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DUMP ME! Beam dump requirements for a 1013 primary beam

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Beam Dump Requirements for a 10^{13} Primary Beam*

* Not intended as advice regarding continued employment.

Introduction

An estimation of the requirements for a beam dump are presented. This estimation is done as part of the preliminary shielding design for the 2 GeV/c separated beam line which is scheduled for installation in FY1990. This beam line is being designed for 10^{13} protons per spill on target. The following criteria are used to establish the dump requirements:

$$p = 28\ GeV/c,$$
$$10^{13}\ protons/spill,$$
$$10^{3}\ spills/hour,$$
$$10^{16}\ protons/hour.$$

It is assumed that the beam dump will be located in a designated radiation area such as one of the experimental buildings at the AGS. The dump is then designed to require less than 1 mrem/hr external to the dump[1]. However, areas which are expected to be less occupied such as the top of the shielding, could have higher radiation levels and thus decreased dimensions.

Hadron Cascade

The estimation of the beam dump for attenuation of the hadron shower has been done using the simulation code CASIM[2,3]. The computations were done using the libraries provided by A. J. Stevens.[4] The star densities are converted to mrem/hr using a conversion factor[5] of 2.1×10^{-3} mrem-cm^3/star (for iron) and the rate given above of 10^{16} protons/hr. This provides a design goal of 5×10^{-14} stars/(cm^3-inc. p) . A model of a beam dump consisting of iron has been used. The 28 GeV/c primary proton beam strikes the dump at z = 200. cm. The length of the iron is 1200 cm and the radius is 400 cm. A small re-entrant cavity starts at z = 0 and extends to the front face of the dump. The re-entrant cavity has an inner radius of 30 cm and an outer radius of 130 cm. The dump is depicted in Figure 1(a) (plan view) and Figure 1(b) (cross-sectional view).

The results from CASIM are given in Figures 2-4. The logarithm of the star density as a function of the longitudinal depth in the shield for several selected radii are presented in Figure 2(a),(b) . Lines have been drawn through the results to guide the eye and show that the form is approximated by an exponential. The behaviour of the star density (at a radius of 0.0 meters) is approximately $e^{-0.039dz}$ where dz is the change in depth in cm. A line at a star density of 5×10^{-14} is drawn to represent the desired goal. The length of the dump is required to be 720 cm (24 feet) of iron to reduce the radiation levels (at r=0) to 1 mrem/hr.

The logarithm of the star densities as a function of the radius (in cm) for several selected depths in the dump are given in Figures 3(a),(b). Again lines have been drawn to guide the eye and demonstrate the exponential behaviour. At a distance of 1.6 meters downstream of the front surface of the beam dump the behaviour can be approximated by $e^{-0.063r}$ where r is the radius in cm. The required radius of the beam dump is 320 cm (10.5 feet). The peak of the hadron cascade is broad and occurs between 150 to 250 cm downstream of the dump face. We conclude that a solid iron cylindrical dump of length 720 cm and radius 320 cm will satisfy our design criteria.

The amount of shielding and floor space can be reduced by shaping the surface of the beam dump to more closely follow the contours of the star density. Contours of equal star density are shown in Figure 4 for the radius verses depth. Although this information is contained in the other projections, the two dimensional contours help to visualize the star densities in the beam dump more readily.

The beam dump should have a concrete exterior surface to reduce the neutrons transmitted in the energy range of .01 MeV to several MeV. Two feet of concrete should be sufficient to accomplish the desired reduction. Often the thickness of the concrete layer is controlled by the dimensions of the available shielding blocks. When substituting concrete for iron a rough rule of thumb is to replace the iron with concrete scaled by the ratios of the densities (for modest amounts).

Muons

The generation of muons in the beam dump has been estimated. Several different methods have been used to establish the beam dump requirements for muons. However, for brevity the results from a calculation using the CASIM program will be presented.

The CASIM program has been run with the previously described iron beam dump, except for an increase in length to 1800 cm. Appropriate changes in the program library[6] have been used to estimate the rem per incident proton contributed by the muons. Figure 5 displays the rem/(incident proton) as a function of depth in the iron beam dump for several radii. The curves are approximately exponential. The curve corresponding to a radius of zero is approximately $e^{-0.0072dz}$ where dz is the change in depth in centimeters. This is close to the analytical form given by A. H. Sullivan[7] which has $e^{-.0076dz}$. It is also noted that the effects of multiple scattering help to reduce the overall length of the dump from estimates done without multiple scattering.[8] A depth of 1400 cm (43 feet) is required to reduce the radiation levels from the muons to 1 mrem/hr assuming 10^{16} protons per hour incident on the beam dump.

The radial dependance of the radiation levels in the iron due to the muons is presented in Figure 6. For a given depth the form is approximately exponential. Near the end of the dump where the distribution has the largest width the distribution is roughly $e^{-0.053dr}$ where dr is the change in radius in centimeters. It is clearly evident that the levels decrease rapidly with increased radius. Because of the rapid radial decrease of the muon flux the width of the beam dump can be reduced with increased depth. At a depth of 600 cm in the beam dump the radius required is 130 cm (see Figure 6) which is already smaller than the required radius for the hadron component (see Figure 4). The end of the beam dump is required to have a radius of less than 50 cm.

The relative intensity of the muons from an upstream target station to those generated in the beam dump will depend on the distance from the target station to the beam dump. This can influence the required size of the beam dump. A simple estimate for the muons will be presented. A calculation using CASIM with an upstream target will be performed when the distance from the target station to the beam dump is determined. The relative intensity of muons from an upstream target station to the beam dump can be scaled by taking the ratio of the flight path to the effective mean free path of pions in iron which can be taken to be 30 cm.[7] We assume that the target station is 1000 cm upstream of the beam dump and that half the beam interacts in the target. Therefore the decay of pions from the target provides 1000/30 times more muons than generated in the beam dump at zero radius. Therefore, the beam dump will need to be increased in length by 220 cm giving an overall length of 1620 cm (53 feet) (the change in solid angle has been included). The change in the radial size will be determined by the increase in muon flux and the change in angle from the production point of the initial pion (which subsequently decays) to the exit point. Approximately 2 meters added to the longitudinal dimension will compensate for this. However, the angle at which the beam dump can be tapered will change due to the transverse distance the muons arrive at the front of the beam dump. This problem can be reduced by obstructing the flight path of the large angle pions/muons. For the present level of discussion we will assume that the 2 meters in longitudinal length will be sufficient and that the radius need not be increased.

The first dipole of the 2 GeV/c beam line can deflect the primary beam by approximately 1 degree. This means an additional .5 meters should be added to the radius to compensate for this deflection.

If necessary the overall length of the beam dump can be decreased by using denser materials in the interior of the beam dump.

Conclusions

We conclude that the radius of beam dump at modest depths is determined by the hadron cascade while the length is determined by the muon component. The muons from the target station will dominate those produced in the beam dump. An iron beam dump of radius 3.2 meters (10.5 feet) and length 16.2 meters (53 feet) should be of sufficient size to accommodate 10^{16} protons per hour with a one interaction length target station approximately 10 meters upstream of the dump.

Several useful discussions with A. J. Stevens are gratefully acknowledged. All computations were performed using Experiment 802 computing facilities.

References

1) It should be noted that the doses are on contact with the surface of the beam dump. For the hadron cascade a reduction in dose of roughly two can be expected for measurements taken at one foot (A. J. Stevens private communication).

2) A. Van Ginneken and M. Awschalom, "High Energy Interactions in Large Targets", Fermilab, Batavia, Il (1975).

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

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

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

6) A. J. Stevens private communication.

7) A. H. Sullivan, NIM **A239** 197 (1985).

8) D. Keefe and C. M. Noble. NIM **64** 173 (1968).

Figure Captions

1) The iron beam dump used in the CASIM calculations is shown a) in plan view and b) cross-sectional view.

2(a),(b)The log of the star densities as a function of the longitudinal position coordinate, z, for several selected radii in the iron beam dump. Calculations done using the program CASIM.

3(a),(b) The log of the star density as a function of the radius for several selected values of the longitudinal coordinate z in the iron beam dump. Calculations done with the program CASIM.

4) Contour of equal star density as a function of radius and longitudinal position in the iron beam dump. calculations done with the program CASIM.

5) The rem per incident proton as a function of depth in an iron beam dump for selected radii. Calculations done with the program CASIM.

6) The rem per incident proton as a function of the radius in an iron beam dump for several selected depths. Calculations done with the program CASIM.

CROSS SECTION (.RY FOR CONSTANT Y= 0.00 CM
ROM X= -500.0ı ıO X= 500.00 CM (VERTICAL) AND
ROM Z= -100.00 TO Z= 1200.00 CM (HORIZONTAL)

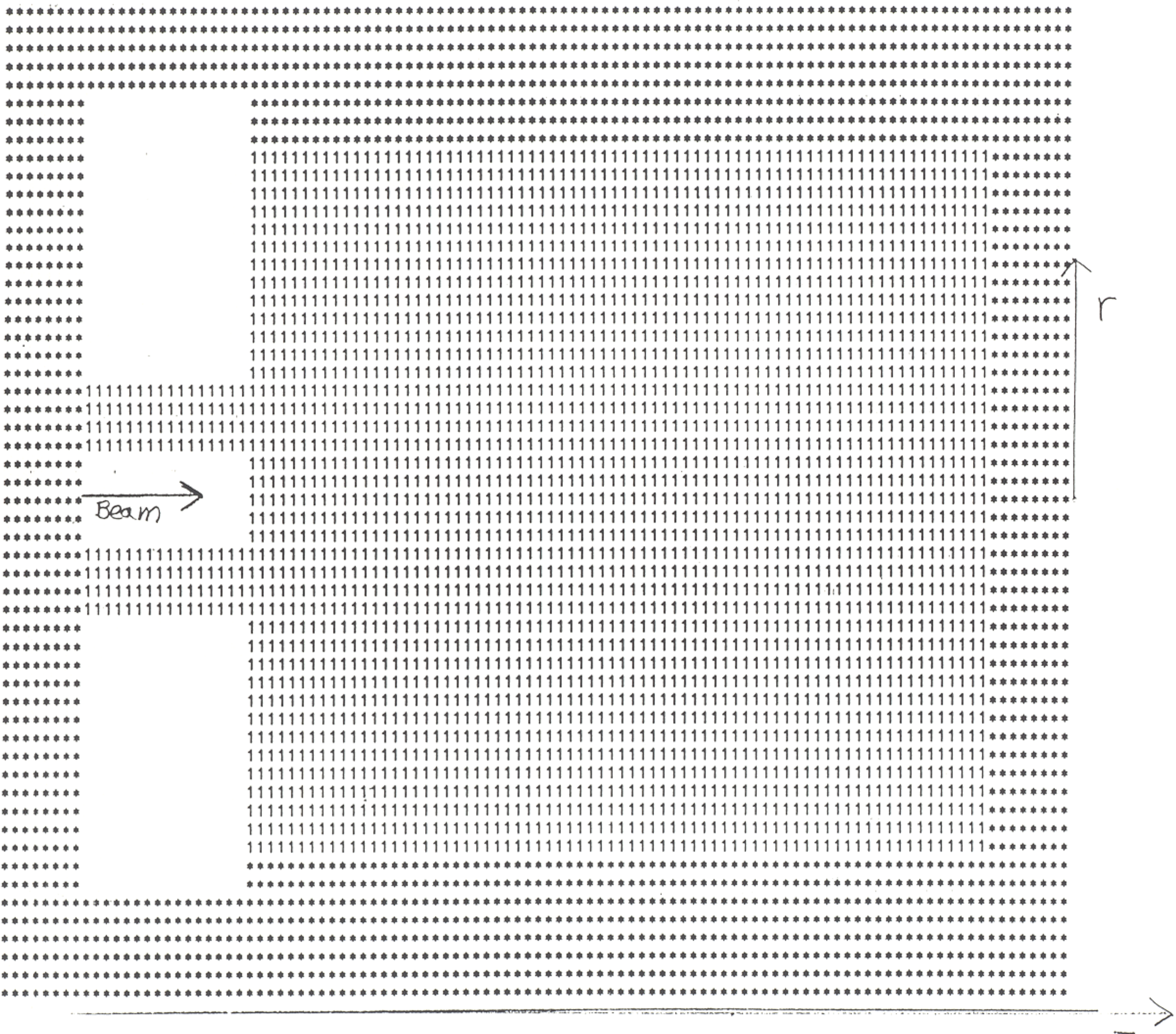


FIG. 1a

CROSS SECTION C RY FOR CONSTANT Z= 200.00 CM
ROM X= -500.00 TO X= 500.00 CM (VERTICAL) AND
ROM Y= -500.00 TO Y= 500.00 CM (HORIZONTAL)

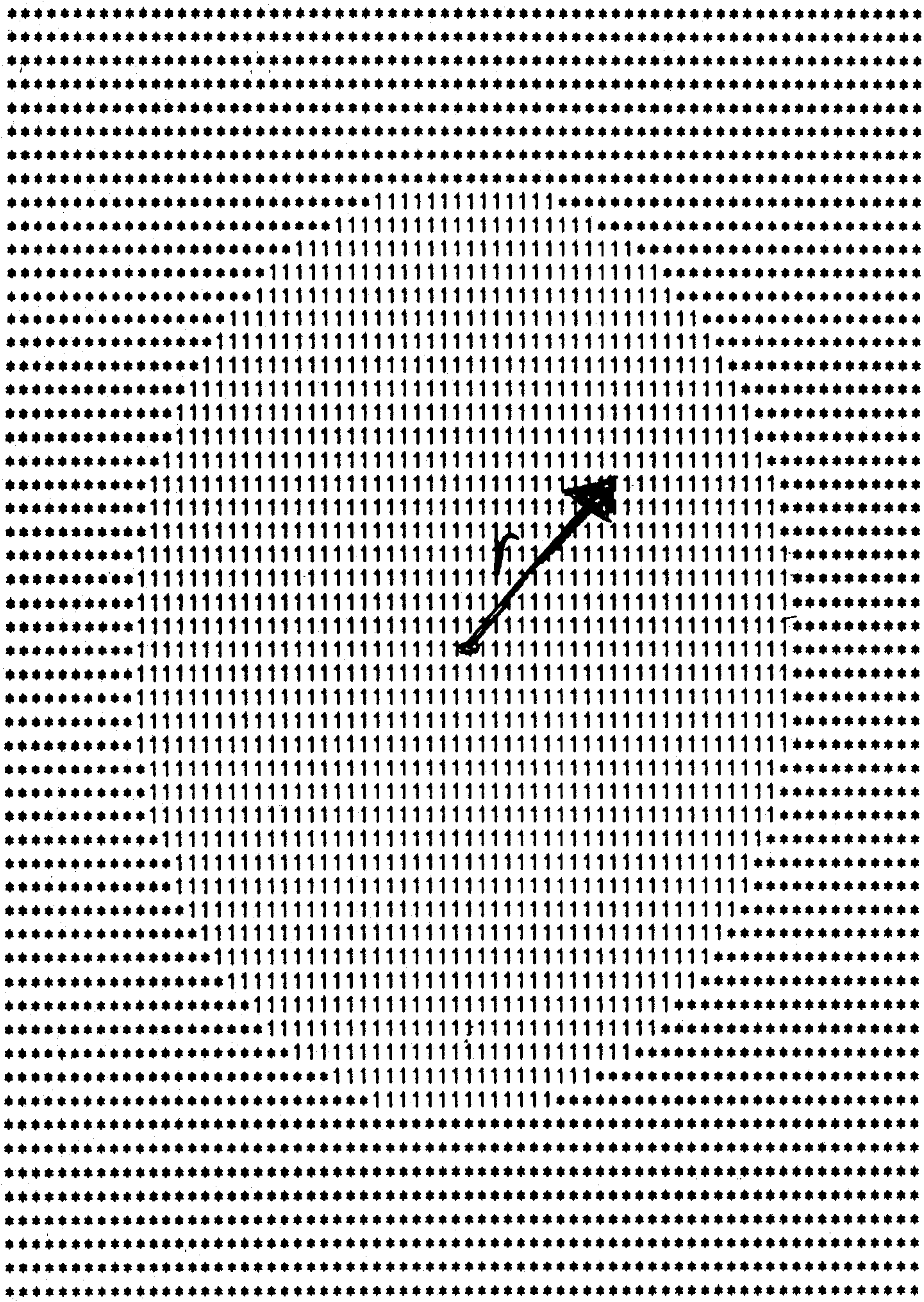
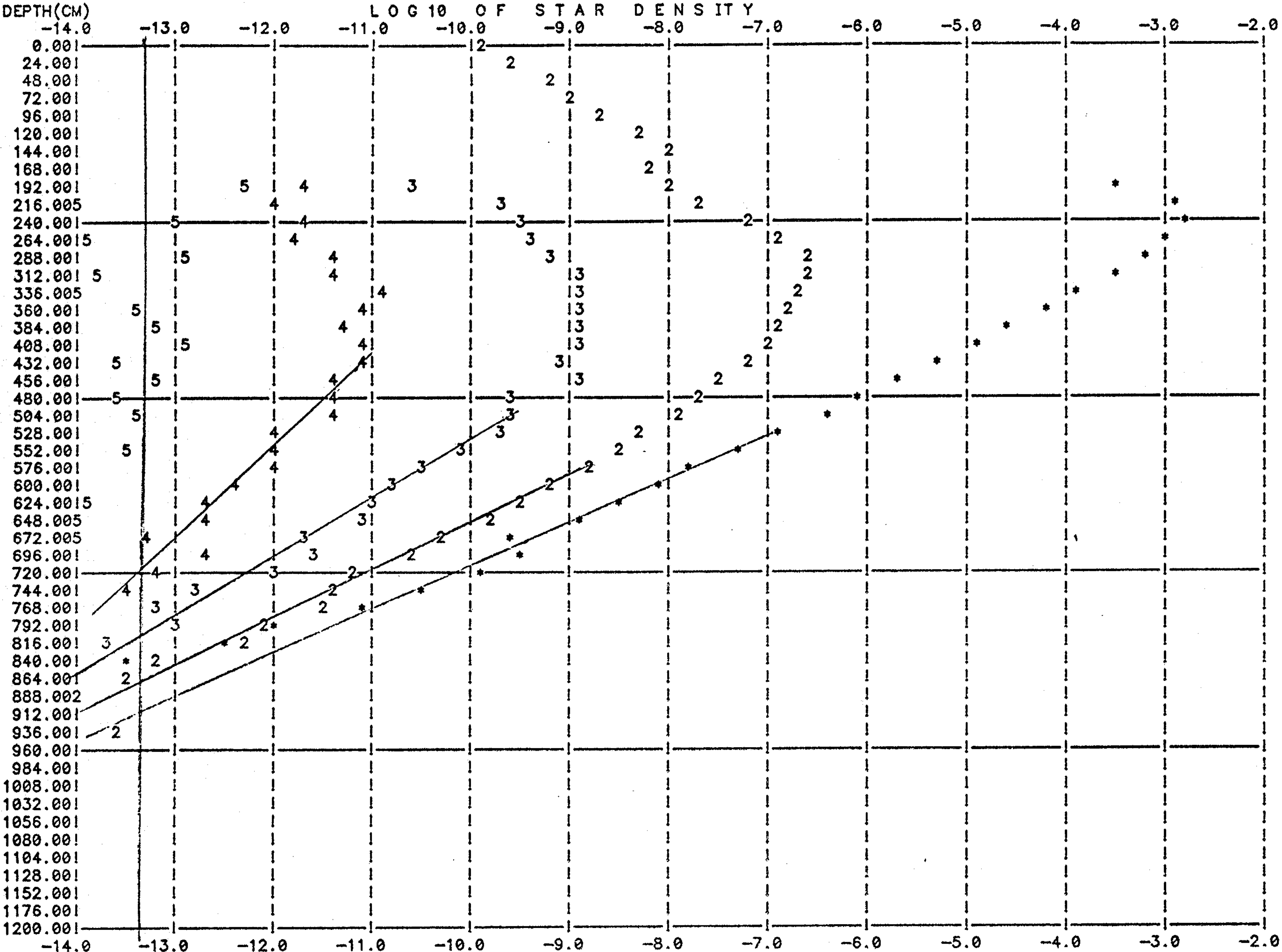


FIG. 1b

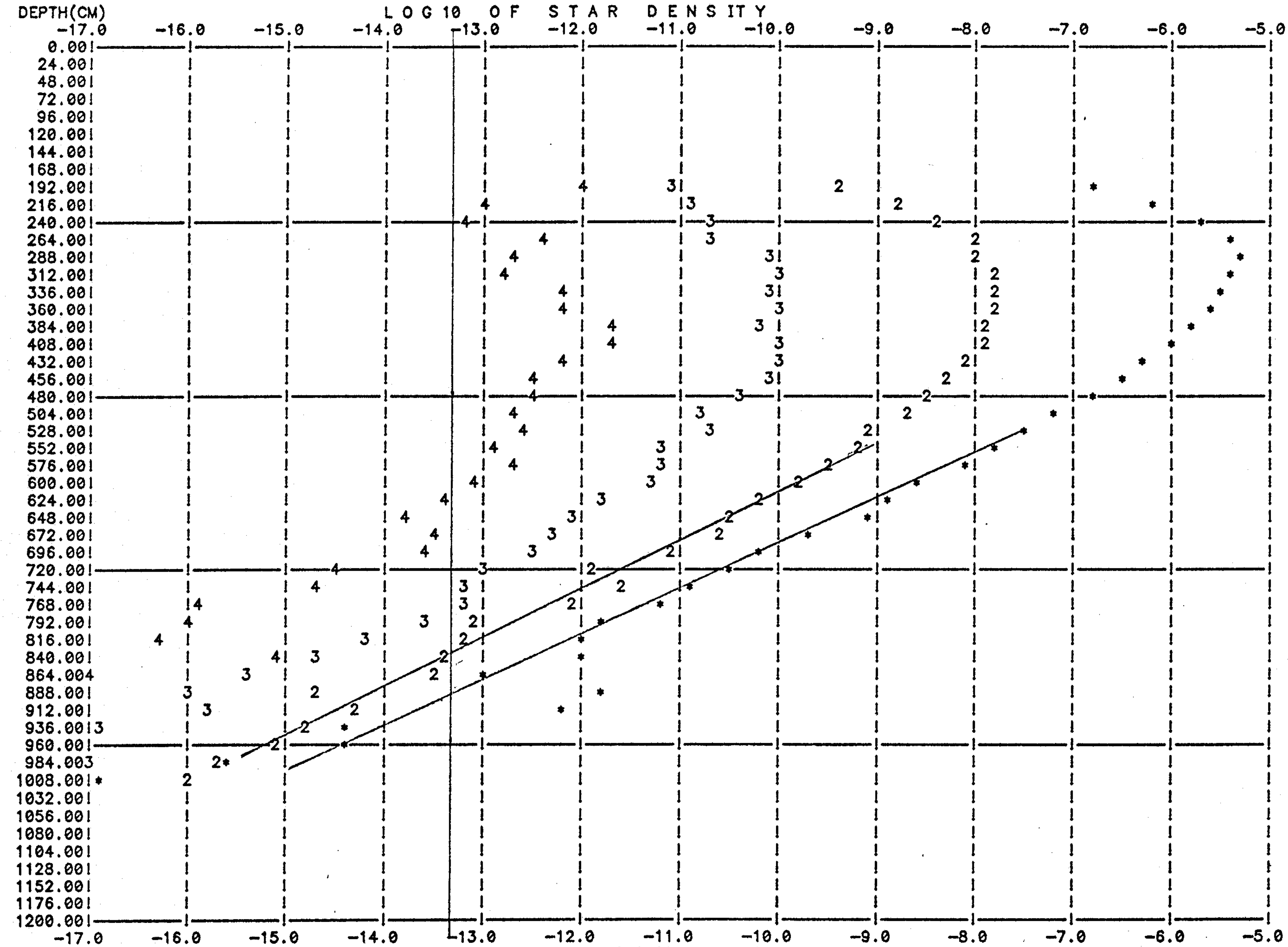
PLOT OF LOG STA ... Y(STARS/CM3*INC.PTCLE)



CURVES: *,2,3,4,5 ARE: R= 0.00 80.00 160.00 240.00 320.00 CM.
ALL GIVEN VALUES OF R AND Z ARE FOR THE SMALLER VALUES OF THE CORRESPONDING BINS.

FIG 2a

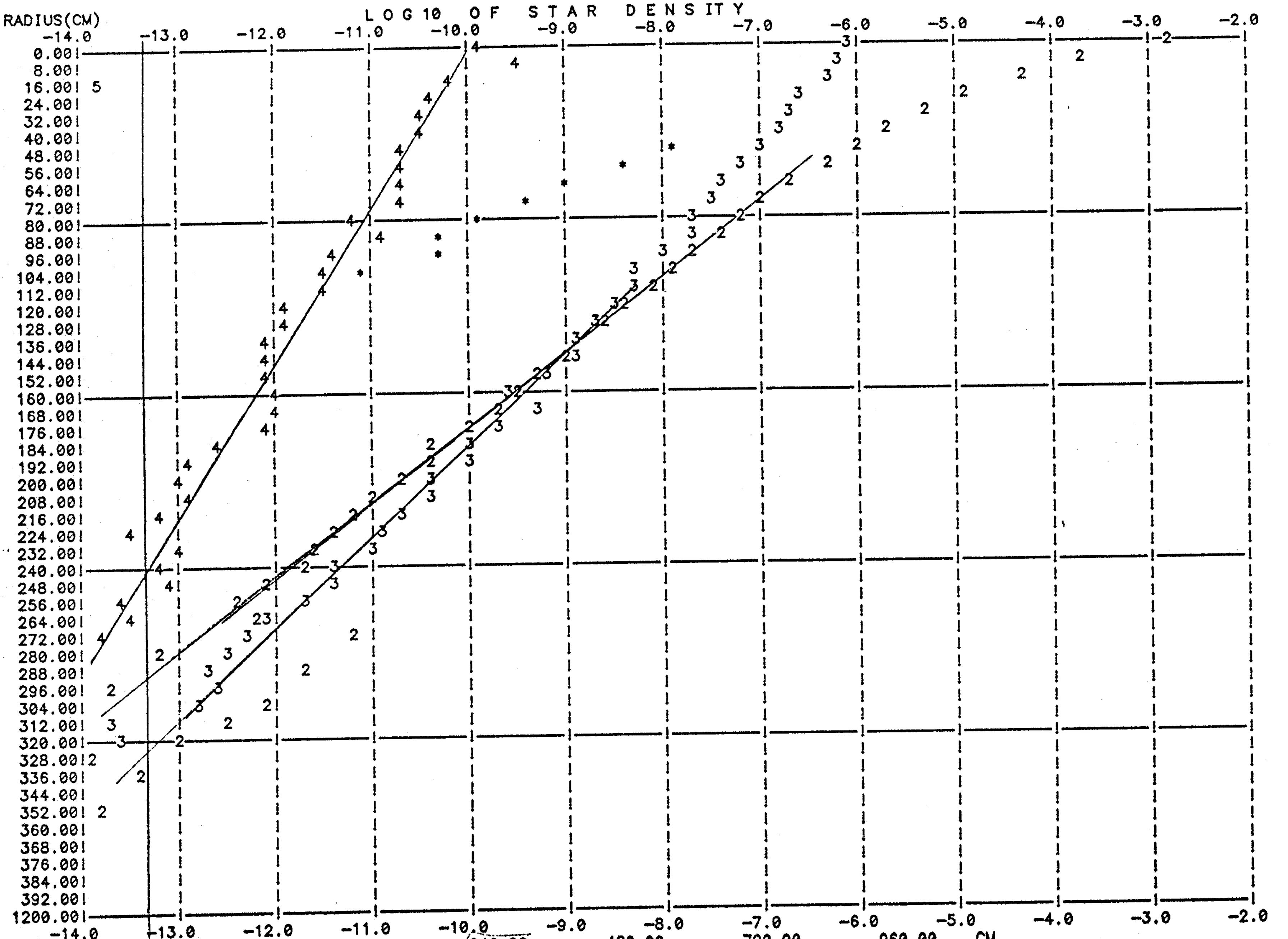
PLOT OF LOG STA) .Y(STARS/CM3*INC.PTCLE)



CURVES: *,2,3,4,5 ARE: R= 40.00 120.00 200.00 280.00 360.00 CM.
ALL GIVEN VALUES OF R AND Z ARE FOR THE SMALLER VALUES OF THE CORRESPONDING BINS.

FIG 2b

PLOT OF LOG STA) .Y(STARS/CM3*INC.PTCLE)

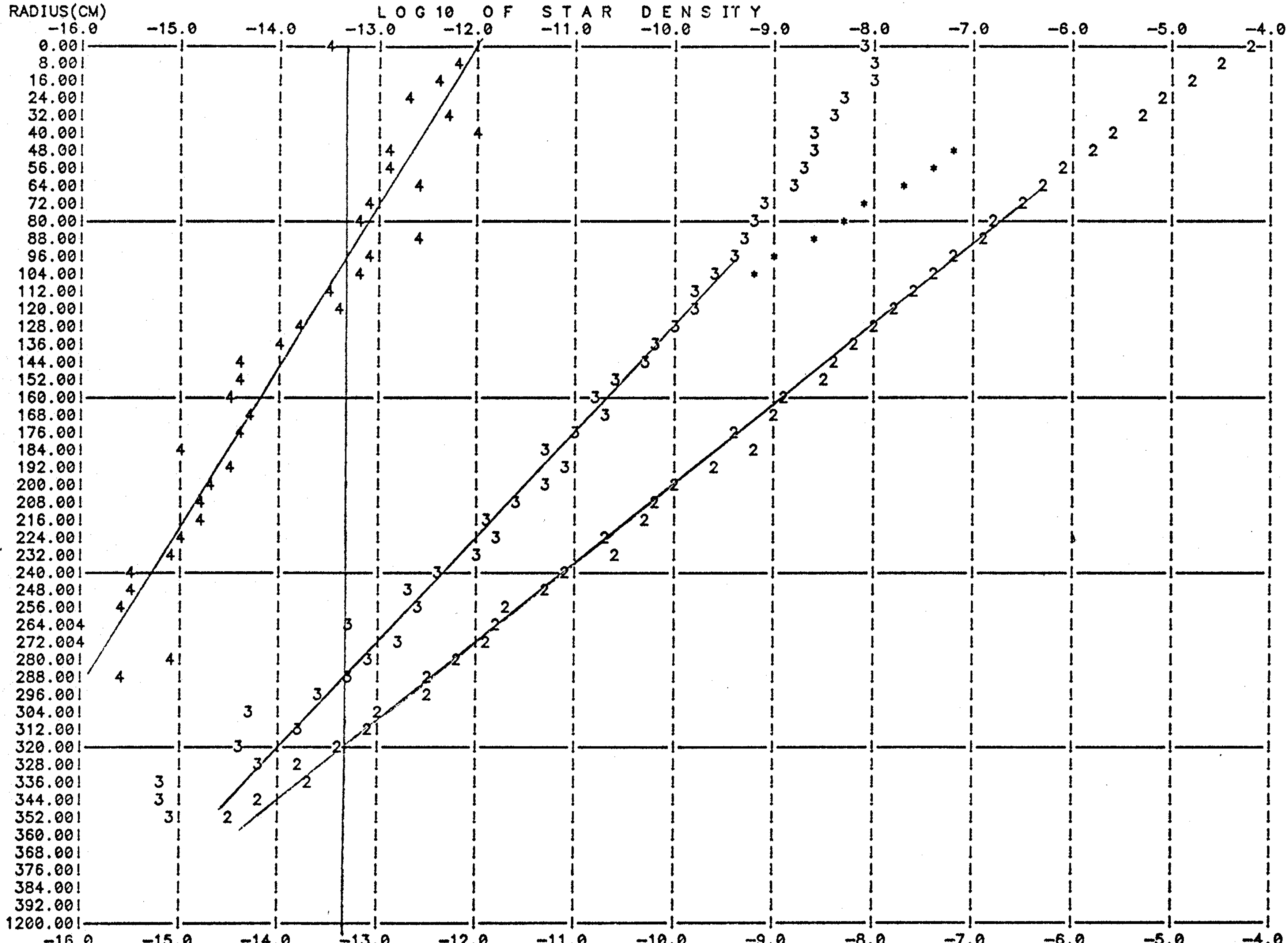


CURVES: *,2,3,4,5 ARE: Z= 0.00

ALL GIVEN VALUES OF R AND Z ARE FOR THE SMALLER VALUES OF THE CORRESPONDING BINS.

FIG. 3a

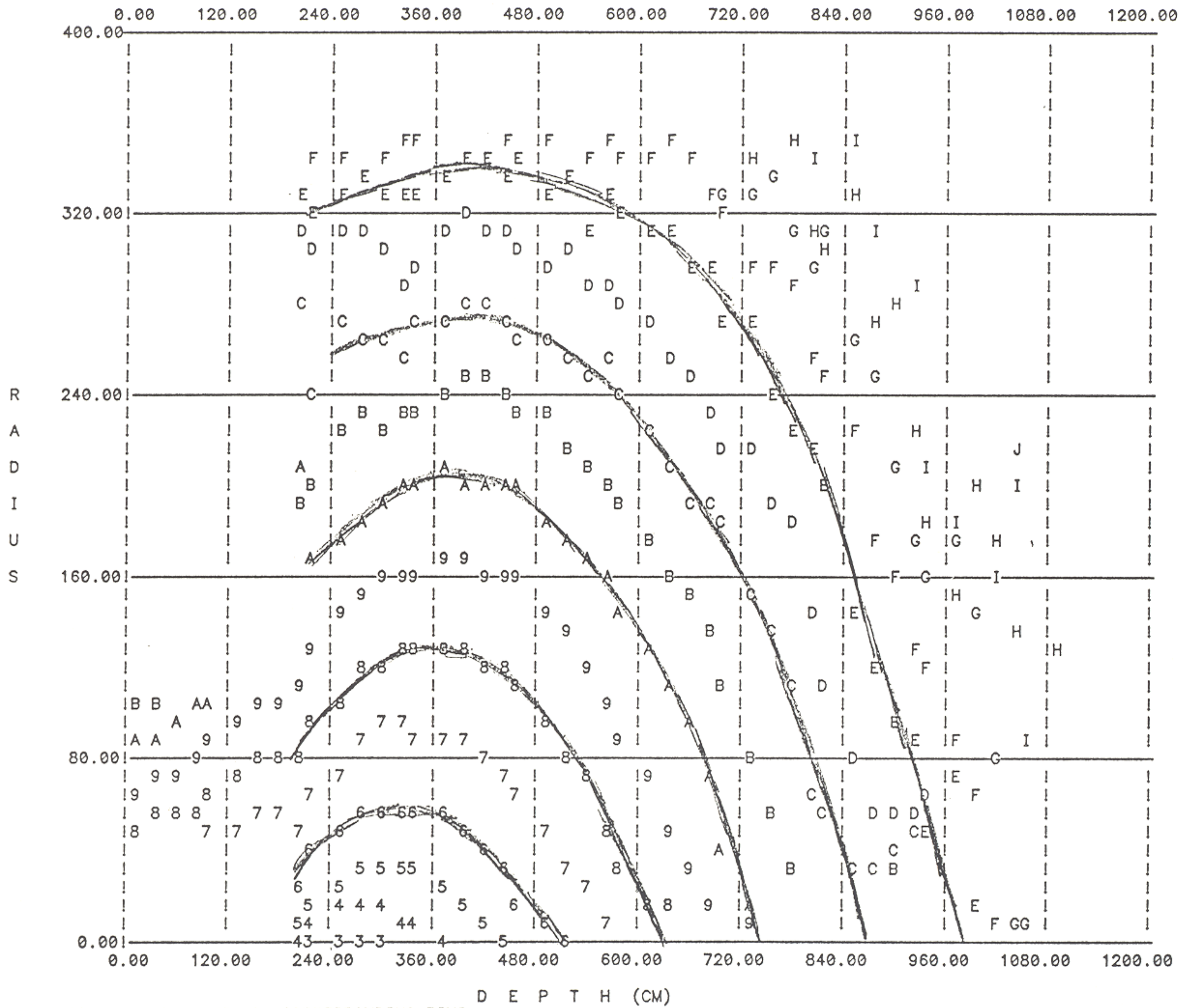
PLOT OF LOG STA .Y(STARS/CM3*INC.PTCLE)



CURVES: *,2,3,4,5 ARE: Z= 120.00 $\boxed{360.00}$ $\boxed{600.00}$ $\boxed{840.00}$ 1080.00 CM.
ALL GIVEN VALUES OF R AND Z ARE FOR THE SMALLER VALUES OF THE CORRESPONDING BINS.

FIG.3b

CONTOURS OF EQU 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)

FORTRAN STOP

FIG,4

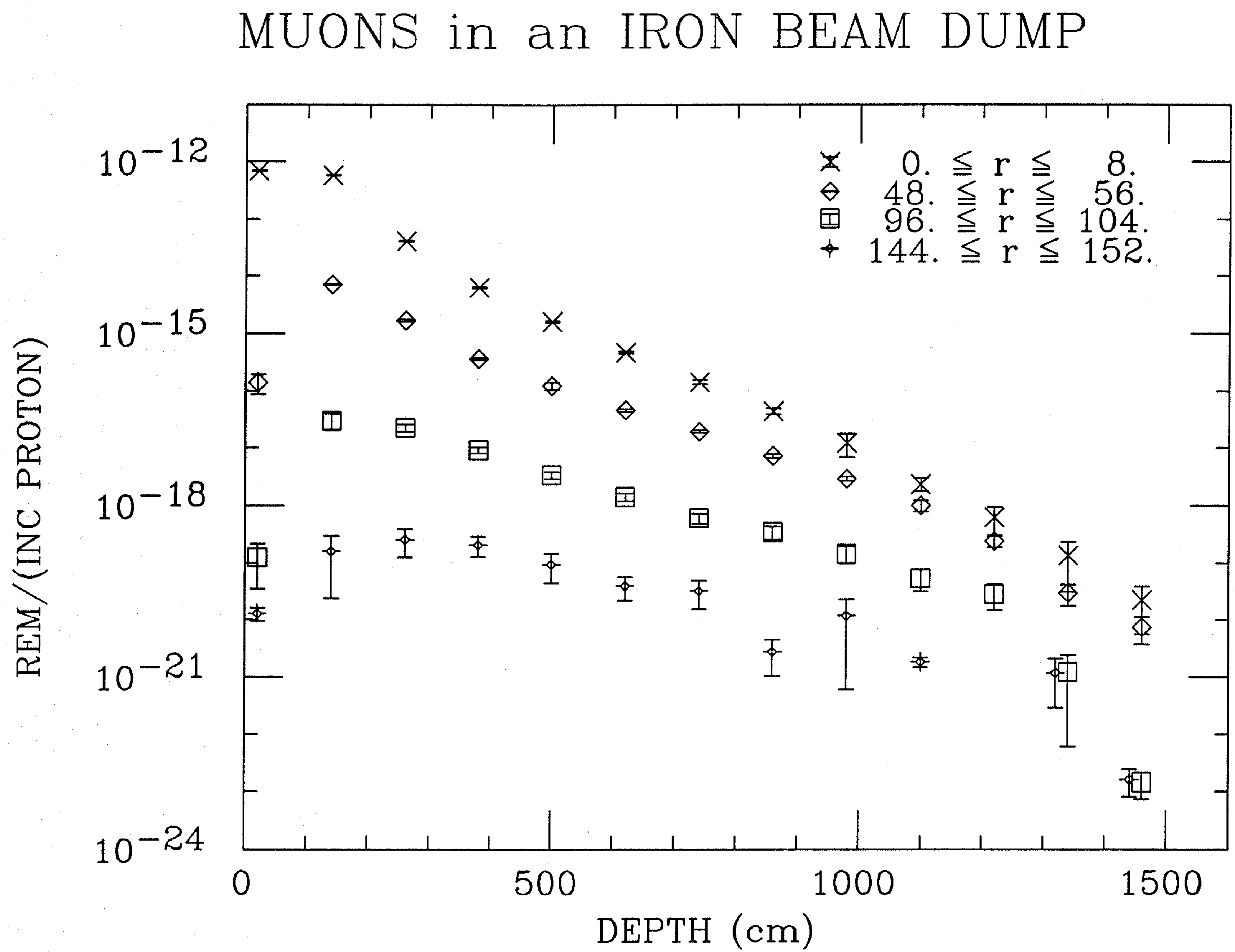

MUONS in an IRON BEAM DUMP
0. ≦ r ≦ 8.
48. ≦ r ≦ 56.
96. ≦ r ≦ 104.
144. ≦ r ≦ 152.
REM/(INC PROTON)
10^{-12}
10^{-15}
10^{-18}
10^{-21}
10^{-24}
0
500
1000
1500
DEPTH (cm)

FIG 5

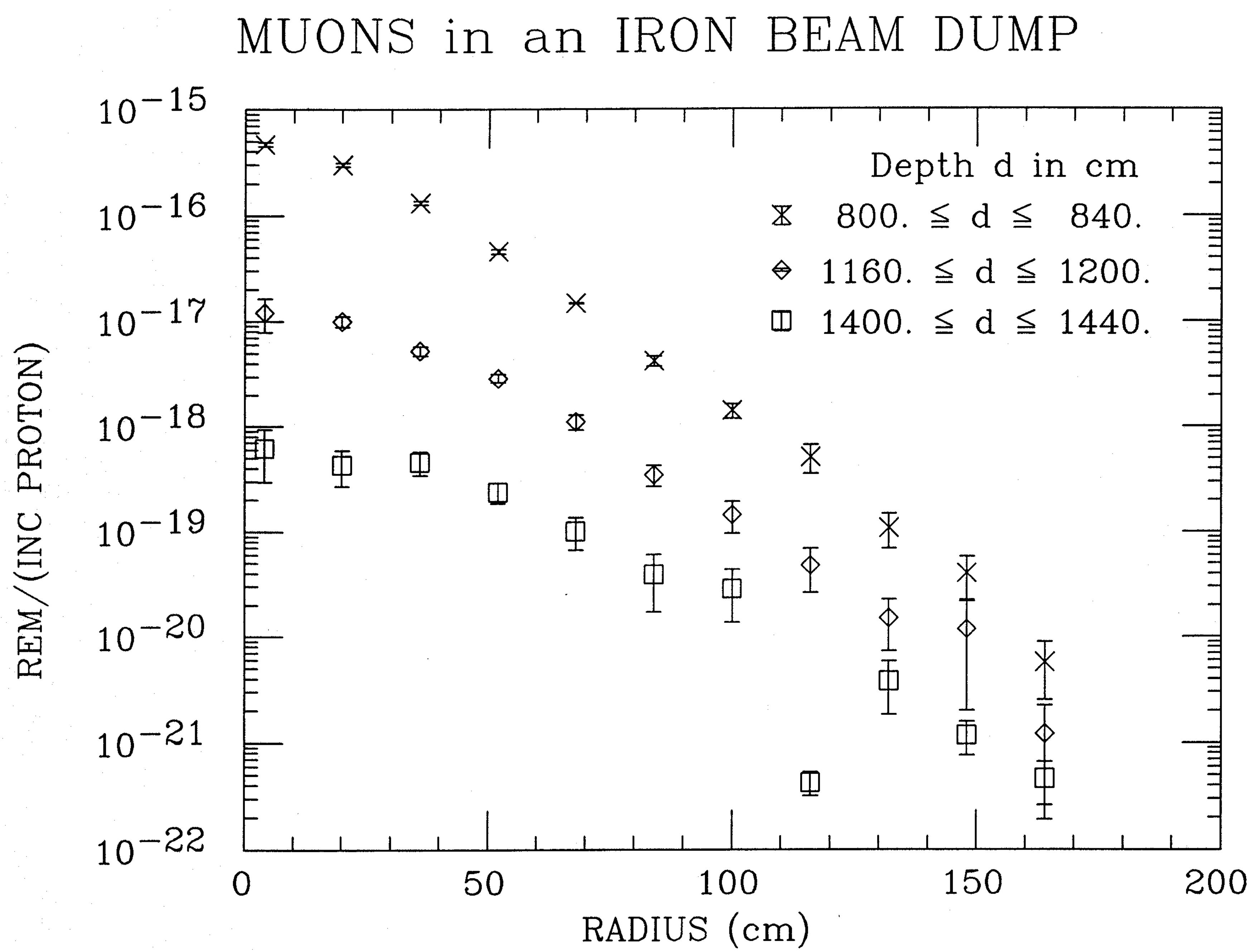

MUONS in an IRON BEAM DUMP
REM/(INC PROTON)
RADIUS (cm)
Depth d in cm
800. ≦ d ≦ 840.
1160. ≦ d ≦ 1200.
1400. ≦ d ≦ 1440.

FIG 6