	0.562	3.533	0.000	0.000	0.991	-0.039		51.305	-2.266	3.415	0.000	0.000	0.000	0.000
Q509	D	432.213	10.260	-0.032	3.554	0.000	0.000	0.956	0.001		55.606	-0.062	3.419	0.000	0.000	0.000	0.000
BEND_1		434.582	12.650	-0.748	3.588	0.000	0.000	1.033	0.042		47.754	2.056	3.426	0.000	0.000	0.000	0.000
BEND_2		440.678	26.352	-1.500	3.642	0.000	0.000	1.352	0.063		26.740	1.390	3.454	0.000	0.000	0.000	0.000
BEND_1		441.037	27.446	-1.544	3.645	0.000	0.000	1.375	0.063		25.755	1.351	3.456	0.000	0.000	0.000	0.000
BEND_2		447.133	50.851	-2.296	3.671	0.000	0.000	1.821	0.084		13.352	0.683	3.509	0.000	0.000	0.000	0.000
SF		448.057	55.196	-2.409	3.673	0.000	0.000	1.898	0.084		12.184	0.582	3.521	0.000	0.000	0.000	0.000
Q508	F	449.502	59.676	0.019	3.677	0.000	0.000	1.974	-0.001		11.247	-0.052	3.541	0.000	0.000	0.000	0.000
BEND_1		451.870	50.684	2.327	3.684	0.000	0.000	1.817	-0.085		13.894	-0.809	3.571	0.000	0.000	0.000	0.000
BEND_2		457.966	27.021	1.555	3.711	0.000	0.000	1.362	-0.064		28.179	-1.534	3.621	0.000	0.000	0.000	0.000
BEND_1		458.326	25.919	1.510	3.713	0.000	0.000	1.339	-0.064		29.296	-1.576	3.623	0.000	0.000	0.000	0.000
BEND_2		464.422	12.214	0.739	3.768	0.000	0.000	1.011	-0.043		52.917	-2.298	3.648	0.000	0.000	0.000	0.000

Linear lattice functions for beam line: MI17
delta(p)/p = 0.000000 symm = F

ELEMENT SEQUENCE element name	quad type	dist [m]	HORIZONTAL betax [m]	alfax [1]	mux [2pi]	x(co) [mm]	px(co) [.001]	Dx [m]	Dpx [1]	VERTICAL betay [m]	alfay [1]	muy [2pi]	y(co) [mm]	py(co) [.001]	Dy [m]	Dpy [1]
SD		465.345	10.957	0.622	3.781	0.000	0.000	0.971	-0.043	57.263	-2.407	3.651	0.000	0.000	0.000	0.000
Q507	D	466.790	9.869	0.031	3.803	0.000	0.000	0.930	-0.004	61.693	0.058	3.655	0.000	0.000	0.000	0.000
BEND_1		469.159	11.891	-0.664	3.839	0.000	0.000	0.993	0.036	52.415	2.392	3.661	0.000	0.000	0.000	0.000
BEND_2		475.255	24.482	-1.402	3.897	0.000	0.000	1.274	0.056	28.002	1.612	3.686	0.000	0.000	0.000	0.000
BEND_1		475.614	25.505	-1.446	3.900	0.000	0.000	1.294	0.056	26.860	1.566	3.689	0.000	0.000	0.000	0.000
BEND_2		481.710	47.629	-2.184	3.928	0.000	0.000	1.701	0.077	12.538	0.783	3.742	0.000	0.000	0.000	0.000
SF		482.633	51.766	-2.296	3.930	0.000	0.000	1.773	0.077	11.201	0.664	3.755	0.000	0.000	0.000	0.000
Q506	F	484.078	56.079	-0.021	3.935	0.000	0.000	1.843	-0.001	10.011	0.056	3.777	0.000	0.000	0.000	0.000
BEND_1		486.447	47.809	2.150	3.942	0.000	0.000	1.695	-0.080	11.957	-0.648	3.812	0.000	0.000	0.000	0.000
BEND_2		492.543	25.965	1.433	3.970	0.000	0.000	1.270	-0.059	24.262	-1.370	3.870	0.000	0.000	0.000	0.000
BEND_1		492.902	24.950	1.391	3.972	0.000	0.000	1.248	-0.059	25.262	-1.413	3.873	0.000	0.000	0.000	0.000
BEND_2		498.998	12.363	0.674	4.028	0.000	0.000	0.950	-0.038	46.880	-2.133	3.901	0.000	0.000	0.000	0.000
SD		499.922	11.219	0.565	4.041	0.000	0.000	0.915	-0.038	50.920	-2.242	3.904	0.000	0.000	0.000	0.000
Q505	D	501.367	10.292	-0.030	4.062	0.000	0.000	0.879	-0.001	55.169	-0.055	3.908	0.000	0.000	0.000	0.000
BEND_1		503.735	12.675	-0.746	4.096	0.000	0.000	0.945	0.036	47.353	2.044	3.916	0.000	0.000	0.000	0.000
BEND_2		509.831	26.338	-1.495	4.150	0.000	0.000	1.229	0.057	26.477	1.379	3.943	0.000	0.000	0.000	0.000
BEND_1		510.191	27.429	-1.539	4.152	0.000	0.000	1.250	0.057	25.500	1.340	3.945	0.000	0.000	0.000	0.000
BEND_2		516.287	50.759	-2.288	4.179	0.000	0.000	1.661	0.078	13.230	0.672	3.999	0.000	0.000	0.000	0.000
SF		517.210	55.090	-2.402	4.181	0.000	0.000	1.733	0.078	12.081	0.571	4.011	0.000	0.000	0.000	0.000
Q504	F	518.655	59.552	0.023	4.185	0.000	0.000	1.805	0.001	11.171	-0.059	4.031	0.000	0.000	0.000	0.000
BEND_1		521.024	50.566	2.324	4.192	0.000	0.000	1.665	-0.076	13.847	-0.816	4.062	0.000	0.000	0.000	0.000
BEND_2		527.120	26.935	1.552	4.219	0.000	0.000	1.264	-0.055	28.261	-1.548	4.112	0.000	0.000	0.000	0.000
BEND_1		527.479	25.835	1.507	4.221	0.000	0.000	1.244	-0.055	29.389	-1.591	4.114	0.000	0.000	0.000	0.000
BEND_2		533.575	12.168	0.735	4.277	0.000	0.000	0.969	-0.035	53.234	-2.320	4.138	0.000	0.000	0.000	0.000
SD		534.499	10.918	0.618	4.289	0.000	0.000	0.937	-0.035	57.621	-2.430	4.141	0.000	0.000	0.000	0.000
Q503	D	535.944	9.838	0.029	4.312	0.000	0.000	0.908	0.004	62.103	0.051	4.145	0.000	0.000	0.000	0.000
BEND_1		538.312	11.868	-0.666	4.348	0.000	0.000	0.988	0.042	52.795	2.402	4.151	0.000	0.000	0.000	0.000
BEND_2		544.408	24.501	-1.407	4.406	0.000	0.000	1.311	0.063	28.259	1.622	4.177	0.000	0.000	0.000	0.000
BEND_1		544.768	25.528	-1.450	4.408	0.000	0.000	1.333	0.063	27.109	1.576	4.179	0.000	0.000	0.000	0.000
BEND_2		550.864	47.729	-2.192	4.436	0.000	0.000	1.783	0.084	12.663	0.793	4.232	0.000	0.000	0.000	0.000
SF		551.787	51.881	-2.304	4.439	0.000	0.000	1.861	0.084	11.307	0.675	4.244	0.000	0.000	0.000	0.000
Q502	F	553.232	56.213	-0.024	4.443	0.000	0.000	1.938	0.001	10.092	0.063	4.266	0.000	0.000	0.000	0.000
BEND_1		555.601	47.935	2.153	4.450	0.000	0.000	1.790	-0.081	12.011	-0.642	4.301	0.000	0.000	0.000	0.000
BEND_2		561.697	26.054	1.436	4.478	0.000	0.000	1.357	-0.061	24.196	-1.357	4.359	0.000	0.000	0.000	0.000
BEND_1		562.056	25.037	1.394	4.480	0.000	0.000	1.335	-0.061	25.186	-1.399	4.362	0.000	0.000	0.000	0.000
BEND_2		568.152	12.408	0.677	4.536	0.000	0.000	1.029	-0.040	46.590	-2.111	4.390	0.000	0.000	0.000	0.000
SD		569.076	11.257	0.569	4.549	0.000	0.000	0.993	-0.040	50.589	-2.220	4.393	0.000	0.000	0.000	0.000
Q501	D	570.521	10.322	-0.028	4.570	0.000	0.000	0.957	0.001	54.788	-0.047	4.398	0.000	0.000	0.000	0.000
MI50		570.521	10.322	-0.028	4.570	0.000	0.000	0.957	0.001	54.788	-0.047	4.398	0.000	0.000	0.000	0.000
BEND_1		572.889	12.695	-0.744	4.604	0.000	0.000	1.034	0.042	46.994	2.036	4.405	0.000	0.000	0.000	0.000
BEND_2		578.985	26.314	-1.490	4.658	0.000	0.000	1.351	0.062	26.228	1.370	4.433	0.000	0.000	0.000	0.000
BEND_1		579.344	27.401	-1.534	4.660	0.000	0.000	1.373	0.062	25.257	1.331	4.435	0.000	0.000	0.000	0.000
BEND_2		585.440	50.651	-2.280	4.686	0.000	0.000	1.817	0.083	13.102	0.663	4.489	0.000	0.000	0.000	0.000
SF		586.364	54.967	-2.393	4.689	0.000	0.000	1.894	0.083	11.972	0.561	4.501	0.000	0.000	0.000	0.000
Q430	F	587.809	59.410	0.025	4.693	0.000	0.000	1.969	-0.001	11.086	-0.066	4.521	0.000	0.000	0.000	0.000

ELEMENT SEQUENCE		I	HORIZONTAL							I	VERTICAL						
element name	quad type	dist [m]	betax [m]	alfax [1]	mux [2pi]	x(co) [mm]	px(co) [.001]	Dx [m]	Dpx [1]		betay [m]	alfay [1]	muy [2pi]	y(co) [mm]	py(co) [.001]	Dy [m]	Dpy [1]
BEND_1		590.177	50.433	2.321	4.700	0.000	0.000	1.813	-0.085		13.785	-0.822	4.552	0.000	0.000	0.000	0.000
BEND_2		596.273	26.844	1.549	4.727	0.000	0.000	1.358	-0.064		28.310	-1.561	4.602	0.000	0.000	0.000	0.000
BEND_1		596.633	25.747	1.503	4.729	0.000	0.000	1.335	-0.064		29.448	-1.604	4.604	0.000	0.000	0.000	0.000
BEND_2		602.729	12.123	0.732	4.785	0.000	0.000	1.007	-0.043		53.498	-2.340	4.629	0.000	0.000	0.000	0.000
SD		603.652	10.880	0.615	4.798	0.000	0.000	0.967	-0.043		57.924	-2.452	4.632	0.000	0.000	0.000	0.000
Q429	D	605.097	9.810	0.026	4.820	0.000	0.000	0.926	-0.004		62.455	0.043	4.635	0.000	0.000	0.000	0.000
BEND_1		607.466	11.850	-0.668	4.856	0.000	0.000	0.989	0.035		53.130	2.409	4.642	0.000	0.000	0.000	0.000
BEND_2		613.562	24.529	-1.412	4.914	0.000	0.000	1.267	0.056		28.500	1.630	4.667	0.000	0.000	0.000	0.000
BEND_1		613.921	25.560	-1.456	4.916	0.000	0.000	1.288	0.056		27.344	1.584	4.669	0.000	0.000	0.000	0.000
BEND_2		620.017	47.845	-2.200	4.944	0.000	0.000	1.693	0.077		12.792	0.803	4.722	0.000	0.000	0.000	0.000
SF		620.941	52.012	-2.313	4.947	0.000	0.000	1.765	0.077		11.419	0.684	4.734	0.000	0.000	0.000	0.000
Q428	F	622.386	56.363	-0.027	4.951	0.000	0.000	1.834	-0.001		10.181	0.068	4.756	0.000	0.000	0.000	0.000
BEND_1		624.754	48.075	2.157	4.959	0.000	0.000	1.687	-0.080		12.080	-0.637	4.790	0.000	0.000	0.000	0.000
BEND_2		630.850	26.147	1.440	4.986	0.000	0.000	1.265	-0.059		24.164	-1.345	4.848	0.000	0.000	0.000	0.000
BEND_1		631.210	25.127	1.398	4.988	0.000	0.000	1.244	-0.059		25.145	-1.387	4.851	0.000	0.000	0.000	0.000
BEND_2		637.306	12.452	0.681	5.044	0.000	0.000	0.948	-0.038		46.354	-2.092	4.879	0.000	0.000	0.000	0.000
SD		638.229	11.294	0.573	5.057	0.000	0.000	0.913	-0.038		50.317	-2.199	4.882	0.000	0.000	0.000	0.000
Q427	D	639.674	10.349	-0.025	5.078	0.000	0.000	0.878	-0.001		54.468	-0.038	4.887	0.000	0.000	0.000	0.000
BEND_1		642.043	12.712	-0.741	5.112	0.000	0.000	0.945	0.037		46.685	2.030	4.894	0.000	0.000	0.000	0.000
BEND_2		648.139	26.281	-1.485	5.166	0.000	0.000	1.232	0.057		25.996	1.363	4.922	0.000	0.000	0.000	0.000
BEND_1		648.498	27.364	-1.528	5.168	0.000	0.000	1.252	0.057		25.030	1.324	4.924	0.000	0.000	0.000	0.000
BEND_2		654.594	50.528	-2.272	5.194	0.000	0.000	1.666	0.078		12.972	0.654	4.979	0.000	0.000	0.000	0.000
SF		655.518	54.828	-2.384	5.197	0.000	0.000	1.738	0.078		11.857	0.552	4.991	0.000	0.000	0.000	0.000
Q426	F	656.963	59.252	0.028	5.201	0.000	0.000	1.810	0.001		10.993	-0.071	5.012	0.000	0.000	0.000	0.000
BEND_1		659.331	50.287	2.317	5.208	0.000	0.000	1.670	-0.076		13.709	-0.826	5.043	0.000	0.000	0.000	0.000
BEND_2		665.427	26.749	1.545	5.235	0.000	0.000	1.268	-0.056		28.326	-1.572	5.093	0.000	0.000	0.000	0.000
BEND_1		665.787	25.655	1.499	5.237	0.000	0.000	1.248	-0.056		29.471	-1.616	5.095	0.000	0.000	0.000	0.000
BEND_2		671.883	12.080	0.728	5.293	0.000	0.000	0.973	-0.035		53.704	-2.359	5.119	0.000	0.000	0.000	0.000
SD		672.806	10.844	0.611	5.306	0.000	0.000	0.941	-0.035		58.165	-2.472	5.122	0.000	0.000	0.000	0.000
Q425	D	674.251	9.784	0.024	5.329	0.000	0.000	0.912	0.004		62.742	0.034	5.126	0.000	0.000	0.000	0.000
BEND_1		676.620	11.836	-0.671	5.364	0.000	0.000	0.992	0.043		53.412	2.413	5.132	0.000	0.000	0.000	0.000
BEND_2		682.716	24.567	-1.418	5.423	0.000	0.000	1.317	0.064		28.721	1.636	5.157	0.000	0.000	0.000	0.000
BEND_1		683.075	25.602	-1.462	5.425	0.000	0.000	1.339	0.064		27.561	1.590	5.159	0.000	0.000	0.000	0.000
BEND_2		689.171	47.975	-2.209	5.453	0.000	0.000	1.791	0.084		12.923	0.810	5.211	0.000	0.000	0.000	0.000
SF		690.094	52.158	-2.322	5.456	0.000	0.000	1.869	0.084		11.535	0.692	5.224	0.000	0.000	0.000	0.000
Q424	F	691.539	56.529	-0.029	5.460	0.000	0.000	1.947	0.001		10.277	0.073	5.245	0.000	0.000	0.000	0.000
BEND_1		693.908	48.226	2.162	5.467	0.000	0.000	1.797	-0.082		12.163	-0.634	5.280	0.000	0.000	0.000	0.000
BEND_2		700.004	26.243	1.445	5.494	0.000	0.000	1.361	-0.061		24.165	-1.335	5.337	0.000	0.000	0.000	0.000
BEND_1		700.363	25.220	1.402	5.497	0.000	0.000	1.340	-0.061		25.140	-1.376	5.340	0.000	0.000	0.000	0.000
BEND_2		706.459	12.494	0.685	5.552	0.000	0.000	1.031	-0.040		46.179	-2.075	5.368	0.000	0.000	0.000	0.000
SD		707.383	11.329	0.577	5.565	0.000	0.000	0.994	-0.040		50.108	-2.181	5.371	0.000	0.000	0.000	0.000
Q423	D	708.828	10.373	-0.022	5.586	0.000	0.000	0.958	0.000		54.215	-0.029	5.376	0.000	0.000	0.000	0.000
BEND_1		711.196	12.723	-0.738	5.620	0.000	0.000	1.034	0.041		46.430	2.028	5.383	0.000	0.000	0.000	0.000
BEND_2		717.292	26.239	-1.479	5.674	0.000	0.000	1.348	0.062		25.786	1.358	5.411	0.000	0.000	0.000	0.000
BEND_1		717.652	27.318	-1.522	5.676	0.000	0.000	1.370	0.062		24.824	1.319	5.414	0.000	0.000	0.000	0.000

Linear lattice functions for beam line: MI17
delta(p)/p = 0.000000 symm = F

ELEMENT SEQUENCE element name	quad type	dist [m]	HORIZONTAL betax [m]	alfax [1]	mux [2pi]	x(co) [mm]	px(co) [.001]	Dx [m]	Dpx [1]	VERTICAL betay [m]	alfay [1]	muy [2pi]	y(co) [mm]	py(co) [.001]	Dy [m]	Dpy [1]
BEND_2		723.748	50.391	-2.263	5.702	0.000	0.000	1.812	0.083	12.840	0.647	5.469	0.000	0.000	0.000	0.000
SF		724.671	54.674	-2.375	5.705	0.000	0.000	1.888	0.083	11.740	0.545	5.481	0.000	0.000	0.000	0.000
Q422	F	726.116	59.078	0.030	5.709	0.000	0.000	1.964	-0.001	10.894	-0.075	5.502	0.000	0.000	0.000	0.000
BEND_1		728.485	50.130	2.312	5.716	0.000	0.000	1.807	-0.085	13.620	-0.828	5.533	0.000	0.000	0.000	0.000
BEND_2		734.581	26.651	1.540	5.743	0.000	0.000	1.353	-0.064	28.307	-1.581	5.584	0.000	0.000	0.000	0.000
BEND_1		734.940	25.561	1.495	5.745	0.000	0.000	1.330	-0.064	29.459	-1.625	5.586	0.000	0.000	0.000	0.000
BEND_2		741.036	12.039	0.723	5.801	0.000	0.000	1.003	-0.043	53.849	-2.375	5.610	0.000	0.000	0.000	0.000
SD		741.960	10.811	0.607	5.814	0.000	0.000	0.963	-0.043	58.340	-2.489	5.613	0.000	0.000	0.000	0.000
Q421	D	743.405	9.761	0.020	5.837	0.000	0.000	0.922	-0.004	62.960	0.024	5.616	0.000	0.000	0.000	0.000
BEND_1		745.773	11.827	-0.674	5.873	0.000	0.000	0.984	0.035	53.639	2.414	5.623	0.000	0.000	0.000	0.000
BEND_2		751.869	24.614	-1.424	5.931	0.000	0.000	1.261	0.056	28.919	1.640	5.647	0.000	0.000	0.000	0.000
BEND_1		752.229	25.653	-1.468	5.933	0.000	0.000	1.282	0.056	27.757	1.594	5.649	0.000	0.000	0.000	0.000
BEND_2		758.325	48.118	-2.218	5.961	0.000	0.000	1.686	0.077	13.054	0.817	5.701	0.000	0.000	0.000	0.000
SF		759.248	52.318	-2.331	5.964	0.000	0.000	1.757	0.077	11.654	0.699	5.713	0.000	0.000	0.000	0.000
Q420	F	760.693	56.709	-0.031	5.968	0.000	0.000	1.826	-0.001	10.379	0.077	5.735	0.000	0.000	0.000	0.000
BEND_1		763.062	48.388	2.167	5.975	0.000	0.000	1.680	-0.079	12.259	-0.632	5.769	0.000	0.000	0.000	0.000
BEND_2		769.158	26.342	1.450	6.003	0.000	0.000	1.260	-0.058	24.201	-1.327	5.826	0.000	0.000	0.000	0.000
BEND_1		769.517	25.316	1.407	6.005	0.000	0.000	1.239	-0.058	25.170	-1.368	5.829	0.000	0.000	0.000	0.000
BEND_2		775.613	12.534	0.690	6.060	0.000	0.000	0.947	-0.038	46.066	-2.060	5.857	0.000	0.000	0.000	0.000
SD		776.537	11.361	0.581	6.073	0.000	0.000	0.912	-0.038	49.967	-2.165	5.860	0.000	0.000	0.000	0.000
Q419	D	777.982	10.394	-0.019	6.094	0.000	0.000	0.878	0.000	54.032	-0.019	5.865	0.000	0.000	0.000	0.000
BEND_1		780.350	12.730	-0.735	6.128	0.000	0.000	0.946	0.037	46.233	2.028	5.872	0.000	0.000	0.000	0.000
BEND_2		786.446	26.188	-1.473	6.182	0.000	0.000	1.234	0.058	25.601	1.356	5.901	0.000	0.000	0.000	0.000
BEND_1		786.805	27.262	-1.516	6.184	0.000	0.000	1.255	0.058	24.641	1.316	5.903	0.000	0.000	0.000	0.000
BEND_2		792.901	50.242	-2.254	6.210	0.000	0.000	1.671	0.079	12.710	0.641	5.959	0.000	0.000	0.000	0.000
SF		793.825	54.508	-2.366	6.213	0.000	0.000	1.744	0.079	11.621	0.538	5.971	0.000	0.000	0.000	0.000
Q418	F	795.270	58.892	0.032	6.217	0.000	0.000	1.816	0.001	10.790	-0.078	5.992	0.000	0.000	0.000	0.000
BEND_1		797.638	49.964	2.306	6.224	0.000	0.000	1.676	-0.077	13.519	-0.829	6.024	0.000	0.000	0.000	0.000
BEND_2		803.734	26.552	1.535	6.251	0.000	0.000	1.274	-0.056	28.254	-1.588	6.074	0.000	0.000	0.000	0.000
BEND_1		804.094	25.465	1.490	6.253	0.000	0.000	1.254	-0.056	29.411	-1.633	6.076	0.000	0.000	0.000	0.000
BEND_2		810.190	12.001	0.719	6.310	0.000	0.000	0.978	-0.035	53.930	-2.389	6.101	0.000	0.000	0.000	0.000
SD		811.113	10.780	0.602	6.323	0.000	0.000	0.946	-0.035	58.448	-2.503	6.103	0.000	0.000	0.000	0.000
Q417	D	812.558	9.742	0.017	6.345	0.000	0.000	0.916	0.004	63.106	0.014	6.107	0.000	0.000	0.000	0.000
BEND_1		814.927	11.822	-0.678	6.381	0.000	0.000	0.997	0.043	53.805	2.412	6.113	0.000	0.000	0.000	0.000
BEND_2		821.023	24.669	-1.430	6.439	0.000	0.000	1.322	0.064	29.091	1.641	6.138	0.000	0.000	0.000	0.000
BEND_1		821.382	25.713	-1.474	6.442	0.000	0.000	1.345	0.064	27.927	1.596	6.140	0.000	0.000	0.000	0.000
BEND_2		827.478	48.272	-2.227	6.469	0.000	0.000	1.798	0.085	13.183	0.822	6.191	0.000	0.000	0.000	0.000
SF		828.402	52.490	-2.341	6.472	0.000	0.000	1.876	0.085	11.772	0.705	6.203	0.000	0.000	0.000	0.000
Q416	F	829.847	56.901	-0.033	6.476	0.000	0.000	1.954	0.001	10.484	0.079	6.224	0.000	0.000	0.000	0.000
BEND_1		832.215	48.558	2.173	6.484	0.000	0.000	1.804	-0.082	12.365	-0.632	6.258	0.000	0.000	0.000	0.000
BEND_2		838.311	26.442	1.455	6.511	0.000	0.000	1.366	-0.061	24.271	-1.321	6.315	0.000	0.000	0.000	0.000
BEND_1		838.671	25.412	1.413	6.513	0.000	0.000	1.343	-0.061	25.235	-1.361	6.318	0.000	0.000	0.000	0.000
BEND_2		844.767	12.571	0.694	6.568	0.000	0.000	1.032	-0.041	46.017	-2.047	6.346	0.000	0.000	0.000	0.000
SD		845.690	11.390	0.585	6.581	0.000	0.000	0.995	-0.041	49.894	-2.151	6.349	0.000	0.000	0.000	0.000
Q415	D	847.135	10.412	-0.016	6.602	0.000	0.000	0.958	0.000	53.924	-0.009	6.354	0.000	0.000	0.000	0.000

Linear lattice functions for beam line: MI17
delta(p)/p = 0.000000 symm = F

ELEMENT SEQUENCE element name	quad type	dist [m]	HORIZONTAL betax [m]	alfax [1]	mux [2pi]	x(co) [mm]	px(co) [.001]	Dx [m]	Dpx [1]	VERTICAL betay [m]	alfay [1]	muy [2pi]	y(co) [mm]	py(co) [.001]	Dy [m]	Dpy [1]
BEND_1		849.504	12.732	-0.731	6.636	0.000	0.000	1.033	0.041	46.098	2.032	6.361	0.000	0.000	0.000	0.000
BEND_2		855.600	26.129	-1.466	6.690	0.000	0.000	1.345	0.062	25.444	1.355	6.390	0.000	0.000	0.000	0.000
BEND_1		855.959	27.198	-1.510	6.692	0.000	0.000	1.367	0.062	24.484	1.315	6.392	0.000	0.000	0.000	0.000
BEND_2		862.055	50.082	-2.245	6.718	0.000	0.000	1.806	0.082	12.584	0.636	6.448	0.000	0.000	0.000	0.000
SF		862.979	54.331	-2.356	6.721	0.000	0.000	1.882	0.082	11.504	0.533	6.461	0.000	0.000	0.000	0.000
Q414	F	864.424	58.695	0.034	6.725	0.000	0.000	1.957	-0.001	10.684	-0.079	6.482	0.000	0.000	0.000	0.000
BEND_1		866.792	49.789	2.299	6.732	0.000	0.000	1.801	-0.085	13.408	-0.828	6.514	0.000	0.000	0.000	0.000
BEND_2		872.888	26.451	1.530	6.759	0.000	0.000	1.348	-0.064	28.168	-1.593	6.565	0.000	0.000	0.000	0.000
BEND_1		873.248	25.368	1.484	6.761	0.000	0.000	1.325	-0.064	29.329	-1.638	6.567	0.000	0.000	0.000	0.000
BEND_2		879.344	11.965	0.715	6.818	0.000	0.000	0.999	-0.043	53.946	-2.400	6.591	0.000	0.000	0.000	0.000
SD		880.267	10.753	0.598	6.831	0.000	0.000	0.959	-0.043	58.485	-2.515	6.594	0.000	0.000	0.000	0.000
Q413	D	881.712	9.726	0.014	6.854	0.000	0.000	0.918	-0.004	63.176	0.004	6.597	0.000	0.000	0.000	0.000
BEND_1		884.081	11.822	-0.681	6.890	0.000	0.000	0.980	0.035	53.909	2.407	6.604	0.000	0.000	0.000	0.000
BEND_2		890.177	24.732	-1.436	6.948	0.000	0.000	1.256	0.056	29.233	1.640	6.628	0.000	0.000	0.000	0.000
BEND_1		890.536	25.780	-1.481	6.950	0.000	0.000	1.276	0.056	28.070	1.595	6.630	0.000	0.000	0.000	0.000
BEND_2		896.632	48.437	-2.236	6.978	0.000	0.000	1.679	0.077	13.307	0.826	6.681	0.000	0.000	0.000	0.000
SF		897.555	52.673	-2.350	6.981	0.000	0.000	1.750	0.077	11.889	0.709	6.693	0.000	0.000	0.000	0.000
Q412	F	899.000	57.103	-0.035	6.985	0.000	0.000	1.819	-0.001	10.592	0.080	6.714	0.000	0.000	0.000	0.000
BEND_1		901.369	48.736	2.180	6.992	0.000	0.000	1.674	-0.079	12.480	-0.634	6.748	0.000	0.000	0.000	0.000
BEND_2		907.465	26.543	1.461	7.019	0.000	0.000	1.257	-0.058	24.373	-1.317	6.804	0.000	0.000	0.000	0.000
BEND_1		907.824	25.508	1.418	7.021	0.000	0.000	1.236	-0.058	25.334	-1.357	6.807	0.000	0.000	0.000	0.000
BEND_2		913.920	12.605	0.699	7.076	0.000	0.000	0.946	-0.037	46.033	-2.038	6.835	0.000	0.000	0.000	0.000
SD		914.844	11.416	0.590	7.089	0.000	0.000	0.912	-0.037	49.892	-2.141	6.838	0.000	0.000	0.000	0.000
Q411	D	916.289	10.426	-0.012	7.110	0.000	0.000	0.878	0.000	53.892	0.001	6.843	0.000	0.000	0.000	0.000
BEND_1		918.657	12.730	-0.727	7.143	0.000	0.000	0.946	0.037	46.026	2.039	6.850	0.000	0.000	0.000	0.000
BEND_2		924.753	26.062	-1.460	7.198	0.000	0.000	1.238	0.058	25.317	1.358	6.879	0.000	0.000	0.000	0.000
BEND_1		925.113	27.127	-1.503	7.200	0.000	0.000	1.259	0.058	24.356	1.317	6.881	0.000	0.000	0.000	0.000
BEND_2		931.209	49.913	-2.235	7.226	0.000	0.000	1.677	0.079	12.462	0.633	6.938	0.000	0.000	0.000	0.000
SF		932.132	54.144	-2.346	7.229	0.000	0.000	1.750	0.079	11.388	0.530	6.950	0.000	0.000	0.000	0.000
Q410	F	933.577	58.489	0.035	7.233	0.000	0.000	1.823	0.001	10.576	-0.080	6.971	0.000	0.000	0.000	0.000
BEND_1		935.946	49.609	2.292	7.240	0.000	0.000	1.683	-0.077	13.289	-0.826	7.004	0.000	0.000	0.000	0.000
BEND_2		942.042	26.351	1.524	7.267	0.000	0.000	1.279	-0.056	28.051	-1.595	7.055	0.000	0.000	0.000	0.000
BEND_1		942.401	25.272	1.478	7.269	0.000	0.000	1.259	-0.056	29.214	-1.641	7.057	0.000	0.000	0.000	0.000
BEND_2		948.497	11.933	0.710	7.326	0.000	0.000	0.982	-0.035	53.897	-2.408	7.082	0.000	0.000	0.000	0.000
SD		949.421	10.729	0.594	7.339	0.000	0.000	0.950	-0.035	58.452	-2.524	7.084	0.000	0.000	0.000	0.000
Q409	D	950.866	9.714	0.010	7.362	0.000	0.000	0.920	0.004	63.170	-0.006	7.088	0.000	0.000	0.000	0.000
BEND_1		953.234	11.827	-0.685	7.398	0.000	0.000	1.001	0.043	53.948	2.398	7.094	0.000	0.000	0.000	0.000
BEND_2		959.330	24.802	-1.443	7.456	0.000	0.000	1.328	0.064	29.344	1.637	7.119	0.000	0.000	0.000	0.000
BEND_1		959.690	25.855	-1.488	7.458	0.000	0.000	1.351	0.064	28.183	1.592	7.121	0.000	0.000	0.000	0.000
BEND_2		965.786	48.610	-2.245	7.486	0.000	0.000	1.805	0.085	13.425	0.828	7.172	0.000	0.000	0.000	0.000
SF		966.709	52.863	-2.360	7.489	0.000	0.000	1.883	0.085	12.002	0.712	7.183	0.000	0.000	0.000	0.000
Q408	F	968.154	57.313	-0.036	7.493	0.000	0.000	1.961	0.001	10.699	0.079	7.204	0.000	0.000	0.000	0.000
BENDDS_1		970.394	47.848	3.004	7.500	0.000	0.000	1.790	-0.114	12.821	-0.830	7.235	0.000	0.000	0.000	0.000
BENDDS_2		974.458	26.891	2.153	7.518	0.000	0.000	1.354	-0.100	21.737	-1.364	7.274	0.000	0.000	0.000	0.000
BENDDS_1		974.817	25.371	2.077	7.520	0.000	0.000	1.318	-0.100	22.734	-1.411	7.277	0.000	0.000	0.000	0.000

"MAD" Version: 8.17　　Run: 22/04/92　14.44.56

Linear lattice functions for beam line: MI17　　Range: #S/#E

delta(p)/p = 0.000000　symm = F　　page 8

ELEMENT SEQUENCE			HORIZONTAL								VERTICAL						
element name	quad type	dist [m]	betax [m]	alfax [1]	mux [2pi]	x(co) [mm]	px(co) [.001]	Dx [m]	Dpx [1]	betay [m]	alfay [1]	muy [2pi]	y(co) [mm]	py(co) [.001]	Dy [m]	Dpy [1]
BENDDS_2		978.881	11.947	1.226	7.557	0.000	0.000	0.940	-0.086	36.371	-1.944	7.299	0.000	0.000	0.000	0.000
Q407	D	981.121	8.239	0.298	7.594	0.000	0.000	0.782	-0.038	42.092	0.283	7.308	0.000	0.000	0.000	0.000
BENDDS_1		983.360	8.969	-0.468	7.637	0.000	0.000	0.764	0.006	34.108	2.369	7.318	0.000	0.000	0.000	0.000
BENDDS_2		987.424	15.015	-1.020	7.694	0.000	0.000	0.817	0.020	18.052	1.582	7.344	0.000	0.000	0.000	0.000
BENDDS_1		987.783	15.766	-1.069	7.698	0.000	0.000	0.825	0.020	16.940	1.512	7.347	0.000	0.000	0.000	0.000
BENDDS_2		991.848	26.698	-1.621	7.730	0.000	0.000	0.935	0.034	7.852	0.724	7.404	0.000	0.000	0.000	0.000
Q406	F	994.087	31.840	0.023	7.742	0.000	0.000	0.969	-0.024	6.116	-0.057	7.458	0.000	0.000	0.000	0.000
BENDDS_1		996.326	26.514	1.656	7.754	0.000	0.000	0.831	-0.080	8.419	-0.869	7.510	0.000	0.000	0.000	0.000
BENDDS_2		1000.390	15.387	1.082	7.786	0.000	0.000	0.535	-0.066	18.921	-1.715	7.562	0.000	0.000	0.000	0.000
BENDDS_1		1000.750	14.628	1.031	7.790	0.000	0.000	0.512	-0.066	20.180	-1.790	7.565	0.000	0.000	0.000	0.000
BENDDS_2		1004.814	8.574	0.458	7.849	0.000	0.000	0.273	-0.052	38.163	-2.635	7.588	0.000	0.000	0.000	0.000
Q405	D	1007.053	7.884	-0.299	7.894	0.000	0.000	0.166	-0.040	46.989	-0.288	7.597	0.000	0.000	0.000	0.000
BENDDS_1		1009.293	11.562	-1.219	7.933	0.000	0.000	0.088	-0.032	40.463	2.203	7.605	0.000	0.000	0.000	0.000
BENDDS_2		1013.357	25.018	-2.092	7.971	0.000	0.000	-0.015	-0.018	24.937	1.616	7.625	0.000	0.000	0.000	0.000
BENDDS_1		1013.716	26.550	-2.170	7.973	0.000	0.000	-0.021	-0.018	23.794	1.564	7.627	0.000	0.000	0.000	0.000
BENDDS_2		1017.780	47.734	-3.043	7.991	0.000	0.000	-0.068	-0.004	13.468	0.976	7.664	0.000	0.000	0.000	0.000
Q404	F	1020.020	57.397	-0.010	7.998	0.000	0.000	-0.075	0.000	10.772	0.034	7.694	0.000	0.000	0.000	0.000
Q403	D	1037.308	10.172	-0.007	8.125	0.000	0.000	-0.023	0.002	56.533	0.015	7.818	0.000	0.000	0.000	0.000
Q402	F	1054.597	58.208	0.011	8.250	0.000	0.000	-0.002	0.001	10.449	-0.033	7.944	0.000	0.000	0.000	0.000
MI40		1054.597	58.208	0.011	8.250	0.000	0.000	-0.002	0.001	10.449	-0.033	7.944	0.000	0.000	0.000	0.000
Q401	D	1071.886	9.956	0.006	8.378	0.000	0.000	0.022	0.002	60.357	-0.018	8.065	0.000	0.000	0.000	0.000
Q400	F	1089.174	57.461	-0.011	8.506	0.000	0.000	0.075	0.000	10.822	0.031	8.183	0.000	0.000	0.000	0.000
BENDDS_1		1091.414	47.872	3.031	8.513	0.000	0.000	0.068	-0.004	13.198	-0.895	8.214	0.000	0.000	0.000	0.000
BENDDS_2		1095.478	26.753	2.166	8.531	0.000	0.000	0.079	0.010	22.723	-1.449	8.251	0.000	0.000	0.000	0.000
BENDDS_1		1095.837	25.223	2.090	8.533	0.000	0.000	0.082	0.010	23.782	-1.498	8.254	0.000	0.000	0.000	0.000
BENDDS_2		1099.901	11.753	1.225	8.571	0.000	0.000	0.149	0.023	38.200	-2.050	8.275	0.000	0.000	0.000	0.000
Q341	D	1102.141	8.051	0.301	8.609	0.000	0.000	0.209	0.034	44.233	0.295	8.284	0.000	0.000	0.000	0.000
BENDDS_1		1104.380	8.749	-0.460	8.653	0.000	0.000	0.306	0.048	35.841	2.492	8.293	0.000	0.000	0.000	0.000
BENDDS_2		1108.444	14.777	-1.023	8.711	0.000	0.000	0.530	0.062	18.902	1.675	8.318	0.000	0.000	0.000	0.000
BENDDS_1		1108.804	15.530	-1.073	8.715	0.000	0.000	0.553	0.062	17.724	1.603	8.321	0.000	0.000	0.000	0.000
BENDDS_2		1112.868	26.537	-1.636	8.747	0.000	0.000	0.833	0.076	8.019	0.785	8.376	0.000	0.000	0.000	0.000
Q340	F	1115.107	31.766	-0.002	8.759	0.000	0.000	0.963	0.020	6.045	-0.008	8.430	0.000	0.000	0.000	0.000
BENDDS_1		1117.347	26.552	1.633	8.771	0.000	0.000	0.922	-0.037	8.099	-0.805	8.483	0.000	0.000	0.000	0.000
BENDDS_2		1121.411	15.560	1.072	8.803	0.000	0.000	0.799	-0.023	18.004	-1.632	8.537	0.000	0.000	0.000	0.000
BENDDS_1		1121.770	14.808	1.022	8.807	0.000	0.000	0.791	-0.023	19.203	-1.705	8.540	0.000	0.000	0.000	0.000
BENDDS_2		1125.834	8.781	0.461	8.865	0.000	0.000	0.725	-0.009	36.415	-2.530	8.565	0.000	0.000	0.000	0.000
Q339	D	1128.074	8.079	-0.301	8.909	0.000	0.000	0.735	0.033	44.926	-0.296	8.574	0.000	0.000	0.000	0.000
BENDDS_1		1130.313	11.784	-1.226	8.947	0.000	0.000	0.876	0.078	38.779	2.087	8.582	0.000	0.000	0.000	0.000
BENDDS_2		1134.377	25.251	-2.088	8.984	0.000	0.000	1.220	0.092	24.094	1.527	8.603	0.000	0.000	0.000	0.000
BENDDS_1		1134.737	26.780	-2.165	8.987	0.000	0.000	1.253	0.092	23.014	1.477	8.606	0.000	0.000	0.000	0.000
BENDDS_2		1138.801	47.881	-3.028	9.005	0.000	0.000	1.654	0.106	13.290	0.916	8.643	0.000	0.000	0.000	0.000
Q338	F	1141.040	57.454	0.015	9.011	0.000	0.000	1.812	-0.001	10.833	-0.015	8.674	0.000	0.000	0.000	0.000
BEND_1		1143.409	48.821	2.234	9.018	0.000	0.000	1.668	-0.078	13.239	-0.753	8.706	0.000	0.000	0.000	0.000
BEND_2		1149.505	26.146	1.486	9.046	0.000	0.000	1.254	-0.057	26.816	-1.473	8.758	0.000	0.000	0.000	0.000
BEND_1		1149.864	25.093	1.442	9.048	0.000	0.000	1.234	-0.057	27.890	-1.516	8.760	0.000	0.000	0.000	0.000

Linear lattice functions for beam line: MI17

Range: #S/#E

delta(p)/p = 0.000000 symm = F

ELEMENT SEQUENCE element name	quad type	dist [m]	HORIZONTAL betax [m]	alfax [1]	mux [2pi]	x(co) [mm]	px(co) [.001]	Dx [m]	Dpx [1]	VERTICAL betay [m]	alfay [1]	muy [2pi]	y(co) [mm]	py(co) [.001]	Dy [m]	Dpy [1]
BEND_2		1155.960	12.074	0.694	9.105	0.000	0.000	0.947	-0.037	50.749	-2.233	8.786	0.000	0.000	0.000	0.000
SD		1156.883	10.897	0.581	9.118	0.000	0.000	0.913	-0.037	54.974	-2.342	8.789	0.000	0.000	0.000	0.000
Q337	D	1158.328	9.921	-0.007	9.140	0.000	0.000	0.881	0.001	59.323	0.023	8.793	0.000	0.000	0.000	0.000
BEND_1		1160.697	12.143	-0.710	9.175	0.000	0.000	0.951	0.038	50.549	2.271	8.800	0.000	0.000	0.000	0.000
BEND_2		1166.793	25.399	-1.465	9.232	0.000	0.000	1.247	0.059	27.375	1.530	8.826	0.000	0.000	0.000	0.000
BEND_1		1167.152	26.468	-1.509	9.234	0.000	0.000	1.269	0.059	26.291	1.486	8.828	0.000	0.000	0.000	0.000
BEND_2		1173.248	49.471	-2.264	9.261	0.000	0.000	1.692	0.080	12.700	0.743	8.882	0.000	0.000	0.000	0.000
SF		1174.172	53.759	-2.379	9.264	0.000	0.000	1.766	0.080	11.432	0.630	8.894	0.000	0.000	0.000	0.000
Q336	F	1175.617	58.220	-0.014	9.268	0.000	0.000	1.840	0.001	10.341	0.017	8.916	0.000	0.000	0.000	0.000
BEND_1		1177.985	49.595	2.241	9.275	0.000	0.000	1.698	-0.077	12.523	-0.702	8.950	0.000	0.000	0.000	0.000
BEND_2		1184.081	26.783	1.501	9.301	0.000	0.000	1.291	-0.056	25.503	-1.427	9.005	0.000	0.000	0.000	0.000
BEND_1		1184.441	25.720	1.457	9.304	0.000	0.000	1.271	-0.056	26.544	-1.470	9.007	0.000	0.000	0.000	0.000
BEND_2		1190.537	12.466	0.717	9.359	0.000	0.000	0.990	-0.036	48.871	-2.192	9.034	0.000	0.000	0.000	0.000
SD		1191.460	11.245	0.605	9.371	0.000	0.000	0.957	-0.036	53.021	-2.302	9.037	0.000	0.000	0.000	0.000
Q335	D	1192.905	10.210	0.007	9.393	0.000	0.000	0.927	0.004	57.344	-0.022	9.041	0.000	0.000	0.000	0.000
BEND_1		1195.274	12.390	-0.699	9.427	0.000	0.000	1.008	0.043	49.062	2.156	9.048	0.000	0.000	0.000	0.000
BEND_2		1201.370	25.380	-1.432	9.483	0.000	0.000	1.334	0.064	27.035	1.456	9.075	0.000	0.000	0.000	0.000
BEND_1		1201.729	26.425	-1.475	9.485	0.000	0.000	1.357	0.064	26.004	1.415	9.077	0.000	0.000	0.000	0.000
BEND_2		1207.825	48.872	-2.208	9.513	0.000	0.000	1.811	0.085	13.038	0.712	9.131	0.000	0.000	0.000	0.000
SF		1208.749	53.052	-2.319	9.515	0.000	0.000	1.889	0.085	11.822	0.605	9.143	0.000	0.000	0.000	0.000
Q334	F	1210.194	57.369	0.014	9.520	0.000	0.000	1.967	0.001	10.810	-0.018	9.164	0.000	0.000	0.000	0.000
BEND_1		1212.562	48.752	2.230	9.527	0.000	0.000	1.815	-0.083	13.229	-0.756	9.196	0.000	0.000	0.000	0.000
BEND_2		1218.658	26.118	1.483	9.554	0.000	0.000	1.371	-0.062	26.857	-1.479	9.248	0.000	0.000	0.000	0.000
BEND_1		1219.018	25.068	1.439	9.556	0.000	0.000	1.348	-0.062	27.936	-1.522	9.250	0.000	0.000	0.000	0.000
BEND_2		1225.114	12.075	0.692	9.613	0.000	0.000	1.032	-0.042	50.880	-2.241	9.276	0.000	0.000	0.000	0.000
SD		1226.037	10.901	0.579	9.626	0.000	0.000	0.993	-0.042	55.121	-2.351	9.279	0.000	0.000	0.000	0.000
Q333	D	1227.482	9.928	-0.008	9.648	0.000	0.000	0.955	-0.001	59.488	0.021	9.283	0.000	0.000	0.000	0.000
BEND_1		1229.851	12.159	-0.712	9.684	0.000	0.000	1.027	0.040	50.700	2.275	9.290	0.000	0.000	0.000	0.000
BEND_2		1235.947	25.441	-1.467	9.740	0.000	0.000	1.331	0.060	27.471	1.534	9.316	0.000	0.000	0.000	0.000
BEND_1		1236.306	26.511	-1.512	9.742	0.000	0.000	1.353	0.060	26.384	1.490	9.318	0.000	0.000	0.000	0.000
BEND_2		1242.402	49.545	-2.267	9.769	0.000	0.000	1.785	0.081	12.742	0.747	9.372	0.000	0.000	0.000	0.000
SF		1243.326	53.838	-2.381	9.772	0.000	0.000	1.860	0.081	11.466	0.634	9.384	0.000	0.000	0.000	0.000
Q332	F	1244.771	58.303	-0.014	9.776	0.000	0.000	1.933	-0.001	10.366	0.020	9.405	0.000	0.000	0.000	0.000
BEND_1		1247.139	49.662	2.245	9.783	0.000	0.000	1.778	-0.084	12.537	-0.699	9.439	0.000	0.000	0.000	0.000
BEND_2		1253.235	26.809	1.504	9.809	0.000	0.000	1.330	-0.063	25.467	-1.422	9.495	0.000	0.000	0.000	0.000
BEND_1		1253.594	25.744	1.460	9.812	0.000	0.000	1.307	-0.063	26.505	-1.464	9.497	0.000	0.000	0.000	0.000
BEND_2		1259.690	12.464	0.719	9.867	0.000	0.000	0.986	-0.042	48.748	-2.184	9.524	0.000	0.000	0.000	0.000
SD		1260.614	11.241	0.606	9.879	0.000	0.000	0.947	-0.042	52.882	-2.293	9.527	0.000	0.000	0.000	0.000
Q331	D	1262.059	10.202	0.009	9.901	0.000	0.000	0.907	-0.004	57.187	-0.020	9.531	0.000	0.000	0.000	0.000
BEND_1		1264.427	12.373	-0.697	9.935	0.000	0.000	0.969	0.035	48.918	2.152	9.538	0.000	0.000	0.000	0.000
BEND_2		1270.523	25.339	-1.430	9.991	0.000	0.000	1.244	0.056	26.941	1.452	9.565	0.000	0.000	0.000	0.000
BEND_1		1270.883	26.382	-1.473	9.994	0.000	0.000	1.264	0.056	25.913	1.411	9.567	0.000	0.000	0.000	0.000
BEND_2		1276.979	48.800	-2.205	10.021	0.000	0.000	1.667	0.076	12.994	0.708	9.621	0.000	0.000	0.000	0.000
SF		1277.902	52.976	-2.316	10.024	0.000	0.000	1.738	0.076	11.785	0.601	9.633	0.000	0.000	0.000	0.000
Q330	F	1279.347	57.289	0.013	10.028	0.000	0.000	1.807	-0.001	10.783	-0.021	9.654	0.000	0.000	0.000	0.000

ELEMENT SEQUENCE element name	quad type	dist [m]	HORIZONTAL betax [m]	alfax [1]	mux [2pi]	x(co) [mm]	px(co) [.001]	Dx [m]	Dpx [1]	VERTICAL betay [m]	alfay [1]	muy [2pi]	y(co) [mm]	py(co) [.001]	Dy [m]	Dpy [1]
BEND_1		1281.716	48.688	2.226	10.035	0.000	0.000	1.664	-0.078	13.213	-0.759	9.686	0.000	0.000	0.000	0.000
BEND_2		1287.812	26.094	1.480	10.062	0.000	0.000	1.252	-0.057	26.888	-1.484	9.738	0.000	0.000	0.000	0.000
BEND_1		1288.171	25.046	1.437	10.064	0.000	0.000	1.232	-0.057	27.970	-1.527	9.740	0.000	0.000	0.000	0.000
BEND_2		1294.267	12.078	0.691	10.121	0.000	0.000	0.947	-0.036	50.994	-2.249	9.766	0.000	0.000	0.000	0.000
SD		1295.191	10.906	0.578	10.134	0.000	0.000	0.914	-0.036	55.250	-2.359	9.769	0.000	0.000	0.000	0.000
Q329	D	1296.636	9.937	-0.009	10.157	0.000	0.000	0.882	0.001	59.636	0.018	9.773	0.000	0.000	0.000	0.000
BEND_1		1299.004	12.176	-0.714	10.192	0.000	0.000	0.953	0.039	50.836	2.279	9.780	0.000	0.000	0.000	0.000
BEND_2		1305.100	25.482	-1.469	10.248	0.000	0.000	1.252	0.059	27.563	1.538	9.806	0.000	0.000	0.000	0.000
BEND_1		1305.460	26.554	-1.514	10.250	0.000	0.000	1.273	0.059	26.473	1.494	9.808	0.000	0.000	0.000	0.000
BEND_2		1311.556	49.615	-2.269	10.277	0.000	0.000	1.699	0.080	12.786	0.751	9.862	0.000	0.000	0.000	0.000
SF		1312.479	53.912	-2.384	10.280	0.000	0.000	1.774	0.080	11.504	0.638	9.874	0.000	0.000	0.000	0.000
Q328	F	1313.924	58.380	-0.013	10.284	0.000	0.000	1.848	0.001	10.394	0.022	9.895	0.000	0.000	0.000	0.000
BEND_1		1316.293	49.723	2.249	10.291	0.000	0.000	1.706	-0.078	12.556	-0.697	9.929	0.000	0.000	0.000	0.000
BEND_2		1322.389	26.831	1.506	10.317	0.000	0.000	1.297	-0.057	25.443	-1.417	9.984	0.000	0.000	0.000	0.000
BEND_1		1322.748	25.764	1.463	10.320	0.000	0.000	1.277	-0.057	26.477	-1.459	9.986	0.000	0.000	0.000	0.000
BEND_2		1328.844	12.460	0.720	10.375	0.000	0.000	0.995	-0.036	48.643	-2.176	10.014	0.000	0.000	0.000	0.000
SD		1329.768	11.234	0.607	10.387	0.000	0.000	0.961	-0.036	52.763	-2.285	10.016	0.000	0.000	0.000	0.000
Q327	D	1331.213	10.192	0.010	10.409	0.000	0.000	0.931	0.004	57.050	-0.017	10.021	0.000	0.000	0.000	0.000
BEND_1		1333.581	12.356	-0.696	10.444	0.000	0.000	1.012	0.043	48.789	2.149	10.028	0.000	0.000	0.000	0.000
BEND_2		1339.677	25.298	-1.428	10.500	0.000	0.000	1.339	0.064	26.852	1.449	10.055	0.000	0.000	0.000	0.000
BEND_1		1340.037	26.340	-1.471	10.502	0.000	0.000	1.362	0.064	25.826	1.407	10.057	0.000	0.000	0.000	0.000
BEND_2		1346.133	48.733	-2.203	10.529	0.000	0.000	1.815	0.085	12.949	0.705	10.111	0.000	0.000	0.000	0.000
SF		1347.056	52.904	-2.314	10.532	0.000	0.000	1.894	0.085	11.746	0.598	10.123	0.000	0.000	0.000	0.000
Q326	F	1348.501	57.214	0.012	10.536	0.000	0.000	1.972	0.001	10.753	-0.023	10.144	0.000	0.000	0.000	0.000
BENDDS_1		1350.741	47.574	3.035	10.543	0.000	0.000	1.799	-0.115	13.392	-0.962	10.174	0.000	0.000	0.000	0.000
BENDDS_2		1354.805	26.454	2.163	10.561	0.000	0.000	1.359	-0.101	23.579	-1.545	10.211	0.000	0.000	0.000	0.000
BENDDS_1		1355.164	24.927	2.085	10.563	0.000	0.000	1.323	-0.101	24.708	-1.596	10.213	0.000	0.000	0.000	0.000
BENDDS_2		1359.228	11.522	1.213	10.602	0.000	0.000	0.940	-0.087	40.048	-2.178	10.234	0.000	0.000	0.000	0.000
Q325	D	1361.467	7.864	0.296	10.640	0.000	0.000	0.780	-0.039	46.497	0.287	10.242	0.000	0.000	0.000	0.000
BENDDS_1		1363.707	8.568	-0.461	10.686	0.000	0.000	0.759	0.005	37.758	2.607	10.250	0.000	0.000	0.000	0.000
BENDDS_2		1367.771	14.655	-1.037	10.745	0.000	0.000	0.807	0.019	19.972	1.769	10.274	0.000	0.000	0.000	0.000
BENDDS_1		1368.130	15.418	-1.087	10.748	0.000	0.000	0.814	0.019	18.727	1.695	10.277	0.000	0.000	0.000	0.000
BENDDS_2		1372.194	26.595	-1.663	10.781	0.000	0.000	0.919	0.033	8.365	0.855	10.329	0.000	0.000	0.000	0.000
Q324	F	1374.434	31.946	-0.025	10.793	0.000	0.000	0.950	-0.024	6.116	0.046	10.381	0.000	0.000	0.000	0.000
BENDDS_1		1376.673	26.792	1.626	10.804	0.000	0.000	0.814	-0.079	7.905	-0.737	10.435	0.000	0.000	0.000	0.000
BENDDS_2		1380.737	15.824	1.073	10.836	0.000	0.000	0.522	-0.065	17.119	-1.530	10.492	0.000	0.000	0.000	0.000
BENDDS_1		1381.097	15.070	1.024	10.840	0.000	0.000	0.498	-0.065	18.244	-1.600	10.495	0.000	0.000	0.000	0.000
BENDDS_2		1385.161	8.990	0.472	10.896	0.000	0.000	0.263	-0.051	34.467	-2.391	10.521	0.000	0.000	0.000	0.000
Q323	D	1387.400	8.244	-0.295	10.939	0.000	0.000	0.157	-0.040	42.523	-0.283	10.530	0.000	0.000	0.000	0.000
BENDDS_1		1389.640	11.933	-1.221	10.977	0.000	0.000	0.079	-0.032	36.728	1.968	10.539	0.000	0.000	0.000	0.000
BENDDS_2		1393.704	25.305	-2.069	11.014	0.000	0.000	-0.024	-0.019	22.920	1.430	10.561	0.000	0.000	0.000	0.000
BENDDS_1		1394.063	26.820	-2.144	11.016	0.000	0.000	-0.031	-0.019	21.910	1.382	10.564	0.000	0.000	0.000	0.000
BENDDS_2		1398.127	47.697	-2.993	11.034	0.000	0.000	-0.078	-0.005	12.868	0.843	10.603	0.000	0.000	0.000	0.000
Q322	F	1400.367	57.123	0.037	11.041	0.000	0.000	-0.084	0.000	10.694	-0.068	10.634	0.000	0.000	0.000	0.000
Q321	D	1417.655	9.700	-0.014	11.172	0.000	0.000	-0.018	0.003	62.587	0.002	10.751	0.000	0.000	0.000	0.000

"MAD" Version: 8.17 Run: 22/04/92 14.44.56

Linear lattice functions for beam line: MI17

Range: #S/#E

delta(p)/p = 0.000000 symm = F

ELEMENT SEQUENCE			HORIZONTAL								VERTICAL						
element name	quad type	dist [m]	betax [m]	alfax [1]	mux [2pi]	x(co) [mm]	px(co) [.001]	Dx [m]	Dpx [1]	betay [m]	alfay [1]	muy [2pi]	y(co) [mm]	py(co) [.001]	Dy [m]	Dpy [1]
MI32		1426.300	25.879	-1.508	11.266	0.000	0.000	0.003	0.002	28.439	1.598	10.783	0.000	0.000	0.000	0.000
Q320	F	1434.944	58.705	-0.037	11.301	0.000	0.000	0.023	0.001	10.641	0.069	10.867	0.000	0.000	0.000	0.000
Q319	D	1452.233	10.438	0.016	11.424	0.000	0.000	0.032	0.002	54.569	0.002	10.995	0.000	0.000	0.000	0.000
BENDDS_1		1454.472	12.794	-0.882	11.456	0.000	0.000	0.039	0.004	45.604	2.829	11.002	0.000	0.000	0.000	0.000
BENDDS_2		1458.536	22.255	-1.446	11.495	0.000	0.000	0.082	0.018	25.866	2.028	11.021	0.000	0.000	0.000	0.000
BENDDS_1		1458.896	23.312	-1.496	11.497	0.000	0.000	0.088	0.018	24.434	1.957	11.023	0.000	0.000	0.000	0.000
BENDDS_2		1462.960	37.768	-2.061	11.519	0.000	0.000	0.188	0.031	11.791	1.154	11.061	0.000	0.000	0.000	0.000
Q318	F	1465.199	43.815	0.312	11.527	0.000	0.000	0.249	0.018	8.369	0.235	11.098	0.000	0.000	0.000	0.000
BENDDS_1		1467.438	35.284	2.524	11.536	0.000	0.000	0.265	0.002	9.439	-0.554	11.140	0.000	0.000	0.000	0.000
BENDDS_2		1471.503	18.217	1.675	11.562	0.000	0.000	0.303	0.016	16.225	-1.116	11.193	0.000	0.000	0.000	0.000
BENDDS_1		1471.862	17.039	1.600	11.565	0.000	0.000	0.309	0.016	17.044	-1.165	11.197	0.000	0.000	0.000	0.000
BENDDS_2		1475.926	7.485	0.751	11.624	0.000	0.000	0.403	0.030	28.798	-1.726	11.226	0.000	0.000	0.000	0.000
Q317	D	1478.165	5.653	-0.029	11.681	0.000	0.000	0.489	0.057	34.274	0.016	11.237	0.000	0.000	0.000	0.000
BENDDS_1		1480.405	7.773	-0.825	11.737	0.000	0.000	0.662	0.088	28.669	1.751	11.248	0.000	0.000	0.000	0.000
BENDDS_2		1484.469	18.044	-1.703	11.793	0.000	0.000	1.048	0.102	16.777	1.175	11.278	0.000	0.000	0.000	0.000
BENDDS_1		1484.828	19.296	-1.780	11.796	0.000	0.000	1.085	0.102	15.951	1.124	11.281	0.000	0.000	0.000	0.000
BENDDS_2		1488.892	37.336	-2.659	11.820	0.000	0.000	1.527	0.116	9.156	0.548	11.336	0.000	0.000	0.000	0.000
Q316	F	1491.132	46.286	-0.311	11.829	0.000	0.000	1.714	0.016	8.107	-0.234	11.379	0.000	0.000	0.000	0.000
BENDDS_1		1493.371	39.809	2.197	11.837	0.000	0.000	1.597	-0.085	11.494	-1.145	11.417	0.000	0.000	0.000	0.000
BENDDS_2		1497.435	24.371	1.602	11.858	0.000	0.000	1.278	-0.072	24.115	-1.961	11.456	0.000	0.000	0.000	0.000
BENDDS_1		1497.795	23.239	1.549	11.860	0.000	0.000	1.252	-0.072	25.551	-2.033	11.459	0.000	0.000	0.000	0.000
BENDDS_2		1501.859	13.062	0.955	11.898	0.000	0.000	0.990	-0.058	45.384	-2.847	11.478	0.000	0.000	0.000	0.000
Q315	D	1504.098	10.419	0.042	11.929	0.000	0.000	0.901	-0.004	54.458	-0.035	11.485	0.000	0.000	0.000	0.000
BEND_1		1506.467	12.442	-0.662	11.963	0.000	0.000	0.961	0.034	46.661	2.033	11.492	0.000	0.000	0.000	0.000
BEND_2		1512.563	24.814	-1.367	12.019	0.000	0.000	1.231	0.055	25.951	1.364	11.520	0.000	0.000	0.000	0.000
BEND_1		1512.922	25.812	-1.409	12.022	0.000	0.000	1.251	0.055	24.985	1.324	11.522	0.000	0.000	0.000	0.000
BEND_2		1519.018	47.285	-2.114	12.049	0.000	0.000	1.649	0.076	12.927	0.653	11.577	0.000	0.000	0.000	0.000
SF		1519.942	51.288	-2.221	12.052	0.000	0.000	1.719	0.076	11.815	0.551	11.589	0.000	0.000	0.000	0.000
Q314	F	1521.387	55.402	0.033	12.057	0.000	0.000	1.787	-0.001	10.952	-0.071	11.610	0.000	0.000	0.000	0.000
BEND_1		1523.755	47.005	2.166	12.064	0.000	0.000	1.645	-0.077	13.663	-0.824	11.641	0.000	0.000	0.000	0.000
BEND_2		1529.851	25.098	1.428	12.092	0.000	0.000	1.239	-0.056	28.275	-1.572	11.692	0.000	0.000	0.000	0.000
BEND_1		1530.211	24.088	1.384	12.095	0.000	0.000	1.219	-0.056	29.421	-1.616	11.694	0.000	0.000	0.000	0.000
BEND_2		1536.307	11.709	0.646	12.154	0.000	0.000	0.940	-0.035	53.671	-2.361	11.718	0.000	0.000	0.000	0.000
SD		1537.230	10.618	0.535	12.167	0.000	0.000	0.908	-0.035	58.136	-2.474	11.721	0.000	0.000	0.000	0.000
Q313	D	1538.675	9.764	-0.044	12.190	0.000	0.000	0.877	0.002	62.722	0.030	11.724	0.000	0.000	0.000	0.000
BENDDS_1		1540.915	12.328	-0.930	12.223	0.000	0.000	0.958	0.054	52.284	3.282	11.731	0.000	0.000	0.000	0.000
BENDDS_2		1544.979	22.386	-1.545	12.263	0.000	0.000	1.205	0.068	29.316	2.369	11.747	0.000	0.000	0.000	0.000
BENDDS_1		1545.338	23.516	-1.599	12.265	0.000	0.000	1.229	0.068	27.643	2.287	11.749	0.000	0.000	0.000	0.000
BENDDS_2		1549.402	39.015	-2.214	12.287	0.000	0.000	1.533	0.082	12.770	1.372	11.784	0.000	0.000	0.000	0.000
Q312	F	1551.642	45.656	0.243	12.295	0.000	0.000	1.644	-0.016	8.540	0.381	11.819	0.000	0.000	0.000	0.000
BENDDS_1		1553.881	37.078	2.576	12.303	0.000	0.000	1.464	-0.111	8.952	-0.397	11.861	0.000	0.000	0.000	0.000
BENDDS_2		1557.945	19.543	1.739	12.328	0.000	0.000	1.040	-0.098	14.316	-0.922	11.920	0.000	0.000	0.000	0.000
BENDDS_1		1558.304	18.320	1.665	12.331	0.000	0.000	1.005	-0.098	14.995	-0.969	11.924	0.000	0.000	0.000	0.000
BENDDS_2		1562.368	8.188	0.828	12.384	0.000	0.000	0.636	-0.084	25.001	-1.493	11.957	0.000	0.000	0.000	0.000
Q311	D	1564.608	6.033	0.033	12.437	0.000	0.000	0.472	-0.053	29.774	0.000	11.970	0.000	0.000	0.000	0.000

Linear lattice functions for beam line: MI17
delta(p)/p = 0.000000 symm = F

ELEMENT SEQUENCE		I	HORIZONTAL							I	VERTICAL						
element name	quad type	dist [m]	betax [m]	alfax [1]	mux [2pi]	x(co) [mm]	px(co) [.001]	Dx [m]	Dpx [1]		betay [m]	alfay [1]	muy [2pi]	y(co) [mm]	py(co) [.001]	Dy [m]	Dpy [1]
BENDDS_1		1566.847	7.854	-0.743	12.491	0.000	0.000	0.391	-0.028		25.000	1.493	11.983	0.000	0.000	0.000	0.000
BENDDS_2		1570.911	17.157	-1.546	12.548	0.000	0.000	0.306	-0.014		14.994	0.969	12.017	0.000	0.000	0.000	0.000
BENDDS_1		1571.271	18.294	-1.617	12.552	0.000	0.000	0.301	-0.014		14.314	0.922	12.020	0.000	0.000	0.000	0.000
BENDDS_2		1575.335	34.703	-2.420	12.577	0.000	0.000	0.273	0.000		8.951	0.397	12.079	0.000	0.000	0.000	0.000
Q310	F	1577.574	42.795	-0.245	12.586	0.000	0.000	0.261	-0.016		8.539	-0.381	12.121	0.000	0.000	0.000	0.000
BENDDS_1		1579.814	36.651	2.057	12.595	0.000	0.000	0.203	-0.031		12.768	-1.372	12.156	0.000	0.000	0.000	0.000
BENDDS_2		1583.878	22.291	1.477	12.618	0.000	0.000	0.106	-0.017		27.641	-2.288	12.191	0.000	0.000	0.000	0.000
BENDDS_1		1584.237	21.247	1.426	12.620	0.000	0.000	0.100	-0.017		29.314	-2.369	12.193	0.000	0.000	0.000	0.000
BENDDS_2		1588.301	12.018	0.846	12.661	0.000	0.000	0.061	-0.003		52.283	-3.283	12.210	0.000	0.000	0.000	0.000
Q309	D	1590.541	9.786	-0.023	12.695	0.000	0.000	0.057	0.000		62.721	-0.030	12.216	0.000	0.000	0.000	0.000
Q308	F	1607.829	59.224	-0.028	12.823	0.000	0.000	0.102	-0.002		10.996	0.069	12.330	0.000	0.000	0.000	0.000
Q307	D	1625.118	10.345	0.024	12.946	0.000	0.000	0.003	-0.006		54.642	0.035	12.455	0.000	0.000	0.000	0.000
Q306	F	1642.407	56.399	0.027	13.072	0.000	0.000	-0.092	-0.002		10.246	-0.067	12.585	0.000	0.000	0.000	0.000
Q305	D	1659.695	9.811	-0.026	13.204	0.000	0.000	-0.057	0.000		62.422	-0.040	12.705	0.000	0.000	0.000	0.000
MI30		1659.695	9.811	-0.026	13.204	0.000	0.000	-0.057	0.000		62.422	-0.040	12.705	0.000	0.000	0.000	0.000
Q304	F	1676.984	59.382	-0.025	13.331	0.000	0.000	-0.098	0.002		11.099	0.064	12.819	0.000	0.000	0.000	0.000
Q303	D	1694.273	10.318	0.027	13.454	0.000	0.000	0.000	0.006		54.981	0.045	12.942	0.000	0.000	0.000	0.000
Q302	F	1711.561	56.249	0.024	13.581	0.000	0.000	0.097	0.002		10.148	-0.060	13.073	0.000	0.000	0.000	0.000
Q301	D	1728.850	9.839	-0.028	13.712	0.000	0.000	0.057	0.000		62.044	-0.049	13.194	0.000	0.000	0.000	0.000
BENDDS_1		1731.089	12.335	-0.913	13.746	0.000	0.000	0.061	0.003		52.036	3.187	13.200	0.000	0.000	0.000	0.000
BENDDS_2		1735.153	22.211	-1.517	13.785	0.000	0.000	0.103	0.017		29.665	2.317	13.217	0.000	0.000	0.000	0.000
BENDDS_1		1735.513	23.321	-1.571	13.788	0.000	0.000	0.109	0.017		28.028	2.240	13.219	0.000	0.000	0.000	0.000
BENDDS_2		1739.577	38.541	-2.175	13.809	0.000	0.000	0.207	0.031		13.364	1.368	13.252	0.000	0.000	0.000	0.000
Q232	F	1741.816	45.045	0.251	13.818	0.000	0.000	0.265	0.016		9.149	0.366	13.286	0.000	0.000	0.000	0.000
BENDDS_1		1744.056	36.541	2.548	13.826	0.000	0.000	0.277	0.000		9.699	-0.433	13.325	0.000	0.000	0.000	0.000
BENDDS_2		1748.120	19.216	1.715	13.851	0.000	0.000	0.305	0.014		15.234	-0.929	13.379	0.000	0.000	0.000	0.000
BENDDS_1		1748.479	18.010	1.641	13.854	0.000	0.000	0.310	0.014		15.918	-0.973	13.383	0.000	0.000	0.000	0.000
BENDDS_2		1752.543	8.058	0.808	13.908	0.000	0.000	0.394	0.028		25.845	-1.469	13.415	0.000	0.000	0.000	0.000
Q231	D	1754.783	5.985	0.018	13.962	0.000	0.000	0.474	0.053		30.415	0.078	13.427	0.000	0.000	0.000	0.000
BENDDS_1		1757.022	7.883	-0.763	14.016	0.000	0.000	0.639	0.084		25.221	1.586	13.440	0.000	0.000	0.000	0.000
BENDDS_2		1761.086	17.400	-1.579	14.073	0.000	0.000	1.008	0.098		14.626	1.020	13.474	0.000	0.000	0.000	0.000
BENDDS_1		1761.446	18.561	-1.651	14.076	0.000	0.000	1.043	0.098		13.911	0.970	13.478	0.000	0.000	0.000	0.000
BENDDS_2		1765.510	35.294	-2.467	14.101	0.000	0.000	1.468	0.112		8.328	0.403	13.540	0.000	0.000	0.000	0.000
Q230	F	1767.749	43.544	-0.252	14.110	0.000	0.000	1.648	0.016		7.884	-0.360	13.585	0.000	0.000	0.000	0.000
BENDDS_1		1769.989	37.301	2.092	14.119	0.000	0.000	1.536	-0.082		11.931	-1.323	13.623	0.000	0.000	0.000	0.000
BENDDS_2		1774.053	22.677	1.506	14.141	0.000	0.000	1.231	-0.068		26.487	-2.259	13.660	0.000	0.000	0.000	0.000
BENDDS_1		1774.412	21.613	1.454	14.144	0.000	0.000	1.207	-0.068		28.140	-2.341	13.662	0.000	0.000	0.000	0.000
BENDDS_2		1778.476	12.172	0.869	14.184	0.000	0.000	0.959	-0.054		50.968	-3.275	13.679	0.000	0.000	0.000	0.000
Q229	D	1780.716	9.851	-0.007	14.217	0.000	0.000	0.876	-0.002		61.508	-0.107	13.685	0.000	0.000	0.000	0.000
BEND_1		1783.084	12.067	-0.709	14.253	0.000	0.000	0.939	0.035		52.969	2.251	13.692	0.000	0.000	0.000	0.000
BEND_2		1789.180	25.331	-1.468	14.310	0.000	0.000	1.216	0.056		29.761	1.555	13.716	0.000	0.000	0.000	0.000
BEND_1		1789.539	26.402	-1.512	14.312	0.000	0.000	1.236	0.056		28.659	1.514	13.718	0.000	0.000	0.000	0.000
BEND_2		1795.635	49.464	-2.271	14.339	0.000	0.000	1.640	0.077		14.464	0.814	13.767	0.000	0.000	0.000	0.000
SF		1796.559	53.765	-2.386	14.342	0.000	0.000	1.711	0.077		13.058	0.708	13.777	0.000	0.000	0.000	0.000
Q228	F	1798.004	58.247	-0.021	14.346	0.000	0.000	1.781	0.001		11.794	0.044	13.796	0.000	0.000	0.000	0.000

Linear lattice functions for beam line: MI17
delta(p)/p = 0.000000 symm = F

ELEMENT SEQUENCE element name	quad type	dist [m]	HORIZONTAL betax [m]	alfax [1]	mux [2pi]	x(co) [mm]	px(co) [.001]	Dx [m]	Dpx [1]	VERTICAL betay [m]	alfay [1]	muy [2pi]	y(co) [mm]	py(co) [.001]	Dy [m]	Dpy [1]
BEND_1		1800.372	49.648	2.237	14.353	0.000	0.000	1.643	-0.076	14.008	-0.708	13.826	0.000	0.000	0.000	0.000
BEND_2		1806.468	26.872	1.500	14.379	0.000	0.000	1.246	-0.055	26.622	-1.360	13.877	0.000	0.000	0.000	0.000
BEND_1		1806.828	25.810	1.456	14.381	0.000	0.000	1.227	-0.055	27.614	-1.399	13.879	0.000	0.000	0.000	0.000
BEND_2		1812.924	12.549	0.719	14.436	0.000	0.000	0.957	-0.034	48.631	-2.048	13.906	0.000	0.000	0.000	0.000
SD		1813.847	11.323	0.608	14.449	0.000	0.000	0.926	-0.034	52.505	-2.147	13.909	0.000	0.000	0.000	0.000
Q227	D	1815.292	10.282	0.008	14.470	0.000	0.000	0.897	0.004	56.395	0.110	13.913	0.000	0.000	0.000	0.000
BENDDS_1		1817.532	12.655	-0.885	14.503	0.000	0.000	0.986	0.057	46.698	3.006	13.920	0.000	0.000	0.000	0.000
BENDDS_2		1821.596	22.174	-1.457	14.542	0.000	0.000	1.248	0.071	25.811	2.134	13.939	0.000	0.000	0.000	0.000
BENDDS_1		1821.955	23.240	-1.508	14.544	0.000	0.000	1.274	0.071	24.305	2.056	13.941	0.000	0.000	0.000	0.000
BENDDS_2		1826.019	37.824	-2.081	14.566	0.000	0.000	1.592	0.085	11.141	1.182	13.981	0.000	0.000	0.000	0.000
Q226	F	1828.259	43.959	0.296	14.575	0.000	0.000	1.709	-0.016	7.616	0.268	14.021	0.000	0.000	0.000	0.000
BENDDS_1		1830.498	35.464	2.521	14.583	0.000	0.000	1.523	-0.115	8.454	-0.497	14.067	0.000	0.000	0.000	0.000
BENDDS_2		1834.562	18.398	1.678	14.609	0.000	0.000	1.083	-0.101	14.923	-1.095	14.126	0.000	0.000	0.000	0.000
BENDDS_1		1834.922	17.218	1.604	14.612	0.000	0.000	1.046	-0.101	15.729	-1.148	14.129	0.000	0.000	0.000	0.000
BENDDS_2		1838.986	7.610	0.761	14.670	0.000	0.000	0.662	-0.088	27.491	-1.746	14.161	0.000	0.000	0.000	0.000
Q225	D	1841.225	5.735	-0.021	14.726	0.000	0.000	0.490	-0.056	33.199	-0.088	14.172	0.000	0.000	0.000	0.000
BENDDS_1		1843.465	7.815	-0.813	14.782	0.000	0.000	0.404	-0.030	28.196	1.614	14.184	0.000	0.000	0.000	0.000
BENDDS_2		1847.529	17.932	-1.677	14.838	0.000	0.000	0.312	-0.016	17.187	1.095	14.213	0.000	0.000	0.000	0.000
BENDDS_1		1847.888	19.165	-1.753	14.841	0.000	0.000	0.306	-0.016	16.417	1.049	14.217	0.000	0.000	0.000	0.000
BENDDS_2		1851.952	36.923	-2.617	14.865	0.000	0.000	0.270	-0.002	10.001	0.529	14.268	0.000	0.000	0.000	0.000
Q224	F	1854.192	45.716	-0.295	14.874	0.000	0.000	0.254	-0.018	9.044	-0.275	14.307	0.000	0.000	0.000	0.000
BENDDS_1		1856.431	39.276	2.177	14.882	0.000	0.000	0.194	-0.032	12.759	-1.233	14.341	0.000	0.000	0.000	0.000
BENDDS_2		1860.495	23.993	1.583	14.903	0.000	0.000	0.093	-0.018	26.043	-2.035	14.377	0.000	0.000	0.000	0.000
BENDDS_1		1860.855	22.874	1.531	14.905	0.000	0.000	0.086	-0.018	27.532	-2.106	14.379	0.000	0.000	0.000	0.000
BENDDS_2		1864.919	12.845	0.937	14.943	0.000	0.000	0.042	-0.004	47.904	-2.906	14.397	0.000	0.000	0.000	0.000
Q223	D	1867.158	10.269	0.033	14.975	0.000	0.000	0.035	-0.002	57.000	0.066	14.404	0.000	0.000	0.000	0.000
Q222	F	1884.447	55.907	0.019	15.104	0.000	0.000	0.028	-0.002	9.929	-0.025	14.533	0.000	0.000	0.000	0.000
MI22		1893.091	24.945	1.418	15.140	0.000	0.000	0.005	-0.003	26.587	-1.536	14.624	0.000	0.000	0.000	0.000
Q221	D	1901.735	9.893	-0.034	15.235	0.000	0.000	-0.019	-0.003	59.897	-0.068	14.658	0.000	0.000	0.000	0.000
Q220	F	1919.024	59.859	-0.017	15.361	0.000	0.000	-0.091	0.000	11.376	0.020	14.774	0.000	0.000	0.000	0.000
BENDDS_1		1921.263	49.884	3.156	15.367	0.000	0.000	-0.084	0.005	13.890	-0.935	14.803	0.000	0.000	0.000	0.000
BENDDS_2		1925.327	27.860	2.263	15.384	0.000	0.000	-0.036	0.019	23.719	-1.483	14.839	0.000	0.000	0.000	0.000
BENDDS_1		1925.687	26.262	2.184	15.386	0.000	0.000	-0.029	0.019	24.802	-1.531	14.841	0.000	0.000	0.000	0.000
BENDDS_2		1929.751	12.139	1.291	15.423	0.000	0.000	0.076	0.033	39.470	-2.078	14.862	0.000	0.000	0.000	0.000
Q219	D	1931.990	8.190	0.344	15.460	0.000	0.000	0.154	0.040	45.506	0.348	14.870	0.000	0.000	0.000	0.000
BENDDS_1		1934.230	8.705	-0.417	15.504	0.000	0.000	0.260	0.051	36.695	2.598	14.879	0.000	0.000	0.000	0.000
BENDDS_2		1938.294	14.322	-0.965	15.563	0.000	0.000	0.495	0.065	19.061	1.741	14.903	0.000	0.000	0.000	0.000
BENDDS_1		1938.653	15.033	-1.014	15.567	0.000	0.000	0.519	0.065	17.838	1.665	14.906	0.000	0.000	0.000	0.000
BENDDS_2		1942.717	25.499	-1.562	15.600	0.000	0.000	0.810	0.079	7.797	0.806	14.962	0.000	0.000	0.000	0.000
Q218	F	1944.957	30.489	0.002	15.613	0.000	0.000	0.947	0.024	5.755	0.008	15.018	0.000	0.000	0.000	0.000
BENDDS_1		1947.196	25.482	1.565	15.625	0.000	0.000	0.916	-0.032	7.720	-0.786	15.074	0.000	0.000	0.000	0.000
BENDDS_2		1951.260	14.998	1.015	15.658	0.000	0.000	0.813	-0.019	17.568	-1.637	15.131	0.000	0.000	0.000	0.000
BENDDS_1		1951.620	14.286	0.966	15.662	0.000	0.000	0.806	-0.019	18.772	-1.712	15.134	0.000	0.000	0.000	0.000
BENDDS_2		1955.684	8.668	0.416	15.722	0.000	0.000	0.759	-0.005	36.144	-2.562	15.159	0.000	0.000	0.000	0.000
Q217	D	1957.923	8.157	-0.344	15.766	0.000	0.000	0.781	0.040	44.840	-0.347	15.167	0.000	0.000	0.000	0.000

Linear lattice functions for beam line: MI17
delta(p)/p = 0.000000 symm = F

ELEMENT SEQUENCE element name	quad type	dist [m]	HORIZONTAL betax [m]	alfax [1]	mux [2pi]	x(co) [mm]	px(co) [.001]	Dx [m]	Dpx [1]	VERTICAL betay [m]	alfay [1]	muy [2pi]	y(co) [mm]	py(co) [.001]	Dy [m]	Dpy [1]
BENDDS_1		1960.163	12.103	-1.291	15.803	0.000	0.000	0.942	0.088	38.914	2.042	15.176	0.000	0.000	0.000	0.000
BENDDS_2		1964.227	26.229	-2.186	15.840	0.000	0.000	1.327	0.102	24.503	1.503	15.197	0.000	0.000	0.000	0.000
BENDDS_1		1964.586	27.829	-2.265	15.842	0.000	0.000	1.363	0.102	23.439	1.456	15.199	0.000	0.000	0.000	0.000
BENDDS_2		1968.650	49.873	-3.160	15.859	0.000	0.000	1.805	0.116	13.802	0.915	15.235	0.000	0.000	0.000	0.000
Q216	F	1970.890	59.866	0.013	15.865	0.000	0.000	1.978	-0.001	11.366	-0.035	15.265	0.000	0.000	0.000	0.000
BEND_1		1973.258	50.875	2.329	15.872	0.000	0.000	1.822	-0.085	13.939	-0.792	15.295	0.000	0.000	0.000	0.000
BEND_2		1979.354	27.175	1.559	15.898	0.000	0.000	1.366	-0.064	27.921	-1.501	15.345	0.000	0.000	0.000	0.000
BEND_1		1979.714	26.071	1.514	15.900	0.000	0.000	1.343	-0.064	29.015	-1.543	15.347	0.000	0.000	0.000	0.000
BEND_2		1985.810	12.307	0.744	15.956	0.000	0.000	1.015	-0.043	52.145	-2.250	15.372	0.000	0.000	0.000	0.000
SD		1986.733	11.040	0.628	15.968	0.000	0.000	0.975	-0.043	56.400	-2.358	15.375	0.000	0.000	0.000	0.000
Q215	D	1988.178	9.937	0.035	15.991	0.000	0.000	0.934	-0.004	60.725	0.070	15.379	0.000	0.000	0.000	0.000
BEND_1		1990.547	11.948	-0.661	16.026	0.000	0.000	0.998	0.036	51.540	2.363	15.386	0.000	0.000	0.000	0.000
BEND_2		1996.643	24.473	-1.394	16.084	0.000	0.000	1.280	0.057	27.459	1.586	15.412	0.000	0.000	0.000	0.000
BEND_1		1997.002	25.491	-1.437	16.086	0.000	0.000	1.300	0.057	26.335	1.540	15.414	0.000	0.000	0.000	0.000
BEND_2		2003.098	47.479	-2.170	16.114	0.000	0.000	1.710	0.078	12.308	0.760	15.469	0.000	0.000	0.000	0.000
SF		2004.021	51.590	-2.281	16.117	0.000	0.000	1.781	0.078	11.013	0.642	15.481	0.000	0.000	0.000	0.000
Q214	F	2005.466	55.869	-0.014	16.122	0.000	0.000	1.852	-0.002	9.881	0.040	15.504	0.000	0.000	0.000	0.000
BEND_1		2007.835	47.603	2.147	16.129	0.000	0.000	1.703	-0.081	11.895	-0.664	15.539	0.000	0.000	0.000	0.000
BEND_2		2013.931	25.805	1.429	16.157	0.000	0.000	1.275	-0.060	24.490	-1.401	15.597	0.000	0.000	0.000	0.000
BEND_1		2014.290	24.793	1.386	16.159	0.000	0.000	1.253	-0.060	25.513	-1.445	15.600	0.000	0.000	0.000	0.000
BEND_2		2020.386	12.270	0.668	16.216	0.000	0.000	0.953	-0.039	47.609	-2.179	15.628	0.000	0.000	0.000	0.000
SD		2021.310	11.137	0.559	16.228	0.000	0.000	0.917	-0.039	51.737	-2.291	15.631	0.000	0.000	0.000	0.000
Q213	D	2022.755	10.226	-0.034	16.250	0.000	0.000	0.881	-0.001	56.091	-0.068	15.635	0.000	0.000	0.000	0.000
BEND_1		2025.123	12.622	-0.750	16.284	0.000	0.000	0.946	0.036	48.192	2.070	15.642	0.000	0.000	0.000	0.000
BEND_2		2031.219	26.357	-1.504	16.338	0.000	0.000	1.228	0.057	27.012	1.403	15.669	0.000	0.000	0.000	0.000
BEND_1		2031.579	27.453	-1.548	16.340	0.000	0.000	1.248	0.057	26.018	1.364	15.671	0.000	0.000	0.000	0.000
BEND_2		2037.675	50.926	-2.302	16.367	0.000	0.000	1.658	0.078	13.467	0.695	15.724	0.000	0.000	0.000	0.000
SF		2038.598	55.284	-2.417	16.369	0.000	0.000	1.729	0.078	12.278	0.593	15.735	0.000	0.000	0.000	0.000
Q212	F	2040.043	59.782	0.016	16.373	0.000	0.000	1.800	0.001	11.312	-0.044	15.755	0.000	0.000	0.000	0.000
BEND_1		2042.412	50.788	2.328	16.380	0.000	0.000	1.661	-0.076	13.925	-0.801	15.786	0.000	0.000	0.000	0.000
BEND_2		2048.508	27.101	1.558	16.406	0.000	0.000	1.259	-0.055	28.065	-1.518	15.836	0.000	0.000	0.000	0.000
BEND_1		2048.867	25.998	1.512	16.408	0.000	0.000	1.240	-0.055	29.171	-1.560	15.838	0.000	0.000	0.000	0.000
BEND_2		2054.963	12.260	0.742	16.464	0.000	0.000	0.965	-0.035	52.552	-2.274	15.863	0.000	0.000	0.000	0.000
SD		2055.887	10.998	0.625	16.477	0.000	0.000	0.933	-0.035	56.853	-2.383	15.865	0.000	0.000	0.000	0.000
Q211	D	2057.332	9.902	0.033	16.499	0.000	0.000	0.904	0.004	61.231	0.065	15.869	0.000	0.000	0.000	0.000
BEND_1		2059.700	11.918	-0.662	16.534	0.000	0.000	0.983	0.042	51.994	2.379	15.876	0.000	0.000	0.000	0.000
BEND_2		2065.796	24.473	-1.398	16.593	0.000	0.000	1.304	0.063	27.734	1.600	15.901	0.000	0.000	0.000	0.000
BEND_1		2066.156	25.493	-1.441	16.595	0.000	0.000	1.327	0.063	26.601	1.554	15.904	0.000	0.000	0.000	0.000
BEND_2		2072.252	47.545	-2.177	16.623	0.000	0.000	1.775	0.084	12.419	0.772	15.958	0.000	0.000	0.000	0.000
SF		2073.175	51.669	-2.288	16.626	0.000	0.000	1.852	0.084	11.103	0.653	15.971	0.000	0.000	0.000	0.000
Q210	F	2074.620	55.964	-0.018	16.630	0.000	0.000	1.930	0.002	9.941	0.048	15.993	0.000	0.000	0.000	0.000
BEND_1		2076.989	47.698	2.148	16.637	0.000	0.000	1.782	-0.081	11.918	-0.655	16.028	0.000	0.000	0.000	0.000
BEND_2		2083.085	25.882	1.431	16.665	0.000	0.000	1.352	-0.060	24.360	-1.385	16.086	0.000	0.000	0.000	0.000
BEND_1		2083.444	24.869	1.388	16.667	0.000	0.000	1.330	-0.060	25.372	-1.428	16.089	0.000	0.000	0.000	0.000
BEND_2		2089.540	12.317	0.671	16.724	0.000	0.000	1.027	-0.039	47.222	-2.155	16.117	0.000	0.000	0.000	0.000

ELEMENT SEQUENCE element name	quad type	dist [m]	HORIZONTAL betax [m]	alfax [1]	mux [2pi]	x(co) [mm]	px(co) [.001]	Dx [m]	Dpx [1]	VERTICAL betay [m]	alfay [1]	muy [2pi]	y(co) [mm]	py(co) [.001]	Dy [m]	Dpy [1]
SD		2090.464	11.178	0.562	16.736	0.000	0.000	0.991	-0.039	51.305	-2.266	16.120	0.000	0.000	0.000	0.000
Q209	D	2091.909	10.260	-0.032	16.758	0.000	0.000	0.956	0.001	55.606	-0.062	16.124	0.000	0.000	0.000	0.000
BEND_1		2094.277	12.650	-0.748	16.792	0.000	0.000	1.033	0.042	47.754	2.056	16.131	0.000	0.000	0.000	0.000
BEND_2		2100.373	26.352	-1.500	16.846	0.000	0.000	1.352	0.063	26.740	1.390	16.159	0.000	0.000	0.000	0.000
BEND_1		2100.732	27.446	-1.544	16.848	0.000	0.000	1.375	0.063	25.755	1.351	16.161	0.000	0.000	0.000	0.000
BEND_2		2106.828	50.851	-2.296	16.874	0.000	0.000	1.821	0.084	13.352	0.683	16.214	0.000	0.000	0.000	0.000
SF		2107.752	55.196	-2.409	16.877	0.000	0.000	1.898	0.084	12.184	0.582	16.226	0.000	0.000	0.000	0.000
Q208	F	2109.197	59.676	0.019	16.881	0.000	0.000	1.974	-0.001	11.247	-0.052	16.246	0.000	0.000	0.000	0.000
BEND_1		2111.565	50.684	2.327	16.888	0.000	0.000	1.817	-0.085	13.894	-0.809	16.276	0.000	0.000	0.000	0.000
BEND_2		2117.661	27.021	1.555	16.914	0.000	0.000	1.362	-0.064	28.179	-1.534	16.326	0.000	0.000	0.000	0.000
BEND_1		2118.021	25.919	1.510	16.916	0.000	0.000	1.339	-0.064	29.296	-1.576	16.328	0.000	0.000	0.000	0.000
BEND_2		2124.117	12.214	0.739	16.972	0.000	0.000	1.011	-0.043	52.917	-2.298	16.353	0.000	0.000	0.000	0.000
SD		2125.040	10.957	0.622	16.985	0.000	0.000	0.971	-0.043	57.263	-2.407	16.356	0.000	0.000	0.000	0.000
Q207	D	2126.485	9.869	0.031	17.007	0.000	0.000	0.930	-0.004	61.693	0.058	16.360	0.000	0.000	0.000	0.000
BEND_1		2128.854	11.891	-0.664	17.043	0.000	0.000	0.993	0.036	52.415	2.392	16.366	0.000	0.000	0.000	0.000
BEND_2		2134.950	24.482	-1.402	17.101	0.000	0.000	1.274	0.056	28.002	1.612	16.391	0.000	0.000	0.000	0.000
BEND_1		2135.309	25.505	-1.446	17.103	0.000	0.000	1.294	0.056	26.860	1.566	16.394	0.000	0.000	0.000	0.000
BEND_2		2141.405	47.629	-2.184	17.131	0.000	0.000	1.701	0.077	12.538	0.783	16.447	0.000	0.000	0.000	0.000
SF		2142.329	51.766	-2.296	17.134	0.000	0.000	1.773	0.077	11.201	0.664	16.460	0.000	0.000	0.000	0.000
Q206	F	2143.774	56.079	-0.021	17.138	0.000	0.000	1.843	-0.001	10.011	0.056	16.482	0.000	0.000	0.000	0.000
BEND_1		2146.142	47.809	2.150	17.146	0.000	0.000	1.695	-0.080	11.957	-0.648	16.517	0.000	0.000	0.000	0.000
BEND_2		2152.238	25.965	1.433	17.173	0.000	0.000	1.270	-0.059	24.262	-1.370	16.575	0.000	0.000	0.000	0.000
BEND_1		2152.598	24.950	1.391	17.176	0.000	0.000	1.248	-0.059	25.262	-1.413	16.578	0.000	0.000	0.000	0.000
BEND_2		2158.694	12.363	0.674	17.232	0.000	0.000	0.950	-0.038	46.880	-2.133	16.606	0.000	0.000	0.000	0.000
SD		2159.617	11.219	0.565	17.244	0.000	0.000	0.915	-0.038	50.920	-2.242	16.609	0.000	0.000	0.000	0.000
Q205	D	2161.062	10.292	-0.030	17.266	0.000	0.000	0.879	-0.001	55.169	-0.055	16.613	0.000	0.000	0.000	0.000
BEND_1		2163.431	12.675	-0.746	17.300	0.000	0.000	0.945	0.036	47.353	2.044	16.621	0.000	0.000	0.000	0.000
BEND_2		2169.527	26.338	-1.495	17.354	0.000	0.000	1.229	0.057	26.477	1.379	16.648	0.000	0.000	0.000	0.000
BEND_1		2169.886	27.429	-1.539	17.356	0.000	0.000	1.250	0.057	25.500	1.340	16.650	0.000	0.000	0.000	0.000
BEND_2		2175.982	50.759	-2.288	17.382	0.000	0.000	1.661	0.078	13.230	0.672	16.704	0.000	0.000	0.000	0.000
SF		2176.906	55.090	-2.402	17.385	0.000	0.000	1.733	0.078	12.081	0.571	16.716	0.000	0.000	0.000	0.000
Q204	F	2178.351	59.552	0.023	17.389	0.000	0.000	1.805	0.001	11.171	-0.059	16.736	0.000	0.000	0.000	0.000
BEND_1		2180.719	50.566	2.324	17.396	0.000	0.000	1.665	-0.076	13.847	-0.816	16.767	0.000	0.000	0.000	0.000
BEND_2		2186.815	26.935	1.552	17.422	0.000	0.000	1.264	-0.055	28.261	-1.548	16.817	0.000	0.000	0.000	0.000
BEND_1		2187.175	25.835	1.507	17.424	0.000	0.000	1.244	-0.055	29.389	-1.591	16.819	0.000	0.000	0.000	0.000
BEND_2		2193.271	12.168	0.735	17.480	0.000	0.000	0.969	-0.035	53.234	-2.320	16.843	0.000	0.000	0.000	0.000
SD		2194.194	10.918	0.618	17.493	0.000	0.000	0.937	-0.035	57.621	-2.430	16.846	0.000	0.000	0.000	0.000
Q203	D	2195.639	9.838	0.029	17.516	0.000	0.000	0.908	0.004	62.103	0.051	16.850	0.000	0.000	0.000	0.000
BEND_1		2198.008	11.868	-0.666	17.551	0.000	0.000	0.988	0.042	52.795	2.402	16.856	0.000	0.000	0.000	0.000
BEND_2		2204.104	24.501	-1.407	17.609	0.000	0.000	1.311	0.063	28.259	1.622	16.882	0.000	0.000	0.000	0.000
BEND_1		2204.463	25.528	-1.450	17.612	0.000	0.000	1.333	0.063	27.109	1.576	16.884	0.000	0.000	0.000	0.000
BEND_2		2210.559	47.729	-2.192	17.640	0.000	0.000	1.783	0.084	12.663	0.793	16.937	0.000	0.000	0.000	0.000
SF		2211.482	51.881	-2.304	17.643	0.000	0.000	1.861	0.084	11.307	0.675	16.949	0.000	0.000	0.000	0.000
Q202	F	2212.927	56.213	-0.024	17.647	0.000	0.000	1.938	0.001	10.092	0.063	16.971	0.000	0.000	0.000	0.000
BEND_1		2215.296	47.935	2.153	17.654	0.000	0.000	1.790	-0.081	12.011	-0.642	17.006	0.000	0.000	0.000	0.000

"MAD" Version: 8.17 Run: 22/04/92 14.44.56
Range: #S/#E

Linear lattice functions for beam line: MI17
delta(p)/p = 0.000000 symm = F

ELEMENT SEQUENCE element name	quad type	dist [m]	HORIZONTAL betax [m]	alfax [1]	mux [2pi]	x(co) [mm]	px(co) [.001]	Dx [m]	Dpx [1]	VERTICAL betay [m]	alfay [1]	muy [2pi]	y(co) [mm]	py(co) [.001]	Dy [m]	Dpy [1]
BEND_2		2221.392	26.054	1.436	17.682	0.000	0.000	1.357	-0.061	24.196	-1.357	17.064	0.000	0.000	0.000	0.000
BEND_1		2221.751	25.037	1.394	17.684	0.000	0.000	1.335	-0.061	25.186	-1.399	17.067	0.000	0.000	0.000	0.000
BEND_2		2227.847	12.408	0.677	17.740	0.000	0.000	1.029	-0.040	46.590	-2.111	17.095	0.000	0.000	0.000	0.000
SD		2228.771	11.257	0.569	17.752	0.000	0.000	0.993	-0.040	50.589	-2.220	17.098	0.000	0.000	0.000	0.000
Q201	D	2230.216	10.322	-0.028	17.774	0.000	0.000	0.957	0.001	54.788	-0.047	17.103	0.000	0.000	0.000	0.000
MI20		2230.216	10.322	-0.028	17.774	0.000	0.000	0.957	0.001	54.788	-0.047	17.103	0.000	0.000	0.000	0.000
BEND_1		2232.584	12.695	-0.744	17.808	0.000	0.000	1.034	0.042	46.994	2.036	17.110	0.000	0.000	0.000	0.000
BEND_2		2238.680	26.314	-1.490	17.862	0.000	0.000	1.351	0.062	26.228	1.370	17.138	0.000	0.000	0.000	0.000
BEND_1		2239.040	27.401	-1.534	17.864	0.000	0.000	1.373	0.062	25.257	1.331	17.140	0.000	0.000	0.000	0.000
BEND_2		2245.136	50.651	-2.280	17.890	0.000	0.000	1.817	0.083	13.102	0.663	17.194	0.000	0.000	0.000	0.000
SF		2246.059	54.967	-2.393	17.893	0.000	0.000	1.894	0.083	11.972	0.561	17.206	0.000	0.000	0.000	0.000
Q130	F	2247.504	59.410	0.025	17.897	0.000	0.000	1.969	-0.001	11.086	-0.066	17.226	0.000	0.000	0.000	0.000
BEND_1		2249.873	50.433	2.321	17.904	0.000	0.000	1.813	-0.085	13.785	-0.822	17.257	0.000	0.000	0.000	0.000
BEND_2		2255.969	26.844	1.549	17.930	0.000	0.000	1.358	-0.064	28.310	-1.561	17.307	0.000	0.000	0.000	0.000
BEND_1		2256.328	25.747	1.503	17.932	0.000	0.000	1.335	-0.064	29.448	-1.604	17.309	0.000	0.000	0.000	0.000
BEND_2		2262.424	12.123	0.732	17.989	0.000	0.000	1.007	-0.043	53.498	-2.340	17.334	0.000	0.000	0.000	0.000
SD		2263.348	10.880	0.615	18.001	0.000	0.000	0.967	-0.043	57.924	-2.452	17.337	0.000	0.000	0.000	0.000
Q129	D	2264.793	9.810	0.026	18.024	0.000	0.000	0.926	-0.004	62.455	0.043	17.340	0.000	0.000	0.000	0.000
BEND_1		2267.161	11.850	-0.668	18.060	0.000	0.000	0.989	0.035	53.130	2.409	17.347	0.000	0.000	0.000	0.000
BEND_2		2273.257	24.529	-1.412	18.118	0.000	0.000	1.267	0.056	28.500	1.630	17.372	0.000	0.000	0.000	0.000
BEND_1		2273.617	25.560	-1.456	18.120	0.000	0.000	1.288	0.056	27.344	1.584	17.374	0.000	0.000	0.000	0.000
BEND_2		2279.713	47.845	-2.200	18.148	0.000	0.000	1.693	0.077	12.792	0.803	17.427	0.000	0.000	0.000	0.000
SF		2280.636	52.012	-2.313	18.151	0.000	0.000	1.765	0.077	11.419	0.684	17.439	0.000	0.000	0.000	0.000
Q128	F	2282.081	56.363	-0.027	18.155	0.000	0.000	1.834	-0.001	10.181	0.068	17.461	0.000	0.000	0.000	0.000
BEND_1		2284.450	48.075	2.157	18.162	0.000	0.000	1.687	-0.080	12.080	-0.637	17.495	0.000	0.000	0.000	0.000
BEND_2		2290.546	26.147	1.440	18.190	0.000	0.000	1.265	-0.059	24.164	-1.345	17.553	0.000	0.000	0.000	0.000
BEND_1		2290.905	25.127	1.398	18.192	0.000	0.000	1.244	-0.059	25.145	-1.387	17.556	0.000	0.000	0.000	0.000
BEND_2		2297.001	12.452	0.681	18.248	0.000	0.000	0.948	-0.038	46.354	-2.092	17.584	0.000	0.000	0.000	0.000
SD		2297.925	11.294	0.573	18.260	0.000	0.000	0.913	-0.038	50.317	-2.199	17.587	0.000	0.000	0.000	0.000
Q127	D	2299.370	10.349	-0.025	18.282	0.000	0.000	0.878	-0.001	54.468	-0.038	17.592	0.000	0.000	0.000	0.000
BEND_1		2301.738	12.712	-0.741	18.316	0.000	0.000	0.945	0.037	46.685	2.030	17.599	0.000	0.000	0.000	0.000
BEND_2		2307.834	26.281	-1.485	18.370	0.000	0.000	1.232	0.057	25.996	1.363	17.627	0.000	0.000	0.000	0.000
BEND_1		2308.193	27.364	-1.528	18.372	0.000	0.000	1.252	0.057	25.030	1.324	17.629	0.000	0.000	0.000	0.000
BEND_2		2314.289	50.528	-2.272	18.398	0.000	0.000	1.666	0.078	12.972	0.654	17.684	0.000	0.000	0.000	0.000
SF		2315.213	54.828	-2.384	18.401	0.000	0.000	1.738	0.078	11.857	0.552	17.696	0.000	0.000	0.000	0.000
Q126	F	2316.658	59.252	0.028	18.405	0.000	0.000	1.810	0.001	10.993	-0.071	17.717	0.000	0.000	0.000	0.000
BEND_1		2319.026	50.287	2.317	18.412	0.000	0.000	1.670	-0.076	13.709	-0.826	17.748	0.000	0.000	0.000	0.000
BEND_2		2325.122	26.749	1.545	18.438	0.000	0.000	1.268	-0.056	28.326	-1.572	17.798	0.000	0.000	0.000	0.000
BEND_1		2325.482	25.655	1.499	18.440	0.000	0.000	1.248	-0.056	29.471	-1.616	17.800	0.000	0.000	0.000	0.000
BEND_2		2331.578	12.080	0.728	18.497	0.000	0.000	0.973	-0.035	53.704	-2.359	17.824	0.000	0.000	0.000	0.000
SD		2332.501	10.844	0.611	18.510	0.000	0.000	0.941	-0.035	58.165	-2.472	17.827	0.000	0.000	0.000	0.000
Q125	D	2333.946	9.784	0.024	18.532	0.000	0.000	0.912	0.004	62.742	0.034	17.831	0.000	0.000	0.000	0.000
BEND_1		2336.315	11.836	-0.671	18.568	0.000	0.000	0.992	0.043	53.412	2.413	17.837	0.000	0.000	0.000	0.000
BEND_2		2342.411	24.567	-1.418	18.626	0.000	0.000	1.317	0.064	28.721	1.636	17.862	0.000	0.000	0.000	0.000
BEND_1		2342.770	25.602	-1.462	18.629	0.000	0.000	1.339	0.064	27.561	1.590	17.864	0.000	0.000	0.000	0.000

ELEMENT SEQUENCE		I	HORIZONTAL							I	VERTICAL						
element name	quad type	dist [m]	betax [m]	alfax [1]	mux [2pi]	x(co) [mm]	px(co) [.001]	Dx [m]	Dpx [1]		betay [m]	alfay [1]	muy [2pi]	y(co) [mm]	py(co) [.001]	Dy [m]	Dpy [1]
BEND_2		2348.866	47.975	-2.209	18.656	0.000	0.000	1.791	0.084		12.923	0.810	17.917	0.000	0.000	0.000	0.000
SF		2349.790	52.158	-2.322	18.659	0.000	0.000	1.869	0.084		11.535	0.692	17.929	0.000	0.000	0.000	0.000
Q124	F	2351.235	56.529	-0.029	18.664	0.000	0.000	1.947	0.001		10.277	0.073	17.950	0.000	0.000	0.000	0.000
BEND_1		2353.603	48.226	2.162	18.671	0.000	0.000	1.797	-0.082		12.163	-0.634	17.985	0.000	0.000	0.000	0.000
BEND_2		2359.699	26.243	1.445	18.698	0.000	0.000	1.361	-0.061		24.165	-1.335	18.042	0.000	0.000	0.000	0.000
BEND_1		2360.059	25.220	1.402	18.700	0.000	0.000	1.340	-0.061		25.140	-1.376	18.045	0.000	0.000	0.000	0.000
BEND_2		2366.155	12.494	0.685	18.756	0.000	0.000	1.031	-0.040		46.179	-2.075	18.073	0.000	0.000	0.000	0.000
SD		2367.078	11.329	0.577	18.768	0.000	0.000	0.994	-0.040		50.108	-2.181	18.076	0.000	0.000	0.000	0.000
Q123	D	2368.523	10.373	-0.022	18.790	0.000	0.000	0.958	0.000		54.215	-0.029	18.081	0.000	0.000	0.000	0.000
BEND_1		2370.892	12.723	-0.738	18.824	0.000	0.000	1.034	0.041		46.430	2.028	18.088	0.000	0.000	0.000	0.000
BEND_2		2376.988	26.239	-1.479	18.878	0.000	0.000	1.348	0.062		25.786	1.358	18.116	0.000	0.000	0.000	0.000
BEND_1		2377.347	27.318	-1.522	18.880	0.000	0.000	1.370	0.062		24.824	1.319	18.119	0.000	0.000	0.000	0.000
BEND_2		2383.443	50.391	-2.263	18.906	0.000	0.000	1.812	0.083		12.840	0.647	18.174	0.000	0.000	0.000	0.000
SF		2384.367	54.674	-2.375	18.909	0.000	0.000	1.888	0.083		11.740	0.545	18.186	0.000	0.000	0.000	0.000
Q122	F	2385.812	59.078	0.030	18.913	0.000	0.000	1.964	-0.001		10.894	-0.075	18.207	0.000	0.000	0.000	0.000
BEND_1		2388.180	50.130	2.312	18.920	0.000	0.000	1.807	-0.085		13.620	-0.828	18.238	0.000	0.000	0.000	0.000
BEND_2		2394.276	26.651	1.540	18.946	0.000	0.000	1.353	-0.064		28.307	-1.581	18.289	0.000	0.000	0.000	0.000
BEND_1		2394.636	25.561	1.495	18.949	0.000	0.000	1.330	-0.064		29.459	-1.625	18.291	0.000	0.000	0.000	0.000
BEND_2		2400.732	12.039	0.723	19.005	0.000	0.000	1.003	-0.043		53.849	-2.375	18.315	0.000	0.000	0.000	0.000
SD		2401.655	10.811	0.607	19.018	0.000	0.000	0.963	-0.043		58.340	-2.489	18.318	0.000	0.000	0.000	0.000
Q121	D	2403.100	9.761	0.020	19.041	0.000	0.000	0.922	-0.004		62.960	0.024	18.321	0.000	0.000	0.000	0.000
BEND_1		2405.469	11.827	-0.674	19.077	0.000	0.000	0.984	0.035		53.639	2.414	18.328	0.000	0.000	0.000	0.000
BEND_2		2411.565	24.614	-1.424	19.135	0.000	0.000	1.261	0.056		28.919	1.640	18.352	0.000	0.000	0.000	0.000
BEND_1		2411.924	25.653	-1.468	19.137	0.000	0.000	1.282	0.056		27.757	1.594	18.355	0.000	0.000	0.000	0.000
BEND_2		2418.020	48.118	-2.218	19.165	0.000	0.000	1.686	0.077		13.054	0.817	18.406	0.000	0.000	0.000	0.000
SF		2418.943	52.318	-2.331	19.168	0.000	0.000	1.757	0.077		11.654	0.699	18.418	0.000	0.000	0.000	0.000
Q120	F	2420.388	56.709	-0.031	19.172	0.000	0.000	1.826	-0.001		10.379	0.077	18.440	0.000	0.000	0.000	0.000
BEND_1		2422.757	48.388	2.167	19.179	0.000	0.000	1.680	-0.079		12.259	-0.632	18.474	0.000	0.000	0.000	0.000
BEND_2		2428.853	26.342	1.450	19.206	0.000	0.000	1.260	-0.058		24.201	-1.327	18.531	0.000	0.000	0.000	0.000
BEND_1		2429.212	25.316	1.407	19.209	0.000	0.000	1.239	-0.058		25.170	-1.368	18.534	0.000	0.000	0.000	0.000
BEND_2		2435.308	12.534	0.690	19.264	0.000	0.000	0.947	-0.038		46.066	-2.060	18.562	0.000	0.000	0.000	0.000
SD		2436.232	11.361	0.581	19.276	0.000	0.000	0.912	-0.038		49.967	-2.165	18.565	0.000	0.000	0.000	0.000
Q119	D	2437.677	10.394	-0.019	19.298	0.000	0.000	0.878	0.000		54.032	-0.019	18.570	0.000	0.000	0.000	0.000
BEND_1		2440.045	12.730	-0.735	19.331	0.000	0.000	0.946	0.037		46.233	2.028	18.577	0.000	0.000	0.000	0.000
BEND_2		2446.141	26.188	-1.473	19.386	0.000	0.000	1.234	0.058		25.601	1.356	18.606	0.000	0.000	0.000	0.000
BEND_1		2446.501	27.262	-1.516	19.388	0.000	0.000	1.255	0.058		24.641	1.316	18.608	0.000	0.000	0.000	0.000
BEND_2		2452.597	50.242	-2.254	19.414	0.000	0.000	1.671	0.079		12.710	0.641	18.664	0.000	0.000	0.000	0.000
SF		2453.520	54.508	-2.366	19.417	0.000	0.000	1.744	0.079		11.621	0.538	18.676	0.000	0.000	0.000	0.000
Q118	F	2454.965	58.892	0.032	19.421	0.000	0.000	1.816	0.001		10.790	-0.078	18.697	0.000	0.000	0.000	0.000
BEND_1		2457.334	49.964	2.306	19.428	0.000	0.000	1.676	-0.077		13.519	-0.829	18.729	0.000	0.000	0.000	0.000
BEND_2		2463.430	26.552	1.535	19.454	0.000	0.000	1.274	-0.056		28.254	-1.588	18.779	0.000	0.000	0.000	0.000
BEND_1		2463.789	25.465	1.490	19.457	0.000	0.000	1.254	-0.056		29.411	-1.633	18.781	0.000	0.000	0.000	0.000
BEND_2		2469.885	12.001	0.719	19.513	0.000	0.000	0.978	-0.035		53.930	-2.389	18.806	0.000	0.000	0.000	0.000
SD		2470.809	10.780	0.602	19.526	0.000	0.000	0.946	-0.035		58.448	-2.503	18.808	0.000	0.000	0.000	0.000
Q117	D	2472.254	9.742	0.017	19.549	0.000	0.000	0.916	0.004		63.106	0.014	18.812	0.000	0.000	0.000	0.000

"MAD" Version: 8.17 Run: 22/04/92 14.44.56

Linear lattice functions for beam line: MI17
Range: #S/#E
delta(p)/p = 0.000000 symm = F

ELEMENT SEQUENCE element name	quad type	dist [m]	HORIZONTAL betax [m]	alfax [1]	mux [2pi]	x(co) [mm]	px(co) [.001]	Dx [m]	Dpx [1]	VERTICAL betay [m]	alfay [1]	muy [2pi]	y(co) [mm]	py(co) [.001]	Dy [m]	Dpy [1]
BEND_1		2474.622	11.822	-0.678	19.585	0.000	0.000	0.997	0.043	53.805	2.412	18.818	0.000	0.000	0.000	0.000
BEND_2		2480.718	24.669	-1.430	19.643	0.000	0.000	1.322	0.064	29.091	1.641	18.843	0.000	0.000	0.000	0.000
BEND_1		2481.078	25.713	-1.474	19.645	0.000	0.000	1.345	0.064	27.927	1.596	18.845	0.000	0.000	0.000	0.000
BEND_2		2487.174	48.272	-2.227	19.673	0.000	0.000	1.798	0.085	13.183	0.822	18.896	0.000	0.000	0.000	0.000
SF		2488.097	52.490	-2.341	19.676	0.000	0.000	1.876	0.085	11.772	0.705	18.908	0.000	0.000	0.000	0.000
Q116	F	2489.542	56.901	-0.033	19.680	0.000	0.000	1.954	0.001	10.484	0.079	18.929	0.000	0.000	0.000	0.000
BEND_1		2491.911	48.558	2.173	19.687	0.000	0.000	1.804	-0.082	12.365	-0.632	18.963	0.000	0.000	0.000	0.000
BEND_2		2498.007	26.442	1.455	19.714	0.000	0.000	1.366	-0.061	24.271	-1.321	19.020	0.000	0.000	0.000	0.000
BEND_1		2498.366	25.412	1.413	19.717	0.000	0.000	1.343	-0.061	25.235	-1.361	19.023	0.000	0.000	0.000	0.000
BEND_2		2504.462	12.571	0.694	19.772	0.000	0.000	1.032	-0.041	46.017	-2.047	19.051	0.000	0.000	0.000	0.000
SD		2505.386	11.390	0.585	19.784	0.000	0.000	0.995	-0.041	49.894	-2.151	19.054	0.000	0.000	0.000	0.000
Q115	D	2506.831	10.412	-0.016	19.806	0.000	0.000	0.958	0.000	53.924	-0.009	19.059	0.000	0.000	0.000	0.000
BEND_1		2509.199	12.732	-0.731	19.839	0.000	0.000	1.033	0.041	46.098	2.032	19.066	0.000	0.000	0.000	0.000
BEND_2		2515.295	26.129	-1.466	19.894	0.000	0.000	1.345	0.062	25.444	1.355	19.095	0.000	0.000	0.000	0.000
BEND_1		2515.654	27.198	-1.510	19.896	0.000	0.000	1.367	0.062	24.484	1.315	19.097	0.000	0.000	0.000	0.000
BEND_2		2521.750	50.082	-2.245	19.922	0.000	0.000	1.806	0.082	12.584	0.636	19.153	0.000	0.000	0.000	0.000
SF		2522.674	54.331	-2.356	19.925	0.000	0.000	1.882	0.082	11.504	0.533	19.166	0.000	0.000	0.000	0.000
Q114	F	2524.119	58.695	0.034	19.929	0.000	0.000	1.957	-0.001	10.684	-0.079	19.187	0.000	0.000	0.000	0.000
BEND_1		2526.487	49.789	2.299	19.936	0.000	0.000	1.801	-0.085	13.408	-0.828	19.219	0.000	0.000	0.000	0.000
BEND_2		2532.583	26.451	1.530	19.963	0.000	0.000	1.348	-0.064	28.168	-1.593	19.270	0.000	0.000	0.000	0.000
BEND_1		2532.943	25.368	1.484	19.965	0.000	0.000	1.325	-0.064	29.329	-1.638	19.272	0.000	0.000	0.000	0.000
BEND_2		2539.039	11.965	0.715	20.022	0.000	0.000	0.999	-0.043	53.946	-2.400	19.296	0.000	0.000	0.000	0.000
SD		2539.962	10.753	0.598	20.035	0.000	0.000	0.959	-0.043	58.485	-2.515	19.299	0.000	0.000	0.000	0.000
Q113	D	2541.407	9.726	0.014	20.058	0.000	0.000	0.918	-0.004	63.176	0.004	19.302	0.000	0.000	0.000	0.000
BEND_1		2543.776	11.822	-0.681	20.094	0.000	0.000	0.980	0.035	53.909	2.407	19.309	0.000	0.000	0.000	0.000
BEND_2		2549.872	24.732	-1.436	20.152	0.000	0.000	1.256	0.056	29.233	1.640	19.333	0.000	0.000	0.000	0.000
BEND_1		2550.231	25.780	-1.481	20.154	0.000	0.000	1.276	0.056	28.070	1.595	19.335	0.000	0.000	0.000	0.000
BEND_2		2556.327	48.437	-2.236	20.181	0.000	0.000	1.679	0.077	13.307	0.826	19.386	0.000	0.000	0.000	0.000
SF		2557.251	52.673	-2.350	20.184	0.000	0.000	1.750	0.077	11.889	0.709	19.398	0.000	0.000	0.000	0.000
Q112	F	2558.696	57.103	-0.035	20.188	0.000	0.000	1.819	-0.001	10.592	0.080	19.419	0.000	0.000	0.000	0.000
BEND_1		2561.064	48.736	2.180	20.195	0.000	0.000	1.674	-0.079	12.480	-0.634	19.453	0.000	0.000	0.000	0.000
BEND_2		2567.160	26.543	1.461	20.223	0.000	0.000	1.257	-0.058	24.373	-1.317	19.509	0.000	0.000	0.000	0.000
BEND_1		2567.520	25.508	1.418	20.225	0.000	0.000	1.236	-0.058	25.334	-1.357	19.512	0.000	0.000	0.000	0.000
BEND_2		2573.616	12.605	0.699	20.280	0.000	0.000	0.946	-0.037	46.033	-2.038	19.540	0.000	0.000	0.000	0.000
SD		2574.539	11.416	0.590	20.292	0.000	0.000	0.912	-0.037	49.892	-2.141	19.543	0.000	0.000	0.000	0.000
Q111	D	2575.984	10.426	-0.012	20.314	0.000	0.000	0.878	0.000	53.892	0.001	19.548	0.000	0.000	0.000	0.000
BEND_1		2578.353	12.730	-0.727	20.347	0.000	0.000	0.946	0.037	46.026	2.039	19.555	0.000	0.000	0.000	0.000
BEND_2		2584.449	26.062	-1.460	20.401	0.000	0.000	1.238	0.058	25.317	1.358	19.584	0.000	0.000	0.000	0.000
BEND_1		2584.808	27.127	-1.503	20.404	0.000	0.000	1.259	0.058	24.356	1.317	19.586	0.000	0.000	0.000	0.000
BEND_2		2590.904	49.913	-2.235	20.430	0.000	0.000	1.677	0.079	12.462	0.633	19.643	0.000	0.000	0.000	0.000
SF		2591.828	54.144	-2.346	20.433	0.000	0.000	1.750	0.079	11.388	0.530	19.655	0.000	0.000	0.000	0.000
Q110	F	2593.273	58.489	0.035	20.437	0.000	0.000	1.823	0.001	10.576	-0.080	19.676	0.000	0.000	0.000	0.000
BEND_1		2595.641	49.609	2.292	20.444	0.000	0.000	1.683	-0.077	13.289	-0.826	19.709	0.000	0.000	0.000	0.000
BEND_2		2601.737	26.351	1.524	20.471	0.000	0.000	1.279	-0.056	28.051	-1.595	19.760	0.000	0.000	0.000	0.000
BEND_1		2602.097	25.272	1.478	20.473	0.000	0.000	1.259	-0.056	29.214	-1.641	19.762	0.000	0.000	0.000	0.000

Linear lattice functions for beam line: MI17
delta(p)/p = 0.000000 symm = F

ELEMENT SEQUENCE			HORIZONTAL							VERTICAL						
element name	quad type	dist [m]	betax [m]	alfax [1]	mux [2pi]	x(co) [mm]	px(co) [.001]	Dx [m]	Dpx [1]	betay [m]	alfay [1]	muy [2pi]	y(co) [mm]	py(co) [.001]	Dy [m]	Dpy [1]
BEND_2		2608.193	11.933	0.710	20.530	0.000	0.000	0.982	-0.035	53.897	-2.408	19.787	0.000	0.000	0.000	0.000
SD		2609.116	10.729	0.594	20.543	0.000	0.000	0.950	-0.035	58.452	-2.524	19.789	0.000	0.000	0.000	0.000
Q109	D	2610.561	9.714	0.010	20.566	0.000	0.000	0.920	0.004	63.170	-0.006	19.793	0.000	0.000	0.000	0.000
BEND_1		2612.930	11.827	-0.685	20.602	0.000	0.000	1.001	0.043	53.948	2.398	19.799	0.000	0.000	0.000	0.000
BEND_2		2619.026	24.802	-1.443	20.660	0.000	0.000	1.328	0.064	29.344	1.637	19.824	0.000	0.000	0.000	0.000
BEND_1		2619.385	25.855	-1.488	20.662	0.000	0.000	1.351	0.064	28.183	1.592	19.826	0.000	0.000	0.000	0.000
BEND_2		2625.481	48.610	-2.245	20.690	0.000	0.000	1.805	0.085	13.425	0.828	19.877	0.000	0.000	0.000	0.000
SF		2626.404	52.863	-2.360	20.693	0.000	0.000	1.883	0.085	12.002	0.712	19.888	0.000	0.000	0.000	0.000
Q108	F	2627.849	57.313	-0.036	20.697	0.000	0.000	1.961	0.001	10.699	0.079	19.909	0.000	0.000	0.000	0.000
BENDDS_1		2630.089	47.848	3.004	20.703	0.000	0.000	1.790	-0.114	12.821	-0.830	19.940	0.000	0.000	0.000	0.000
BENDDS_2		2634.153	26.891	2.153	20.721	0.000	0.000	1.354	-0.100	21.737	-1.364	19.979	0.000	0.000	0.000	0.000
BENDDS_1		2634.512	25.371	2.077	20.724	0.000	0.000	1.318	-0.100	22.734	-1.411	19.982	0.000	0.000	0.000	0.000
BENDDS_2		2638.576	11.947	1.226	20.761	0.000	0.000	0.940	-0.086	36.371	-1.944	20.004	0.000	0.000	0.000	0.000
Q107	D	2640.816	8.239	0.298	20.798	0.000	0.000	0.782	-0.038	42.092	0.283	20.013	0.000	0.000	0.000	0.000
BENDDS_1		2643.055	8.969	-0.468	20.841	0.000	0.000	0.764	0.006	34.108	2.369	20.023	0.000	0.000	0.000	0.000
BENDDS_2		2647.119	15.015	-1.020	20.898	0.000	0.000	0.817	0.020	18.052	1.582	20.049	0.000	0.000	0.000	0.000
BENDDS_1		2647.479	15.766	-1.069	20.902	0.000	0.000	0.825	0.020	16.940	1.512	20.052	0.000	0.000	0.000	0.000
BENDDS_2		2651.543	26.698	-1.621	20.934	0.000	0.000	0.935	0.034	7.852	0.724	20.109	0.000	0.000	0.000	0.000
Q106	F	2653.782	31.840	0.023	20.946	0.000	0.000	0.969	-0.024	6.116	-0.057	20.163	0.000	0.000	0.000	0.000
BENDDS_1		2656.022	26.514	1.656	20.958	0.000	0.000	0.831	-0.080	8.419	-0.869	20.215	0.000	0.000	0.000	0.000
BENDDS_2		2660.086	15.387	1.082	20.990	0.000	0.000	0.535	-0.066	18.921	-1.715	20.267	0.000	0.000	0.000	0.000
BENDDS_1		2660.445	14.628	1.031	20.994	0.000	0.000	0.512	-0.066	20.180	-1.790	20.270	0.000	0.000	0.000	0.000
BENDDS_2		2664.509	8.574	0.458	21.053	0.000	0.000	0.273	-0.052	38.163	-2.635	20.293	0.000	0.000	0.000	0.000
Q105	D	2666.749	7.884	-0.299	21.098	0.000	0.000	0.166	-0.040	46.989	-0.288	20.302	0.000	0.000	0.000	0.000
BENDDS_1		2668.988	11.562	-1.219	21.136	0.000	0.000	0.088	-0.032	40.463	2.203	20.310	0.000	0.000	0.000	0.000
BENDDS_2		2673.052	25.018	-2.092	21.175	0.000	0.000	-0.015	-0.018	24.937	1.616	20.330	0.000	0.000	0.000	0.000
BENDDS_1		2673.412	26.550	-2.170	21.177	0.000	0.000	-0.021	-0.018	23.794	1.564	20.332	0.000	0.000	0.000	0.000
BENDDS_2		2677.476	47.734	-3.043	21.195	0.000	0.000	-0.068	-0.004	13.468	0.976	20.369	0.000	0.000	0.000	0.000
Q104	F	2679.715	57.397	-0.010	21.202	0.000	0.000	-0.075	0.000	10.772	0.034	20.399	0.000	0.000	0.000	0.000
Q103	D	2697.004	10.172	-0.007	21.329	0.000	0.000	-0.023	0.002	56.533	0.015	20.523	0.000	0.000	0.000	0.000
Q102	F	2714.292	58.208	0.011	21.454	0.000	0.000	-0.002	0.001	10.449	-0.033	20.649	0.000	0.000	0.000	0.000
MI10		2714.292	58.208	0.011	21.454	0.000	0.000	-0.002	0.001	10.449	-0.033	20.649	0.000	0.000	0.000	0.000
Q101	D	2731.581	9.956	0.006	21.582	0.000	0.000	0.022	0.002	60.357	-0.018	20.770	0.000	0.000	0.000	0.000
Q100	F	2748.870	57.461	-0.011	21.710	0.000	0.000	0.075	0.000	10.822	0.031	20.888	0.000	0.000	0.000	0.000
BENDDS_1		2751.109	47.872	3.031	21.717	0.000	0.000	0.068	-0.004	13.198	-0.895	20.919	0.000	0.000	0.000	0.000
BENDDS_2		2755.173	26.753	2.166	21.735	0.000	0.000	0.079	0.010	22.723	-1.449	20.956	0.000	0.000	0.000	0.000
BENDDS_1		2755.533	25.223	2.090	21.737	0.000	0.000	0.082	0.010	23.782	-1.498	20.959	0.000	0.000	0.000	0.000
BENDDS_2		2759.597	11.753	1.225	21.775	0.000	0.000	0.149	0.023	38.200	-2.050	20.980	0.000	0.000	0.000	0.000
Q641	D	2761.836	8.051	0.301	21.813	0.000	0.000	0.209	0.034	44.233	0.295	20.989	0.000	0.000	0.000	0.000
BENDDS_1		2764.076	8.749	-0.460	21.857	0.000	0.000	0.306	0.048	35.841	2.492	20.998	0.000	0.000	0.000	0.000
BENDDS_2		2768.140	14.777	-1.023	21.915	0.000	0.000	0.530	0.062	18.902	1.675	21.023	0.000	0.000	0.000	0.000
BENDDS_1		2768.499	15.530	-1.073	21.919	0.000	0.000	0.553	0.062	17.724	1.603	21.026	0.000	0.000	0.000	0.000
BENDDS_2		2772.563	26.537	-1.636	21.951	0.000	0.000	0.833	0.076	8.019	0.785	21.081	0.000	0.000	0.000	0.000
Q640	F	2774.803	31.766	-0.002	21.963	0.000	0.000	0.963	0.020	6.045	-0.008	21.135	0.000	0.000	0.000	0.000
BENDDS_1		2777.042	26.552	1.633	21.975	0.000	0.000	0.922	-0.037	8.099	-0.805	21.188	0.000	0.000	0.000	0.000

ELEMENT SEQUENCE			HORIZONTAL							VERTICAL						
element name	quad type	dist [m]	betax [m]	alfax [1]	mux [2pi]	x(co) [mm]	px(co) [.001]	Dx [m]	Dpx [1]	betay [m]	alfay [1]	muy [2pi]	y(co) [mm]	py(co) [.001]	Dy [m]	Dpy [1]
BENDDS_2		2781.106	15.560	1.072	22.007	0.000	0.000	0.799	-0.023	18.004	-1.632	21.242	0.000	0.000	0.000	0.000
BENDDS_1		2781.465	14.808	1.022	22.011	0.000	0.000	0.791	-0.023	19.203	-1.705	21.245	0.000	0.000	0.000	0.000
BENDDS_2		2785.529	8.781	0.461	22.069	0.000	0.000	0.725	-0.009	36.415	-2.530	21.270	0.000	0.000	0.000	0.000
Q639	D	2787.769	8.079	-0.301	22.113	0.000	0.000	0.735	0.033	44.926	-0.296	21.279	0.000	0.000	0.000	0.000
BENDDS_1		2790.008	11.784	-1.226	22.150	0.000	0.000	0.876	0.078	38.779	2.087	21.287	0.000	0.000	0.000	0.000
BENDDS_2		2794.072	25.251	-2.088	22.188	0.000	0.000	1.220	0.092	24.094	1.527	21.308	0.000	0.000	0.000	0.000
BENDDS_1		2794.432	26.780	-2.165	22.190	0.000	0.000	1.253	0.092	23.014	1.477	21.311	0.000	0.000	0.000	0.000
BENDDS_2		2798.496	47.881	-3.028	22.208	0.000	0.000	1.654	0.106	13.290	0.916	21.348	0.000	0.000	0.000	0.000
Q638	F	2800.735	57.454	0.015	22.215	0.000	0.000	1.812	-0.001	10.833	-0.015	21.379	0.000	0.000	0.000	0.000
BEND_1		2803.104	48.821	2.234	22.222	0.000	0.000	1.668	-0.078	13.239	-0.753	21.411	0.000	0.000	0.000	0.000
BEND_2		2809.200	26.146	1.486	22.249	0.000	0.000	1.254	-0.057	26.816	-1.473	21.463	0.000	0.000	0.000	0.000
BEND_1		2809.559	25.093	1.442	22.252	0.000	0.000	1.234	-0.057	27.890	-1.516	21.465	0.000	0.000	0.000	0.000
BEND_2		2815.655	12.074	0.694	22.309	0.000	0.000	0.947	-0.037	50.749	-2.233	21.491	0.000	0.000	0.000	0.000
SD		2816.579	10.897	0.581	22.321	0.000	0.000	0.913	-0.037	54.974	-2.342	21.494	0.000	0.000	0.000	0.000
Q637	D	2818.024	9.921	-0.007	22.344	0.000	0.000	0.881	0.001	59.323	0.023	21.498	0.000	0.000	0.000	0.000
BEND_1		2820.392	12.143	-0.710	22.379	0.000	0.000	0.951	0.038	50.549	2.271	21.505	0.000	0.000	0.000	0.000
BEND_2		2826.488	25.399	-1.465	22.435	0.000	0.000	1.247	0.059	27.375	1.530	21.531	0.000	0.000	0.000	0.000
BEND_1		2826.848	26.468	-1.509	22.438	0.000	0.000	1.269	0.059	26.291	1.486	21.533	0.000	0.000	0.000	0.000
BEND_2		2832.944	49.471	-2.264	22.465	0.000	0.000	1.692	0.080	12.700	0.743	21.587	0.000	0.000	0.000	0.000
SF		2833.867	53.759	-2.379	22.467	0.000	0.000	1.766	0.080	11.432	0.630	21.599	0.000	0.000	0.000	0.000
Q636	F	2835.312	58.220	-0.014	22.471	0.000	0.000	1.840	0.001	10.341	0.017	21.621	0.000	0.000	0.000	0.000
BEND_1		2837.681	49.595	2.241	22.478	0.000	0.000	1.698	-0.077	12.523	-0.702	21.655	0.000	0.000	0.000	0.000
BEND_2		2843.777	26.783	1.501	22.505	0.000	0.000	1.291	-0.056	25.503	-1.427	21.710	0.000	0.000	0.000	0.000
BEND_1		2844.136	25.720	1.457	22.507	0.000	0.000	1.271	-0.056	26.544	-1.470	21.712	0.000	0.000	0.000	0.000
BEND_2		2850.232	12.466	0.717	22.563	0.000	0.000	0.990	-0.036	48.871	-2.192	21.739	0.000	0.000	0.000	0.000
SD		2851.156	11.245	0.605	22.575	0.000	0.000	0.957	-0.036	53.021	-2.302	21.742	0.000	0.000	0.000	0.000
Q635	D	2852.601	10.210	0.007	22.597	0.000	0.000	0.927	0.004	57.344	-0.022	21.746	0.000	0.000	0.000	0.000
BEND_1		2854.969	12.390	-0.699	22.631	0.000	0.000	1.008	0.043	49.062	2.156	21.753	0.000	0.000	0.000	0.000
BEND_2		2861.065	25.380	-1.432	22.687	0.000	0.000	1.334	0.064	27.035	1.456	21.780	0.000	0.000	0.000	0.000
BEND_1		2861.425	26.425	-1.475	22.689	0.000	0.000	1.357	0.064	26.004	1.415	21.782	0.000	0.000	0.000	0.000
BEND_2		2867.521	48.872	-2.208	22.716	0.000	0.000	1.811	0.085	13.038	0.712	21.836	0.000	0.000	0.000	0.000
SF		2868.444	53.052	-2.319	22.719	0.000	0.000	1.889	0.085	11.822	0.605	21.848	0.000	0.000	0.000	0.000
Q634	F	2869.889	57.369	0.014	22.723	0.000	0.000	1.967	0.001	10.810	-0.018	21.869	0.000	0.000	0.000	0.000
BEND_1		2872.258	48.752	2.230	22.730	0.000	0.000	1.815	-0.083	13.229	-0.756	21.901	0.000	0.000	0.000	0.000
BEND_2		2878.354	26.118	1.483	22.758	0.000	0.000	1.371	-0.062	26.857	-1.479	21.953	0.000	0.000	0.000	0.000
BEND_1		2878.713	25.068	1.439	22.760	0.000	0.000	1.348	-0.062	27.936	-1.522	21.955	0.000	0.000	0.000	0.000
BEND_2		2884.809	12.075	0.692	22.817	0.000	0.000	1.032	-0.042	50.880	-2.241	21.981	0.000	0.000	0.000	0.000
SD		2885.732	10.901	0.579	22.830	0.000	0.000	0.993	-0.042	55.121	-2.351	21.984	0.000	0.000	0.000	0.000
Q633	D	2887.177	9.928	-0.008	22.852	0.000	0.000	0.955	-0.001	59.488	0.021	21.988	0.000	0.000	0.000	0.000
BEND_1		2889.546	12.159	-0.712	22.887	0.000	0.000	1.027	0.040	50.700	2.275	21.995	0.000	0.000	0.000	0.000
BEND_2		2895.642	25.441	-1.467	22.944	0.000	0.000	1.331	0.060	27.471	1.534	22.021	0.000	0.000	0.000	0.000
BEND_1		2896.001	26.511	-1.512	22.946	0.000	0.000	1.353	0.060	26.384	1.490	22.023	0.000	0.000	0.000	0.000
BEND_2		2902.097	49.545	-2.267	22.973	0.000	0.000	1.785	0.081	12.742	0.747	22.077	0.000	0.000	0.000	0.000
SF		2903.021	53.838	-2.381	22.976	0.000	0.000	1.860	0.081	11.466	0.634	22.089	0.000	0.000	0.000	0.000
Q632	F	2904.466	58.303	-0.014	22.980	0.000	0.000	1.933	-0.001	10.366	0.020	22.110	0.000	0.000	0.000	0.000

ELEMENT SEQUENCE element name	quad type	dist [m]	HORIZONTAL betax [m]	alfax [1]	mux [2pi]	x(co) [mm]	px(co) [.001]	Dx [m]	Dpx [1]	VERTICAL betay [m]	alfay [1]	muy [2pi]	y(co) [mm]	py(co) [.001]	Dy [m]	Dpy [1]
BEND_1		2906.834	49.662	2.245	22.986	0.000	0.000	1.778	-0.084	12.537	-0.699	22.144	0.000	0.000	0.000	0.000
BEND_2		2912.930	26.809	1.504	23.013	0.000	0.000	1.330	-0.063	25.467	-1.422	22.200	0.000	0.000	0.000	0.000
BEND_1		2913.290	25.744	1.460	23.015	0.000	0.000	1.307	-0.063	26.505	-1.464	22.202	0.000	0.000	0.000	0.000
BEND_2		2919.386	12.464	0.719	23.071	0.000	0.000	0.986	-0.042	48.748	-2.184	22.229	0.000	0.000	0.000	0.000
SD		2920.309	11.241	0.606	23.083	0.000	0.000	0.947	-0.042	52.882	-2.293	22.232	0.000	0.000	0.000	0.000
Q631	D	2921.754	10.202	0.009	23.105	0.000	0.000	0.907	-0.004	57.187	-0.020	22.236	0.000	0.000	0.000	0.000
BEND_1		2924.123	12.373	-0.697	23.139	0.000	0.000	0.969	0.035	48.918	2.152	22.243	0.000	0.000	0.000	0.000
BEND_2		2930.219	25.339	-1.430	23.195	0.000	0.000	1.244	0.056	26.941	1.452	22.270	0.000	0.000	0.000	0.000
BEND_1		2930.578	26.382	-1.473	23.197	0.000	0.000	1.264	0.056	25.913	1.411	22.272	0.000	0.000	0.000	0.000
BEND_2		2936.674	48.800	-2.205	23.225	0.000	0.000	1.667	0.076	12.994	0.708	22.326	0.000	0.000	0.000	0.000
SF		2937.598	52.976	-2.316	23.227	0.000	0.000	1.738	0.076	11.785	0.601	22.338	0.000	0.000	0.000	0.000
Q630	F	2939.043	57.289	0.013	23.232	0.000	0.000	1.807	-0.001	10.783	-0.021	22.359	0.000	0.000	0.000	0.000
BEND_1		2941.411	48.688	2.226	23.239	0.000	0.000	1.664	-0.078	13.213	-0.759	22.391	0.000	0.000	0.000	0.000
BEND_2		2947.507	26.094	1.480	23.266	0.000	0.000	1.252	-0.057	26.888	-1.484	22.443	0.000	0.000	0.000	0.000
BEND_1		2947.867	25.046	1.437	23.268	0.000	0.000	1.232	-0.057	27.970	-1.527	22.445	0.000	0.000	0.000	0.000
BEND_2		2953.963	12.078	0.691	23.325	0.000	0.000	0.947	-0.036	50.994	-2.249	22.471	0.000	0.000	0.000	0.000
SD		2954.886	10.906	0.578	23.338	0.000	0.000	0.914	-0.036	55.250	-2.359	22.474	0.000	0.000	0.000	0.000
Q629	D	2956.331	9.937	-0.009	23.360	0.000	0.000	0.882	0.001	59.636	0.018	22.478	0.000	0.000	0.000	0.000
BEND_1		2958.700	12.176	-0.714	23.395	0.000	0.000	0.953	0.039	50.836	2.279	22.485	0.000	0.000	0.000	0.000
BEND_2		2964.796	25.482	-1.469	23.452	0.000	0.000	1.252	0.059	27.563	1.538	22.511	0.000	0.000	0.000	0.000
BEND_1		2965.155	26.554	-1.514	23.454	0.000	0.000	1.273	0.059	26.473	1.494	22.513	0.000	0.000	0.000	0.000
BEND_2		2971.251	49.615	-2.269	23.481	0.000	0.000	1.699	0.080	12.786	0.751	22.567	0.000	0.000	0.000	0.000
SF		2972.175	53.912	-2.384	23.484	0.000	0.000	1.774	0.080	11.504	0.638	22.579	0.000	0.000	0.000	0.000
Q628	F	2973.620	58.380	-0.013	23.488	0.000	0.000	1.848	0.001	10.394	0.022	22.600	0.000	0.000	0.000	0.000
BEND_1		2975.988	49.723	2.249	23.495	0.000	0.000	1.706	-0.078	12.556	-0.697	22.634	0.000	0.000	0.000	0.000
BEND_2		2982.084	26.831	1.506	23.521	0.000	0.000	1.297	-0.057	25.443	-1.417	22.689	0.000	0.000	0.000	0.000
BEND_1		2982.443	25.764	1.463	23.523	0.000	0.000	1.277	-0.057	26.477	-1.459	22.691	0.000	0.000	0.000	0.000
BEND_2		2988.539	12.460	0.720	23.579	0.000	0.000	0.995	-0.036	48.643	-2.176	22.719	0.000	0.000	0.000	0.000
SD		2989.463	11.234	0.607	23.591	0.000	0.000	0.961	-0.036	52.763	-2.285	22.721	0.000	0.000	0.000	0.000
Q627	D	2990.908	10.192	0.010	23.613	0.000	0.000	0.931	0.004	57.050	-0.017	22.726	0.000	0.000	0.000	0.000
BEND_1		2993.276	12.356	-0.696	23.647	0.000	0.000	1.012	0.043	48.789	2.149	22.733	0.000	0.000	0.000	0.000
BEND_2		2999.372	25.298	-1.428	23.703	0.000	0.000	1.339	0.064	26.852	1.449	22.760	0.000	0.000	0.000	0.000
BEND_1		2999.732	26.340	-1.471	23.706	0.000	0.000	1.362	0.064	25.826	1.407	22.762	0.000	0.000	0.000	0.000
BEND_2		3005.828	48.733	-2.203	23.733	0.000	0.000	1.815	0.085	12.949	0.705	22.816	0.000	0.000	0.000	0.000
SF		3006.751	52.904	-2.314	23.736	0.000	0.000	1.894	0.085	11.746	0.598	22.828	0.000	0.000	0.000	0.000
Q626	F	3008.196	57.214	0.012	23.740	0.000	0.000	1.972	0.001	10.753	-0.023	22.849	0.000	0.000	0.000	0.000
BENDDS_1		3010.436	47.574	3.035	23.746	0.000	0.000	1.799	-0.115	13.392	-0.962	22.879	0.000	0.000	0.000	0.000
BENDDS_2		3014.500	26.454	2.163	23.765	0.000	0.000	1.359	-0.101	23.579	-1.545	22.916	0.000	0.000	0.000	0.000
BENDDS_1		3014.859	24.927	2.085	23.767	0.000	0.000	1.323	-0.101	24.708	-1.596	22.918	0.000	0.000	0.000	0.000
BENDDS_2		3018.923	11.522	1.213	23.805	0.000	0.000	0.940	-0.087	40.048	-2.178	22.939	0.000	0.000	0.000	0.000
Q625	D	3021.163	7.864	0.296	23.844	0.000	0.000	0.780	-0.039	46.497	0.287	22.947	0.000	0.000	0.000	0.000
BENDDS_1		3023.402	8.568	-0.461	23.889	0.000	0.000	0.759	0.005	37.758	2.607	22.955	0.000	0.000	0.000	0.000
BENDDS_2		3027.466	14.655	-1.037	23.948	0.000	0.000	0.807	0.019	19.972	1.769	22.979	0.000	0.000	0.000	0.000
BENDDS_1		3027.826	15.418	-1.087	23.952	0.000	0.000	0.814	0.019	18.727	1.695	22.982	0.000	0.000	0.000	0.000
BENDDS_2		3031.890	26.595	-1.663	23.984	0.000	0.000	0.919	0.033	8.365	0.855	23.034	0.000	0.000	0.000	0.000

"MAD" Version: 8.17 Run: 22/04/92 14.44.56
Range: #S/#E

Linear lattice functions for beam line: MI17
delta(p)/p = 0.000000 symm = F

ELEMENT SEQUENCE element name	quad type	dist [m]	HORIZONTAL betax [m]	alfax [1]	mux [2pi]	x(co) [mm]	px(co) [.001]	Dx [m]	Dpx [1]	VERTICAL betay [m]	alfay [1]	muy [2pi]	y(co) [mm]	py(co) [.001]	Dy [m]	Dpy [1]
Q624	F	3034.129	31.946	-0.025	23.996	0.000	0.000	0.950	-0.024	6.116	0.046	23.086	0.000	0.000	0.000	0.000
BENDDS_1		3036.369	26.792	1.626	24.008	0.000	0.000	0.814	-0.079	7.905	-0.737	23.140	0.000	0.000	0.000	0.000
BENDDS_2		3040.433	15.824	1.073	24.040	0.000	0.000	0.522	-0.065	17.119	-1.530	23.197	0.000	0.000	0.000	0.000
BENDDS_1		3040.792	15.070	1.024	24.043	0.000	0.000	0.498	-0.065	18.244	-1.600	23.200	0.000	0.000	0.000	0.000
BENDDS_2		3044.856	8.990	0.472	24.100	0.000	0.000	0.263	-0.051	34.467	-2.391	23.226	0.000	0.000	0.000	0.000
Q623	D	3047.096	8.244	-0.295	24.143	0.000	0.000	0.157	-0.040	42.523	-0.283	23.235	0.000	0.000	0.000	0.000
BENDDS_1		3049.335	11.933	-1.221	24.180	0.000	0.000	0.079	-0.032	36.728	1.968	23.244	0.000	0.000	0.000	0.000
BENDDS_2		3053.399	25.305	-2.069	24.218	0.000	0.000	-0.024	-0.019	22.920	1.430	23.266	0.000	0.000	0.000	0.000
BENDDS_1		3053.759	26.820	-2.144	24.220	0.000	0.000	-0.031	-0.019	21.910	1.382	23.269	0.000	0.000	0.000	0.000
BENDDS_2		3057.823	47.697	-2.993	24.238	0.000	0.000	-0.078	-0.005	12.868	0.843	23.308	0.000	0.000	0.000	0.000
Q622	F	3060.062	57.123	0.037	24.245	0.000	0.000	-0.084	0.000	10.694	-0.068	23.339	0.000	0.000	0.000	0.000
Q621	D	3077.351	9.700	-0.014	24.376	0.000	0.000	-0.018	0.003	62.587	0.002	23.456	0.000	0.000	0.000	0.000
MI62		3085.995	25.879	-1.508	24.470	0.000	0.000	0.003	0.002	28.439	1.598	23.488	0.000	0.000	0.000	0.000
Q620	F	3094.639	58.705	-0.037	24.505	0.000	0.000	0.023	0.001	10.641	0.069	23.572	0.000	0.000	0.000	0.000
Q619	D	3111.928	10.438	0.016	24.628	0.000	0.000	0.032	0.002	54.569	0.002	23.700	0.000	0.000	0.000	0.000
BENDDS_1		3114.167	12.794	-0.882	24.660	0.000	0.000	0.039	0.004	45.604	2.829	23.707	0.000	0.000	0.000	0.000
BENDDS_2		3118.231	22.255	-1.446	24.698	0.000	0.000	0.082	0.018	25.866	2.028	23.726	0.000	0.000	0.000	0.000
BENDDS_1		3118.591	23.312	-1.496	24.701	0.000	0.000	0.088	0.018	24.434	1.957	23.728	0.000	0.000	0.000	0.000
BENDDS_2		3122.655	37.768	-2.061	24.723	0.000	0.000	0.188	0.031	11.791	1.154	23.766	0.000	0.000	0.000	0.000
Q618	F	3124.894	43.815	0.312	24.731	0.000	0.000	0.249	0.018	8.369	0.235	23.803	0.000	0.000	0.000	0.000
BENDDS_1		3127.134	35.284	2.524	24.740	0.000	0.000	0.265	0.002	9.439	-0.554	23.845	0.000	0.000	0.000	0.000
BENDDS_2		3131.198	18.217	1.675	24.766	0.000	0.000	0.303	0.016	16.225	-1.116	23.898	0.000	0.000	0.000	0.000
BENDDS_1		3131.557	17.039	1.600	24.769	0.000	0.000	0.309	0.016	17.044	-1.165	23.902	0.000	0.000	0.000	0.000
BENDDS_2		3135.621	7.485	0.751	24.828	0.000	0.000	0.403	0.030	28.798	-1.726	23.931	0.000	0.000	0.000	0.000
Q617	D	3137.861	5.653	-0.029	24.885	0.000	0.000	0.489	0.057	34.274	0.016	23.942	0.000	0.000	0.000	0.000
BENDDS_1		3140.100	7.773	-0.825	24.941	0.000	0.000	0.662	0.088	28.669	1.751	23.953	0.000	0.000	0.000	0.000
BENDDS_2		3144.164	18.044	-1.703	24.997	0.000	0.000	1.048	0.102	16.777	1.175	23.983	0.000	0.000	0.000	0.000
BENDDS_1		3144.524	19.296	-1.780	25.000	0.000	0.000	1.085	0.102	15.951	1.124	23.986	0.000	0.000	0.000	0.000
BENDDS_2		3148.588	37.336	-2.659	25.024	0.000	0.000	1.527	0.116	9.156	0.548	24.041	0.000	0.000	0.000	0.000
Q616	F	3150.827	46.286	-0.311	25.032	0.000	0.000	1.714	0.016	8.107	-0.234	24.084	0.000	0.000	0.000	0.000
BENDDS_1		3153.067	39.809	2.197	25.041	0.000	0.000	1.597	-0.085	11.494	-1.145	24.122	0.000	0.000	0.000	0.000
BENDDS_2		3157.131	24.371	1.602	25.061	0.000	0.000	1.278	-0.072	24.115	-1.961	24.161	0.000	0.000	0.000	0.000
BENDDS_1		3157.490	23.239	1.549	25.064	0.000	0.000	1.252	-0.072	25.551	-2.033	24.164	0.000	0.000	0.000	0.000
BENDDS_2		3161.554	13.062	0.955	25.101	0.000	0.000	0.990	-0.058	45.384	-2.847	24.183	0.000	0.000	0.000	0.000
Q615	D	3163.794	10.419	0.042	25.133	0.000	0.000	0.901	-0.004	54.458	-0.035	24.190	0.000	0.000	0.000	0.000
BEND_1		3166.162	12.442	-0.662	25.167	0.000	0.000	0.961	0.034	46.661	2.033	24.197	0.000	0.000	0.000	0.000
BEND_2		3172.258	24.814	-1.367	25.223	0.000	0.000	1.231	0.055	25.951	1.364	24.225	0.000	0.000	0.000	0.000
BEND_1		3172.618	25.812	-1.409	25.225	0.000	0.000	1.251	0.055	24.985	1.324	24.227	0.000	0.000	0.000	0.000
BEND_2		3178.714	47.285	-2.114	25.253	0.000	0.000	1.649	0.076	12.927	0.653	24.282	0.000	0.000	0.000	0.000
SF		3179.637	51.288	-2.221	25.256	0.000	0.000	1.719	0.076	11.815	0.551	24.294	0.000	0.000	0.000	0.000
Q614	F	3181.082	55.402	0.033	25.260	0.000	0.000	1.787	-0.001	10.952	-0.071	24.315	0.000	0.000	0.000	0.000
BEND_1		3183.451	47.005	2.166	25.268	0.000	0.000	1.645	-0.077	13.663	-0.824	24.346	0.000	0.000	0.000	0.000
BEND_2		3189.547	25.098	1.428	25.296	0.000	0.000	1.239	-0.056	28.275	-1.572	24.397	0.000	0.000	0.000	0.000
BEND_1		3189.906	24.088	1.384	25.298	0.000	0.000	1.219	-0.056	29.421	-1.616	24.399	0.000	0.000	0.000	0.000
BEND_2		3196.002	11.709	0.646	25.358	0.000	0.000	0.940	-0.035	53.671	-2.361	24.423	0.000	0.000	0.000	0.000

ELEMENT SEQUENCE element name	quad type	dist [m]	HORIZONTAL betax [m]	alfax [1]	mux [2pi]	x(co) [mm]	px(co) [.001]	Dx [m]	Dpx [1]	VERTICAL betay [m]	alfay [1]	muy [2pi]	y(co) [mm]	py(co) [.001]	Dy [m]	Dpy [1]
SD		3196.925	10.618	0.535	25.371	0.000	0.000	0.908	-0.035	58.136	-2.474	24.426	0.000	0.000	0.000	0.000
Q613	D	3198.370	9.764	-0.044	25.394	0.000	0.000	0.877	0.002	62.722	0.030	24.429	0.000	0.000	0.000	0.000
BENDDS_1		3200.610	12.328	-0.930	25.427	0.000	0.000	0.958	0.054	52.284	3.282	24.436	0.000	0.000	0.000	0.000
BENDDS_2		3204.674	22.386	-1.545	25.467	0.000	0.000	1.205	0.068	29.316	2.369	24.452	0.000	0.000	0.000	0.000
BENDDS_1		3205.033	23.516	-1.599	25.469	0.000	0.000	1.229	0.068	27.643	2.287	24.454	0.000	0.000	0.000	0.000
BENDDS_2		3209.097	39.015	-2.214	25.490	0.000	0.000	1.533	0.082	12.770	1.372	24.489	0.000	0.000	0.000	0.000
Q612	F	3211.337	45.656	0.243	25.499	0.000	0.000	1.644	-0.016	8.540	0.381	24.524	0.000	0.000	0.000	0.000
BENDDS_1		3213.576	37.078	2.576	25.507	0.000	0.000	1.464	-0.111	8.952	-0.397	24.566	0.000	0.000	0.000	0.000
BENDDS_2		3217.640	19.543	1.739	25.531	0.000	0.000	1.040	-0.098	14.316	-0.922	24.625	0.000	0.000	0.000	0.000
BENDDS_1		3218.000	18.320	1.665	25.534	0.000	0.000	1.005	-0.098	14.995	-0.969	24.629	0.000	0.000	0.000	0.000
BENDDS_2		3222.064	8.188	0.828	25.588	0.000	0.000	0.636	-0.084	25.001	-1.493	24.662	0.000	0.000	0.000	0.000
Q611	D	3224.303	6.033	0.033	25.641	0.000	0.000	0.472	-0.053	29.774	0.000	24.675	0.000	0.000	0.000	0.000
BENDDS_1		3226.543	7.854	-0.743	25.695	0.000	0.000	0.391	-0.028	25.000	1.493	24.688	0.000	0.000	0.000	0.000
BENDDS_2		3230.607	17.157	-1.546	25.752	0.000	0.000	0.306	-0.014	14.994	0.969	24.722	0.000	0.000	0.000	0.000
BENDDS_1		3230.966	18.294	-1.617	25.755	0.000	0.000	0.301	-0.014	14.314	0.922	24.725	0.000	0.000	0.000	0.000
BENDDS_2		3235.030	34.703	-2.420	25.781	0.000	0.000	0.273	0.000	8.951	0.397	24.784	0.000	0.000	0.000	0.000
Q610	F	3237.270	42.795	-0.245	25.790	0.000	0.000	0.261	-0.016	8.539	-0.381	24.826	0.000	0.000	0.000	0.000
BENDDS_1		3239.509	36.651	2.057	25.799	0.000	0.000	0.203	-0.031	12.768	-1.372	24.861	0.000	0.000	0.000	0.000
BENDDS_2		3243.573	22.291	1.477	25.822	0.000	0.000	0.106	-0.017	27.641	-2.288	24.896	0.000	0.000	0.000	0.000
BENDDS_1		3243.933	21.247	1.426	25.824	0.000	0.000	0.100	-0.017	29.314	-2.369	24.898	0.000	0.000	0.000	0.000
BENDDS_2		3247.997	12.018	0.846	25.865	0.000	0.000	0.061	-0.003	52.283	-3.283	24.915	0.000	0.000	0.000	0.000
Q609	D	3250.236	9.786	-0.023	25.899	0.000	0.000	0.057	0.000	62.721	-0.030	24.921	0.000	0.000	0.000	0.000
Q608	F	3267.525	59.224	-0.028	26.026	0.000	0.000	0.102	-0.002	10.996	0.069	25.035	0.000	0.000	0.000	0.000
Q607	D	3284.813	10.345	0.024	26.149	0.000	0.000	0.003	-0.006	54.642	0.035	25.160	0.000	0.000	0.000	0.000
Q606	F	3302.102	56.399	0.027	26.276	0.000	0.000	-0.092	-0.002	10.246	-0.067	25.290	0.000	0.000	0.000	0.000
Q605	D	3319.391	9.811	-0.026	26.407	0.000	0.000	-0.057	0.000	62.422	-0.040	25.410	0.000	0.000	0.000	0.000
MI60		3319.391	9.811	-0.026	0.000	0.000	0.000	-0.057	0.000	62.422	-0.040	0.000	0.000	0.000	0.000	0.000

total length =	3319.390646	mux =	26.407483	muy =	25.410007
delta(s) =	0.000000 mm	dmux =	-2.417258	dmuy =	-2.238283
		betax(max) =	59.866430	betay(max) =	63.176026
		Dx(max) =	1.978201	Dy(max) =	0.000000
		Dx(r.m.s.) =	1.190819	Dy(r.m.s.) =	0.000000

"MAD" Version: 8.17

LINEAR LATTICE FUNCTIONS OF THE PROTON 8 GEV BEAM LINE

ELEMENT SEQUENCE				HORIZONTAL							VERTICAL						
element name		quad type	dist [m]	betax [m]	alfax [1]	mux [2pi]	x(co) [mm]	px(co) [.001]	Dx [m]	Dpx [1]	betay [m]	alfay [1]	muy [2pi]	y(co) [mm]	py(co) [.001]	Dy [m]	Dpy [1]
P8_GEV			0.000	6.270	0.174	0.000	0.000	0.000	1.860	0.038	20.060	0.050	0.000	0.000	0.000	0.000	0.000
BOOSTER			0.000	6.270	0.174	0.000	0.000	0.000	1.860	0.038	20.060	0.050	0.000	0.000	0.000	0.000	0.000
EPB_2	us		7.388	12.668	-1.040	0.156	0.000	0.000	2.141	0.038	22.049	-0.319	0.057	0.000	0.000	0.000	0.000
	ds		10.436	20.525	-1.540	0.186	0.000	0.000	2.132	-0.044	24.306	-0.419	0.078	0.000	0.000	0.000	0.000
EPB_2	us		10.741	21.479	-1.590	0.188	0.000	0.000	2.119	-0.044	24.565	-0.433	0.080	0.000	0.000	0.000	0.000
	ds		13.789	32.686	-2.091	0.206	0.000	0.000	1.860	-0.126	27.483	-0.521	0.099	0.000	0.000	0.000	0.000
Q1A		F	15.211	38.508	-0.325	0.213	0.000	0.000	1.672	-0.213	29.401	-2.101	0.107	0.000	0.000	0.000	0.000
Q1B		D	20.771	23.697	-0.354	0.242	0.000	0.000	0.023	-0.295	83.042	-1.052	0.125	0.000	0.000	0.000	0.000
EPB_1	us		28.217	61.170	-3.238	0.274	0.000	0.000	-2.175	-0.295	33.904	2.554	0.147	0.000	0.000	0.000	0.000
	ds		31.265	82.630	-3.810	0.281	0.000	0.000	-2.951	-0.214	20.226	1.919	0.166	0.000	0.000	0.000	0.000
Q2A		F	32.446	91.106	-0.582	0.283	0.000	0.000	-3.190	-0.094	16.156	1.037	0.176	0.000	0.000	0.000	0.000
Q2B		D	62.748	10.334	-0.496	0.507	0.000	0.000	-2.414	-0.049	57.480	-0.017	0.410	0.000	0.000	0.000	0.000
SDB	us		64.491	13.599	-1.100	0.530	0.000	0.000	-2.622	-0.124	51.911	1.652	0.415	0.000	0.000	0.000	0.000
	ds		67.539	21.138	-1.343	0.559	0.000	0.000	-3.242	-0.281	42.505	1.433	0.426	0.000	0.000	0.000	0.000
Q3A		F	74.404	45.154	0.735	0.594	0.000	0.000	-5.132	0.057	26.609	-0.804	0.459	0.000	0.000	0.000	0.000
Q3B		D	82.236	7.487	0.824	0.664	0.000	0.000	-2.102	0.290	82.717	-0.784	0.485	0.000	0.000	0.000	0.000
SDB	us		91.686	13.282	-1.087	0.865	0.000	0.000	-0.291	0.190	34.953	1.935	0.513	0.000	0.000	0.000	0.000
	ds		94.734	20.772	-1.340	0.894	0.000	0.000	0.000	0.000	24.421	1.521	0.530	0.000	0.000	0.000	0.000
QF		F	102.894	51.056	0.000	0.934	0.000	0.000	0.000	0.000	8.727	0.000	0.625	0.000	0.000	0.000	0.000
B3_DOWN	us		103.427	49.048	2.367	0.936	0.000	0.000	0.000	0.000	9.112	-0.486	0.634	0.000	0.000	0.000	0.000
	ds		109.498	25.175	1.560	0.964	0.000	0.000	0.000	0.000	20.007	-1.309	0.709	0.000	0.000	0.159	0.052
QVD1		D	120.161	7.553	-0.507	1.106	0.000	0.000	0.000	0.000	62.191	2.353	0.757	0.000	0.000	0.711	-0.006
QVF1		F	127.724	40.973	-0.053	1.177	0.000	0.000	0.000	0.000	1.690	0.559	0.889	0.000	0.000	0.241	-0.043
QVD2		D	137.697	4.300	0.000	1.313	0.000	0.000	0.000	0.000	62.346	0.000	1.179	0.000	0.000	0.000	-0.024
QVF1		F	147.671	40.973	0.053	1.449	0.000	0.000	0.000	0.000	1.690	-0.559	1.469	0.000	0.000	-0.241	-0.043
QVD1		D	155.234	7.553	0.507	1.519	0.000	0.000	0.000	0.000	62.191	-2.353	1.601	0.000	0.000	-0.711	-0.006
B3_UP	us		165.897	25.175	-1.560	1.662	0.000	0.000	0.000	0.000	20.007	1.309	1.649	0.000	0.000	-0.159	0.052
	ds		171.967	49.048	-2.367	1.689	0.000	0.000	0.000	0.000	9.112	0.486	1.723	0.000	0.000	0.000	0.000
QF		F	172.501	51.056	0.000	1.691	0.000	0.000	0.000	0.000	8.727	0.000	1.733	0.000	0.000	0.000	0.000
B2	us		176.971	32.496	1.837	1.709	0.000	0.000	0.000	0.000	15.043	-1.020	1.797	0.000	0.000	0.000	0.000
	ds		183.042	15.157	1.020	1.753	0.000	0.000	0.117	0.038	32.400	-1.837	1.841	0.000	0.000	0.000	0.000
QD		D	187.512	8.823	0.000	1.816	0.000	0.000	0.290	0.052	50.965	-0.006	1.859	0.000	0.000	0.000	0.000
B2	us		191.983	15.160	-1.020	1.880	0.000	0.000	0.584	0.066	32.480	1.830	1.876	0.000	0.000	0.000	0.000
	ds		198.053	32.505	-1.838	1.924	0.000	0.000	1.101	0.104	15.163	1.020	1.920	0.000	0.000	0.000	0.000
QF		F	202.524	51.070	0.000	1.941	0.000	0.000	1.560	0.031	8.826	0.000	1.984	0.000	0.000	0.000	0.000
B2	us		206.994	32.505	1.838	1.959	0.000	0.000	1.373	-0.044	15.161	-1.020	2.047	0.000	0.000	0.000	0.000
	ds		213.065	15.160	1.020	2.003	0.000	0.000	1.224	-0.005	32.475	-1.830	2.091	0.000	0.000	0.000	0.000
QD		D	217.535	8.823	0.000	2.066	0.000	0.000	1.207	0.052	50.957	0.006	2.109	0.000	0.000	0.000	0.000
B2	us		222.005	15.157	-1.020	2.130	0.000	0.000	1.691	0.110	32.395	1.836	2.126	0.000	0.000	0.000	0.000
	ds		228.076	32.496	-1.837	2.174	0.000	0.000	2.474	0.148	15.041	1.020	2.171	0.000	0.000	0.000	0.000
QF		F	232.546	51.056	0.000	2.191	0.000	0.000	3.119	0.000	8.727	0.000	2.235	0.000	0.000	0.000	0.000
B2	us		233.829	45.576	2.266	2.195	0.000	0.000	2.946	-0.148	9.917	-0.588	2.257	0.000	0.000	0.000	0.000
	ds		239.900	23.028	1.449	2.225	0.000	0.000	2.163	-0.110	22.036	-1.407	2.324	0.000	0.000	0.000	0.000
B2	us		240.204	22.157	1.408	2.228	0.000	0.000	2.130	-0.110	22.907	-1.448	2.326	0.000	0.000	0.000	0.000
	ds		246.275	10.023	0.591	2.294	0.000	0.000	1.580	-0.071	45.425	-2.259	2.357	0.000	0.000	0.000	0.000

LINEAR LATTICE FUNCTIONS OF THE PROTON 8 GEV BEAM LINE

"MAD" Version: 8.17

ELEMENT SEQUENCE			I	HORIZONTAL								I	VERTICAL						
element name		quad type	dist [m]	betax [m]	alfax [1]	mux [2pi]	x(co) [mm]	px(co) [.001]	Dx [m]	Dpx [1]		betay [m]	alfay [1]	muy [2pi]	y(co) [mm]	py(co) [.001]	Dy [m]	Dpy [1]	
QD		D	247.558	8.825	0.000	2.316	0.000	0.000	1.497	0.000		50.887	0.000	2.361	0.000	0.000	0.000	0.000	
B2	us		248.840	10.023	-0.591	2.338	0.000	0.000	1.580	0.071		45.425	2.258	2.365	0.000	0.000	0.000	0.000	
	ds		254.911	22.157	-1.408	2.405	0.000	0.000	2.130	0.110		22.907	1.448	2.395	0.000	0.000	0.000	0.000	
B2	us		255.216	23.028	-1.449	2.407	0.000	0.000	2.163	0.110		22.037	1.407	2.397	0.000	0.000	0.000	0.000	
	ds		261.286	45.576	-2.266	2.437	0.000	0.000	2.946	0.148		9.918	0.588	2.465	0.000	0.000	0.000	0.000	
QF		F	262.569	51.056	0.000	2.441	0.000	0.000	3.119	0.000		8.728	0.000	2.487	0.000	0.000	0.000	0.000	
B2	us		263.852	45.576	2.266	2.445	0.000	0.000	2.946	-0.148		9.917	-0.588	2.509	0.000	0.000	0.000	0.000	
	ds		269.922	23.028	1.449	2.475	0.000	0.000	2.163	-0.110		22.032	-1.406	2.576	0.000	0.000	0.000	0.000	
B2	us		270.227	22.157	1.408	2.477	0.000	0.000	2.130	-0.110		22.901	-1.448	2.578	0.000	0.000	0.000	0.000	
	ds		276.298	10.023	0.591	2.544	0.000	0.000	1.580	-0.071		45.413	-2.258	2.609	0.000	0.000	0.000	0.000	
QD		D	277.581	8.825	0.000	2.566	0.000	0.000	1.497	0.000		50.872	0.000	2.613	0.000	0.000	0.000	0.000	
B2	us		278.863	10.023	-0.591	2.588	0.000	0.000	1.580	0.071		45.413	2.258	2.617	0.000	0.000	0.000	0.000	
	ds		284.934	22.157	-1.408	2.655	0.000	0.000	2.130	0.110		22.901	1.448	2.647	0.000	0.000	0.000	0.000	
B2	us		285.239	23.028	-1.449	2.657	0.000	0.000	2.164	0.110		22.031	1.406	2.649	0.000	0.000	0.000	0.000	
	ds		291.309	45.576	-2.266	2.687	0.000	0.000	2.947	0.148		9.916	0.588	2.717	0.000	0.000	0.000	0.000	
QF		F	292.592	51.056	0.000	2.691	0.000	0.000	3.120	0.000		8.727	0.000	2.739	0.000	0.000	0.000	0.000	
B2	us		297.062	32.496	1.837	2.709	0.000	0.000	2.474	-0.148		15.045	-1.021	2.803	0.000	0.000	0.000	0.000	
	ds		303.133	15.157	1.020	2.753	0.000	0.000	1.691	-0.110		32.404	-1.837	2.847	0.000	0.000	0.000	0.000	
QD		D	307.603	8.823	0.000	2.816	0.000	0.000	1.207	-0.052		50.972	-0.006	2.865	0.000	0.000	0.000	0.000	
B2	us		312.074	15.160	-1.020	2.880	0.000	0.000	1.224	0.005		32.484	1.830	2.882	0.000	0.000	0.000	0.000	
	ds		318.144	32.505	-1.838	2.924	0.000	0.000	1.373	0.044		15.164	1.021	2.926	0.000	0.000	0.000	0.000	
QF		F	322.615	51.070	0.000	2.941	0.000	0.000	1.560	-0.031		8.826	0.000	2.990	0.000	0.000	0.000	0.000	
B2	us		327.085	32.505	1.838	2.959	0.000	0.000	1.101	-0.104		15.159	-1.020	3.053	0.000	0.000	0.000	0.000	
	ds		333.156	15.160	1.020	3.003	0.000	0.000	0.584	-0.066		32.471	-1.830	3.097	0.000	0.000	0.000	0.000	
QD		D	337.626	8.823	0.000	3.066	0.000	0.000	0.290	-0.052		50.950	0.006	3.115	0.000	0.000	0.000	0.000	
B2	us		342.097	15.157	-1.020	3.130	0.000	0.000	0.116	-0.038		32.391	1.836	3.132	0.000	0.000	0.000	0.000	
	ds		348.167	32.496	-1.837	3.174	0.000	0.000	0.000	0.000		15.040	1.020	3.177	0.000	0.000	0.000	0.000	
QF		F	352.638	51.056	0.000	3.191	0.000	0.000	0.000	0.000		8.727	0.000	3.241	0.000	0.000	0.000	0.000	
B2	us		357.108	32.496	1.837	3.209	0.000	0.000	0.000	0.000		15.046	-1.021	3.305	0.000	0.000	0.000	0.000	
	ds		363.179	15.157	1.020	3.253	0.000	0.000	0.116	0.038		32.409	-1.837	3.349	0.000	0.000	0.000	0.000	
QD		D	367.649	8.823	0.000	3.316	0.000	0.000	0.290	0.052		50.979	-0.006	3.367	0.000	0.000	0.000	0.000	
B2	us		372.119	15.160	-1.020	3.380	0.000	0.000	0.584	0.066		32.488	1.831	3.384	0.000	0.000	0.000	0.000	
	ds		378.190	32.505	-1.838	3.424	0.000	0.000	1.101	0.104		15.165	1.021	3.428	0.000	0.000	0.000	0.000	
QF		F	382.660	51.070	0.000	3.441	0.000	0.000	1.560	0.031		8.826	0.000	3.492	0.000	0.000	0.000	0.000	
B2	us		387.131	32.505	1.838	3.459	0.000	0.000	1.373	-0.044		15.158	-1.020	3.555	0.000	0.000	0.000	0.000	
	ds		393.201	15.160	1.020	3.503	0.000	0.000	1.224	-0.005		32.466	-1.829	3.599	0.000	0.000	0.000	0.000	
QD		D	397.672	8.823	0.000	3.566	0.000	0.000	1.207	0.052		50.943	0.006	3.617	0.000	0.000	0.000	0.000	
B2	us		402.142	15.157	-1.020	3.630	0.000	0.000	1.691	0.110		32.387	1.836	3.634	0.000	0.000	0.000	0.000	
	ds		408.213	32.496	-1.837	3.674	0.000	0.000	2.474	0.148		15.039	1.020	3.679	0.000	0.000	0.000	0.000	
QF		F	412.683	51.056	0.000	3.691	0.000	0.000	3.120	0.000		8.727	0.000	3.743	0.000	0.000	0.000	0.000	
B2	us		413.966	45.576	2.266	3.695	0.000	0.000	2.947	-0.148		9.918	-0.588	3.765	0.000	0.000	0.000	0.000	
	ds		420.036	23.028	1.449	3.725	0.000	0.000	2.164	-0.110		22.042	-1.407	3.832	0.000	0.000	0.000	0.000	
B2	us		420.341	22.157	1.408	3.728	0.000	0.000	2.130	-0.110		22.913	-1.449	3.834	0.000	0.000	0.000	0.000	
	ds		426.412	10.023	0.591	3.794	0.000	0.000	1.580	-0.071		45.438	-2.259	3.864	0.000	0.000	0.000	0.000	
QD		D	427.695	8.825	0.000	3.816	0.000	0.000	1.497	0.000		50.901	0.000	3.869	0.000	0.000	0.000	0.000	

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LINEAR LATTICE FUNCTIONS OF THE PROTON 8 GEV BEAM LINE

ELEMENT SEQUENCE element name		quad type	dist [m]	HORIZONTAL betax [m]	alfax [1]	mux [2pi]	x(co) [mm]	px(co) [.001]	Dx [m]	Dpx [1]	VERTICAL betay [m]	alfay [1]	muy [2pi]	y(co) [mm]	py(co) [.001]	Dy [m]	Dpy [1]
B2	us		428.977	10.023	-0.591	3.838	0.000	0.000	1.580	0.071	45.438	2.259	3.873	0.000	0.000	0.000	0.000
	ds		435.048	22.157	-1.408	3.905	0.000	0.000	2.130	0.110	22.913	1.449	3.903	0.000	0.000	0.000	0.000
B2	us		435.353	23.028	-1.449	3.907	0.000	0.000	2.163	0.110	22.042	1.407	3.905	0.000	0.000	0.000	0.000
	ds		441.423	45.576	-2.266	3.937	0.000	0.000	2.946	0.148	9.918	0.588	3.972	0.000	0.000	0.000	0.000
QF		F	442.706	51.056	0.000	3.941	0.000	0.000	3.119	0.000	8.727	0.000	3.995	0.000	0.000	0.000	0.000
B2	us		443.989	45.576	2.266	3.945	0.000	0.000	2.946	-0.148	9.916	-0.587	4.017	0.000	0.000	0.000	0.000
	ds		450.059	23.028	1.449	3.975	0.000	0.000	2.163	-0.110	22.026	-1.406	4.084	0.000	0.000	0.000	0.000
B2	us		450.364	22.157	1.408	3.977	0.000	0.000	2.130	-0.110	22.895	-1.447	4.086	0.000	0.000	0.000	0.000
	ds		456.435	10.023	0.591	4.044	0.000	0.000	1.580	-0.071	45.400	-2.257	4.116	0.000	0.000	0.000	0.000
QD		D	457.717	8.825	0.000	4.066	0.000	0.000	1.497	0.000	50.858	0.000	4.121	0.000	0.000	0.000	0.000
B2	us		459.000	10.023	-0.591	4.088	0.000	0.000	1.580	0.071	45.400	2.257	4.125	0.000	0.000	0.000	0.000
	ds		465.071	22.157	-1.408	4.155	0.000	0.000	2.130	0.110	22.895	1.447	4.155	0.000	0.000	0.000	0.000
B2	us		465.375	23.028	-1.449	4.157	0.000	0.000	2.163	0.110	22.026	1.406	4.157	0.000	0.000	0.000	0.000
	ds		471.446	45.576	-2.266	4.187	0.000	0.000	2.946	0.148	9.916	0.587	4.225	0.000	0.000	0.000	0.000
QF		F	472.729	51.056	0.000	4.191	0.000	0.000	3.119	0.000	8.727	0.000	4.247	0.000	0.000	0.000	0.000
B2	us		474.011	45.576	2.266	4.195	0.000	0.000	2.946	-0.148	9.918	-0.588	4.269	0.000	0.000	0.000	0.000
	ds		480.082	23.028	1.449	4.225	0.000	0.000	2.163	-0.110	22.042	-1.407	4.336	0.000	0.000	0.000	0.000
B2	us		480.387	22.157	1.408	4.227	0.000	0.000	2.130	-0.110	22.913	-1.449	4.338	0.000	0.000	0.000	0.000
	ds		486.457	10.023	0.591	4.294	0.000	0.000	1.580	-0.071	45.438	-2.259	4.368	0.000	0.000	0.000	0.000
QD		D	487.740	8.825	0.000	4.316	0.000	0.000	1.497	0.000	50.901	0.000	4.373	0.000	0.000	0.000	0.000
B2	us		489.023	10.023	-0.591	4.338	0.000	0.000	1.580	0.071	45.438	2.259	4.377	0.000	0.000	0.000	0.000
	ds		495.093	22.157	-1.408	4.405	0.000	0.000	2.130	0.110	22.913	1.449	4.407	0.000	0.000	0.000	0.000
B2	us		495.398	23.028	-1.449	4.407	0.000	0.000	2.164	0.110	22.042	1.407	4.409	0.000	0.000	0.000	0.000
	ds		501.469	45.576	-2.266	4.437	0.000	0.000	2.947	0.148	9.918	0.588	4.476	0.000	0.000	0.000	0.000
QF		F	502.752	51.056	0.000	4.441	0.000	0.000	3.120	0.000	8.727	0.000	4.499	0.000	0.000	0.000	0.000
B2	us		507.222	32.496	1.837	4.459	0.000	0.000	2.474	-0.148	15.039	-1.020	4.563	0.000	0.000	0.000	0.000
	ds		513.293	15.157	1.020	4.503	0.000	0.000	1.691	-0.110	32.387	-1.836	4.607	0.000	0.000	0.000	0.000
QD		D	517.763	8.823	0.000	4.566	0.000	0.000	1.207	-0.052	50.943	-0.006	4.625	0.000	0.000	0.000	0.000
B2	us		522.233	15.160	-1.020	4.630	0.000	0.000	1.224	0.005	32.466	1.829	4.642	0.000	0.000	0.000	0.000
	ds		528.304	32.505	-1.838	4.674	0.000	0.000	1.373	0.044	15.158	1.020	4.686	0.000	0.000	0.000	0.000
QF		F	532.774	51.070	0.000	4.691	0.000	0.000	1.560	-0.031	8.826	0.000	4.750	0.000	0.000	0.000	0.000
B2	us		537.245	32.505	1.838	4.709	0.000	0.000	1.101	-0.104	15.165	-1.021	4.813	0.000	0.000	0.000	0.000
	ds		543.315	15.160	1.020	4.753	0.000	0.000	0.584	-0.066	32.488	-1.831	4.857	0.000	0.000	0.000	0.000
QD		D	547.786	8.823	0.000	4.816	0.000	0.000	0.290	-0.052	50.979	0.006	4.875	0.000	0.000	0.000	0.000
B2	us		552.256	15.157	-1.020	4.880	0.000	0.000	0.116	-0.038	32.409	1.837	4.892	0.000	0.000	0.000	0.000
	ds		558.327	32.496	-1.837	4.924	0.000	0.000	0.000	0.000	15.046	1.021	4.936	0.000	0.000	0.000	0.000
QF		F	562.797	51.056	0.000	4.941	0.000	0.000	0.000	0.000	8.727	0.000	5.001	0.000	0.000	0.000	0.000
B2	us		567.268	32.496	1.837	4.959	0.000	0.000	0.000	0.000	15.040	-1.020	5.065	0.000	0.000	0.000	0.000
	ds		573.338	15.157	1.020	5.003	0.000	0.000	0.116	0.038	32.391	-1.836	5.109	0.000	0.000	0.000	0.000
QD		D	577.809	8.823	0.000	5.066	0.000	0.000	0.290	0.052	50.950	-0.006	5.126	0.000	0.000	0.000	0.000
B2	us		582.279	15.160	-1.020	5.130	0.000	0.000	0.584	0.066	32.471	1.830	5.144	0.000	0.000	0.000	0.000
	ds		588.350	32.505	-1.838	5.174	0.000	0.000	1.101	0.104	15.159	1.020	5.188	0.000	0.000	0.000	0.000
QF		F	592.820	51.070	0.000	5.191	0.000	0.000	1.560	0.031	8.826	0.000	5.252	0.000	0.000	0.000	0.000
B2	us		597.290	32.505	1.838	5.209	0.000	0.000	1.373	-0.044	15.164	-1.021	5.315	0.000	0.000	0.000	0.000
	ds		603.361	15.160	1.020	5.253	0.000	0.000	1.224	-0.005	32.484	-1.830	5.359	0.000	0.000	0.000	0.000

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LINEAR LATTICE FUNCTIONS OF THE PROTON 8 GEV BEAM LINE

ELEMENT SEQUENCE			I	HORIZONTAL								I	VERTICAL						
element name		quad type	dist [m]	betax [m]	alfax [1]	mux [2pi]	x(co) [mm]	px(co) [.001]	Dx [m]	Dpx [1]			betay [m]	alfay [1]	muy [2pi]	y(co) [mm]	py(co) [.001]	Dy [m]	Dpy [1]
QD		D	607.831	8.823	0.000	5.316	0.000	0.000	1.207	0.052			50.972	0.006	5.377	0.000	0.000	0.000	0.000
B2	us		612.302	15.157	-1.020	5.380	0.000	0.000	1.691	0.110			32.404	1.837	5.394	0.000	0.000	0.000	0.000
	ds		618.372	32.496	-1.837	5.424	0.000	0.000	2.474	0.148			15.045	1.021	5.438	0.000	0.000	0.000	0.000
QF		F	622.843	51.056	0.000	5.441	0.000	0.000	3.120	0.000			8.727	0.000	5.502	0.000	0.000	0.000	0.000
B2	us		624.125	45.576	2.266	5.445	0.000	0.000	2.947	-0.148			9.916	-0.588	5.525	0.000	0.000	0.000	0.000
	ds		630.196	23.028	1.449	5.475	0.000	0.000	2.164	-0.110			22.031	-1.406	5.592	0.000	0.000	0.000	0.000
B2	us		630.501	22.157	1.408	5.477	0.000	0.000	2.130	-0.110			22.901	-1.448	5.594	0.000	0.000	0.000	0.000
	ds		636.571	10.023	0.591	5.544	0.000	0.000	1.580	-0.071			45.413	-2.258	5.624	0.000	0.000	0.000	0.000
QD		D	637.854	8.825	0.000	5.566	0.000	0.000	1.497	0.000			50.872	0.000	5.628	0.000	0.000	0.000	0.000
B2	us		639.137	10.023	-0.591	5.588	0.000	0.000	1.580	0.071			45.413	2.258	5.633	0.000	0.000	0.000	0.000
	ds		645.207	22.157	-1.408	5.655	0.000	0.000	2.130	0.110			22.901	1.448	5.663	0.000	0.000	0.000	0.000
B2	us		645.512	23.028	-1.449	5.657	0.000	0.000	2.163	0.110			22.032	1.406	5.665	0.000	0.000	0.000	0.000
	ds		651.583	45.576	-2.266	5.687	0.000	0.000	2.946	0.148			9.917	0.588	5.732	0.000	0.000	0.000	0.000
QF		F	652.866	51.056	0.000	5.691	0.000	0.000	3.119	0.000			8.728	0.000	5.754	0.000	0.000	0.000	0.000
B2	us		654.148	45.576	2.266	5.695	0.000	0.000	2.946	-0.148			9.918	-0.588	5.777	0.000	0.000	0.000	0.000
	ds		660.219	23.028	1.449	5.725	0.000	0.000	2.163	-0.110			22.037	-1.407	5.844	0.000	0.000	0.000	0.000
B2	us		660.524	22.157	1.408	5.727	0.000	0.000	2.130	-0.110			22.907	-1.448	5.846	0.000	0.000	0.000	0.000
	ds		666.594	10.023	0.591	5.794	0.000	0.000	1.580	-0.071			45.425	-2.258	5.876	0.000	0.000	0.000	0.000
QD3		D	667.877	8.819	0.026	5.816	0.000	0.000	1.496	-0.004			50.921	-0.149	5.880	0.000	0.000	0.000	0.000
B2	us		669.160	9.882	-0.533	5.838	0.000	0.000	1.569	0.062			46.148	1.994	5.885	0.000	0.000	0.000	0.000
	ds		675.230	21.138	-1.322	5.907	0.000	0.000	2.065	0.101			25.861	1.345	5.913	0.000	0.000	0.000	0.000
B2	us		675.535	21.956	-1.361	5.909	0.000	0.000	2.095	0.101			25.051	1.312	5.915	0.000	0.000	0.000	0.000
	ds		681.606	43.265	-2.150	5.941	0.000	0.000	2.824	0.139			13.099	0.655	5.969	0.000	0.000	0.000	0.000
QF3		F	682.888	48.464	0.011	5.945	0.000	0.000	2.987	-0.003			11.725	-0.044	5.986	0.000	0.000	0.000	0.000
B2	us		687.359	30.724	1.748	5.964	0.000	0.000	2.350	-0.146			19.334	-1.128	6.034	0.000	0.000	0.000	0.000
	ds		693.429	14.366	0.947	6.010	0.000	0.000	1.581	-0.108			37.323	-1.833	6.070	0.000	0.000	0.000	0.000
QD2		D	698.171	8.437	-0.039	6.082	0.000	0.000	1.076	-0.061			56.775	0.050	6.087	0.000	0.000	0.000	0.000
B2	us		702.370	14.146	-0.981	6.145	0.000	0.000	1.006	-0.015			38.654	1.960	6.101	0.000	0.000	0.000	0.000
	ds		708.441	31.160	-1.823	6.191	0.000	0.000	1.030	0.023			19.430	1.204	6.136	0.000	0.000	0.000	0.000
QF2		F	713.979	55.059	-0.210	6.213	0.000	0.000	1.152	-0.027			10.060	0.074	6.201	0.000	0.000	0.000	0.000
B2	us		717.382	42.017	1.821	6.224	0.000	0.000	0.899	-0.076			13.712	-0.744	6.248	0.000	0.000	0.000	0.000
	ds		723.452	23.694	1.198	6.255	0.000	0.000	0.554	-0.038			26.892	-1.426	6.300	0.000	0.000	0.000	0.000
QD1		D	727.527	15.796	0.088	6.289	0.000	0.000	0.402	-0.020			39.983	-0.124	6.319	0.000	0.000	0.000	0.000
QF1		F	742.257	51.861	0.218	6.375	0.000	0.000	0.365	-0.017			12.030	-0.191	6.437	0.000	0.000	0.000	0.000
LAMBERT	us		753.636	15.271	0.932	6.441	0.000	0.000	0.005	-0.032			43.156	-2.068	6.520	0.000	0.000	0.000	0.000
	ds		755.922	11.648	0.653	6.468	0.000	0.000	-0.028	0.003			53.193	-2.320	6.528	0.000	0.000	0.000	0.000
QMI_101		D	757.945	9.956	-0.006	6.499	0.000	0.000	-0.022	0.002			60.357	0.018	6.533	0.000	0.000	0.000	0.000
P8_GEV			757.945	9.956	-0.006	6.499	0.000	0.000	-0.022	0.002			60.357	0.018	6.533	0.000	0.000	0.000	0.000

total length = 757.945390	mux	=	6.498521	muy	= 6.533351
delta(s) = 0.000000 mm	dmux	=	-8.761530	dmuy	= -9.616657
	betax(max)	=	91.105871	betay(max)	= 83.041945
	Dx(max)	=	5.132168	Dy(max)	= 0.710720
	Dx(r.m.s.)	=	1.862388	Dy(r.m.s.)	= 0.106179

"MAD" Version: 8.17

LINEAR LATTICE FUNCTIONS OF THE PROTON 150 GEV BEAM LINE

ELEMENT SEQUENCE element name		quad type	dist [m]	HORIZONTAL betax [m]	alfax [1]	mux [2pi]	x(co) [mm]	px(co) [.001]	Dx [m]	Dpx [1]	VERTICAL betay [m]	alfay [1]	muy [2pi]	y(co) [mm]	py(co) [.001]	Dy [m]	Dpy [1]
P150_GEV			0.000	58.068	0.000	0.000	0.000	0.000	0.000	0.000	10.280	0.000	0.000	0.000	0.000	0.000	0.000
INJECTOR			0.000	58.068	0.000	0.000	0.000	0.000	0.000	0.000	10.280	0.000	0.000	0.000	0.000	0.000	0.000
QMI_520		F	0.000	58.068	0.000	0.000	0.000	0.000	0.000	0.000	10.280	0.000	0.000	0.000	0.000	0.000	0.000
QMI_521		D	17.289	10.811	0.006	0.121	0.000	0.000	0.000	0.000	57.663	-0.050	0.126	0.000	0.000	0.000	0.000
LAM1	us		30.607	42.434	-1.973	0.231	0.000	0.000	0.000	0.000	16.285	0.906	0.196	0.000	0.000	0.000	0.000
	ds		32.807	51.672	-2.226	0.238	0.000	0.000	0.000	0.000	12.841	0.660	0.220	0.000	0.000	-0.006	-0.006
QMI_522		F	34.577	57.358	0.001	0.243	0.000	0.000	0.000	0.000	11.362	-0.004	0.244	0.000	0.000	-0.016	-0.006
LAM2	us		36.347	51.665	2.228	0.248	0.000	0.000	0.000	0.000	12.873	-0.669	0.267	0.000	0.000	-0.028	-0.007
	ds		41.147	32.928	1.675	0.267	0.000	0.000	0.000	0.000	21.891	-1.209	0.313	0.000	0.000	-0.089	-0.019
CMAG1	us		42.401	28.909	1.530	0.273	0.000	0.000	0.000	0.000	25.102	-1.351	0.322	0.000	0.000	-0.113	-0.019
	ds		45.409	20.751	1.183	0.293	0.000	0.000	0.000	0.000	34.242	-1.689	0.338	0.000	0.000	-0.180	-0.026
Q84_1		D	49.231	14.057	0.137	0.330	0.000	0.000	0.000	0.000	46.626	-0.050	0.353	0.000	0.000	-0.273	-0.014
VB1	us		51.136	15.512	-0.639	0.350	0.000	0.000	0.000	0.000	41.486	1.822	0.360	0.000	0.000	-0.284	-0.002
	ds		54.143	20.179	-0.912	0.378	0.000	0.000	0.000	0.000	31.470	1.509	0.373	0.000	0.000	-0.280	0.005
VB2	us		54.550	20.935	-0.949	0.381	0.000	0.000	0.000	0.000	30.261	1.466	0.375	0.000	0.000	-0.278	0.005
	ds		57.557	27.464	-1.222	0.401	0.000	0.000	0.000	0.000	22.383	1.153	0.394	0.000	0.000	-0.253	0.012
VB3	us		57.963	28.472	-1.259	0.403	0.000	0.000	0.000	0.000	21.463	1.111	0.397	0.000	0.000	-0.248	0.012
	ds		60.971	36.862	-1.531	0.418	0.000	0.000	0.000	0.000	15.722	0.798	0.423	0.000	0.000	-0.202	0.019
Q84_2		F	65.449	50.254	0.095	0.434	0.000	0.000	0.000	0.000	11.134	-0.105	0.479	0.000	0.000	-0.120	0.014
Q84_3		D	82.204	11.205	-0.096	0.559	0.000	0.000	0.000	0.000	60.171	-0.043	0.591	0.000	0.000	0.036	0.008
HB3A	us		84.697	14.215	-0.855	0.591	0.000	0.000	0.000	0.000	51.146	2.201	0.598	0.000	0.000	0.052	0.006
	ds		90.767	29.088	-1.595	0.639	0.000	0.000	-0.069	-0.023	28.611	1.510	0.623	0.000	0.000	0.085	0.005
HB3B	us		91.123	30.238	-1.638	0.641	0.000	0.000	-0.077	-0.023	27.552	1.469	0.625	0.000	0.000	0.087	0.005
	ds		97.194	54.618	-2.378	0.665	0.000	0.000	-0.195	-0.016	13.940	0.773	0.675	0.000	0.000	0.115	0.005
Q84_4		F	99.687	64.384	0.025	0.672	0.000	0.000	-0.231	-0.007	11.297	0.028	0.708	0.000	0.000	0.129	0.010
HB4A	us		102.180	54.389	2.418	0.678	0.000	0.000	-0.230	0.003	13.636	-0.706	0.740	0.000	0.000	0.165	0.015
	ds		108.250	29.670	1.654	0.703	0.000	0.000	-0.282	-0.020	26.248	-1.371	0.792	0.000	0.000	0.249	0.012
Q84_5		D	117.169	10.655	0.098	0.788	0.000	0.000	-0.470	-0.039	56.916	0.043	0.829	0.000	0.000	0.352	-0.002
HB5A	us		119.662	12.541	-0.608	0.823	0.000	0.000	-0.606	-0.059	48.010	2.145	0.836	0.000	0.000	0.319	-0.017
	ds		125.733	23.950	-1.271	0.880	0.000	0.000	-1.032	-0.081	26.248	1.439	0.864	0.000	0.000	0.204	-0.021
HB5B	us		126.089	24.868	-1.310	0.883	0.000	0.000	-1.061	-0.081	25.240	1.397	0.866	0.000	0.000	0.196	-0.021
	ds		132.159	44.798	-1.973	0.912	0.000	0.000	-1.622	-0.104	12.578	0.688	0.921	0.000	0.000	0.057	-0.024
Q84_6		F	134.652	52.974	-0.019	0.920	0.000	0.000	-1.841	-0.029	10.331	-0.024	0.957	0.000	0.000	-0.002	-0.022
HB6A	us		137.145	44.971	1.942	0.928	0.000	0.000	-1.763	0.048	12.842	-0.746	0.992	0.000	0.000	-0.054	-0.020
	ds		143.216	25.300	1.298	0.956	0.000	0.000	-1.542	0.025	26.363	-1.480	1.046	0.000	0.000	-0.177	-0.020
HB6B	us		143.571	24.390	1.260	0.959	0.000	0.000	-1.533	0.025	27.432	-1.523	1.048	0.000	0.000	-0.185	-0.020
	ds		149.642	12.997	0.616	1.014	0.000	0.000	-1.445	0.004	50.373	-2.255	1.074	0.000	0.000	-0.281	-0.011
Q84_7		D	152.135	11.071	-0.099	1.048	0.000	0.000	-1.466	-0.056	59.728	-0.045	1.081	0.000	0.000	-0.302	0.002
HB7A	us		154.628	14.082	-0.856	1.080	0.000	0.000	-1.727	-0.118	50.781	2.183	1.088	0.000	0.000	-0.273	0.014
	ds		160.699	29.008	-1.603	1.129	0.000	0.000	-2.512	-0.141	28.442	1.496	1.114	0.000	0.000	-0.180	0.016
HB7B	us		161.054	30.164	-1.647	1.131	0.000	0.000	-2.562	-0.141	27.393	1.455	1.116	0.000	0.000	-0.174	0.016
	ds		167.125	54.689	-2.394	1.155	0.000	0.000	-3.484	-0.163	13.907	0.765	1.166	0.000	0.000	-0.077	0.016
Q84_8		F	169.618	64.536	0.012	1.161	0.000	0.000	-3.808	-0.007	11.300	0.021	1.198	0.000	0.000	-0.036	0.018
HB8A	us		172.111	54.579	2.413	1.168	0.000	0.000	-3.518	0.150	13.673	-0.714	1.231	0.000	0.000	0.012	0.020
	ds		178.181	29.889	1.654	1.192	0.000	0.000	-2.675	0.128	26.396	-1.382	1.283	0.000	0.000	0.123	0.017

LINEAR LATTICE FUNCTIONS OF THE PROTON 150 GEV BEAM LINE

"MAD" Version: 8.17

ELEMENT SEQUENCE element name		quad type	dist [m]	betax [m]	alfax [1]	mux [2pi]	x(co) [mm]	px(co) [.001]	Dx [m]	Dpx [1]	betay [m]	alfay [1]	muy [2pi]	y(co) [mm]	py(co) [.001]	Dy [m]	Dpy [1]
HB8B	us		178.537	28.728	1.610	1.194	0.000	0.000	-2.630	0.128	27.393	-1.421	1.285	0.000	0.000	0.129	0.017
	ds		184.607	13.791	0.851	1.243	0.000	0.000	-1.924	0.105	48.686	-2.086	1.311	0.000	0.000	0.230	0.017
Q84_9		D	187.100	10.805	0.100	1.276	0.000	0.000	-1.701	0.033	57.238	0.046	1.319	0.000	0.000	0.266	0.007
HB9A	us		189.593	12.697	-0.609	1.311	0.000	0.000	-1.757	-0.037	48.268	2.160	1.326	0.000	0.000	0.262	-0.004
	ds		195.664	24.069	-1.264	1.368	0.000	0.000	-2.052	-0.060	26.352	1.449	1.353	0.000	0.000	0.254	0.001
HB9B	us		196.020	24.982	-1.303	1.370	0.000	0.000	-2.073	-0.060	25.336	1.408	1.356	0.000	0.000	0.254	0.001
	ds		202.090	44.777	-1.958	1.399	0.000	0.000	-2.503	-0.082	12.575	0.694	1.411	0.000	0.000	0.251	-0.002
Q52_10A		F	203.847	51.081	-0.753	1.405	0.000	0.000	-2.624	-0.011	10.693	0.199	1.435	0.000	0.000	0.249	0.005
Q52_10B		F	205.319	49.274	1.947	1.409	0.000	0.000	-2.536	0.130	11.169	-0.531	1.457	0.000	0.000	0.266	0.019
HB10A	us		207.076	39.304	2.877	1.416	0.000	0.000	-2.212	0.197	14.365	-1.103	1.479	0.000	0.000	0.309	0.026
	ds		213.147	13.074	1.444	1.459	0.000	0.000	-1.084	0.174	33.440	-2.038	1.524	0.000	0.000	0.467	0.026
HB10B	us		213.502	12.077	1.360	1.463	0.000	0.000	-1.021	0.174	34.909	-2.093	1.526	0.000	0.000	0.476	0.026
	ds		219.573	4.259	-0.072	1.624	0.000	0.000	-0.025	0.154	65.974	-3.024	1.546	0.000	0.000	0.606	0.017
Q84_11		D	223.030	7.883	-1.199	1.728	0.000	0.000	0.514	0.171	85.047	-0.068	1.553	0.000	0.000	0.651	-0.009
Q84_12A		F	228.982	39.200	-2.437	1.783	0.000	0.000	1.631	0.131	55.573	0.273	1.567	0.000	0.000	0.465	-0.015
Q52_12B		F	230.861	43.314	0.289	1.790	0.000	0.000	1.766	0.014	62.069	-3.804	1.572	0.000	0.000	0.466	0.016
Q84_13A		D	235.395	33.956	-0.160	1.809	0.000	0.000	1.672	0.032	115.589	-3.215	1.580	0.000	0.000	0.578	0.007
Q52_13B		D	237.275	38.861	-2.510	1.817	0.000	0.000	1.831	0.138	114.032	3.875	1.583	0.000	0.000	0.556	-0.029
Q84_14		F	240.984	65.985	-2.542	1.829	0.000	0.000	2.452	0.107	74.914	2.816	1.589	0.000	0.000	0.414	-0.028
CMAG2	us		246.199	73.290	-0.527	1.841	0.000	0.000	2.641	0.028	67.938	0.389	1.601	0.000	0.000	0.329	-0.015
	ds		249.206	76.612	-0.578	1.847	0.000	0.000	2.726	0.028	65.750	0.338	1.608	0.000	0.000	0.272	-0.023
LAM3	us		256.224	85.580	-0.700	1.861	0.000	0.000	2.923	0.028	61.837	0.219	1.626	0.000	0.000	0.113	-0.023
	ds		261.024	92.690	-0.781	1.869	0.000	0.000	3.057	0.028	60.122	0.138	1.639	0.000	0.000	0.032	-0.011
LAM4	us		261.431	93.328	-0.788	1.870	0.000	0.000	3.069	0.028	60.013	0.131	1.640	0.000	0.000	0.027	-0.011
	ds		266.231	101.282	-0.869	1.878	0.000	0.000	3.203	0.028	59.145	0.050	1.652	0.000	0.000	0.000	0.000
QTEV		F	275.712	115.066	2.318	1.892	0.000	0.000	3.405	-0.071	61.918	-1.871	1.678	0.000	0.000	0.000	0.000
QTEV		D	281.844	61.729	2.499	1.903	0.000	0.000	2.475	-0.106	110.309	-2.423	1.690	0.000	0.000	-0.001	0.000
B_TEV	us		284.530	54.918	0.941	1.911	0.000	0.000	2.316	-0.048	111.902	0.216	1.694	0.000	0.000	-0.001	0.000
	ds		290.651	44.681	0.731	1.930	0.000	0.000	2.047	-0.040	109.606	0.159	1.702	0.000	0.000	-0.001	0.000
B_TEV	us		290.930	44.276	0.721	1.931	0.000	0.000	2.036	-0.040	109.518	0.157	1.703	0.000	0.000	-0.001	0.000
	ds		297.052	36.731	0.511	1.956	0.000	0.000	1.818	-0.032	107.941	0.101	1.712	0.000	0.000	-0.001	0.000
B_TEV	us		297.331	36.448	0.502	1.957	0.000	0.000	1.809	-0.032	107.885	0.098	1.712	0.000	0.000	-0.001	0.000
	ds		303.453	31.593	0.291	1.986	0.000	0.000	1.640	-0.024	107.027	0.042	1.721	0.000	0.000	-0.001	0.000
B_TEV	us		303.732	31.433	0.282	1.987	0.000	0.000	1.634	-0.024	107.005	0.039	1.722	0.000	0.000	-0.001	0.000
	ds		309.853	29.270	0.072	2.019	0.000	0.000	1.515	-0.015	106.866	-0.017	1.731	0.000	0.000	-0.001	0.000
QTEV		D	310.861	29.271	-0.234	2.025	0.000	0.000	1.502	-0.001	106.506	0.964	1.732	0.000	0.000	-0.001	0.000
P150_GEV			310.861	29.271	-0.234	2.025	0.000	0.000	1.502	-0.001	106.506	0.964	1.732	0.000	0.000	-0.001	0.000

total length = 310.861180	mux	=	2.024914	muy	= 1.732277
delta(s) = 0.000000 mm	dmux	=	-3.090670	dmuy	= -2.432575
	betax(max)	=	116.736062	betay(max)	= 117.765105
	Dx(max)	=	3.808460	Dy(max)	= 0.650552
	Dx(r.m.s.)	=	1.790782	Dy(r.m.s.)	= 0.290232

"MAD" Version: 8.17

LINEAR LATTICE FUNCTIONS OF THE PBAR 150 GEV BEAM LINE

ELEMENT SEQUENCE element name		quad type	dist [m]	betax [m]	alfax [1]	HORIZONTAL mux [2pi]	x(co) [mm]	px(co) [.001]	Dx [m]	Dpx [1]	betay [m]	alfay [1]	VERTICAL muy [2pi]	y(co) [mm]	py(co) [.001]	Dy [m]	Dpy [1]
PBAR150_GEV			0.000	58.068	0.000	0.000	0.000	0.000	0.000	0.000	10.280	0.000	0.000	0.000	0.000	0.000	0.000
INJECTOR			0.000	58.068	0.000	0.000	0.000	0.000	0.000	0.000	10.280	0.000	0.000	0.000	0.000	0.000	0.000
QMI_520		F	0.000	58.068	0.000	0.000	0.000	0.000	0.000	0.000	10.280	0.000	0.000	0.000	0.000	0.000	0.000
QMI_521		D	17.289	10.811	0.006	0.121	0.000	0.000	0.000	0.000	57.663	-0.050	0.126	0.000	0.000	0.000	0.000
LAM1	us		30.607	42.434	-1.973	0.231	0.000	0.000	0.000	0.000	16.285	0.906	0.196	0.000	0.000	0.000	0.000
	ds		32.807	51.672	-2.226	0.238	0.000	0.000	0.000	0.000	12.841	0.660	0.220	0.000	0.000	-0.006	-0.006
QMI_522		F	34.577	57.358	0.001	0.243	0.000	0.000	0.000	0.000	11.362	-0.004	0.244	0.000	0.000	-0.016	-0.006
LAM2	us		36.347	51.665	2.228	0.248	0.000	0.000	0.000	0.000	12.873	-0.669	0.267	0.000	0.000	-0.028	-0.007
	ds		41.147	32.928	1.675	0.267	0.000	0.000	0.000	0.000	21.891	-1.209	0.313	0.000	0.000	-0.089	-0.019
CMAG1	us		42.401	28.909	1.530	0.273	0.000	0.000	0.000	0.000	25.102	-1.351	0.322	0.000	0.000	-0.113	-0.019
	ds		45.409	20.751	1.183	0.293	0.000	0.000	0.000	0.000	34.242	-1.689	0.338	0.000	0.000	-0.180	-0.026
Q84_1		D	49.231	14.053	0.141	0.330	0.000	0.000	0.000	0.000	46.638	-0.061	0.353	0.000	0.000	-0.273	-0.014
VB1	us		51.136	15.482	-0.631	0.351	0.000	0.000	0.000	0.000	41.569	1.802	0.360	0.000	0.000	-0.284	-0.002
	ds		54.143	20.095	-0.902	0.378	0.000	0.000	0.000	0.000	31.655	1.495	0.373	0.000	0.000	-0.280	0.005
VB2	us		54.550	20.843	-0.939	0.381	0.000	0.000	0.000	0.000	30.457	1.453	0.375	0.000	0.000	-0.278	0.005
	ds		57.557	27.308	-1.210	0.401	0.000	0.000	0.000	0.000	22.641	1.146	0.394	0.000	0.000	-0.254	0.012
VB3	us		57.963	28.307	-1.247	0.403	0.000	0.000	0.000	0.000	21.726	1.104	0.397	0.000	0.000	-0.249	0.012
	ds		60.971	36.622	-1.518	0.418	0.000	0.000	0.000	0.000	16.008	0.797	0.422	0.000	0.000	-0.203	0.019
Q84_2		F	65.449	49.839	0.152	0.435	0.000	0.000	0.000	0.000	11.413	-0.120	0.477	0.000	0.000	-0.122	0.013
Q84_3		D	81.859	10.236	-0.070	0.564	0.000	0.000	0.000	0.000	60.282	-0.053	0.585	0.000	0.000	0.021	0.008
HB3A	us		84.352	12.992	-0.802	0.599	0.000	0.000	0.000	0.000	51.274	2.200	0.592	0.000	0.000	0.039	0.007
	ds		90.423	27.382	-1.569	0.651	0.000	0.000	0.069	0.023	28.739	1.511	0.617	0.000	0.000	0.071	0.004
HB3B	us		90.779	28.514	-1.614	0.654	0.000	0.000	0.077	0.023	27.679	1.470	0.619	0.000	0.000	0.072	0.004
	ds		96.849	52.770	-2.382	0.679	0.000	0.000	0.192	0.015	14.037	0.777	0.669	0.000	0.000	0.095	0.004
Q84_4		F	99.342	62.658	-0.059	0.685	0.000	0.000	0.226	0.006	11.377	0.029	0.701	0.000	0.000	0.106	0.008
HB4A	us		101.835	53.304	2.287	0.692	0.000	0.000	0.223	-0.003	13.724	-0.708	0.733	0.000	0.000	0.135	0.013
	ds		107.906	29.846	1.578	0.716	0.000	0.000	0.272	0.019	26.337	-1.370	0.785	0.000	0.000	0.204	0.010
Q84_5		D	116.825	11.515	0.066	0.798	0.000	0.000	0.456	0.038	56.933	0.053	0.821	0.000	0.000	0.287	-0.002
HB5A	us		119.318	13.676	-0.667	0.830	0.000	0.000	0.588	0.058	47.969	2.156	0.829	0.000	0.000	0.259	-0.014
	ds		125.389	25.664	-1.308	0.883	0.000	0.000	1.005	0.080	26.115	1.443	0.856	0.000	0.000	0.158	-0.020
HB5B	us		125.744	26.608	-1.346	0.885	0.000	0.000	1.033	0.080	25.104	1.401	0.858	0.000	0.000	0.151	-0.020
	ds		131.815	46.835	-1.987	0.913	0.000	0.000	1.585	0.102	12.433	0.685	0.914	0.000	0.000	0.024	-0.022
Q84_6		F	134.308	54.962	0.064	0.920	0.000	0.000	1.801	0.029	10.201	-0.025	0.950	0.000	0.000	-0.032	-0.023
HB6A	us		136.801	46.261	2.088	0.928	0.000	0.000	1.725	-0.046	12.704	-0.745	0.986	0.000	0.000	-0.093	-0.025
	ds		142.871	25.179	1.385	0.956	0.000	0.000	1.515	-0.023	26.255	-1.486	1.040	0.000	0.000	-0.243	-0.025
HB6B	us		143.227	24.209	1.344	0.959	0.000	0.000	1.506	-0.023	27.328	-1.530	1.042	0.000	0.000	-0.252	-0.025
	ds		149.298	12.166	0.640	1.016	0.000	0.000	1.428	-0.002	50.391	-2.269	1.068	0.000	0.000	-0.376	-0.016
Q84_7		D	151.791	10.140	-0.062	1.053	0.000	0.000	1.454	0.057	59.814	-0.055	1.075	0.000	0.000	-0.407	0.001
HB7A	us		154.284	12.840	-0.790	1.089	0.000	0.000	1.718	0.119	50.886	2.181	1.082	0.000	0.000	-0.372	0.017
	ds		160.354	27.083	-1.557	1.141	0.000	0.000	2.510	0.142	28.555	1.496	1.108	0.000	0.000	-0.256	0.021
HB7B	us		160.710	28.206	-1.602	1.143	0.000	0.000	2.561	0.142	27.505	1.456	1.110	0.000	0.000	-0.249	0.021
	ds		166.780	52.311	-2.369	1.169	0.000	0.000	3.491	0.165	13.997	0.768	1.160	0.000	0.000	-0.123	0.021
Q84_8		F	169.273	62.160	-0.068	1.175	0.000	0.000	3.818	0.008	11.376	0.022	1.192	0.000	0.000	-0.073	0.017
HB8A	us		171.766	52.923	2.261	1.182	0.000	0.000	3.528	-0.150	13.759	-0.716	1.225	0.000	0.000	-0.035	0.015
	ds		177.837	29.730	1.560	1.207	0.000	0.000	2.686	-0.127	26.494	-1.381	1.276	0.000	0.000	0.047	0.012

"MAD" Version: 8.17

LINEAR LATTICE FUNCTIONS OF THE PBAR 150 GEV BEAM LINE

ELEMENT SEQUENCE element name		quad type	dist [m]	betax [m]	alfax [1]	HORIZONTAL mux [2pi]	x(co) [mm]	px(co) [.001]	Dx [m]	Dpx [1]	betay [m]	alfay [1]	VERTICAL muy [2pi]	y(co) [mm]	py(co) [.001]	Dy [m]	Dpy [1]
HB8B	us		178.192	28.635	1.519	1.209	0.000	0.000	2.641	-0.127	27.490	-1.420	1.278	0.000	0.000	0.051	0.012
	ds		184.263	14.451	0.818	1.257	0.000	0.000	1.937	-0.105	48.760	-2.083	1.305	0.000	0.000	0.125	0.012
Q84_9		D	186.756	11.606	0.057	1.288	0.000	0.000	1.716	-0.032	57.287	0.056	1.312	0.000	0.000	0.152	0.006
HB9A	us		189.249	13.825	-0.680	1.320	0.000	0.000	1.775	0.039	48.255	2.172	1.320	0.000	0.000	0.153	-0.001
	ds		195.320	25.972	-1.321	1.372	0.000	0.000	2.078	0.061	26.234	1.455	1.347	0.000	0.000	0.166	0.005
HB9B	us		195.675	26.925	-1.359	1.374	0.000	0.000	2.100	0.061	25.214	1.412	1.349	0.000	0.000	0.168	0.005
	ds		201.746	47.317	-2.001	1.402	0.000	0.000	2.538	0.084	12.435	0.692	1.405	0.000	0.000	0.192	0.003
Q52_10A		F	203.832	55.015	-0.522	1.408	0.000	0.000	2.686	0.001	10.273	0.131	1.434	0.000	0.000	0.199	0.009
Q52_10B		F	205.304	51.687	2.712	1.412	0.000	0.000	2.567	-0.161	11.040	-0.668	1.457	0.000	0.000	0.221	0.021
HB10A	us		207.391	36.353	3.533	1.420	0.000	0.000	2.096	-0.238	15.809	-1.392	1.482	0.000	0.000	0.278	0.028
	ds		213.461	7.125	1.282	1.481	0.000	0.000	0.723	-0.215	39.539	-2.516	1.521	0.000	0.000	0.450	0.028
HB10B	us		213.817	6.261	1.150	1.490	0.000	0.000	0.646	-0.215	41.352	-2.582	1.523	0.000	0.000	0.460	0.028
	ds		219.887	5.968	-1.102	1.759	0.000	0.000	-0.595	-0.194	79.511	-3.702	1.540	0.000	0.000	0.605	0.019
Q84_11		D	221.617	11.339	-2.218	1.793	0.000	0.000	-0.949	-0.230	88.803	-0.143	1.543	0.000	0.000	0.624	-0.007
Q84_12A		F	229.776	102.011	-5.503	1.832	0.000	0.000	-3.124	-0.176	44.232	0.971	1.564	0.000	0.000	0.369	-0.021
Q52_12B		F	231.656	112.207	0.153	1.834	0.000	0.000	-3.290	-0.002	45.208	-1.462	1.570	0.000	0.000	0.348	-0.002
Q84_13A		D	240.617	77.430	-0.864	1.850	0.000	0.000	-2.781	-0.036	95.742	-0.214	1.592	0.000	0.000	0.384	-0.009
Q52_13B		D	242.497	90.052	-6.010	1.854	0.000	0.000	-3.007	-0.204	86.140	5.027	1.595	0.000	0.000	0.346	-0.031
Q84_14		F	244.477	117.948	-4.215	1.857	0.000	0.000	-3.448	-0.126	65.159	3.029	1.599	0.000	0.000	0.280	-0.025
CMAG2	us		249.665	113.072	0.973	1.864	0.000	0.000	-3.385	0.028	60.533	0.117	1.613	0.000	0.000	0.205	-0.013
	ds		252.673	107.368	0.923	1.868	0.000	0.000	-3.301	0.028	59.981	0.067	1.621	0.000	0.000	0.154	-0.021
LAM3	us		256.223	101.030	0.862	1.873	0.000	0.000	-3.202	0.028	59.718	0.007	1.630	0.000	0.000	0.081	-0.021
	ds		261.023	93.140	0.781	1.881	0.000	0.000	-3.068	0.028	60.035	-0.073	1.643	0.000	0.000	0.006	-0.010
LAM4	us		261.429	92.508	0.774	1.882	0.000	0.000	-3.057	0.028	60.097	-0.080	1.644	0.000	0.000	0.002	-0.010
	ds		266.229	85.463	0.693	1.891	0.000	0.000	-2.922	0.028	61.251	-0.160	1.657	0.000	0.000	-0.022	0.000
QTEV		D	302.461	60.099	-1.643	1.977	0.000	0.000	-1.940	-0.028	91.474	1.897	1.735	0.000	0.000	-0.014	0.001
QTEV		F	308.593	104.281	-2.126	1.989	0.000	0.000	-2.391	-0.028	48.741	1.993	1.750	0.000	0.000	-0.008	0.001
B_TEV	us		310.244	105.677	0.374	1.991	0.000	0.000	-2.372	0.030	44.887	0.777	1.756	0.000	0.000	-0.007	0.001
	ds		316.365	101.498	0.308	2.001	0.000	0.000	-2.214	0.022	36.710	0.559	1.780	0.000	0.000	-0.003	0.001
B_TEV	us		316.645	101.326	0.305	2.001	0.000	0.000	-2.208	0.022	36.401	0.549	1.781	0.000	0.000	-0.003	0.001
	ds		322.766	97.993	0.239	2.011	0.000	0.000	-2.101	0.014	31.021	0.330	1.810	0.000	0.000	0.001	0.001
B_TEV	us		323.045	97.860	0.236	2.011	0.000	0.000	-2.097	0.014	30.839	0.320	1.812	0.000	0.000	0.001	0.001
	ds		329.167	95.372	0.170	2.022	0.000	0.000	-2.039	0.005	28.256	0.102	1.845	0.000	0.000	0.005	0.001
QTEV		F	337.610	92.915	0.943	2.036	1.208	0.339	-1.991	0.024	29.198	-0.471	1.892	0.000	0.000	0.010	0.001
PBAR150_GEV			337.610	92.915	0.943	2.036	1.208	0.339	-1.991	0.024	29.198	-0.471	1.892	0.000	0.000	0.010	0.001

total length = 337.609600	mux =	2.035855	muy =	1.892398
delta(s) = 0.000211 mm	dmux =	-3.782767	dmuy =	-3.077021
	betax(max) =	121.384591	betay(max) =	95.742264
	Dx(max) =	3.817833	Dy(max) =	0.624147
	Dx(r.m.s.) =	2.045643	Dy(r.m.s.) =	0.237092

"MAD" Version: 8.17

LINEAR LATTICE FUNCTIONS OF THE PROTON 120/PBAR 8 GEV BEAM LINE

ELEMENT SEQUENCE element name		quad type	dist [m]	HORIZONTAL betax [m]	alfax [1]	mux [2pi]	x(co) [mm]	px(co) [.001]	Dx [m]	Dpx [1]	VERTICAL betay [m]	alfay [1]	muy [2pi]	y(co) [mm]	py(co) [.001]	Dy [m]	Dpy [1]
P120_GEV			0.000	58.068	0.000	0.000	0.000	0.000	0.000	0.000	10.280	0.000	0.000	0.000	0.000	0.000	0.000
INJECTOR			0.000	58.068	0.000	0.000	0.000	0.000	0.000	0.000	10.280	0.000	0.000	0.000	0.000	0.000	0.000
QMI_520		F	0.000	58.068	0.000	0.000	0.000	0.000	0.000	0.000	10.280	0.000	0.000	0.000	0.000	0.000	0.000
QMI_521		D	17.289	10.811	0.006	0.121	0.000	0.000	0.000	0.000	57.663	-0.050	0.126	0.000	0.000	0.000	0.000
LAM1	us		30.607	42.434	-1.973	0.231	0.000	0.000	0.000	0.000	16.285	0.906	0.196	0.000	0.000	0.000	0.000
	ds		32.807	51.672	-2.226	0.238	0.000	0.000	0.000	0.000	12.841	0.660	0.220	0.000	0.000	-0.006	-0.006
QMI_522		F	34.577	57.358	0.001	0.243	0.000	0.000	0.000	0.000	11.362	-0.004	0.244	0.000	0.000	-0.016	-0.006
LAM2	us		36.347	51.665	2.228	0.248	0.000	0.000	0.000	0.000	12.873	-0.669	0.267	0.000	0.000	-0.028	-0.007
	ds		41.147	32.928	1.675	0.267	0.000	0.000	0.000	0.000	21.891	-1.209	0.313	0.000	0.000	-0.089	-0.019
CMAG1	us		42.401	28.909	1.530	0.273	0.000	0.000	0.000	0.000	25.102	-1.351	0.322	0.000	0.000	-0.113	-0.019
	ds		45.409	20.751	1.183	0.293	0.000	0.000	0.000	0.000	34.242	-1.689	0.338	0.000	0.000	-0.180	-0.026
Q84_1		D	49.231	14.057	0.137	0.330	0.000	0.000	0.000	0.000	46.626	-0.050	0.353	0.000	0.000	-0.273	-0.014
VB1	us		51.136	15.512	-0.639	0.350	0.000	0.000	0.000	0.000	41.486	1.822	0.360	0.000	0.000	-0.284	-0.002
	ds		54.143	20.179	-0.912	0.378	0.000	0.000	0.000	0.000	31.470	1.509	0.373	0.000	0.000	-0.280	0.005
VB2	us		54.550	20.935	-0.949	0.381	0.000	0.000	0.000	0.000	30.261	1.466	0.375	0.000	0.000	-0.278	0.005
	ds		57.557	27.464	-1.222	0.401	0.000	0.000	0.000	0.000	22.383	1.153	0.394	0.000	0.000	-0.253	0.012
VB3	us		57.963	28.472	-1.259	0.403	0.000	0.000	0.000	0.000	21.463	1.111	0.397	0.000	0.000	-0.248	0.012
	ds		60.971	36.862	-1.531	0.418	0.000	0.000	0.000	0.000	15.722	0.798	0.423	0.000	0.000	-0.202	0.019
Q84_2		F	65.449	50.254	0.095	0.434	0.000	0.000	0.000	0.000	11.134	-0.105	0.479	0.000	0.000	-0.120	0.014
Q84_3		D	82.204	11.205	-0.096	0.559	0.000	0.000	0.000	0.000	60.171	-0.043	0.591	0.000	0.000	0.036	0.008
HB3A	us		84.697	14.215	-0.855	0.591	0.000	0.000	0.000	0.000	51.146	2.201	0.598	0.000	0.000	0.052	0.006
	ds		90.767	29.088	-1.595	0.639	0.000	0.000	-0.069	-0.023	28.611	1.510	0.623	0.000	0.000	0.085	0.005
HB3B	us		91.123	30.238	-1.638	0.641	0.000	0.000	-0.077	-0.023	27.552	1.469	0.625	0.000	0.000	0.087	0.005
	ds		97.194	54.618	-2.378	0.665	0.000	0.000	-0.195	-0.016	13.940	0.773	0.675	0.000	0.000	0.115	0.005
Q84_4		F	99.687	64.384	0.025	0.672	0.000	0.000	-0.231	-0.007	11.297	0.028	0.708	0.000	0.000	0.129	0.010
HB4A	us		102.180	54.389	2.418	0.678	0.000	0.000	-0.230	0.003	13.636	-0.706	0.740	0.000	0.000	0.165	0.015
	ds		108.250	29.670	1.654	0.703	0.000	0.000	-0.282	-0.020	26.248	-1.371	0.792	0.000	0.000	0.249	0.012
Q84_5		D	117.169	10.655	0.098	0.788	0.000	0.000	-0.470	-0.039	56.916	0.043	0.829	0.000	0.000	0.352	-0.002
HB5A	us		119.662	12.541	-0.608	0.823	0.000	0.000	-0.606	-0.059	48.010	2.145	0.836	0.000	0.000	0.319	-0.017
	ds		125.733	23.950	-1.271	0.880	0.000	0.000	-1.032	-0.081	26.248	1.439	0.864	0.000	0.000	0.204	-0.021
HB5B	us		126.089	24.868	-1.310	0.883	0.000	0.000	-1.061	-0.081	25.240	1.397	0.866	0.000	0.000	0.196	-0.021
	ds		132.159	44.798	-1.973	0.912	0.000	0.000	-1.622	-0.104	12.578	0.688	0.921	0.000	0.000	0.057	-0.024
Q84_6		F	134.652	52.974	-0.019	0.920	0.000	0.000	-1.841	-0.029	10.331	-0.024	0.957	0.000	0.000	-0.002	-0.022
HB6A	us		137.145	44.971	1.942	0.928	0.000	0.000	-1.763	0.048	12.842	-0.746	0.992	0.000	0.000	-0.054	-0.020
	ds		143.216	25.300	1.298	0.956	0.000	0.000	-1.542	0.025	26.363	-1.480	1.046	0.000	0.000	-0.177	-0.020
HB6B	us		143.571	24.390	1.260	0.959	0.000	0.000	-1.533	0.025	27.432	-1.523	1.048	0.000	0.000	-0.185	-0.020
	ds		149.642	12.997	0.616	1.014	0.000	0.000	-1.445	0.004	50.373	-2.255	1.074	0.000	0.000	-0.281	-0.011
Q84_7		D	152.135	11.071	-0.099	1.048	0.000	0.000	-1.466	-0.056	59.728	-0.045	1.081	0.000	0.000	-0.302	0.002
HB7A	us		154.628	14.082	-0.856	1.080	0.000	0.000	-1.727	-0.118	50.780	2.183	1.088	0.000	0.000	-0.273	0.014
	ds		160.699	29.008	-1.603	1.129	0.000	0.000	-2.512	-0.141	28.442	1.496	1.114	0.000	0.000	-0.180	0.016
HB7B	us		161.054	30.164	-1.647	1.131	0.000	0.000	-2.562	-0.141	27.393	1.455	1.116	0.000	0.000	-0.174	0.016
	ds		167.125	54.689	-2.394	1.155	0.000	0.000	-3.484	-0.163	13.907	0.765	1.166	0.000	0.000	-0.077	0.016
Q84_8		F	169.618	64.536	0.012	1.161	0.000	0.000	-3.808	-0.007	11.300	0.021	1.198	0.000	0.000	-0.036	0.018
HB8A	us		172.111	54.579	2.413	1.168	0.000	0.000	-3.518	0.150	13.673	-0.714	1.231	0.000	0.000	0.012	0.020
	ds		178.181	29.889	1.654	1.192	0.000	0.000	-2.675	0.128	26.396	-1.382	1.283	0.000	0.000	0.123	0.017

"MAD" Version: 8.17

LINEAR LATTICE FUNCTIONS OF THE PROTON 120/PBAR 8 GEV BEAM LINE

ELEMENT SEQUENCE				HORIZONTAL							VERTICAL						
element name		quad type	dist [m]	betax [m]	alfax [1]	mux [2pi]	x(co) [mm]	px(co) [.001]	Dx [m]	Dpx [1]	betay [m]	alfay [1]	muy [2pi]	y(co) [mm]	py(co) [.001]	Dy [m]	Dpy [1]
HB8B	us		178.537	28.728	1.610	1.194	0.000	0.000	-2.630	0.128	27.393	-1.421	1.285	0.000	0.000	0.129	0.017
	ds		184.607	13.791	0.851	1.243	0.000	0.000	-1.924	0.105	48.686	-2.086	1.311	0.000	0.000	0.230	0.017
Q84_9		D	187.100	10.805	0.100	1.276	0.000	0.000	-1.701	0.033	57.238	0.046	1.319	0.000	0.000	0.266	0.007
HB9A	us		189.593	12.697	-0.609	1.311	0.000	0.000	-1.757	-0.037	48.268	2.160	1.326	0.000	0.000	0.262	-0.004
	ds		195.664	24.069	-1.264	1.368	0.000	0.000	-2.052	-0.060	26.352	1.449	1.353	0.000	0.000	0.254	0.001
HB9B	us		196.020	24.982	-1.303	1.370	0.000	0.000	-2.073	-0.060	25.336	1.408	1.356	0.000	0.000	0.254	0.001
	ds		202.090	44.777	-1.958	1.399	0.000	0.000	-2.503	-0.082	12.575	0.694	1.411	0.000	0.000	0.251	-0.002
Q52_10A		F	203.847	51.102	-0.785	1.405	0.000	0.000	-2.624	-0.013	10.688	0.206	1.435	0.000	0.000	0.249	0.005
Q52_10B		F	205.319	49.477	1.859	1.409	0.000	0.000	-2.541	0.125	11.124	-0.509	1.457	0.000	0.000	0.266	0.018
HB10A	us		207.076	39.843	2.791	1.416	0.000	0.000	-2.227	0.191	14.208	-1.066	1.480	0.000	0.000	0.308	0.025
	ds		213.147	14.091	1.452	1.457	0.000	0.000	-1.136	0.168	32.689	-1.977	1.525	0.000	0.000	0.461	0.025
HB10B	us		213.502	13.086	1.373	1.461	0.000	0.000	-1.077	0.168	34.114	-2.030	1.527	0.000	0.000	0.470	0.025
	ds		219.573	4.539	0.035	1.605	0.000	0.000	-0.118	0.148	64.280	-2.938	1.547	0.000	0.000	0.596	0.016
Q84_11		D	223.030	7.231	-1.027	1.711	0.000	0.000	0.399	0.161	82.627	0.110	1.555	0.000	0.000	0.638	-0.011
Q84_12A		F	228.982	35.216	-2.115	1.771	0.000	0.000	1.437	0.121	51.024	0.432	1.569	0.000	0.000	0.439	-0.017
Q52_12B		F	230.861	38.325	0.486	1.779	0.000	0.000	1.560	0.011	56.735	-3.537	1.575	0.000	0.000	0.436	0.014
Q84_13A		D	235.395	27.995	-0.006	1.802	0.000	0.000	1.463	0.030	107.110	-2.712	1.584	0.000	0.000	0.538	0.004
Q52_13B		D	237.275	31.972	-2.163	1.812	0.000	0.000	1.617	0.134	103.302	4.510	1.587	0.000	0.000	0.510	-0.033
Q84_14		F	240.984	55.612	-1.879	1.826	0.000	0.000	2.214	0.090	61.180	2.900	1.595	0.000	0.000	0.354	-0.030
CAMG2	us		246.199	54.316	0.308	1.841	0.000	0.000	2.255	-0.001	54.481	0.343	1.609	0.000	0.000	0.260	-0.017
	ds		249.206	52.641	0.249	1.850	0.000	0.000	2.251	-0.001	52.604	0.281	1.618	0.000	0.000	0.200	-0.024
LAM3	us		256.224	50.143	0.107	1.871	0.000	0.000	2.241	-0.001	49.667	0.137	1.640	0.000	0.000	0.032	-0.024
	ds		261.024	49.580	0.010	1.887	0.000	0.000	2.234	-0.001	48.821	0.039	1.656	0.000	0.000	-0.083	-0.024
LAM4	us		261.431	49.574	0.002	1.888	0.000	0.000	2.233	-0.001	48.793	0.031	1.657	0.000	0.000	-0.093	-0.024
	ds		266.231	50.019	-0.095	1.903	0.000	0.000	2.226	-0.001	48.973	-0.068	1.673	0.000	0.000	-0.207	-0.024
QMR_F11A		D	272.222	52.303	-0.864	1.922	0.000	0.000	2.226	0.026	50.111	0.433	1.692	0.000	0.000	-0.349	-0.020
QMR_F11B		F	282.409	87.928	-0.155	1.946	0.000	0.000	2.746	-0.008	33.827	-0.132	1.732	0.000	0.000	-0.510	-0.027
HBF11A	us		286.118	76.225	1.664	1.953	0.000	0.000	2.506	-0.070	40.696	-1.095	1.748	0.000	0.000	-0.648	-0.038
	ds		292.188	57.840	1.365	1.968	0.000	0.000	2.116	-0.058	55.968	-1.421	1.768	0.000	0.000	-0.845	-0.026
HBF11B	us		292.493	57.013	1.350	1.969	0.000	0.000	2.099	-0.058	56.840	-1.438	1.769	0.000	0.000	-0.853	-0.026
	ds		298.564	42.443	1.050	1.988	0.000	0.000	1.781	-0.046	76.272	-1.763	1.784	0.000	0.000	-0.978	-0.015
QMR_F12		D	308.232	27.322	0.055	2.035	0.000	0.000	1.345	-0.021	113.112	-0.116	1.800	0.000	0.000	-1.108	0.006
P120_GEV			308.232	27.322	0.055	2.035	0.000	0.000	1.345	-0.021	113.112	-0.116	1.800	0.000	0.000	-1.108	0.006

total length =	308.232430	mux	=	2.034641	muy	=	1.800038
delta(s) =	0.000000 mm	dmux	=	-2.938907	dmuy	=	-2.940718
		betax(max)	=	87.928293	betay(max)	=	113.112082
		Dx(max)	=	3.808461	Dy(max)	=	1.107760
		Dx(r.m.s.)	=	1.677286	Dy(r.m.s.)	=	0.340017

Linear lattice functions for proton ABORT beam line.

"MAD" Version: 8.17

	ELEMENT SEQUENCE		I	HORIZONTAL							I	VERTICAL						
	element name	quad type	dist [m]	betax [m]	alfax [1]	mux [2pi]	x(co) [mm]	px(co) [.001]	Dx [m]	Dpx [1]		betay [m]	alfay [1]	muy [2pi]	y(co) [mm]	py(co) [.001]	Dy [m]	Dpy [1]
begin	ABORT		0.000	57.461	-0.011	0.000	0.000	0.000	0.075	0.000		10.823	0.031	0.000	0.000	0.000	0.000	0.000
	Q400	F	0.000	57.461	-0.011	0.000	0.000	0.000	0.075	0.000		10.823	0.031	0.000	0.000	0.000	0.000	0.000
	3Q84	ds	1.067	54.905	2.371	0.003	0.000	0.000	0.073	-0.003		11.366	-0.548	0.015	0.000	0.000	0.000	0.000
	KICKER	us	1.335	53.642	2.338	0.004	0.000	0.000	0.072	-0.003		11.669	-0.579	0.019	0.000	0.000	0.000	0.000
		ds	3.235	45.191	2.109	0.010	0.000	0.000	0.067	-0.003		14.281	-0.796	0.043	0.000	0.000	0.000	0.000
	KICKER	us	3.635	43.523	2.061	0.011	0.000	0.000	0.065	-0.003		14.936	-0.842	0.047	0.000	0.000	0.000	0.000
		ds	5.535	36.127	1.832	0.019	0.000	0.000	0.060	-0.003		18.549	-1.059	0.065	0.000	0.000	0.000	0.000
	3Q84	us	16.221	10.744	0.543	0.110	0.000	0.000	0.031	-0.003		54.255	-2.282	0.120	0.000	0.000	0.000	0.000
	Q401	D	17.288	10.178	-0.006	0.127	0.000	0.000	0.029	-0.001		56.705	0.020	0.123	0.000	0.000	0.000	0.000
		ds	18.355	10.769	-0.556	0.143	0.000	0.000	0.029	0.000		54.173	2.318	0.126	0.000	0.000	0.000	0.000
	LAM1	us	31.291	45.506	-2.129	0.242	0.000	0.000	0.033	0.000		13.885	0.796	0.204	0.000	0.000	0.000	0.000
		ds	33.291	54.508	-2.372	0.249	0.000	0.000	0.034	0.000		11.171	0.561	0.230	0.000	0.000	0.004	0.004
	3Q84	us	33.509	55.549	-2.399	0.249	0.000	0.000	0.034	0.000		10.932	0.535	0.233	0.000	0.000	0.005	0.004
	Q402	F	34.576	58.136	0.011	0.252	0.000	0.000	0.034	-0.001		10.401	-0.029	0.249	0.000	0.000	0.009	0.004
		ds	35.643	55.503	2.419	0.255	0.000	0.000	0.032	-0.002		11.062	-0.600	0.265	0.000	0.000	0.014	0.005
	LAM2	us	35.861	54.453	2.392	0.256	0.000	0.000	0.032	-0.002		11.329	-0.626	0.268	0.000	0.000	0.015	0.005
		ds	41.861	30.190	1.652	0.280	0.000	0.000	0.019	-0.002		23.269	-1.363	0.328	0.000	0.000	0.080	0.017
	CMAG	us	42.111	29.372	1.621	0.281	0.000	0.000	0.019	-0.002		23.958	-1.394	0.330	0.000	0.000	0.084	0.017
		ds	46.311	17.936	1.102	0.310	0.000	0.000	0.010	-0.002		37.834	-1.910	0.352	0.000	0.000	0.169	0.024
	3Q52	us D	53.231	8.596	0.248	0.404	0.000	0.000	-0.004	-0.002		70.147	-2.760	0.374	0.000	0.000	0.334	0.024
		ds	54.552	8.738	-0.357	0.429	0.000	0.000	-0.007	-0.002		72.592	0.951	0.377	0.000	0.000	0.354	0.006
	B2	us	54.770	8.900	-0.386	0.433	0.000	0.000	-0.007	-0.002		72.178	0.945	0.377	0.000	0.000	0.355	0.006
		ds	60.841	18.336	-1.169	0.512	0.000	0.000	0.016	0.010		61.662	0.787	0.392	0.000	0.000	0.355	-0.006
	B2	us	61.141	19.049	-1.207	0.514	0.000	0.000	0.019	0.010		61.192	0.779	0.392	0.000	0.000	0.353	-0.006
		ds	67.212	38.459	-1.990	0.550	0.000	0.000	0.119	0.023		52.691	0.621	0.409	0.000	0.000	0.284	-0.017
	3Q52	us F	82.887	132.523	-4.011	0.585	0.000	0.000	0.475	0.023		39.684	0.209	0.465	0.000	0.000	0.013	-0.017
		ds	84.208	153.185	-11.990	0.587	0.000	0.000	0.522	0.049		36.530	2.124	0.471	0.000	0.000	-0.010	-0.017
	3Q52	us D	92.312	409.622	-19.650	0.592	0.000	0.000	0.915	0.049		12.012	0.901	0.534	0.000	0.000	-0.150	-0.017
		ds	93.633	432.572	2.684	0.593	0.000	0.000	0.946	-0.001		10.653	0.152	0.553	0.000	0.000	-0.179	-0.026
	WALL		104.000	378.955	2.488	1.597	0.000	0.000	0.932	-0.001		17.829	-0.844	1.688	0.000	0.000	-0.449	-0.026
	pipe		108.120	358.781	2.409	1.598	0.000	0.000	0.927	-0.001		26.412	-1.239	1.719	0.000	0.000	-0.557	-0.026
	pipe		112.239	339.250	2.331	1.600	0.000	0.000	0.921	-0.001		38.254	-1.635	1.739	0.000	0.000	-0.664	-0.026
	pipe		116.359	320.364	2.253	1.602	0.000	0.000	0.915	-0.001		53.355	-2.031	1.754	0.000	0.000	-0.771	-0.026
	pipe		120.479	302.121	2.175	1.604	0.000	0.000	0.910	-0.001		71.717	-2.426	1.764	0.000	0.000	-0.879	-0.026
	pipe		124.598	284.522	2.097	1.607	0.000	0.000	0.904	-0.001		93.337	-2.822	1.772	0.000	0.000	-0.986	-0.026
	pipe		128.718	267.567	2.019	1.609	0.000	0.000	0.899	-0.001		118.217	-3.218	1.779	0.000	0.000	-1.093	-0.026
	pipe		132.838	251.256	1.941	1.612	0.000	0.000	0.893	-0.001		146.357	-3.613	1.784	0.000	0.000	-1.201	-0.026
	pipe		136.957	235.589	1.862	1.614	0.000	0.000	0.887	-0.001		177.757	-4.009	1.788	0.000	0.000	-1.308	-0.026
	DUMP	us	136.957	235.589	1.862	1.614	0.000	0.000	0.887	-0.001		177.757	-4.009	1.788	0.000	0.000	-1.308	-0.026
		ds	141.757	218.146	1.771	1.618	0.000	0.000	0.881	-0.001		218.453	-4.470	1.792	0.000	0.000	-1.433	-0.026
end	ABORT		141.757	218.146	1.771	1.618	0.000	0.000	0.881	-0.001		218.453	-4.470	1.792	0.000	0.000	-1.433	-0.026

APPENDIX B

SCHEDULE 44

FERMILAB
PROPOSED FY 1994 BUDGET REQUEST
CONSTRUCTION PROJECT DATA SHEET
GENERAL SCIENCE AND RESEARCH - PLANT AND CAPITAL EQUIPMENT
HIGH ENERGY PHYSICS
(TABULAR DOLLARS IN THOUSANDS. NARRATIVE MATERIAL IN WHOLE DOLLARS.)

CHICAGO OPERATIONS
Field Office

FERMI NATIONAL ACCELERATOR

1. Title and Location of Project:
Fermilab Main Injector
Fermi National Accelerator Laboratory, Batavia, Illinois

2. Project No. 92-G-302

3. Date A-E work initiated: 3rd Quarter FY 1992

3a. Date physical construction starts: 3rd Quarter FY 1992

4. Date construction ends: 4th Quarter FY 1997

5. Previous cost estimate: $185,000

6. Current cost estimate: $217,450
Date: August, 1992

7. Financial Schedule:

Fiscal Year	Authorization	Appropriation	Obligation	Cost
1992	$217,450	$11,650	$11,650	$5,840
1993		30,000	30,000	26,920
1994		52,000	52,000	47,670
1995		57,000	57,900	58,540
1996		56,900	56,000	62,910
1997		9,900	9,900	15,570
Total	$217,450	$217,450	$217,450	$217,450

8. Brief Physical Description of Project

This project provides for the construction of a new accelerator, designated the Fermilab Main Injector, which will replace the aging Fermilab Main Ring accelerator in all its functions. The Fermilab Main Injector will provide particles for injection into the existing Fermilab superconducting Tevatron accelerator and for direct delivery to the existing fixed target experimental and test beam areas. The accelerator is 3.3 km in circumference and is capable of accelerating protons and antiprotons to 150 GeV. It is constructed using conventional iron core magnets. Also provided are five new beamlines which tie the Main Injector into the existing accelerator complex, transport 120 GeV proton beams to the fixed target experimental areas, and provide particle beams for the testing and calibration of SSC detector components and subsystems.

The Fermilab Main Injector accelerator will recycle many technical components from the existing Main Ring, including quadrupole magnets, some power supplies and correction magnets, radio frequency (RF) systems, some controls components, and diagnostic devices. The Main Injector will be located on the southwest side of the Fermilab site, tangent to the existing Tevatron at the F-zero straight section.

Specifically provided for in the scope of the project are:

CONSTRUCTION PROJECT DATA SHEET

1. Title and location of Project:
Fermilab Main Injector
Fermi National Accelerator Laboratory, Batavia, Illinois

2. Project No. 92-G-302

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a. Construction of a 3.3 km ring enclosure with service buildings and utilities, and fabrication of new technical components including dipole magnets, high current power supplies, and vacuum systems.

b. Construction of beamline enclosures, service buildings, utilities, and technical components required to implement the 8 GeV Booster-to-Main Injector beamline, the 150 GeV proton and antiproton Main Injector-to-Tevatron transfer lines, and the 120 GeV Main Injector-to-Antiproton Production Target beamline.

c. Construction of technical components required to implement the delivery of 120 GeV beam from the Main Injector to the A-zero Transfer Hall, from which distribution to the existing experimental areas is possible; construction of a new sub-station and 345KV power lines for delivery of electrical power to the Main Injector location.

d. Modifications to the Tevatron ring tunnel at the F-zero straight section for installation of the 150 GeV proton and antiproton transfer lines.

f. Refurbishment and reinstallation in the Main Injector ring enclosure of those technical components which will be recycled from the old Main Ring.

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

The primary purpose of this project is to greatly increase the Tevatron collider luminosity which can be delivered to the two existing collider detector facilities at Fermilab. Fermilab is the only operational high energy physics facility in the world with sufficiently high energy to produce the top quark, the last unobserved fundamental building block forming the basis of our current understanding of the structure of matter. Increasing the luminosity available at the Fermilab Proton-Antiproton Collider to $5x10^{31}$ $cm^{-2}sec^{-1}$ will maximize the likelihood of discovery of the Top quark if it lies within the range indicated by all present experimental data. The project will also increase the number of protons which can be delivered to the Tevatron for acceleration and delivery to the fixed target experimental areas. Other important purposes of the project are to provide a new capability for 120 GeV beams for fixed target physics research, and to provide year-round beams for the testing and calibration of SSC detector components and subsystems simultaneously with Tevatron collider operations for physics research.

Increasing the collider luminosity requires increasing the number of protons and antiprotons injected into the Tevatron. The substantial improvement in injection intensities results from the large effective aperture of the Main Injector ring, and from its rapid repetition rate capability. These are achieved through tighter focussing, improved field quality, and the elimination of overpasses which were installed in the Main Ring to accommodate the collider detector facilities. The Main Injector will be capable of accelerating protons to 120 GeV every 1.5 seconds for antiproton production, as compared to a 2.4 second cycle for the present Main Ring. The beam intensity injected into the Tevatron by the Main Injector will approach $6x10^{13}$ protons per 60 second cycle, which is about two times as great as could be achieved with the Main Ring. The Tevatron proton-antiproton colliding beam luminosity will be increased to at least $5x10^{13}$ $cm^{-2}sec^{-1}$, which is five times greater than could be achieved using the Main Ring. These performance goals are expected to be reached after some months of operational experience with the upgraded facilities.

10. Details of Cost Estimate

	Item Cost	Total Cost
a. EDI&A at 15.8% of construction costs		$25,040
b. Main Injector construction costs		$158,440
1. Conventional construction	$75,110	

	2. Special facilities	83,330	
c.	Contingency at 18.5% of above cost		$33,970
	Total		$217,450

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.

CONSTRUCTION PROJECT DATA SHEET

1. Title and location of Project:
Fermilab Main Injector
Fermi National Accelerator Laboratory, Batavia, Illinois

2. Project No. 92-G-302

12. Schedule of Project Funding and Other Related Funding Requirements

	Prior Years	FY1992	FY 1993	FY 1994	FY 1995	FY1996	FY1997	TOTAL
a. Total project cost								
1. Total facility costs								
(a) Construction line item	$0	$5,840	$26,920	$47,670	$58,540	$62,910	$15,570	$217,450
Total facility cost	$0	$5,840	$26,920	$47,670	$58,540	$62,910	$15,570	$217,450
2. Other project costs								
(a) R&D costs necessary to complete construction (G&A included)	$5,390	$3,680	$4,140	$3,260	$470	$0	$0	$16,940
(b) Pre-operating costs	$0	$0	$0	$0	$0	$1,490	$1,990	$3,480
(c) Capital equipment	$0	$200	$200	$200	$200	$100	$100	$1,000
(d) Inventories and Spares	$0	$0	$0	$0	$4,290	$3,470	$0	$7,760
Total other project costs	$5,390	$3,880	$4,340	$3,460	$4,960	$5,060	$2,090	$29,180
Total project costs	$5,390	$9,720	$31,260	$51,130	$63,500	$67,970	$17,660	$246,630

b. Total related incremental annual funding requirements (estimated life of project: 20 years)

1. Power costs for Main Injector slow spill operations	$5,400
2. Experimental Areas operating costs with 120 GeV slow spill beam	$1,200
Total incremental annual funding	$6,600

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, 10.
2. Other project costs
(a) Direct R&D operating costs - This provides for project conceptual design activities, for design and development of new components, and for the fabrication and testing of prototypes. R&D on all elements of the project to optimize performance and minimize costs will continue through early stages of the project. Specifically included are development of the high current dipole magnet, the associated power supply system. A small number of dipole magnets and power supplies will be fabricated and tested using R&D operating funds.
(b) Pre-operating costs - Includes personnel and power costs for a several month commissioning period.
(c) Capital equipment - Includes test instruments, electronics, and other general equipment to support 12.a.1 and 2.
(d) Inventories and Spares - Provides for special process spares for the major technical components, primarily magnets and power supplies, and for an increase in common use inventories for Main Injector related items.

1. Title and location of Project:
Fermilab Main Injector
Fermi National Accelerator Laboratory, Batavia, Illinois

2. Project No. 92-G-302

---

b. Total incremental funding requirements - It is assumed that the Fermilab Tevatron complex will continue to operate both the fixed target and collider programs, with each running about 40% of the time. The Main Injector replaces the existing Main Ring in all its functional roles and it is designed to require nearly the same amount of power to operate for those purposes. The new Main Injector capability for test beam operations simultaneously with Tevatron operations for physics research will require an average increase in power plus other operating cost of about $6.6M annually. The increase in operating costs in 12.b.1 and 2 reflects solely the incremental demands of delivering 120 GeV protons to the fixed target experimental areas during Tevatron collider operations.

14. Incorporation of Fallout Shelters in Future Federal Buildings

Not specifically incorporated into this project as sufficient space is available at other locations on the site.

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. A Section 404 permit from the Army Corps of Engineers has been secured for this project.

16. Evaluation of Flood Hazard

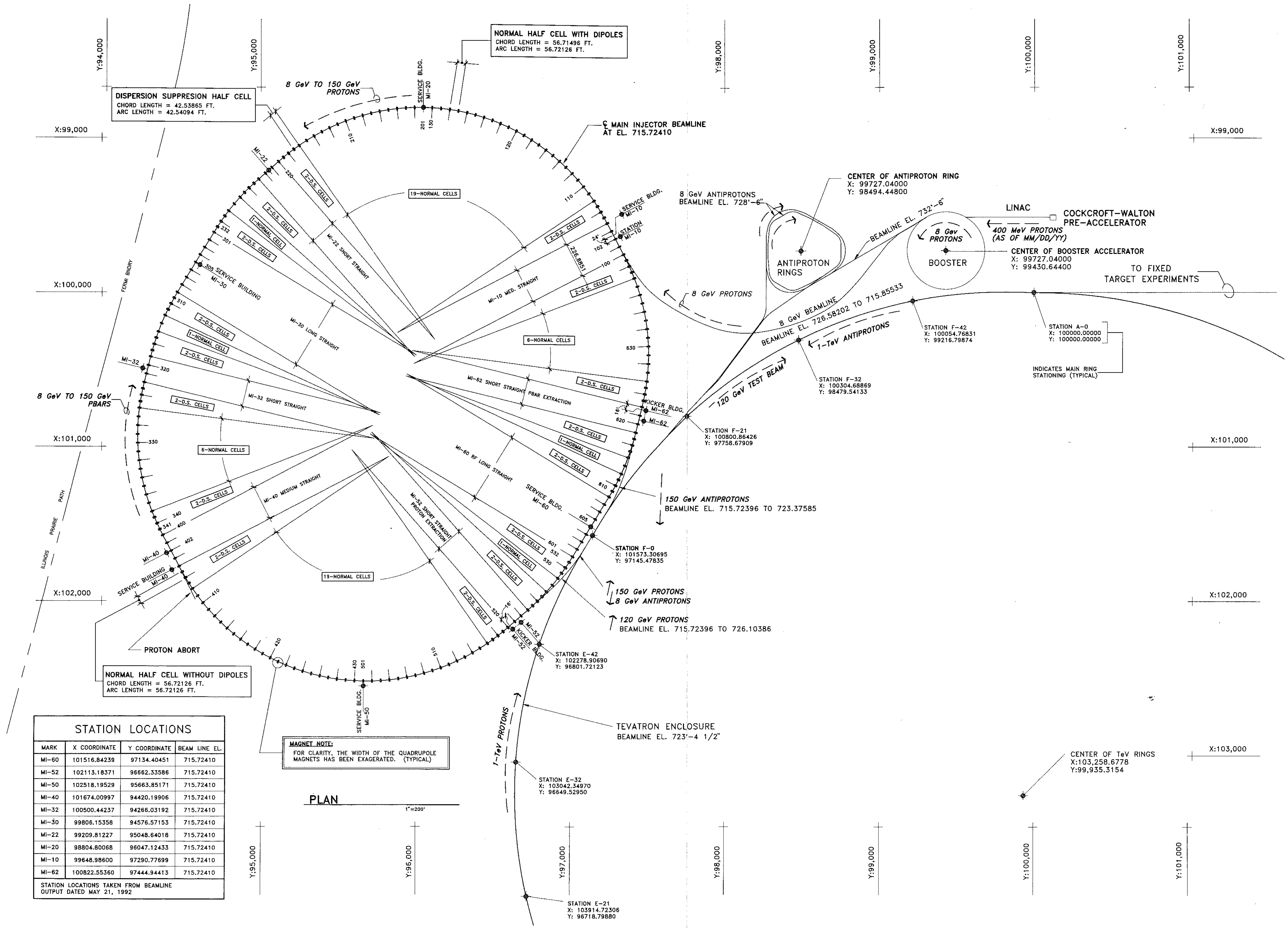
This project will be partially located in the flood plain of Indian Creek, which originates on the Fermilab site. An active drainage system will allow the control of water levels within the region encompassed by the Main Injector ring. Measures will be taken to insure that the water retention capacity of the Indian Creek drainage basin is maintained both during the construction and operational phases of the project. Components installed in the underground Main Injector ring and beamline enclosures will be protected by pumps, as are all existing underground enclosures on the Fermilab site. Service buildings and enclosure access points will be located well above the floodplain. Construction will be in accordance with Executive Order 11988. An Army Corps of Engineers permit has been secured for this project.

17. Environmental Impact

An Environmental Assessment has been prepared for this project and a Finding of No Significant Impact issued by the Department of Energy. Wetlands disturbed during the course of the project will be restored as closely as possible to their original condition. Mitigation plans for any disturbance and/or loss of wetlands will only be finalized after consultation with the Corps of Engineers. Compensatory wetlands will be created in the vicinity of the disturbed wetlands in a ratio of 1-1/2 to 1 of existing wetlands impacted by construction of the Main Injector site. An Army Corps of Engineers permit has been secured for this project. The project will be in compliance with the National Environmental Policy Act.

18. Accessibility to the Handicapped

All tunnel enclosures and service buildings are occupied only temporarily. They do not provide permanent working space, and are considered hazardous areas with restricted access under laboratory policy. As such, no special measures for accessibility to the handicapped will be provided in these areas.



PLAN
1"=200'

STATION LOCATIONS			
MARK	X COORDINATE	Y COORDINATE	BEAM LINE EL.
MI-60	101516.84239	97134.40451	715.72410
MI-52	102113.18371	96662.33586	715.72410
MI-50	102518.19529	95663.85171	715.72410
MI-40	101674.00997	94420.19906	715.72410
MI-32	100500.44237	94266.03192	715.72410
MI-30	99806.15358	94576.57153	715.72410
MI-22	99209.81227	95048.64018	715.72410
MI-20	98804.80068	96047.12433	715.72410
MI-10	99648.98600	97290.77699	715.72410
MI-62	100822.55360	97444.94413	715.72410

STATION LOCATIONS TAKEN FROM BEAMLINE OUTPUT DATED MAY 21, 1992

REV.	DATE	DESCRIPTIONS
		REVISIONS

	NAME	DATE
DESIGNED	T. LACKOWSKI	
DRAWN	S. DIXON	
CHECKED		
APPROVED		
SUBMITTED		

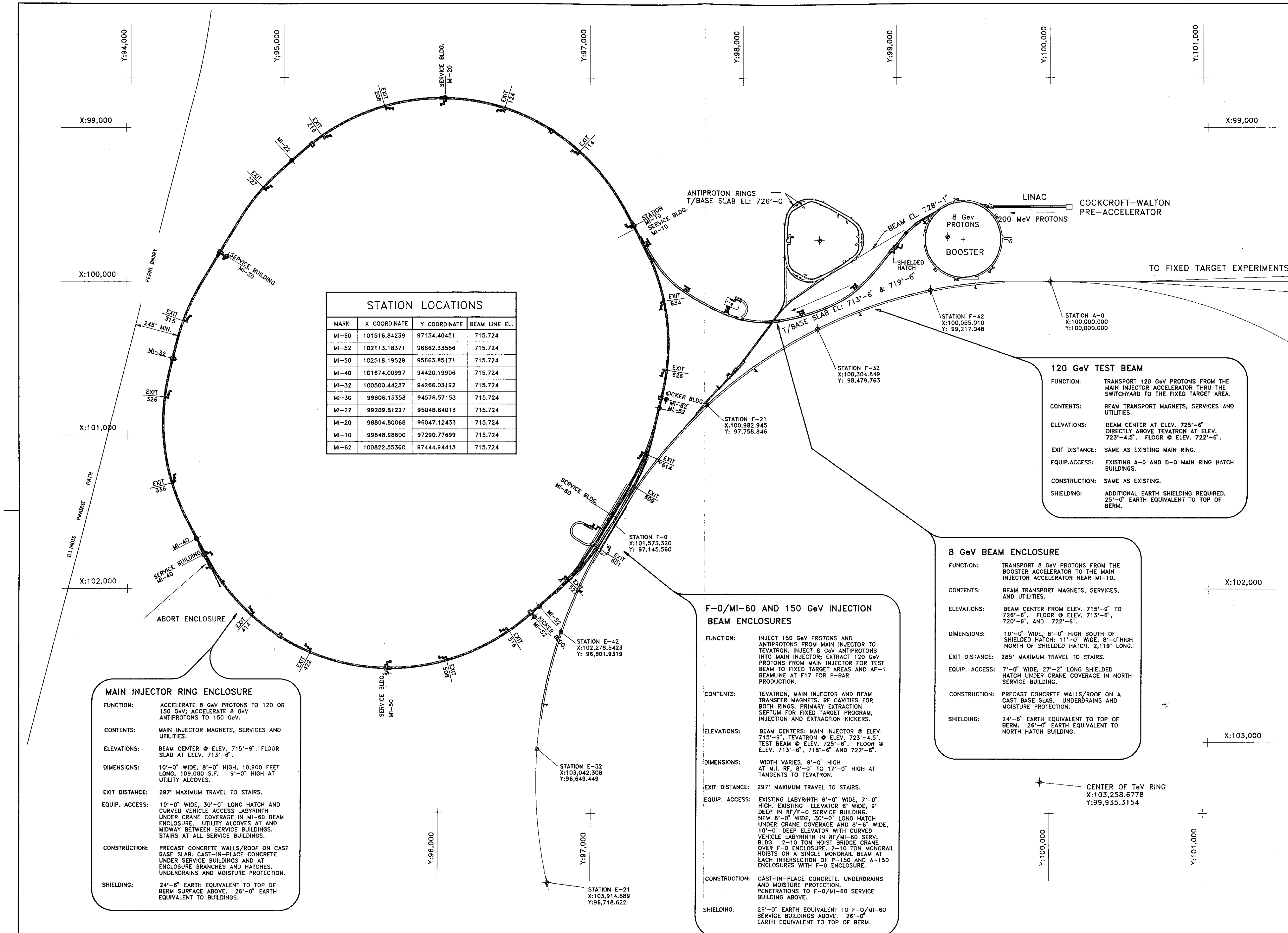
SCALE: 1" = 200'-0" (200 0 200 400 SCALE FEET)

FERMI NATIONAL ACCELERATOR LABORATORY
UNITED STATES DEPARTMENT OF ENERGY

MAIN INJECTOR
BEAMLINE GEOMETRICS

DRAWING NO. 6-6-2 TITLE-I AS-1 REV.

AUG. 1992



STATION LOCATIONS

MARK	X COORDINATE	Y COORDINATE	BEAM LINE EL.
MI-60	101516.84239	97134.40451	715.724
MI-52	102113.18371	96662.33586	715.724
MI-50	102518.19529	95663.85171	715.724
MI-40	101674.00997	94420.19906	715.724
MI-32	100500.44237	94266.03192	715.724
MI-30	99806.15358	94576.57153	715.724
MI-22	99209.81227	95048.64018	715.724
MI-20	98804.80068	96047.12433	715.724
MI-10	99648.98600	97290.77699	715.724
MI-62	100822.55360	97444.94413	715.724

120 GeV TEST BEAM

FUNCTION: TRANSPORT 120 GeV PROTONS FROM THE MAIN INJECTOR ACCELERATOR THRU THE SWITCHYARD TO THE FIXED TARGET AREA.

CONTENTS: BEAM TRANSPORT MAGNETS, SERVICES AND UTILITIES.

ELEVATIONS: BEAM CENTER AT ELEV. 725'-6" DIRECTLY ABOVE TEVATRON AT ELEV. 723'-4.5". FLOOR @ ELEV. 722'-6".

EXIT DISTANCE: SAME AS EXISTING MAIN RING.

EQUIP.ACCESS: EXISTING A-0 AND D-0 MAIN RING HATCH BUILDINGS.

CONSTRUCTION: SAME AS EXISTING.

SHIELDING: ADDITIONAL EARTH SHIELDING REQUIRED. 25'-0" EARTH EQUIVALENT TO TOP OF BERM.

8 GeV BEAM ENCLOSURE

FUNCTION: TRANSPORT 8 GeV PROTONS FROM THE BOOSTER ACCELERATOR TO THE MAIN INJECTOR ACCELERATOR NEAR MI-10.

CONTENTS: BEAM TRANSPORT MAGNETS, SERVICES, AND UTILITIES.

ELEVATIONS: BEAM CENTER FROM ELEV. 715'-9" TO 726'-6". FLOOR @ ELEV. 713'-6", 720'-6", AND 722'-6".

DIMENSIONS: 10'-0" WIDE, 8'-0" HIGH SOUTH OF SHIELDED HATCH; 11'-0" WIDE, 8'-0" HIGH NORTH OF SHIELDED HATCH. 2,119' LONG.

EXIT DISTANCE: 285' MAXIMUM TRAVEL TO STAIRS.

EQUIP. ACCESS: 7'-0" WIDE, 27'-2" LONG SHIELDED HATCH UNDER CRANE COVERAGE IN NORTH SERVICE BUILDING.

CONSTRUCTION: PRECAST CONCRETE WALLS/ROOF ON A CAST BASE SLAB. UNDERDRAINS AND MOISTURE PROTECTION.

SHIELDING: 24'-6" EARTH EQUIVALENT TO TOP OF BERM. 26'-0" EARTH EQUIVALENT TO NORTH HATCH BUILDING.

MAIN INJECTOR RING ENCLOSURE

FUNCTION: ACCELERATE 8 GeV PROTONS TO 120 OR 150 GeV; ACCELERATE 8 GeV ANTIPROTONS TO 150 GeV.

CONTENTS: MAIN INJECTOR MAGNETS, SERVICES AND UTILITIES.

ELEVATIONS: BEAM CENTER @ ELEV. 715'-9". FLOOR SLAB AT ELEV. 713'-6".

DIMENSIONS: 10'-0" WIDE, 8'-0" HIGH, 10,900 FEET LONG. 109,000 S.F. 9'-0" HIGH AT UTILITY ALCOVES.

EXIT DISTANCE: 297' MAXIMUM TRAVEL TO STAIRS.

EQUIP. ACCESS: 10'-0" WIDE, 30'-0" LONG HATCH AND CURVED VEHICLE ACCESS LABYRINTH UNDER CRANE COVERAGE IN MI-60 BEAM ENCLOSURE. UTILITY ALCOVES AT AND MIDWAY BETWEEN SERVICE BUILDINGS. STAIRS AT ALL SERVICE BUILDINGS.

CONSTRUCTION: PRECAST CONCRETE WALLS/ROOF ON CAST BASE SLAB. CAST-IN-PLACE CONCRETE UNDER SERVICE BUILDINGS AND AT ENCLOSURE BRANCHES AND HATCHES. UNDERDRAINS AND MOISTURE PROTECTION.

SHIELDING: 24'-6" EARTH EQUIVALENT TO TOP OF BERM SURFACE ABOVE. 26'-0" EARTH EQUIVALENT TO BUILDINGS.

F-0/MI-60 AND 150 GeV INJECTION BEAM ENCLOSURES

FUNCTION: INJECT 150 GeV PROTONS AND ANTIPROTONS FROM MAIN INJECTOR TO TEVATRON. INJECT 8 GeV ANTIPROTONS INTO MAIN INJECTOR; EXTRACT 120 GeV PROTONS FROM MAIN INJECTOR FOR TEST BEAM TO FIXED TARGET AREAS AND AP-1 BEAMLINE AT F17 FOR P-BAR PRODUCTION.

CONTENTS: TEVATRON, MAIN INJECTOR AND BEAM TRANSFER MAGNETS. RF CAVITIES FOR BOTH RINGS. PRIMARY EXTRACTION SEPTUM FOR FIXED TARGET PROGRAM, INJECTION AND EXTRACTION KICKERS.

ELEVATIONS: BEAM CENTERS: MAIN INJECTOR @ ELEV. 715'-9", TEVATRON @ ELEV. 723'-4.5", TEST BEAM @ ELEV. 725'-6". FLOOR @ ELEV. 713'-6", 718'-6" AND 722'-6".

DIMENSIONS: WIDTH VARIES, 9'-0" HIGH AT M.I. RF, 8'-0" TO 17'-0" HIGH AT TANGENTS TO TEVATRON.

EXIT DISTANCE: 297' MAXIMUM TRAVEL TO STAIRS.

EQUIP. ACCESS: EXISTING LABYRINTH 6'-0" WIDE, 7'-0" HIGH. EXISTING ELEVATOR 6' WIDE, 9' DEEP IN RF/F-0 SERVICE BUILDING. NEW 8'-0" WIDE, 30'-0" LONG HATCH UNDER CRANE COVERAGE AND 8'-6" WIDE, 10'-0" DEEP ELEVATOR WITH CURVED VEHICLE LABYRINTH IN RF/MI-60 SERV. BLDG. 2-10 TON HOIST BRIDGE CRANE OVER F-0 ENCLOSURE. 2-10 TON MONORAIL HOISTS ON A SINGLE MONORAIL BEAM AT EACH INTERSECTION OF P-150 AND A-150 ENCLOSURES WITH F-0 ENCLOSURE.

CONSTRUCTION: CAST-IN-PLACE CONCRETE. UNDERDRAINS AND MOISTURE PROTECTION. PENETRATIONS TO F-0/MI-60 SERVICE BUILDING ABOVE.

SHIELDING: 26'-0" EARTH EQUIVALENT TO F-0/MI-60 SERVICE BUILDINGS ABOVE. 26'-0" EARTH EQUIVALENT TO TOP OF BERM.

REV.	DATE	DESCRIPTIONS
		REVISIONS

PLOT-DATE

FLUOR DANIEL — CHICAGO ILLINOIS

PROJECT NO. - 21842300

	NAME	DATE
DESIGNED	T. LAREN	JULY, 92
DRAWN	I. MASIS	JULY, 92
CHECKED	A. VASONIS	JULY, 92
APPROVED		

	NAME	DATE
DESIGNED	T. LACKOWSKI	
DRAWN	T. LACKOWSKI	
CHECKED		
APPROVED		
SUBMITTED		

PROJECT NORTH

SCALE: 1" = 200'-0" (200 0 200 400 FEET)

FERMI NATIONAL ACCELERATOR LABORATORY

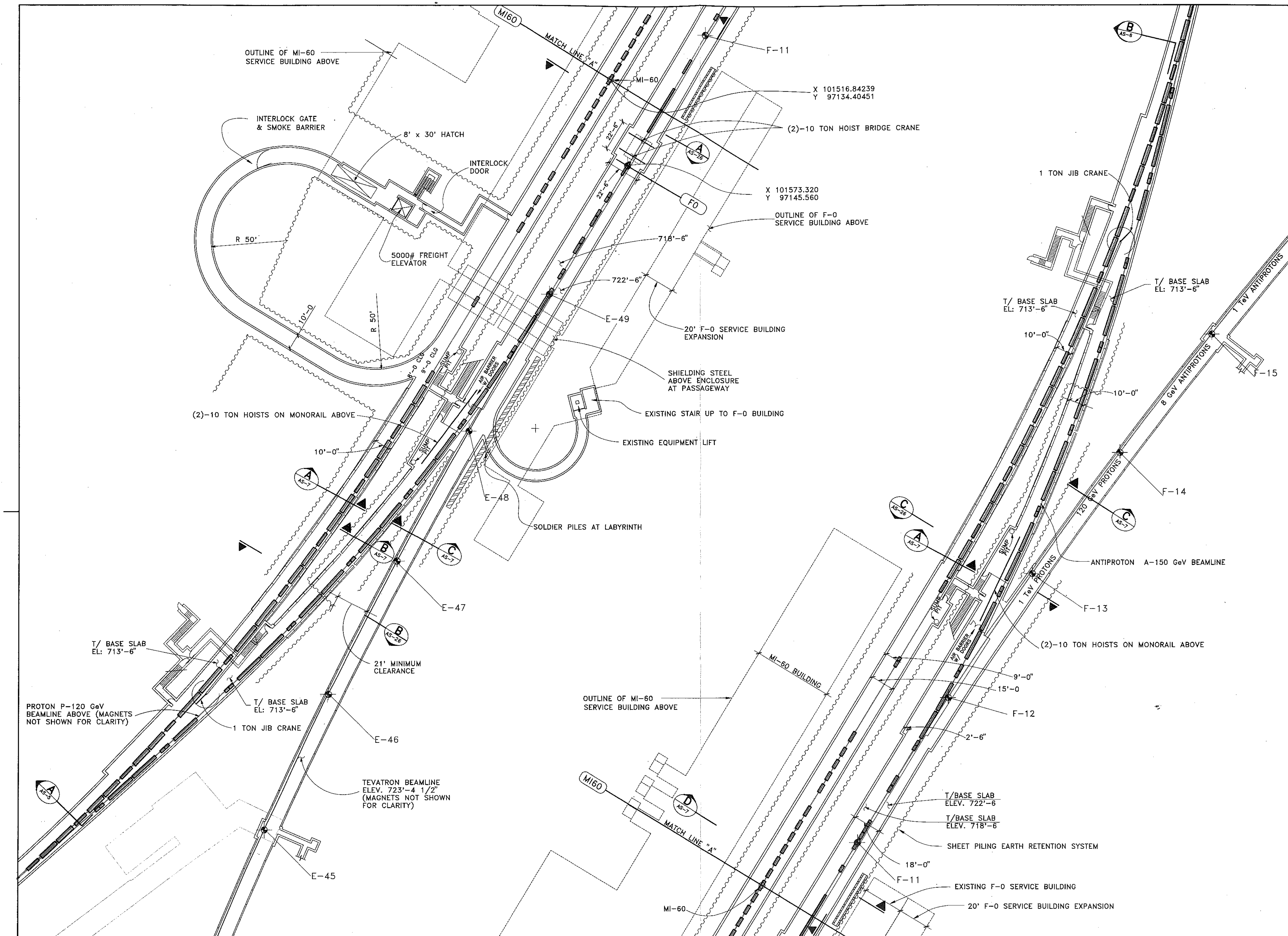
UNITED STATES DEPARTMENT OF ENERGY

FERMILAB MAIN INJECTOR

ENCLOSURE CRITERIA PLAN

DRAWING NO. 6-6-2 TITLE-1 AS-2 REV.

AUG. 1992



REV.	DATE	DESCRIPTIONS
		REVISIONS

FLUOR DANIEL CHICAGO ILLINOIS
PROJECT NO. -- 21842300

	NAME	DATE
DESIGNED	R.JEDZINIAK	JULY,1992
DRAWN	R.JEDZINIAK	JULY,1992
CHECKED	A.VASONIS	JULY,1992
APPROVED		

AS-3

	NAME	DATE
DESIGNED	T. LACKOWSKI	
DRAWN	T. LACKOWSKI / T. BURKE	
CHECKED		
APPROVED		
SUBMITTED		

PROJECT NORTH

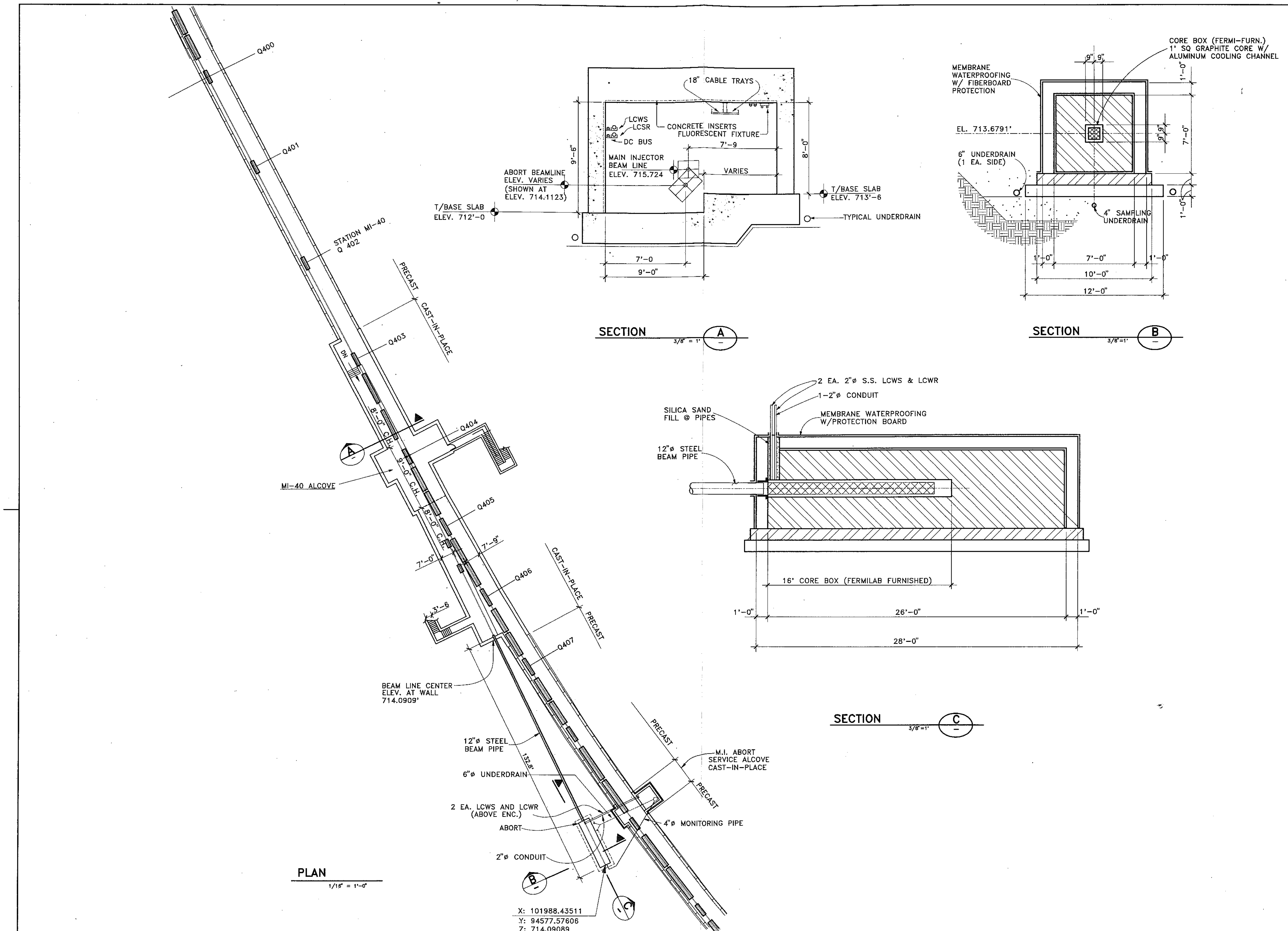
SCALE: 1" = 20'-0"

FERMI NATIONAL ACCELERATOR LABORATORY
UNITED STATES DEPARTMENT OF ENERGY

FERMILAB MAIN INJECTOR
F-0 / MI-60 ENCLOSURE PLAN

DRAWING NO. 6-6-2 TITLE-1 AS-3 REV.

AUG. 1992



REV.	DATE	DESCRIPTIONS
		REVISIONS

FLUOR DANIEL CHICAGO ILLINOIS

PROJECT NO. – 21842300

	NAME	DATE
DESIGNED	R.JEDZINIAK	JULY,1992
DRAWN	A.SKUZA	JULY,1992
CHECKED	A.VASONIS	JULY,1992
APPROVED		

	NAME	DATE
DESIGNED	T.LACKOWSKI	
DRAWN	T.LACKOWSKI/T.BURKE	
CHECKED		
APPROVED		
SUBMITTED		

PROJECT NORTH (W, S, E)

SCALE:
1/16"=1'-0" SCALE 8 0 8 16 24 32 40 FEET
3/8"=1'-0" SCALE 1 0 1 2 3 4 5 6 7 FEET

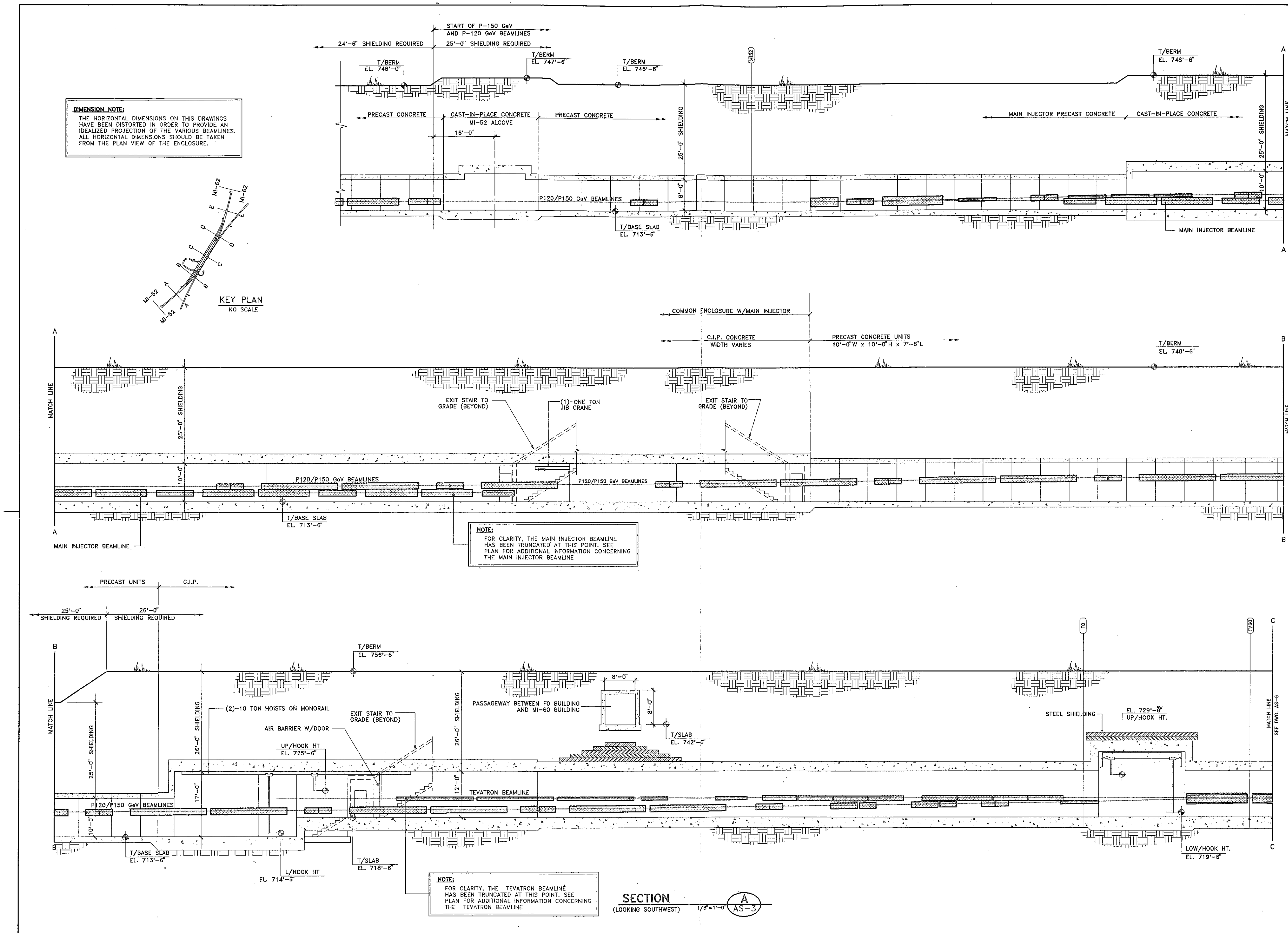
FERMI NATIONAL ACCELERATOR LABORATORY
UNITED STATES DEPARTMENT OF ENERGY

FERMILAB MAIN INJECTOR
ABORT PLAN AND SECTION

DRAWING NO. 6-6-2 TITLE-1 AS-4 REV.

AUG. 1992

AS-4



REV.	DATE	DESCRIPTIONS
		REVISIONS

FLUOR DANIEL
CHICAGO ILLINOIS
PROJECT NO. – 21842300

	NAME	DATE
DESIGNED	R.JEDZINIAK	JULY,1992
DRAWN	A.SKUZA	JULY,1992
CHECKED	A.VASONIS	JULY,1992
APPROVED		

	NAME	DATE
DESIGNED	T. LACKOWSKI	
DRAWN	S. DIXON	
CHECKED		
APPROVED		
SUBMITTED		

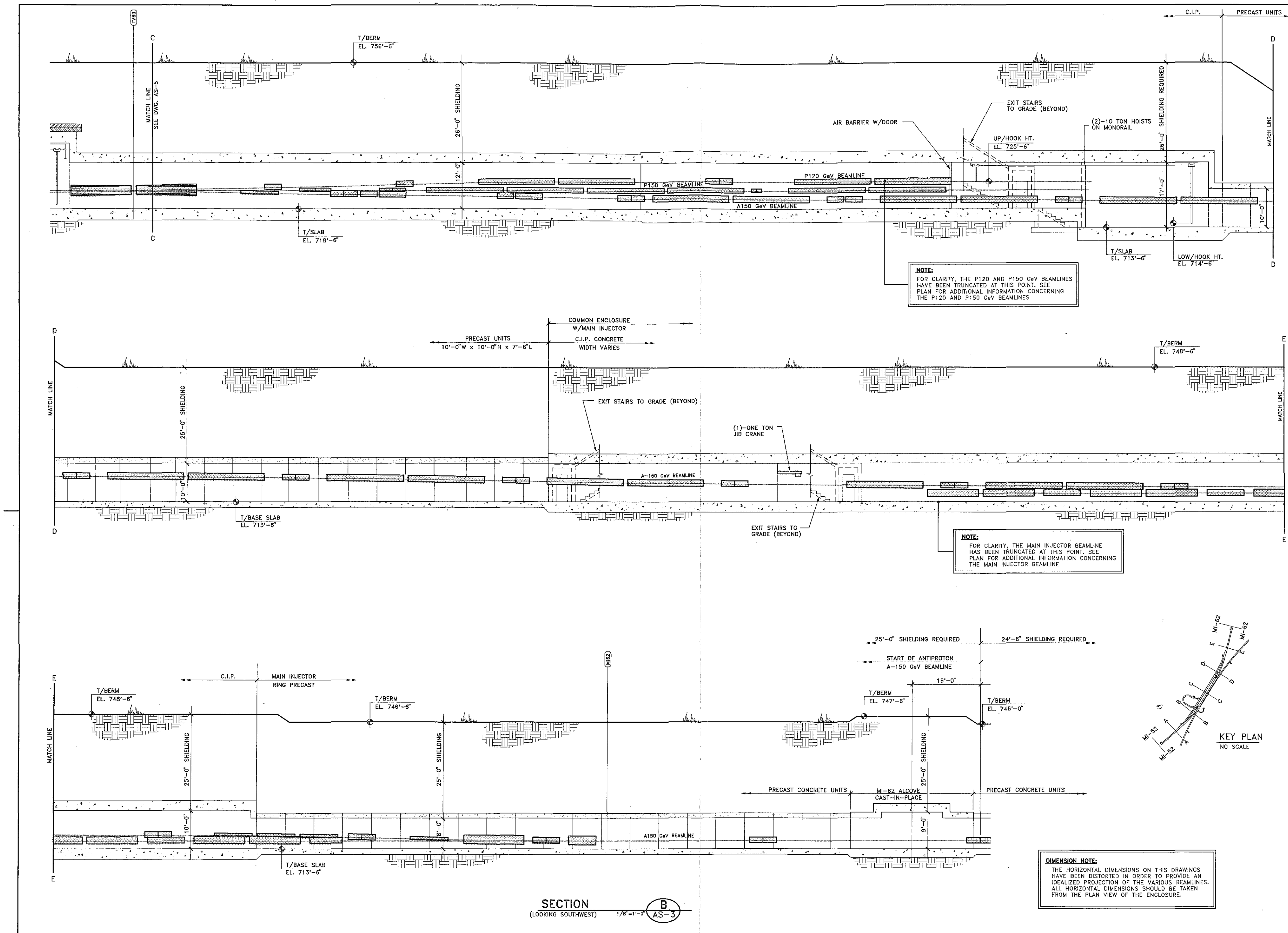
SCALE: 1/8"=1'-0" SCALE 0 4 8 12 16 20 FEET

FERMI NATIONAL ACCELERATOR LABORATORY
UNITED STATES DEPARTMENT OF ENERGY

FERMILAB MAIN INJECTOR
P-150 GeV ENCLOSURE LONG. SECTION

DRAWING NO. 6-6-2 TITLE-1 AS-5 REV.

AUG. 1992



REV.	DATE	DESCRIPTIONS REVISIONS

FLUOR DANIEL
CHICAGO ILLINOIS
PROJECT NO. - 21842300

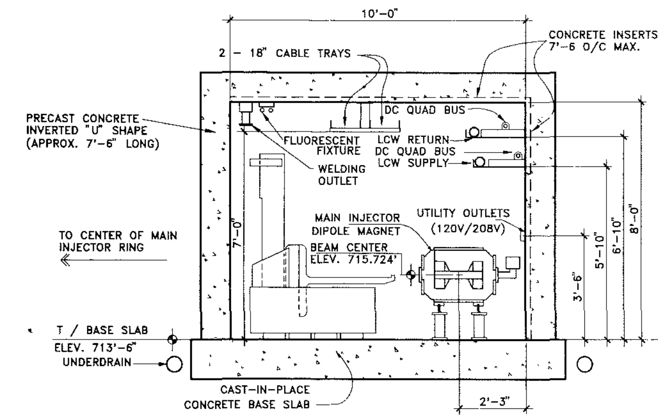
	NAME	DATE
DESIGNED	R.JEDZINIAK	JULY,1992
DRAWN	A.SKUZA	JULY,1992
CHECKED	A.VASONIS	JULY,1992
APPROVED		

	NAME	DATE
DESIGNED	T. LACKOWSKI	
DRAWN	S. DIXON	
CHECKED		
APPROVED		
SUBMITTED		

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

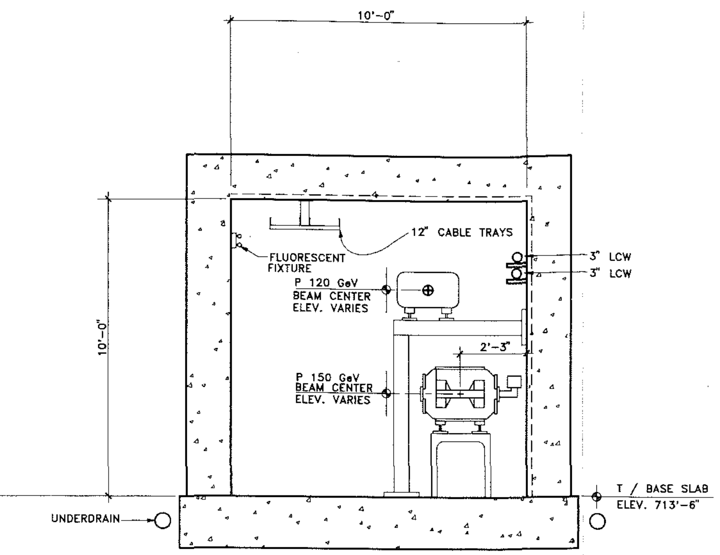
FERMI NATIONAL ACCELERATOR LABORATORY
UNITED STATES DEPARTMENT OF ENERGY
FERMILAB MAIN INJECTOR
A-150 GeV ENCLOSURE LONG. SECTION
DRAWING NO. 6-6-2 TITLE-1 AS-6 REV.
AUG. 1992

AS-6



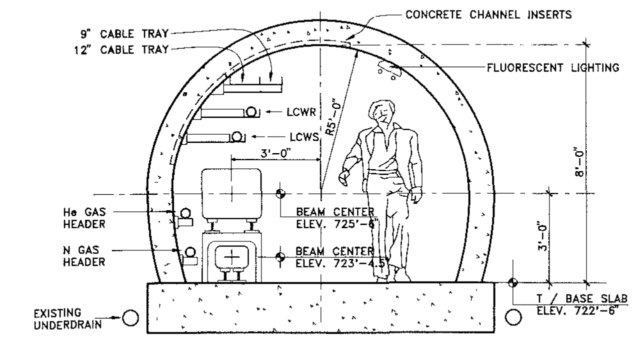
TYPICAL SECTION THROUGH MAIN INJECTOR ENCLOSURE

SECTION 1/2"=1'-0" (A / AS-3)



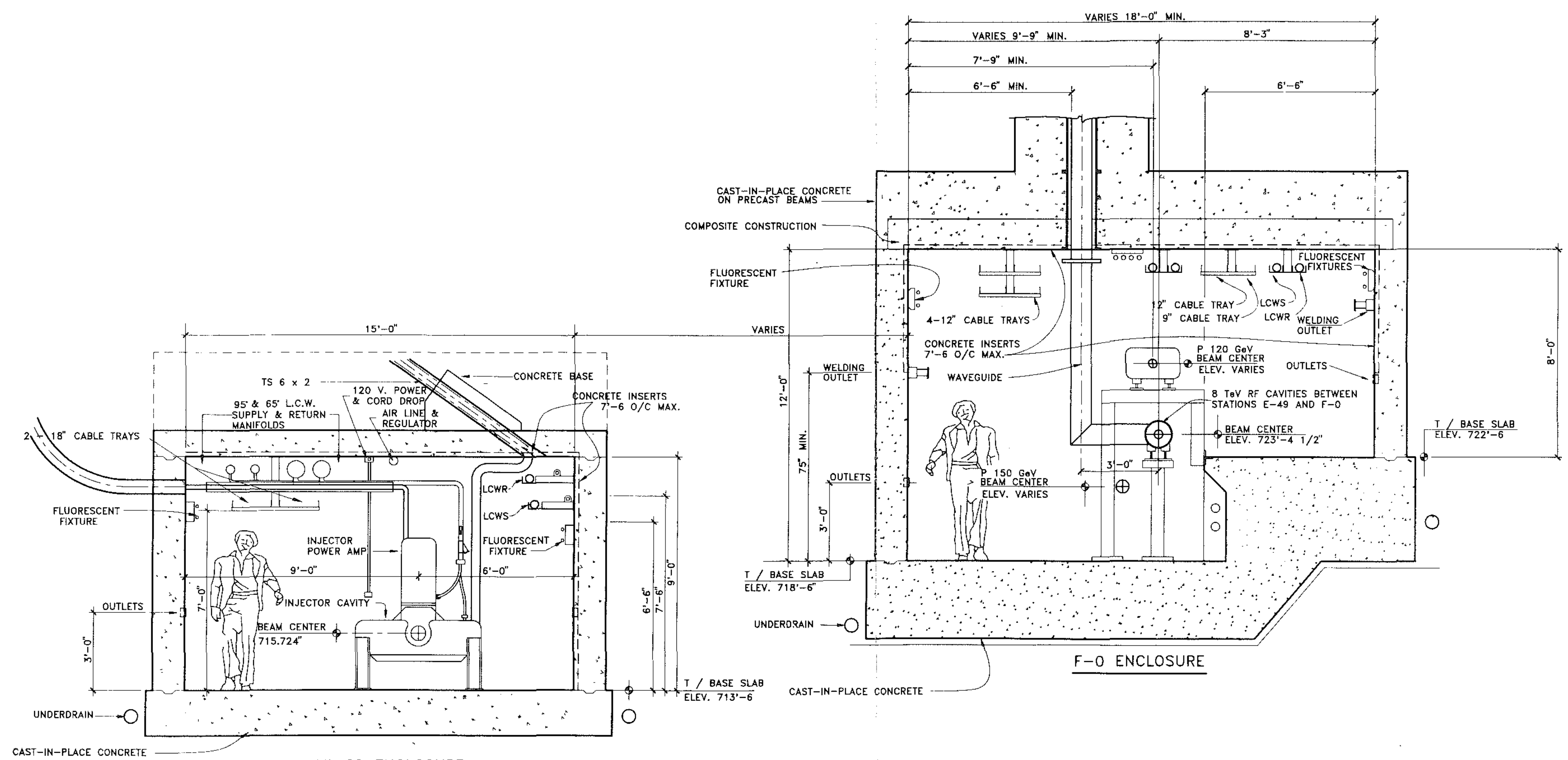
P 150 ENCLOSURE SECTION

SECTION 1/2"=1'-0" (B / AS-3)



EXISTING TEVATRON RING ENCLOSURE BETWEEN F-0 AND A-0

SECTION 1/2"=1'-0" (C / AS-3)



SECTION 1/2"=1'-0" (D / AS-3)

REV.	DATE	DESCRIPTIONS
		REVISIONS

PLOT-DATE

FLUOR DANIEL CHICAGO ILLINOIS
PROJECT NO. - 21842300

	NAME	DATE
DESIGNED	R. JEDZINIAK	JULY,1992
DRAWN	I. MASIS	JULY,1992
CHECKED	A. VASONIS	JULY,1992
APPROVED		

	NAME	DATE
DESIGNED	T.LACKOWSKI	
DRAWN	T.LACKOWSKI/T.BURKE	
CHECKED		
APPROVED		
SUBMITTED		

SCALE: 1/2"=1'-0" SCALE 0 1 2 3 4 5 FEET

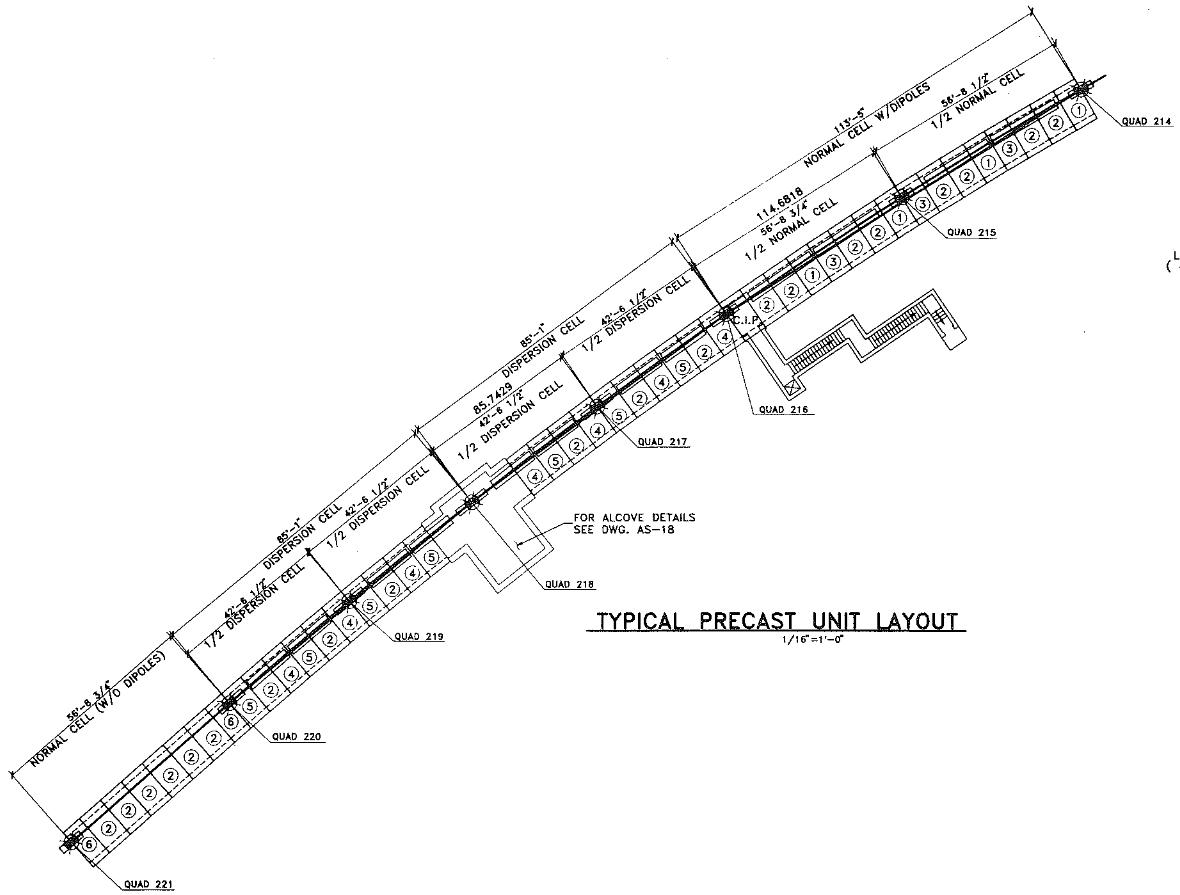
FERMI NATIONAL ACCELERATOR LABORATORY
UNITED STATES DEPARTMENT OF ENERGY

FERMILAB MAIN INJECTOR
INJECTOR ENCLOSURE SECTIONS

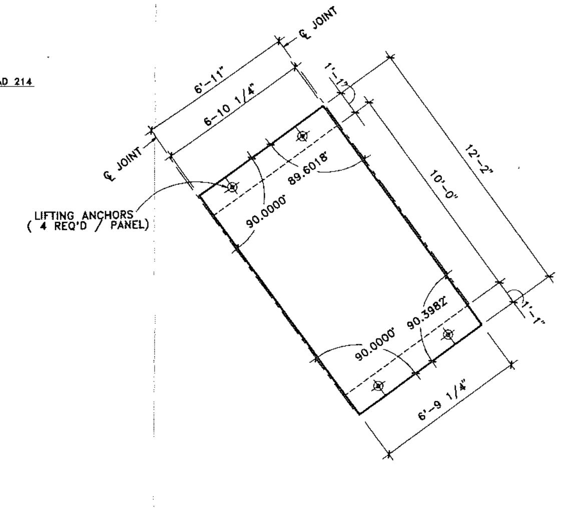
DRAWING NO 6-6-2 TITLE-1 AS-7 REV.

AUG. 1992

AS-7

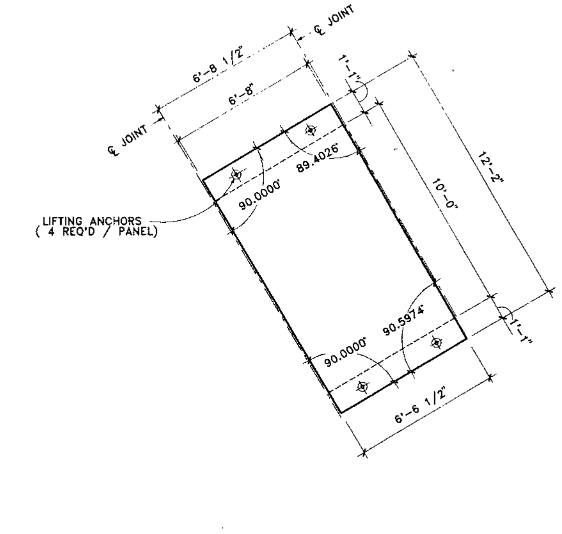


TYPICAL PRECAST UNIT LAYOUT
1/16"=1'-0"



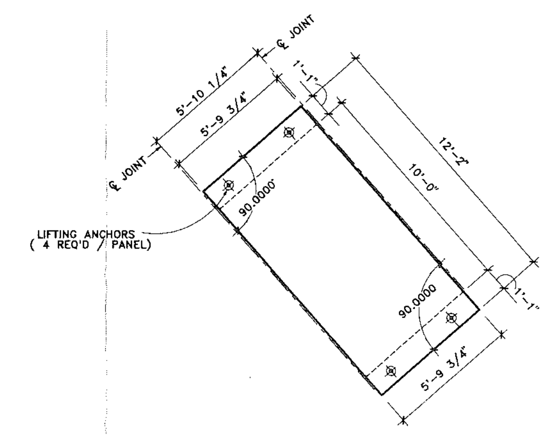
PRECAST UNIT TYPE "4"
3/8"=1'-0"

PRECAST UNIT TYPE "5" (OPPOSITE HAND)
3/8"=1'-0"



PRECAST UNIT TYPE "1"
3/8"=1'-0"

PRECAST UNIT TYPE "3" (OPPOSITE HAND)
3/8"=1'-0"



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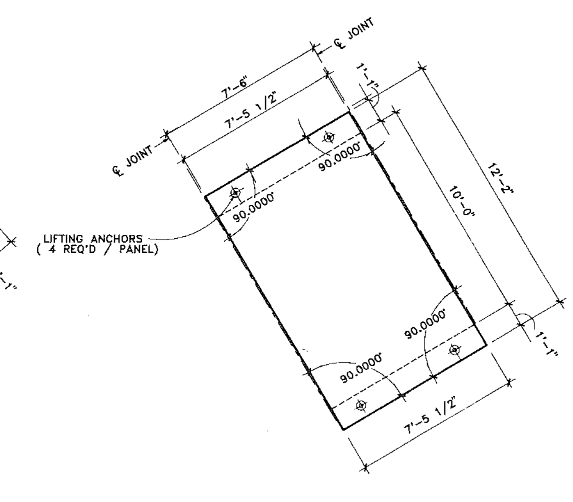

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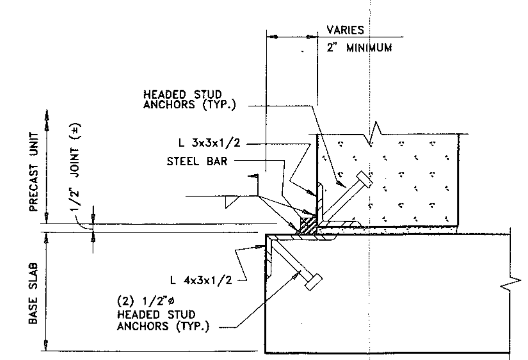
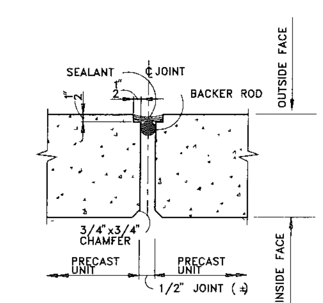
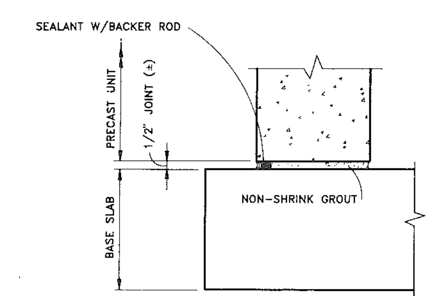


TYPICAL PRECAST ANCHOR DETAIL
NO SCALE



TYPICAL PRECAST JOINT DETAIL
NO SCALE



TYPICAL PRECAST BASE DETAIL
NO SCALE

TYP. NORMAL CELL (W/O DIPOLES) PRECAST PLACING SCHED.			
ENCLOSURE SEGMENT	WORK POINT #	DISTANCE FROM STATION POINT TO WORK POINT ON REFERENCE LINE	PERPENDICULAR OFFSET FROM REFERENCE LINE TO WORK POINT
QUAD 220 THROUGH 221	220 + 0	0'-0"	2- 3"
	220 + 1	5'-10 1/4"	2'-3"
	220 + 2	13'-4 1/4"	2'-3"
	220 + 3	20'-10 1/4"	2'-3"
	220 + 4	28'-4 1/4"	2'-3"
	220 + 5	35'-10 1/4"	2'-3"
	220 + 6	43'-4 1/4"	2'-3"
	220 + 7	50'-10 1/4"	2'-3"
	221 + 0	58'-8 3/4"	2'-3"

TYP. NORMAL CELL (W/DIPOLES) PRECAST PLACING SCHED.			
ENCLOSURE SEGMENT	WORK POINT #	DISTANCE FROM STATION POINT TO WORK POINT ON REFERENCE LINE	PERPENDICULAR OFFSET FROM REFERENCE LINE TO WORK POINT
QUAD 214 THROUGH QUAD 216	214 + 0	0'-0"	2'-3"
	214 + 4	28'-4 1/4"	3'-1 3/4"
	215 + 0	56'-8 1/2"	3'-5 1/4"
	215 + 4	85'-0 3/4"	3'-1 3/4"
	216 + 0	113'-5"	2'-3"

TYP. DISPERSION CELL PRECAST PLACING SCHED.			
ENCLOSURE SEGMENT	WORK POINT #	DISTANCE FROM STATION POINT TO WORK POINT ON REFERENCE LINE	PERPENDICULAR OFFSET FROM REFERENCE LINE TO WORK POINT
QUAD 218 THROUGH 220	218 + 0	0'-0"	2'-3"
	218 + 3	21'-3 1/4"	2'-8 1/4"
	219 + 0	42'-6 1/2"	2'-10"
	219 + 3	63'-9 3/4"	2'-8 1/4"
	220 + 0	85'-1"	2'-3"

PLOT-DATE

REV.	DATE	DESCRIPTIONS
		REVISIONS

FLUOR DANIEL
CHICAGO ILLINOIS
PROJECT NO. – 21842300

	NAME	DATE
DESIGNED	R. JEDZINIAK	JULY,1992
DRAWN	A.SKUZA	JULY,1992
CHECKED	A. VASONIS	JULY,1992
APPROVED		

	NAME	DATE
DESIGNED	TOMSKI,MIKE GRIMSON	
DRAWN	MIKE GRIMSON	
CHECKED		
APPROVED		
SUBMITTED		

PROJECT NORTH

SCALE:
1/16"=1'-0" SCALE FEET
3/8"=1'-0" SCALE FEET

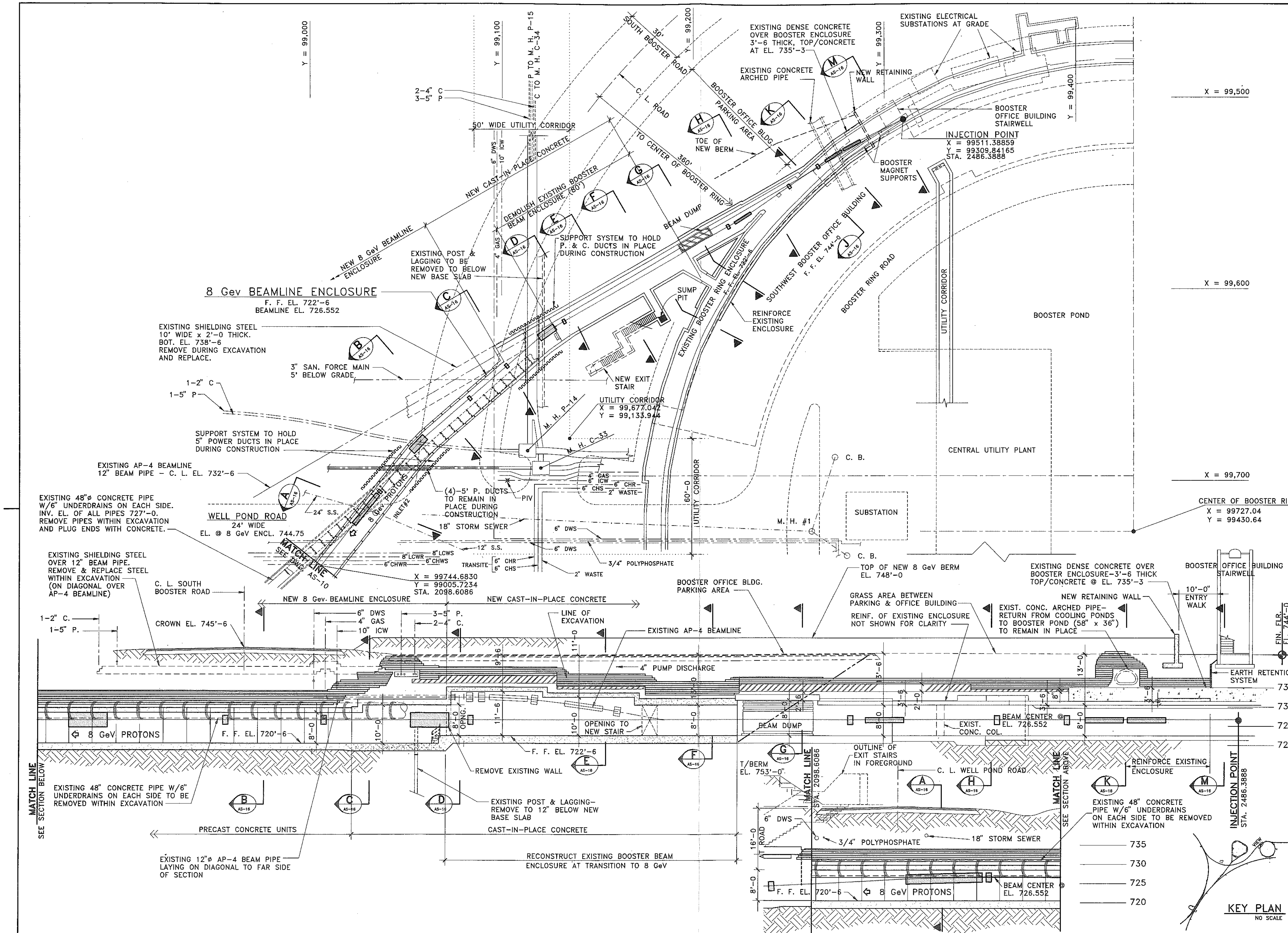
FERMI NATIONAL ACCELERATOR LABORATORY
UNITED STATES DEPARTMENT OF ENERGY

FERMILAB MAIN INJECTOR
PRECAST ENCLOSURE DETAILS

DRAWING NO. 6-6-2 TITLE-1 AS-8 REV.

AUG. 1992

AS-8



DESIGNED	R.JEDZINIAK	JULY,1992
DRAWN	R.DELA CRUZ	JULY,1992
CHECKED	A.VASONIS	JULY,1992
APPROVED		

FLUOR DANIEL — CHICAGO ILLINOIS — PROJECT NO. - 21842300

	NAME	DATE
DESIGNED	TOMSKI	
DRAWN	JONSKI	
CHECKED		
APPROVED		
SUBMITTED		

REV. | DATE | DESCRIPTIONS — REVISIONS

PROJECT NORTH

SCALE: 1/16"=1'-0" PLAN SCALE; 1/8"=1'-0" SECTION SCALE

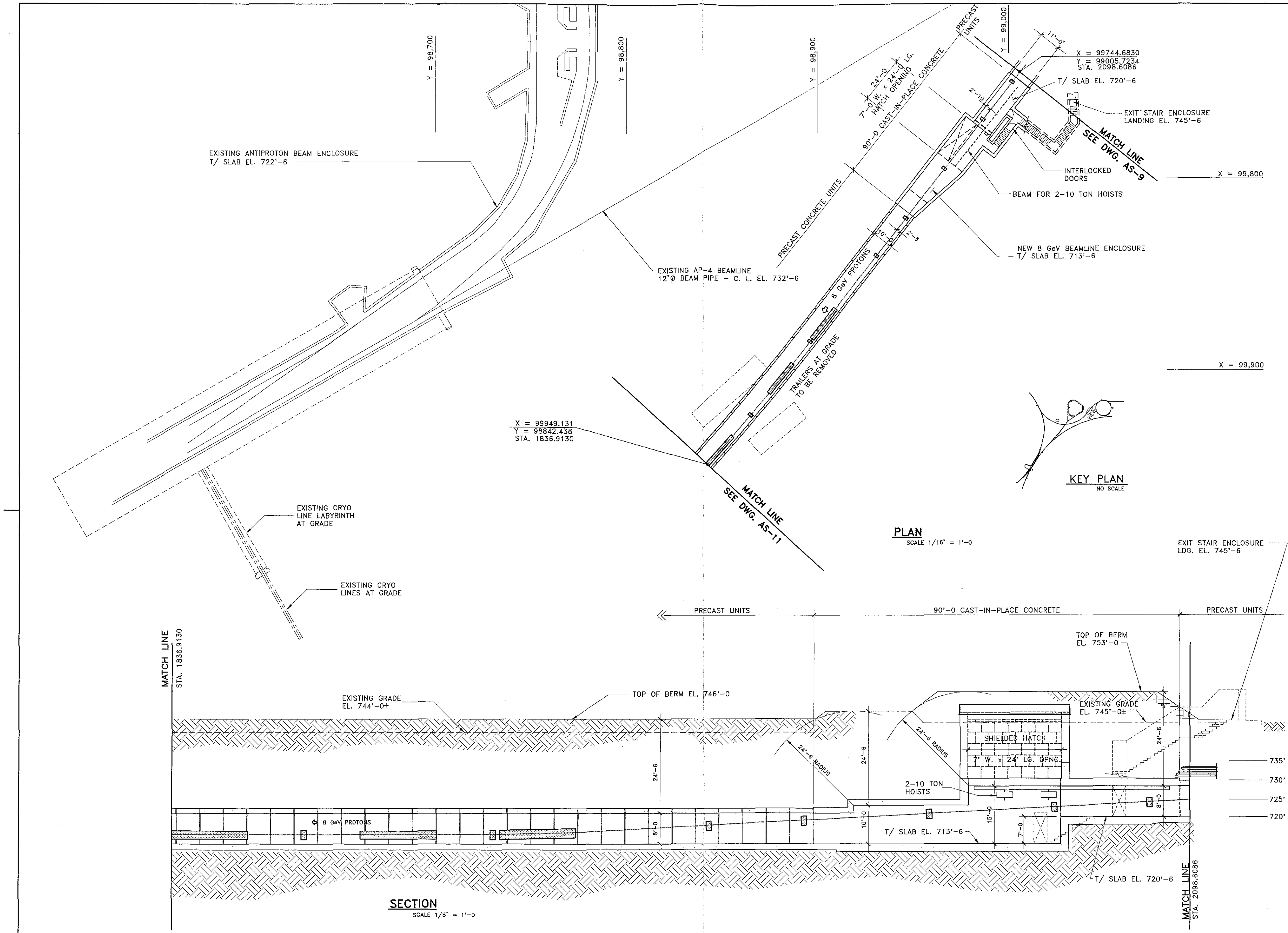
FERMI NATIONAL ACCELERATOR LABORATORY
UNITED STATES DEPARTMENT OF ENERGY

FERMILAB MAIN INJECTOR
8 GeV BEAMLINE SHT. 1

DRAWING NO. 6-6-2 TITLE-1 AS-9 REV.

AUG. 1992

AS-9



REV.	DATE	DESCRIPTIONS
		REVISIONS

FLUOR DANIEL CHICAGO ILLINOIS

PROJECT NO. – 21842300

	NAME	DATE
DESIGNED	R.JEDZINIAK	JULY,1992
DRAWN	I.MASIS	JULY,1992
CHECKED	A.VASONIS	JULY,1992
APPROVED		

	NAME	DATE
DESIGNED	T. LACKOWSKI	
DRAWN	J. HACKEMER	
CHECKED		
APPROVED		
SUBMITTED		

PROJECT NORTH

SCALE:
1/16"=1'-0" PLAN SCALE
1/8"=1'-0" SECTION SCALE

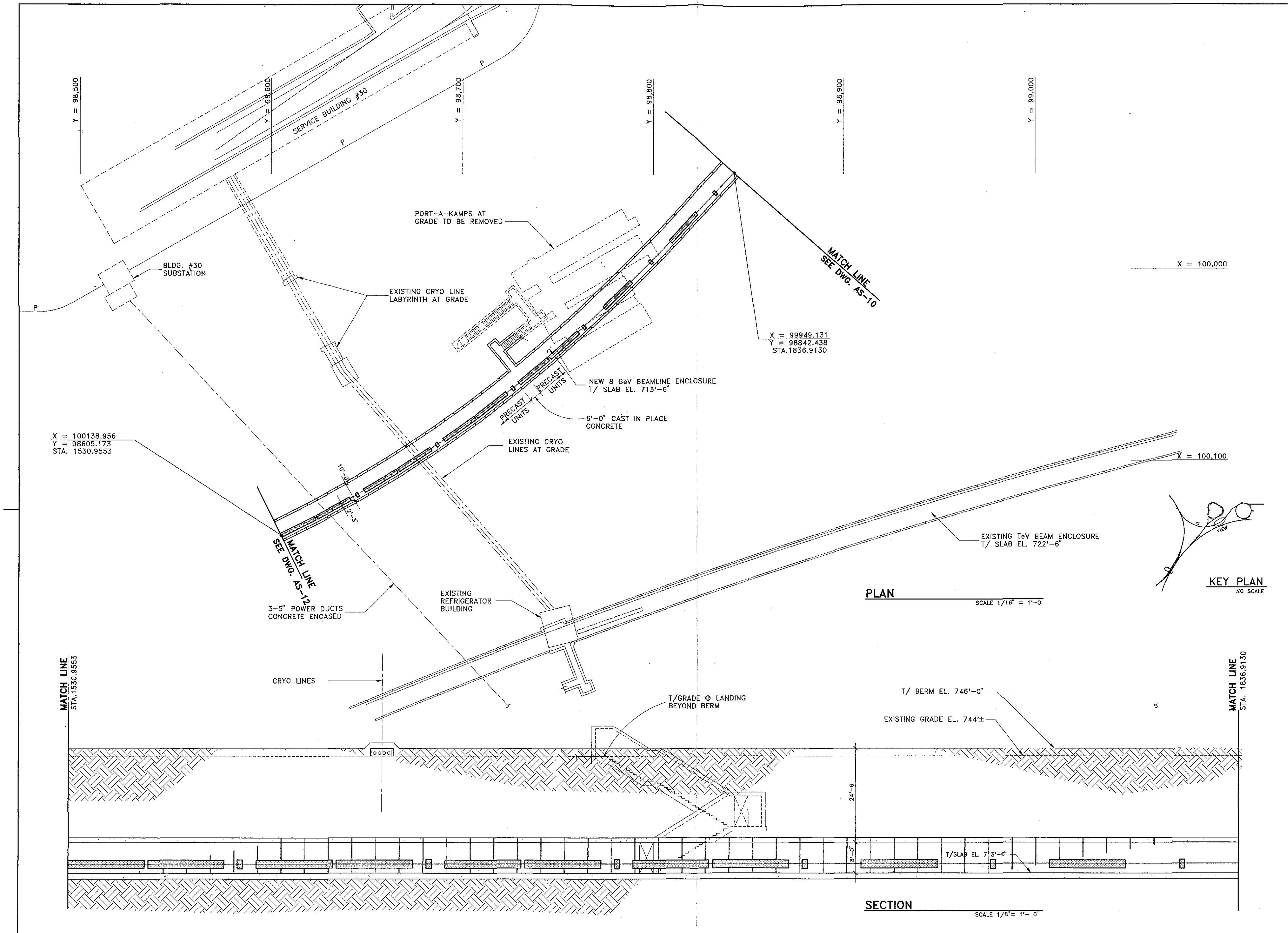
FERMI NATIONAL ACCELERATOR LABORATORY
UNITED STATES DEPARTMENT OF ENERGY

FERMILAB MAIN INJECTOR
8 GeV BEAMLINE SHT. 2

DRAWING NO. 6-6-2 TITLE-1 AS-10 REV.

AUG. 1992

AS-10



REV.	DATE	DESCRIPTIONS
		REVISIONS

FLUOR DANIEL CHICAGO ILLINOIS

PROJECT NO. – 21842300

	NAME	DATE
DESIGNED	R.JEDZINIAK	JULY,1992
DRAWN	I.MASIS	JULY,1992
CHECKED	D.ABRAHAM	JULY,1992
APPROVED		

	NAME	DATE
DESIGNED	T. LACKOWSKI	
DRAWN	J. HACKEMER	
CHECKED		
APPROVED		
SUBMITTED		

PROJECT NORTH

SCALE:
1/16"=1'-0" 0 8 16 24 32 40 SCALE FEET — PLAN SCALE
1/8"=1'-0" 0 8 16 SCALE FEET — SECTION SCALE

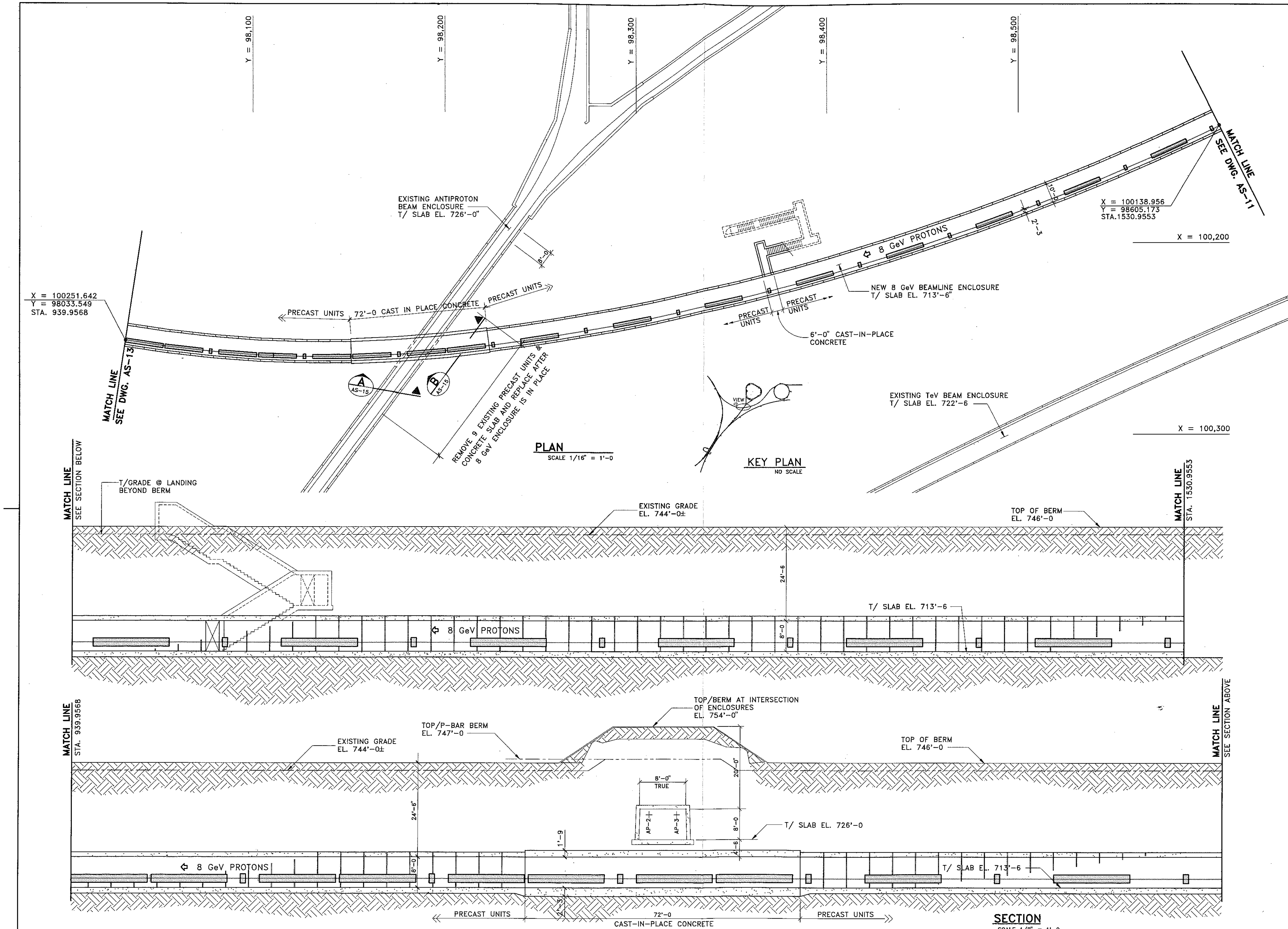
FERMI NATIONAL ACCELERATOR LABORATORY
UNITED STATES DEPARTMENT OF ENERGY

FERMILAB MAIN INJECTOR
8 GeV BEAMLINE SHT. 3

DRAWING NO. 6-6-2 TITLE-1 AS-11 REV.

AUG. 1992

AS-11



REV.	DATE	DESCRIPTIONS
		REVISIONS

FLUOR DANIEL CHICAGO ILLINOIS

PROJECT NO. – 21842300

	NAME	DATE
DESIGNED	R.JEDZINIAK	JULY,1992
DRAWN	I.MASIS	JULY,1992
CHECKED	A.VASONIS	JULY,1992
APPROVED		

	NAME	DATE
DESIGNED	T. LACKOWSKI	
DRAWN	J. HACKEMER	
CHECKED		
APPROVED		
SUBMITTED		

PROJECT NORTH

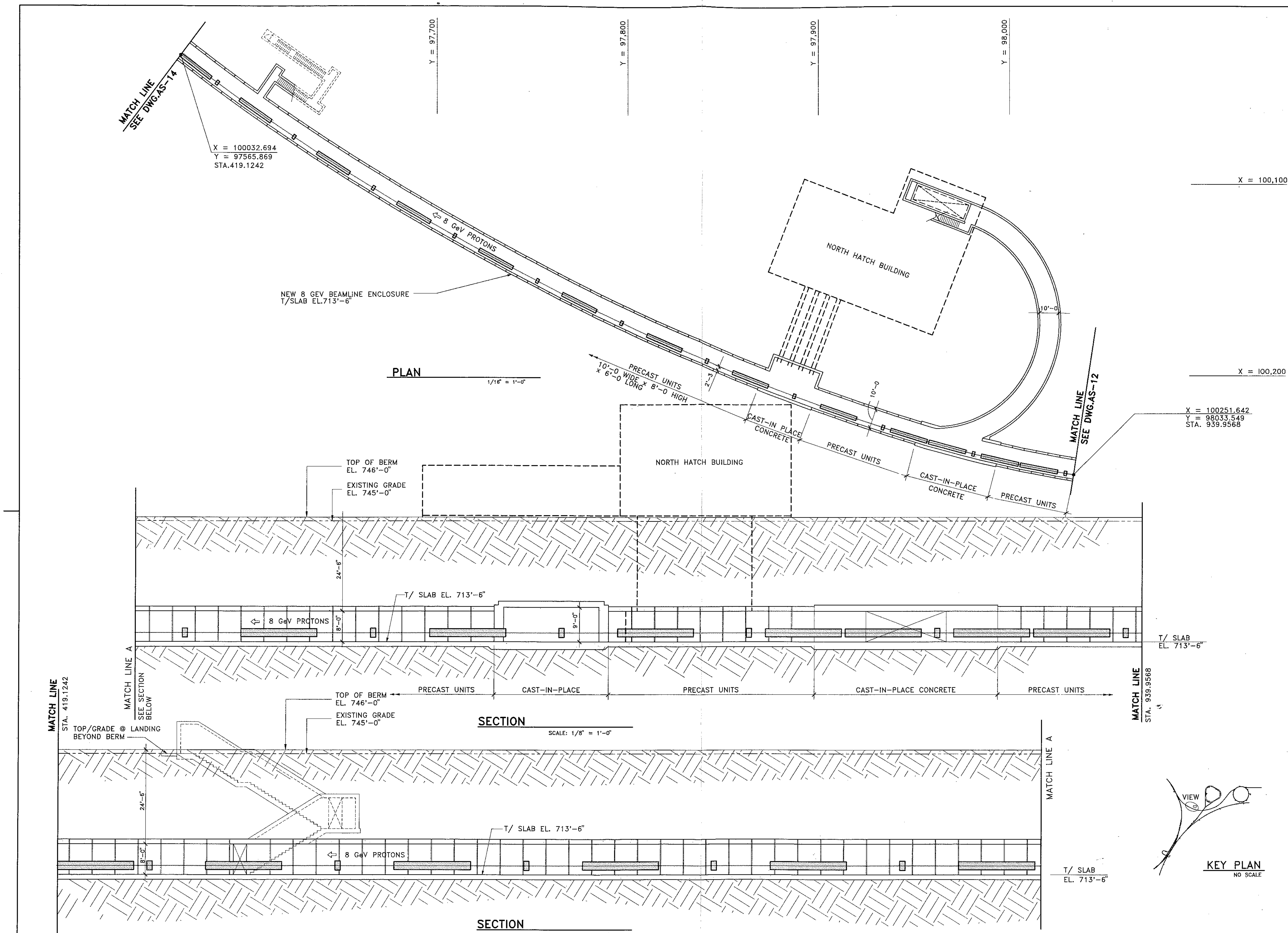
SCALE:
1/16"=1'-0" PLAN SCALE
1/8"=1'-0" SECTION SCALE

FERMI NATIONAL ACCELERATOR LABORATORY
UNITED STATES DEPARTMENT OF ENERGY

FERMILAB MAIN INJECTOR
8 GeV BEAMLINE SHT. 4

DRAWING NO. 6-6-2 TITLE-1 AS-12 REV.

AUG. 1992



REV.	DATE	DESCRIPTIONS
		REVISIONS

FLUOR DANIEL CHICAGO ILLINOIS

PROJECT NO. – 21842300

	NAME	DATE
DESIGNED	R.JEDZINIAK	JULY,1992
DRAWN	I.MASIS	JULY,1992
CHECKED	A.VASONIS	JULY,1992
APPROVED		

	NAME	DATE
DESIGNED	T. LACKOWSKI	
DRAWN	J. HACKEMER	
CHECKED		
APPROVED		
SUBMITTED		

SCALE:
1/16"=1'-0" 8 0 8 16 24 32 40 SCALE FEET
PLAN SCALE
1/8"=1'-0" 8 0 8 16 SCALE FEET
SECTION SCALE

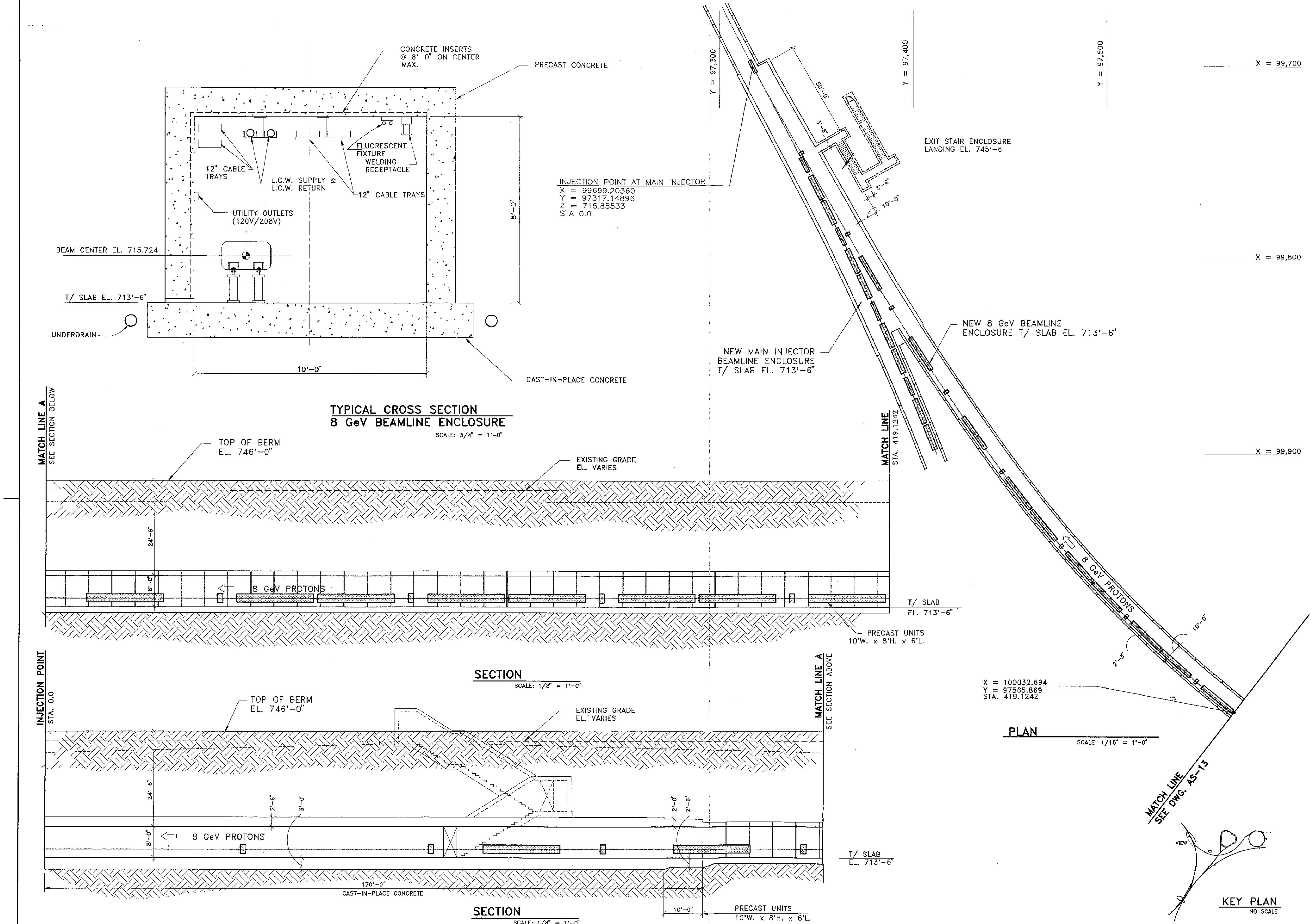
FERMI NATIONAL ACCELERATOR LABORATORY
UNITED STATES DEPARTMENT OF ENERGY

FERMILAB MAIN INJECTOR
8 GeV BEAMLINE SHT. 5

DRAWING NO. 6-6-2 TITLE-1 AS-13 REV.

AUG. 1992

AS-13



REV.	DATE	DESCRIPTIONS REVISIONS

FLUOR DANIEL CHICAGO ILLINOIS
PROJECT NO. – 21842300

	NAME	DATE
DESIGNED	R.JEDZINIAK	JULY,1992
DRAWN	R.DELA CRUZ	JULY,1992
CHECKED	A.VASONIS	JULY,1992
APPROVED		

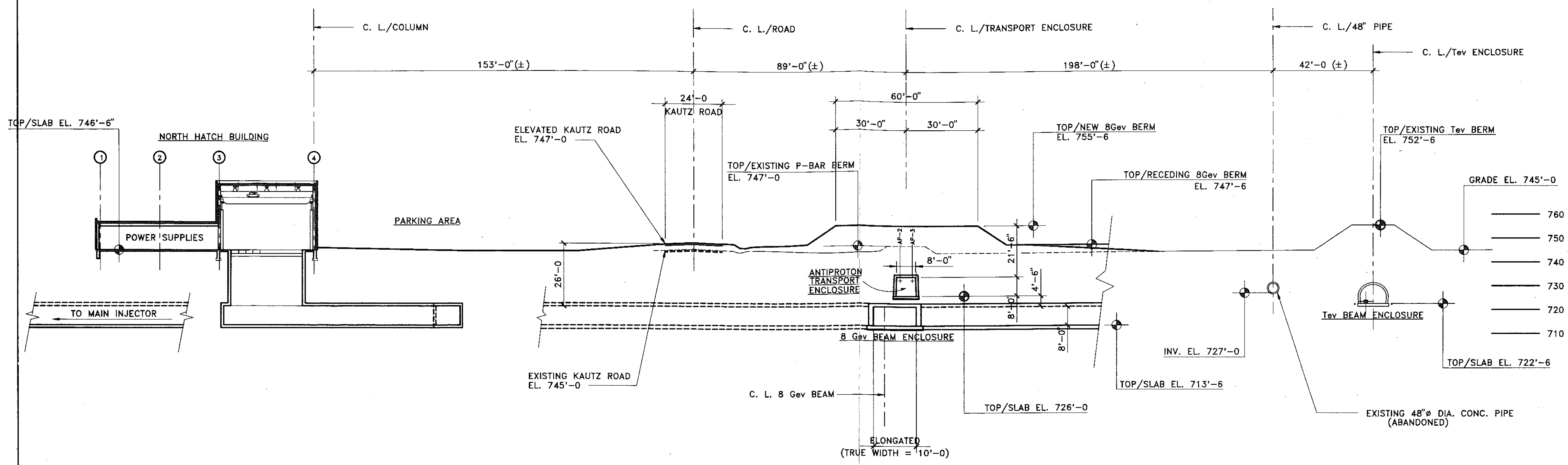
	NAME	DATE
DESIGNED	T. LACKOWSKI	
DRAWN	J. HACKEMER	
CHECKED		
APPROVED		
SUBMITTED		

PROJECT NORTH

SCALE: 1/16"=1'-0" PLAN SCALE; 1/8"=1'-0" SECTION SCALE; 3/4"=1'-0" SECTION SCALE

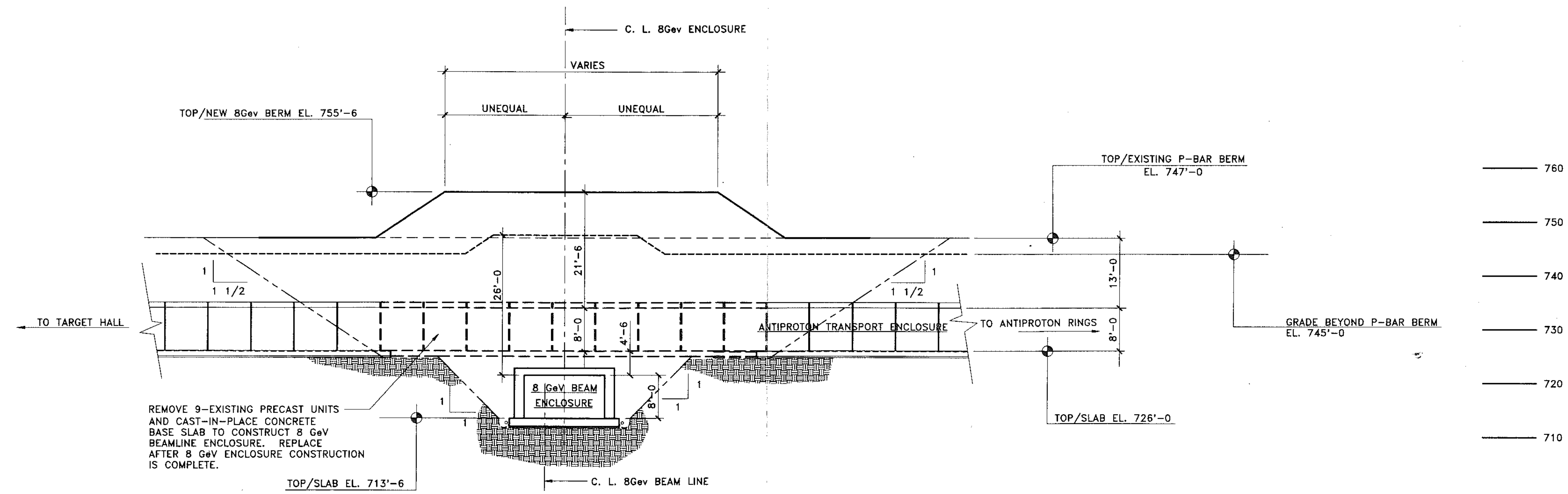
FERMI NATIONAL ACCELERATOR LABORATORY
UNITED STATES DEPARTMENT OF ENERGY
FERMILAB MAIN INJECTOR
8 GeV BEAMLINE SHT. 6
DRAWING NO. 6-6-2 TITLE-1 AS-14 REV.
AUG. 1992

AS-14



SECTION ACROSS ANTIPROTON TRANSPORT ENCLOSURE LOOKING WEST (A / AS-12)

SCALE 1/16"= 1'- 0"



SECTION ACROSS ANTIPROTON TRANSPORT ENCLOSURE LOOKING SOUTH (B / AS-12)

SCALE 1/8"= 1'-0"

REV.	DATE	DESCRIPTIONS
		REVISIONS

PLOT-DATE

FLUOR DANIEL — CHICAGO ILLINOIS
PROJECT NO. – 21842300

	NAME	DATE
DESIGNED	R.JEDZINIAK	JULY,1992
DRAWN	RAY DELA CRUZ	JULY,1992
CHECKED	A.VASONIS	JULY,1992
APPROVED		

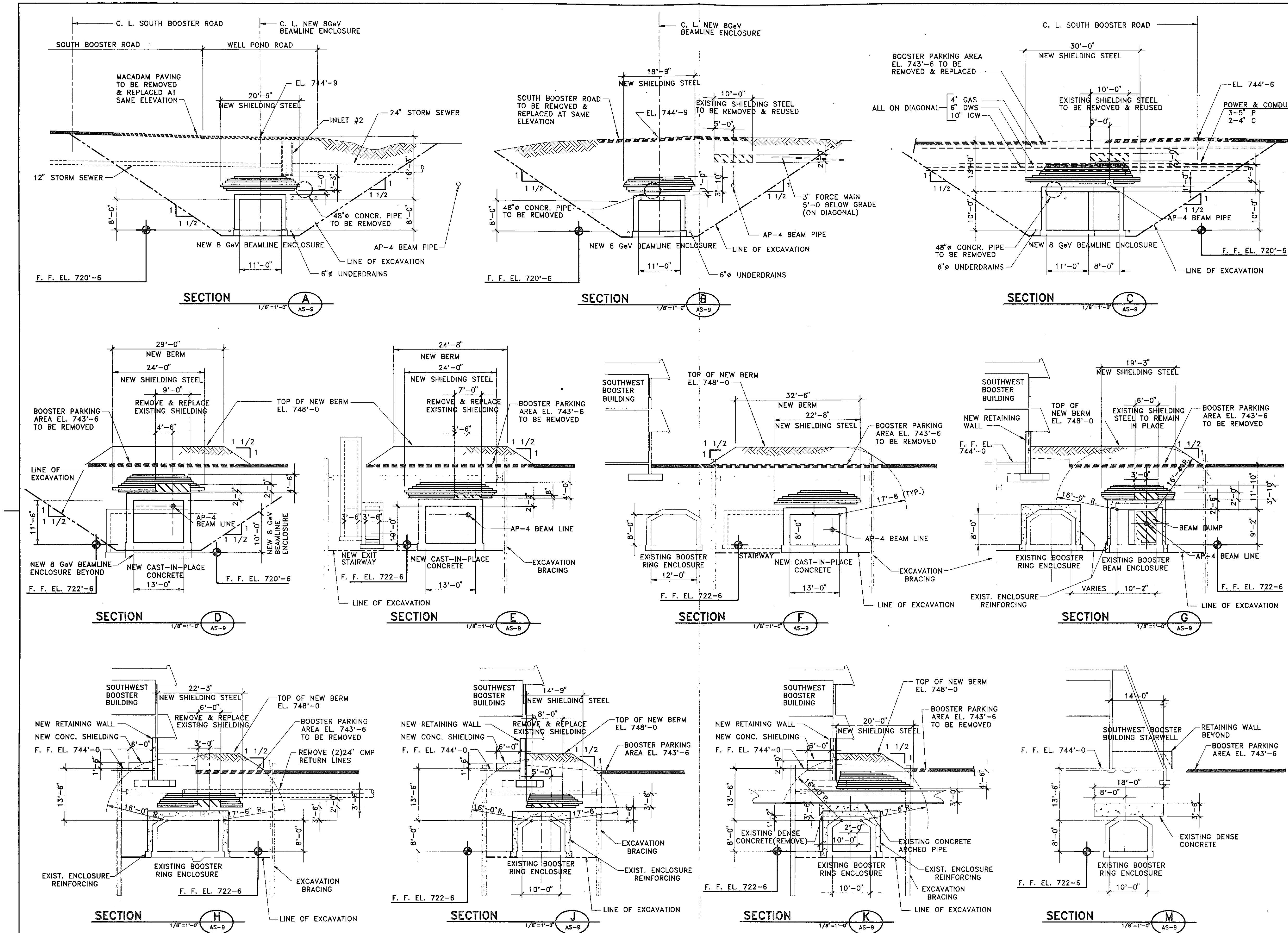
	NAME	DATE
DESIGNED	T.LACKOWSKI/J.HACKEMER	
DRAWN	J.HACKEMER	
CHECKED		
APPROVED		
SUBMITTED		

PROJECT NORTH

SCALE: 1/16"=1'-0" UPPER SECTION; 1/8"=1'-0" LOWER SECTION

FERMI NATIONAL ACCELERATOR LABORATORY
UNITED STATES DEPARTMENT OF ENERGY
FERMILAB MAIN INJECTOR
8 GeV SECTION SHT. 1
DRAWING NO. 6-6-2 TITLE-1 AS-15 REV.
AUG. 1992

AS-15



REV.	DATE	DESCRIPTIONS
		REVISIONS

FLUOR DANIEL — CHICAGO ILLINOIS — PROJECT NO. – 21842300

	NAME	DATE
DESIGNED	R.JEDZINIAK	JULY,1992
DRAWN	R.DELA CRUZ	JULY,1992
CHECKED	A.VASONIS	JULY,1992
APPROVED		

	NAME	DATE
DESIGNED	T.LACKOWSKI	
DRAWN	J.HACKEMER,J.GEHARD	
CHECKED		
APPROVED		
SUBMITTED		

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

FERMI NATIONAL ACCELERATOR LABORATORY

UNITED STATES DEPARTMENT OF ENERGY

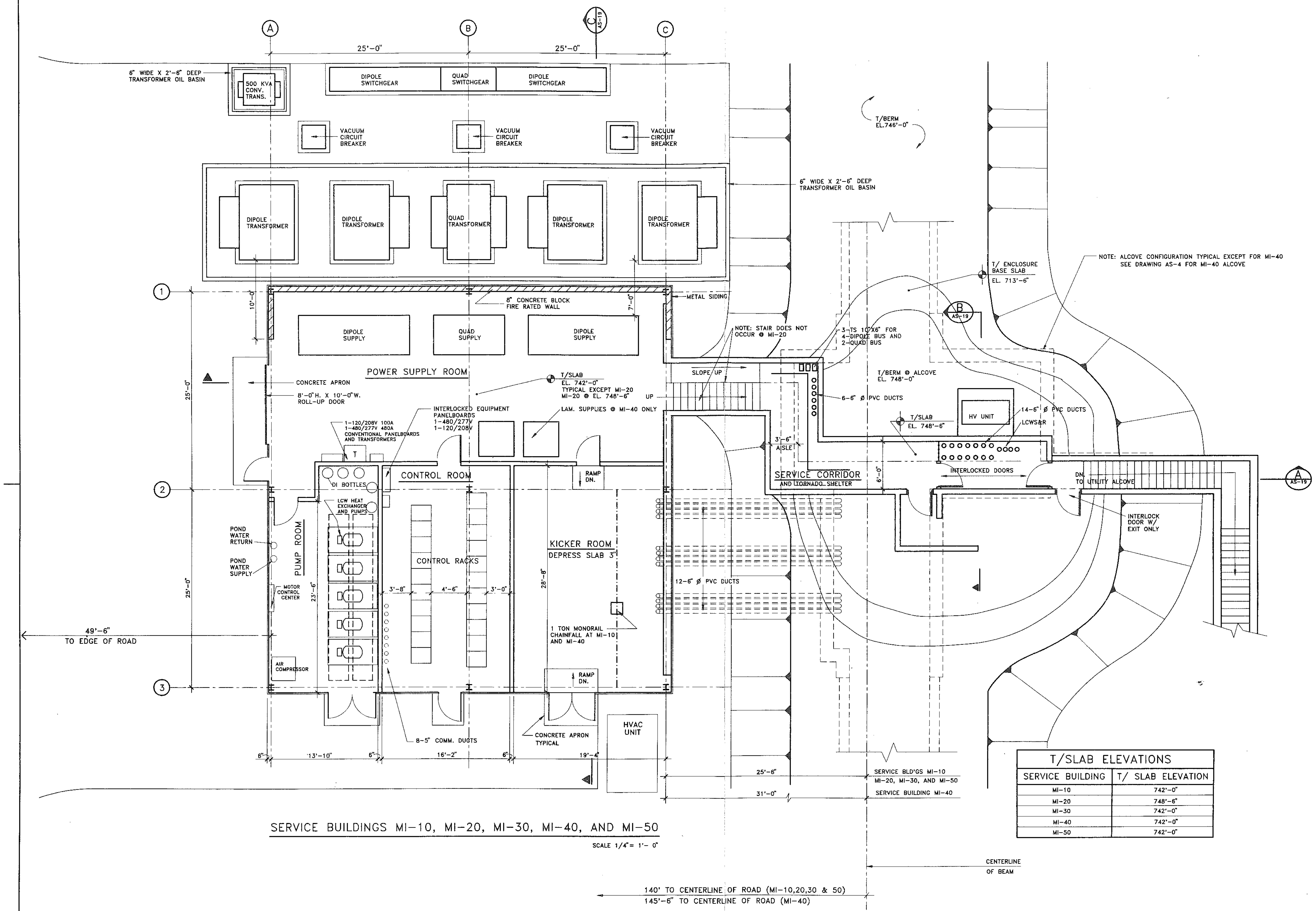
FERMILAB MAIN INJECTOR

8 GeV SECTIONS SHT. 2

DRAWING NO. 6-6-2 TITLE-1 AS-16 REV.

AUG. 1992

AS-16



T/SLAB ELEVATIONS

SERVICE BUILDING	T/ SLAB ELEVATION
MI-10	742'-0"
MI-20	748'-6"
MI-30	742'-0"
MI-40	742'-0"
MI-50	742'-0"

SERVICE BUILDINGS MI-10, MI-20, MI-30, MI-40, AND MI-50

SCALE 1/4"= 1'- 0"

REV.	DATE	DESCRIPTIONS
		REVISIONS

FLUOR DANIEL CHICAGO ILLINOIS

PROJECT NO. - 21842300

	NAME	DATE
DESIGNED	R. JEDZINIAK	JULY,1992
DRAWN	A. SKUZA	JULY,1992
CHECKED	A. VASONIS	JULY,1992
APPROVED		

	NAME	DATE
DESIGNED	T.LACKOWSKI	
DRAWN	T.LACKOWSKI/L.JENKINS	
CHECKED		
APPROVED		
SUBMITTED		

SCALE: 1/4"=1'-0"

FERMI NATIONAL ACCELERATOR LABORATORY

UNITED STATES DEPARTMENT OF ENERGY

FERMILAB MAIN INJECTOR

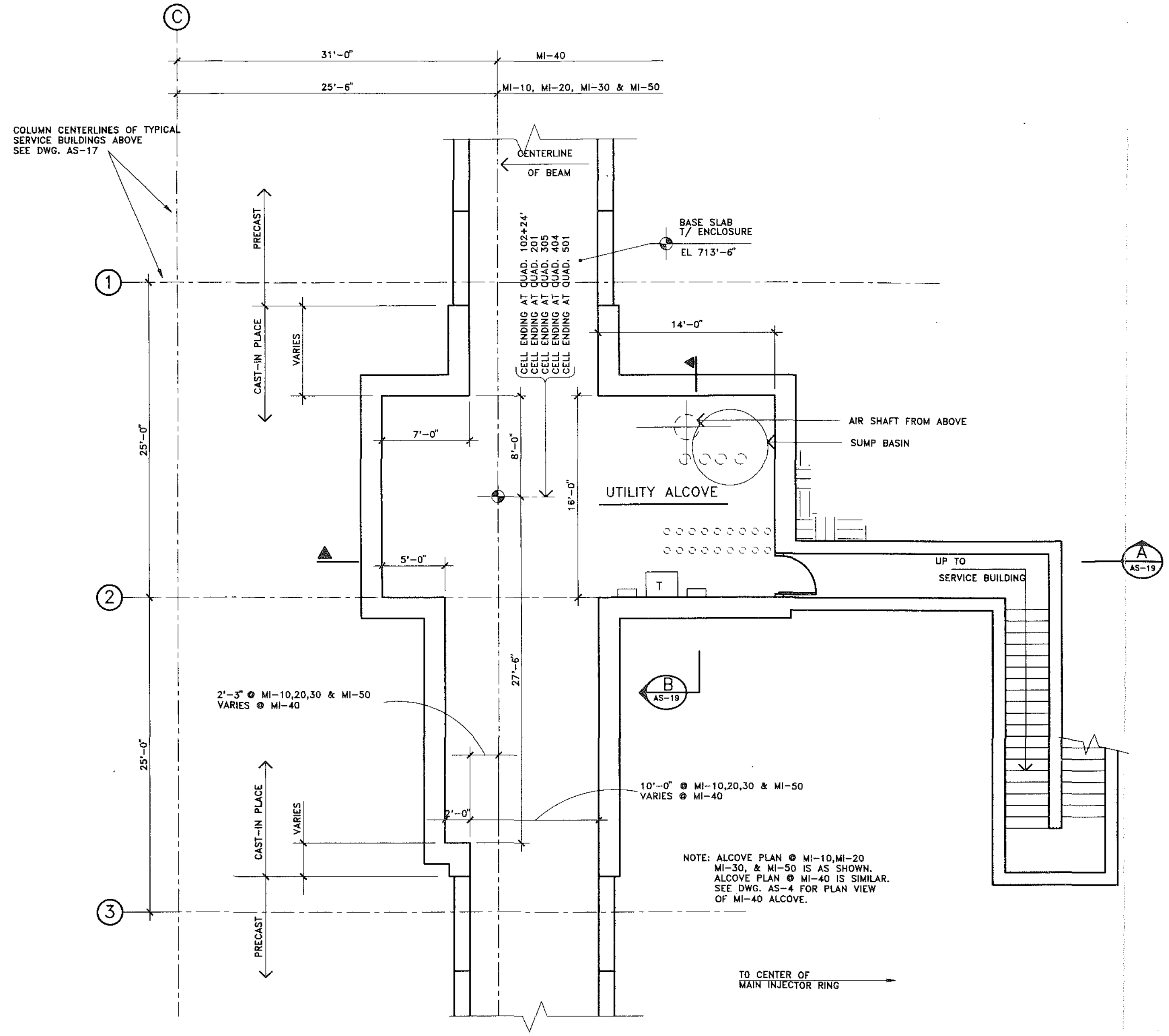
TYPICAL SERVICE BUILDING PLAN

DRAWING NO. 6-6-2 TITLE-1 AS-17 REV.

AUG. 1992

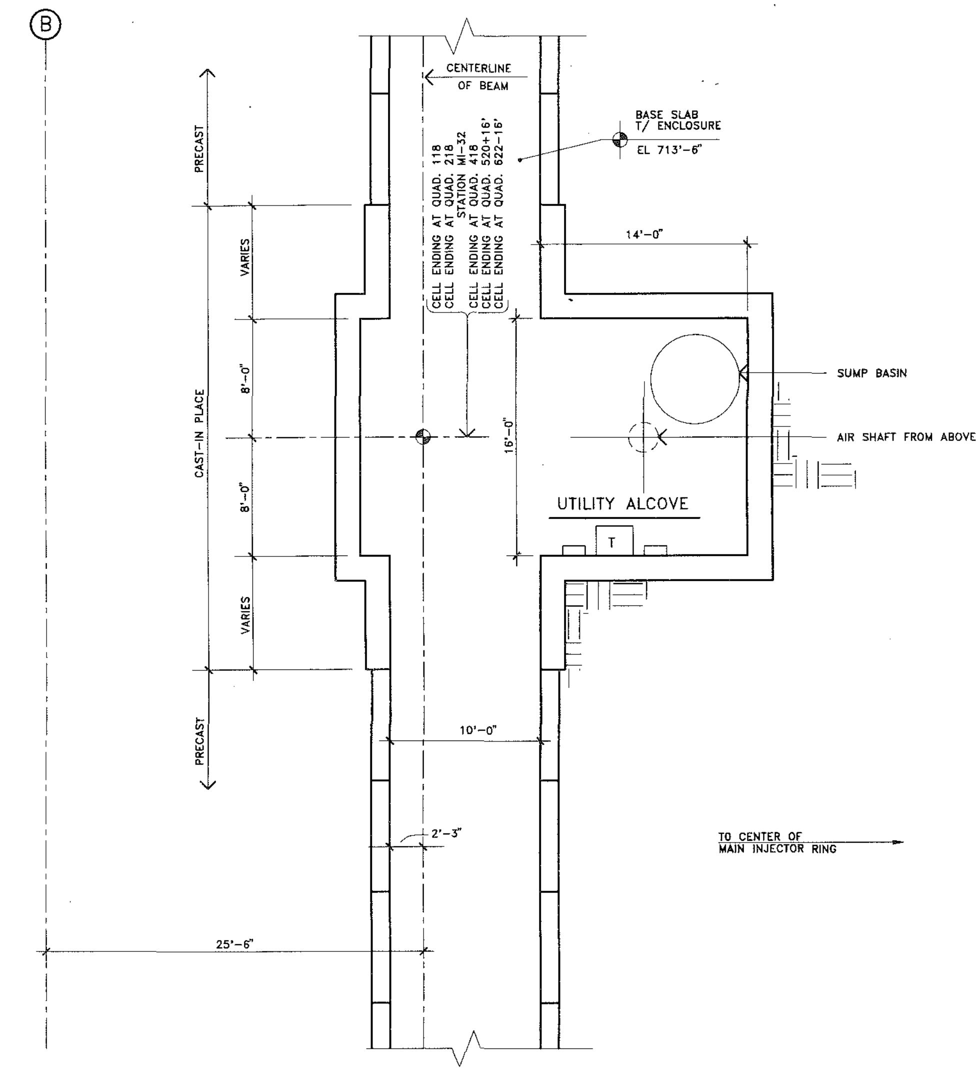
PLOT-DATE

AS-17



ALCOVE PLAN AT TYPICAL SERVICE BUILDINGS

1/4" = 1'-0"



ALCOVE PLAN AT KICKER BUILDINGS
AND BETWEEN TYPICAL SERVICE BUILDINGS

1/4" = 1'-0"

REV.	DATE	DESCRIPTIONS
		REVISIONS

FLUOR DANIEL CHICAGO ILLINOIS

PROJECT NO. - 21842300

	NAME	DATE
DESIGNED	R.JEDZINIAK	JULY,1992
DRAWN	R.DELA CRUZ	JULY,1992
CHECKED	A.VASONIS	JULY,1992
APPROVED		

	NAME	DATE
DESIGNED	TOMSKI	
DRAWN	TOMSKI	
CHECKED		
APPROVED		
SUBMITTED		

SCALE: 1/4"=1'-0" SCALE 4 0 4 8 FEET

FERMI NATIONAL ACCELERATOR LABORATORY

UNITED STATES DEPARTMENT OF ENERGY

FERMILAB MAIN INJECTOR

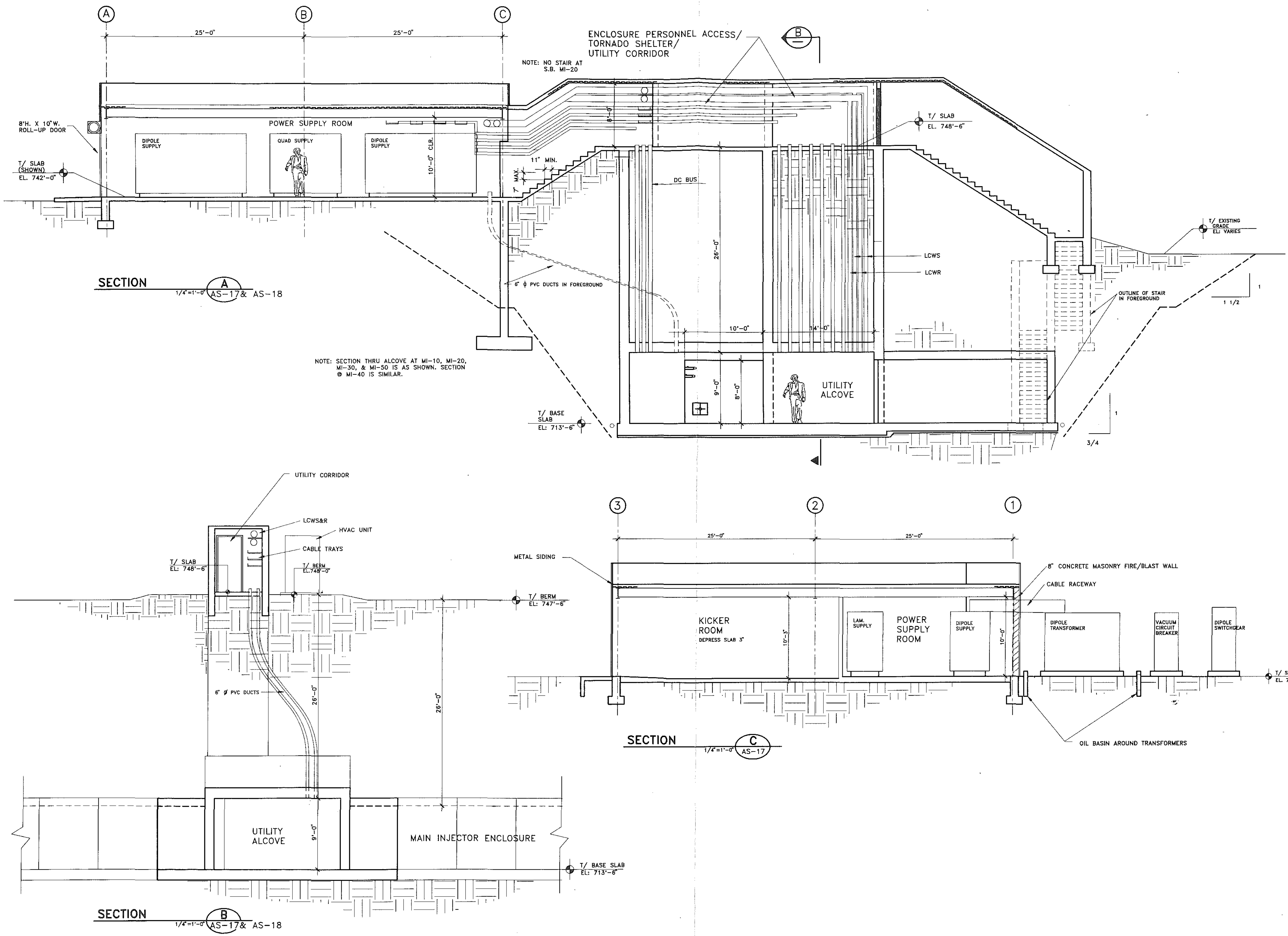
ALCOVE PLANS

DRAWING NO. 6-6-2 TITLE-1 AS-18 REV.

AUG. 1992

PLOT-DATE

AS-18



REV.	DATE	DESCRIPTIONS
		REVISIONS

FLUOR DANIEL CHICAGO ILLINOIS
PROJECT NO. - 21842300

	NAME	DATE
DESIGNED	R. JEDZINIAK	JULY,1992
DRAWN	I. MASIS	JULY,1992
CHECKED	A. VASONIS	JULY,1992
APPROVED		

	NAME	DATE
DESIGNED	T.LACKOWSKI	
DRAWN	T.LACKOWSKI/L.JENKINS	
CHECKED		
APPROVED		
SUBMITTED		

SCALE: 1/4"=1'-0"

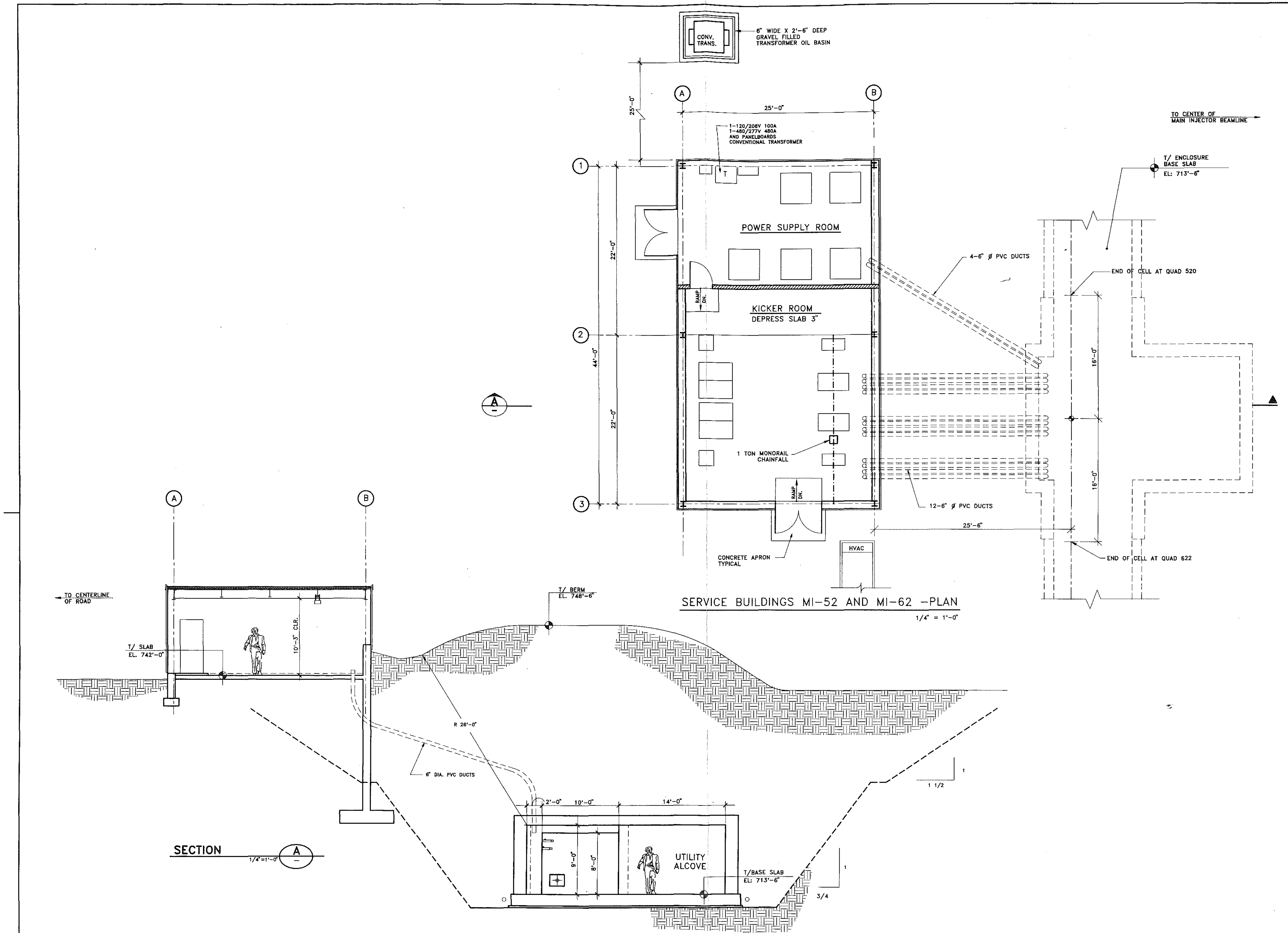
FERMI NATIONAL ACCELERATOR LABORATORY
UNITED STATES DEPARTMENT OF ENERGY

FERMILAB MAIN INJECTOR
SERVICE BUILDING SECTION

DRAWING NO. 6-6-2 TITLE-1 AS-19 REV.

AUG. 1992

PLOT-DATE



REV.	DATE	DESCRIPTIONS

REVISIONS

PLOT-DATE

FLUOR DANIEL
CHICAGO ILLINOIS
PROJECT NO. - 21842300

	NAME	DATE
DESIGNED	R.JEDZINIAK	JULY,1992
DRAWN	A.SKUZA	JULY,1992
CHECKED	A.VASONIS	JULY,1992
APPROVED		

	NAME	DATE
DESIGNED	TOMSKI	
DRAWN	TOMSKI	
CHECKED		
APPROVED		
SUBMITTED		

SCALE:
1/4"=1'-0" SCALE 4 0 4 8 FEET

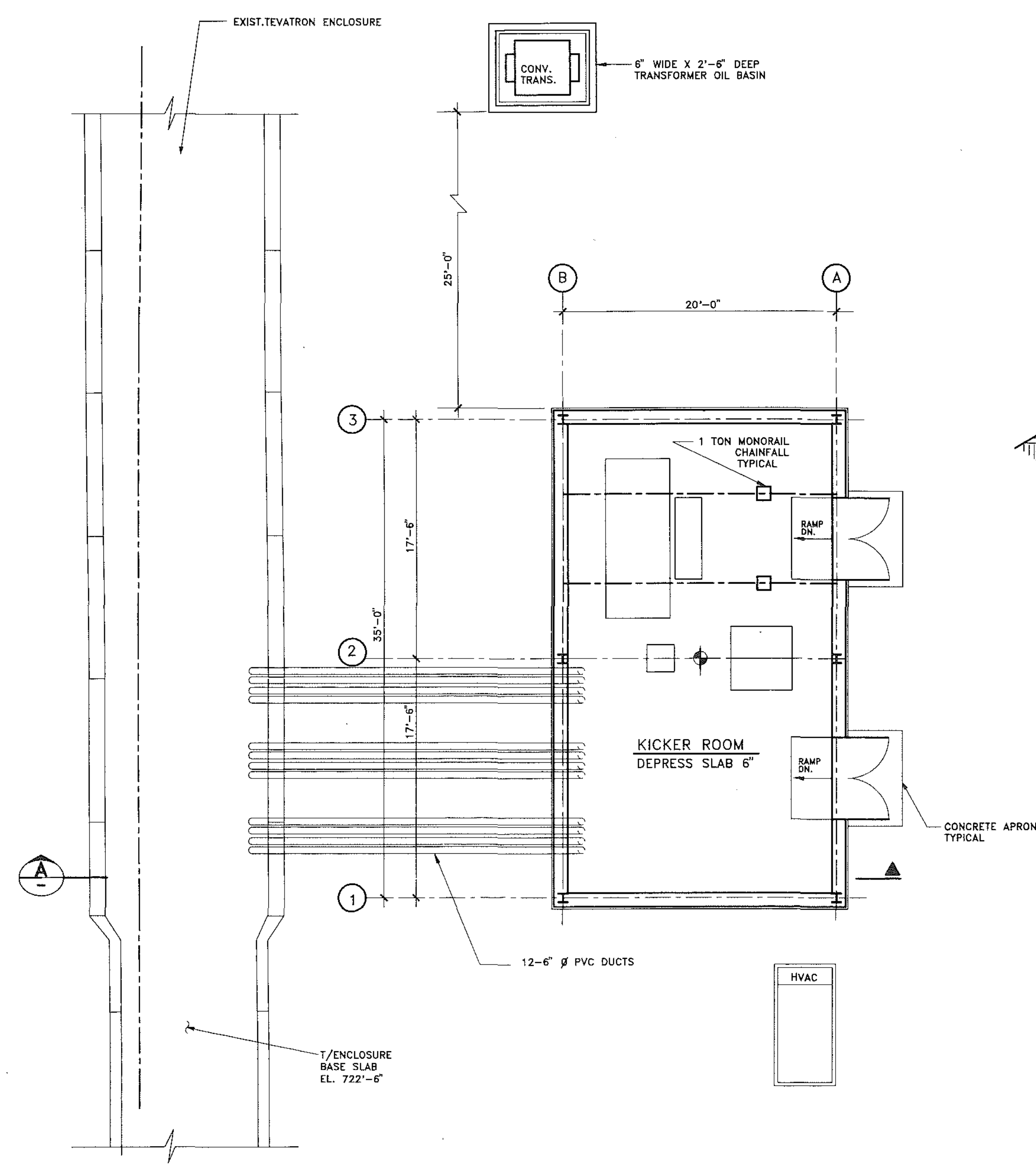
FERMI NATIONAL ACCELERATOR LABORATORY
UNITED STATES DEPARTMENT OF ENERGY

FERMILAB MAIN INJECTOR
KICKER SERV. BLDG'S MI-52 & MI-62

DRAWING NO. 6-6-2 TITLE-1 AS-20 REV.

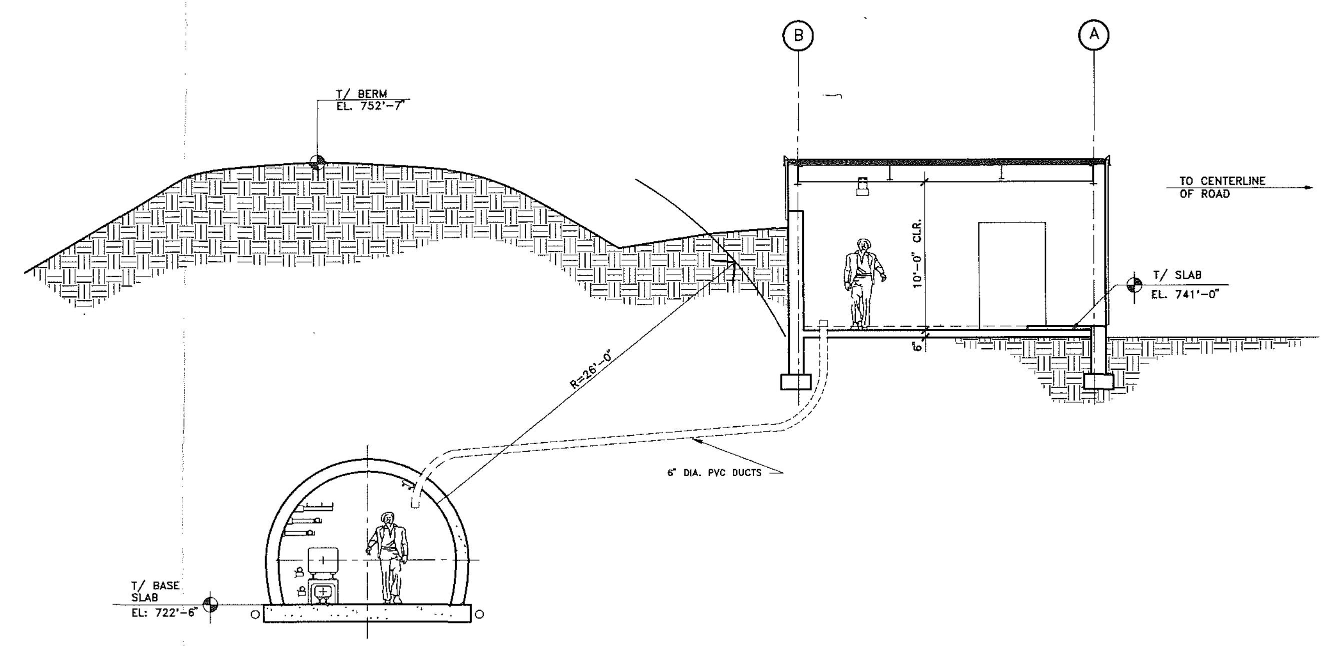
AUG. 1992

AS-20



KICKER SERVICE BUILDING F-17

1/4" = 1'-0"



SECTION A

1/4"=1'-0"

REV.	DATE	DESCRIPTIONS
		REVISIONS

FLUOR DANIEL CHICAGO ILLINOIS

PROJECT NO. - 21842300

	NAME	DATE
DESIGNED	R.JEDZINIAK	JULY,1992
DRAWN	R.DELA CRUZ	JULY,1992
CHECKED	A.VASONIS	JULY,1992
APPROVED		

	NAME	DATE
DESIGNED	FLUOR DANIEL	
DRAWN	FLUOR DANIEL	
CHECKED		
APPROVED		
SUBMITTED		

PROJECT NORTH

SCALE: 1/4"=1'-0" 4 0 4 8 SCALE FEET

FERMI NATIONAL ACCELERATOR LABORATORY

UNITED STATES DEPARTMENT OF ENERGY

FERMILAB MAIN INJECTOR

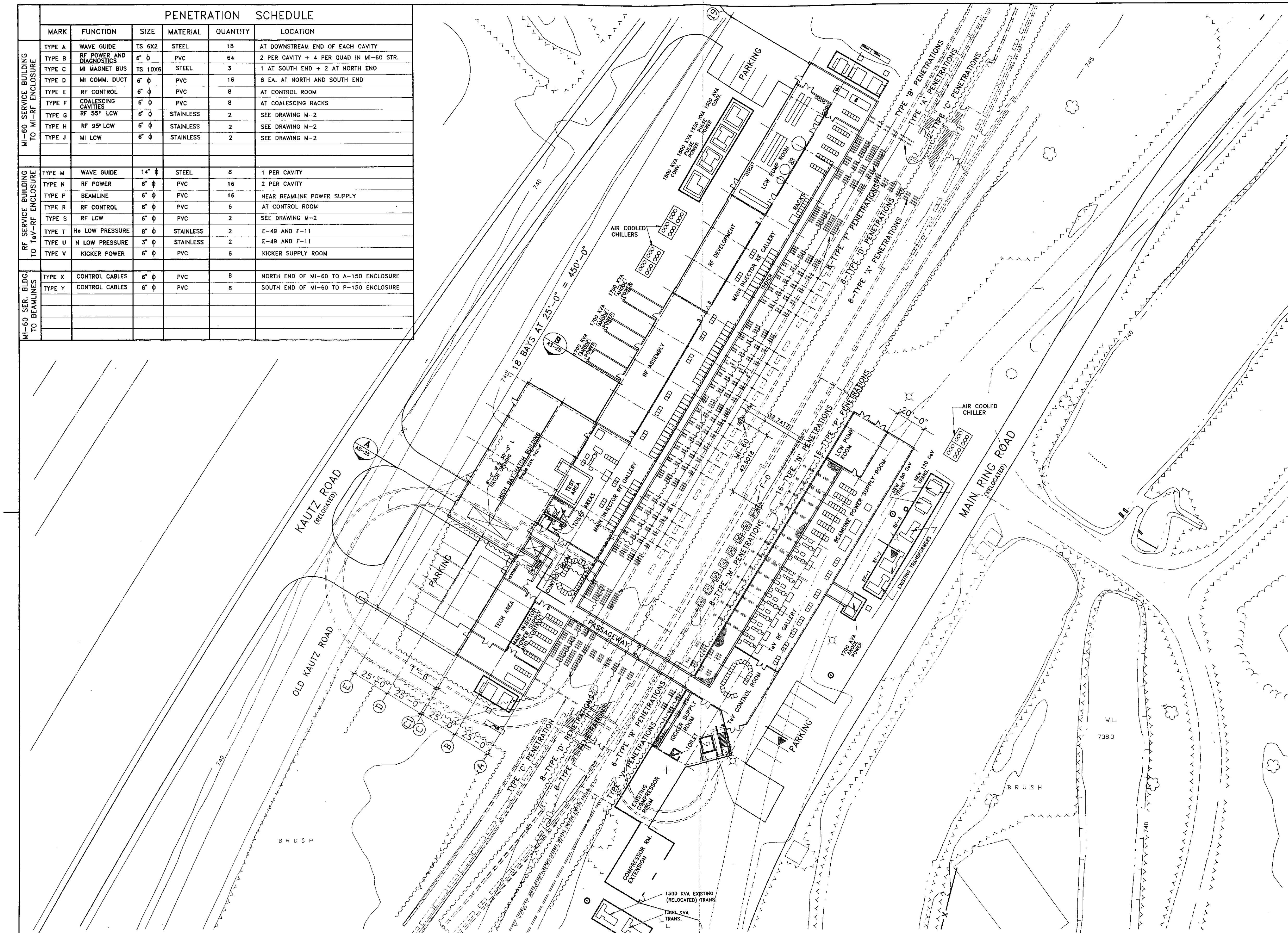
KICKER SERVICE BUILDING F-17

DRAWING NO. 6-6-2 TITLE-1 AS-21 REV.

AUG. 1992

PLOT-DATE

	PENETRATION SCHEDULE					
	MARK	FUNCTION	SIZE	MATERIAL	QUANTITY	LOCATION
MI-60 SERVICE BUILDING TO MI-RF ENCLOSURE	TYPE A	WAVE GUIDE	TS 6X2	STEEL	18	AT DOWNSTREAM END OF EACH CAVITY
	TYPE B	RF POWER AND DIAGNOSTICS	6" ϕ	PVC	64	2 PER CAVITY + 4 PER QUAD IN MI-60 STR.
	TYPE C	MI MAGNET BUS	TS 10X6	STEEL	3	1 AT SOUTH END + 2 AT NORTH END
	TYPE D	MI COMM. DUCT	6" ϕ	PVC	16	8 EA. AT NORTH AND SOUTH END
	TYPE E	RF CONTROL	6" ϕ	PVC	8	AT CONTROL ROOM
	TYPE F	COALESCING CAVITIES	6" ϕ	PVC	8	AT COALESCING RACKS
	TYPE G	RF 55° LCW	6" ϕ	STAINLESS	2	SEE DRAWING M-2
	TYPE H	RF 95° LCW	6" ϕ	STAINLESS	2	SEE DRAWING M-2
	TYPE J	MI LCW	6" ϕ	STAINLESS	2	SEE DRAWING M-2
RF SERVICE BUILDING TO TeV-RF ENCLOSURE	TYPE M	WAVE GUIDE	14" ϕ	STEEL	8	1 PER CAVITY
	TYPE N	RF POWER	6" ϕ	PVC	16	2 PER CAVITY
	TYPE P	BEAMLINE	6" ϕ	PVC	16	NEAR BEAMLINE POWER SUPPLY
	TYPE R	RF CONTROL	6" ϕ	PVC	6	AT CONTROL ROOM
	TYPE S	RF LCW	6" ϕ	PVC	2	SEE DRAWING M-2
	TYPE T	He LOW PRESSURE	8" ϕ	STAINLESS	2	E-49 AND F-11
	TYPE U	N LOW PRESSURE	3" ϕ	STAINLESS	2	E-49 AND F-11
	TYPE V	KICKER POWER	6" ϕ	PVC	6	KICKER SUPPLY ROOM
MI-60 SER. BLDG. TO BEAMLINES	TYPE X	CONTROL CABLES	6" ϕ	PVC	8	NORTH END OF MI-60 TO A-150 ENCLOSURE
	TYPE Y	CONTROL CABLES	6" ϕ	PVC	8	SOUTH END OF MI-60 TO P-150 ENCLOSURE



REV.	DATE	DESCRIPTIONS
		REVISIONS

PLOT-DATE

FLUOR DANIEL
CHICAGO ILLINOIS
PROJECT NO. - 21842300

	NAME	DATE
DESIGNED	R. JEDZINIAK	JULY,1992
DRAWN	REY DELA CRUZ	JULY,1992
CHECKED	A. VASONIS	JULY,1992
APPROVED		

	NAME	DATE
DESIGNED	T.LACKOWSKI	
DRAWN	T.LACKOWSKI/T.BURKE	
CHECKED		
APPROVED		
SUBMITTED		

PROJECT NORTH

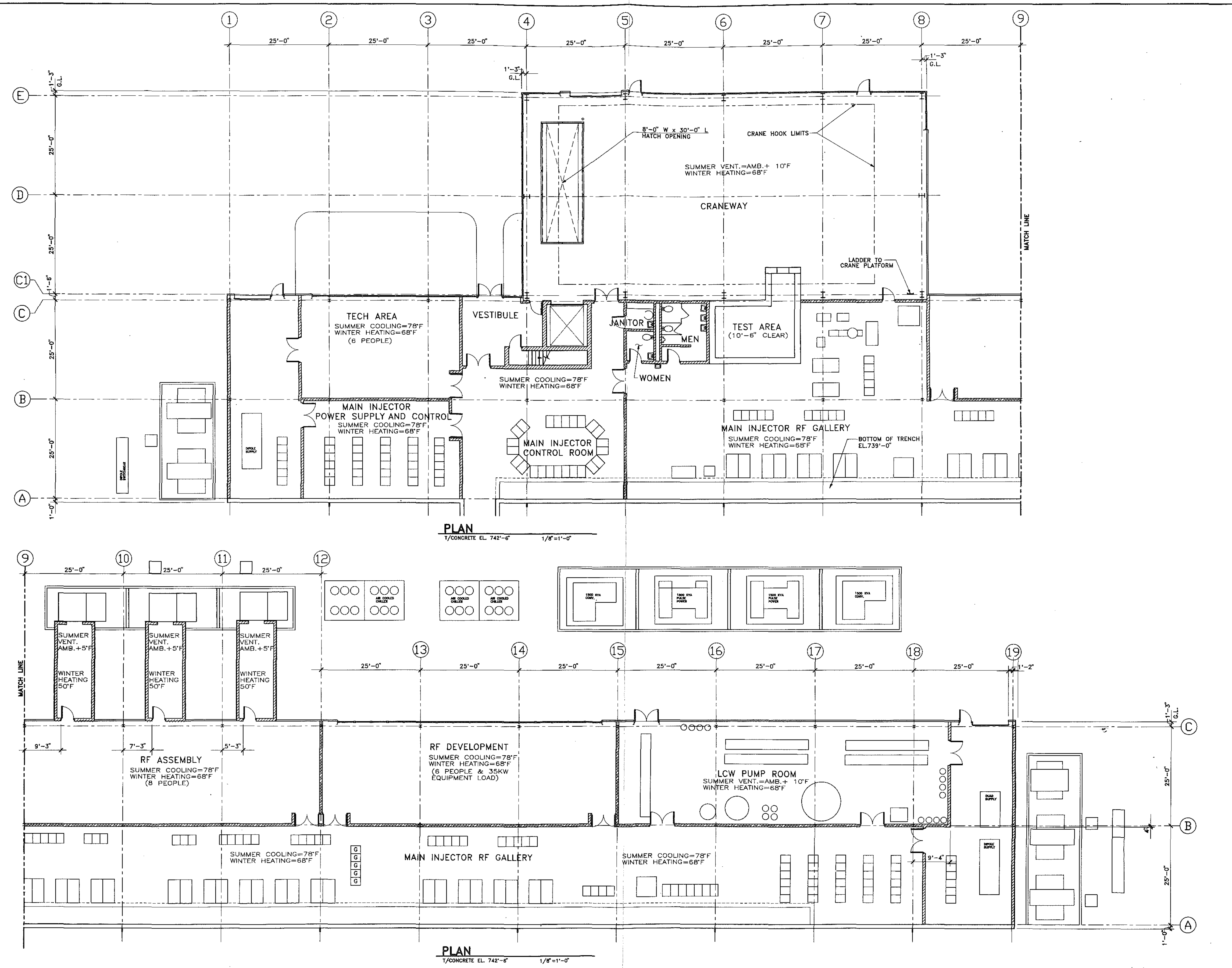
SCALE:
1" = 20'-0"

FERMI NATIONAL ACCELERATOR LABORATORY
UNITED STATES DEPARTMENT OF ENERGY

FERMILAB MAIN INJECTOR
F-0 / MI-60 PLAN

DRAWING NO. 6-6-2 TITLE-1 AS-22 REV.

AUG. 1992



REV.	DATE	DESCRIPTIONS
		REVISIONS

PLOT-DATE

FLUOR DANIEL
CHICAGO ILLINOIS
PROJECT NO. – 21842300

	NAME	DATE
DESIGNED	T. LAREN	JULY,1992
DRAWN	R. DELA CRUZ	JULY,1992
CHECKED	A. VASONIS	JULY,1992
APPROVED		

	NAME	DATE
DESIGNED	FLUOR DANIEL	
DRAWN	FLUOR DANIEL	
CHECKED		
APPROVED		
SUBMITTED		

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

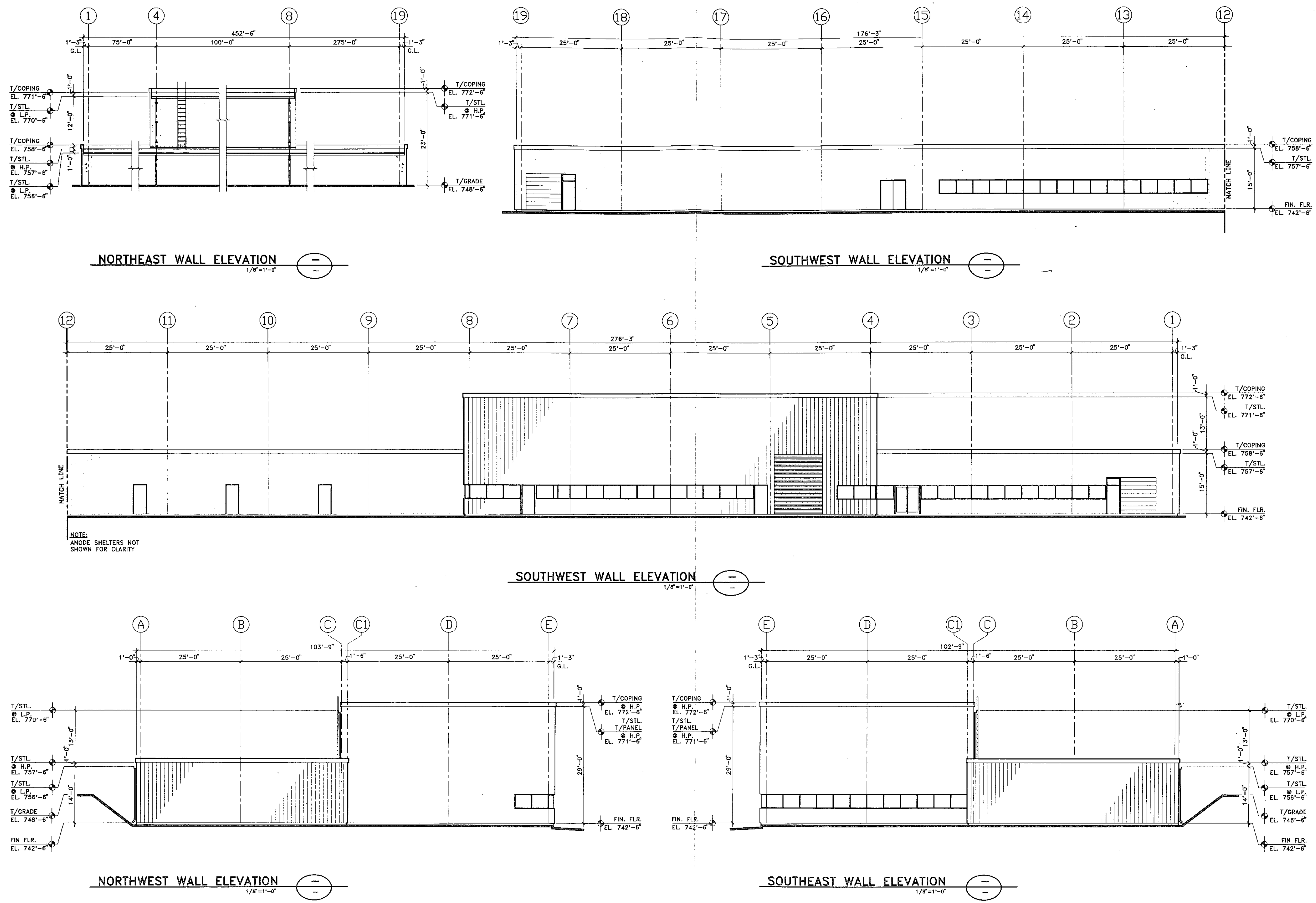
FERMI NATIONAL ACCELERATOR LABORATORY
UNITED STATES DEPARTMENT OF ENERGY

FERMILAB MAIN INJECTOR
MI-60 FLOOR PLAN

DRAWING NO. 6-6-2 TITLE-1 AS-23 REV.

AUG. 1992

AS-23



REV.	DATE	DESCRIPTIONS
		REVISIONS

PLOT-DATE

FLUOR DANIEL
CHICAGO ILLINOIS
PROJECT NO. – 21842300

	NAME	DATE
DESIGNED	T.LAREN/J.REDEKER	JULY,1992
DRAWN	J.REDEKER	JULY,1992
CHECKED	T.LAREN	JULY,1992
APPROVED		

AS-24

	NAME	DATE
DESIGNED	FLUOR DANIEL INC.	
DRAWN	FLUOR DANIEL INC.	
CHECKED	FLUOR DANIEL INC.	
APPROVED		
SUBMITTED		

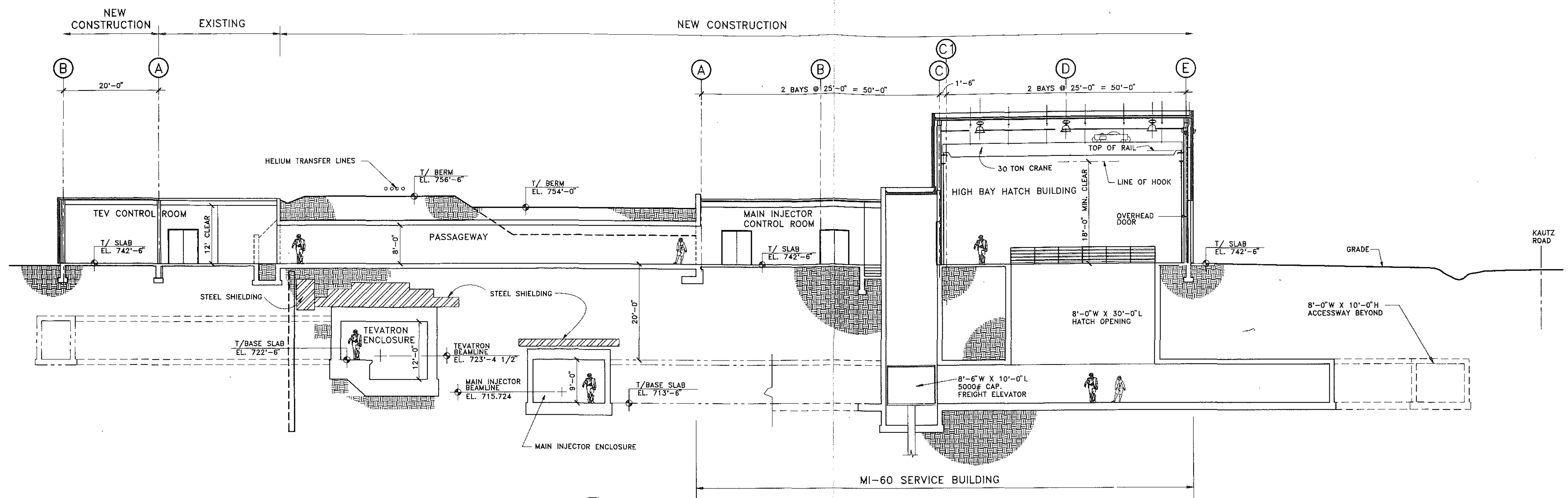
SCALE: 1/8"=1'-0" 8 0 8 16 SCALE FEET

FERMI NATIONAL ACCELERATOR LABORATORY
UNITED STATES DEPARTMENT OF ENERGY

FERMILAB MAIN INJECTOR
MI-60 BUILDING ELEVATIONS

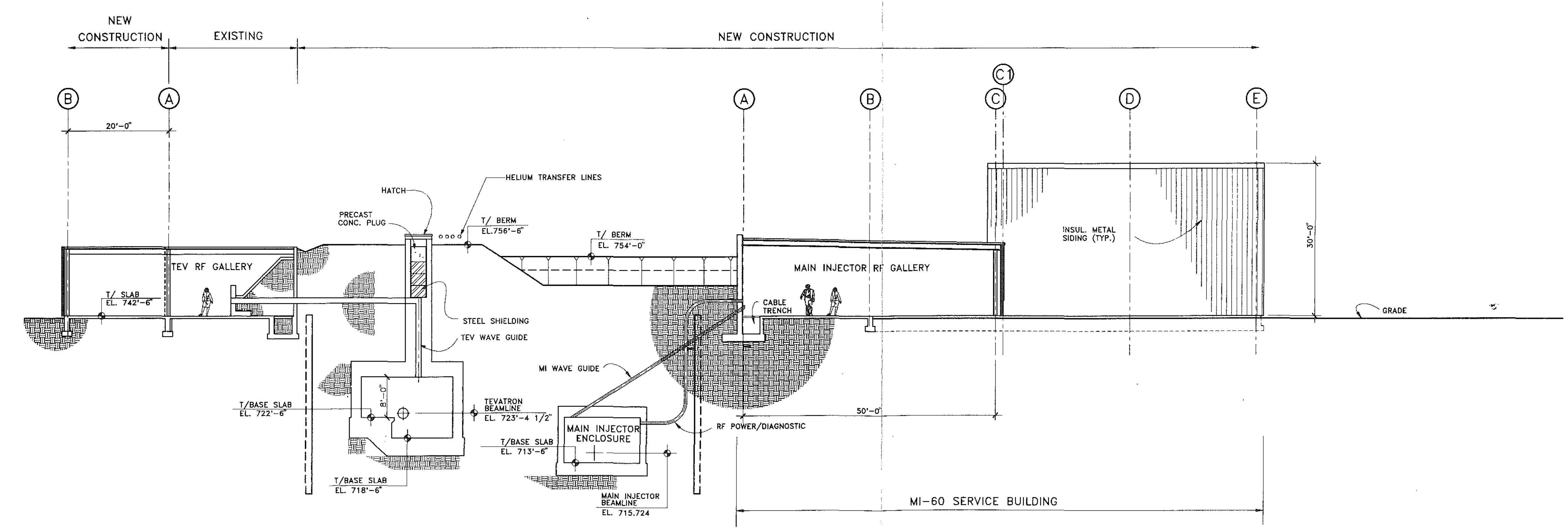
DRAWING NO. 6-6-2 TITLE-1 AS-24 REV.

AUG. 1992



SECTION (A / AS-22)

SCALE 1/8" = 1'-0"



SECTION (B / AS-22)

SCALE 1/8" = 1'-0"

REV.	DATE	DESCRIPTIONS
		REVISIONS

PLOT-DATE

FLUOR DANIEL — CHICAGO ILLINOIS

PROJECT NO. – 21842300

	NAME	DATE
DESIGNED	R.JEDZINIAK	JULY,1992
DRAWN	A.SKUZA	JULY,1992
CHECKED	A.VASONIS	JULY,1992
APPROVED		

	NAME	DATE
DESIGNED	T.LACKOWSKI	
DRAWN	J.BANKS/L.JENKINS	
CHECKED		
APPROVED		
SUBMITTED		

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

FERMI NATIONAL ACCELERATOR LABORATORY

UNITED STATES DEPARTMENT OF ENERGY

FERMILAB MAIN INJECTOR

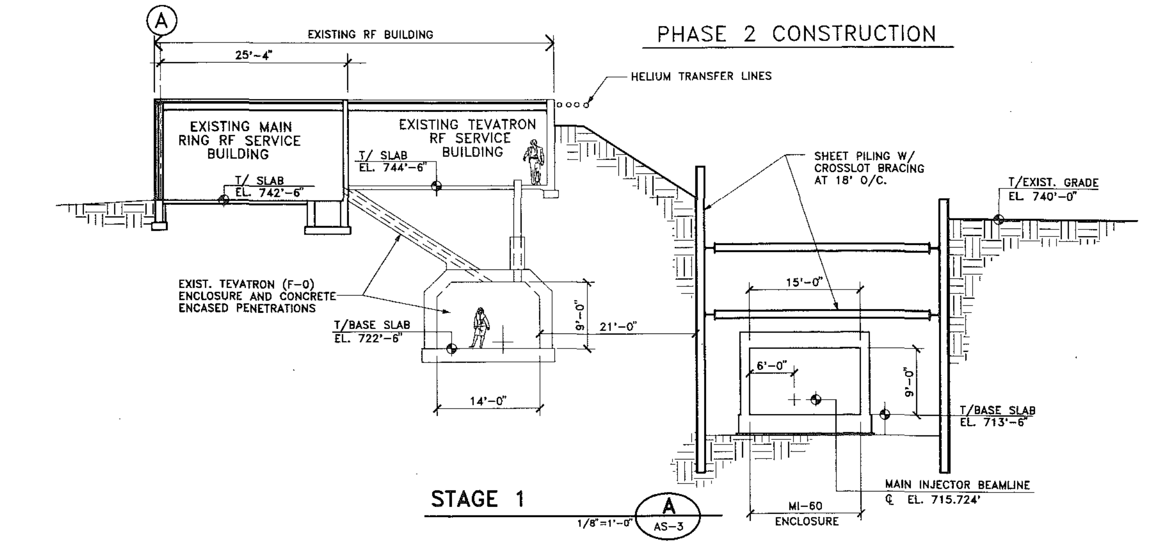
MI-60 BUILDING SECTIONS

DRAWING NO. 6-6-2 TITLE-1 AS-25 REV.

AUG. 1992

AS-25

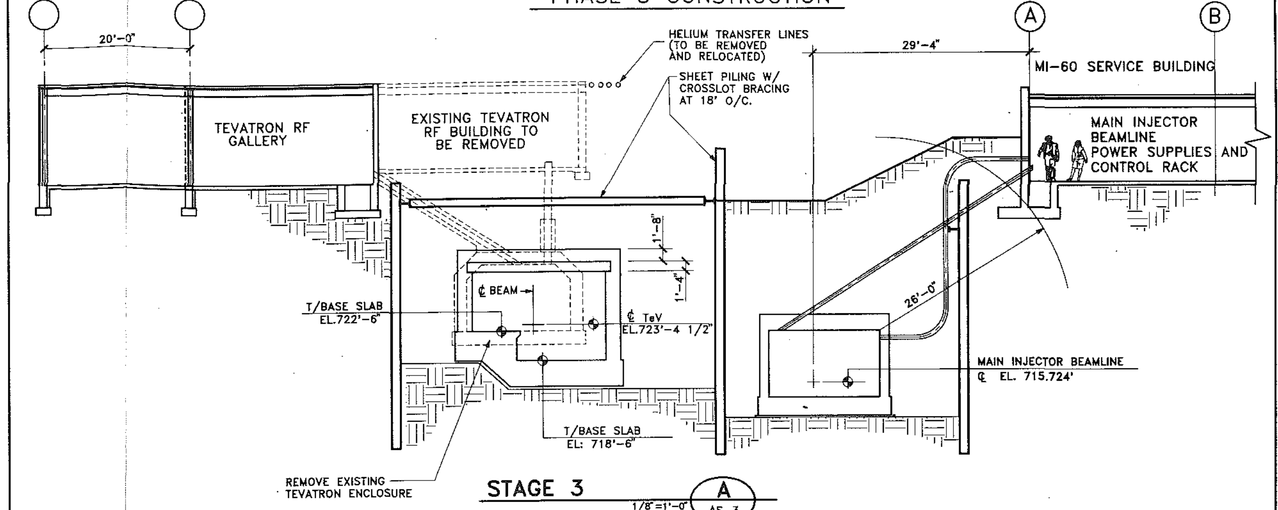
PHASE 2 CONSTRUCTION



STAGE 1 1/8"=1'-0" (A / AS-3)

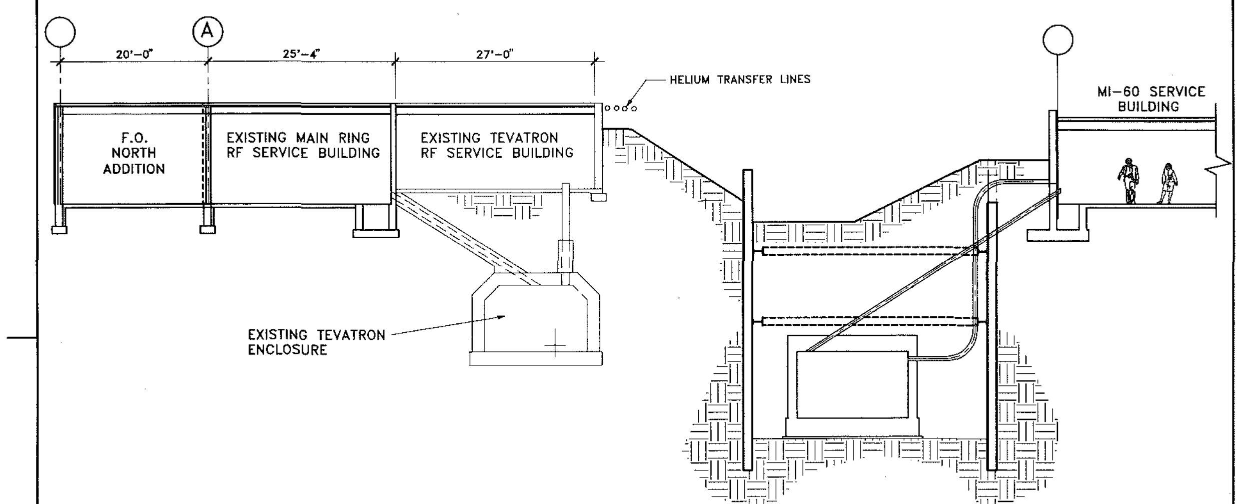
THRU F-0 / MI-60 CONSTRUCTION

PHASE 3 CONSTRUCTION



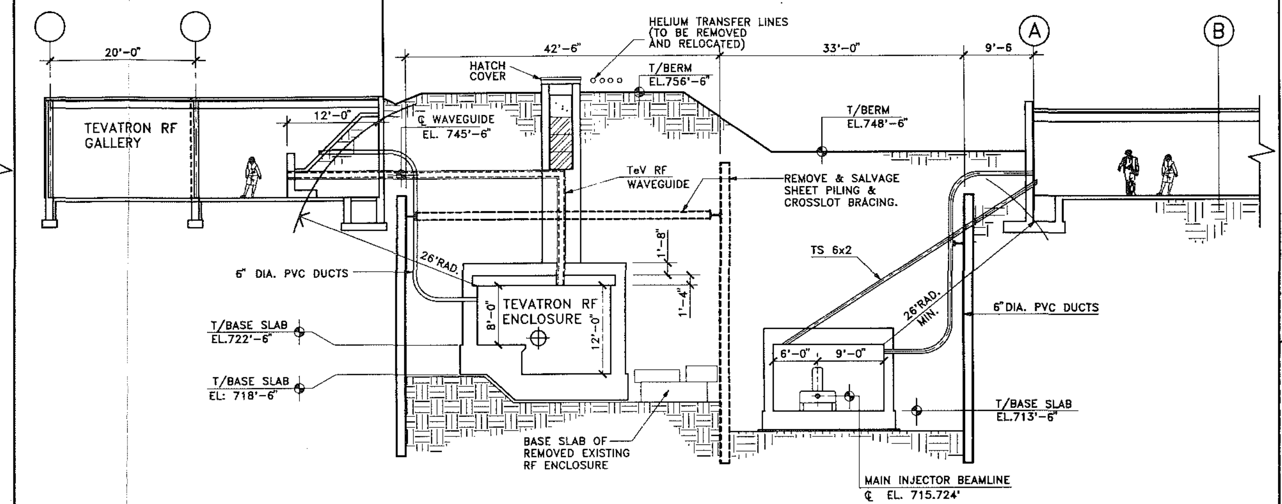
STAGE 3 1/8"=1'-0" (A / AS-3)

THRU F-0 / MI-60 CONSTRUCTION



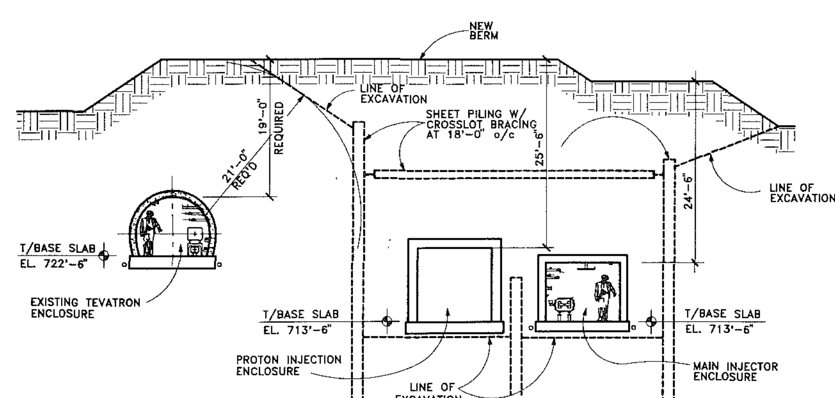
STAGE 2 1/8"=1'-0" (A / AS-3)

THRU F-0 / MI-60 CONSTRUCTION

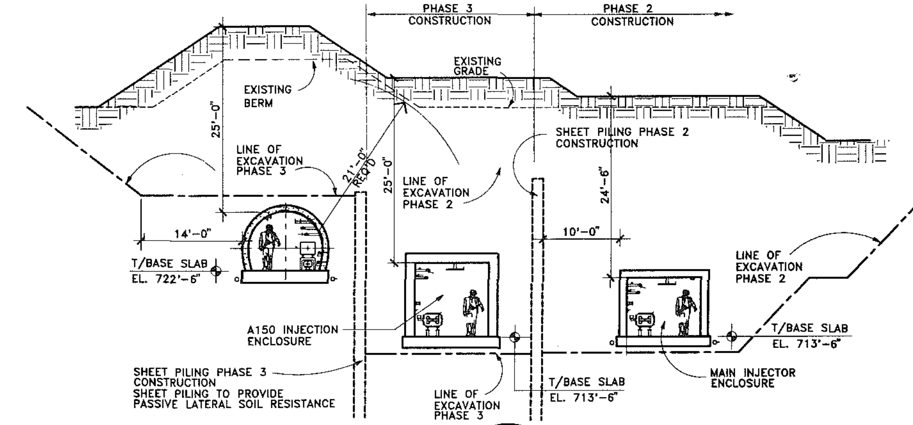


STAGE 4 1/8"=1'-0" (A / AS-3)

THRU F-0 / MI-60 CONSTRUCTION



SECTION 1/8"=1'0" (B / AS-3)



SECTION 1/8"=1'-0" (C / AS-3)

REV.	DATE	DESCRIPTIONS
		REVISIONS

PLOT-DATE

FLUOR DANIEL — CHICAGO ILLINOIS — PROJECT NO. – 21842300

	NAME	DATE
DESIGNED	R.JEDZINIAK	JULY,1992
DRAWN	A.SKUZA	JULY,1992
CHECKED	A.VASONIS	JULY,1992
APPROVED		

	NAME	DATE
DESIGNED	TOMSKI	
DRAWN	TOMSKI	
CHECKED		
APPROVED		
SUBMITTED		

SCALE: 1/8"=1'-0" SCALE 8 0 8 16 FEET

FERMI NATIONAL ACCELERATOR LABORATORY

UNITED STATES DEPARTMENT OF ENERGY

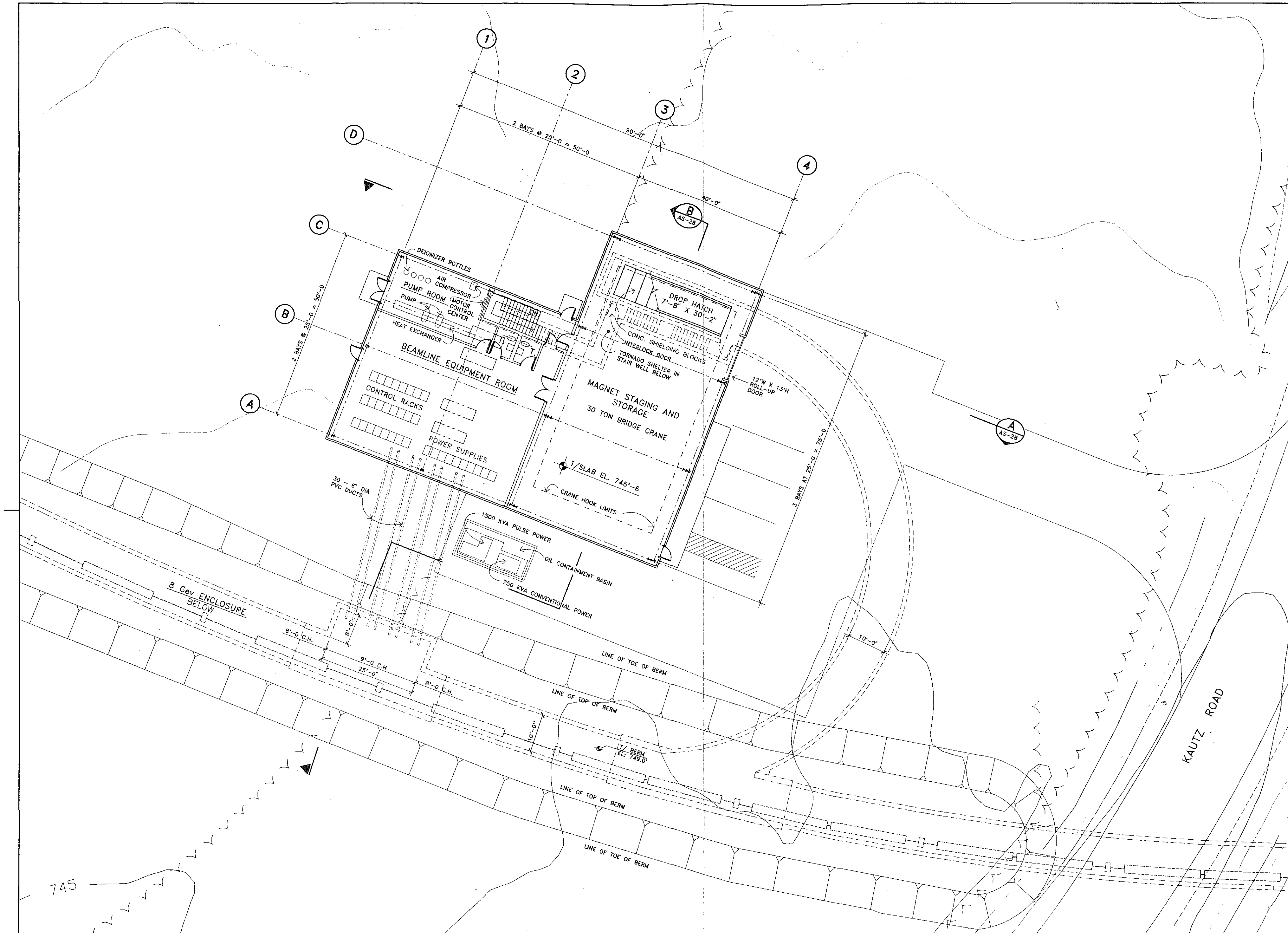
FERMILAB MAIN INJECTOR

MI-60 CONSTRUCTION SECTIONS

DRAWING NO. 6-6-2 TITLE-1 AS-26 REV.

AUG. 1992

AS-26



REV.	DATE	DESCRIPTIONS
		REVISIONS

PLOT-DATE

FLUOR DANIEL
CHICAGO ILLINOIS

PROJECT NO. - 21842300

	NAME	DATE
DESIGNED	R.JEDZINIAK	JULY,1992
DRAWN	A.SKUZA	JULY,1992
CHECKED	A.VASONIS	JULY,1992
APPROVED		

	NAME	DATE
DESIGNED	TOMSKI	
DRAWN	T.BURKE,J.W.B.	
CHECKED		
APPROVED		
SUBMITTED		

W S E
PROJECT NORTH

SCALE:
1/8"=1'-0" 8 0 8 16 SCALE FEET

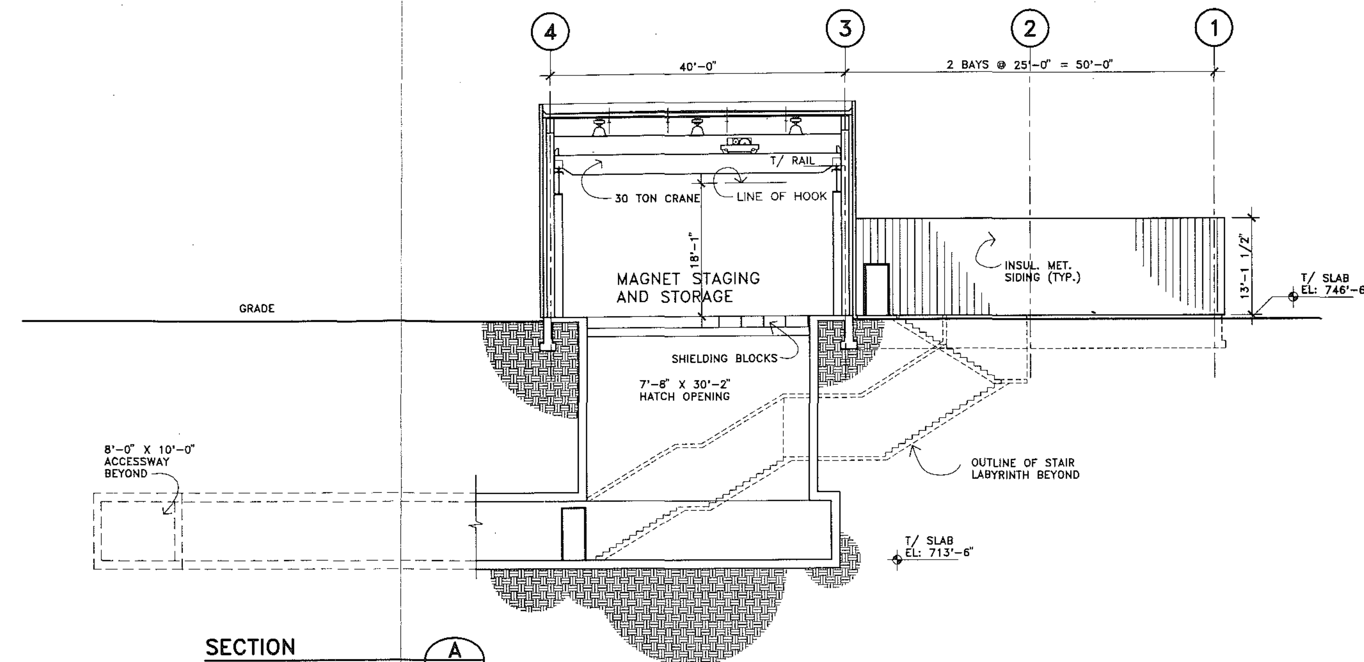
FERMI NATIONAL ACCELERATOR LABORATORY
UNITED STATES DEPARTMENT OF ENERGY

FERMILAB MAIN INJECTOR
NORTH HATCH BUILDING PLAN

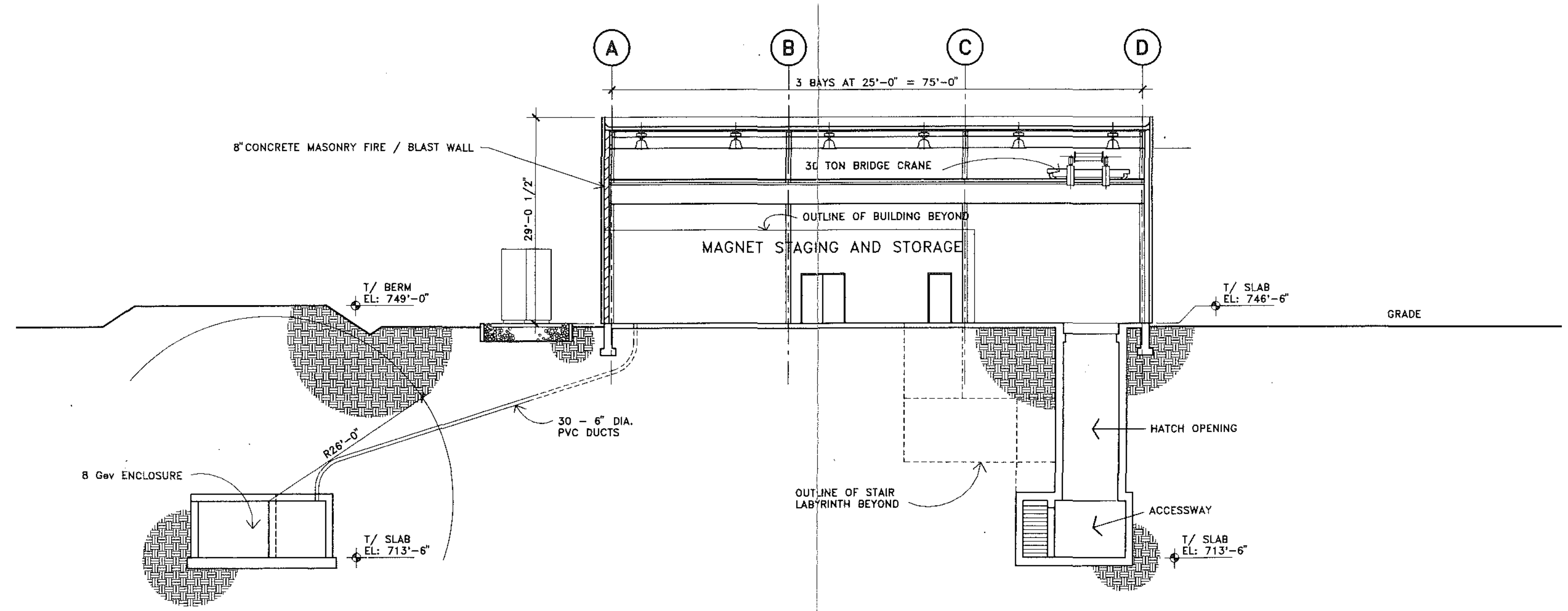
DRAWING NO. 6-6-2 TITLE-1 AS-27 REV.

AUG. 1992

AS-27



SECTION A (AS-27)
1/8" = 1'-0"



SECTION B (AS-27)
1/8" = 1'-0"

REV.	DATE	DESCRIPTIONS
		REVISIONS

PLOT-DATE

FLUOR DANIEL CHICAGO ILLINOIS
PROJECT NO. - 21842300

	NAME	DATE
DESIGNED	R. JEDZINIAK	JULY,1992
DRAWN	I. MASIS	JULY,1992
CHECKED	A. VASONIS	JULY,1992
APPROVED		

	NAME	DATE
DESIGNED	TOMSKI	
DRAWN	T.BURKE,J.W.B.	
CHECKED		
APPROVED		
SUBMITTED		

SCALE: 1/8"=1'-0" 8 0 8 16 SCALE FEET

FERMI NATIONAL ACCELERATOR LABORATORY
UNITED STATES DEPARTMENT OF ENERGY
FERMILAB MAIN INJECTOR
NORTH HATCH BUILDING SECTIONS
DRAWING NO. 6-6-2 TITLE-1 AS-28 REV.
AUG. 1992

AS-28