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DUMP IT: Conceptual design of E864 beam dump and shield walls

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* *Not intended as advice regarding E864 or its AGS support staff!!!*

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Conceptual Design of E864 Beam Dump and Shield Walls

The conceptual design of the shielding for E864 in the A3 beam line is presented. The design criteria and calculations for both the beam stop and side wall shielding are detailed below.

Experimental Requirements

Experiment 864 has proposed to run Au beams with an intensity of 10^7 ions/spill. The experiment has requested that systems be designed to allow for a possible intensity upgrade to 10^8 Au ions/spill. In addition, the experiment has requested that the ability to use secondary beams during proton operations for detector testing and calibration.

Design Criteria

The goal of the conceptual shield design is to meet the experimental requirements for heavy ion running with 10^8 Au ions/spill. A radiation level of 1 mrem/hr for 10^8 Au/spill is used as a reference level in the shield design. The goal of 1 mrem/hr is arbitrary and it is expected that the following considerations will be used in establishing the actual shield design:

1. Locations where the shielding cannot be easily ungraded in the future should have the initial construction for 10^8 Au/spill. Locations where future upgrade are practical could have initial construction for the 10^7 Au spill which the experiment is expected to run for the first 1-2 years.

2. Locations with low occupancy can be designed to have elevated radiation levels.

3. Practical considerations such as limited space and available shielding block sizes will determine the actual thickness.

The shielding for heavy ion operations will be sufficient to accommodate any secondary beam operations. The exception is the beam stop. The muon content in the secondary beam will penetrate the stop and require limitation on energy and intensity of the secondary beam. It is expected that this will be protected by interlocks. In addition, the interlocks will be needed to protect against deflecting low energy secondary beams off the beam stop.

The heavy ion beams will be treated as A independent nucleons for the purposes of the shielding simulation. The ions will be assumed to have 15 A•GeV/c to accommodate the possible running of light ions. This will provide a small overestimate of the radiation levels for Au beams (11.6 A•GeV/c) and a larger overestimate for muons. It will be shown that the muons do not dominate the shielding design and thus the large overestimate of the muons is unimportant. The assumed normal operating parameters for the shield design are:

A = 197
p = 15 A•GeV/c
I = 10^8 Au/spill
1000 spill/hour
20% interaction in experimental target
100% interaction in the beam stop
L = 1 mrem/hr (the design dose equivalent rate).

Thus, for normal operations the shielding has been designed for 2 x 10^{13} protons/hr at 15 GeV/c and an external radiation level of 1 mrem/hr.

Method

The Monte Carlo program CASIM [1,2,3] was used to simulate aspects of the shielding both for the hadron cascade and for muons. CASIM produces tables of star density per incident nucleon for the shielding material. The desired shielding thickness is obtained by converting star density to dose equivalent and matching the desired operating assumptions. Thus, the desired star density is:

$$sd = L/(I*C),$$

where sd is the star density (stars/(cm^3-interacting particle)), I is the equivalent nucleon interaction rate (interactions/hour), L is the design dose equivalent rate, and C a conversion factor depending on the material. The conversion factor for iron is 3.7 x 10^{-3} mrem/(star/cm^3) and 6.0 x 10^{-3} mrem/(star/cm^3) for heavy concrete.[1,4,5] Heavy concrete is simulated with the same composition as light concrete but with a density of 3.61 gm/cm^2 instead of 2.4 gm/cm^3.

The geometry of the experimental area has been approximated in cylindrical geometry rather than attempt to duplicate the rectangular geometry of the proposed shield design. This greatly increases the speed of the calculations. Where large asymmetries exist, cylindrical geometry will be run for slices on several different planes to approximate the difference.

Beam Stop

The beam stop was simulated with a solid iron core. Iron was chosen since a beam stop of heavy concrete becomes unreasonable large for the energies and intensities assumed for this design. A small re-entrant cavity 2 meters deep and surrounded by heavy concrete was placed at the front of the beam stop. Figure 1 displays the contours of star density in the radius-z plane. In Fig. II the behavior of the star density as a function of depth is presented for several fixed radial positions in the beam stop. The design goal of 1 mrem/hr for 10^8 Au/spill is equivalent to about 1.4×10^{-11} stars/cm^3-inc proton and therefore requires the length of the beam stop to be 5.5 meters (18 feet) of iron. The star density as a function of radius is shown in Fig. III for several values of depth in the iron. The design goal suggests that the iron must have a transverse size of 2.25 meters (7.4 feet).

Experiment 864 will have two spectrometer magnets upstream of the beam stop. These dipoles will deflect the full energy beam 1.4 meters to beam left and .7 meters to beam right in proposed running configurations. Therefore, these dimensions should be added to the left and right sides of the beam stop. In the simplest case the beam stop should have a radius of iron 3.65 meters (12 feet). However, it is expected that limited space on the east side will require interlocks to prevent full deflection. The east side of the beam stop is one area in which practical considerations may prevent the shield from meeting the design goal.

The dose equivalent due to muons generated in the beam dump has been calculated using CASIM. Figure IV shows the mrem per incident 15 Gev/c proton entering an iron dump as a function of depth in the iron. The results for a radius of .5 meter demonstrate that the muons only contribute at small transverse dimensions (small angles). A length of 5.2 meters (17 feet) is required to meet the design goal. This dimension is slightly smaller than required for hadrons.

Figure V compares the contributions of muons and hadrons on the beam axis. At the requested intensity and energy the hadrons determine the length and width of the beam dump. Practical considerations may require limiting the length of the beam stop. Figure V shows that the hadrons have a greater effective attenuation in stop than the muons and will be the primary consideration if the stop is shortened.

End Wall and Stop

The shielding thickness for the side walls, roof, and end wall have been determined by requiring 20% of the Au beam to interact in the E864 target. CASIM was used to generate the hadron cascade. The two spectrometer magnets do not effectively shield most of the end cave wall. Therefore, the spectrometer magnets were not included in the calculation for the end wall.

Figure VI displays the required wall thickness in gm/cm^2 of light concrete as a function of radius (distance from the beam axis). Values are not shown for small distances where the beam dump requirements dominate the thickness.

Muons from the E864 target were modeled using CASIM. The results are shown in Fig. VII. Comparing Fig. VI to Fig. VII, it can be concluded that the hadrons determine the end wall thickness for radii greater than about 2 meters. For smaller radii the requirements of the beam dump dominate the shielding design.

Roof

CASIM was used to examine the roof thickness. A vertical slice over the beam line was used to input the dimensions into the cylindrical geometry. The calculations were done with and without the magnets in place. A view of this approximate geometry is shown in Fig. VIII.

The results of the CASIM calculations are presented in Fig. IX. It is apparent that the magnet steel provides substantial shielding of the downstream roof section.

East Side Wall

The east side wall was calculated in a fashion similar to the roof. Dimensions at beam height to the east were used to approximate the geometry. Calculations were done both with and without the magnets in place. The coils of the magnets were approximated to be half density copper for magnet M1 and half density aluminum for M2. A schematic of the approximated geometry is displayed in Fig. X. The results of the CASIM calculations are shown in Fig. XI. The magnets are less effective in shielding the side walls as compared to the roof because of the lower density coils in the side directions. At distances greater than 25 meters downstream of the target the required shielding thickness begins to rise, resulting from the decreased shielding from the magnets.

West Side Wall

The west wall is done in analogous fashion to the east wall. Figure XII presents the results of the CASIM calculations. The required thickness is substantially less than the east wall because of the increased transverse distance from the beam line.

Secondary Beam Operations

It is expected that most of secondary beam operations for E864 will be adequately protected by a combination of the shielding supplemented with interlocks.

It is expected that muons in high energy secondary beams will penetrate the beam stop and exceed the levels designed for heavy ion operations. The existing A3 beam stop had 18 feet of iron equivalent. Fault studies with 15 GeV/c negatives demonstrated that the stop needed to supplemented with additional iron to decrease the muon penetration. For E864, it is expected that a combination of limiting the secondary beam energy, limiting the beam intensity, and redefining the radiological classification behind the beam stop will be used.

The intensities for secondary beam operations are expected to be well below the 10^{10}/spill 15 GeV/c proton equivalent used for shielding the heavy ion beam. Therefore, normal secondary beam targeting and possible collisions along the beam path will be well below the possible levels the heavy ion beams could create. The exception is the possible deflection of the secondary beam itself. The actual shield design will be examined for the possible levels created by deflecting the lower energy secondary beams. Interlocks will then be designed to protect against such conditions.

Comments

There are several systematic items that should be considered in using the presented materials to create the actual shield design. It is known for protons that CASIM tends to overestimate the radiation in forward angles and underestimate at large angles. It has been assumed that heavy ion interaction creates the same radiation pattern as protons. It has been assumed that all nucleons interact in each collision, i.e., all collisions are zero impact parameter. This causes an overestimate of approximately a factor of four for radiation caused by a thin target. Finally, the effect of magnetic fields has been ignored. These systematic features should be considered in converting the conceptual design to the actual shield.

References

1. A. Van Ginnekin and M. Awschalom, "High Energy Interactions in Large Targets," Fermilab, Batavia, IL (1972).

2. A. Van Ginneken, "CASIM. Program to Simulate Hadronic Cascades in Bulk Matter," Fermilab FN-272 (1975).

3. A.J. Stevens, "CASIM on VAX," AGS/ADD Technical Note 287 (1987).

4. G.R. Stevenson, "Dose Equivalent per Star in Hadron Cascade Calculations," CERN Report TIS-RP/173 (1986).

5. A.J. Stevens, "Analysis of Radiation Levels Associated with Operations of the RHIC Transfer Line," (1992).

Figure Captions

I. Contours of star density given by CASIM for 15 GeV/c protons striking an iron beam stop.

II. Star density as a funciton of depth in the iron beam stop for 15 GeV/c protons. The curves are for radii of 0. (solid), 0.5 (dashed), and 1. (dot-dashed) meters. The design goal of 1 mrem/hr for 10^8 Au ions/spill is shown.

III. Star density as a function of radius in the iron beam stop for 15 GeV/c protons. The curves are for depths of 1. (solid) and 2 (dashed) and 4 (dot-dashed) meters. The design goal of 1 mrem/hr for 10^8 Au ions/spill is shown.

IV. Mrem per incident proton due to muons as a function of depth in the iron beam stop for 15 GeV/c protons. The curves are for radii of 0. (solid) and 0.5 (dashed) meters. The design goal of 1 mrem/hr for 10^8 Au ions/spill is shown.

V. Mrem per incident proton as a funciton of depth in the iron beam stop for 15 GeV/c protons. The curves are for hadrons (solid) and muons (dashed) at a radius of 0. meters. The design goal of 1 mrem/hr for 10^8 Au ions/spill is shown.

VI. The thickness in gm/cm^2 of light concrete required to shield the end of the E864 blockhouse as a funciton of radius. The solid curve is for 1 mrem/hr at 10^8 Au/spill and the dashed curve is for 10 mrem/hr. The source is hadrons produced in the E864 target with 20% beam interaction, located 32 meters upstream of the end wall.

VII. The thickness in gm/cm^2 of light concrete required to shield the end of the E864 blockhouse as a funciton of radius. The solid curve is for 1 mrem/hr at 10^8 Au/spill and the dashed curve is for 10 mrem/hr. The source is muons produced in the E864 target with 20% beam interaction, located 32 meters upstream of the end wall.

VIII. Schematic side view of the geometry used for the roof relative to the beam line and the spectrometer magnets M1 and M2. The roof is shown 1 meter above the beam height. The experimental target is placed directly in front of the M1.

IX. The thickness in gm/cm^2 of light concrete required to shield the roof over the E864 experimental area as a function of length. The target is at 5 meters. The solid curve shows the thickness for 1 mrem/hr at 10^8 Au/spill and no spectrometer. The required thickness with magnets in place for 1 mrem/hr (dashed) and 10 mrem/hr (dot-dashed) with 10^8 Au/spill are also shown. The source is hadrons produced in the E864 target with 20% beam interaction.

X. Schematic top view of the geometry used for the east wall relative to the beam line and the spectrometer magnets M1 and M2. The experimental target is placed directly in front of the M1.

XI. The thickness in gm/cm^2 of light concrete required to shield the east side of the E864 experimental area as a function of length. The target is at 5 meters. The solid curve shows the thickness for 1 mrem/hr at 10^8 Au/spill and no spectrometer magnets. The required thickness with magnets in place for 1 mrem/hr (dashed) and 10 mrem/hr (dot-dashed) with 10^8 Au/spill are also shown. The source is hadrons produced in the E864 target with 20% beam interaction.

XII. The thickness in gm/cm^2 of light concrete required to shield the west side of the E864 experimental area as a funciton of length. The target is at 5 meters. The solid curve shows the thickness for 1 mrem/hr at 10^8 Au/spill and no spectrometer magnets. The required thickness with magnets in place for 1 mrem/hr (dashed) and 10 mrem/hr (dot-dashed) with 10^8 Au/spill are also shown. The source is hadrons produced in the E864 target with 20% beam interaction.

CON[illegible]URS OF EQUAL STAR DENSITY (STARS/CM3*INC.PTCLE)
CONTOURS ARE SHOWN FOR INTEGRAL POWERS OF 10

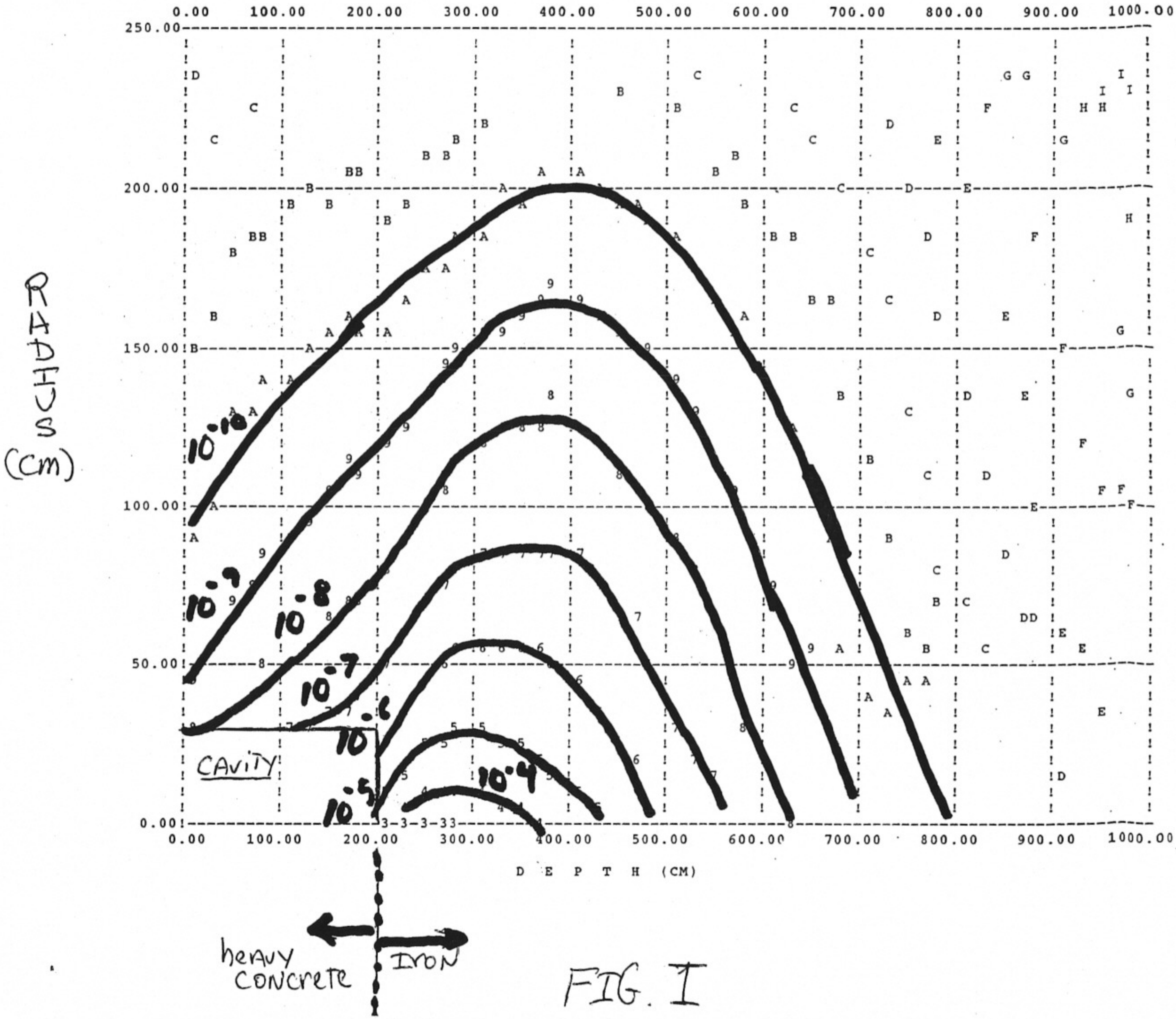


FIG. I

Star Density in E864 Beam Stop

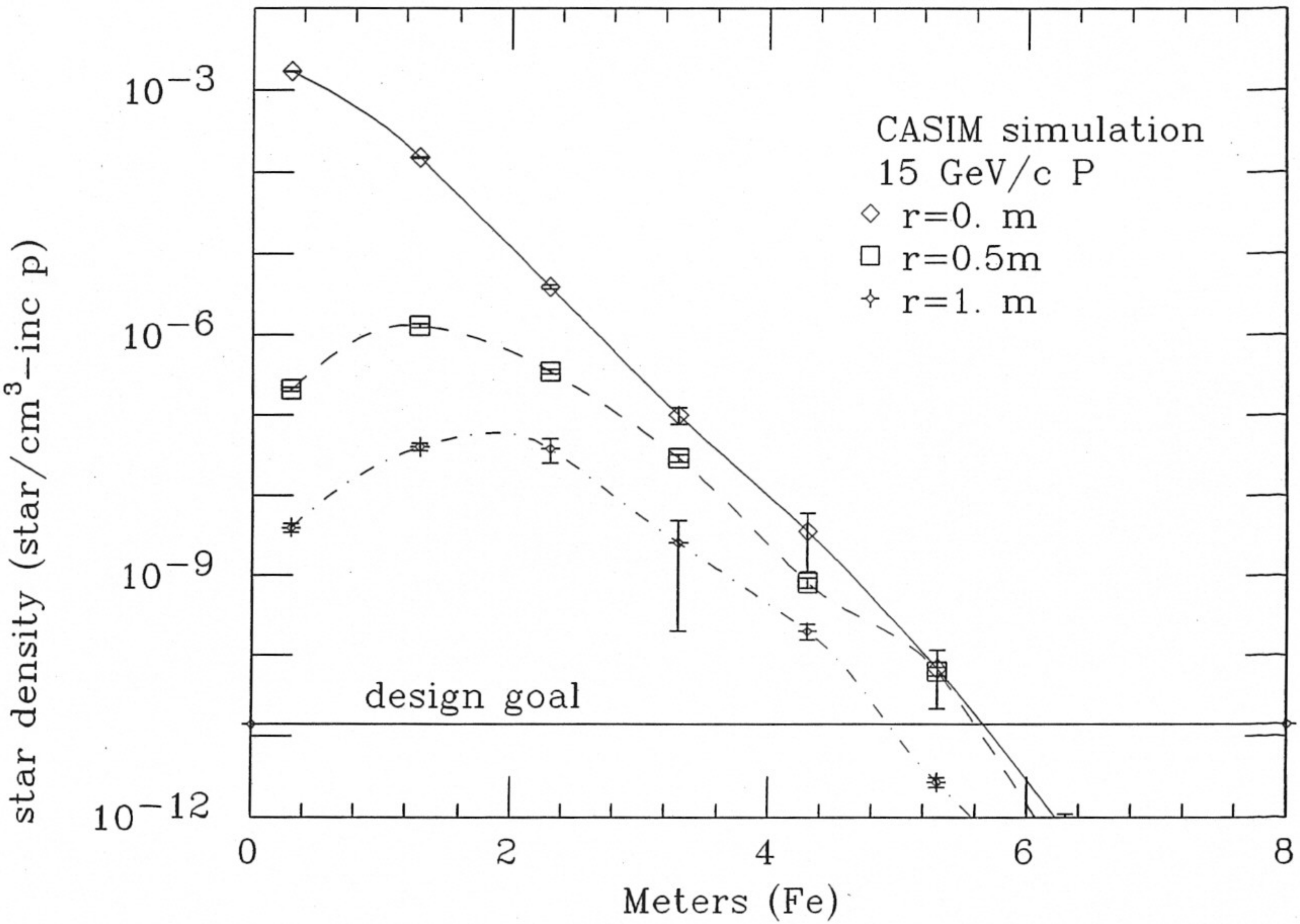


FIG. II

Star Density in E864 Beam Stop

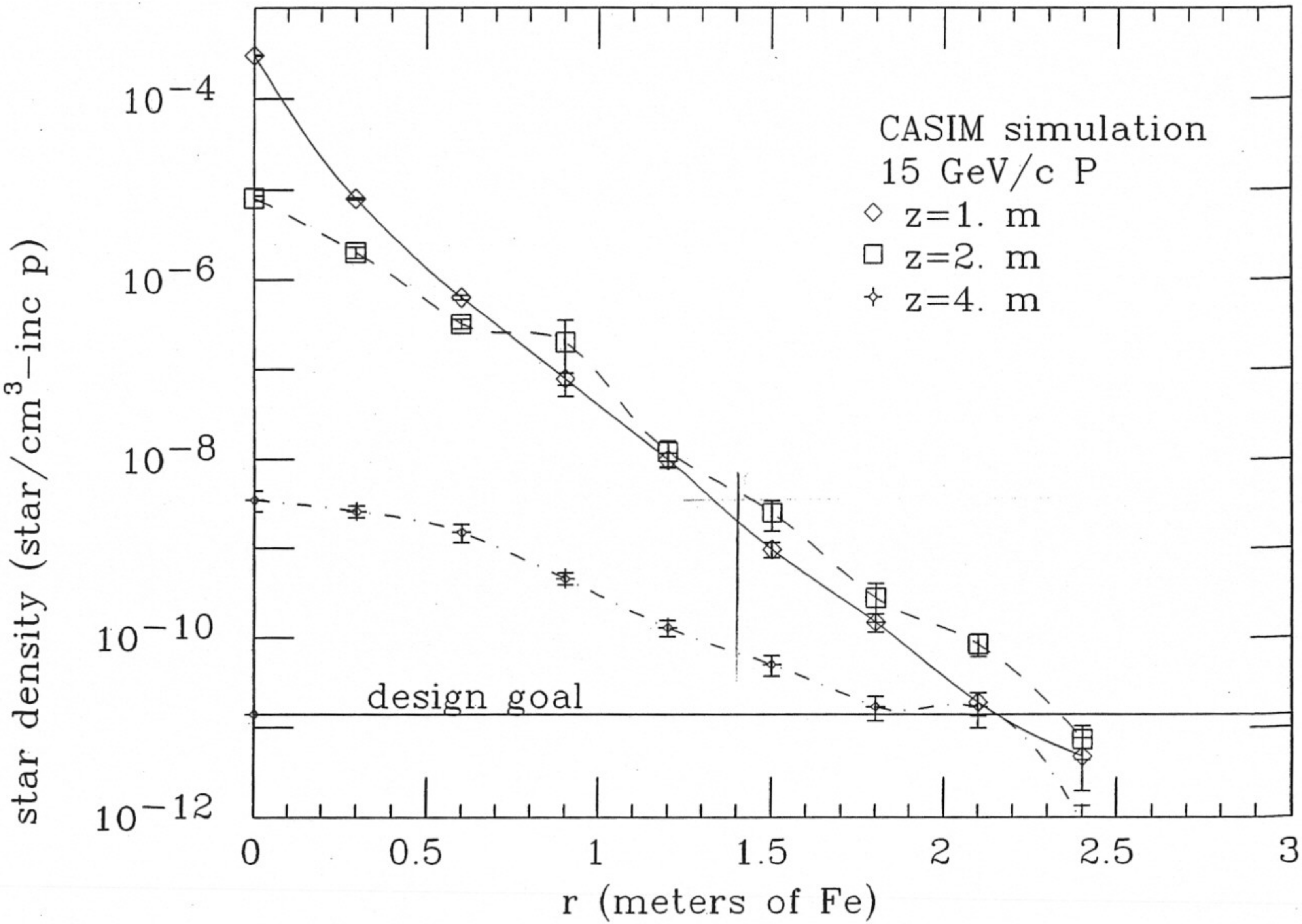
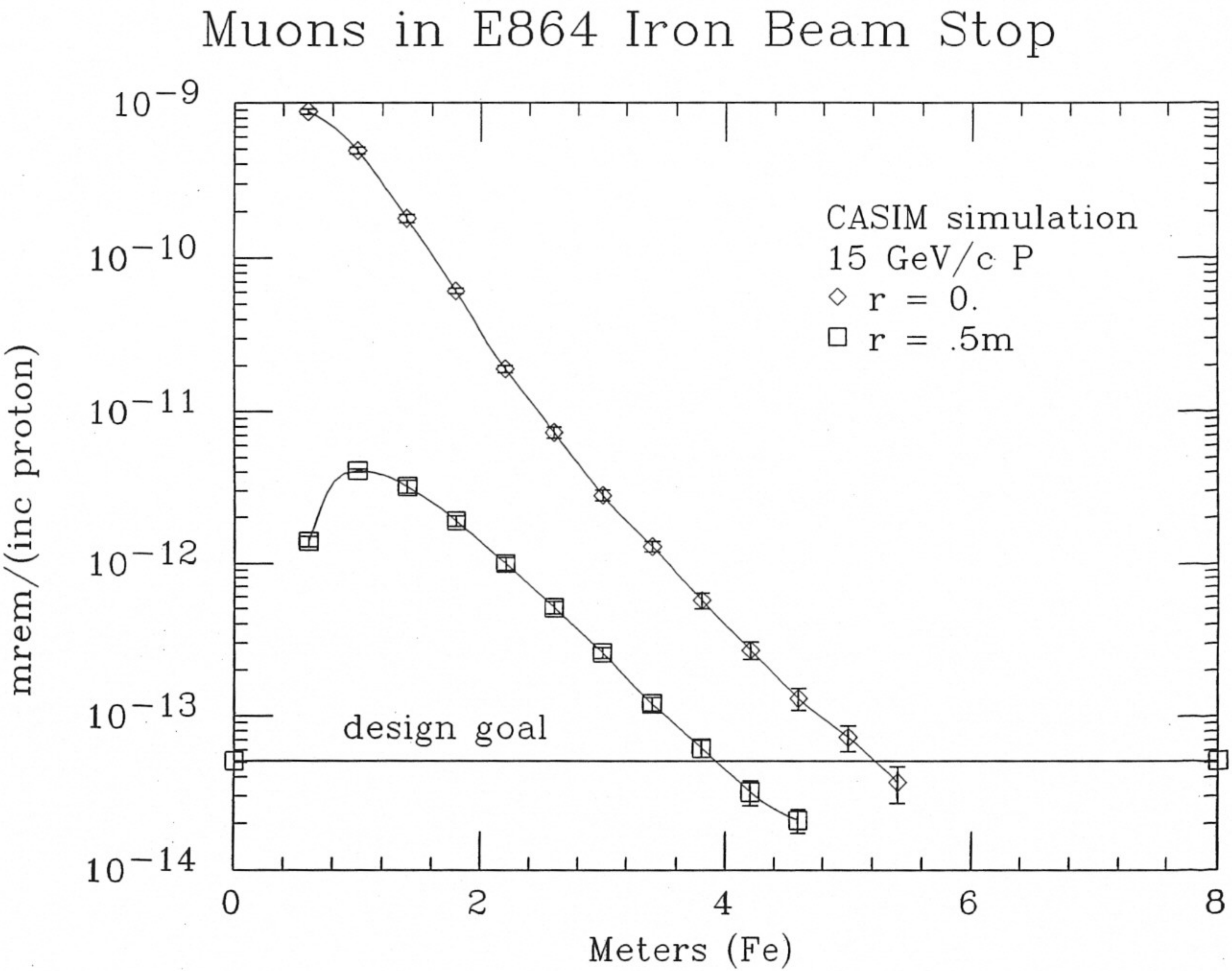


FIG. III



Muons in E864 Iron Beam Stop
CASIM simulation
15 GeV/c P
◇ r = 0.
□ r = .5m
design goal
mrem/(inc proton)
Meters (Fe)
10^{-9}
10^{-10}
10^{-11}
10^{-12}
10^{-13}
10^{-14}
0
2
4
6
8

FIG. IV

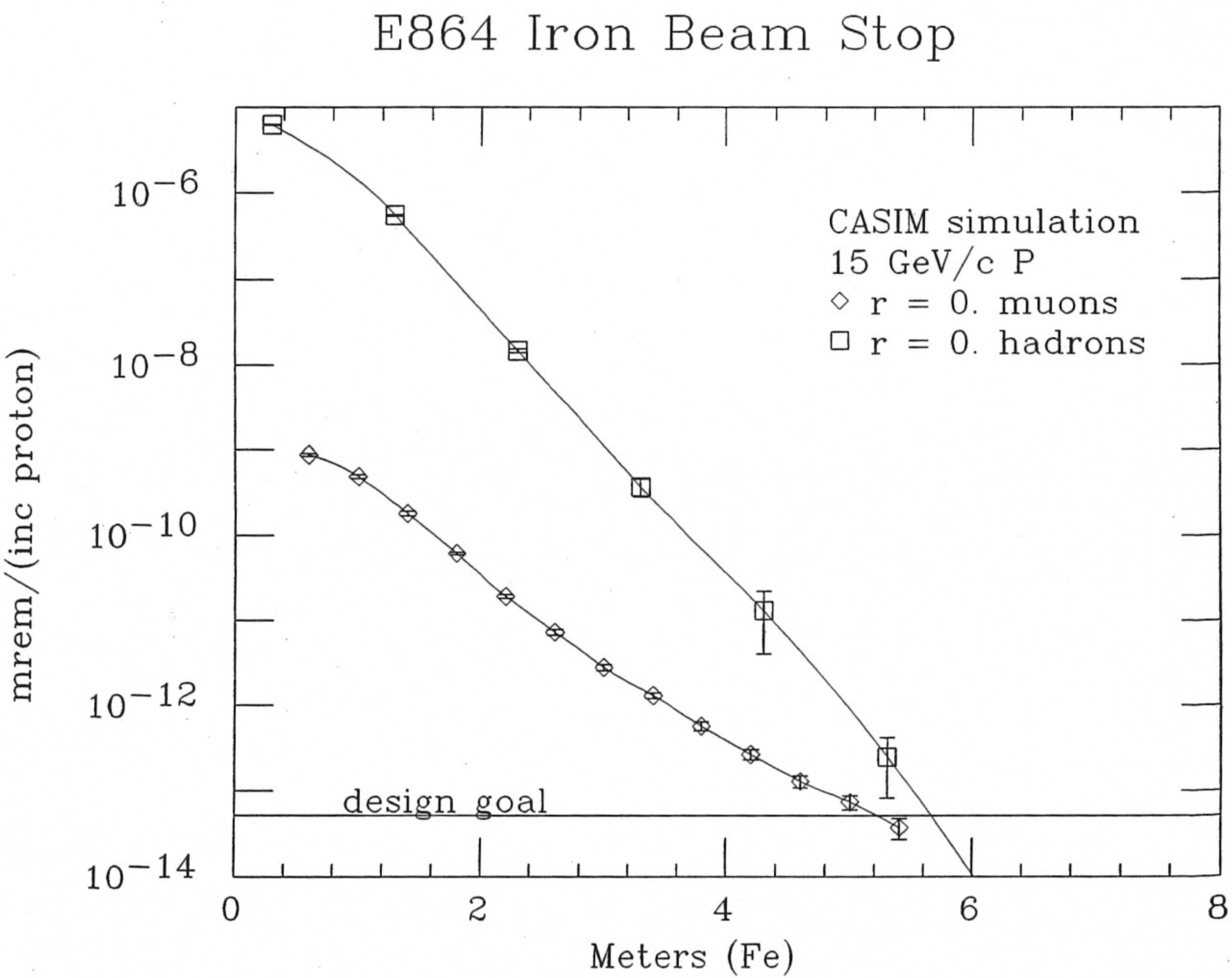

E864 Iron Beam Stop
CASIM simulation
15 GeV/c P
◇ r = 0. muons
□ r = 0. hadrons
design goal
mrem/(inc proton)
10^{-6}
10^{-8}
10^{-10}
10^{-12}
10^{-14}
0
2
4
6
8
Meters (Fe)

FIG. V

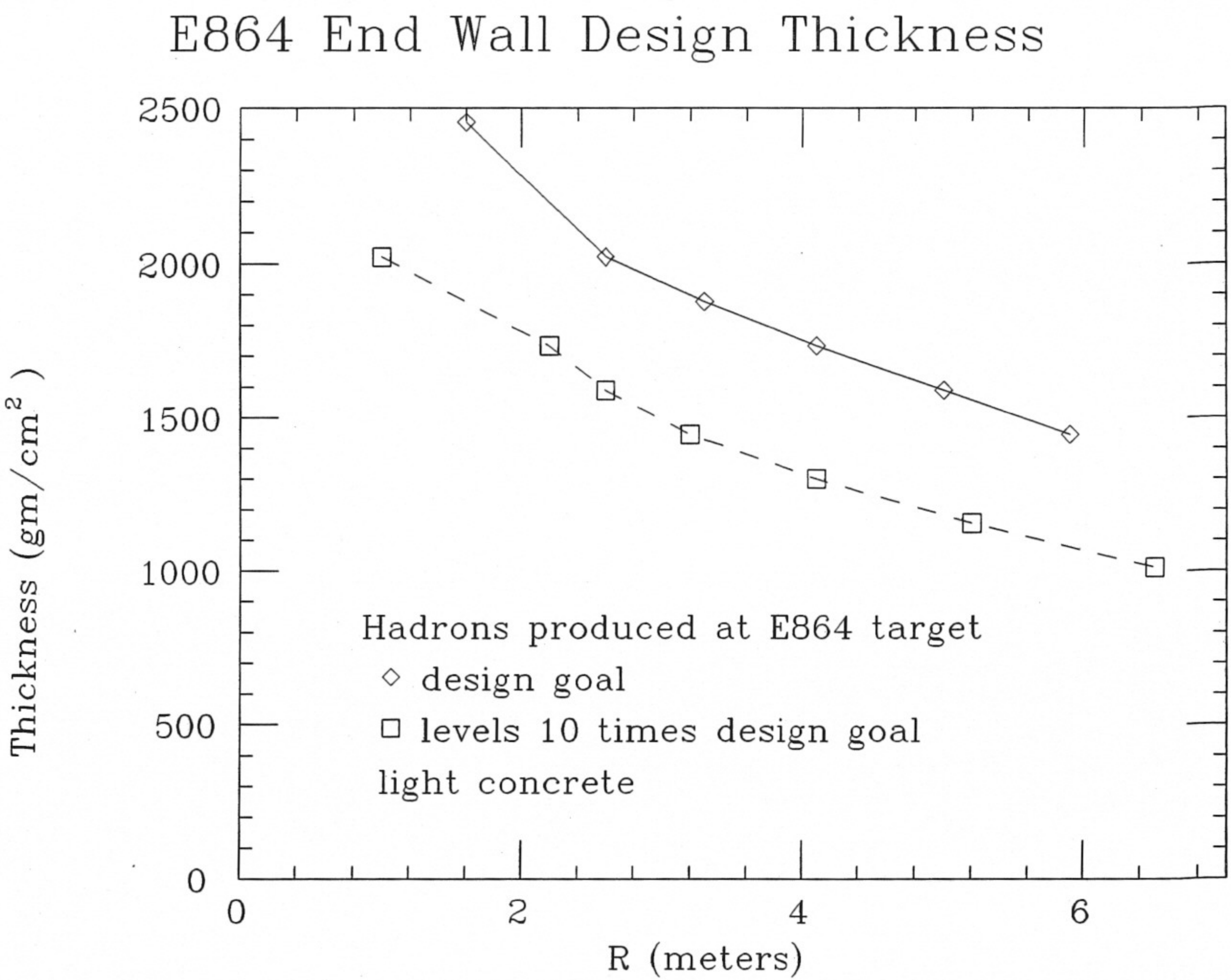

E864 End Wall Design Thickness
2500
2000
1500
1000
500
0
0
2
4
6
Thickness (gm/cm²)
R (meters)
Hadrons produced at E864 target
◇ design goal
□ levels 10 times design goal
light concrete

FIG. VI

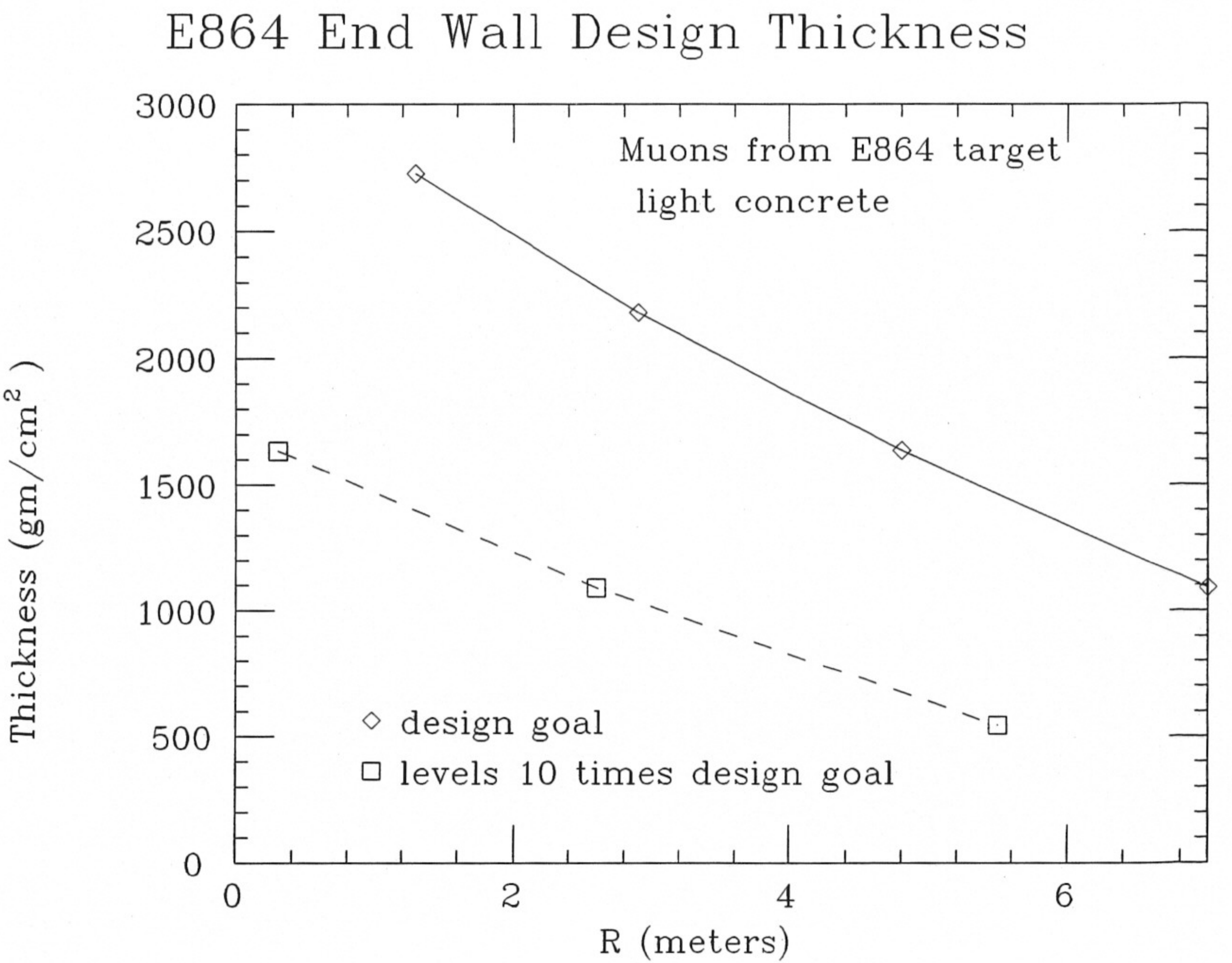

E864 End Wall Design Thickness
Muons from E864 target
light concrete
Thickness (gm/cm^2)
3000
2500
2000
1500
1000
500
0
0
2
4
6
R (meters)
design goal
levels 10 times design goal

FIG. VII

CROSS SECTION OF GEOMETRY FOR CONSTANT Y= 0.00 CM
ROM X= -300.00 TO X= 300.00 CM (VERTICAL) AND
ROM Z= 0.00 TO Z= 4000.00 CM (HORIZONTAL)

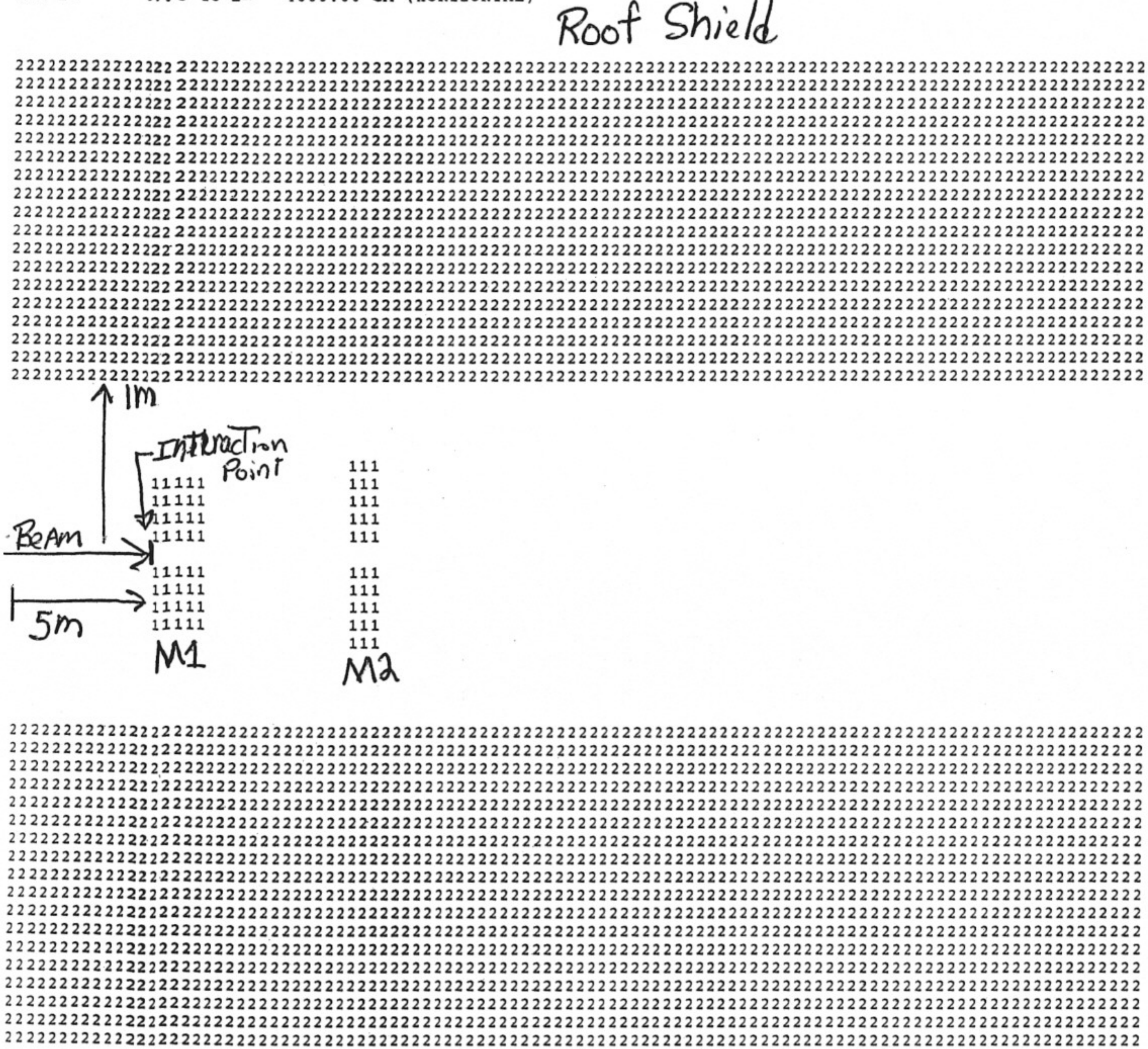


FIG. VIII

E864 Roof Shield Design Thickness

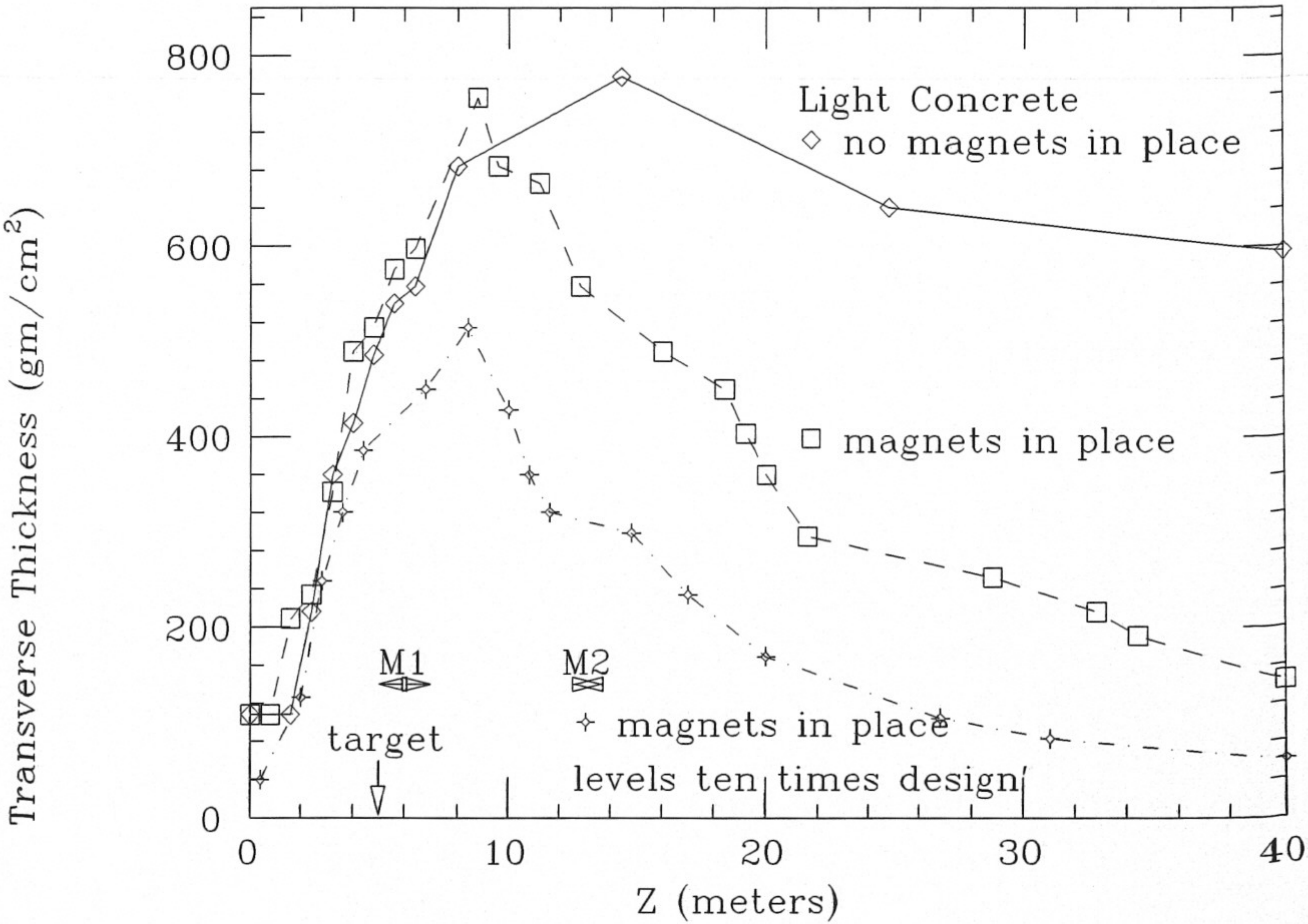


FIG. IX

CROSS SECTI OF GEOMETRY FOR CONSTANT Y= 0.00 CM
ROM X= -5 .00 TO X= 500.00 CM (VERTICAL) AND
ROM Z= 0.00 TO Z= 4000.00 CM (HORIZONTAL)

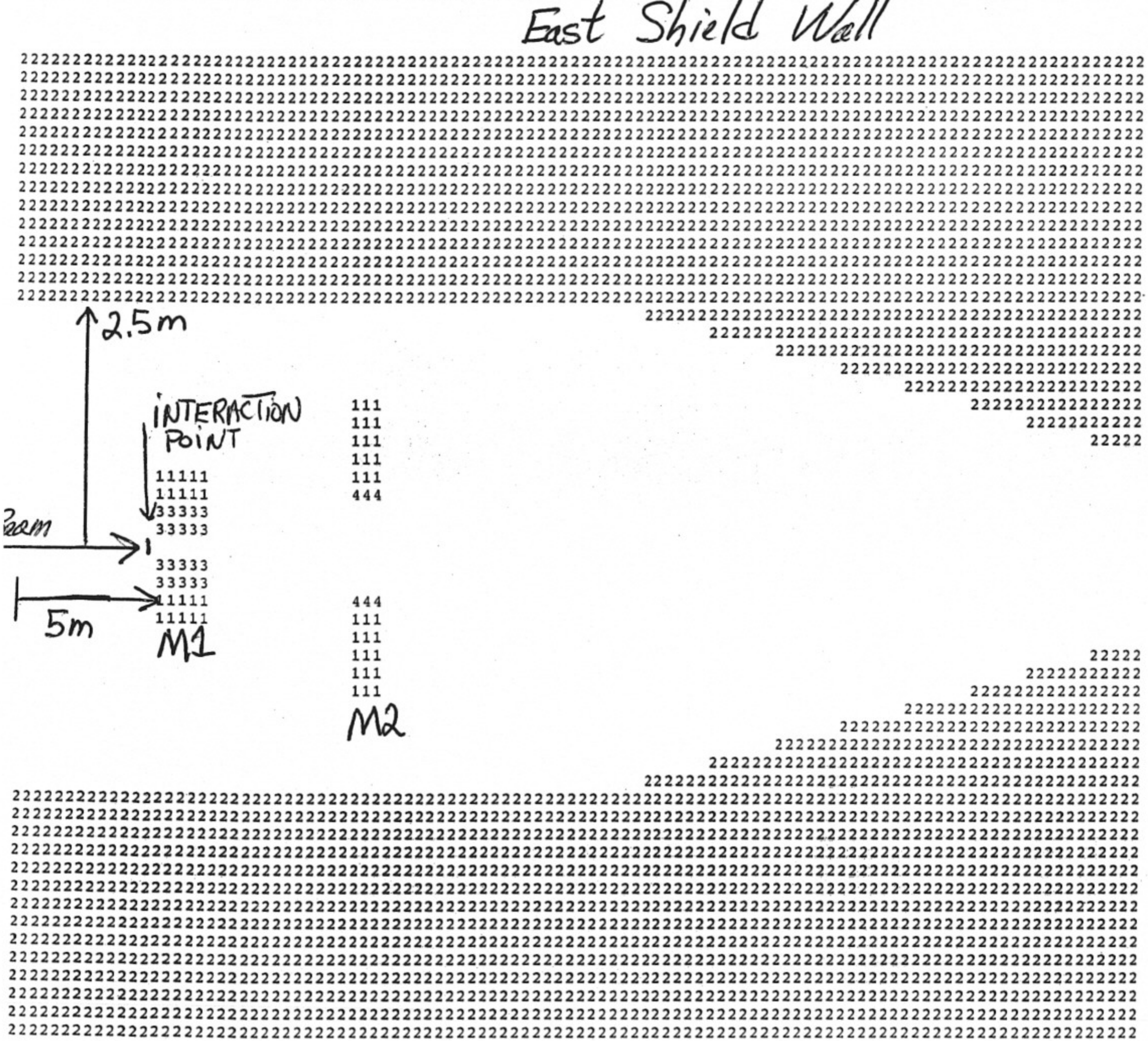


FIG. X

E864 East Shield Wall Design Thickness

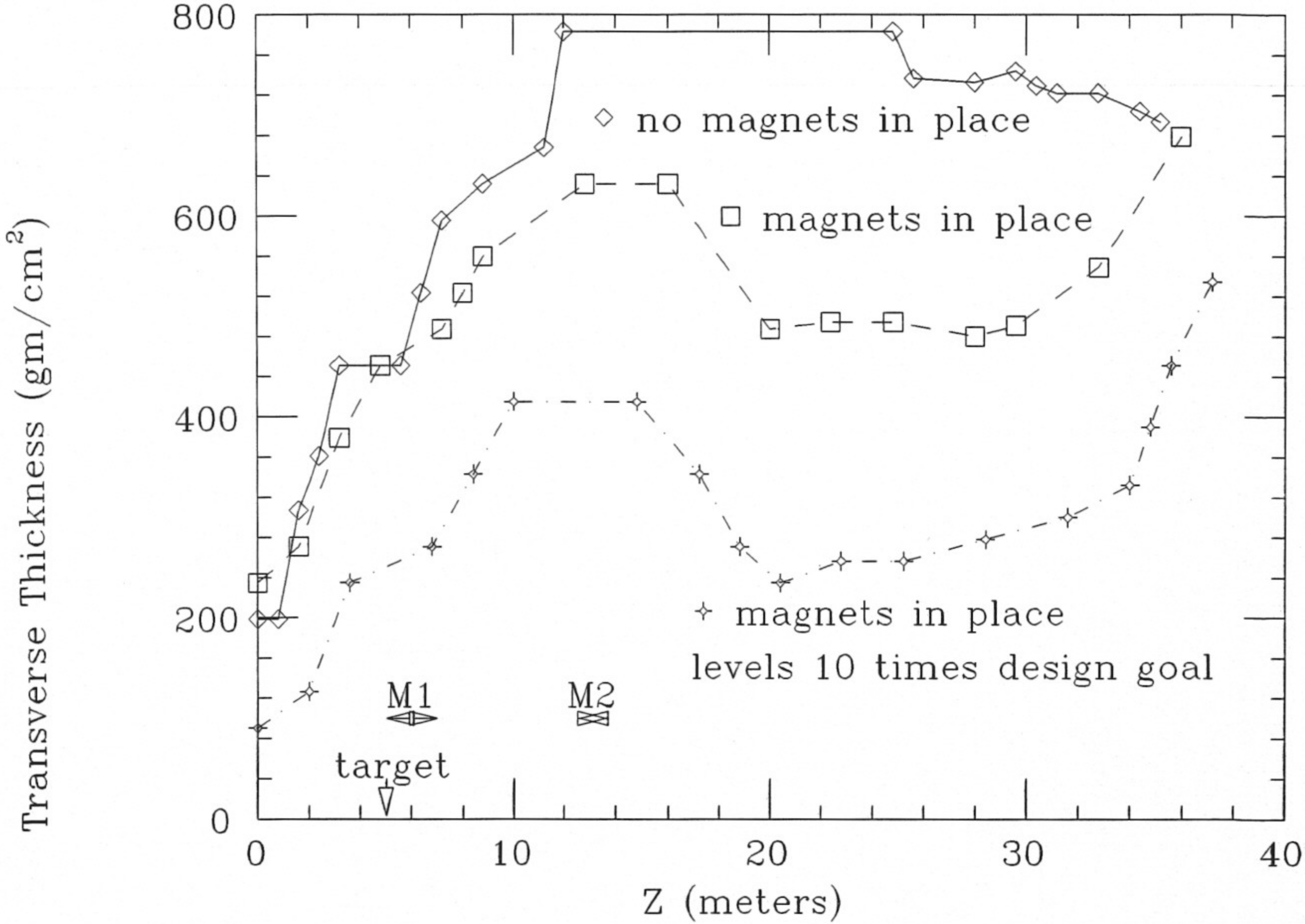


FIG. XI

E864 West Shield Wall Design Thickness

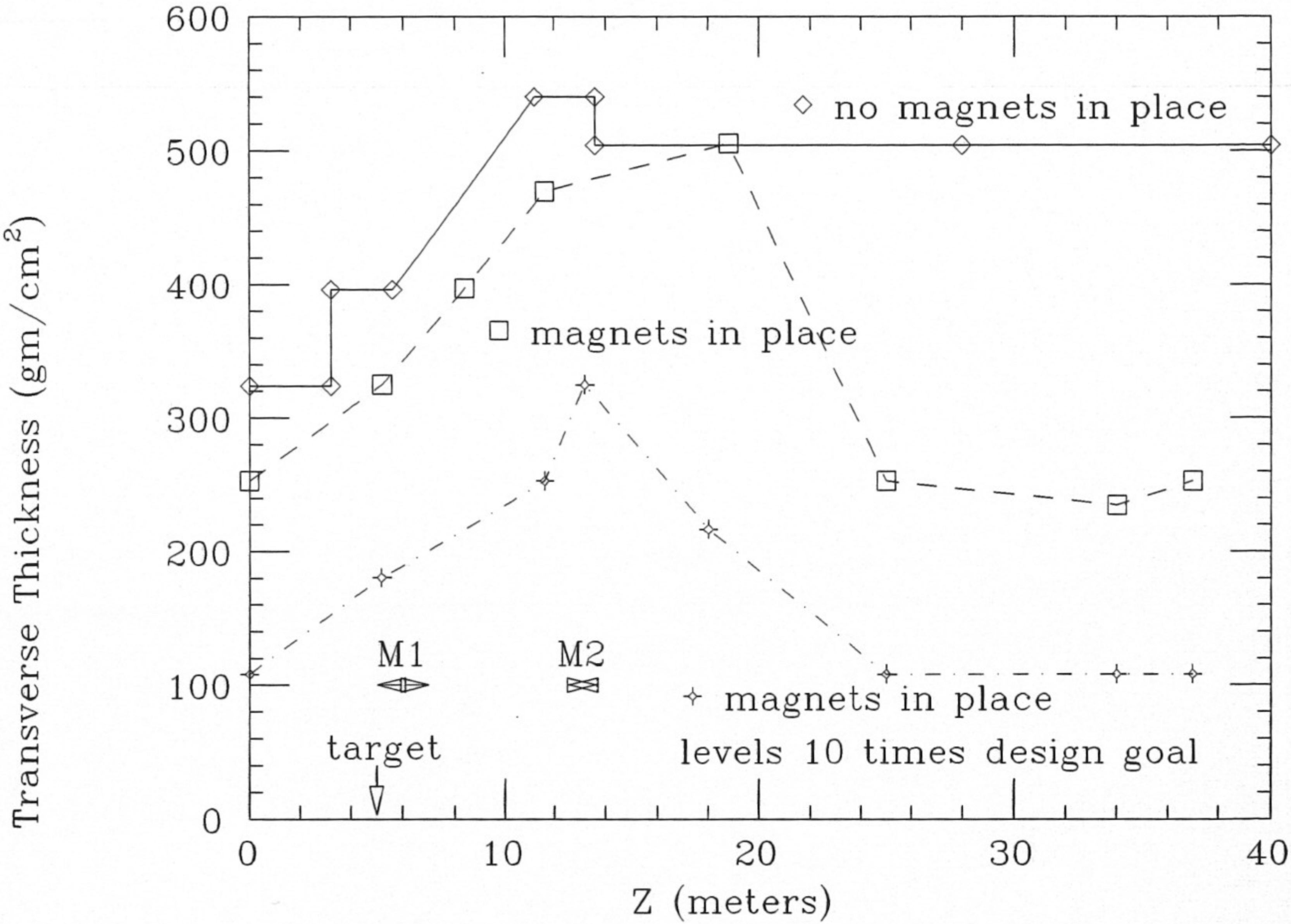


FIG. XII