Fermi National Accelerator Laboratory

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Design Report: Linac Experimental Area

C. Ankenbrandt, S. Bjerklie, D. Boehnlein, M. Foley, C. Johnstone, T. Kroc, J. Lackey, A. Lennox, A. Leveling, E. McCrory, M. Popovic, C. Schmidt and K. Vaziri

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LINAC EXPERIMENTAL AREA

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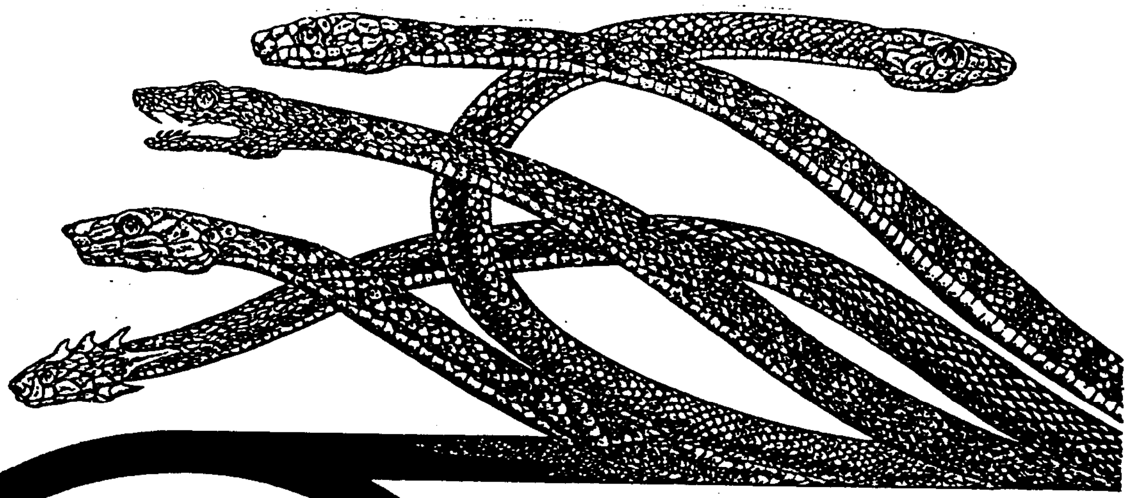

FERMI NATIONAL ACCELERATOR LABORATORY
BATAVIA, ILLINOIS

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LINAC EXPERIMENTAL AREA

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EXECUTIVE SUMMARY

The design of a new Linac Experimental Area is described. Construction of the facility would make possible a vigorous program of research in atomic physics, medical physics, health physics, and accelerator physics. The program would use the many cycles of beam available from the Fermilab Linac without interfering with the high energy physics program. The recent Linac Upgrade Project made the beam twice as energetic and hence more useful for the proposed program. The upgrade also left behind civil construction (a ramp for the removal of replaced sections of the old drift tube linac) that is ideal to house the beam and, with economical modifications, the experimental area. The design also makes use of leftover resources (components, installed utilities, etc.) from the decommissioned electron cooling ring, the high energy end of the old 200-MeV Linac, and the former 200-MeV transfer line to the Booster.

A workshop was held (cf. the Proceedings of the 400-MeV Beam International Workshop, Fermilab, October 1993) to explore this opportunity, to survey outside interest, and to study the applications and research potential of such an area. The workshop indicated that substantial interest did in fact exist among several prominent research groups in the aforementioned fields. The interest is sufficient to sustain a longterm research program based primarily on an outside user community. Several written indications of interest were received after the workshop (e.g "Relativistic Atomic Physics at Fermilab" from University of New Mexico, Los Alamos National Laboratory, Rutherford Appleton Laboratory and Fermilab and "Proton therapy research by the UW-Madison Medical Physics Dept.: a proposal for collaboration with Fermilab"). Shortly thereafter, the design described here was commissioned by the Accelerator Division management to explore the costs and continuing resources incurred in implementing and supporting a 400-MeV beam research area. This design economically achieves the performance goals dictated by the proposed program. The fact that the beam consists of H^- ions rather than bare protons makes beam manipulations possible which contribute enormously to the capabilities and the flexibility of the facility.

CHAPTER I. RESEARCH AND PERFORMANCE GOALS

The purpose of the proposed Linac Experimental Area is to provide facilities for research and development in medical physics, accelerator physics, atomic physics, and health physics. The activities which have been proposed for the area would foster symbiotic interactions among these subfields of physics. Furthermore, locating these activities at Fermilab would provide significant opportunities for two-way technology transfer between these fields and high energy physics. The added operational responsibilities would represent only a modest burden to Accelerator Division personnel, and it is reasonable to expect that the impact on the High Energy Physics Program and accelerator operations at Fermilab will be imperceptible to the outsider.

The potential for medical research, in particular for activities related to proton therapy, is especially compelling. For example, the proposed development of pulsed-beam scanning techniques for delivering uniform doses that conform accurately to irregular three-dimensional tumor volumes is sorely needed. Development of methods of measuring three-dimensional dose distributions can profit from the considerable related expertise in detectors for high energy physics at Fermilab. Also, there is considerable interest in proton tomography, particularly in conjunction with proton therapy to produce images of patients about to be treated. Interest in a medical research program has already been expressed by major medical institutions, universities, other national laboratories, and foreign institutions (cf. Appendix A). Much of the medical research proposed for this area requires an operationally flexible, well-calibrated proton beam, which is currently not available in this energy regime. Practitioners of proton therapy at various sites worldwide would find a well-characterized beam invaluable for research and development, e.g. for testing beam delivery ideas and cross-calibrating dose-measuring devices.

The development of a 400 MeV experimental beamline would offer special opportunities for health physics research. A major objective of such a program would be to provide more specific knowledge of issues relevant to an accelerator environment. The radiation fields at high-energy accelerator facilities differ greatly in composition and energy spectra from those of nuclear facilities, where most of the presently available health physics information was obtained and is directly applicable. For example, the behavior of neutrons above 14 MeV in detectors is usually extrapolated from lower energies; there are many indications that this extrapolation may not be accurate. Similarly, there is considerable information on the response of shielding materials to neutrons at lower energies for which radioactive sources are available, but there have been only a few parasitic uncontrolled experiments at higher energies. A careful program of studies would make it possible to lay the foundation of shielding optics on an analytic basis. Furthermore, data on activation and radiation damage of materials are very much needed for characterization of radioactive waste and other activated materials. Such data would also be valuable for industrial development of materials and electronic components intended for high energy/high rate radiation environments, including detectors for high energy physics. Other radiation physics applications include development of more accurate radiation detectors for dosimetry and benchmarking of the radiation transport codes. As the need for such research is well recognized, this experimental area would attract interest throughout the health physics community.

The broad spectrum of proposed applications in accelerator research ranges from characterizing basic beam parameters and device calibration to development of beam detectors and advances in accelerator technology. Further information on these opportunities can be found in the Proceedings of the 400-MeV Beam International Workshop, Fermilab, October 1993.

To illustrate the symbiotic nature of the proposed program, the exquisitely precise experimental techniques pioneered in the field of atomic physics (cf. for example P. G. Harris et al., "Measurement and reduction of momentum spread in the LAMPF linac beam," Nuclear Instruments and Methods A292, 254-258 (1990)) will also provide novel accelerator diagnostic tools. A collaboration of accelerator and atomic physicists has proposed advanced laser diagnostic techniques, which, when applied to relativistic H^- beams, not only open a unique window on the dynamics of the H^- ion but also provide unique opportunities for measurement of Linac beam parameters. The atomic physics goal of the proponents is to produce a scientific atlas of the electromagnetic physics and spectroscopy of the simplest three-body system, the H^- ion. The same laser apparatus and setup proposed for atomic physics research will make possible unprecedented accuracy in and, often, absolute determination of a class of beam and device parameters which address accelerator performance issues definitively and, in some cases, resolve long-standing controversies. For example, the absolute value of the Linac energy is not well-known, and its temporal stability is a matter of operational significance; it can be determined by measuring the position of a narrow resonance in the H^--photon system. Similarly, the uncertainties in the determination of the momentum spread of the Linac beam arising from imperfect knowledge of the beam optical parameters of the magnetic spectrometer can be resolved. The proposed studies of the nature of H^- interactions in a foil are also relevant to future accelerator development.

The performance goal of the 400-MeV beam design is to provide the wide range of beam parameters required by the proposed experiments and applications. Intensity requests range from one proton per 200-MHz rf bucket to 7×10^6 protons per rf bucket, the range in emittance covers 0.1π to 6π mm-mrad, and the requested momentum spread ranges from the nominal Linac spread of 0.2-0.3% down to 0.01%. The beamline was specially designed to regulate intensity, phase-space attributes, and momentum spread in a precise and reliable, but operationally simple, manner. The performance goals that can realistically be achieved with the present beamline design are listed in Table I.1. Design details are given in the section on beamline layout and optics.

Table I.1 Operational Parameters of the 400-MeV Beam Area

Beam Energy Range	100-400 MeV
Intensity Control	few protons/pulse to 4.2×10^{10} protons/pulse
Emittance Selection	0.1π to 6π mm-mrad
Pulse Length	picosecs to 40 μsec
Transverse Beam Size	.5 mm to 75 mm
Momentum Spread, $\Delta p/p$	0.3% to .05%
Energy Calibration	$\pm 10^{-4}$
Momentum Spread Determination	$\pm 10^{-5}$

Applications and experiments proposed and supported by stable collaborations comprising a number of scientific institutions are listed below. For most of these activities, draft proposals are available in a form appropriate for submission to the Program Planning Office and, if required, for review by the Physics Advisory Committee. All these proposed applications are well suited for utilizing presently unused beam cycles of the Fermilab Linac. Brief descriptions of the individual applications are given in abstracts included as Appendix A of this document. Further documentation on the proposed experiments can be found in the Proceedings of the 400-MeV Beam International Workshop and the preliminary draft proposals.

PHYSICS APPLICATIONS:

Absolute Momentum and Momentum Spread Determinations
Beam Loss Mechanisms in H^- Foil Stripping
Diagnostic Device Calibration and Characterization
Development of a Laser-Driven Bunch-Length Detector
Beam-based Cavity Impedance and Wake field Measurements
Kicker Calibration and Development
Dosimetry, Materials Activation, and Shielding Studies
Instrumentation Calibration
Relativistic Atomic Physics Using High Intensity Lasers
Strong EM Field Effects in Laser-H^- Interactions

MEDICAL APPLICATIONS:

Pulsed-Beam Scanning Techniques for Proton Therapy
Measurements of Dose Distributions as a Function of Beam Properties
The Relationship of Beam Optics to Gantry Design
Devel. of Detectors and Methods for Measuring 3-D Dose Distributions
Proton Radiography and Computed Tomography R&D
Medical Calibration Studies

CHAPTER II. BEAMLINE LAYOUT AND OPTICS

Overview

The upstream half of the existing Linac Upgrade ramp is suitable without further civil construction as an enclosure for a primary beamline derived from the Linac. The downstream half, presently an open pit with concrete floor and walls, can be enclosed with a dirt-shielded roof to provide an experimental area that, albeit modest in size, is adequate for most if not all proposed uses. The two areas will be separated physically by a high-intensity beam dump and an egress labyrinth. Figure 1a shows a layout of the beamline; Figure 1b shows the high-intensity dump. The location and angle of the ramp are such that the beam must be deflected beginning immediately downstream of the Linac accelerator through a total horizontal angle of about 45 degrees. A 15-Hz pulsed bending system enables independent selection of individual 15-Hz cycles of Linac beam. The major DC bends are positioned near the SE wall of the ramp enclosure to maintain an aisle for equipment and personnel that runs the length of the primary beamline and the Linac accelerator. Equipment, components, and personnel can travel the entire length with access to the freight elevator at the upstream end of the Linac. The beam optics takes advantage of the 45-degree bend to produce high dispersion at a horizontal focus located in a 3m-long beam-shaping region between the last bend, CR3, and the dump. Thin collimating strippers are used in this region to convert the unwanted parts of the beam to protons, thereby defining the final H^- beam characteristics. Two dipoles of opposite polarity cause the oppositely charged H^- and proton beams to "dogleg" to the left and right, respectively, creating parallel beams 4.5 inches apart at the face of the dump. The H^- beam, its phase space distributions and intensity now tailored to the needs of the experimenters, is transmitted to the experimental area via a beam pipe through the dump, whereas the unwanted protons are disposed of in the dump. The total length of the primary beamline from the Linac to the entrance of the dump is about 28m.

Beam Trajectory and Enclosure Geometry

Extraction: On any 15-Hz clock cycle for which beam is to be delivered to the Linac Experimental Area, pulsed dipoles will deflect the Linac beam horizontally from its normal trajectory. (On the other hand, whenever the Booster requires beam, the pulsed dipole supply will not be triggered and the beam will pass undisturbed.) This process is somewhat like extraction from a circular accelerator and is called that in this document. Extraction will be accomplished using one pulsed kick magnet, 5 inches long, upstream of the present Chopper followed by three identical pulsed septum magnets, each 18 inches long, downstream of the Chopper. (Information on the way these pulsed magnets are constructed and powered is contained below in the section on magnets. The Chopper is basically a pulsed electrostatic capacitor that selects part of the Linac beam pulse and deflects it into the transfer line for injection into the Booster synchrotron. Beam destined for the Linac Experimental Area must obviously first traverse the Chopper before entering the upstream septum magnet; during that time, both Chopper plates are charged to full capacity, so it is nondeflecting.) The three septum magnets, each bending by 5 degrees, are required to displace the beam enough to miss the next element in the Linac beam line, quadrupole QB2 in the transfer and diagnostic lines. The magnet that provides the initial horizontal kick to bump beam past the septum plate and position it squarely in the field region of the first septum magnet is a full-core ORBUMP-style magnet inserted between Q1 and the Chopper. The bend angle needed to clear the septum wall is small, only 1.6^0, and the 5-inch length of the kick magnet is determined by the desire to drive it in series with the septum magnets, thereby requiring only one pulsed supply for extracting beam. At the entrance to the upstream septum magnet, the beam separation is 1.85 in., providing over an inch of edge-to-edge clearance between transfer/diagnostic line beam and beam to the proposed experimental area.

Line layout: When the ramp straightens, its net angle is 45.4^0 from the Linac. (Since the bearing of the Linac is almost directly due project-south, the beam in the Linac Experimental Area will be headed project-southwest.). The pulsed extraction magnets provide 16.6 degrees of the required bend. Leftover dipoles from the decommissioned electron cooling ring comprise the remaining 28.8^0 of bend. Because of their 10^0 operating limit at 400-MeV, it is best to distribute the remaining bend evenly among three dipoles, even though in principle they can be operated in saturation. This leaves a comfortable margin above their design operating point.

The position of the first bend after extraction is constrained by the need to miss the corner which divides the ramp entrance from the existing Linac enclosure. To steer the beam along an appropriate trajectory, the first dipole is located a couple of meters downstream of the septum magnets. Two more 9.6^0 bends are required to match the curvature of the ramp. The position of these two bends is chosen to follow the curvature of the wall in that area, to provide 3 meters of space upstream of the dump for the collimating foils and quadrupoles that tailor the beam distributions

FIGURE 1a. PROPOSED 400-MEV BEAMLINE

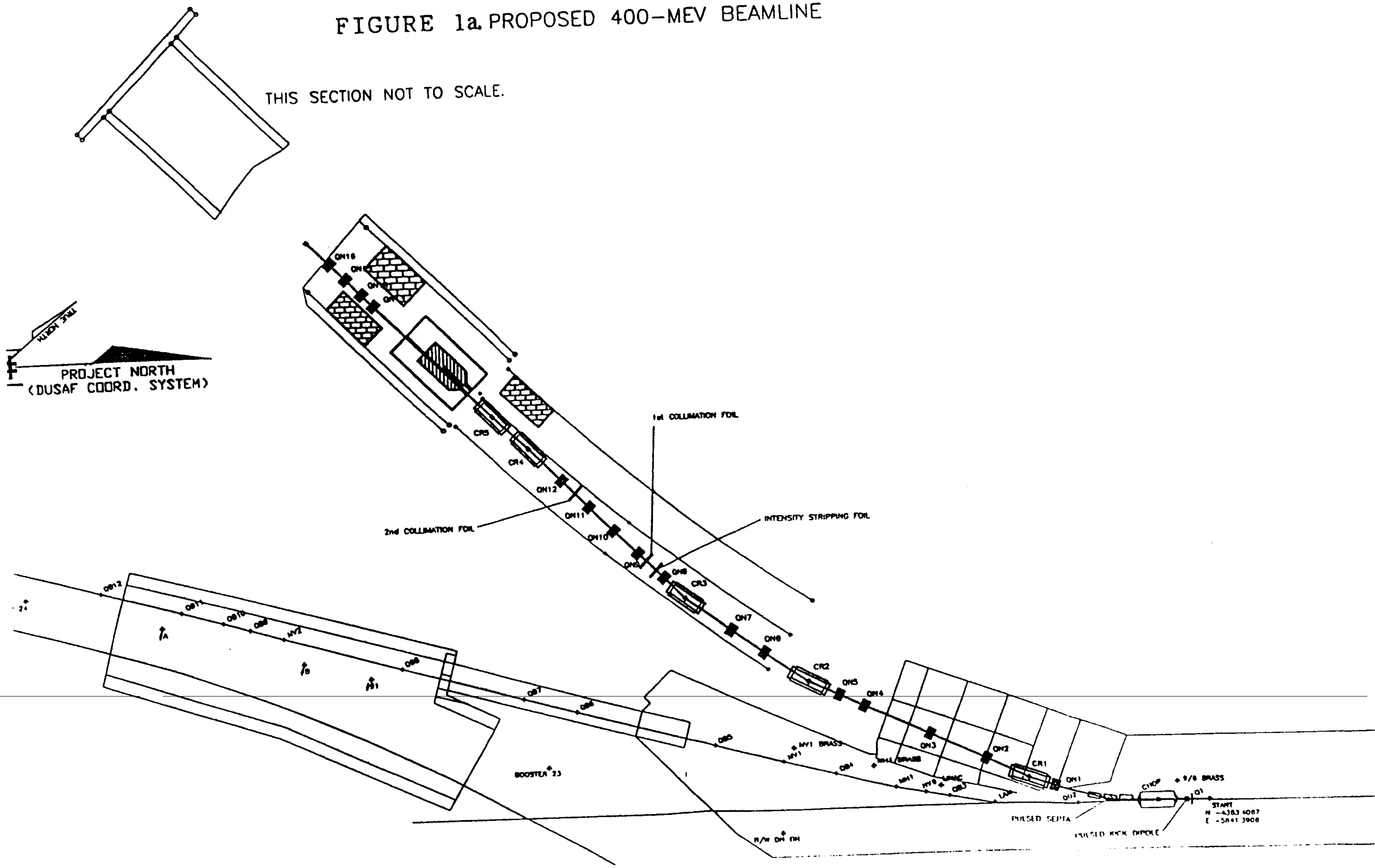
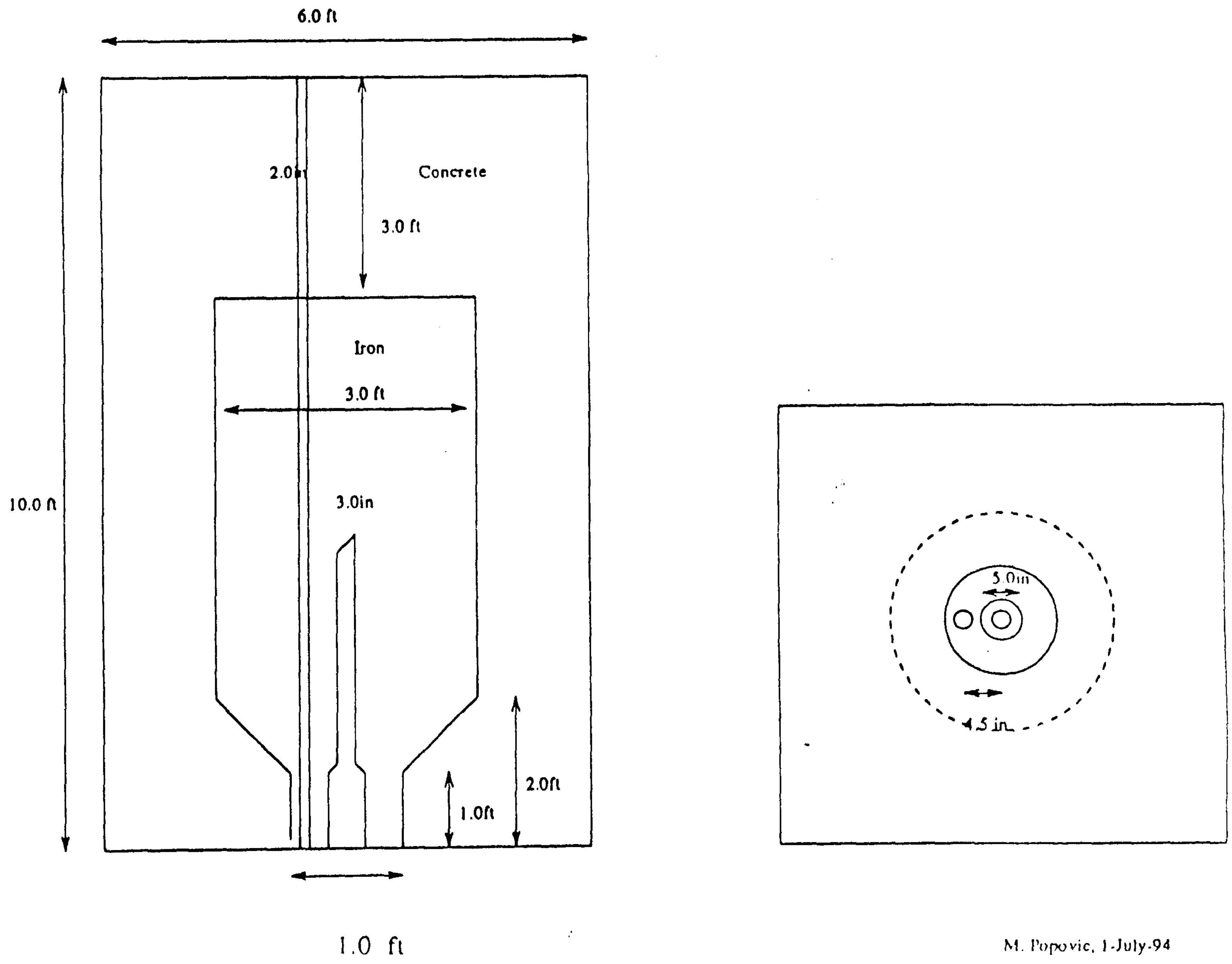


Fig. 1b. Main Dump



M. Popovic, 1-July-94

entering the experimental area, and to set the distance between the beamline and the SE wall in the experimental area. Experimenters requested at least 3 ft. of clearance; the present design provides 4.2 ft.

The ramp has a slight 1.5^0 upward slope; the beam can easily be pitched upward a corresponding amount by a short vertical trim magnet.

Beam transfer to experimental area and high intensity dump: Downstream of the collimating foils, the beam contains protons as well as H^- atoms; the two charge states must be separated and transported to and through the dump, respectively (cf. Figures 1a and 1b). A pair of equal and opposite bends (CR4 and CR5) is used to perform the separation, with beam on the west being deposited into the dump, and oppositely-charged beam on the east transported through the dump and into the experimental area. (In general, a low-intensity H^- beam will be fed into the experimental area and a high-intensity beam of protons stopped in the dump.) The horizontal separation of the two beam centerlines is 4.5 in. at the entrance to the high-intensity dump. The net separation, beam edge to edge, is approximately 3 in. at the dump.

Beam Optics and Control

The design of the primary beamline must address and satisfy a variety of experimental requirements on beam intensity, phase space distributions, and momentum spread. The present design achieves flexible control over these beam parameters by the following measures. Both the transverse phase-space distributions and the momentum spread are limited by means of collimators at dispersed horizontal foci. The H^- intensity is controlled through use of stripping foils of varying thicknesses; of course the Linac beam current, the duration of the beam pulse, and the repetition rate can also be used to control the intensity. The central beam energy is also a parameter that can be reduced in steps by allowing the beam to drift through unpowered individual sections of Linac; continuous control can be achieved by changing the inter-tank phasing in the Linac accelerator, accompanied of course by appropriate scaling of primary beamline devices (T. Kroc, Proceedings of the 400-MeV Beam International Conference, Fermilab (Oct. 24-27, 1993), pp. 129-133).

Momentum Spread: Figures 2 and 3 show the transverse lattice functions and the horizontal dispersion along the beamline. To control the momentum spread, the first seven quadrupoles establish a highly-dispersed horizontal focus at the first collimation foil. The next four quadrupoles reinstate a high dispersion focus at the position of the second collimation foil. For Linac beam having normal horizontal emittance and momentum spread, the contribution of the horizontal emittance to the beam size at the collimators is only slightly smaller than the contribution of the momentum spread. Nevertheless, severe horizontal collimation at two places separated by considerable phase advance still greatly reduces the final momentum spread of the H^- beam. Because the beam current to the experimental area typically has to be reduced by at least a factor of a hundred, pinhole collimators can be utilized which are a fraction of the undispersed beam size, resulting in a substantial reduction in the momentum spread. Collimation at the second point of high dispersion also serves to limit the beam divergence. Using one millimeter-diameter pinholes, which correspond to less than one standard deviation of the undispersed beam profile (assuming a Gaussian distribution), the momentum spread of the H^- beam is reduced about a factor of four.

Phase-space: The pinhole sizes control the emittances and phase-space attributes such as transverse beam size and divergence. The drift space between collimators is approximately 3 m, so 0.5 mm pinholes will produce the minimum emittance and phase space parameters presented in Table I.1 in the opening chapter of this report. The maximum phase space parameters shown in that table represent the normal characteristics of Linac beam.

Intensity: The overall intensity of the H^- beam can be limited by a transmission foil whose thickness can be chosen to select the desired final intensity independent of phase-space parameters. Nominally, the foil thickness is expected to range from 50-200 $\mu g/cm^2$. (The current Booster stripping foil at injection is 300 $\mu g/cm^2$; it strips more than 99% of the H^- beam to protons.)

Apertures: The main optical constraint, besides the aforementioned collimators at high-dispersion foci, is the 3.25 in. aperture restriction, which is the standard beampipe and quadrupole aperture for Linac beam lines. The largest β in the present line design is 72 m, producing a maximum beam size which is less than 2 in. In this line, all dipoles also have a 3.25 in. vertical aperture, and their horizontal good-field aperture is 8 in. Experimental apparatus having smaller apertures can be accommodated by limiting the beam phase spaces by means of the collimators.

Beam transfer and dump optics: The last quadrupole in the primary line, QN12, controls beam parameters at the entrance to the high-intensity dump. In this design, a small H^- beam, about 0.5 in. horizontally by 1 in.

Fig. 2 400-MeV Beamline Optics

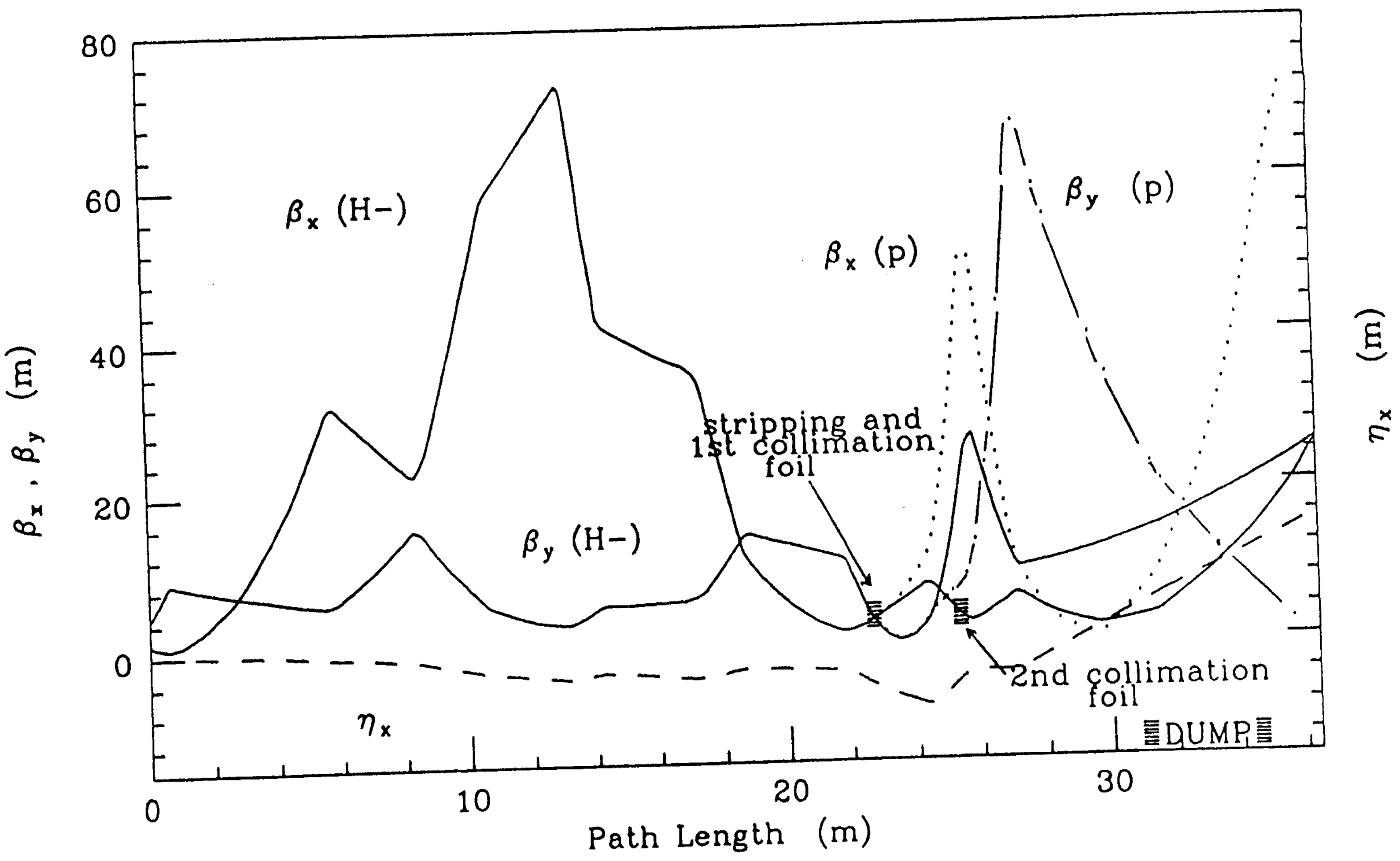
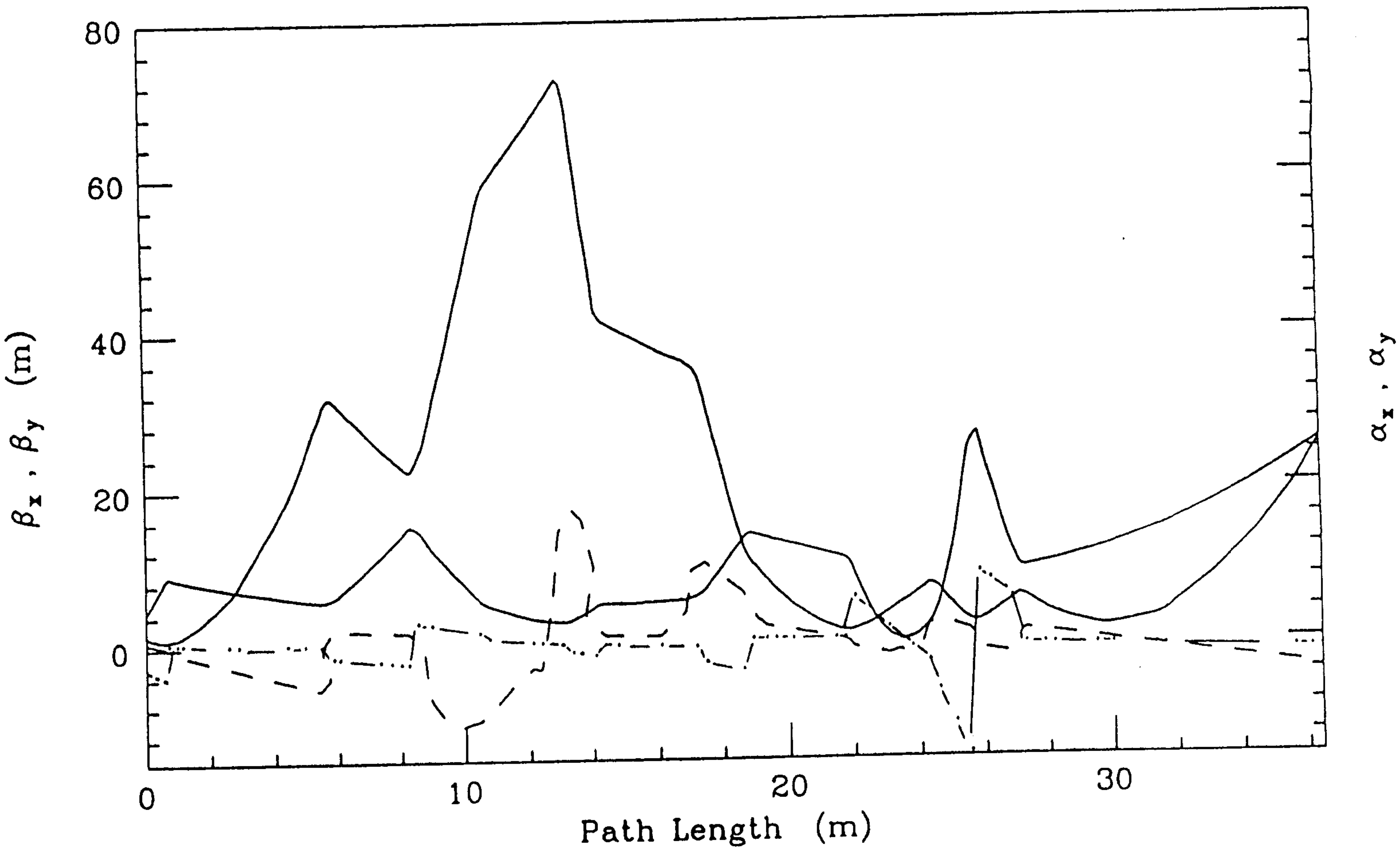


Fig. 3   400-MeV Beamline Optics



vertically, is formed at the entrance to the dump and transported through it in 2-inch-diameter beampipe. At the dump exit the H^- beam size is about an inch both horizontally and vertically. (These H^- beam sizes are maximum values for normal unscraped Linac beam.) The proton beam size is about half an inch horizontally and an inch vertically entering the dump. The protons are diverging horizontally as they enter the dump. This allows for a slow dissipation of the proton current along the length of the dump cavity to avoid localized overheating of the dump core.

Experimental Area: Four quadrupoles downstream of the dump in the H^- line image the beam from the second collimation foil onto experimental apparatus or targets. These four quadrupoles can be tuned to deliver a wide range in transverse beam characteristics to the experiments; they serve as the functional end of the primary beamline.

CHAPTER III. MAGNETS, POWER SUPPLIES, AND CONTROLLERS

Primary Beamline and Experimental Area Magnets

All quadrupoles earmarked for use in the proposed beamline are left over from the old beam line that transported 200-MeV beam from the Linac to the Booster before the Linac Upgrade. Similarly, the DC dipoles that will be used are left over from the decommissioned electron cooling ring. These magnets are currently in storage. An inventory of the beamline components is given in Table III.1.

Extraction: Extraction will be accomplished using one five-inch-long pulsed kick magnet upstream of the present Chopper followed by three identical pulsed septum magnets downstream of the Chopper. It will be necessary to modify the end flanges of the Chopper vacuum tank in order to provide the clearance needed for the beam and to make appropriate vacuum connections. All four magnets will be powered in series (at 30 kA for 400 MeV) using an existing 10 kA pulsed power supply and a suitable transformer.

The first short pulsed dipole deflects the beam past the septum of the first septum magnet. The bend angle of the kick dipole and each of the three full-length septum magnets will be 1.6^0 and 5^0, respectively; thus the total bend angle of the pulsed extraction set will be 16.6^0.

The septum magnets will be fabricated using existing Booster ORBUMP-style half-cores. (ORBUMPs are the pulsed magnets used for Booster injection and have been adopted here partly because of their compatibility with the power supply formerly used to power S2, the pulsed septum magnet in the old 200-MeV transfer line.) Each half-core will be fashioned into a pulsed septum magnet by covering it on the open side with a conducting plate. For the upstream kick magnet, a spare ORBUMP half-core will be split to make a shorter full-core magnet. Enough half-cores exist in the spares inventory to fabricate the pulsed magnets. Coils will need to be fabricated for the pulsed extraction magnets. The cross-section of the initial kick dipole is displayed in Figure 4 followed by the septum magnet cross section in Figure 5. Magnet characteristics are given in Table III.2.

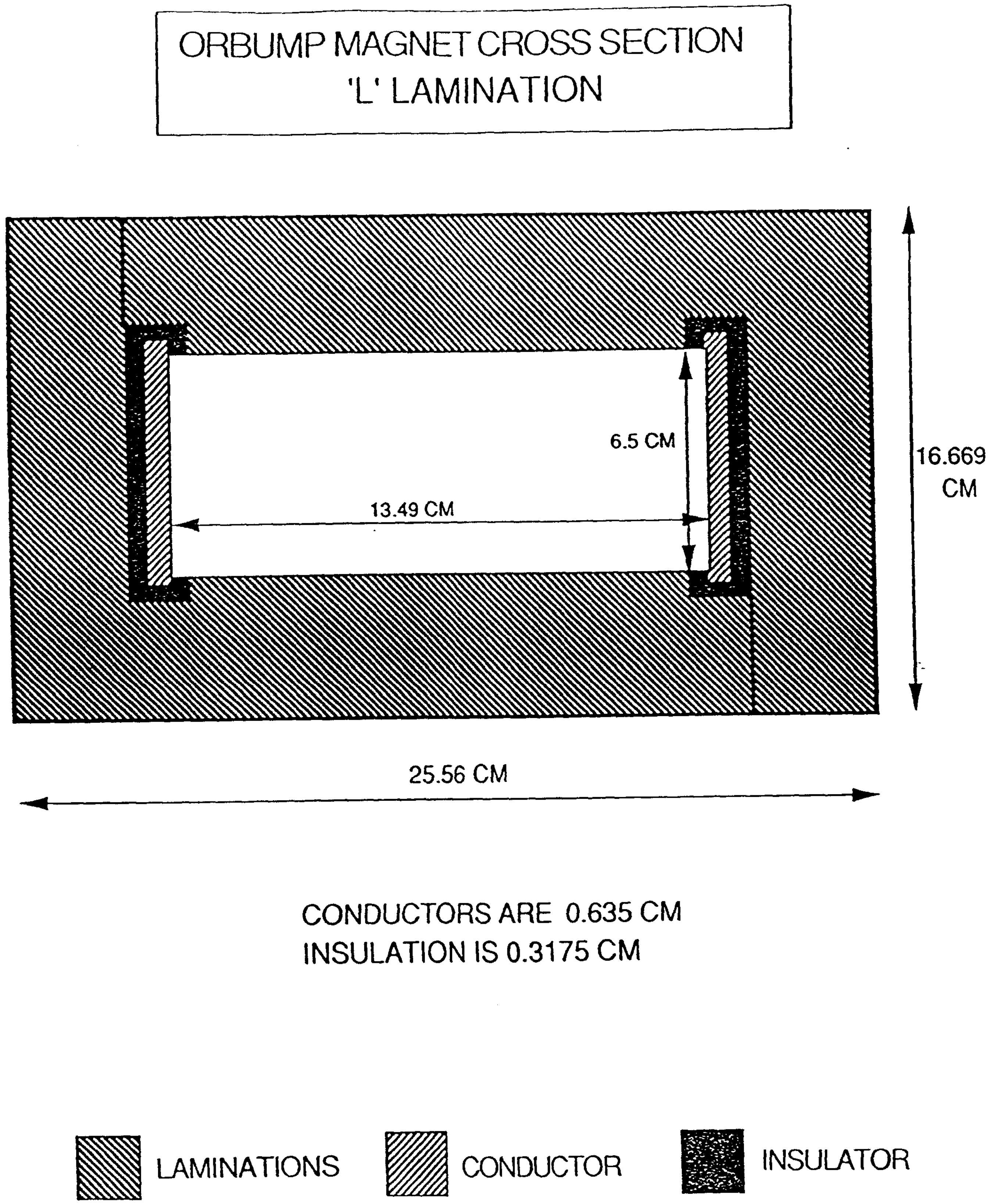

ORBUMP MAGNET CROSS SECTION
'L' LAMINATION
6.5 CM
13.49 CM
16.669 CM
25.56 CM
CONDUCTORS ARE 0.635 CM
INSULATION IS 0.3175 CM
LAMINATIONS
CONDUCTOR
INSULATOR

Fig. 4

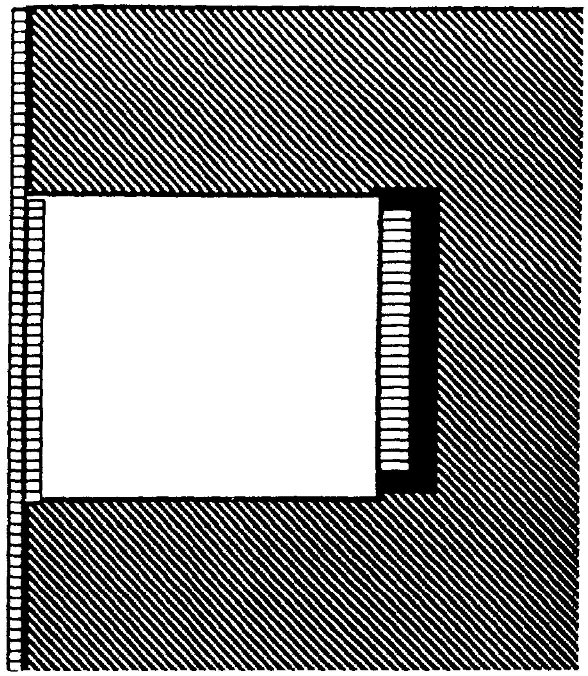


Figure 5. Septum Magnet Cross Section

TABLE III.2. EXTRACTION-SYSTEM MAGNET PARAMETERS

Parameter	Kick Dipole	Extraction Septa
Nominal Current	30000 Amps	30000 Amps
Bend Angle	27.9 mR	87.3 mR
Physical Length	0.127 m	0.4454 m
Inside Width	0.1349 m	0.06428 m
Inside Height	0.06509 m	0.06509 m

Dipoles: The electron cooling ring dipoles are four-foot-long, straight, laminated magnets. Figure 6 shows a cross section. Upper and lower saddle coils are installed between the two half cores which are then bolted together. The 3.25" vertical aperture of these magnets matches the standard beampipe diameter. The large horizontal good-field aperture of eight inches is designed to accommodate two beams. Thus they are ideally suited to serve as the dogleg pair of magnets to separate and transport both the H^- beam and the stripped proton beam to the high-intensity dump. Each coil is composed of two double pancakes with each pancake containing a separate water circuit designed to operate at 65 psi. The

Table III.1 Primary Beamline Component Inventory

Component	Type	# Required	Magnet Storage	Restricted Storage	On Loan	AD Storage	Special Process Spares
Dipole	electron cooling ring	5	4	2	2		
Quads	200-MeV green or Loma Linda	16	13			5	
Septum and Kick Dipole	ORBUMP half-cores	4					6
Vertical Bender	Linac supertrim	1				parts available-fabrication by AD	
Correction Elements	400-MeV transfer-line trims	10				6	

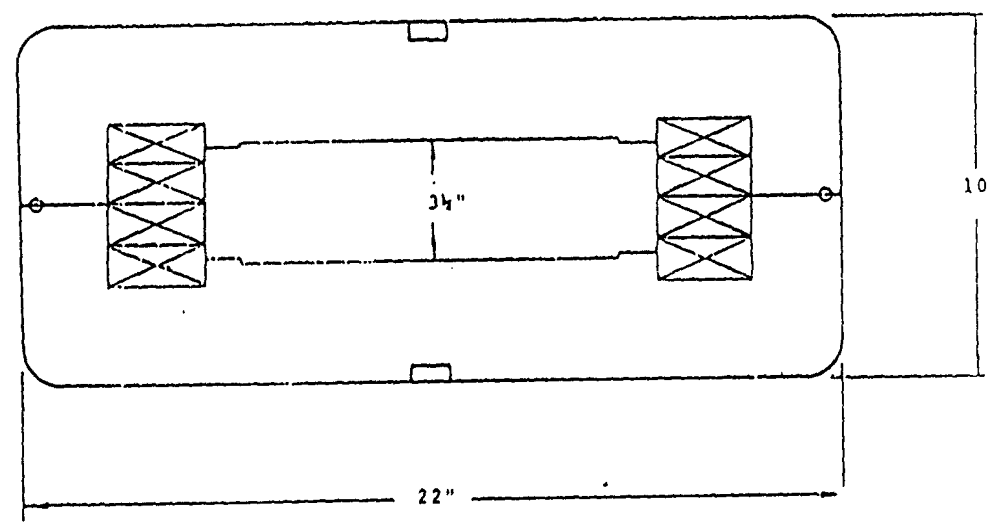


Fig. 6. Dipole Magnet Cross Section

dipole field quality has been characterized extensively and shown to be reproducible to 1-2 parts in 10^4. Table III.3 displays important parameters descriptive of these electron cooling ring dipoles.

TABLE III.3. COOLING-RING DIPOLE PARAMETERS

Field Strength	4.3 kG
Magnet Length	48 in
Magnet Gap	3.25 in
Coil Aperture	12 in
Field Aperture	+/-4 in
Field Quality ($\Delta B/B$, +/-3")	+/-10^{-4}
Coil Turns (top and bottom)	40
Copper Conductor Cross Section	0.46 in by 0.46 in
Water Cooling Hole Diameter	0.25 in
Conductor Corner Radius	0.063 in
Conductor Current	711 Amps
Magnet Inductance	0.010 h
Coil Resistance	0.025 Ω
Voltage Drop	17.8 V
Power	12.6 kW
Cooling Water Pressure	65 psi
Number of Water Paths	4
Water Flow	4.4 GPM
Temperature Rise	13.1^{0}C
Outside Dimensions	10 in by 22 in
Iron Weight	2100 lb
Copper Weight	288 lb

Quadrupoles: The 16 quadrupoles to be used in the beamline are existing 3.25"-aperture quadrupoles manufactured by High Voltage Engineering Corporation and formerly used in the decommissioned 200-MeV transfer line. (The same kind of magnets are used in the present 400-MeV transfer line; there are enough spares on hand for both lines.) The magnet assembly consists of a yoke and pole weldment which has been precision-machined as one piece to yield four identical quadrants, a design which should minimize harmonic content. The four water-cooled coils are connected in series and operate at 40 psi. The quadrupoles can be operated above their top rating of 2.1 kG/inch at 50 A, but saturation effects dominate and gains diminish. Table III.4 provides an operational overview of these magnets.

TABLE III.4. QUADRUPOLES (200-MEV TRANSFER-LINE STYLE)

Height	27.5 in
Width	22.5 in
Length: Steel Only	10 in
Coils	16.5 in
Weight	700 lb
Aperture	3.25 in
Field Length	11.8 in
Rated Gradient	2.1 kG/in
Maximum Coil Voltage	40 V
Maximum Coil Current	50 A
Cooling Water Pressure	40 psi
Water Flow	1.0 GPM

Trims: A few trims are planned for the proposed beamline. They will be existing air-core trims of the type used in the 400-MeV transfer line. Inner and outer coils are nested for simultaneous vertical and horizontal correction. The strength of the outer coil is 510 gauss-cm/amp and that of the inner coil is 432 gauss-cm/amp. At the maximum current of 10 A, the bend angle for 400 MeV beam is slightly greater than one mr. A heftier, but still modest, vertical trim will be needed to bend the beam up 1.5^0 to match the slope of the floor of the enclosure. Several candidate trims are available.

Power Supplies and Controllers

No R&D work is required on power supplies since all models are currently being used on active or previously active accelerator components, including the pulsed extraction supply. Controllers or working designs for controllers exist for all supplies. Table III.5 summarizes the power supply types and specifications along with their associated controllers. Further detail on the supplies is provided below.

Extraction: To power the four pulsed dipole extraction magnets, the output of the 10 kA supply formerly used to power the S2 magnet in the old 200-MeV line will be raised to 30 kA via a suitable transformer. A similar modification has already been performed on identical supplies for other applications (the lithium lens, for example). The supply is capable of 15 Hz operation, enabling extraction on a pulse-by-pulse basis. The S1 supply, another leftover from the 200-MeV transfer line, can be scavenged for spare parts when needed.

Dipole magnet power supplies: The supplies which power the five dipole magnets formerly used in the electron cooling ring are model #4770E-20500 (20 volt, 500 amp) switching type supplies manufactured by Power Ten Inc. The supplies are 10.5" H X 22" D X 19" W rack mounted and weigh approximately 83 pounds. They are 93% efficient and are cooled by forced air. The input is 480 VAC, 3 phase and requires an external disconnect and contactor. The supplies will be operated in constant current mode and have a load regulation of 0.1% of max. output current.

Quadrupole magnet power supplies: The 16 quadrupole magnets will be powered by model #HP-4050 (40 volts, 50 amp) linear type power supplies manufactured by Hewlett Packard Corp. The supplies are 7" H X 17.5" D X 19" W rack mounted and weigh 95 pounds. They are approximately 60% efficient and are cooled by forced air. The input is 230 VAC single phase and requires an external disconnect and contactor. The supplies will be operated in a constant current mode and have a load regulation of 0.2% of max. output current.

Trim magnet power supplies: The trim magnets will be powered by model #220 servo amplifiers (80 volts, 10 amps) manufactured by Copley Controls Inc. The amplifiers are capable of 10 amps continuous current , 15 amps peak current and can be operated in all four voltage/current quadrants. These amplifiers can be operated in a DC mode or ramped mode. Six amplifiers are mounted to a water cooled copper plate. Up to four of these plates (24 amplifiers) are rack mounted. Bulk power for the amplifiers is provided by a model # TCR-80T150 (80 volt , 150 amp) linear type power supply manufactured by EMI. The supply is 12.5" H X 24" D X 19" W rack mounted and weighs 150 pounds. They are approximately 60% efficient and are cooled by forced air. The input is 480 VAC, 3 phase and requires an external disconnect switch. The bulk supply is capable of supplying current to 24 Copley amplifiers.

CHAPTER IV. STRIPPING AND COLLIMATION FOIL DEVICES AND DIAGNOSTICS

In addition to the standard types of beam diagnostics including Beam Position Monitors (BPMs), MultiWires (MWs), toroids and loss monitors, devices will be required in the new beamline to maintain and change stripping and collimation foils in the beam interaction region downstream of dipole CR3 (cf. Figure 1a for a layout of the beamline). These devices along with the diagnostics and monitoring software are described below.

Stripping and Collimation Foil Devices

As described in the section on beam optics, the line will contain a device to insert one of a set of stripping foils to limit overall H^- intensity and a pair of thin stripping collimators to define H^- beam characteristics by limiting phase space distributions. The stripping foils and collimators will be installed in the type of foil changer designed for the 400-MeV transfer line (J. Lackey, Fermilab Booster Note #BN-90-005, 2/17/92). It is a foil-changing mechanism capable of holding as many as six foils, allowing for quick, remotely-controlled changes in either the stripping foils or collimators without breaking vacuum. A stepping motor with precise position control will operate the changer for reproducible alignment of collimators.

Diagnostics

BPMs: The new beamline will have seven 200-MHz BPMs identical to those installed in the 400-MeV transfer line—five upstream of the dump and two in the experimental area. They will be used during commissioning to establish the beam trajectory down the beamline and through the experimental apparatus. Once the operational tune is set, the BPMs will be used routinely to monitor status of the line using software developed for the transfer line diagnostics. The transfer line BPM hardware includes a VMEbus crate, Motorola MVME133 (processor board), a Proteon P1542 token ring interface, an in-house System Services Module, a battery-backed RAM module, an in-house Universal Clock Decoder board, and several fast digitizers built by Omnibyte. Each BPM signal will have a dedicated channel. The BPM readout will use a trigger and gate-generator module like that used in the 400-MeV transfer line; the extraction pulse will replace the Chopper pulse in the logic, and the intensity gate will be derived from the first BPM in the line (J. Lackey, internal note, unpublished). Data acquisition and application software which retrieves data from the VME-based hardware over the ACNET has already been developed by S. Lackey et al.

Multiwires: Four multiwires identical to those used in the 400-MeV transfer line will be fabricated and installed in the beamline for beam characterization and profile measurement. The paddles, which are flipped in and out of the beam via a ferrofluidic feedthrough to maintain the vacuum during paddle movement, will have wire spacing of 0.5 or 1.0 mm.

Miscellaneous: Four toroids and four loss monitors will be needed to monitor beam current and losses. A toroid will be placed just downstream of the septum magnets to measure extracted beam. Another pair of toroids just upstream of the dump will register the current split between the H^- and proton beamlines. At least one toroid will be required in the experimental area to record currents and be a part of the current-limiting controls on the area. The four loss monitors will be distributed along the line.

CHAPTER V. RADIATION HAZARDS AND RADIATION SHIELDING

Overview

Conceptually and operationally the new facility divides into a primary beamline and an experimental area. The primary beamline is treated as an integral part of the Linac accelerator capable of accepting full Linac beam. Radiation hazards in the primary beamline are defined and handled in accordance with the Fermilab Radiological Control Manual. The experimental area is limited to an average maximum beam current of one hundred nanoamps. Conventional radiation shielding and safety systems are proposed to safeguard this area against all potential experimental configurations and loss scenarios as stipulated by the Fermilab Radiological Control Manual.

Introduction

The principal radiation hazards in the primary beamline are the normal operating losses and accident losses associated with the full beam power of the Linac. In the experimental area, current will be reduced by two orders of magnitude from the normal Linac beam current, but, unlike Linac operation, the radiation hazard includes depositing a significant portion of the low-intensity beam within the enclosure as a routine part of experimental operations. The worst case accident scenarios involve transmission of one or more Linac primary beam pulses to the experimental area.

With the source terms defined, the occupancy and desired level of radiological posting determine the amount of shielding required for the facility. The surface of the berm over the proposed facility and parking areas adjacent to it are envisioned to be defined as minimal occupancy areas. Since there is no planned functional use of the berm and maximum expected occupancy of the parking lot by any individual would be less than 40 hours per year, these areas would be classifed as minimal occupancy. The proposed counting house will be defined as an area of unlimited occupancy. Passive shielding and active systems are proposed below to meet these criteria without requiring any radiological postings.

In the following text, normal operating conditions and accident conditions are explained along with anticipated radiation levels in areas adjacent to the proposed beam enclosures. The primary beamline conditions are expected to be similar to those of the existing 400 MeV Linac. Experimental beam line conditions are presented in tabular form to summarize the results of Monte Carlo calculations. The shielding and radiation containment systems, both active and passive, which restrict exposure to prescribed limits outside the enclosures are then discussed. Procedures such as access control will also be mentioned to demonstrate compliance with existing radiation safety guidelines and practices.

Primary Beamline

The primary beamline is an extension of the Fermilab Linac and will be treated for safety purposes as an integral part of that accelerator. The safety envelope of the primary beamline will be the same as the Linac. That is, the maximum charge transmitted through the primary beamline will be 35 mA for 30 μsec @15Hz (53.5 mA-sec/hr in SAD units). Increasing these prescribed limits would require a revised and approved Linac shielding assessment.

Normal Operating Losses: During normal operation, the Fermilab Linac generates a 30μsec, 35 mA beam pulse at a maximum repetition rate of 15Hz. The corresponding average current is 16 μA. This will be the maximum charge transmitted down the primary beamline in an hour. Normal operating losses are expected to be similar to those in comparable existing beam lines and are predicted to be a couple of percent or less distributed along the primary beam line The highest loss point would be expected at the extraction septum and should exhibit loss rates similar to those incurred at the entrance to the Lambertson magnet in the transfer line to the Booster (<1%). A new primary dump will be constructed for the end of the primary beamline and will be designed to absorb the maximum Linac beam power as a normal condition.

Accident Conditions: The accident condition for the primary beam line consists of the loss of full Linac beam power at one point for an hour as required by the Fermilab Radiological Control Manual. The severity and actual duration of the accident condition will be established by performance of shielding assessment prior to commissioning of the new beam line. This practice is consistent with commissioning of the 400 MeV Linac Upgrade in the fall of 1993.

Occupancy of Areas Adjacent to the Proposed Primary Beamline: The occupancy for areas adjacent to and on the primary beam enclosure berm are defined here based upon intended use of these areas. The surface of the berm and the area adjacent to it are envisioned to be defined as minimal occupancy areas. Since there is no planned functional use of this area by personnel, the berm is expected to be occupied less than 40 hours per year by any individual. In addition, it is intended that no radiological postings will be required for this area. Based upon these conditions and the requirements of the Fermilab Radiological Control Manual, a combination of shield design and interlock detectors is required to ensure that radiation dose rates remain below 0.25 mrem/hr for normal operating conditions and below 10 mrem/hr for accident conditions.

Radiation Shielding and Safety Systems: It has been demonstrated that, under both normal operating conditions and accident conditions, the combination of passive shielding (12 ft of soil) and interlock detectors surrounding the existing Linac prevents radiation levels in outdoor areas above the limit for minimal occupancy. The same amount of passive shielding and a similar interlock detector arrangement would be used for the primary beamline.

Certain accident configurations could produce high instantaneous rates at specific locations outside the Linac enclosure due to operation of the existing Linac, and the same situation can be assumed for the new primary beamline. The worst case accident condition would be deposition of the full Linac beam power outside of the primary beam dump. The Linac, however, is protected from generating such high beam losses for extended periods by two independent systems. The Linac controls system, operated by the Linac department, consists of active monitors, alarms, beam inhibits, etc. which provide normal control for Linac beam power. The Radiation Safety System (RSS) is an independent fail-safe system designed and maintained by the AD ES&H Department which independently monitors radiological parameters. The Radiation Safety System inhibits Linac beam in the event radiological rate limits are exceeded by turning off critical devices. Critical devices are beam line components which, when de-energized, prevent primary beam from being transported to the area or enclosure being protected.

With the appropriate combination of administrative controls, passive shielding, accelerator controls, and the Radiation Safety System, it has been demonstrated that radiation doses outside the Linac enclosure under normal and accident conditions remain within the limits of the Fermilab Radiological Control Manual. This multi-tiered approach will be applied to the new primary beamline to ensure that the radiation limits for the intended occupancy are never exceeded.

Access: Given that this line is a[illegible] tension of the Linac and its enclosure is connected to the Linac enclosure, any access or maintenance will fall under Linac jurisdiction and will follow existing Linac procedures.

Experimental Area

The experimental area begins downstream of a high-intensity, primary-beam dump which physically separates the area from the Linac enclosure. The Linac control system combined with primary beamline components will be used to deliver an average beam current not exceeding 100 nA to the experimental area. In other units, the maximum charge transmitted to the experimental area will be limited to 0.36 mA-sec/hr.

Discussion of the experimental area is complicated because it must be shown that normal operating controls and safety systems will limit beam current to one hundred nanoamps, and, in the event of an accident, critical devices will prevent primary beam from reaching this enclosure.

An additional safety issue arises due to the frequent access of users into the experimental area which can occur simultaneous with normal Linac operation.

Normal Operating Losses: In the experimental area, the maximum amount of beam lost locally, (an experimental target, for example), will be restricted to an average of 15nA through the use of administrative controls. Each experimental use will require a review of procedures, apparatus, and controls to ensure that greater than a 15 nA normal loss will be prevented. The remainder of the beam power will be deposited in a low-intensity dump located downstream of the experimental setups. A new beam dump will be designed and constructed to absorb an average beam current of one hundred nA.

Accident Conditions for the Experimental Area: There are two accident conditions to be considered. The first accident condition involves localized beam losses in the experimental area outside the beam dump which exceed the 15nA normal operating losses. The limit of this accident condition would be the deposition of the full 100 nA secondary beam current within the experimental beam area and outside of the secondary beam dump. The second accident condition would involve the failure of the Linac controls system in a manner such that one or more primary Linac beam pulses is transported to the experimental area and deposited outside the experimental area beam dump. The severity and duration of the accident condition will be established by performance of shielding assessment prior to commissioning of the new beam line. The Radiation Safety System would be configured to protect against these accident conditions as required by the Fermilab Radiological Control Manual. This practice is consistent with commissioning of the 400 MeV Linac Upgrade in the fall of 1993.

Occupancy of Areas Adjacent to the Proposed Experimental Beamline: The occupancy for areas on the experimental area beam enclosure berm and in areas adjacent to it are defined here based upon intended use of these areas. The surface of the berm and parking areas adjacent to it are envisioned to be defined as minimal occupancy areas. Since there is no planned functional use of the berm and maximum expected occupancy of the parking lot by any individual would be less than 40 hours per year, these areas would be classifed as minimal occupancy. It is intended that no radiological postings will be required for this area. Based upon these conditions and the requirements of the Fermilab Radiological Control Manual, a shield design and configuration of interlock detectors will be required such that radiation dose rates remain below 0.25 mrem/hr for normal operating conditions and below 10 mrem/hr for accident conditions.

In addition to the foregoing, a trailer or similar structure for use by experimenters will be placed near the experimental area beam enclosure. The experimenter's trailer will be classified as an unlimited occupancy area. It is intended that no radiological postings will be required for this area. Based upon these conditions and the requirements of the Fermilab Radiological Control Manual, a shield design and interlock detectors are required such that radiation dose rates remain below 0.025 mrem/hr for normal operating conditions and below 1 mrem/hr for accident conditions.

Linac Controls System: The Linac Controls System will be extended to provide the capability to control and limit beam power to the experimental area to an average of 100 nA beam current. This control would serve as the nominal means to limit beam intensity and would be independent of the Radiation Safety System.

Radiation Shielding and Safety Systems: All sources and passive shielding have been computer-modeled to predict radiation levels outside the experimental beam line enclosure. With a 15nA average beam current as the source term for normal operating losses, it was found that the one foot of concrete (the roof) covered by 12' of soil will reduce radiation levels to below 0.25 mrem/hr at the surface of the berm and below 0.025

mrem/hr at 13 feet from the surface under normal operating conditions. For normal operation, the assumptions and results of the calculations are summarized in Table V.1. The projected rates have also been checked by scaling measurements which were made of radiation levels in the Booster tunnel just outside the straight ahead dump (T. Leveling, private communication).

For the accident condition in which 100 nA beam current is lost, it has been determined by scaling that the dose rates would be less than 1.0 mrem/hr at the surface of the berm and less than 0.25 mrem/hr in areas designated as unlimited occupancy.

The second accident condition considered is one in which the Linac controls system fails and one or more primary Linac beam pulses is transported to the experimental area and deposited outside the experimental area beam dump. To protect against this accident, a beam-limiting Radiation Safety System would be employed which depends on current-integrator instrumentation for beam intensity determination. Such a system may consist of a SEM and toroid connected to a critical device controller which, upon detection of an accident condition such as an overcurrent beam pulse, would inhibit beam to the new primary beam line. This system would be independent of the Linac and experimental area beam control system and the Linac primary beam. As a part of the Radiation Safety System, it would be routinely tested and maintained by the AD ES&H Department Interlock Group. The accident condition with assumptions and calculations are summarized in Table V.2.

A final layer of protection against accident conditions over the berm over the experimental area could consist of interlock detectors (chipmunks or scarecrows) connected to the Radiation Safety System; however, it is very unlikely that such protection is required. Of the two accident conditions considered for the secondary beam area, the continuous 100 nA loss is the worst case and is adequately protected by the beam-limiting Radiation Safety System.

Access to Experimental Beam Enclosure: The experimental beam line enclosure would be equipped with a complete door interlock safety system typical of all Accelerator Division beam line enclosures. A local interlocked key tree would be provided to allow keys to be issued locally at the experimenter trailer or the west Booster fan room.

Two labyrinth accesses are planned for the experimental area. The main access to the experimental area would be from outdoors and would connect to the northwest side of the proposed experimental beam line enclosure. This access would serve as the normal personnel and equipment access to the experimental enclosure. A second labyrinth would lead from the experimental area beam enclosure to the primary beamline enclosure. This labyrinth would not ordinarily be used but would serve as an emergency escape in the event the main experimental area labyrinth would become inaccessible. This labyrinth would have an interlocked gate equipped with a crash bar. Breaking through the gate would immediately drop the Linac Radiation Safety System and inhibit the Linac beam by disabling critical devices. The gate would be located in the labyrinth so that normal and accident loss conditions would be less than 10 mrem/hr and less than 100 mrem/hr respectively. It is anticipated that the experimental area beam line will be posted as a radiation area due to residual activity resulting from experiment operation.

The experimental area would be accessible during operation of the Linac because of the need to support frequent user activity in the experimental area. The inside of the enclosure would need to be protected from two sources of potential radiation exposure. First, critical devices in the primary beam area would be necessary to prevent primary beam from entering the experimental area while people are in it. These critical devices would need to meet the requirements of the Fermilab Radiological Control Manual and would need to be reviewed and approved by the ES&H Section. Second, interlock detectors would need to be provided in or near the dump labyrinth access to inhibit Linac primary beam in the event of an accident condition resulting from primary beam lost in the Linac beam enclosure. Interlock detectors are used for the same purpose at a number of locations in various accelerator enclosures within Accelerator Division.

If the Linac is on, the access will be limited to controlled access. Supervised access will be permitted in the experimental area only in the event the Linac is in supervised access. Initially, a Fermilab employee (a beamline physicist) or other qualified staff will accompany experimental users during accesses. Once experts are identified from the individual experiments and approval is obtained from Accelerator Division management, they could ultimately serve as escorts into the experimental area.

Table V.1. Radiation Levels for Experimental Area: Normal Conditions

Assumptions:	
Design Beam Current	≤100nA, average
Normal Operating Point Losses	restricted by administrative controls to ≤ 15nA continuous losses at a point outside of beam dumps
Shielding	13 feet
Beam Pipe Location	2 feet from beam enclosure wall
Dose Equivalent per Proton at berm surface:	0.35 E-18 rem/proton*
Dose Equivalent per Proton at 13 feet from berm surface	0.10 E-18 rem/proton*

Loss Rate	Sources	Dose Rate at shielding surface	Radiation Dose Rates 13' from surface	Radiation Dose Rates a Labyrinth Door
≤15nA continuous (3.4 x 1014 p/hr)	beam-on experimental apparatus or beam pipe	0.12 mrem/hr	0.035 mrem/hr	< 0.25 mrem/hr

*based on calculations described in Appendix B

Table V.2. Radiation Levels for Experimental Area: Accident Conditions

Assumptions:	
Design Beam Current	≤100 nA, average
Case 1 Accidental Losses	100 nA continuous losses at a point outside of beam dumps
Case 2 Accidental Losses:	3-pulse accident 1.3 x 10^{-13} protons/pulse (50 mA, 40 msec beam pulse), full Linac beam, limited by Radiation Safety System Current Limiter Trip
Shielding	13 feet
Beam Pipe Location	2 feet from beam enclosure wall
Dose Equivalent per Proton at berm surface:	0.35 $X10^{-18}$ rem/proton*
Dose Equivalent per Proton at 13 feet from berm surface	0.10 $X10^{-18}$ rem/proton*

Case / Loss Rate	Sources	Dose or Dose Rate at shielding surface	Radiation Dose or Dose Rate at 13' from surface	Radiation Dose or Dose Rates at Labyrinth Door
Case 1	beam-on experimental apparatus or beam pipe	0.8 mrem/hr	0.23 mrem/hr	< 1.6 mrem/hr
Case 2	beam-on experimental apparatus or beam pipe	0.013 mrem/trip	0.004 mrem/trip	< 0.25 mrem/hr

*based on calculations described in Appendix B

CHAPTER VI. CIVIL CONSTRUCTION, UTILITIES, AND INSTALLATION

The Facilities Engineering Services Section (FESS) at Fermilab has prepared a design, schedule, and cost estimate for the civil construction aspects of this proposed project. FESS produced a document that is incorporated in this report as Appendix D.

The implications of the construction schedule for accelerator operations can be understood as follows. At present, the upstream and downstream ends of the Linac Upgrade ramp are separated by a roughly cubical volume, about 10 ft. on a side, of concrete shielding blocks. Those blocks provide the shielding and physical separation without which it would not be safe to run the Linac beam past the ramp. In the proposed Linac Experimental Area, the high-intensity dump and adjacent labyrinth will provide a similar level of shielding and physical separation between the upstream area and the open pit. Accordingly, the only significant chunk of contiguous downtime needed is the one week required to install the high-intensity dump and labyrinth in place of the cube of shielding blocks. Once that is done, the Linac enclosure will be properly shielded again, and further civil construction, such as roofing the experimental area, can proceed without further interruption to accelerator operations. Of course, installation of beamline components upstream of the high-intensity dump would be more efficient if it coincided with an extended shutdown, but if necessary that work could proceed piecemeal during short interruptions of accelerator operation.

Utilities, including both electrical power and water, are already available from decommissioned installations. The primary beamline and the experimental area will be powered from electrical installations that previously served the high-energy end of the old 200-MeV Linac and the old electron cooling ring, respectively. Power to the primary beamline will be routed from the Linac gallery through penetrations into the Linac enclosure. All power cabling will cross from the east wall of the Linac enclosure over to the SE wall of the ramp enclosure through an existing cable tray located in the south end of the Linac enclosure, so as not to interfere with the travel of the crane. Except for possibly the first four quadrupole magnets in the experimental area which are functionally a part of the primary beamline, power to the experimental area will be fed from the 0.5 MW transformer located in the west Booster fan room through a series of conduits (see FESS report) in the hardstand which connects to the enclosure. Table VII.1 summarizes the available power and shows the power consumption requirements as estimated for the primary beamline and the experimental area.

Cooling water for both enclosures is also available from installations that formerly served the decommissioned portion of the old 200-MeV Linac. The old Linac LCW skid 9, which includes an existing pump, will be modified by removing the sand filter and adding a deionizer bottle, heat exchanger, temperature control valve, and appropriate fittings. The total water flow required by both the primary beamline and the experimental enclosure has been estimated at 70 GPM. Skid 9 will provide about 65 PSI as required by the cooling ring dipoles. Copper piping and hosing to the individual elements will be used, allowing in-house installation. Like the electrical cabling, all plumbing will cross at the south end of the Linac enclosure to avoid the crane. Specific details of the proposed installation are given in an internal memo dated 6/22/94 from Karl Williams of the Mechanical Support Department.

The present Mechanical Support staff is sufficient to handle the installation of the beamline. Those responsibilities are shown in the installation schedule presented in Table VII.2. If it is desired to install all components, including the four quadrupoles in the experimental area, at once rather than piecemeal, a six-week accelerator shutdown is needed. As during the Linac upgrade installation, NTF can continue to run during the installation work with the proper scheduling. Construction and installation activities in the experimental area will not impact accelerator operations at all.

Table VII. 1

PRIMARY BEAM LINE / LINAC BASEMENT POWER REQUIREMENTS

ELEMENT	QTY	INPUT POWER REQUIREMENTS	AVAILABLE POWER
COOLING RING DIPOLE MAGNET POWER SUPPLY	5	480VAC, 3 PHASE, 67 AMPS	480VAC, 200 AMPS
GREEN QUADRUPOLE MAGNET POWER SUPPLY	12	208VAC, 3 PHASE, 33 AMPS	208VAC, 50 AMPS
TRIM MAGNET POWER SUPPLY	1	480VAC, 3 PHASE, 9 AMPS	480VAC, 50 AMPS
RELAY RACKS	10	110VAC, 1 PHASE, 45 AMPS	110VAC,

LINAC BASEMENT TO PRIMARY BEAM LINE CABLING REQUIREMENTS

ELEMENT	CABLE TYPE	QUANTITY
COOLING RING DIPOLE MAGNET	125 MCM	8
GREEN QUADRUPOLE MAGNET	#2 WELDING CABLE	24
TRIM MAGNETS	4 COND. #12 CABLE	5
TEMPERATURE AND FLOW SWITCHES	4 COND. #22 CABLE	17

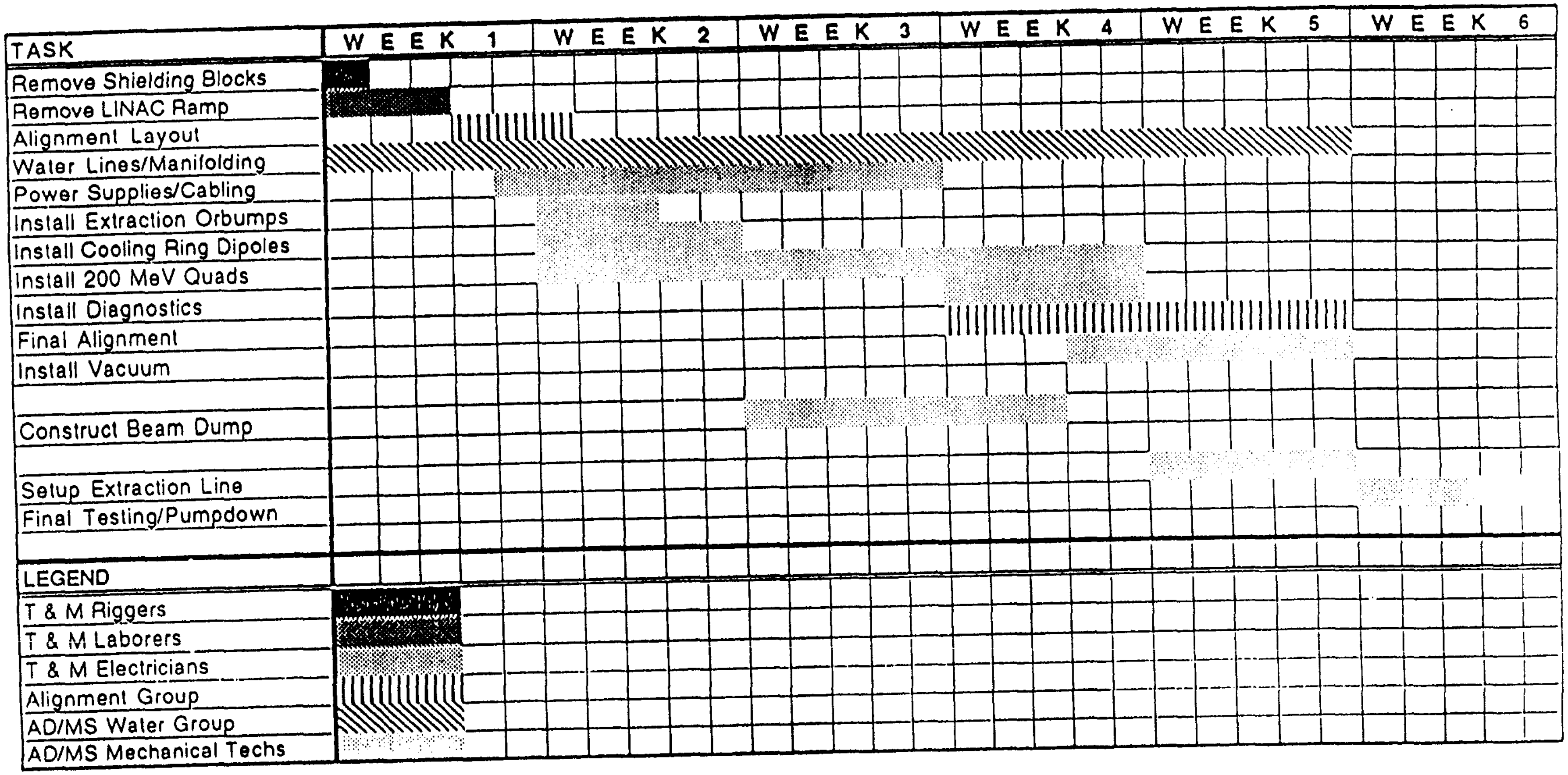
EXPERIMENTAL AREA / WEST BOOSTER FAN ROOM POWER REQUIREMENTS

ELEMENT	QTY	INPUT POWER REQUIREMENTS	AVAILABLE POWER
GREEN QUADRUPOLE MAGNET POWER SUPPLY	4	208VAC, 3 PHASE, 15 AMPS	280VAC, 50 AMPS
480VAC SERVICE OUTLETS		480VAC, 3 PHASE	480VAC, 250 AMPS
208VAC SERVICE OUTLETS		208VAC, 3 PHASE	208VAC, 35 AMPS
110VAC SERVICE OUTLETS		110VAC, 1 PHASE	110VAC,

EXPERIMENTAL AREA / WEST BOOSTER FAN ROOM CABLING REQUIREMENTS

ELEMENT	CABLE TYPE	QUANTITY
GREEN QUADRUPOLE MAGNET	#2 WELDING CABLE	8
480VAC SERVICE OUTLETS		
208VAC SERVICE OUTLETS		
110VAC SERVICE OUTLETS		

Table VII. 2 400 MeV EXPERIMENTAL LINE - INSTALLATION SCHEDULE



APPLICATIONS AND EXPERIMENTAL DESCRIPTIONS:

PHYSICS

Absolute Momentum and Momentum Spread Determinations: FERMILAB, LANL[1]. RAL[2], UNM[3] There persists an uncertainty in the absolute determination of the momentum definition and momentum spread of the Fermilab Linac H^- beam.
EXPERIMENT: An absolute momentum and a momentum spread measurement can be implemented by a laser-excited resonance technique which exploits the well-calibrated, extremely narrow resonances exhibited by H^0 and H^-, respectively. The Rydberg resonances in H^0 can be used to yield an energy determination of a 400-MeV H^- beam to 10^{-4}. The accuracy of the momentum spread measurement would also be about one part in 10^{-4}, or close to an order of magnitude more accurate than current measurements.

[1]Los Alamos National Laboratory
[2]Rutherford Appleton Laboratory
[3]University of New Mexico

Beam Loss Mechanisms in H^- Foil Stripping: FERMILAB, LANL, RAL, UNM High intensity foil stripping used for injecting H^- at the PSR has been shown to produce long-lived states of neutral hydrogen and to be the dominant injection loss mechanism at the facility, constantly irradiating specific locations. By inference, high loss points in the cells near injection into Fermilab's Booster Synchrotron suggest that this might be a loss mechanism to consider in addition to being a basic accelerator design parameter which is not fully understood.
EXPERIMENT: This experiment will use the LANL/UNM experimental apparatus which has already been used to successfully explore some features of H^- foil stripping.

Device Calibration and Characterization: The standard set of beam diagnostics can best be tested and calibrated with an actual proton beam.
EXPERIMENT: Toroids, resistive wall monitors, beam position monitors, ion profile monitors and beam pickups and probes in general can be characterized for the effect of beam size, intensity, signal to noise, linearity, and a host of other descriptive measurements which are often inferred from other calibration methods. A test beam is obviously most

important in the development of intercepting beam diagnostics such as the retinue of CCD-associated technology--frame grabbers, video switchers, and laser spot analysis software for position and profile measurements.

Development of a Laser-Driven Bunch-Length Detector: FERMILAB, SERPUKHOV To measure the instantaneous bunch length of the Linac beam.
EXPERIMENT: A laser with a picosecond pulse can be used to instantaneously photoionize a single rf bunch of H^- ions. If a small gradient focusing field is applied and electrons are collected onto an electron multiplier array (multichannel plate) as a function of longitudinal position, then the signal is a snapshot or direct measure of the instantaneous bunch length.

Beam-based Cavity Impedance and Wake field Measurements: FERMILAB, TESLA[1] 400-MeV beam can be used as a probe to measure cavity impedances and the effect of beam loading and wake fields.
EXPERIMENT: Small perturbations due to the wake field can be explored using ultrasensitive laser-resonance tagging and neutralization techniques.

[1]TeV Electron Superconducting Linear Accelerator

Kicker Calibration and Development: FERMILAB To quote G. Jackson, "the measurement of kicker waveforms is devilishly difficult".
EXPERIMENT: A test beam is the ultimate probe of the kicker waveform. Fast kickers are currently in the design stage for the Main Injector.

Photon Physics and Laser Wake field Measurements in Hydrogen: UNM, LANL Because of the requirement for far vacuum ultraviolet photons (far beyond present laser capabilities), much of the physics of H^- and neutral hydrogen and the dynamics of photon interactions with matter can only be studied with a relativistic H^-beam. Many of the striking and significant features of the only pure 2- and 3-body Coulomb system have been observed only in such experiments (they have yet to be observed in astrophysical phenomena). A 400-MeV H^- beam is ideal for studying photon processes, not only the bare photon interaction, but also the effect on the atomic system of a strong perturbing field, i.e. the electric field of the laser.
EXPERIMENT: Experiments of an electromagnetic or astrophysics nature can be run in a parasitic mode to the foil and laser diagnostic work. By exploiting the Doppler shift to make a tunable laser, photons can be used to probe both H^- and neutral hydrogen.

Health Physics and Radiation Physics Studies: FERMILAB RADIATION PHYSICS GROUP OF ES&H SECTION. The field of accelerator health physics is one in which a great deal of research needs to be done. The radiation fields which are present at accelerator facilities differ greatly in their nature and their energies from those of nuclear facilities, where much of the present health physics work is done. Research in a variety of areas is typically performed using radiation from encapsulated radioactive materials or from nuclear reactors. The results found in such radiation fields do not necessarily reflect those that would be found in the fields produced by an accelerator used for research in high energy or nuclear physics or for medical applications. The development of a 400 MeV experimental beamline would offer a unique opportunity to create an experimental area dedicated to research in accelerator health physics.

The potential applications of a proton beamline to health physics research include work in shielding studies, dosimetry, materials activation, software benchmarking and development of instrumentation. By placing a target and appropriate collimators upstream of the Health Physics Experimental Area, a neutron beam could be produced to further this research. Shielding studies are the most demanding in terms of experimental configuration. The experimental area would therefore be configured for shielding experiments. Such a configuration will allow it to easily accommodate experiments in other areas of accelerator health physics. Detailed proposals are being writtten by the Radiation Physics Group of ES&H section.
EXPERIMENTS: Some examples of the type of research include:

• Controlled studies of shielding effectiveness using various materials and configurations can be conducted. These could be used to benchmark and validate computer models used for shielding calculations.

• The effectiveness of various labyrinth designs can be studied by arranging the shielding test blocks into test labyrinths.

• Studies in high energy (>20 MeV) neutron dosimetry could be conducted. The need for such studies is evidenced by the fact that no standard for the dosimetry of high energy neutrons presently exists. Dosimetry intercomparisons could be conducted.

• The activation of various materials exposed to the accelerator beam could be measured. Such studies would represent an important step forward in the characterization of radioactive waste generated by Fermilab and other accelerators.

• Health physics instrumentation could be developed for accelerator-produced radiation fields under controlled conditions.

As the need for such research is well recognized, a dedicated research facility would attract interest throughout the health physics community.

MEDICAL

Pulsed-Beam Scanning Techniques for Proton Therapy: LBL[1], LLUMC[2], MGH[3], UW[4] Medical facilities have a strong interest in developing scanning techniques for proton therapy. To date only slow spill beam with 1% or less intensity variations have been considered applicable to scanning. Since pulsed beam structure is more common in accelerators and such strict intensity uniformity is difficult to achieve over time, developing techniques to utilize short pulses of beam and detectors which accurately correct for intensity fluctuations would be a breakthrough in scanning technology.
EXPERIMENT: The 1-30 microsecond beam pulses (200 MHz rf structure) of the Fermilab Linac would be used to develop and evaluate pulsed-beam scanning techniques. Both raster and conformal scanning can be explored.

[1]Lawrence Berkeley Laboratory
[2]Loma Linda University Medical Center
[3]Massachusetts General Hospital
[4]University of Wisconsin

Measurements of Dose Distributions as Function of Beam Properties: FERMILAB, LBL, LLUMC, MGH, UW The correlation of dose distribution to incident beam parameters has never been studied in a experiment where the parameters can be varied independently.
EXPERIMENT: A simple beamline can be implemented with variable optics to provide independent control over different beam parameters such as horizontal and vertical sizes, distributions, angular divergences, and energy and energy spread (the last attribute is under Linac control). Dose distributions in phantoms can be measured accurately and methodically as beam characteristics are changed in a controlled manner.

The Relationship of Beam Optics to Gantry Design: FERMILAB, LBL, LLUMC, MGH, UW The size and expense of dose delivery systems is almost completely determined by the beam transport characteristics. Beam compaction in one or both planes and, in general, the optimization of a beam delivery system have not been thoroughly investigated.
EXPERIMENT: Magnet design and mechanical and optical beamline design are fortes of the Fermilab Accelerator Division. Most of the medical community would be interested in a compact beam delivery system.

Develop Detectors and Methods for 3-D Dose Distribution Measurements: FERMILAB, LBL, LLUMC, MGH, UW Much work remains to be done on 3-D dose distributions. 3-D dose distribution detection techniques and realistic algorithms represent a substantive advance and enhancement in radiation treatment. A standardized 3-D detection system is very much needed to establish uniformity and quantitative measures for treatment.
EXPERIMENT: The Fermilab Linac Beam can be used to study 3-D dose distributions in phantoms. Methods, 3-D detection systems and the required software calculations can be subsequently developed. Specifically, a sophisticated, portable 3-D detection system can be designed, calibrated, and maintained by Fermilab, but leased to participating medical facilities. A common detector for proton therapy programs represents a major upgrade in the quality assurance and control in the field.

Proton Radiography and Computed Tomography R&D: FERMILAB, LBL, LLUMC, MGH, UW Proton radiography and computed tomography have been proposed, but little development has occurred, predominantly due to the cost and lack of proton beams for such work. Proton radiography and reconstructed computed images have several distinct advantages over conventional CAT scanning, particularly in terms of resolution.
EXPERIMENT: Again the Fermilab Linac beam can be used to probe phantoms with known density distributions, and software and hardware developed to accurately reproduce these distributions from the detected protons. Cross-sectional slices of the density distribution can be reconstructed from the proton energy-loss measurements to build a complete description of the experimental entity (and eventually of a patient's anatomy).

Medical Calibration Studies: FERMILAB, LBL, LLUMC, MGH, UW The Bragg peak is extremely sensitive to the exact proton energy, and dose

distribution profiles change as a function of the energy spread of the beam. Because of systematic uncertainties between facilities, comparisons have not been able to accurately reconcile measurements and methodology in the field of proton therapy. Discrepancies do exist and this is a serious issue in proton therapy treatment. Radiation exposure to secondary neutrons is another related issue needed to complete the dose picture.
EXPERIMENT: A well-calibrated beam with known properties can be parasitically derived from the physics applications described in the previous section (Absolute Momentum and Momentum Spread Determination, in particular, although other applications comprise the same experimental setup). Users from the various interested facilities (LLUMC, MGH, NASA, UW for example) can use beam time to conduct their dose measurements and detector calibration experiments. Medical facilities such as LLUMC have charged for beam time in the past, and the demand was far greater than the limited beam time available.

Appendix B

Radiation Shielding for the
400 MeV Proton Beam Line
Kamran Vaziri

I have calculated the effects of skyshine, ground water activation, the lateral shielding, forward dump requirements and activation, access labyrinth attenuation, and induced activity in the planned 400 MeV proton beamline components. The parameters used in these calculations are the results of combined fits to experimental measurements and Monte Carlo calculations.

The present calculations are based on a 15Hz beam, with 1.3×10^{13} protons/pulse. An accident has been taken to be two full intensity pulses. It is assumed the beam pipe is 4 feet below a concrete roof, two feet away from one wall and six feet away from the other wall. The shielding requirements for a straight ahead dump have also been approximated and compared to the Monte Carlo calculations of M. Popovic. I have also calculated the shielding requirements for normal operations which corresponds to 10.% loss of a 100nA DC beam.

Skyshine

The dose rate from skyshine, H, at a distance r from the source is ;

$$H(r) = 3 \times 10^{-13} \frac{e^{(-r/\lambda)}}{r^2}$$

where H is in rem per neutron emitted and r is in meters. The neutron attenuation mean free path in air is energy dependent and it is 620 meters at 400MeV. The number of neutrons produced per 400MeV interacting proton is approximately equal to 2. It is also assumed that half of all neutrons are emitted into the upper hemisphere.
The dose rates at different distances from the source are;

r(meters)	10	20	40	50
Dose (mrem/pulse)	28	7.2	1.8	1.2
Normal loss (mrem/hr)	63	16.2	4.1	2.7
Dose (mrem/2 pulses)	56	14.4	3.6	2.4

These estimated doses will be observed, whenever the beam interacts with any target, *without any roof shielding* over head. The amount of shielding determined later on in this report will reduce these doses by several orders of magnitude. However, a gap between the roof shielding blocks can cause a problem in the vicinity of the experimental areas.

Lateral shielding

Even though the transverse dose rates around the loss point are azimuthally symmetric, the location of the beam pipe will determine the amount of shielding needed for the roof and the walls. For the roof I have assumed that it is 4 feet above the beam pipe. For the walls I have taken the case where the beam pipe is only 2 feet away from one of the walls, and 6 feet away from the other wall.

Table below gives the dose rates on the roof as a function of concrete shielding thickness;

Roof

Concrete thickness (ft)	3	4	5	12
Accident dose (mrem)	82	28	10	0.001
Normal Loss (mrem/hr)	93	32	11.3	0.16

Note that the normal losses dominate the accidental loss of two full intensity pulses. For the normal dose rates between 2.5 to 100 mrem/hr we are required to display "Radiation Area" signs and have fences with locked gates. It seems that between 4 to 5 feet of concrete shielding for the roof will be sufficient.

For the wall that is 2 feet away from the beam pipe, the dose rates outside the concrete shield are as follows;

near wall

Concrete thickness (ft)	7	8	12
Accident dose (mrem)	2.	0.7	0.018
Normal Loss (mrem/hr)	2.3	0.8	.31
Distance from shield (ft) for unlimited occupancy	18	8	2(0.25) 36(0.025)

Far wall

Distance from shield (ft) for unlimited occupancy	14	4	0 18(0.025)

An 8 feet thick concrete wall will require the experimenters' trailers to be parked 8 ft away from the near shield wall. A 9 feet thick concrete shield will render the parking lot unlimited occupancy status. As shown, similar shielding for the opposing wall will be unlimited occupancy.

Labyrinth Attenuation

A standard way of reducing the leakage of radiation through the beamline access tunnel is by constructing a multi-legged labyrinth rather than one straight tunnel. It is assumed (conservatively) that the beam loss is located directly opposite the labyrinth opening, in which case the source term can be estimated using

$$\Phi(90) = \frac{2\times10^{-10}\left(1-e^{-3.6E^{1.6}}\right)}{\left(90+40/\sqrt{E}\right)^2} \qquad \text{Sv/proton at 1 m,}$$

where E is the proton energy in GeV. The general attenuation of a labyrinth consisting of n legs and cross sectional area of A are given by

$$H_n = \Phi(90)\frac{\left(K\times A^{3/2}\right)^{n-1}}{L_1^2\left(L_2\bullet L_3\ldots L_n\right)^3} \qquad \text{Sv/proton at 1 m,}$$

where K is related to the scattering coefficient and the wall material concerned. For 400 MeV protons generating the above source term in a concrete labyrinth, K is about 0.26.

The labyrinth designed for this beam line consists of three legs. It has a rectangular cross section, six feet wide and eight feet high. The first leg is 18 feet long, the second leg is 20 feet long and the entrance door is placed 22 feet down the third leg. The dose rate due to normal losses (15 nA) on the beam line at the entrance to the labyrinth, is less than 0.25

mrem/hour. The number of protons per hour due to an accidental loss of three $1.3x10^{13}$ protons per pulse, is less than that due to normal losses.

Forward shielding/dump

The 400 MeV protons range in iron is about 15 cm. For a forward shield or dump, an iron cylinder core to range out the protons and an outer layer of concrete and/or soil will shield against the soft neutrons that can not be shielded by iron. I have calculated the shielding requirement for a dump made completely out of concrete. It is assumed that the full 100 nAmp DC beam will be dumped. It will require about 20 feet of concrete to reduce the dose rate to below 1 mrem/hr. The 400 MeV dump design by M. Popovic had a 200 cm iron core and 70 cm of concrete. This is equivalent to about 19 feet of concrete. Lateral shielding calculations also predict the same dose rate in the transverse direction as that obtained by MARS Monte Carlo calculation.

About 40 Joules per second will be deposited in the dump, when the normal beam is transported to the dump. The core temperature of the dump will rise by 0.26 °C per second. The heat transfer rate will be 0.19 Joules per second. Increasing the beam diameter by a factor of two will reduce the temperature increase to 0.07 °C per second and the heat transfer rate will be 0.1 Joules per second. Heat transfer through concrete should take care of this heat.

Induced activity in the dump

Activation of the beam dumps is influenced by the secondaries produced in the dump and hence depends on the incident proton energy. Taking a spallation mean free path of 132 $g\text{-}cm^{-2}$ for 400 MeV protons in iron and an induced activity gamma ray attenuation mean free path of 14.9 $g\text{-}cm^{-2}$, the induced activity dose rate factor per unit beam of energy E(MeV) will be

$$D_0 = 4.967 \times 10^{-16} E^{0.15} \qquad \text{Sv-h}^{-1}\text{per proton.s}^{-1}.$$

Assuming the same dump geometry as above, with a 90 cm diameter iron core with two whole separated by 4.5 ins. symmetrically placed around the core axis. One hole is straight through for the beam line and the other one is shallow. The end of the shallow hole is slanted to spread the beam over a larger area. The depth of the dump cavity should be enough to protect the upstream face of the dump. Below I will calculate the induced activity in the dump after a week (T) of continuous beam dumping followed by one hour of cooling down (t), using;

$$D = D_0 \Phi \times \ln\left(\frac{T+t}{t}\right) \qquad \text{Sv-h}^{-1},$$

where Φ is the beam flux in $protons/cm^2$-s. This quantity is calculated using an average current of 15nA, and an elliptical beam cross section of $2.54x1.27\ cm^2$. I have assumed the dimensions of the dump are those given in Milorad's abstract submitted to April '94 meeting of APS. Given the above equation, Dose rate at 1 m by induced radioactivity without shielding will be 58 mrem/hr.

This is the activity induced in the volume where the beam hits. There is at least 40cm of iron between the activated volume and the surface of the iron cylinder (ignoring the concrete layer). The mean free path for the average gamma energies of the activity in iron is 2.01 cm. Thus, 40 cm of iron will result in a dose rate of 0.26 nano-rem/hr. Obviously there won't be any problems on the side and down stream of the dump, due to the dump's self shielding. Only looking through the upstream hole will expose one to radiation. Since the attenuation length of gammas through air is a lot longer than it is through iron, making the hole deeper will not reduce the direct exposure significantly. The dump hole should be deep enough, so that we can use an iron plug to shield the people around it. A 10 cm hole with a plug of similar length will reduce the dose rate to 0.8mrem/hr, or a 14 cm hole with a plug of similar length will reduce the dose rate to 0.11mrem/hr. Note the dump hole does not have to be 14cm. We can have a 10cm deep hole with a 10 cm long plug that has a 4 cm thick cap.

Induced Activity Dose Rate Near the Beamline

Beamline elements are usually activated through the spallation reactions induced by high energy secondary hadrons, and by capture reactions particularly of thermal reactions. The average dose conversion factor from induced activity on the beamline components is about 220 fSv/hr at 1 meter from one Becquerel of activity. The dose rate at 1meter from a beamline for protons of energy E(MeV), at a time t days after irradiation with a beam loss of 1W/meter for a period of T days is given by,

$$D = 13E^{-0.08}\ln\left(\frac{T+t}{t}\right) \qquad \mu\text{Sv/hr.}$$

Using this relation, with seven days of beam operation, after one hour cooling the dose rate at one meter from the beam elements will be 4.1 mrem/hr. It will require 19 days of cooling after shut down for the dose rate from the beam line to reduce below 0.25 mrem/hr. Also one day cooling after a one year of beamline operation will reduce the dose rate to 4.8 mrem/hr at one meter. It will require three years of cooling for the dose rate from the activated beam components to get below 0.25 mrem/hr at one meter.

Air activation

The principal radioactive isotopes of immediate interest that are found in irradiated air are the short lived positron emitters that are produced in oxygen and nitrogen by spallation reactions. The cross section for the production of these isotopes is practically independent of the incident hadron energy above 100 MeV. The production of ^{41}Ar by thermal neutron capture in the natural argon in air has also to be considered in an overall assessment of the radioactivity in air. Only ^{13}N, ^{11}C, and ^{41}Ar are considered here. The other isotopes are too short lived, or do not cause a significant dose and therefore are not of interest here. A ventilation system that has a delay path of greater than 30 minutes from the production point to the release point will justify this short list. The combined production cross sections for each of the isotopes of interest are given in the table below. Assuming the proton beam is exposed to air at the dump or a production target, the equilibrium activity induced by a 150nA proton beam is also given.

Isotope	production cross section (mb)	Equilibrium activity (mCi)
^{13}N	9.8	1.4
^{11}C	9.0	1.3
^{41}Ar	640	0.35

For r air changes per hour, starting with an equilibrium activity A_0, and assuming that the transport of the radionuclide with take t hours, the activity outside the enclosure is

$$A(outside) = A_0 e^{-\lambda t} \frac{r}{\lambda + r}$$

where λ is the decay constant of the isotope in hr^{-1}. Figure 1 shows the long term average dose for different quantities of radioactive air released as a function of distance from the point of release, and assuming a very conservative average wind velocity of 1 m/s. The lowest curve on Figure 1 corresponds to 270 Ci activity release, and at 1 mile this dose reduces to about 19 µrem. If all of the above equilibrium activity is transported outside the enclosure (without decay) per second, this would amount to 3562 TBq per year. From Figure one - extrapolating to 1 mile - this will be equivalent to 4.4 mrem/year.

Ground water activation

The ground water activation does not seem to be a problem given the neutron flux densities involved with the 400 MeV proton beam. It seems that the amount of activation is very low and a sump pump to the surface water would probably be sufficient. Useful baseline information could perhaps be obtained from a study of whether any activation has occurred due to the operation of the 400 MeV LINAC, probably through the analysis of floor samples.

However, I will try to make an estimate using the new concentration model (TM-1851). From Milorad Popovic calculations of the dose in the soil under the 400 MeV dump, an estimation can be made of the activity transported to the aquifer.

The highest dose in the soil right under the dump was 0.90E-16 rems/proton. For the calculation of the radioactivation of soil this value has to be converted to star density per proton. I have taken Fermilab's standard thick soil value of 10.8E-6 rem/stars/cm3. For the adjusted distance to aquifer, I have assumed the proton line is at 740 feet above the sea level. The proton intensity was assumed to be 1E12 protons/second, which is slightly above the average of 160 nAmps DC beam. The final concentration of tritium at the site of some hypothetical (see model description in TM-1851) user is;

$C_{fi}=3.34 \times 10^{-3}$ pCi/ml/year.

The laboratory's limit is 20 pCi/ml/year. Note that this calculation is for tritium only which has a leaching rate of 90%. Activation due to ^{22}Na, which has a leaching rate of 13.5%, will be lower by a factor of 48. It should also be mentioned that the dose to star density conversion is for energies above 1. GeV, and this conversion factor may be decreasing with energy, but it is not physically possible to make 1000 times more stars with 400 MeV of kinetic energy.

Appendix C

Fermilab MS 306

February 23, 1994

To: Steve Holmes
Dave Finley
From: Chuck Ankenbrandt
Subject: Managing the 400 MeV Program

This is the written advice you requested about how Fermilab should manage its interaction with the proposed project to use available beam cycles from the Fermilab Linac for applications such as medical physics, atomic physics, health physics, accelerator physics, and/or detector development, testing, and calibration. (More detail about the nature of the proposed activities is and will be available elsewhere.) For brevity, and with tongue only partly in cheek, I refer to these proposed activities as "the 400 MeV program" in homage to the vigorous 400 GeV program of yore.

Since the lab has a lot of experience dealing with HEP experiments, a reasonable way to phrase the management question is this: To what extent are the procedures and policies that the lab has developed to manage its interaction with HEP experimental activities appropriate as is, or adaptable with minor changes, to the 400 MeV program? (Probably the most relevant experience is managing HEP test beam activities, and bureaucratic procedures related to test beam activities can be copied where appropriate.) Obviously, some bureaucratic adaptations will be necessary, but it seems to me just as obvious that new procedures should be invented only when necessary.

The proposed activities are different in various ways from high energy physics experiments. Besides the obvious differences in the physics, the individual activities proposed are typically smaller in scope and expense than a typical HEP experiment, even a smallish one; they tend to be programmatic, unlike many HEP experiments; and they are mainly directed toward applications rather than new fundamental insights about nature. Furthermore, the Accelerator Division is obviously the appropriate division to manage this program for a variety of reasons, whereas most of the experience in managing HEP experiments resides in the Research Division. These

Preliminary beam-line concepts have been developed. After the workshop, a few draft proposals and expressions of interest have already been received from potential outside users. This material should be pulled together, sharpened, and augmented to facilitate evaluation by the Director's Office and its advisors.

Just as with many HEP proposals, the experimenters will need significant help from laboratory staff (e.g. Wayne's World and other support groups) in developing the design; this is particularly true here because the proposition involves developing a new, albeit small and simple, experimental area. Preliminary consultations with such support groups will be a necessary part of the process of preparing a presentable package.

Although the proposition is not HEP, and although the PAC's expertise is heavily weighted toward HEP, the Director may still choose to seek the advice of the PAC on the proposition, if not to evaluate the merits of the physics, then at least to assure the PAC that the impact on the HEP program will be minimal. Or he might augment the PAC with a few consulting experts in the relevant scientific subfields and ask for an evaluation of the science. Or he might seek advice from a separate ad hoc committee of such experts. Undoubtedly he will request something like an Impact Statement from the Accelerator Division. (Putting objectivity aside for one sentence, I would hope that the Accelerator Division's impact analysis would display the same sort of can-do attitude as the Research Division brings to the proposals of HEP users.) In the present case, the Director may find the documentation useful not only for evaluation by advisory groups but also in approaching the DOE for supplemental funding or in seeking support from other agencies. The initial action from the Director's Office, assuming it is favorable, will presumably be like a Stage I approval of a small HEP experiment. The documentation to support such a decision would, I imagine, be at the level of what we in the accelerator business would call a conceptual design report.

Proceeding to Stage II approval essentially requires negotiation of a document like an MOU between the lab and the experimenters, i.e. a document spelling out costs, schedules, responsibilities of the institutions involved, etc. The sort of information needed for Stage II approval in this case will require that a real engineering design of the area be carried out, and this will require not just consultation with, but significant involvement of, Fermilab support departments

Manager should reside fairly high in the organization, so that the person can effectively represent the program to the rest of the organization. I further believe that, if the head of an existing department is to assume the responsibility of Program Manager, the Linac Department is the appropriate place to embed this activity because that department is directly and heavily impacted and is geographically contiguous. Ideally the beam-line physicist would join the Linac Department at this time if he or she is not already a member of it. (Even when the area is operational, the role of beam-line physicist may be time-consuming; although the beam is likely to be simple, frequent minor reconfigurations may be necessary to cope with the evolving demands of the program.) Embedding some of the responsibility for the area in the Linac Department would serve the purpose of helping a rather small department achieve "critical mass". Of course, support groups would be instrumental in keeping the area running smoothly.

I envision that the interaction with the experimenters would be analogous to the lab's interaction with test-beam users. The involvement of Program Planning, the Director's Office, and the PAC in the decision-making process about details of the program would normally be minimal or null. The experimental activities of a given set of users would be treated as an entity called an experiment and given an identifying designation, perhaps a T-number. Each experiment would have a spokesperson and would be covered by a simple MOU which could usually be mostly generic boiler-plate, i.e. a standard document with only a few paragraphs that are specific to the given activity. Each experiment would have a lab employee designated as liaison. The same person should be liaison for all activities of a given class, e.g. all activities related to medical physics; this would bring a degree of coherence to the management of the program and would simplify the coordination of related activities. If activities of all classes are approved, then there would be a total of three or four liaisons, one for medical, one for atomic, one for accelerator, and perhaps one for everything else.

The Program Manager would have line responsibility for the program, subject of course to the usual kinds of review by his superiors in line management. There ought to be a program committee which serves in an advisory capacity to the Program Manager. The program committee ought to include the liaisons, some outside users, and representatives of the Linac Department, the Accelerator Operations Department and Division Headquarters.

Appendix D

Project Definition Report

Eng. Project No. 4-1-28

Rev.0

June 1994

LINAC EXTRACTION

FACILITIES ENGINEERING SERVICES SECTION
FERMI NATIONAL ACCELERATOR LABORATORY
BATAVIA, ILLINOIS

Operated By Universities Research Association, Inc.
Under Contract with the United States Department of Energy

LINAC EXTRACTION
PROJECT NO. 4-1-28
PROJECT DEFINITION
COST ESTIMATE

Prepared by:

FERMI NATIONAL ACCELERATOR LABORATORY
FACILITIES ENGINEERING SERVICES SECTION
Eng. Project No. 4-1-28

June 1, 1994

Rev.0

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A. DESCRIPTION OF CIVIL DESIGN FEATURES

The Linac Extraction consists of placing a new concrete roof over existing access way for the Linac Enclosure. This existing access was originally built under Facilities Engineering Services Project No. 4-1-9 titled "Linac Enclosure Access". The access was built to provide for the removal of existing Linac Accelerator Cavities and the installation of the new Linac Accelerator.

The Linac Extraction has a cross section of 10'W x 12'H at the upstream end of the enclosure to 10'W x 9'H at the downstream end and is approximately 84' long. A personnel and equipment access is located near the downstream end of the enclosure a has a cross of 6'W x 8'H and slopes from the floor of the Linac Extraction Enclosure to grade. In addition a vertical access hatch (7'W x 12'L) with removable shielding blocks will be installed in the roof near the downstream end of the enclosure and will be utilized only for experimental equipment to large for access through the passageway. Support for two trailers including pier supports, electrical services and communication ducts will be installed to the south of the enclosure for use of the experiments conducted in the Linac Extraction and will be connected to the enclosure through a power and communication duct bank. The enclosure will be designed to support and will be constructed with 12' of dirt shielding providing unlimited occupancy

HVAC and electrical distribution have been included in this design similar to other bearr line enclosure found within Fermilab.

Process water was not included as part of the scope of the civil construction package costed with the technical components.

B. COST ESTIMATE BASIS

The basis for this estimate are the drawings in Appendix B dated June 1994 and .rbal discussions between the 400 MEV Collaboration and the Engineering and Plar ,roup of FESS. It is assumed that all construction will be competitive bid fixed pric ,tracts.

C. COST ESTIMATE METHODOLOGY

Unit prices are taken for Means and based on recent vendor quotes. All r ;ts are in 1994 dollars. Unit costs include the sub-subcontractors overhead and p' ut not the subcontractors overhead and profit.

D. COST ADDENDUM

SHIELDING ASSESSMENT DOCUMENTATION

The cost of shielding assessment documentation is included in engi. design, inspection, and administration, and to be accomplished by the A/E coı.

ESCALATION

No escalation has been factored into the total project cost at this time.

OVERHEAD AND PROFIT

Subcontractor overhead and profit is taken as 15%. This accounts for some upswing in the construction industry over the next several months but sill assumes favorable economic conditions for competitive bidding.

ENGINEERING, DESIGN, INSPECTION, AND ADMINISTRATION (EDI&A)

Engineering, design, inspection, and administration costs are consistent with DOE and FESS guidelines. Accelerator Division costs include A/E administration, design data input, project review and project administration. Title III assumes a Research Division field inspector, with all other Title III services provided by the A&E consultant. Safety personnel costs are assumed to be provided by the Accelerator Division. FESS assumes a maximum of 100 man-hours of its time will be expended on this project for project start-up and documentation filing at project closeout.

The total EDIA applied to the project is 21%. Breakdown by the various phase of design is listed below.

CDR	4%
TITLE II/III	17%
TOTAL	21%

CONTINGENCY

Contingency at this phase of design is taken at 20%.

E. COST ESTIMATE ASSUMPTIONS

The following assumptions were made and discussed with the 400 MEV collaboration.

1. The cost of the trailers, setting of trailers and the power and communication cabling are not included in this project.

2. All power required for the experiments can be taken from existing transformers and panelboards

3. All process water distribution (LCW, CW&S) piping cost are not included under the civil construction package.

4. No environmental studies or permitting is included except for NEPDES.

F. SCHEDULE

The following schedule is predicated on the assumption that a funding profile to match the construction needs will be established and maintained.

The schedule has been developed without consideration to the accelerator operation schedule. Work requiring accelerator beam off conditions is assumed to be accomplished during normal beam off conditions.

ACTIVITY	SCHEDULE
Approval to start Title II	0 DAYS
Completion of Title II	120 DAYS
Bids returned	150 DAYS
Notice to proceed (Start Construction)	180 DAYS
Accelerator Shutdown	215 DAYS
Completion of Project	330 DAYS

G. COST ESTIMATE SUMMARY

DESCRIPTION	PROJECT COST	OPERATING
Construction Cost	322,000	
Subcontractors OH&P @ 15%	48,000	
SUBTOTAL	370,000	
EDI&A @ 4%		15,000
EDI&A @ 17%	63,000	
SUBTOTAL	433,000	15,000
Contingency @ 10%	43,000	2,000
Management Reserve @ 10%	43,000	
TOTAL	519,000	17,000

FERMILAB F.E.S. COST ESTIMATE	Project: LINAC EXTRACTION	Status: PDR	WBS:	Project No.: 4-1-28	Date: 06/15/94	Rev. Date:	Page: 1/ 4

Project Engr.	Prices By	Qty By	Checked By
TL	JG	JG	

	PHASE 1 AMOUNT
SUMMARY OF CONSTRUCTION COSTS	
02 SITE WORK	37,000
03 CONCRETE	153,000
05 METAL	33,000
08 DOORS, WINDOWS, & GLASS	10,000
15 MECHANICAL	22,000
16 ELECTRICAL	13,000
SUBTOTAL	268,000
OVERHEAD & PROFIT @ 20.00%	54,000
SUBTOTAL	322,000
TOTAL CONSTRUCTION COST: $322,000	

FERMILAB F.E.S. COST ESTIMATE	Project: LINAC EXTRACTION	Status: PDR	WBS	Project No.: 4-1-28	Date: 06/15/94	Rev. Date	Page: 2/ 4

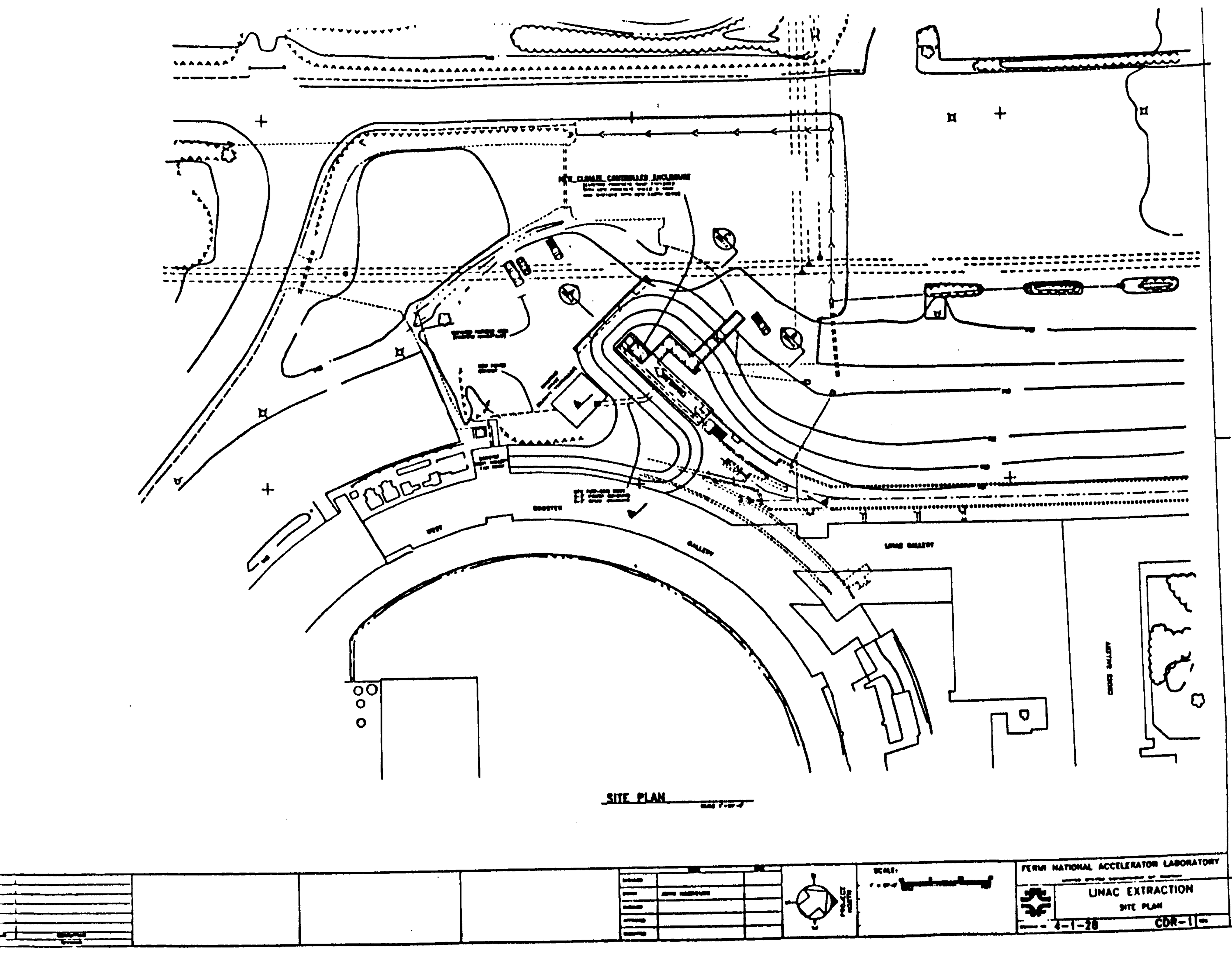
Item		Quantity	Units	Unit Cost	PHASE 1 AMOUNT		
02 SITE WORK	$37,000						
021 SITE PREPARATION	$7,000						
100 SITE PREP.	$7,000						
0011 Mobilize Equipment		1.00	Lot	2,000.00	2,000		
0012 Survey & Set Grades		1.00	Lot	2,000.00	2,000		
0013 Misc. Demo. & Utility Protection		1.00	Lot	3,000.00	3,000		
022 EARTHWORK	$29,500						
130 EXCAVATION & BACKFILL	$29,500						
0011 Excavate For Access & Retaining Walls		16.00	HRS	125.00	2,000		
0012 Backfill Earth & Build Berm		3400	CY	3.50	11,900		
0013 Load & Haul-In Earth Backfill		3400	CY	2.50	8,500		
0014 Gran. Backfill @ Walls, 2'x 13'x 85'x 2ea.		170	CY	30.00	5,100		
0015 Final Grading		16.00	HRS	125.00	2,000		
03 CONCRETE	$153,000						
033 CAST IN PLACE CONCRETE	$109,500						
130 CONCRETE, C.I.P.	$109,500						
0011 Ramp Slab, 1'-4"x 8'-8"x 79'		35.00	CY	220.00	7,700		
0012 Ramp Cap Walls, 2'x 8'x 65'x 2ea.		80.00	CY	300.00	24,000		
0013 Ramp End Wall, 1'x 5'x 15'		3.00	CY	400.00	1,200		
0014 Dowels Drilled		150	EA	20.00	3,000		
0015 Hatch Walls, 1'x 12'x 42'		20.00	CY	320.00	6,400		
0016 Enclosure Roof, 18"x 15'x 85'		75.00	CY	300.00	22,500		
0017 Ramp Enclosure Walls, 1'x 8'x 163'		50.00	CY	300.00	15,000		
0018 Ramp Enclosure Roof, 1'x 8'x 60'		20.00	CY	300.00	6,000		
0019 C.I.P. Concrete Shielding,Pumped, 3'x 9'x 19'		20.00	CY	220.00	4,400		
0020 C.I.P. Concrete Shielding, 4'x 11'x 15'		25.00	CY	180.00	4,500		
0021 Corr. Metal Deck		340	SF	1.60	500		
0022 Misc. Steel		1.00	Lot	2,000.00	2,000		
0023 Conc. Floor Ribs, 12"x 12"x 7'x 4ea.		1.00	CY	400.00	400		
0024 Misc. Concrete		20.00	CY	300.00	6,000		
0025 Waterstops		180	LF	8.00	1,400		
0026 Dampproofing		6000	SF	0.75	4,500		

FERMILAB F.E.S. COST ESTIMATE	Project: LINAC EXTRACTION	Status: PDR	WBS:	Project No.: 4-1-28	Date: 06/15/94	Rev. Date:	Page: 3/ 4

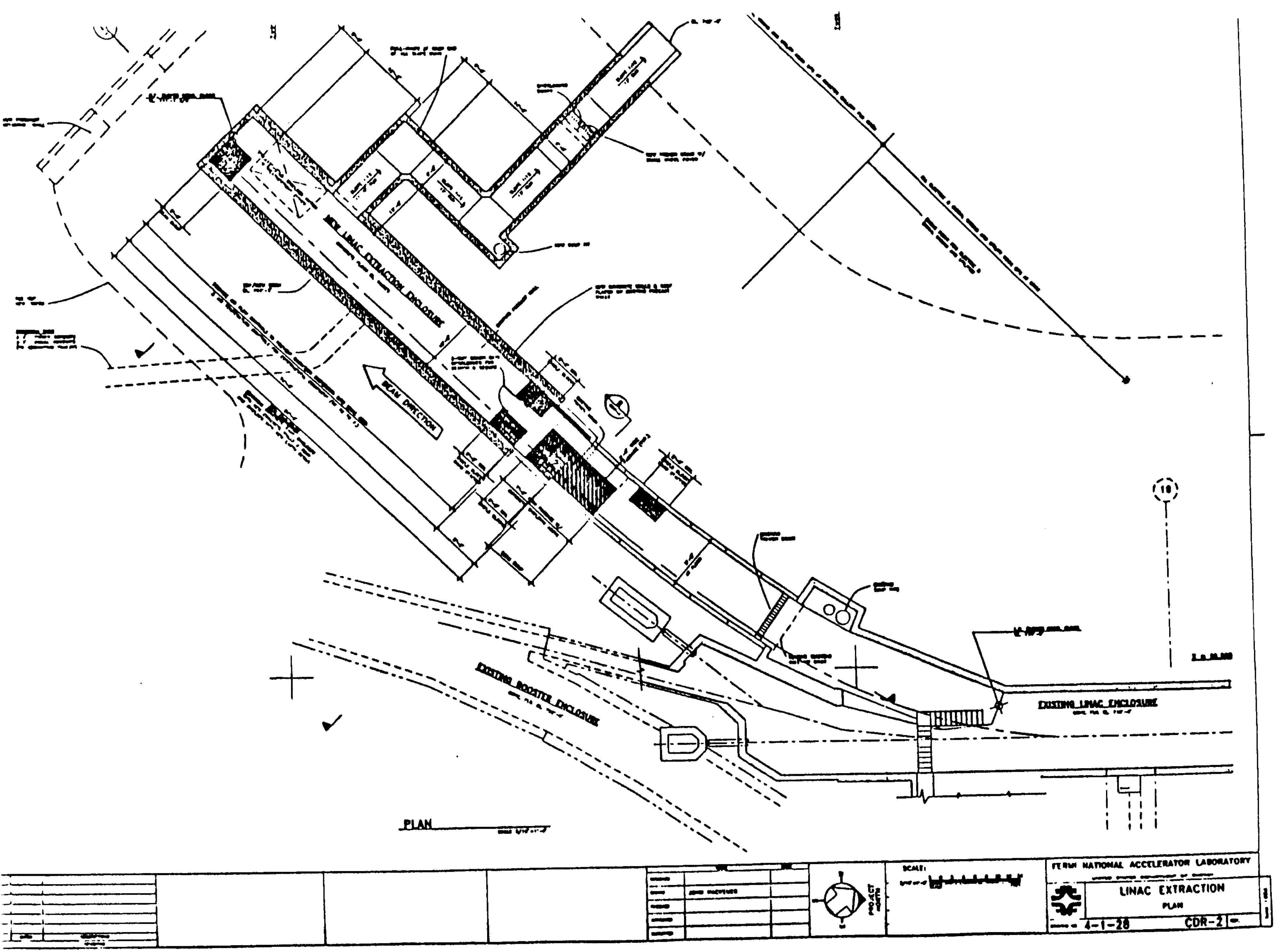
Item			Quantity	Units	Unit Cost	PHASE 1 AMOUNT		
034 PRECAST CONCRETE		$43,100						
100 PRECAST RETAINING WALL	$7,000							
0011 Precast "L" Units, 14'Lg.			5.00	EA	800.00	4,000		
0012 Haul-In & Place Precast Units			1.00	Day	3,000.00	3,000		
200 CONCRETE SHIELD BLOCKS, HAND STACKED	$3,500							
0011 Shield Blocks, 3'x 6'x 7'			5.00	CY	300.00	1,500		
0012 Haul-In & Hand Stack Shield Blocks			32.00	HRS	45.00	1,400		
0013 Truck			8.00	HRS	70.00	600		
210 CONCRETE SHIELD BLOCKS	$32,600							
0011 Shield Blocks, 6'x 7'-6"x 7'-6"			13.00	CY	300.00	3,900		
0012 Shield Blocks, 6'x 3'-6"x 7'-6"x 2ea.			12.00	CY	300.00	3,600		
0013 Shield Blocks, 5'x 5'x 7'-6"			7.00	CY	300.00	2,100		
0014 Hatch Blocks, 7'x 12'x 12'			40.00	CY	300.00	12,000		
0015 Haul-In Shield Blocks W/Flat Bed			24.00	HRS	100.00	2,400		
0016 Place Blocks W/Crane & Crew			3.00	Days	2,500.00	7,500		
0017 Handwork			24.00	Days	45.00	1,100		
05 METAL		$33,000						
055 METAL FABRICATIONS		$33,300						
100 STEEL SHIELDING	$33,300							
0011 Steel Shielding, 6'x 6'x 10'			95.00	Tons	200.00	19,000		
0012 Haul-In & Place Steel Shielding			95.00	Tons	150.00	14,300		
08 DOORS, WINDOWS, & GLASS		$10,000						
081 METAL DOORS & FRAMES		$9,900						
100 DOORS & FINISHES	$9,900							
0011 Steel Crash Door			1.00	Lot	1,000.00	1,000		
0012 6'x 7' H.M. Door, Interlocked			1.00	Lot	1,000.00	1,000		
0013 Steel Hatch Cover, 9'x 14'			1.00	Lot	4,000.00	4,000		
0014 Paint Enclosure Interior			4000	SF	0.60	2,400		
0015 Misc. Painting			1.00	Lot	500.00	500		
0016 Misc. Finishes			1.00	Lot	1,000.00	1,000		

FERMILAB F.E.S. COST ESTIMATE	Project: LINAC EXTRACTION	Status: PDR	WBS	Project No.: 4-1-28	Date: 06/15/94	Rev. Date	Page: 4/ 4

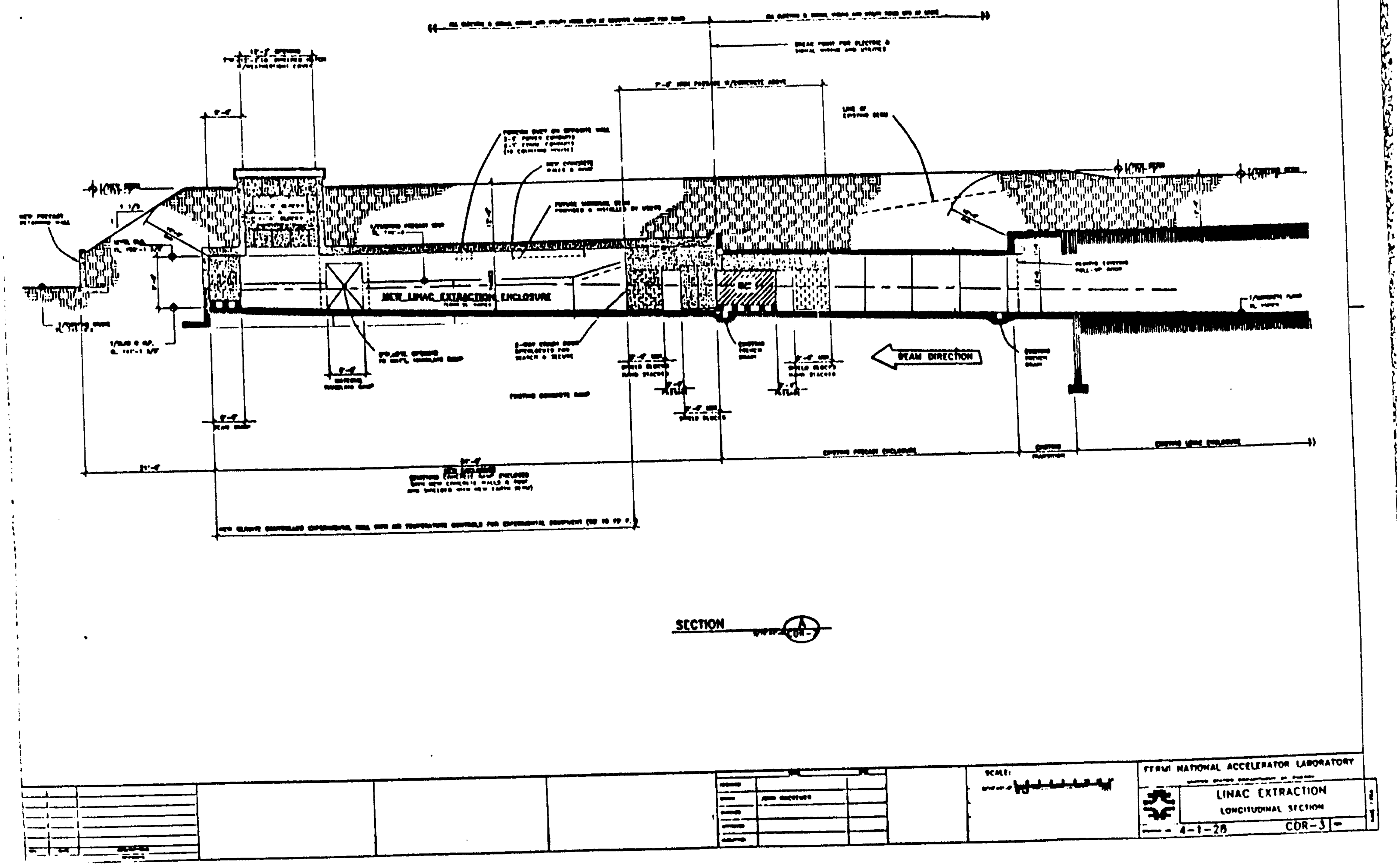
Item		Quantity	Units	Unit Cost	PHASE 1 AMOUNT		
15 MECHANICAL	$22,000						
151 PIPES & FITTINGS	$22,200						
100 MECHANICAL	$22,200						
0011 Trench Drain & Cover, 2,x 6'		1.00	Lot	1,200.00	1,200		
0012 Sump Pit W/Pump		1.00	Lot	1,000.00	1,000		
0013 6" Underdrains		300	LF	10.00	3,000		
0014 Exhaust Fan W/Sil. Pipe		1.00	Lot	2,000.00	2,000		
0015 Dehumidification & Climate Control		1.00	Lot	15,000.00	15,000		
16 ELECTRICAL	$13,000						
160 RACEWAYS	$13,300						
100 ELECTRICAL	$13,300						
0011 Misc. Panels		1.00	Lot	4,000.00	4,000		
0012 3/4" Cond. W/5#12		300	LF	7.00	2,100		
0013 Lights, 1x4 Fluor.		10.00	EA	160.00	1,600		
0014 Outlets, 110V		10.00	EA	100.00	1,000		
0015 Misc. Electrical Mod's.		32.00	HRS	50.00	1,600		
0016 8-5" Power/Comm. Duct, Conc. Enc.		50.00	LF	60.00	3,000		



UNAC GALLERY
CROSS GALLERY
BOOSTER
WEST
GALLERY
SITE PLAN
SCALE:
PROJECT NORTH
FERMI NATIONAL ACCELERATOR LABORATORY
UNAC EXTRACTION
SITE PLAN
4-1-28
CDR-1



NEW LINAC EXTRACTION ENCLOSURE
BEAM DIRECTION
EXISTING BOOSTER ENCLOSURE
EXISTING LINAC ENCLOSURE
PLAN
FERMI NATIONAL ACCELERATOR LABORATORY
LINAC EXTRACTION
PLAN
4-1-28
CDR-2
PROJECT NORTH
SCALE:


NEW LINAC EXTRACTION ENCLOSURE
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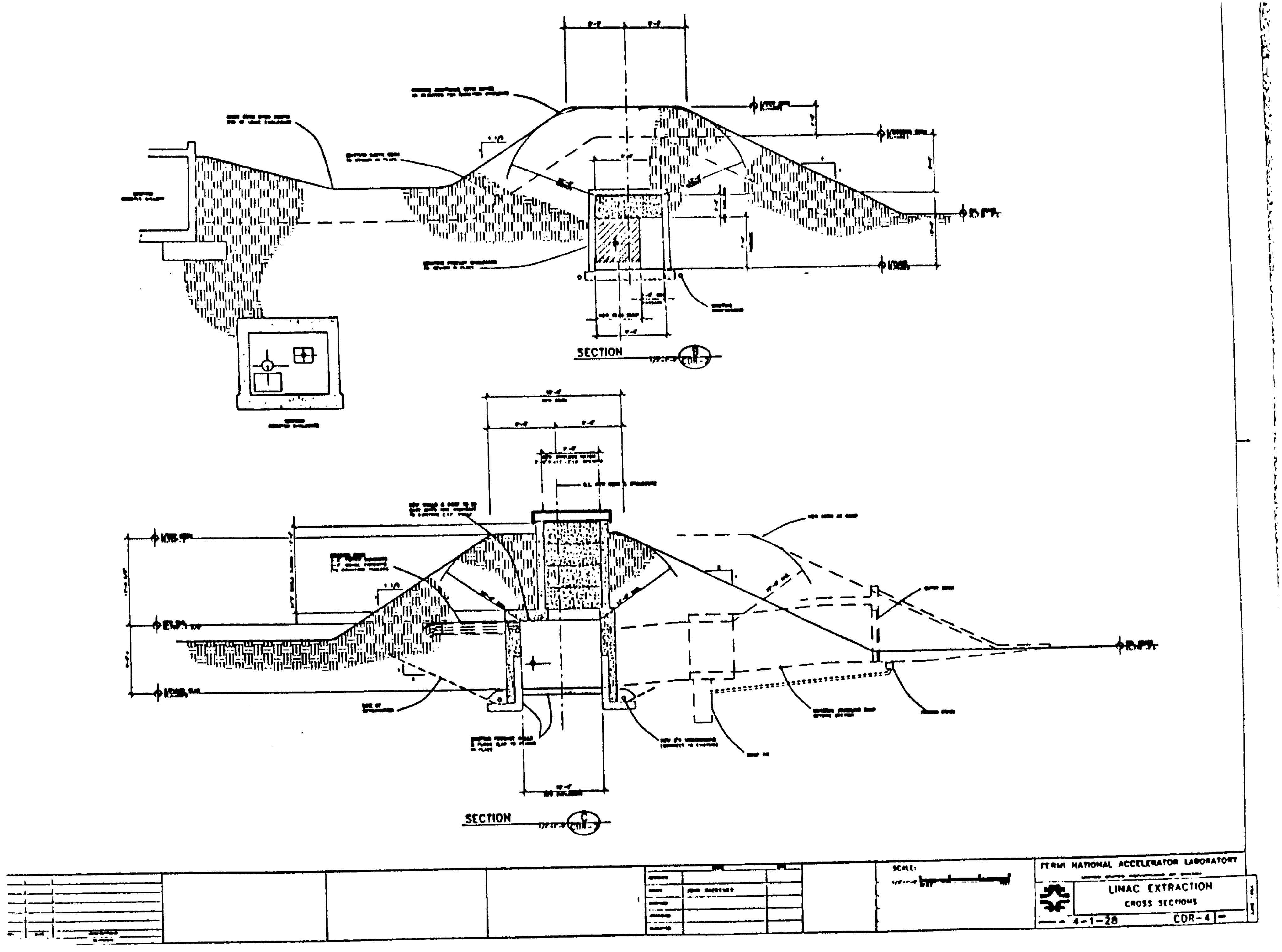
SECTION
FERMI NATIONAL ACCELERATOR LABORATORY
LINAC EXTRACTION
LONGITUDINAL SECTION
SCALE:
4-1-28
CDR-3


SECTION B
SECTION C
SCALE:
FERMI NATIONAL ACCELERATOR LABORATORY
LINAC EXTRACTION
CROSS SECTIONS
4-1-28
CDR-4