Material Procurement Report for the FNAL $\bar{p}p$
Forward Detector's Toroids and $\cos\theta$ Dipole Magnets

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Abstract

We outline the possibilities of starting construction of the $\bar{p}p$ forward detector toroids and $\cos\theta$ dipole magnets described in CDF Note 64 as soon as possible using material that already exists on the FNAL site. Personal inspection of the steel supplies indicates that as much as 2000 tons of steel or over 50% of all the steel needed for the toroids is now available at the FNAL boneyard. Copper inventories indicate that there is enough copper on the FNAL site to construct both the toroid magnets and the $\cos\theta$ dipole magnets.

A construction schedule of one toroid in FY81, two toroids in FY82, and the final toroid in FY83 is shown to be feasible. Floor space and loading requirements for the IR Hall housing the forward detector are examined and finally, budgets for the initial FY81 phase and the completed project are given. The FY81 costs are \$393K and to-completion costs are \$1506K.

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I. General Description

In this section we describe the general characteristics of the forward detector toroid and $\cos\theta$ dipole system. A complete description of the forward detector can be found in the Forward Detector Group's Note CDF #64 and $\bar{p}$ Note #78 of August 5, 1980, while a description of the central detector can be found in "Design of a Magnetic Detector Facility for Colliding Beams at Fermilab".

To obtain good muon identification out to 30° from the forward direction while keeping the toroid size "reasonable" requires that the first 25' diameter toroid be mounted no more than 16' from the IP. Each toroid is 40" thick with a 6-8" instrumentation gap between them so that the first set of toroids ends about 23' downstream from the IP. See Figure 1 for plan view details.

To sample the forward directions for hadrons, photons, and electrons out to 15° the forward set of two toroids have a 14' diameter aperture into which fits a $\cos\theta$ dipole magnet and some tracking chambers to momentum analyze the forward going hadrons, electrons, and muons. Downstream in the region from 23' to 39' are the various detection devices for hadrons/electron/photon identification and from 40' to 47' are the rear set of two toroids which provide muon ID and tracking from 0° to 15° . The 25' diameter of these toroids require that they be located no more than 40' downstream so that they provide continuous angular coverage for muons. We summarize in Table 1 below.

Table 1

Toroid Characteristics

diameter	25'
thickness	4'
weight (15° toroids)	300 tons
(0° toroids)	400 tons
total weight (8 toroids)	2900 tons
angular aperture	
inner	15°-30°
outer	0°-15°
B-field	18kGauss
Energy loss/toroid	1.2 GeV/40"
Interaction lengths	6.0
Radiation lengths	57
Measuring Stations	3

In Figure 2 we show a "beams-eye" view of the toroids and $\cos\theta$ dipole structure. The forward toroids are designed to split apart vertically to allow access to both the central detector and the forward detector as well as allowing installation of the $\cos\theta$ dipole unit. The dipole magnet is a 14' diameter, 8 1/2' long insert and weighs 127 tons.

In Figure 3 is shown the toroid in the split configuration. Each 350 ton unit is moved some 7 1/2' perpendicular to the beam direction providing an access of 15' minimum to about 24' maximum. The total width of the split toroid is 40' which allows 5' clearance on either side of the toroid if the building is made 50' wide at this point.

Figure 4 shows the floor plan for the forward detector with the split toroids in the "open" position. The present size of the building, whose dimensions are shown in the figure provide adequate, though none too spacious accommodations. However, shrinking the building as shown in the shaded areas might cause some access problems for the forward detector as currently designed. The hook of the 20 ton crane should if possible be able to access every portion of the building to within 8'-10' of each wall.

The $\cos\theta$ dipole structure is shown in place in the toroid aperture in Figure 2. It gives a 5 kG field in the horizontal direction over a 2 meter path for a transverse momentum kick of 0.33 GeV/c. It is constructed within a 12' diameter steel structure which provides both support and magnetic flux return thus keeping the entire unit both mechanically and magnetically separate from the toroids. Further details are shown in Figure 16. The unit is designed so that it too can be split down the middle. Provisions also have been made to allow an additional layer of trim coils to be added so that the field can be made as uniform as possible.

In order to gain experience with the magnetic and mechanical properties of the toroid and $\cos\theta$ dipole magnet system we are constructing a 1/12th scale model of the toroid-dipole system at U.W.-Madison. Complete magnetic measurements will be available from the 1/12th prototype in about three months.

II. Toroid Design

Figure 5 shows a plan view of the proposed detector. There are four large toroid magnets labeled 1-4 in the figure. Toroids 1, and 4 are B-types with small three foot inner aperture while Toroids 2, and 3 are A-types with a large 12 foot or 15° aperture. The toroids will be constructed similar to the E-310 24' toroids whose construction is shown in Figure 6.

Both types of toroids have an outside diameter of 25', for reasons described later under "materials", and are composed of two pieces or sub-toroids each 40" (1 meter) thick with a 6" gap between them to accommodate instrumentation. Each unit is about 8 1/2' thick, is made from 10-05 steel (low carbon) and weighs approximately 800 tons.

The type-A toroids are also designed to split apart vertically so that one may access both the inner and endcap detector regions. Each piece will weigh 400 tons and will be mounted on jacks and multi-tons so that it can be rolled in and out of position, and its height can be adjusted to compensate for any sagging of the floor.

a) Materials

We need some 3700 tons of low carbon 10-05 steel which is ideal magnet steel. It comes in standard size blocks of 40' x 50" x 8" weighing 28 tons, and 20' x 50" x 8" weighing 14 tons. All edges and surfaces are pretty flat so that by pre-selecting specific blocks the toroids can be constructed with a minimum of grinding. The grinding assures good mating of the surfaces and will allow the toroids to be driven to full magnetic excitation of 18 KG with about 110,000 amp-turns.

Both sets of toroids are constructed from their 50" x 8" x L' steel blocks where the maximum L is 12.5 feet. The exact length blocks needed, their placement and numbers are shown on the accompanying Figures 9-12. Each sub-toroid is six blocks high (50" dimension), and two blocks wide so that the unit is 25' high, and each is five blocks thick (8" dimension) so that the total thickness of each sub-toroid is 40". Each unit thus requires a total of 60 flame cut and machined blocks of various lengths which are detailed on the accompanying sketches. The total number of 20' and 40' blocks required to build the eight sub-toroids is:

94 40' blocks

80 20' blocks

or a total of 3645 tons.

i) FNAL Steel

From inventory sheets and personal inspection (see Figure 7) we have determined that some 1500 tons or about 40% of the steel

needed for the entire project is now available at the FNAL boneyard.

If we relax our requirements somewhat we can add an additional 500 tons of material bringing the total amount of material to 2000 tons or 50% of the forward detectors toroid requirements.

ii) Outside Vendors

The steel can also be provided by U.S. Steel from their Gary, Indiana plant and some of this steel is shown in Figure 8. It is identical in shape and composition to most of the FNAL Boneyard steel, the price was

\$197/ton	through	July 31, 1980
\$203/ton	through	September 30, 1980

We also have a verbal quote at this time for current steel prices and the price has increased to \$230/ton on November 1, 1980. Further increases to as much as \$250/ton are expected on January 1, 1981.

b) Fabrication

Figures 9 and 10 give the construction details for the A-type toroids. Each unit is two blocks wide, six blocks high, and five blocks deep. All circular surfaces are to be flame cut while all mating surfaces are to be machine ground to assure a good magnetic circuit. Only the 8" wide surfaces need such grinding since the vertical interface between the 8" vertically mounted slope runs parallel to the B field, and so that any air gaps are of little consequence - Figures 11 and 12 give similar construction details for the B-type toroids.

The drawings show that we have quadrant symmetry and that each of the five depth layers are identical. We determine the needs for one quadrant and multiply by 4 x 5 to obtain the total requirements per sub-toroid, and then multiply by four to determine the total number of pieces. We summarize the requirements and tabulate them in Table 2.

Table 2Steel Requirements - A-type Toroids

<u>Item</u>	<u># required/unit</u>	<u># total</u>	<u># blocks</u>	<u>type block</u>
9'	4 x 5 = 20	80	40	20'
12.5'	4 x 5 = 20	80	27	40'
6'	4 x 5 = 20	80	14	40'

B-type Toroids

9'	4 x 5 = 20	80	40	20'
12.5'	2 x 4 x 5 = 40	160	53	40'

Total Requirements

<u># blocks</u>	<u>type block</u>	<u>weight (tons)</u>
(40 + 40) = 80	20' (13.6 tons each)	1088
(27 + 14 + 53) = 94	40' (27.2 tons each)	<u>2557</u>
		3645 tons

The total tonnage required is 3645 tons. The total amount of steel in the toroids is calculated to be 2812 tons (Table 3) which yields a 23% waste factor, or some 833 tons. We note that the procedures shown in Figure 7, and 9 yield material efficiency of 0.74 for the type-A toroid, and 0.84 for the type B-toroid, or an average material efficiency 0.79. Since we have .05 waste in cutting to specific length we find the total material efficiency is 0.75. We expect nesting to bring the total material efficiency up to about 80%. It is the consensus of most fabrication people that efficiencies above 80% are difficult if attainable at all!

Table 3

Physical Characteristics (Sub-Toroids)

A-type

$$V = \pi(12.5^2 - 6.5^2) \times 3.33' = 1193 \text{ ft}^3$$

$$W = 1433 \times .25 = .25 \text{ tons/ft}^3 = 300 \text{ tons}$$

B-type

$$V = \pi(12.5^2 - 1.5^2) \times 3.33 = 1611 \text{ ft}^3$$

$$W = 1934 \times .25 = 403 \text{ tons}$$

Total Tonnage

$$4 \times 300 + 4 \times 403 = 2812 \text{ tons}$$

To date, nine heavy steel fabrication plants in the Chicago area have been contacted and five have shown interest in the project. We have received the following responses:

Danly Machine	\$202K
Verson Press	\$666K
Lasker Boiler	\$644K
Rexnord	\$750K
Whiting	\$274K

Checking this E-310 history these bids look consistent. We find Verson to be historically a higher bidder. Extrapolating the Danly bid on E-310 of \$55K by 40/9 or the ratio of the number of toroid layers we find them to be very consistent with 1974 prices. Danly did the construction of the E-310 toroids.

c) Transportation

Current information yields cost of transport from U.S. Steel Gary to the Fabrication Mill, then to FNAL to be about \$75K either by rail or truck. Assuming much of the steel would be coming from FNAL would not alter these costs very much since the U.S. Steel to Fabrication Mill and Mill to FNAL distances are similar and the same loading and off-loading problems persist.

d) Support Design for Movable Toroids

Splitting the toroid magnets along the vertical diameter and moving them out of the beam line requires designing a supporting structure that will withstand the weight of the structure and provide stability against over-turning moment due to inertia forces and a guiding system ("rails") that allows the movement of the semi-toroids in and out of the beam line. A solution (I) to such a support structure is shown in Figure 13a. This solution is less dependent on the foundation than the one shown in Figure 13b (solution (II)), it is relatively expensive as shown; with structural steel plates 3" thick.

However, it is possible at least in principle to make this beam out of reinforced concrete with some wearing plate around it. The main objection of course is that a large beam would block the passage of particles across the floor in the 45' direction of the building up to 52 1/2" height.

Solution II is definitely less expensive and only blocks passage of particles immediately beneath the semi toroids. However this solution requires that the floor slab would have a substantial moment and shear capacity, which is likely to be provided only if the foundation is going to be the flat slab type instead of the caisson type or if the floor will have at least a grid system which of course is a good approximation of a flat slab. This limitation should not be too severe since some preliminary analysis indicates that with a subgrade modulus of $200\#/in^3$ (minimum @ the building site location according to soil testing lab) the deflection can be less when a slab is used in place of a series of a caissons.

III. Toroid Coils

To push the toroids to full excitation of 18 kG requires an $Ni = 110,000$ amp-turns assuming $\mu = 200$, and $r = 2.5$ meters.

$$B = \mu \frac{Ni}{2\pi r} = \frac{200 \times 4\pi \times 10^{-7}}{2.5 \times 2\pi} \times 1.1 \times 10^5 = 1.76 \text{ tesla}$$

Assuming 1000 amps, we then need 110 turns, and present plans call for the coils being wound as shown in Figure 14 to facilitate the splitting of the A-toroids. We plan to use an extruded copper tube with water cooling of dimensions shown in Figure 15 and which is on site at FNAL. This design was used on the E-310 24' toroids, which are nominally run at 1000 amps, so that the design changes anticipated are minimal. If the excitation scheme shown does not produce a decent field, then we will go to the four coils scheme which is also shown in Figure 14.

The materials needed for the coil fabrication already exists at FNAL. At present there is 127K' of copper conductor of dimension .825" x .625" with a 1/4" diameter channel for cooling (see enclosure A).

For the toroids we need referring to Figure 14

	<u>per toroid</u>	<u>total</u>
A-toroids:		
at 28' per turn x 110 turns =	3080'	6160'
B-toroids		
at 37' per turn x 110 turns =	4070'	8140'
or a total of 14,300' or 12.8 tons of conductor.		

We summarize our needs as:

Table 4

Toroid Coils

B	18 kGauss	
Amp-turns = Ni	110,000	
No. of turns	110	
Current	1,000 amps	
Current density	333 amps/cm ²	
Conductor	.625"x.825" with 1/4" diameter hole - copper	
Resistance per turn	.49 mΩ for A-type	.647 mΩ for B type
Volts/turn at 1000 amps	.49 volts	.647 volts
Power/turn at 1000 amps	490 watts	647 watts
Coil area	50.2 in ²	18x6 matrix = 108 turns
Coil width	14.85"	
Coil thickness	3.75"	
Length/turn	28' for A toroid	37' for B toroid
Power	53.9 KW	71.2 KW
total amount of copper	14,300 feet	
weight at (1.79 lbs/ft)	12.8 tons	
cost at 3.32/ft	\$47.5K	
fabrication costs	\$30K	

IV. Cos θ Dipole Magnet

Momentum analysis in the forward spectrometer is provided by a quasi cos θ dipole, located in the inner aperture of the wide angle toroid. A pure cos θ dipole provides a constant and uniform B-field everywhere within the current carrying volumes. For further details see the analysis in Appendix A. The magnet is 7' long and provides a 5 kilogauss field over a width of about 12'. It is of a modified cos θ construction being essentially a distorted solenoid window-frame magnet with the possible feature of adding a second layer of trim coils if needed to bring the magnets field as close as practical to that of a perfect cos θ field. Both longitudinal and transverse cross-sections are shown in Figure 16.

The coil consists of 1000 turns, being 8 layers deep with 125 turn per layer. It is 103" wide subtending an angle of 90° with respect to the beam pipe and is about 6" thick. The winding are from the material shown in Figure 15. The amount of material required is about 52K feet or same 46.5 tons. This material already exists on the FNAL site as outlined in enclosure A. We summarize below in Table 5.

Table 5
Cos θ Dipole Magnet

B	5 k Gauss
Volume	12' diameter x 8 1/2' length = 21 m ³
Number turns	1000
Current	1500 amps/turn
Current density	500 A/cm ²
Resistance/turn	.773 milli - Ω
Volts/turn at 1500 Amps	1.16
Power/turn	1.74 kW
Coil Area (effective)	465 in ²
Coil Width	103"
Coil thickness	5"
Length/turn	52'
Coil Mass	46.5 tons
Power	1.74 MW/magnet
Total amount of copper	52,000'/magnet
Material cost \$3.32/ft	\$172.6 K/magnet

The magnet will need a power supply that will deliver some Vi combinations of 1.74 MW and the coils can be designed so that by jumpering various coils in parallel arrangements the total resistance can be made to match any supplies.

V. Building Floor and Crane Requirements

Figure 17 shows the floor plane for the entire $\bar{p}p$ detector facility. For building sizes we have used the dimensions quoted in a CDF note of September 19, 1980. We understand that revised drawings of October 16, 1980 call for reducing the length of the wide portion of the hall from 60' to 50'. These reductions are shown shaded in the figure.

Inspection of the floor plan shows that the original hall dimensions though adequate are none too spacious, but sufficient to allow "uncumbered" accesses to all parts of the forward detector via lifts, etc. as well as allowing one to transport electronics, power supplies and other apparatus around from one part of the detector to another to aid in "debugging" and other general construction and maintenance programs.

To shrink the building in the two proposed spots would cause some crowding in two areas. First the forward toroids in the split apart position would be extremely close to the wall ending the wide portion of the IR Hall, blocking all access into that part of the hall for anything but the lightest equipment, as well as any sort of auxiliary support structures. Secondly moving the back wall near the tunnel entrance in 10' on each end reduces the distance between it and the rear toroids to less than 5'. Here we also have the same crowding as above.

Figure 17 also gives the weight or floor loading requirements of the forward detector. The wide angle toroid and $\cos\theta$ dipole system weighs 720 tons and split vertically at the beam line and moves out perpendicular to the beam

line to the position shown in order to achieve reasonable access to both the central detector and forward detector each half can be moved 7.5' from the beam to a point 5' from the wall. The 50' building width at this point is pretty much the minimal width that guarantees good access. We note that the floor structure has to be designed to support 360 tons half-toroids out to this displaced position.

To conclude, inspection of Figure 17 shows that it would be desirable to have crane coverage over an area of $\pm 15'$ perpendicular to the beam and $\pm 50'$ along the beam direction though most of the component blocks of the toroids weigh about 10 tons it would be possible to have some 16-17 ton blocks so that a 20 ton crane is desirable. Finally since the forward detector has both lead shower counters and steel hadron calorimeters of large weight and dimensions the possibility of component parts exceeding 10 tons is very likely so that again a 20 ton crane seems the preferred choice.

We summarize below

Table 6

Building, Floor, and Crane Requirements

<u>Building</u>	length	120'
	width	36'
	central section length	60'
	central section width	50'
<u>Floor Loading</u>	Forward toroid and dipole	720 tons
	shower and hadron calorimeter	600 tons
	small angle toroid	800 tons
<u>Crane</u>	20 tons, hook to travel	
	$\pm 50'$ along the beam and	
	$\pm 15'$ perpendicular to the beam.	

VI. Schedule

In Figure 18 we present the times needed for the various construction phases of the toroids and their coils. From initial design to final check-out a toroid coil system requires about 30 weeks or 7 months. The most time consuming aspects are:

a) Bid Package Response

It is estimated this process can take 6-8 weeks during which nothing can proceed. It hopefully only has to be done once.

b) Fabrication

The total job of fabricating all the toroids is estimated to be 2-3 months for flame cutting and 8-9 months of 1 shift/day on a planer. This yields the 3 weeks and 8 weeks shown on the chart for flame cutting and planing a single toroid. With luck this work would proceed in parallel with other tasks, or possibly more than 1 toroid can be fabricated at a time.

c) Installation

Using E-310 experiences we figure that it will take 3 welders and a millright about a month to construct one toroid in place. The "split-apart" toroids will take more time, possibly 5 weeks due to their more complicated stacking procedures and need for a break-apart stand and track arrangement.

d) Transportation

Trucks normally carry 20 ton loads, railroad cars carry 30 ton loads, so that a 400 ton toroid would require 20 truck trips which could be conveniently spread over a 3 week period. This would solve some of the storage problems at the fabrication mills.

We summarize in Table 7 below.

Table 7
Summary of Schedule

	<u># of weeks</u>
<u>Toroid</u> - Engineering and Design	2
Drafting - Bids Out	4
Fabrication - bid response	6-8
Fabrication flame cut	3
planing	8
Transportation to fabrication	3
to FNAL Site	3
Installation	4-5
 <u>Coils</u> - Design	 2
drafting - bids out	4
Coil fabrication bid response	6-8
Coil fabrication	6-8
Coil transport	2-3
Coil testing	2
 Total time required per toroid	 30

(See Figure 18 for details)

VII. Summary of Costs

All costs shown are of two types

- a) hard bids at current prices from at least two vendors
(underlined)
- b) extrapolations from the 1975 experiences and cost
records for construction of the E174 magnets.

Table 8

1.	PSL engineering and drafting	10K
2.	Steel 3645 tons at \$230/ton	<u>839K</u>
3.	Transportation (rail or truck)	<u>75K</u>
4.	Fabrication (flame cutting machining)	250K
5.	Installation at FNAL (Belding Engineering)	120K
6.	Coil materials (these materials may be on FNAL site)	<u>47.5</u>
7.	Coil fabrication	40K
8.	Coil installation	5K
9.	Support structures	<u>120K</u>
Total Cost (Estimate)		\$1506K

VIII. FY81 Construction

A modest phase I proposal calls for the construction of one of the wide-aperture toroid units in FY81. The FNAL Boneyard has all of the steel needed for such a project and all of the copper needed for the coils. Such a project would take about six months to complete and would serve to familiarize all parties concerned with the problems of building large toroid magnets. We list the phase I costs below.

Table 9

Phase I Costs

1. PSL Engineering and Drafting	10K
2. Steel (FNAL-900 tons)	207K
3. Transportation	20K
4. Fabrication	65K
5. Installation	30K
6. Coil Materials (FNAL Site)	7.5K
7. Coil Fabrication	12K
8. Coil Installation	2K
9. Supports	<u>40K</u>
Total	393K

Appendix A

R. Morse
 pp Note
 September 17, 1980

Cos θ -Dipole Magnets

I. General Characteristics

A "cos θ -dipole" magnet is constructed by arranging the windings such that the shaded regions shown in Figure 1 carry a uniform current density in opposite directions along the $\pm z$ directions.

The field produced by such a configuration is uniform everywhere within the current carrying region, and it is directed in the y-direction with field strength.

$$B = \mu_0 J a$$

This result is derived in Section II.

This configuration is produced by displacing two circles of radius "b" a distance "a" from their common center in opposite directions along the x-axis. Here $\mu_0 = 4\pi \times 10^{-7}$, J is the current density in amps/m² and 'a' is the displacement. Note the maximum coil thickness is 2a.

The cross-sectional area of this current carrying region is given to good approximation by (See Section III for details)

$$A = 4ab$$

so that the total current or number of amp-turns is

$$Ni = 4abJ$$

from which we obtain

$$B = \mu_0 \frac{Ni}{4b}$$

To relate this result to something more familiar we consider a solenoid whose field only at the center is given by

$$B = \mu_0 \frac{Ni}{\ell}$$

In Figure 2 we show a cross-sectional area of the solenoid, whose field is not uniform or pure-dipole within the current

carrying region.

$$Ni = JA = J\ell w$$

$$B = \mu_0 Jw$$

Fig 2

Finally we note that for the same number of "ampere-turns"
 $Ni = JA$ or the same coil cross-sectional area and current densities
 that

$$B_{\cos\theta} = \frac{1}{2} B_{\text{solenoid}}$$

One can see this most simply by noting in Figure 1 for $\ell = 2b$
 and that

$$B_{\cos\theta} = \mu_0 \frac{Ni}{4b} = \mu_0 \frac{Ni}{2\ell} = \frac{1}{2} B_{\text{solenoid}}$$

II. Derivation of "Cos θ Dipole" Field Strengths

a) We want to determine the magnetic field strength inside
 of a wire of radius "b" carrying a current i as shown in Figure 3.

Fig 3

$$\begin{aligned} \nabla \times \mathbf{B} &= \mu_0 \mathbf{J} \\ \int \nabla \times \mathbf{B} \cdot d\mathbf{S} &= \mu_0 \int \mathbf{J} \cdot d\mathbf{S} = \mu_0 i_{\text{enc1}} \\ &= \int \mathbf{B} \cdot d\mathbf{\ell} = \mu_0 i_{\text{enclosed}} \end{aligned}$$

where we are careful to integrate the equations only over the
 surface S and including only that current inside the enclosed
 area. This yields using the density $J = i/\pi b^2$ the result.

$$\begin{aligned} B(2\pi r) &= \mu_0 \left(\frac{i}{\pi b^2} \right) \pi r^2 \\ B_\phi &= \frac{\mu_0 i}{2\pi b^2} r \hat{\phi} \end{aligned}$$

The field grows linearly in r and circles the wire as shown.

Using

$$B_{\phi} = (\nabla \times A)_{\phi}$$

and $\vec{J} = J\hat{z}$, since J is confined solely to the z -direction we obtain

$$B_{\phi} = - \frac{\partial A_z}{\partial r} = \frac{\mu_0 i}{2\pi b^2} r \phi$$

which yields a vector potential that is solely along z and equals

$$A_z = - \frac{\mu_0 i}{4\pi b^2} r^2 \hat{z}$$

inside of the wire.

b) We now calculate the vector potential in the overlap region for two partially intersecting wires carrying currents i in opposite directions as shown in Figure 4.

$$A_z = - \frac{\mu_0 i}{4\pi b^2} (r_1^2 - r_2^2) \hat{z}$$

where

$$r_1^2 = R^2 + a^2 - 2aR\cos\theta$$

$$r_2^2 = R^2 + a^2 + 2aR\cos\theta$$

and their difference yields

$$r_1^2 - r_2^2 = -4aR\cos\theta$$

Fig 4

and the total vector potential at R for these two equal but opposite currents is

$$A_z = \frac{\mu_0 i}{\pi b^2} aR\cos\theta \hat{z} = \frac{\mu_0 i}{\pi b^2} ax\hat{z}$$

Using $B = \nabla \times A$ we obtain

$$B_y = \frac{\partial A_z}{\partial x} = \frac{\mu_0 i}{\pi b^2} a \hat{y}$$

which is a constant field in the y-direction everywhere inside of the intersection regions. Since there is no current in this region we need no material. Thus to generate this field we only need to get opposite currents of uniform density flowing in the non-intersecting or shaded regions shown in Figure 4.

c) We now convert the expression to something more familiar by noting

$$J = \frac{i}{\pi b^2}$$

and this yields

$$B = \mu_0 J a$$

To obtain the total number of amp-turns needed we note that

$$N_i = J A$$

where A is the area of one of the crescent shaped areas in Figure 4.

To good approximation this area is given by

$$A \approx 4ab$$

so that

$$B = \mu_0 J a = \mu_0 \left(\frac{N_i}{A} \right) a = \frac{\mu_0 N_i}{4b} = \frac{\mu_0 N_i}{2D}$$

where "a" is the displacement, "b" the radius, and 'D' the vertical diameter of the coil system.

III. Conduction Area

To calculate the crescent shaped conduction area, and thus the general magnet dimensions we refer to Figure 5 and note that Area-IV, the area of interest is given by

$$\begin{aligned} A_{IV} &= A_{\text{circle}} - A_{II} - A_{III} \\ &= A_{\text{circle}} - 2A_{II} \end{aligned}$$

Fig 5

which is just the shaded area shown in Figure 6.

This area is given by

$$A = 2 \int_{x=0}^{x=a} \sqrt{b^2 - x^2} dx$$

$$= 2b^2 \left[\frac{a}{b} \sqrt{1 - \frac{a^2}{b^2}} + \sin^{-1} \frac{a}{b} \right]$$

$$\approx 4ab \text{ for } a/b < 0.5$$

Fig. 6

All distances are in feet

RM 10/14/80

Scale 1/4" = 1'

← this semi-toroid shown in the "split apart" position
Fig 1

toroid
coils

coils
flux
return

CDF

Flux return, conserve & so
 $B_0 l_0 = B_{lin} l_{lin}$
 $B_{lin} = B_0 \left(\frac{l_0}{l_{lin}} \right)$

Dipole = $d = 12' = 3.66 \text{ m}$
 $\ell = 8\frac{1}{2} \quad 2.6 \text{ m}$

RM 10/16/80

Scale $1/4" = 1'$

Fig 2

50

45

Fig 3

40

35

30

25

20

15

10

5

0

COF

1050
pole magnet
diffusion

COF

7 1/2

1000
pole

PM 10/16/20

Scale 1/4" = 1'

$$\tan 15^\circ = .27$$

Scale $1/8" = 1'$

Fig 5

Fig 6

FINAL FIG 7
BONEYARD
STEEL

US STEEL
'GARY'

Fig 8

$$\text{material} = 4 \times 4 \times (9 + 12 + 6.0)$$

$$= 4 \times 4 \times 27 = 432 \text{ units}$$

A- Type

Roll weight = 300 tons

Fig 9

A-type

60 pieces required
per sub-toroid

steel size
20' x 50" x 8"

Fig 10

$$A = \pi(12^2 - 1.5^2) = 445 \text{ units}$$

$$\text{material} = 4 \times (9 + 12 + 12) \times 4 = 528 \text{ units}$$

$$\text{waste} = 83 \text{ units}$$

$$\% \text{ usage} = 445/528 = 84\% \text{ (intrinsic)}$$

B-type

$$\text{Weight} = 800 \text{ tons}$$

$$\text{half weight} = 400 \text{ tons/piece}$$

Fig 11.

B-type

Fig 12

NATIONAL BUREAU OF STANDARDS NATIONAL RESEARCH LABORATORY WASHINGTON, D. C. 20540	
TITLE PROJECT NO. DRAWING NO. DATE	DESIGNED BY CHECKED BY APPROVED BY SCALE

Fig 13 a

Toroid Coil Placement and length requirements

A-Type Toroid

B-Type Toroid

We show both the 2-coil and 4-coil toroid excitation scheme. $Ni = 110,000$ amp-turns with a design current $i = 1000$ amps.

A-type

B-type

DO NOT SCALE

Fig 14

Material Specifications

1. Copper Alloy No. 102. ASTM Spec B188-66a
2. 100% IACS minimum.
3. Soft annealed Rockwell E-45 maximum as delivered to coil fabricators.
4. Bright annealed or pickled.
5. All surfaces including hole shall be free from slivers, burrs, scale, restrictions, or any other surface defects.

$$A = .625 \times .825 - \pi/4 \left(\frac{1}{4} \right)^2 =$$

$$A = .5156 - .0491 = .4665 \text{ in}^2$$

$$R = 1.742 \times 10^{-5} \Omega/\text{ft.}$$

$$\rho = 1.72 \times 10^{-8} \Omega\text{-in}$$

Engineering Reference Numbers:

R = 17.5 micro ohms/ft. Nominal @ 20°C

R = 18.85 micro ohms/ft. Nominal @ 40°C

Weight = 1.79 #/ft.

Area = .4665 sq. in. Nominal copper cross sections

NOTES—UNLESS OTHERWISE SPECIFIED	FINISHES	DRAWN	MANDLEY	MATERIAL
1. TOLERANCES ON DIMENSIONS ± 2. BREAK EDGES 1/64 MAXIMUM 3. 30° CHAMFER ENDS OF ALL SCREW THREADS 4. 1-1/2 PITCH THREAD RELIEF WITH ROUND NOSE TOOL ON ALL MACHINE CUT SCREW THREADS 5. ON WELDMENTS REMOVE SHARP EDGES, BURRS, LOOSE SCALE AND WELD SPATTER 6. VISUAL COMPARISON OF FINISHES WITH G. E. "SURFACE ROUGHNESS SCALE" NO. 8665947G1 IS ACCEPTABLE.	SAW CUT FLAME CUT SHEAR	*	CHK'D	NEUTRINO EXPERIMENT E-1A
			APPR'D	24 MAGNET
	ROUGH MACHINE	250/	NO. REQ.	MAIN COIL CONDUCTOR
	AVERAGE MACHINE	125/	USED ON	PHYSICAL SCIENCES LABORATORY UNIVERSITY OF WISCONSIN
	SMOOTH MACHINE	63/	1625D009	
			1625D022	
			SCALE 2=1	1625A010
			DATE 11/20/74	

pp Forward Detector Cos θ dipole magnet

ID = 12' = 3.65 m
length = 8 1/2' = 2.6 m
NI = 1.5 x 10⁶ amp turns.
1000 turns
1500 amps.

B = 5000 Gauss

14'

coil 5" thick = 8 turns, deep
103" wide = 125 turns/layer.
 $\theta = \frac{103''}{66''} = 1.56 \text{ rads} = 90^\circ$

RM 10/16/80

Scale 1/4" = 1'

Volume = 1300 ft³

Weight = 126 tons. - total

Weygote = 86 tons
Copper = 40 tons

8 1/2'

Cos θ Dipole

Fig 1

IR Hall Space and

Floor loading requirements.

Scale $\frac{1}{4}'' = 5'$

10/21/80

RM

Fig 17

Forward Detector Toroids Schedule - Weeks

Fig 18

Fermilab

E-WON

February 18, 1977

Enclosure A

TO: DISTRIBUTION

FROM: E. L. Kneip ~~E-L~~

SUBJECT: Available Lamination Steel and Copper Conductor.

This memorandum is generated to advise possibly interested Laboratory groups of the present inventory status of lamination steel and copper conductor under the physical control of Engineering Services. Except as noted, this material is available (on a transfer of fund basis) for use on Laboratory projects. Interested parties can contact Ed Kneip, extension 4077.

Lamination Steel, 13 3/8" x 117" x .0625"

Released to Energy Doubler/Saver:

10,332 sheets stored at Sanderson Industries.
16,368 sheets stored at Fermilab.

Available for other projects:

4,920 sheets stored at Fermilab.

Material is stored by bundle of average 333 sheets count.
Material cost is \$.17 per pound (\$4.74 per sheet).

Lamination Steel, 17 3/4" x 118" x .0625"

Material stored at Fermilab available for any project use:

9,812 sheets

Material is stored by bundle of average 199 sheet count.
Material cost is \$.17 per pound (\$6.27 per sheet).

Copper Conductor, .920" x .570" x .250" dia. hole

Available for any project use:

20,280 feet

Material is stored by crates of average 10 rolls per crate, 90 feet per roll. Material cost is \$2.08 per pound (\$3.75 per foot).

Copper Conductor, 1.063" x .559" x .250" dia. hole

Available for any project use:

20,816 feet

Material is stored by crates of average 10 rolls per crate,
90 feet per roll. Material cost is \$2.02 per pound
(\$4.25 per foot).

Copper Conductor, .825" x .625" x .250" dia. hole

Available for any project use:

140,280 feet

Material is stored by crates of average 11 rolls per
crate, 90 feet per roll. Material cost is \$1.88 per
pound (\$3.32 per foot).

Copper Conductor, .916" x .882" x .360" dia. hole

Available for any project use:

319 feet

Material is stored in one crate, 4 rolls at 70 ft. and
1 roll at 39 ft. Material cost is \$1.43 per pound
(\$3.95 per foot).

ELK:pm

cc: R. Auskalnis
D. DeWitt
J. Finks
W. Hanson
H. Hinterberger
P. Horak
R. Lenz
J. McCook
J. O'Meara
J. Schiltz
E. West
Accelerator Div./Dept. Heads
Research Div./Dept. Heads

*United
States
Steel
Corporation*

CENTRAL STEEL DIVISION

JOHN F. MUSSMAN
MANAGER OF SALES

THOMAS E. RICHMOND
ASSISTANT MANAGER OF SALES

CHICAGO DISTRICT SALES OFFICE
208 SOUTH LA SALLE STREET
CHICAGO, ILLINOIS
MAIL: P. O. BOX 1283
CHICAGO, ILLINOIS 60690
312/329-2000

July 3, 1980

UNIVERSITY OF WISCONSIN
Physical Sciences Laboratory
3725 Schneider Drive
Stoughton, Wisconsin

Attention: Mr. Lynnwood Thomas, Purchasing Agent

SUBJECT: DISTRESSED SLABS

Dear Sir:

Confirming our telephone conversation of June 17, 1980, we offer semi-finished slabs C 07 Max Mn.50 Max 8"/10" x 42"/62" x 40'0" Max - 3200 ton Price \$207.00 Net Ton

The prices quoted are net, F.O.B. cars, Batavia, Illinois, based on shipment in 60,000# minimum carload lots from our mill at Gary, Indiana. These prices reflect our current mill prices and current transportation charges from mill to destination of 49¢ per CWT plus .8 and 1.2% fuel surcharge.

Our price of \$197.00 per Net Ton is effective on shipments through July 31, 1980 and is subject to renegotiation at that time. Freight charges of \$10.00 per Net Ton are subject to change without notice and billings will represent freight rates at time of shipment.

TERMS - Net payment within 30 days or discount of 1/2% for payment within 10 days, both from date of invoice. Discount will be allowed on the shipping mill value of the materials. Invoices may be paid in a group as follows:

All invoices dated from the first to the fifteenth, incl., of the month, may be discounted, in a group, on or before the 25th of the same month; or may be paid net, in a group, on or before the fifteenth of the second month.

All invoices dated from the sixteenth to the end of the month, inclusive, may be discounted, in a group, on or before the tenth of the following month; or may be paid net, in a group, on or before the end of the second month.

(continued)

UNIVERSITY OF WISCONSIN
Page Two
July 3, 1980

The product described herein may contain various surface conditions, be of various sizes and shapes, contain storage rust or handling damage.

Paragraphs 5 and 9, on the reverse hereof, are inapplicable to this sale.

Seller does not warrant that the products furnished hereunder will be produced and tested in accordance with any specification. No warranty of merchantability, suitability for any particular purpose, or any other representation or warranty, whether express or implied, is made respecting these products, or the production thereof.

In no event shall Seller be liable in warranty, negligence, strict liability or in any other cause of action in contract or tort for personal injury, property damage or incidental or consequential damages.

It has been a pleasure for us to quote on your requirements and we look forward to receiving your order.

Very truly yours,

UNITED STATES STEEL CORPORATION

A V Aho

Service Representative, Chicago

A.V.Aho/lak

*United
States
Steel
Corporation*

CENTRAL STEEL DIVISION

JOHN F. MUSSMAN
MANAGER OF SALES

THOMAS E. RICHMOND
ASSISTANT MANAGER OF SALES

CHICAGO DISTRICT SALES OFFICE
208 SOUTH LA SALLE STREET
CHICAGO, ILLINOIS
MAIL: P. O. BOX 1283
CHICAGO, ILLINOIS 60690
312/329-2000

August 14, 1980

UNIVERSITY OF WISCONSIN
Physical Sciences Laboratory
3725 Schneider Drive
Stoughton, Wisconsin 53589

Attention: Mr. Lynnwood Thomas, Purchasing Agent

SUBJECT: DISTRESSED SLABS

Dear Sir:

Confirming our telephone conversation of August 14, 1980, we offer semi-finished slabs C.07 Max Mn.50 Max 8"/10" x 42"/62" x 40'0" Max - 3200 ton Price \$213.00 Net Ton.

The prices quoted are net, F.O.B. cars, Batavia, Illinois, based on shipment in 60,000# minimum carload lots from our mill at Gary, Indiana. These prices reflect our current mill prices and current transportation charges from mill to destination of 49¢ per CWT plus .8 and 1.2% fuel surcharge.

Our price of \$203.00 per Net Ton F.O.B. Gary, Indiana is effective on shipments through September 30, 1980 and is subject to renegotiation at that time. Freight charges of \$10.00 per Net Ton are subject to change without notice and billings will represent freight rates at time of shipment.

TERMS - Net payment within 30 days or discount of 1/2% for payment within 10 days, both from date of invoice. Discount will be allowed on the shipping mill value of the materials. Invoices may be paid in a group as follows:

All invoices dated from the first to the fifteenth, incl., of the month, may be discounted, in a group, on or before the 25th of the same month; or may be paid net, in a group, on or before the fifteenth of the second month.

All invoices dated from the sixteenth to the end of the month, inclusive, may be discounted, in a group, on or before the tenth of the following month; or may be paid net, in a group, on or before the end of the second month.

(continued)

ALL SALES ARE SUBJECT TO THE CONDITIONS SET FORTH ON REVERSE SIDE OF THIS SHEET

UNIVERSITY OF WISCONSIN
Page Two
August 14, 1980

The product described herein may contain various surface conditions, be of various sizes and shapes, contain storage rust or handling damage.

Paragraphs 5 and 9, on the reverse hereof, are inapplicable to this sale.

Seller does not warrant that the products furnished hereunder will be produced and tested in accordance with any specification. No warranty of merchantability, suitability for any particular purpose, or any other representation or warranty, whether express or implied, is made respecting these products, or the production thereof.

In no event shall Seller be liable in warranty, negligence, strict liability or in any other cause of action in contract or tort for personal injury, property damage or incidental or consequential damages.

It has been a pleasure for us to quote on your requirements and we look forward to receiving your order.

Very truly yours,

UNITED STATES STEEL CORPORATION

A handwritten signature in cursive script, appearing to read "A.V. Aho", is positioned above the typed name of the service representative.

Service Representative, Chicago

A.V.Aho/lak

DANLY MACHINE CORPORATION

2100 South LaSalle Avenue, Chicago, Illinois 60608 • Telephone 243-1400 Area Code 312

August 20, 1980

University of Wisconsin-Madison
3725 Schneider Drive, Route 4
Stoughton, Wisconsin 53589

Attention: Mr. Linwood C. Thomas

Subject: Danly Proposal No. 8783-J

Gentlemen:

In response to your inquiry dated July 30, 1980, we will torch cut and machine the following:

Four (4) Type "A" Rings With Lifting Holes.....	\$25,870.00 Ea.
Four (4) Type "B" Rings With Lifting Holes.....	\$24,750.00 Ea.

NOTE: The above are current approximate prices
based on sketches.

\$103,480
\$99,000.
\$202,480.

University of Wisconsin to furnish low carbon steel plates F.O.B. our plant, Cicero, Illinois.

In case of error or damage, we cannot be responsible for any material or other costs except as contained in the above quotation.

In the event that we are favored with an order, we will require four (4) sets of drawings or one (1) translucent reproducible for manufacturing purposes.

Delivery: To be determined, after receipt of material, purchase order and necessary manufacturing drawings.

Terms and Conditions: See attached.

Yours very truly,

DANLY MACHINE CORPORATION

Robert F. Koperny
Manager - Contract Sales

REK/JTC/rb

100-25-4157

MECHANICAL & HYDRAULIC PRESSES • DIE SETS • DIE MAKERS' SUPPLIES

Circle 10 on Reader Service Card

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ALLSTEEL
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CO.

1355 EAST NINETY-THIRD STREET, CHICAGO, ILLINOIS 60610
AC 312/933-8200 • TELEX 02-53444

AUGUST 13, 1980

UNIVERSITY OF WISCONSIN
PHYSICAL SCIENCES LABORATORY
SCHNEIDER DRIVE & U.S. 51
P. O. BOX 6
STOUGHTON, WI. 53589

ATTENTION: MR. LINWOOD C. THOMAS

SUBJECT: YOUR VERBAL INQUIRY
OUR PROPOSAL #G-147-80, REV. 1

GENTLEMEN:

PER YOUR REQUEST, WE ARE PLEASED TO SUBMIT OUR QUOTATION TO COVER FLAME CUTTING,
DRILL/TAP AND MACHINING ONLY:

- 4 - TYPE "A" (NUMBERS 1 & 4) TOROIDS PER MR. R. MORSE'S WRITEUP AND SKETCHES
DATED 7-25-80 AND VERBAL CONVERSATIONS. EACH OF THESE TOROIDS CONSIST OF
FIVE (5) CIRCLES 25 FEET OUTSIDE DIAMETER 2.5 FEET INSIDE DIAMETER BY
8 INCHES THICK. EACH CIRCLE WILL CONSIST OF TWELVE (12) SEGMENTS WITH
MACHINED VERTICAL CENTERLINE JOINTS.

THE ABOVE FOR. \$342,560.00 LOT

- 4 - TYPE "B" (NUMBERS 2 & 3) TOROIDS PER MR. R. MORSE'S WRITEUP AND SKETCHES
DATED 7-25-80 AND VERBAL CONVERSATIONS. EACH OF THESE TOROIDS CONSISTS OF
FIVE (5) CIRCLES 25 FEET OUTSIDE DIAMETER WITH INSIDE DIAMETERS STARTING
WITH 9 FEET AND INCREASING ON A 15° ANGLE TO 13 FEET. EACH PLATE CIRCLE
IS 8 INCHES THICK. EACH CIRCLE WILL CONSISTS OF TWELVE (12) SEGMENTS WITH
MACHINED VERTICAL CENTERLINE JOINTS.

THE ABOVE FOR. \$323,547.00 LOT

GRAND TOTAL "A" & "B" TOROIDS W/JOINT. \$666,107.00 LOT

ALTERNATE - SAME AS ABOVE EXCEPT CENTERLINE MACHINE JOINTS ARE OMITTED AND
SEGMENTS FOR EACH 25 FOOT CIRCLE WILL BE ONE (1) PIECE WHERE DESIGN PERMITS.

- 4 - TYPE "A" (NUMBERS 1 & 4) TOROIDS, SIX (6) SEGMENTS. PRICE. . . . \$288,240.00 LOT

- 4 - TYPE "B" (NUMBERS 2 & 3) TOROIDS, EIGHT (8) SEGMENTS. PRICE. . . \$287,333.00 LOT

ALTERNATE GRAND TOTAL "A" & "B" TOROIDS W/OUT CENTERLINE JOINT. . \$575,573.00 LOT

* CONTINUED *

NOTES:

1. THIS PRICE IS ONLY FOR AN APPROPRIATION ESTIMATE GOOD THRU DECEMBER 1980. FINAL ESTIMATE WILL BE PRESENTED UPON RECEIPT OF YOUR APPROVED PRODUCTION DRAWINGS.
2. THE OUTER AND INNER DIAMETERS WILL BE FLAME CUT ONLY AND THESE SURFACES WILL BE SUBJECT TO $\frac{10}{2}$ TO 2^0 TAPER THRU THE 8 INCH PLATES THICKNESS.
3. ALL MACHINED SEGMENTS WHEN ASSEMBLED AS A FULL CIRCLE COULD BE IRREGULAR AT THE JOINTS OF OUTSIDE AND INSIDE DIAMETERS BY AS MUCH AS $1/4$ INCH MAX.
4. ALL PLATES FURNISHED BY UNIVERSITY OF WISCONSIN TO BE SUFFICIENTLY FLAT TO SATISFY YOUR GAP REQUIREMENTS. HOWEVER, IN EVENT THE PLATES ARE RECEIVED BOWED TO AN EXTENT THAT WOULD EXCEED YOUR GAP REQUIREMENTS STRAIGHTENING OF THE PLATES WOULD BE AT AN ADDITIONAL CHARGE.
5. ALL MACHINED SURFACES TO HAVE 125 MICRO FINISH.
6. PER VERBAL DISCUSSION, DRILLING AND TAPPING FOR LIFTING AND HANDLING HOLES HAS BEEN ADDED TO ALL SEGMENTS OF BOTH ALTERNATE QUOTES. THIS WILL ENABLE MORE EFFICIENT ON-SITE ERECTION THEREBY REDUCING TIME AND COST OF ASSEMBLY.
7. UNIVERSITY OF WISCONSIN TO FURNISH ALL PLATES, CODE IDENTIFIED AND SEQUENCE STACKED, F.O.B. OUR PLANT, CHICAGO.
8. DELIVERY - TO BE DETERMINED UPON RECEIPT OF APPROVED PRODUCTION DRAWINGS AND FINAL PRICE REVIEW.
9. PRICES ARE F.O.B. OUR PLANT, CHICAGO WITH NO PROTECTIVE TREATMENT TO ANY MACHINED, BURNED OR AS ROLLED SURFACES.
10. NO ASSEMBLY STACK AT OUR PLANT IS INCLUDED.
11. PRICE DOES NOT INCLUDE SHIMPLATE AT BASE SHOWN ON SUBMITTED SKETCHES.
12. NO PROVISION FOR SCRAP ALLOWANCE OR DETERMINATION IS INCLUDED.
13. SHOULD WE BE FAVORED WITH THIS ORDER, WE WILL REQUIRE THREE SETS OF DWGS.
14. TERMS: NET 10 DAYS FROM DATE OF INVOICE.

ALL PRICES QUOTED ARE SUBJECT TO THIRTY (30) DAYS ACCEPTANCE. THE ATTACHED CONDITIONS OF SALE (VER-80-1000) TO APPLY.

THANK YOU FOR THE OPPORTUNITY OF SUBMITTING A QUOTATION ON YOUR REQUIREMENTS AND IF WE CAN BE OF ANY FURTHER ASSISTANCE, PLEASE LET US KNOW.

/CR

CC: R. PODGORNİK, SALES REP.

ENCLOSURE: CONDITIONS OF SALE
(VER-80-1000)

VERY TRULY YOURS,

VERNON ALLSTEEL PRESS COMPANY

FRANK GLINSKI JR.
MARKETING MANAGER
CUSTOMER SPECIAL SERVICES

VERSON

ALLSTEEL
PRESS
CO

1355 EAST NINETY-THIRD STREET, CHICAGO, ILLINOIS 60619
AC 312/933-8200 • TELEX 02-53444

JULY 23, 1980

UNIVERSITY OF WISCONSIN
PHYSICAL SCIENCES LABORATORY
3725 SCHNEIDER DRIVE
STOUGHTON, WI. 53589

ATTENTION: MR. LINWOOD C. THOMAS

SUBJECT: YOUR VERBAL REQUEST
OUR PROPOSAL #G-147-80

GENTLEMEN:

PER YOUR REQUEST, WE ARE PLEASED TO SUBMIT OUR QUOTATION TO COVER FLAME CUTTING AND MACHINING ONLY:

- 4 - MAGNETS PER VERBAL CONVERSATION. EACH MAGNET WILL CONSIST OF FIVE (5) CIRCLES MEASURING 25 FEET OUTSIDE DIAMETER BY 2 FT. INSIDE DIAMETER. EACH CIRCLE WILL CONSIST OF TWELVE (12) SECTIONS.

TOTAL PRICE. \$327,045.00

NOTES:

1. THIS PRICE IS ONLY FOR AN APPROPRIATION ESTIMATE GOOD THRU DECEMBER 1980. FINAL ESTIMATE WILL BE PRESENTED UPON THE RECEIPT OF YOUR APPROVED DRAWINGS.
2. THE OUTER DIAMETER AND INSIDE DIAMETER WILL BE FLAME CUT ONLY WITH A $\frac{1}{2}^{\circ}$ TO 2° TAPER FROM TOP/BOTTOM SURFACE OF EACH PLATE.
3. ALL MACHINED SECTIONS WHEN ASSEMBLED AS A FULL RING WILL BE IRREGULAR AT THE JOINTS OF THE FLAME CUT SURFACES BY APPROXIMATELY $1/4"$.
4. ALL PLATES FURNISHED BY UNIVERSITY OF WISCONSIN TO BE SUFFICIENTLY FLAT TO SATISFY YOUR GAP REQUIREMENTS. HOWEVER, IN THE EVENT THE PLATES ARE RECEIVED BOWED TO AN EXTENT THAT WOULD EXCEED YOUR GAP REQUIREMENTS STRAIGHTENING OF THE PLATES WOULD BE AT AN ADDITIONAL CHARGE.
5. ALL MACHINED SURFACES TO HAVE 125 MICRO FINISH.
6. UNIVERSITY OF WISCONSIN TO FURNISH ALL PLATES F.O.B. OUR PLANT, CHICAGO.
7. DELIVERY - TO BE DETERMINED UPON RECEIPT OF APPROVED DRAWINGS.
8. TERMS - NET 10 DAYS FROM DATE OF INVOICE.

ALL PRICES QUOTED ARE SUBJECT TO THIRTY (30) DAYS ACCEPTANCE. THE ATTACHED CONDITIONS OF SALE (VER-80-1000) TO APPLY.

* CONTINUED *

ALL QUOTATIONS, ORDERS AND CONTRACTS ARE SUBJECT TO ACCEPTANCE OF HOME OFFICE AND ARE NOT BINDING UNTIL THEY ARE APPROVED BY OUR CONTROL.

THANK YOU FOR THE OPPORTUNITY OF SUBMITTING A QUOTATION ON YOUR REQUIREMENTS
AND IF WE CAN BE OF ANY FURTHER ASSISTANCE, PLEASE LET US KNOW.

VERY TRULY YOURS,

VERSON ALLSTEEL PRESS COMPANY

FRANK GLINSKI JR.
MARKETING MANAGER
CUSTOMER SPECIAL SERVICES

/CR

CC: R. PODGORNIK, SALES REP.

ENCLOSURE: CONDITIONS OF SALE
(VER-80-1000)

LASKER BOILER & ENGINEERING CORP.

BOILER MAKERS STEEL PLATE ENGINEERS

3201 SOUTH WOLCOTT AVENUE

TELEPHONE
AC 312-523-3700

CHICAGO, ILLINOIS 60608

August 20, 1980

University of Wisconsin
Physical Sciences Laboratory
3725 Schneider Drive
Route #4
Stoughton, Wisconsin 53589

Attention: Mr. Linwood C. Thomas
Mechanical Coordinator

Re: Your letter of August 14, 1980
Our Estimate No. 35025

Gentlemen:

In accordance with your request for cost estimate pertaining to fabrication and machining of Torroid Assemblies, we offer the following:

It is understood that others will furnish all plates F.O.B. rail or truck our shop Chicago, Illinois. This material will be approximately 8" thick x 60" wide and come in 40' or 20" lengths. Total required pieces would be determined in the event of order.

As per our discussion it is assumed that the surface points of each plate will not be machined. These plates would be laid out, preburnt, allowing sufficient stock for machining purposes. The Torroid sections (a total of 60 per section, or a total of 480 pieces involved) would be burnt to a 25'-0" diameter $\pm 3/16$ on the diameter.

The Torroid sections (Type A) would be laid out and burnt to a given internal dimension (step condition) starting with an approximate 9' diameter at initial face and with a completion dimension of approximately 13'-0" at the outer face. Face dimension, including gap, to be approximately 86".

The Type B Torroids would be laid out, burnt and incorporating an approximate 36" diameter whole $\pm 3/16$ true center of each assembly.

As noted on sketches (Type A & B) the sides and one end of each plate will be machined milled to an approximate surface condition 125 RMS. The upper and lower surface of each plate, as previously mentioned, will not be machined.

University of Wisconsin
Attn: Mr. Linwood C. Thomas
August 20, 1980

We feel, from our conversation, that you indicated possibly a maximum of 1/2" out of flat over a 40' length. If these plates are cut to proper length, the out of flatness condition should decrease somewhat. There is a distinct possibility that you may require some additional flattening of certain plates after these items have been cut to proper length. This could be determined at a later date.

We also note that the internal diameter, as burned on the Type A Torroid, would encompass an approximate 15° taper with each sandwich plate or section, having approximately a 3" step internally. As discussed, we will submit an alternate proposition for shop fit and alignment of one (1) complete Torroid Assembly involving a total of 60 plates.

Although not indicated, we would suggest (if possible) that two (2) drilled and tapped holes be placed on each plate for handling purposes. If the assembly is shop assembled in the flat condition we feel these holes would be a mandatory requirement for handling or positioning.

Our price to furnish all gases, labor to layout, complete all burning as required, and complete all machine work as enumerated above, not assembled, F.O.B. rail or truck our plant.....\$644,000.00.

The following alternates would apply:

Alternate #1

If required flattening is mandatory on some of the Torroid plates, our charge would be \$46.00 per man hour in shop.

Alternate #2

To floor assemble, match mark completed Torroid Assembly consisting of 60 plates add to the base price.....\$11,800.00 lot.

Our estimated shipping weight, based on eight (8) Torroids, is 5,650,000#.

The above prices are based on labor rates effective this date, and based on completion of work on or before June 30, 1981. In the event work is expended after this date, approximate escalation on labor 7%-8%.

Scheduling: We are hesitant at this time to commit a schedule until a material schedule or delivery could be developed. The above prices do not include any applicable taxes. Prices quoted are F.O.B. our shop Chicago, Illinois.

Very truly yours,

LASKER BOILER & ENGINEERING CORP.

C. W. Lasker

CWL/ik

LASKER BOILER & ENGINEERING CORP.

BOILER MAKERS STEEL PLATE ENGINEERS

3201 SOUTH WOLCOTT AVENUE

CHICAGO, ILLINOIS 60608

TELEPHONE
AC 312-523-3700

August 22, 1980

University of Wisconsin
Physical Sciences Laboratory
3725 Schneider Drive - Route 4
Stoughton, Wisconsin 53589

Attention: Mr. Linwood C. Thomas
Mechanical Coordinator

Re: Our Estimate No. 35025
Toroid Assemblies

Dear Mr. Thomas:

In reviewing the concept of fabrication of the Toroid Magnet Sections, I was looking over the rough sketch after our quotation had been submitted. It would appear to me that where one short edge of each plate is machined that these edges would not come to rest in a metal to metal condition on the vertical centerline.

We wish to point out that a problem may arise if the plates are not in the perfectly flat condition. Example: Assume a plate to be approximately 1/2" out of flat. If this particular plate is positioned on a horizontal mill and the short end faced to the 125 RMS condition, that when it is rested or sandwiched on to an adjacent plate the out of flatness condition may cause a gap or small opening where the short edges come in contact with one another. I believe the condition would greatly enhance itself to this problem if additional plates are stacked one upon the other.

I feel that after you have looked this condition over, you may want to give me a call by phone and discuss this problem. It may be that I am not looking at the situation properly, and that it could be clarified by phone.

Very truly yours,

LASKER BOILER & ENGINEERING CORP.

C. W. Lasker

CWL/ik

PRELIMINARY

QUOTATION

9341-MW

Nordberg Machinery Group

BOX 383 • MILWAUKEE, WISCONSIN, 53201, U.S.A. • TELEPHONE 414-643-3000

September 11, 1980

Physical Sciences Laboratory
3725 Schneider Drive, Route 4
Stoughton, Wisconsin 53589

Attention: Mr. Linwood C. Thomas

Dear Mr. Thomas:

We are pleased to confirm our verbal quotation in accordance with our phone conversation on September 8, 1980, as follows:

Torch cut and mill mating edges on four-hundred-eighty (480) parts that make up a toroid magnet, per your sketches. Two (2) eyebolt holes in each piece for handling parts are included in this quote.

NOTE: Up to 2° error can be expected in torch cut edges.

Preliminary price estimate, based on your sketches = \$750,000-\$800,000.

The above price is quoted F.O.B. our plant and based on your furnishing the material freight prepaid to our facility.

We trust the above meets with your approval.

Very truly yours,

Thomas C. Rocque

Thomas C. Rocque,
Contract Engineer

cp

WHITING CORPORATION

HARVEY, ILLINOIS 60426 U.S.A.
AREA CODE 312-331-4000

September 16, 1980

Mr. Linwood C. Thomas, Mechanical Coordinator
University of Wisconsin-Madison
3725 Schneider Drive, Route 4
Stoughton, Wisconsin 53589

Dear Mr. Thomas:

Thank you for the opportunity to quote the machining of Torroid magnets.

The following is our quote:

Type A 4/pcs 40" thick 25/ft OD (240 slabs)

Type B 4/pcs 40" thick 25/ft OD (240 slabs)

Machine per rough sketch furnished with quotation request at a
price of\$273,568.41.

The price does not include surface cleaning. Surface cleaning is an
additional\$ 13,344.68.

Delivery based on available capacity at time of receipt of material.

Yours very truly,

WHITING CORPORATION

V. J. Farrell
Materials Manager

VJF/vjm

A Subsidiary of Wheelabrator-Frye Inc.

RMI Company

EXTRUSION PLANT

P. O. BOX 579
ASHTABULA, OHIO 44004
216/997-5141 TWX 810-427-2926

August 8, 1980

University of Wisconsin - Madison
Physical Sciences Laboratory
3725 Schneider Drive, Route 4
Stoughton, Wisconsin 53589

Attention: Mr. L. C. Thomas

Dear Linwood:

We are pleased to quote per the attached and following terms and conditions for the extrusion of CDA-102 Copper Alloy conductor per print 1625A010.

Scope of Work

RMI Company to receive copper billet, from source of your choice, and extrude per above print to coils of approximately 100 feet in length. Extrusion to be performed via one or more of the methods outlined below.

I. Conversion

- A. To produce approximately 15,000 feet of conductor 30% oversize via drilled billet extrusion technique, our price will be \$1.80 per pound of incoming billet material.
- B. To produce approximately 15,000 feet of conductor 30% oversize via solid billet/bridge die construction, our price will be \$1.69 per pound of incoming billet material.
- C. To produce approximately 15,000 feet of conductor to print tolerances via either extrusion technique above, our price will be \$2.07 per pound of incoming billet material.
- D. RMI would recommend a trial quantity of material be extruded to establish parameters and tool conditions. A trial quantity of six to eight billets would be extruded for a lot price of \$2,400.00.
- E. There will be a one-time tooling charge for any of the above setups of \$6,000.00.
- F. All pricing is based on receiving billets in extrudable condition.

August 8, 1980
Mr. L. C. Thomas
Page 2

II. Billet Sizes and Requirements

A. Drilled Billet

1. 6.0 $\pm$.025 inch O.D. x 1.0 $\pm$.025 inch I.D. x 24.0 $\pm$.125 inch length.
 - a. Billets to have a 1.0 inch radius on the outside lead edge one end.
 - b. Will require 148 billets.

B. Solid Billet

1. 6.0 $\pm$.025 inch O.D. x 24.0 $\pm$.125 inch length.
 - a. Billets to be flat faced.
 - b. Will require 144 billets.

C. Incoming billet surface to be 125 RMS or better.

D. Total runout on drilled billet not to exceed .005" T.I.R.

E. All billets to be shipped at no charge to RMI Company, Ashtabula, Ohio.

III. Processing

A. Extrusions to be shipped in as-extruded condition.

IV. Delivery

A. Eight to ten weeks after receipt of order and billets for initial quantities. Subsequent quantities subject to mutually agreeable scheduling.

The above prices are quoted on a best efforts basis F.O.B. Ashtabula, Ohio.
This quotation is effective for sixty (60) days.

Very truly yours,

RMI COMPANY

A handwritten signature in dark ink, appearing to read "JWH", is written over a horizontal line. Below the line, the name "J. W. Henderson" and title "Commercial Engineer" are printed.

J. W. Henderson
Commercial Engineer

JWH:cw

Attachment