Attachment A

" Shielding of the West Booster Tower Building from the Radiation Arising from the Operational losses of 8 GeV proton Beam at the Booster Extraction Region during Main Injector Era",
C.M. Bhat and P. Martin (May 1996)

# Radiation Shielding of the West Booster Tower Building from the Radiation Arising from the Operational losses at the Booster Extraction Region during Main Injector Era.

C.M. Bhat and P. Martin
Fermi National Accelerator Laboratory
P.O. Box 500, Batavia, Illinois 60510*
Jan. 26, 1995, Revised on May 1996

The primary motivation of this study is to investigate a scheme to shield the West Booster Tower from the radiation due to the 8GeV proton beam loss at the Booster to Main Injector extraction region during the normal operational conditions. Previously it has been planned ( Ref. 1) to shield this region by making a major excavation under the West Booster Tower. Excavating and piling up about 4ft to 5ft of steel under the building without affecting the building will be a challenge for civil construction and as well as will be considerably expensive to the Main Injector project. Here we are proposing an alternative but a cost effective method.

Following assumptions will go into our radiation shielding calculations:

- 1 ft of steel shielding adds a soil equivalent of 2.89ft.
- 1 ft of heavy concrete shielding has a soil equivalent of 1.5ft.
- An operational loss of 2.0E11p@8GeV/sec at the Lambertson (i.e. 7.2E14p/hour)
- An accidental loss of 5.7E16p@8GeV/accident (Ref 2)

The operational loss mentioned above is a significiant fraction of the average operational loss described in PSAR (Ref. 2). A beam loss of 1E19p@8GeV/year is estimated in PSAR. Assuming an average operational period as 6000 hours/year, the loss per hour is 1.67E15p. In the present case we have assumed that for every Booster batch of 5E12p@8GeV with 84 bunches, about 6E10 protons will be lost at Lambertson alone. With a maximum of 6 booster batch in 1.8sec, this beam loss will be about 43% of the total operational loss as mentioned in PSAR.

For determining the amount of shielding required following guide lines have been considered :

-The necessary shielding for 8GeV beam line enclosure is 24.5ft of earth equivalent (Ref. 2). Or, radiation level less than 0.025 mrem/hour for normal operational losses and/or less than 1 mrem/accident for accidental beam losses ( no precaution needed and no occupancy limit ) (Ref. 3)

Under the West Booster Tower, the 8 GeV beam line tunnel takes two wings. One is for Booster Ring and another is for 8 GeV beam line leading to MI. Presently this is called AP4 beam line. Fig. 1 and 2 show plan view and the cross-sectional view of this region respectively. Under the West Booster Tower building a significant area has been covered by 3.5ft thichk heavy concrete. The heavy concrete used here is 1.55 times denser than the normal concrete. This has about 78% of normal concrete and 22% of steel( Ref. 4). Because of the density difference between normal concrete and heavy concrete we assume that 1ft of heavy concrete is equivalent to 1.5ft of normal concrete (or soil). Besides there is a concrete arched pipe of 5ft dia, to let the water to go out of Booster pond.

The Booster beam is at an elevation of 726.582ft (with tunnel ceiling at 730.5 ft) and the floor of the West Booster Tower is at an elevation of 744ft. Thus, there is only a total shielding of about **15.52ft soil equivalent including the heavy concrete.** Hence, we need a minimum of additional 9.25ft soil equivalent shielding material between floor of the West Booster Tower and the Beam line to meet the PSAR requirements. Here we investigate a possibility of adding steel on the top of the Lambertson to reduce the radiation levels in and around the West Booster Tower Building to an acceptable limit.

The geometry of the tunnel with Lambertson and other utilities is very complicated. The maximum vertical space between tunnel ceiling and the body of the Lambertson is only 3.2ft. Besides this vertical spacing varies from location to location as we go down steamA of the beam line. To estimate the required shielding thickness we did Monte Carlo calculations using CASIM ( Ref. 5) with cylindrical geometry. By this we could estimate radiation level at the surface for different shielding thicknesses of iron. To include the exact three dimentional geometry of the whole region we used a separate computer program which uses 24.5ft soil equivalent as a constraint. Of course, the same thing can be done with the program CASIM. The primary problem in using CASIM for such complicated geometry will be with high statistics needed for reliable calculations and a large computation time.

The results of CASIM calculations for the cases investigated here are listed in the Table I. The Fig. 3 shows contours of equal star densities from CASIM for this region without any additional shielding. This gives 15mrem/hour under normal operating conditions. If we fill up the entire gap between Lambertson and the tunnel roof with steeli.e.. with about 3ft steeland about 2.4 in clearance, we will be able to add a maximum shielding of 8.67ft soil equivalent. Fig. 4 shows results of CASIM calculations for 3ft of iron above the Lambertson and we estimate about 0.04 mrem/hour for operational losses. This gives an adequate shielding only for no occupancy limit.

sign ('Caution' Radiologically Controlled Area ) in the Booster tower. For accidental beam losses we expect about 3 mrem/acc.

The void due the arched pipe under the West Booster Tower adds to shielding deficit at some regions in the Building. This can be overcome by extending the steel shielding to about another 6 ft downstream of the Lambertson. Fig. 5a and 5b show results obtained with exact geometry which support the results obtained by using CASIM. The Fig. 5b shows the results for three different shielding widths viz., 4ft, 3ft and 2.5ft ( with a 2ft wide Lambertson) with a maximum thickness of 3ft. From this we find that 3.0ft thick, 3ft wide and 13ft long steelshielding above the Lambertson will give a soil equivalent shielding of 26ft ( including the thickness of the Lambertson Iron). If the thickness of the Lambertson is not included then we find that soil equivalent is only 23.9ft. Hence the area right above the Lambertson will be under shielded both for normal as well as accidental losses if no other precaution is taken. However, the radiation level in the West Booster tower falls rapidly as we go down stream of the beam line as shown in Figs. 6. A possible solution to protect right above the Lambertson is, to use interlocked detectors in the vicinity of the Lambertson and other places. This method of shielding reduces cost of civil construction considerably.

## Summary

We have estimated the radiation level at the surface near West Booster Tower arising due to losses of about 2E11p@8GeV/sec at the extraction Lambertson from Booster to MI as 15mrem/hour. This can be brought down to 0.04mrem/hour by adding about 13ftX3ftX3ft steel block above the Lambertson. For accidental beam losses the radiation level can be brought down to 3 mrem/acc. This requires posting of signs as "Caution - Radiation Area" . For unlimitted occupancy for accidental beam losses we will require interlocked detectors with trip levels set properly so that the total radiation will not be in access of 1 mrem/hour(Ref. 3).

We would like to thank A. Leveling, A. Van Ginneken and N. Mokhov for their useful comments.

## References

1. Title 1 Design Report Fermilab Main Injector 1992
2. Fermilab Main Injector Priliminary Safety Analysis Report, 1992
3. Fermilab Radiological Control Manual
4. Tom Pawlak (Private communication 1994).
5. A. Van Ginneken, CASIM code.

Table I. Comparison of the expected radiation as a function of thickness of the steel-stacked over the Lambertson. Operational beam loss is taken to be 2E11p@8GeV/sec. This is about 43% of the total operational beam loss set by PSAR. Acidental beam loss is 5.7E16p@8GeV/accident. The star densities have been evaluated using CASIM with cylindrical geometry.

| Location | Different Scenario | Number of Stars/cc/p@8GeV | Radiation/p loss (rem) | Total radiation (mrem/hour) |
|---|---|---|---|---|
| 744ft Elevation 'A' in Fig.2, Worst Scenario | Without Shielding | 2E-12 | 2E-17 | 15 ( Operational loss)<br>1140 ( Accidental loss) |
| | 2ft of iron | 1E-13 | 1E-18 | .7 ( Operational loss)<br>57 ( Accidental loss) |
| | 3ft of iron | 5E-15 | 5E-20 | 0.04 ( Operational loss)<br>3 ( Accidental loss) |
| Booster Gallery 'B' in Fig.2. | Without Shielding | 6E-14 | 6E-19 | .5 ( Operational loss)<br>40 ( Accidental loss) |
| | 2ft of iron | 1E-14 | 1E-19 | .07 (Operational loss)<br>6 ( Accidental loss) |
| | 3ft of iron | 1.5E-16 | 1.5E-21 | .0015 ( Operational loss)<br>0.15 ( Accidental loss) |

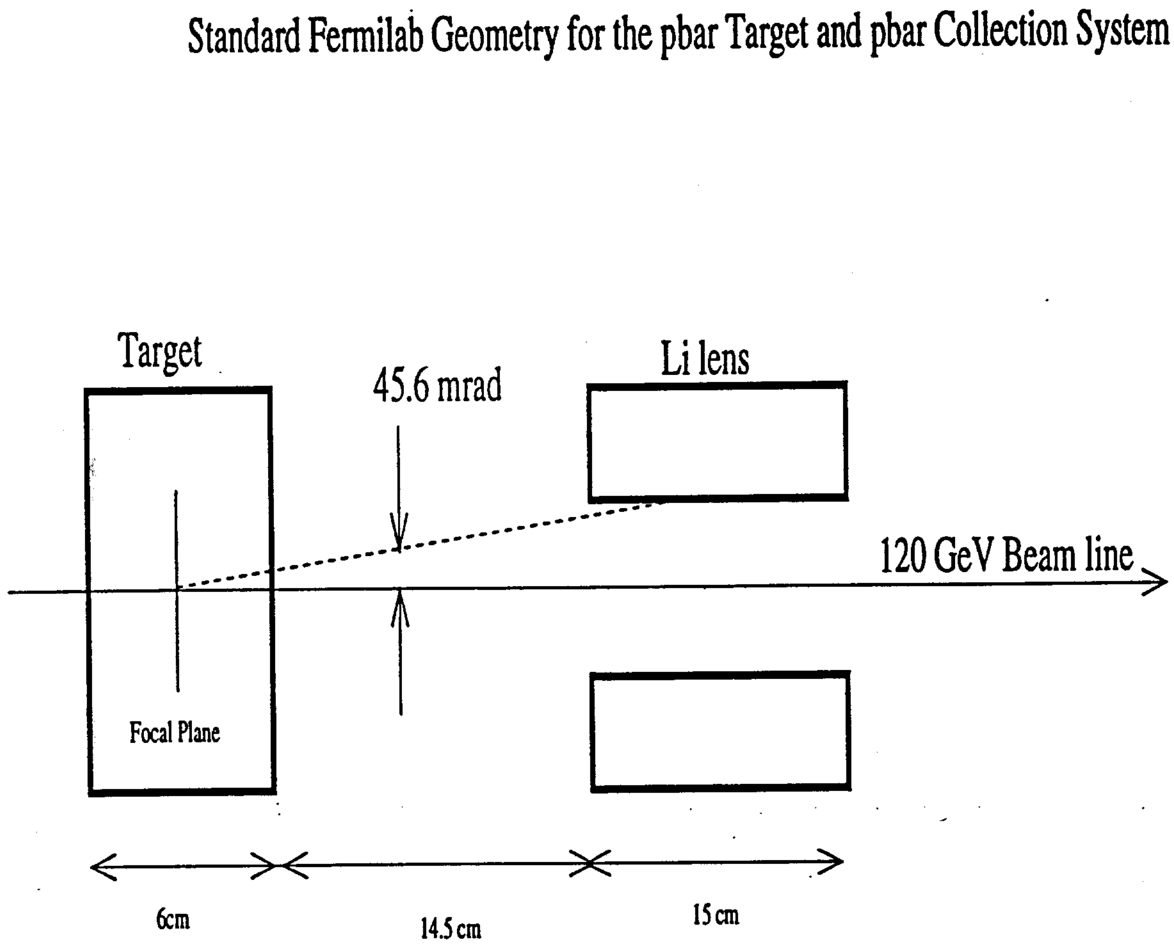



Figure 2: A schematic view of the pbar collection system. The 8 GeV pbar bending magnet is not shown.

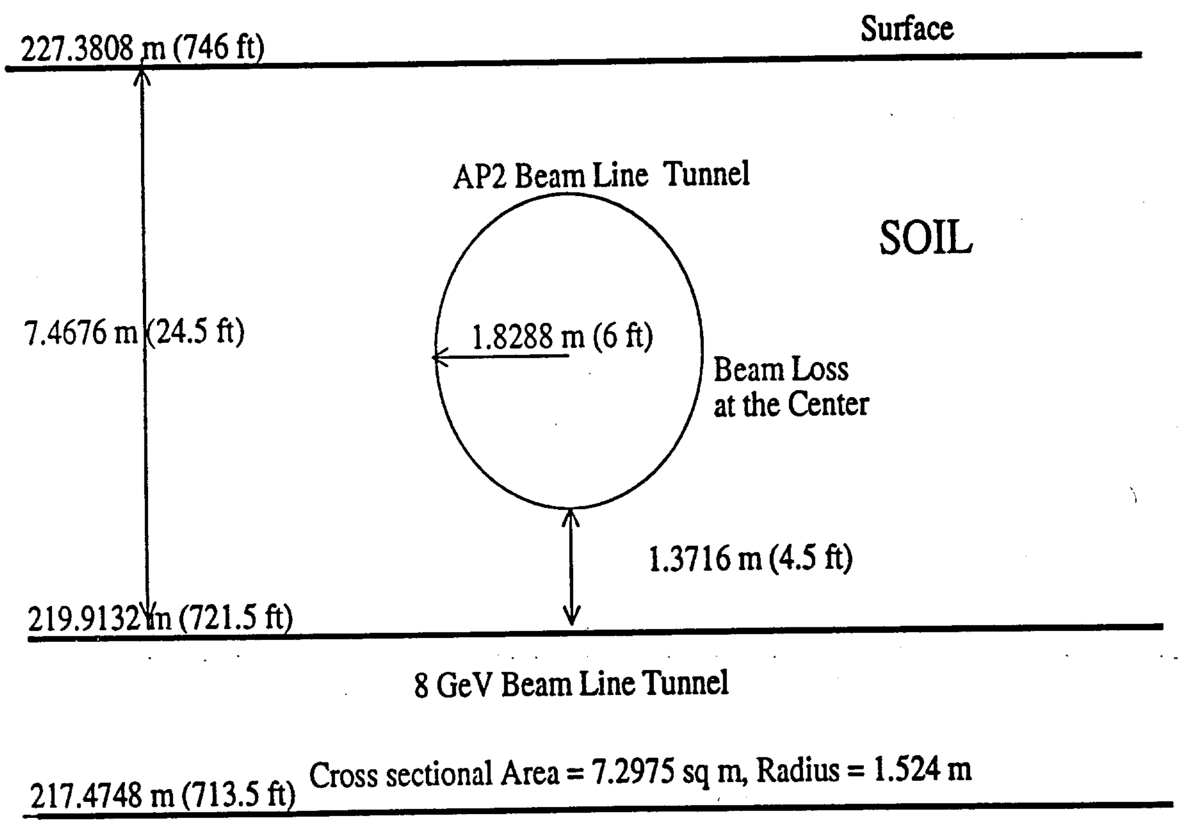



Figure 3: Geometry used in the Monte Carlo calculations to estimate the radiation dose in 8 GeV beam line tunnel due to an accidental beam loss in the AP2/AP3 beam line.

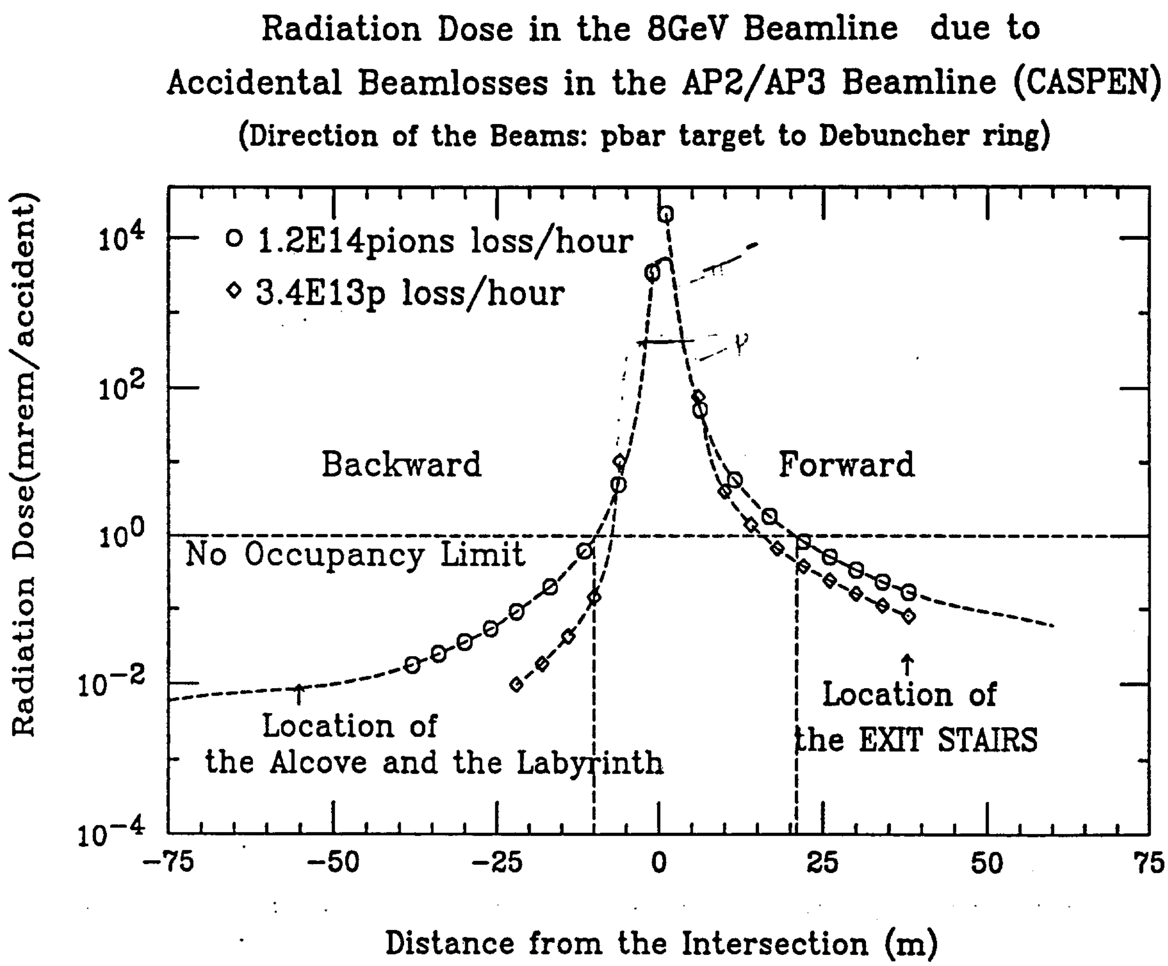
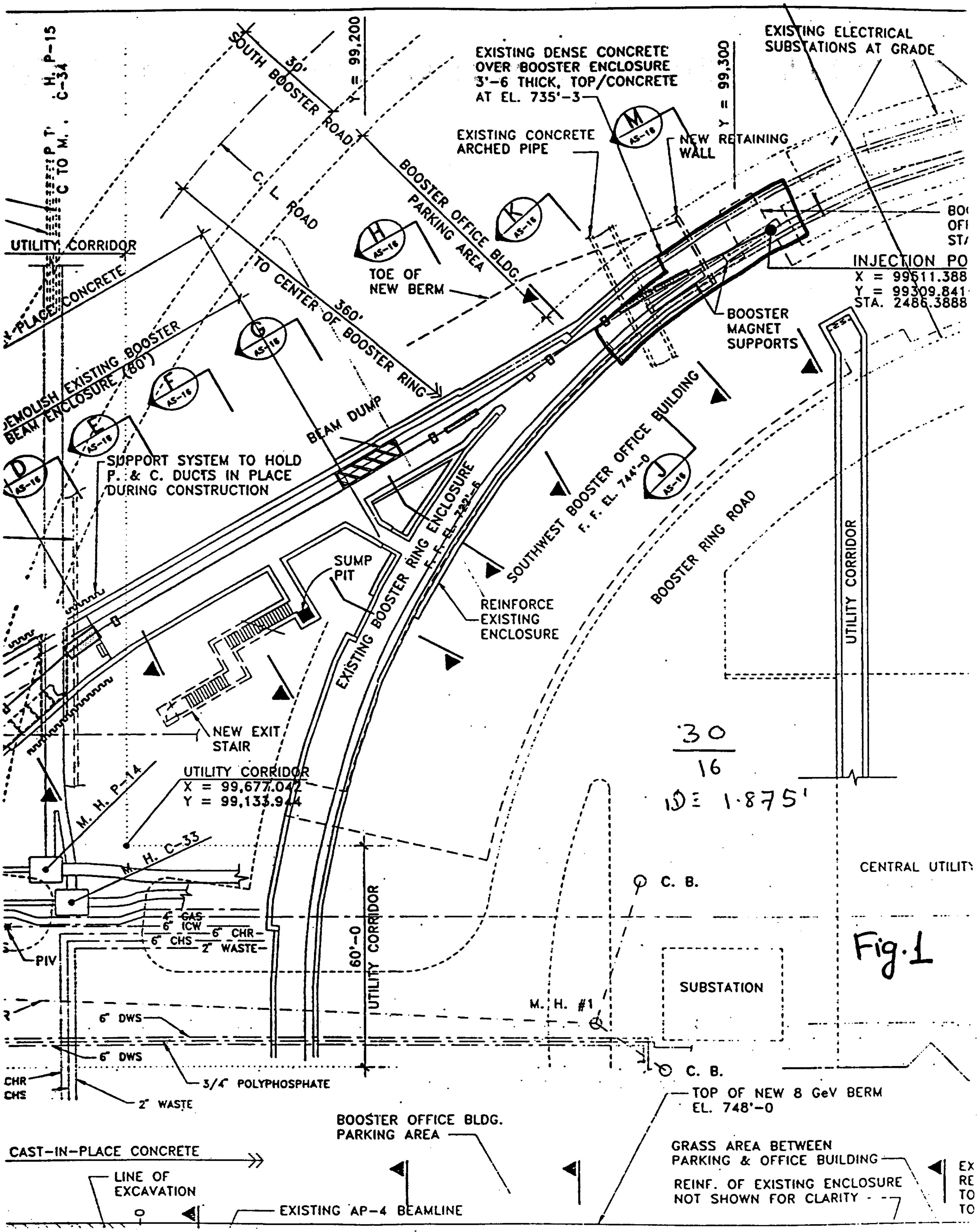



Figure 4: Results of the Monte Carlo calculations with computer code CASPEN for protons and pions. The locations of the EXITs (from the 8 GeV beam-line) which are on the both sides of the intersections are indicated by arrows. The origin is the point of intersection of two beam lines.



SOUTH BOOSTER ROAD
30'
Y = 99,200
Y = 99,300
P. T. C TO M. H. P-15 C-34
C. L. ROAD
TO CENTER OF BOOSTER RING 360'
BOOSTER OFFICE BLDG. PARKING AREA
EXISTING DENSE CONCRETE OVER BOOSTER ENCLOSURE 3'-6 THICK, TOP/CONCRETE AT EL. 735'-3
EXISTING CONCRETE ARCHED PIPE
NEW RETAINING WALL
EXISTING ELECTRICAL SUBSTATIONS AT GRADE
INJECTION PO
X = 99511.388
Y = 99309.841
STA. 2486.3888
BOOSTER MAGNET SUPPORTS
TOE OF NEW BERM
UTILITY CORRIDOR
PLACE CONCRETE
DEMOLISH EXISTING BOOSTER BEAM ENCLOSURE (80')
SUPPORT SYSTEM TO HOLD P. & C. DUCTS IN PLACE DURING CONSTRUCTION
BEAM DUMP
SUMP PIT
NEW EXIT STAIR
EXISTING BOOSTER RING ENCLOSURE F. F. EL. 722'-6
SOUTHWEST BOOSTER OFFICE BUILDING F. F. EL. 744'-0
REINFORCE EXISTING ENCLOSURE
BOOSTER RING ROAD
UTILITY CORRIDOR
UTILITY CORRIDOR X = 99,677.042 Y = 99,133.944
M. H. P-14
M. H. C-33
4" GAS
6" ICW
6" CHR
6" CHS
2" WASTE
PIV
60'-0
UTILITY CORRIDOR
C. B.
C. B.
M. H. #1
SUBSTATION
CENTRAL UTILITY
30/16
ID = 1.875'
6" DWS
6" DWS
3/4" POLYPHOSPHATE
CHR
CHS
2" WASTE
TOP OF NEW 8 GeV BERM EL. 748'-0
BOOSTER OFFICE BLDG. PARKING AREA
CAST-IN-PLACE CONCRETE
GRASS AREA BETWEEN PARKING & OFFICE BUILDING
REINF. OF EXISTING ENCLOSURE NOT SHOWN FOR CLARITY
LINE OF EXCAVATION
EXISTING AP-4 BEAMLINE


Fig. 1

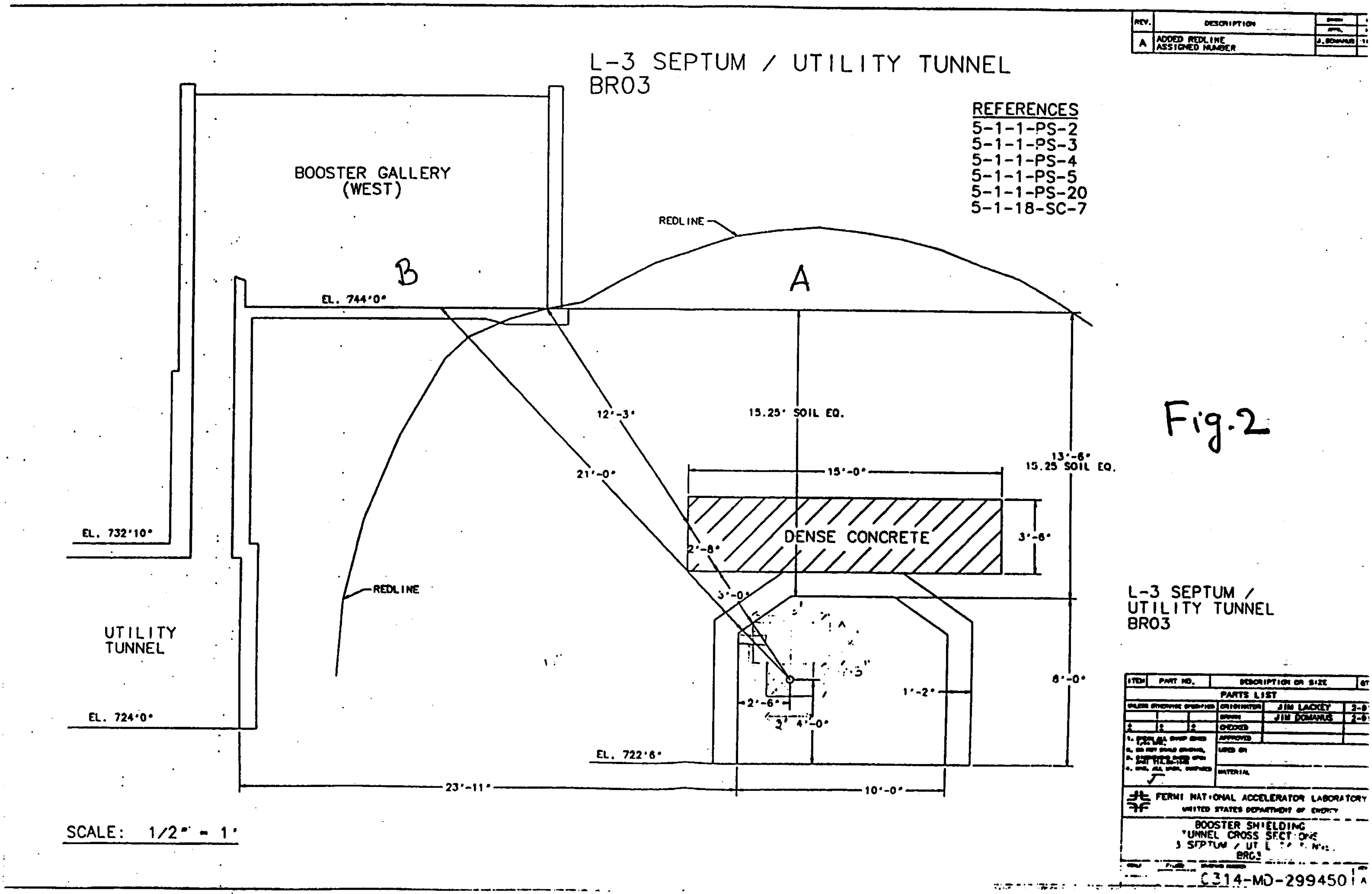

L-3 SEPTUM / UTILITY TUNNEL
BR03
REFERENCES
5-1-1-PS-2
5-1-1-PS-3
5-1-1-PS-4
5-1-1-PS-5
5-1-1-PS-20
5-1-18-SC-7
BOOSTER GALLERY (WEST)
REDLINE
B
A
EL. 744'0"
12'-3"
15.25' SOIL EQ.
21'-0"
15'-0"
13'-6"
15.25 SOIL EQ.
EL. 732'10"
DENSE CONCRETE
2'-8"
3'-6"
3'-0"
REDLINE
UTILITY TUNNEL
L-3 SEPTUM / UTILITY TUNNEL
BR03
1'-2"
8'-0"
2'-6"
4'-0"
EL. 724'0"
EL. 722'6"
23'-11"
10'-0"
SCALE: 1/2" = 1'
REV.
DESCRIPTION
A
ADDED REDLINE
ASSIGNED NUMBER
J. DOMANUS
ITEM
PART NO.
DESCRIPTION OR SIZE
PARTS LIST
ORIGINATOR
JIM LACKEY
JIM DOMANUS
CHECKED
APPROVED
USED ON
MATERIAL
FERMI NATIONAL ACCELERATOR LABORATORY
UNITED STATES DEPARTMENT OF ENERGY
BOOSTER SHIELDING
C314-MD-299450
A

Fig.2

1CROSS SECTION OF GEOMETRY FOR CONSTANT X= 0.00 CM
FROM Y= 0.00 TO Y= 300.00 CM (VERTICAL) AND
FROM Z= 0.00 TO Z= 5000.00 CM (HORIZONTAL)

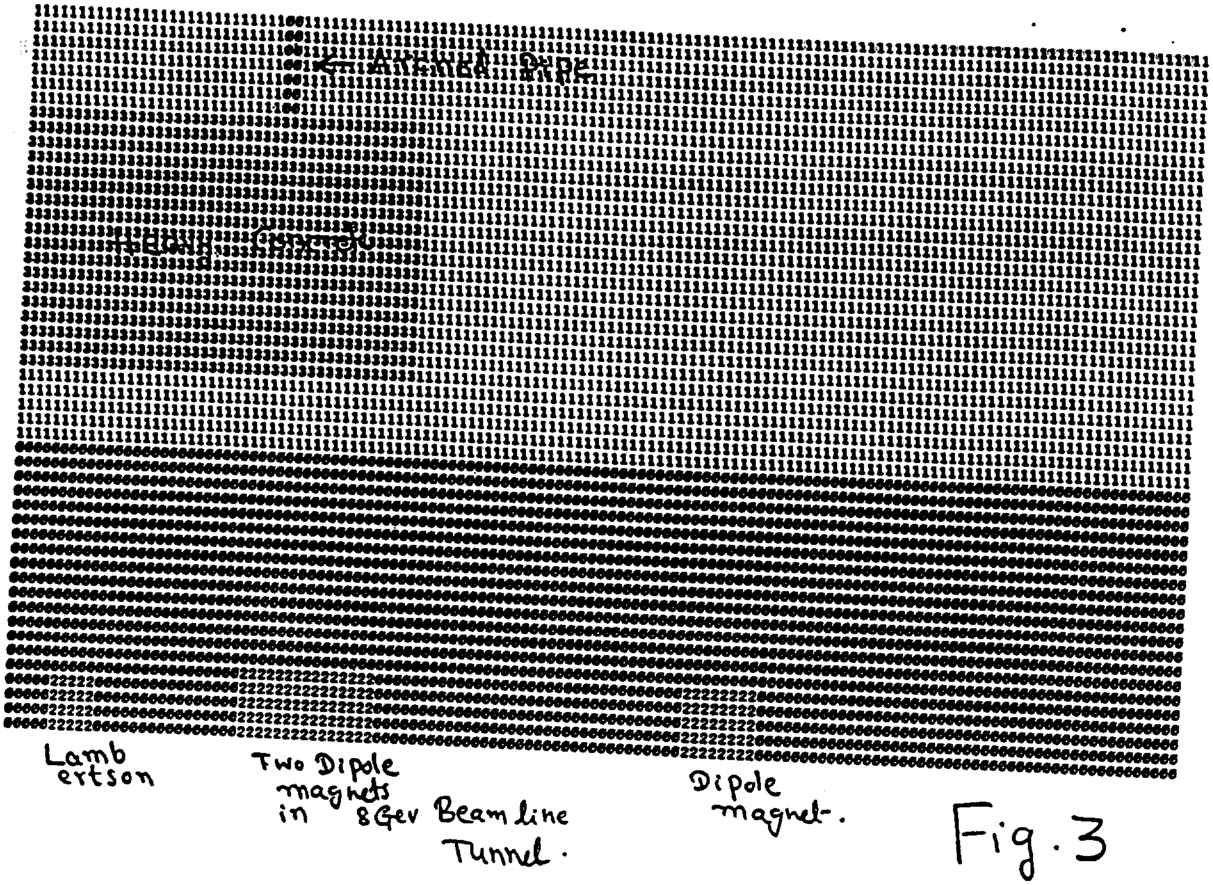
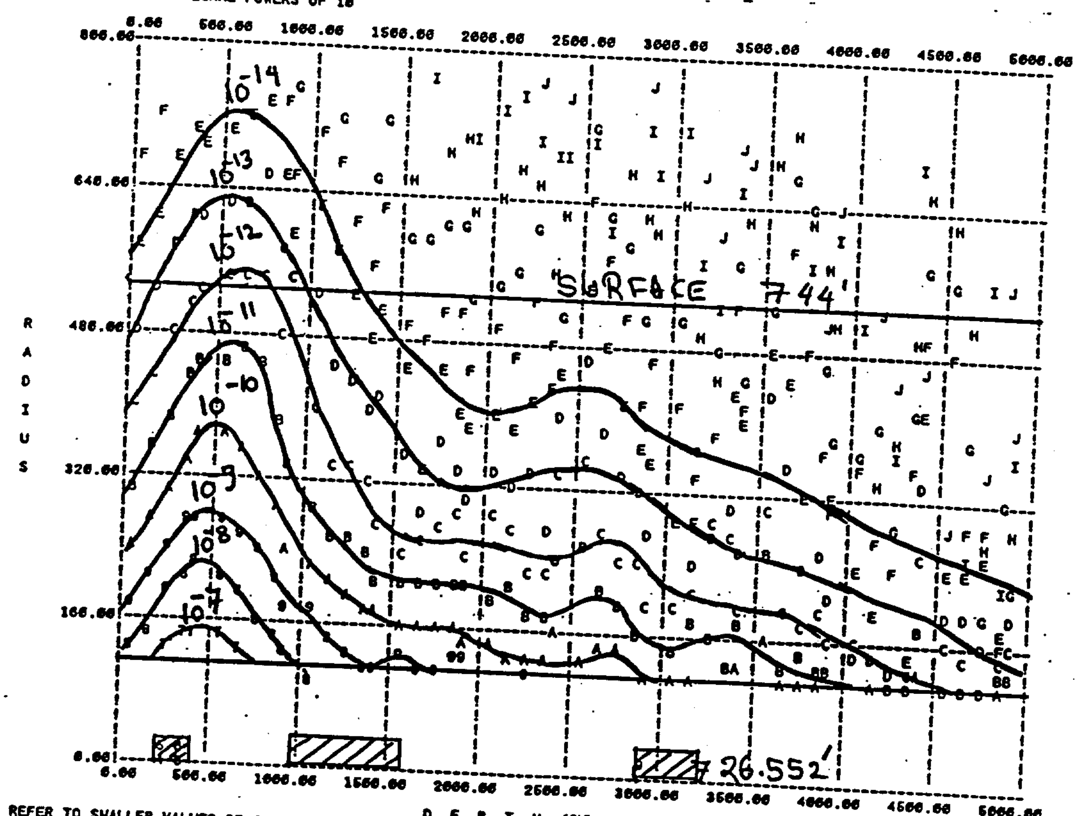


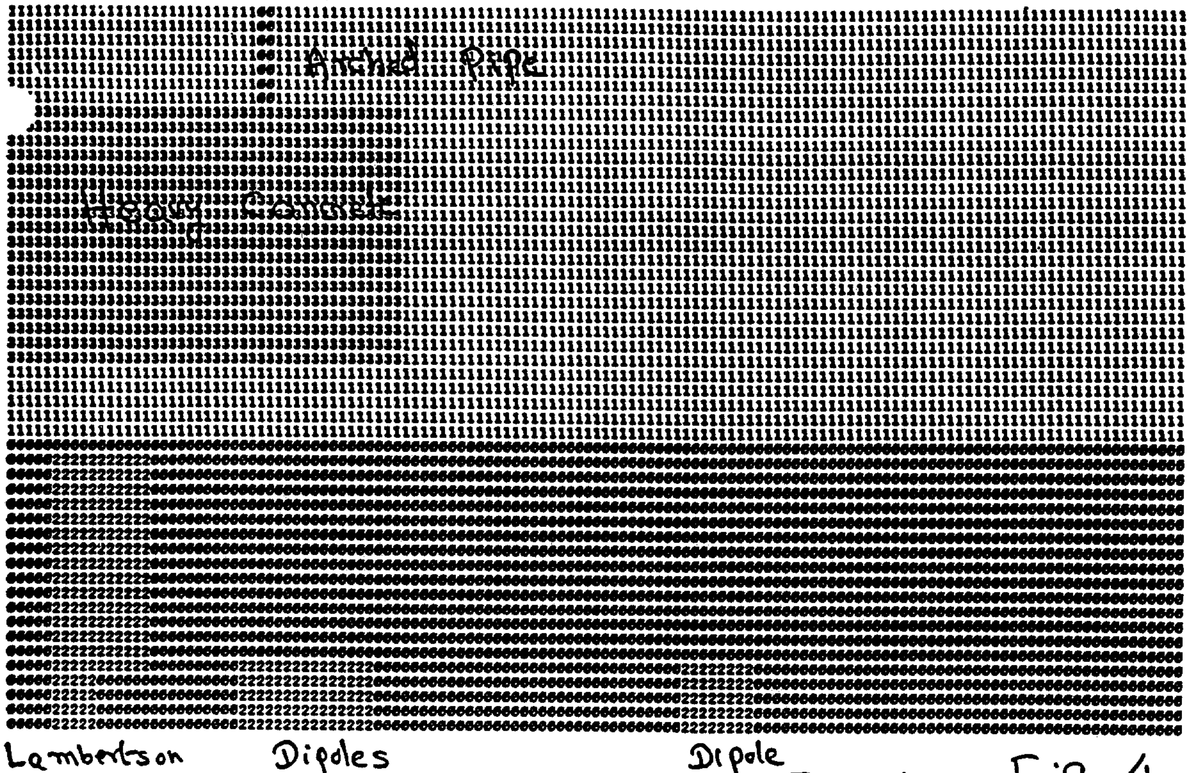

Fig. 3

1CONTOURS OF EQUAL STAR DENSITY (STARS/CM3*INC.PTCLE)
CONTOURS ARE SHOWN FOR INTEGRAL POWERS OF 10



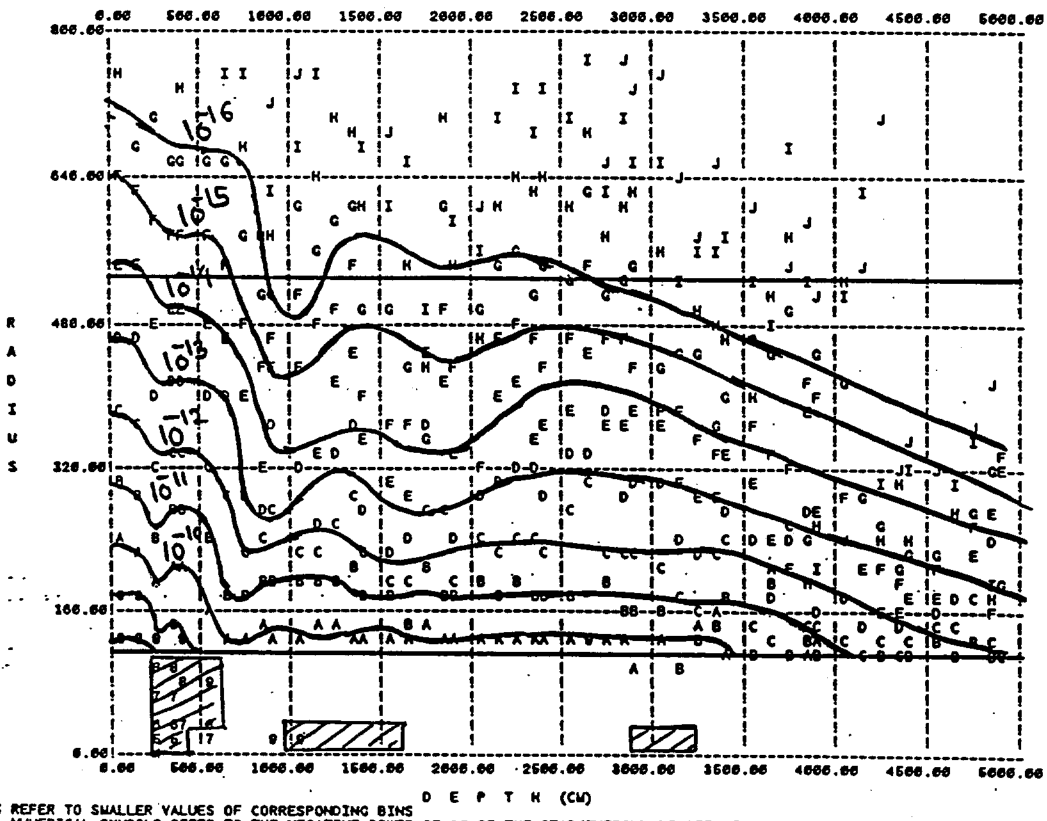

R-LABELS REFER TO SMALLER VALUES OF CORRESPONDING BINS
LEGEND : NUMERICAL SYMBOLS REFER TO THE NEGATIVE POWER OF 10 OF THE STAR(ENERGY) DENSITY E.G., 5 REFERS TO THE 10**-5 CONTOUR
OTHER POWERS OF 10(SYMBOLS) :-10(A),-11(B),-12(C),-13(D),-14(E),-15(F),-16(G),-17(H),-18(I),-19(J)
1(Z),2(Y),3(X),4(W),5(V),6(U),7(T),8(S),9(R),10(Q)

1CROSS SECTION OF GEOMETRY FOR CONSTANT X= 0.00 CM
FROM Y= 0.00 TO Y= 300.00 CM (VERTICAL) AND
FROM Z= 0.00 TO Z= 5000.00 CM (HORIZONTAL)



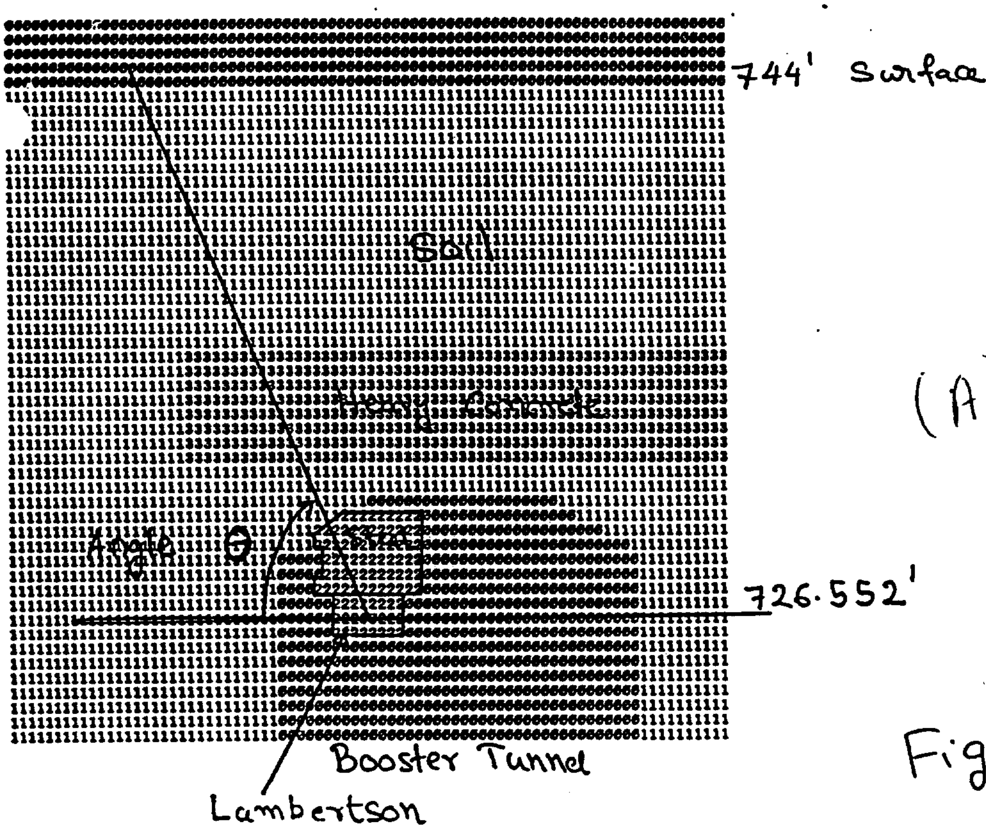

8 GeV Beam line Tunnel. Fig. 4

1CONTOURS OF EQUAL STAR DENSITY (STARS/CM3*INC.PTCLE)
CONTOURS ARE SHOWN FOR INTEGRAL POWERS OF 10




R-LABELS REFER TO SMALLER VALUES OF CORRESPONDING BINS
LEGEND : NUMERICAL SYMBOLS REFER TO THE NEGATIVE POWER OF 10 OF THE STAR(ENERGY) DENSITY E.G., 5 REFERS TO THE 10**-5 CONTOUR
OTHER POWERS OF 10(SYMBOLS) :-10(A),-11(B),-12(C),-13(D),-14(E),-15(F),-16(G),-17(H),-18(I),-19(J)
1(Z),2(Y),3(X),4(W),5(V),6(U),7(T),8(S),9(R),10(Q)

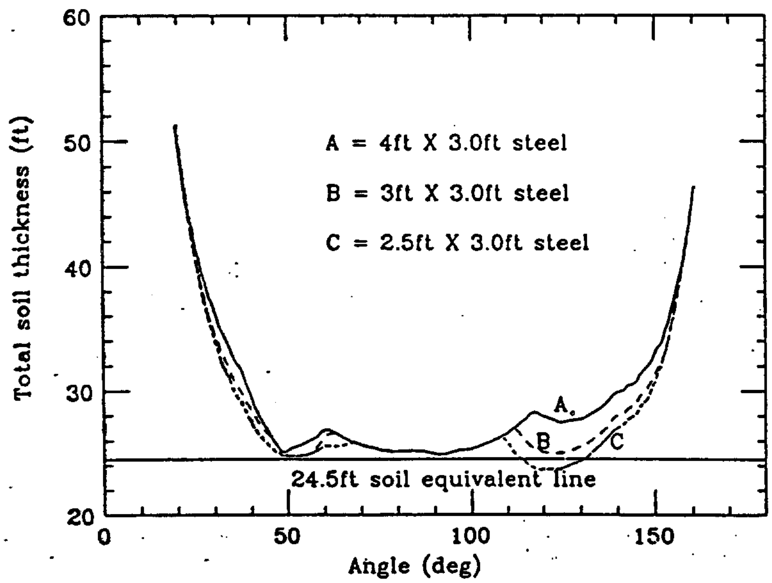
CROSS SECTION OF GEOMETRY FOR CONSTANT Z= 1.00 ft
FROM X= -4.00 TO X= 20.00 ft (VERTICAL) AND
FROM Y= 10.00 TO Y= -10.00 ft (HORIZONTAL)




(A)

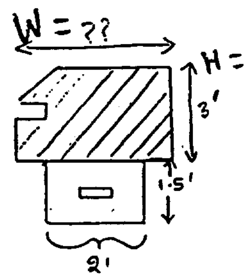
Fig. 5

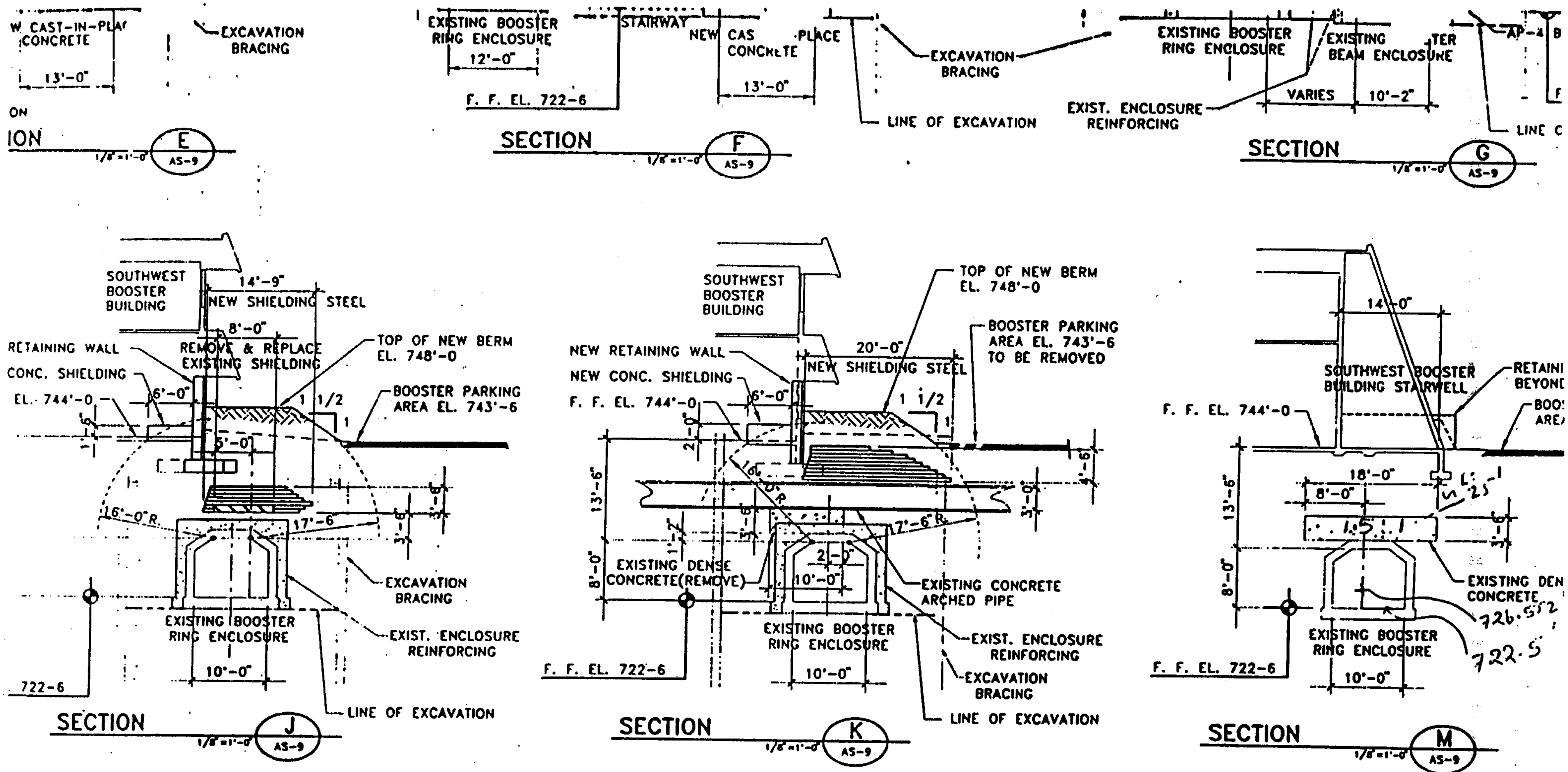
Equivalent Soil Thickness above the Booster to MI Extraction Lambertson (with 3.0ft steel shielding)




3.5ft thick heavy concrete buried in soil is assumed

(B)






| DANIEL | | | NAME | DATE | | SCALE: | FERMI NATIONAL ACCELERATOR |
|---|---|---|---|---|---|---|---|
| - 21842300 | | DESIGNED | T.LACKOWSKI | | | 1/8"=1'-0" 0 4 8 10 SCALE FEET | UNITED STATES DEPARTMENT OF |
| | DATE | DRAWN | J.HACKEMER,J.GEHARD | | | | FERMILAB MAIN |
| | JULY,1992 | CHECKED | | | | | 8 GeV SECTIONS |
| | JULY,1992 | APPROVED | | | | | DRAWING NO. 6-6-2 TITLE-1 A |
| | JULY,1992 | SUBMITTED | | | | | |