Fermilab

$\bar{p}$ Note #359

8 GeV Target Station Radiation Shielding

P. Yurista

1/17/84

Fermilab

P.Yurista
1/17/84

8 GEV TARGET STATION RADIATION SHIELDING

This note is to collect and centralize all of the present calculations for the civil construction of the 8 GeV target station for the TeV I project. This will serve as a reference for radiation concerns of any proposed modifications to the Title 1 design.[1] The areas studied are:

1. Target vault -
   a. above ground dose rates,
   b. soil activation,
   c. residual activity adjacent to steel shielding.
2. Accident conditions -
   a. upstream quadrupoles,
   b. downstream dipoles.

The energy and intensity parameters used are 8 GeV in all cases with 3E12p/2 sec upstream of and including the target and 1E11p/2 sec downstream of the target.

TARGET VAULT

The basic design of the target vault was modeled for the program MAXIM[2] in two ways. One was with cylindrical approximations for above ground dose rates where the material interfaces are taken in the vertical plane through the target/dump to ground level (Fig. 1). The second model was more detailed to closely approximate the design for soil activation (Figs. 2, 3).

In the case of the above ground dose rates we have a berm elevation of 747'-6" over the target vault and local steel shielding to 3' above the beam line (elevation 727'-10") with a two-foot void space above that. From MAXIM run PMYOCHS we find a star density of 2E-14 $\frac{\text{Stars}}{\text{cm}^3\cdot\text{p}}$ on top of the berm. Since normal targeting is the same as worst case conditions we have as our limiting situation 3E12p/2 sec for a dose rate of:

$$\left(2E\text{-}14\ \frac{\text{Stars}}{\text{cm}^3\cdot\text{p}}\right)\left(\frac{3E12\ \text{p}}{2\ \text{sec}}\right)\left(\frac{3600\ \text{sec}}{\text{m}}\right)\left(\frac{0.01\ \text{mrem}}{\text{Star/cm}^3}\right) = 1.1\ \text{mrem/hr}$$

This meets the site Radiation Guide[3] for a minimal occupancy area with no special precautions.

A recent design change proposes to leave the area above the vault at grade level (744') and use it for additional parking space. This would involve the loss of 3½' of earth shielding. As a result the area would no longer meet site guide lines without additional provisions. Since the design has a 2' void space within the vault over the steel, additional shielding may be included here. Using the rule of thumb, 3' of soil is equivalent to 1' of steel, we would then need 14" of steel to replace the 3½' of earth berm. If this steel is placed within the void area there is no shielding "replacement cost" since we do not lose 14" of soil in the process which would occur if we placed the steel outside of the enclosure. We then have 4'-2" of steel above the beam line with a grade elevation (744') for the equivalent shielding effect as before.

The soil activation with subsequent leaching and transport to off site water supplies was calculated following TM-816.[4] The design does not include any drains below the target/dump area however there will be drains along the sides of the vault at the elevation of the base slab. The soil to the sides of the vault for a distance of three feet is protected by these drains, which will go to a dedicated sump that will be monitored. All the soil below the base slab and beyond 3' to the sides are considered unprotected. The geometry was modeled to allow for study of four separate regions of soil. The total star production per incident proton in these various regions was calculated in MAXIM run PMYOXSJ and are:

Region		Stars/inc.p
1	unprotected soil below slab elevation	3.22 E-4
2	unprotected soil to the right	1.87 E-3
3	unprotected soil to the left	2.76 E-4
4	protected soil	1.21 E-2

The leachable activity production calculated from TM-816 is 3.7 E-9 $\frac{\rho Ci}{Star}$ for H_3 and 9.0 E-10 $\frac{\rho Ci}{Star}$ for Na_{22}, the two isotopes we are concerned with.

The activity reaching off site water supplies also depends on the transport rate and the distance to the aquifer. The distance to the aquifer (677') was taken conservatively for the sides to be from the elevation of the base slab (722'-6" and for the soil below the base from elevation 718'. The transport velocities used are 7.2 ft/yr for H_3 and 3.2 ft/yr for Na_{22}. We then have decay factors of:

	Sides	Bottom
H_3	$e^{-\left(\frac{45.5/7.2}{17}\right)} = 0.6895$	$e^{-\left(\frac{41/7.2}{17}\right)} = 0.7154$
Na_{22}	$e^{-\left(\frac{45.5/3.2}{3.72}\right)} = 0.0219$	$e^{-\left(\frac{41/3.2}{3.72}\right)} = 0.0319$

Assuming a use rate of E19 p/yr we calculate the activity reaching an off site water supply under the laboratory policy of assuming all the activity goes to one well and is diluted at a rate of 40 gallons/day,

$$H_3 = \frac{3.7\times10^{-9}\ \frac{\rho Ci}{Star})(E19\ p/yr)}{5.55\ E7\ \ ml/yr}\ [(.7154)(3.22\ E\text{-}4)+(.6895)(2.146\ E\text{-}3)](\frac{Stars}{p})$$

$$= 1.14\ \frac{\rho Ci}{ml}$$

$$Na_{22} = \frac{(9.0\times10^{-10}\ \frac{\rho Ci}{Star})(E19\ p/yr)}{5.55\ E7\ \ ml/yr}\ [(.0319)(3.22\ E\text{-}4)+(.0219)(2.164\ E\text{-}3)]\ \frac{Stars}{p}$$

$$= .0093\ \frac{\rho Ci}{ml}$$

With release limits of 20 $\frac{\rho Ci}{ml}$ H_3 and 0.2 $\frac{\rho Ci}{ml}$ Na_{22} we have a weighted sum of

$$\sum \frac{1.14}{20} + \frac{0.0093}{0.2} = 0.1035$$

or 10% of our combined limit.

If for some reason the under drains fail such as becoming plugged or collapsing, the resulting addition of the protected soil to calculations gives us 5.9 $\frac{\rho Ci}{ml}$ H_3 and 0.046 $\frac{\rho Ci}{ml}$ Na_{22} for 53% of our limit.

The geometry was modified to include one less foot of steel on the outside but leaving the inside unchanged for personnel shielding of residual activity. Since the soil activation is so low, modification to this situation, if it will still meet the limits, would simplify civil construction design and costs by allowing the outer wall to be straight as well as save costs in steel shielding. MAXIM run PMYOBOB modeled this case and gives star production in regions of the same description as the previous case of:

Region		Stars/inc. p
1	unprotected below	7.8 E-4
2	unprotected right	5.35 E-3
3	unprotected left	2.19 E-4
4	protected	4.36 E-2

With the same assumptions as before we have:

$$H_3 = \frac{(3.7\ E\text{-}9\ \frac{\rho Ci}{Star})(E19\ p/yr)}{5.55\ E7\ \ ml/yr}[(.7154)(7.8\ E\text{-}4)+(.6895)(5.57\ E03)]\ \frac{Stars}{p}$$

$$= 2.93\ \frac{\rho Ci}{ml}$$

$$Na_{22} = \frac{9.0\ E\text{-}10\ \frac{\rho Ci}{Star}(E19\ p/yr)}{5.55\ E7\ \ ml/yr}[(.0319)(7.8\ E\text{-}4)+(.0219)(5.57\ E\text{-}3)]\ \frac{Stars}{p}$$

$$= .024\ \frac{\rho Ci}{ml}$$

and the weighted sum $\sum = \frac{2.93}{20} + \frac{.024}{.2} = 0.267$. Even in the worst case of the under drains completely failing we have 22.99 ρCi/ml H_3 and .18 ρCi/ml Na_{22} for a weighted sum of 2.05. Although this represents 205% of our lim t, even in the worst case an imposed administrative restriction on total protons/year will easily ensure compliance.

Dose rates from residual activity on the side of the shielding steel during personnel access is calculated following Chapter 12 of the Radiation Guide.[3] Here we assume an activation period of 3E12 ρ/2sec continuously for one month with a one day cooldown. At the surface of 3' of steel shielding we have a star density of $2.2\times10^{-8}\ \frac{Stars}{cm^3\cdot p}$ from MAXIM run PMYOCHS. This steel shielding would subtend a solid angle of approximately 2π as seen by a detector placed 1' away from it. Then using the conversion factor $\omega(30, 1) = \frac{2.5\ 10^{-6}\ Rad/hr}{Star/cm^3/sec}$, we find:

$$\dot{D} = \frac{\Omega}{4\pi}\cdot S\cdot\omega = \frac{2\pi}{4\pi}\left(\frac{2.2\times10^{-8}\ Star}{cm^3\cdot p}\right)\left(\frac{3E12p}{sec}\right)\left(\frac{2.5\times10^{-6}\ Rad/m}{Star/cm^3\cdot sec}\right)$$

$$= 41.3\ mrad/hr$$

Now with attenuation by 10'' of concrete exterior to the steel (no account has been made for activation of the concrete) and assuming 1.5 MeV gammas [μ(concrete, 1.5 MeV) = .0519 cm²/gm[4]];

$$\dot{D} = 41.3\ \frac{mrad}{hr}\ e^{-(25.4\ cm)(2.4\ gm/cm^3)(.0519\ cm^2/gm)}$$

$$= 1.7\ mrad/hr \cong 1.7\ mrem/hr$$ (since 1 rem = 1 rad for hard x-rays and gammas)

Work exterior to the target vault will not be restricted by these levels.

ACCIDENT CONDITIONS

The upstream quadrupoles in the extraction line to the target need to be considered for possible loss conditions. These quadrupoles were modeled as a single magnet the size of an EPB dipole (Fig. 4). The materials to ground level were modeled cylindrically. For a berm elevation of 747'-6" and a beam elevation of 727'-10" (17' of shielding), MAXIM run PMYOGYB gives us 1.5E-13 $\frac{\text{Stars}}{\text{cm}^3\cdot\text{p}}$ for a one hour accident condition of:

$$\left(\frac{1.5\text{E-13 Stars}}{\text{cm}^3\cdot\text{p}}\right)\left(\frac{3\text{E12p}}{2\text{ sec}}\right)\left(\frac{3600\text{ sec}}{\text{hr}}\right)\left(\frac{.01\text{ mrem}}{\text{Star/cm}^3}\right) = 8.1\text{ mrem/hr}$$

This is satisfactory for a minimal occupancy area with no posting.[3] The parking lot mentioned earlier does not extend over these magnets, hence the berm should be left at 747'-6". If it were removed, additional shielding steel would have to be incorporated to compensate. In this area to add steel you will have to replace soil shielding so that less than the 3' equivalence is obtained for each foot of steel used.

The downstream dipoles are at a slightly higher elevation of approximately 731'-10". With the berm at 747'-6" and the ceiling height of 734'-6" there is 13' of shielding. Scaling the results from the upstream location for the lower intensity and less shielding we get:

$$(8.1\text{ mrem/hr})(10^{4/3})\left(\frac{\text{E11}}{3\text{E12}}\right) = 5.8\text{ mrem/hr}$$

This is satisfactory for a minimal occupancy area with no posting.[3] The parking lot proposal does affect this area and at an elevation of 744' we lose 3½' of shielding. It is then necessary to add steel shielding which we do at the expense of replacing soil with it. Scaling this to the loss of 3½' of soil results in:

$$10^{\frac{3.5'}{3'}} = 10^{\frac{x(\text{Fe})}{1'}} \times 10^{\frac{-x(\text{soil})}{3'}} = 10^{\frac{2x}{3}}$$

$x = 1.75'$ of steel (attenuation made up by replacing soil with steel)

It will be necessary to shield the magnet where the ceiling is at 732'-6" but with steel only on the order of 8".

CONCLUSION

The dose rate over the target vault meets site guidelines with a berm at elevation 747'-6". For a parking lot at 744' an extra 14" of steel for a total of 4'-2" needs to be included within the vault over the target and dump. Soil activation is low and will still meet site guidelines after removing 1' of steel to the outboard side permitting a straight tunnel wall. Accident conditions over extraction line magnets are satisfactory with a berm. Without the berm additional steel shielding will be required.

REFERENCES

1. Tevatron I, Title I Design Report Antiproton Source Civil Construction, Job. No. 6-2-1, April 15, 1983.

2. A.VanGinneken, CASIM Program to Simulate Transport of Hadronic Cascades in Bulk Matter, Fermilab Report FN-272, January 1975.

3. Radiation Guide, 4th Edition, April 1983.

4. P.Gollon, Soil Activation Calculations for the Anti-Proton Target Area, Fermilab Report TM-816, September 14, 1978.

FIGURES

1. 8 GeV target station vault cylindrical model.

2. 8 GeV target station soil activation longitudinal cross section.

3. 8 GeV target station soil activation transverse cross section.

4. 8 GeV target station upstream magnet cylindrical model.

5. Contours of equal star density MAXIM run PMYOCHS for geometry of Fig. 1.

6. Contours of equal star density MAXIM run PMYOGYB for geometry of Fig. 4.

FERMILAB

ENGINEERING NOTE

SECTION	PROJECT	SERIAL-CATEGORY	PAGE

SUBJECT: 8 Gev Target Station vault Cylindrical model

NAME: [illegible signature]

DATE: 1/10/84

REVISION DATE:

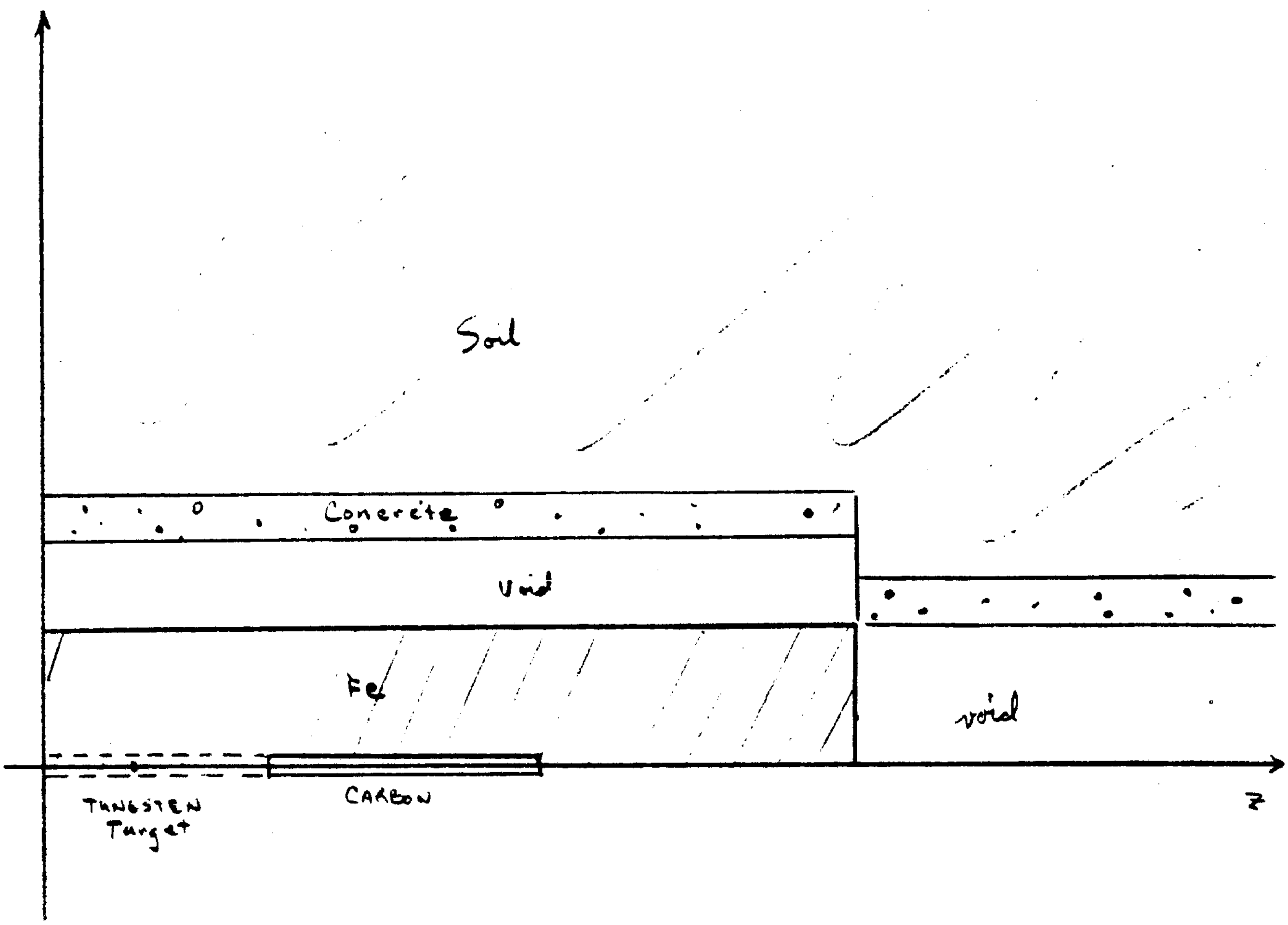


FIG 1

FERMILAB ENGINEERING NOTE

SECTION	PROJECT	SERIAL-CATEGORY	PAGE

SUBJECT: 8 Gev target soil activation
Longitudinal Cross section

NAME: A. McGuire

DATE: 1/10/84

REVISION DATE:

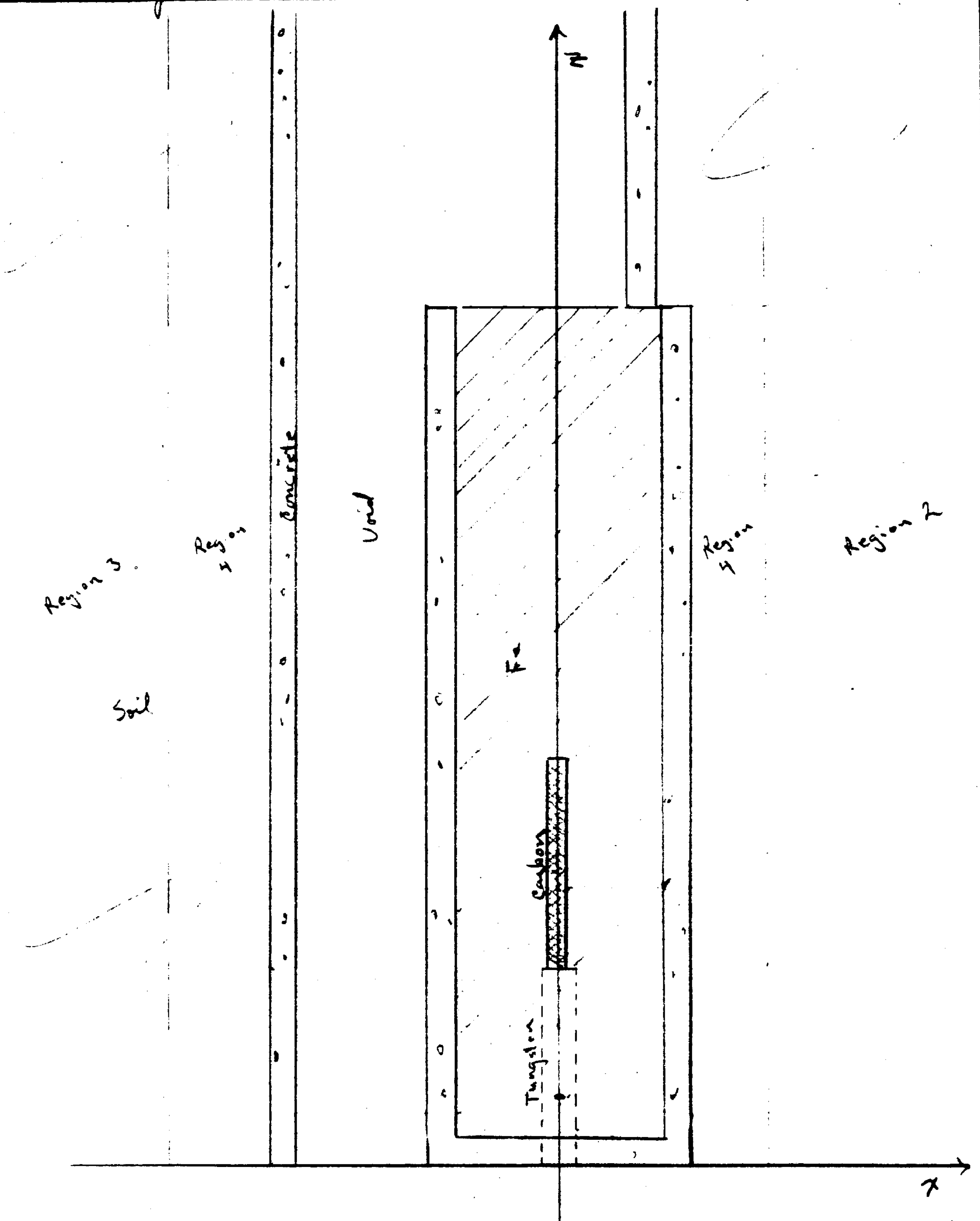


FIG 2

FERMILAB

ENGINEERING NOTE

SECTION	PROJECT	SERIAL-CATEGORY	PAGE

SUBJECT 8 GeV Target Station soil activation
Transverse cross section

NAME [illegible]

DATE 1/10/84

REVISION DATE

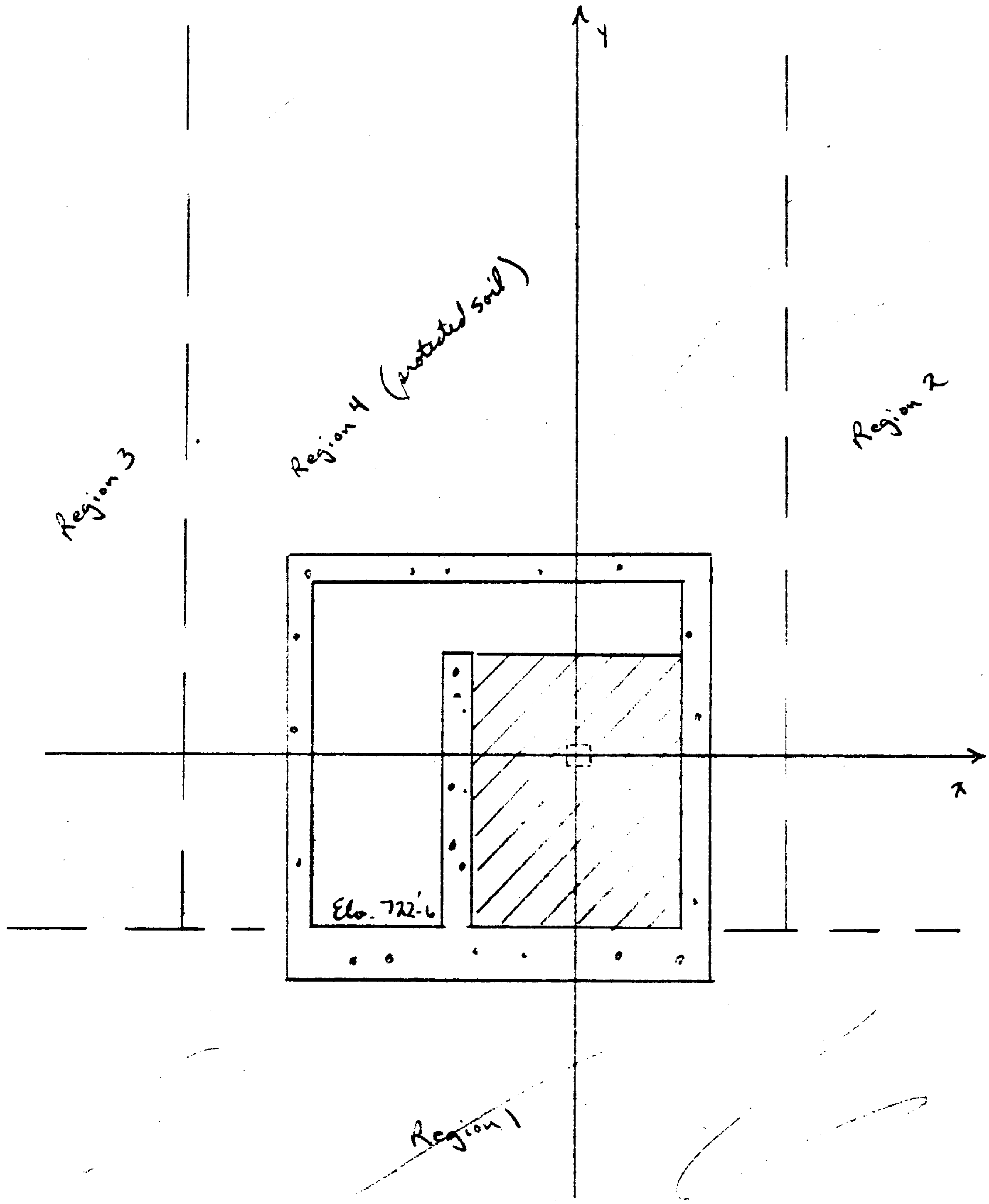


FIG 3

FERMILAB
ENGINEERING NOTE

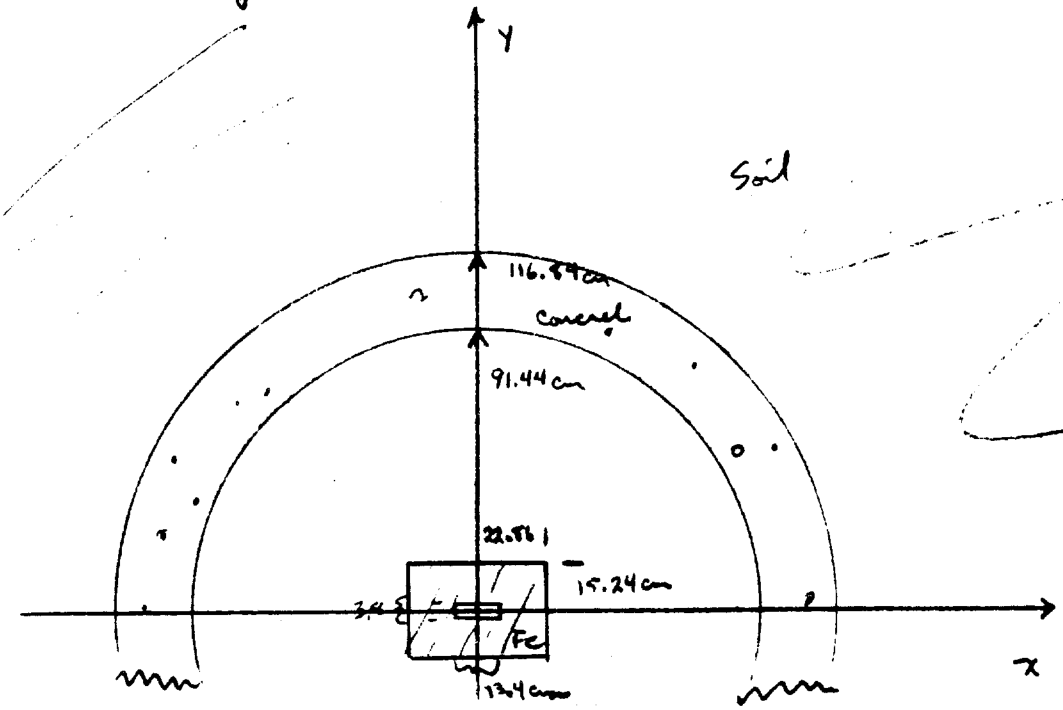
SECTION	PROJECT	SERIAL-CATEGORY	PAGE

SUBJECT: 8 GeV target station upstream magnets cylindrical model

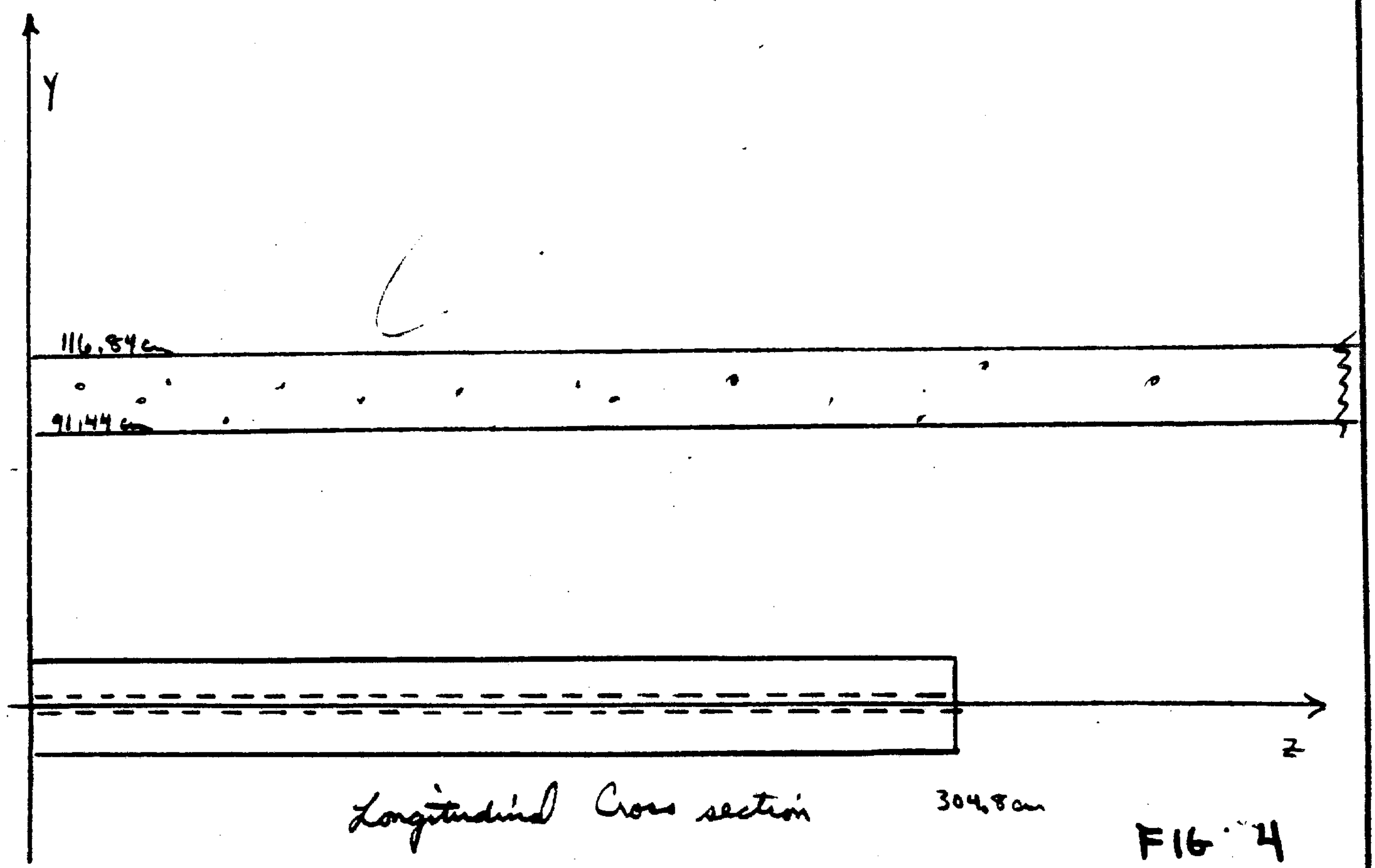
NAME: [illegible]

DATE: 1/10/84

REVISION DATE:



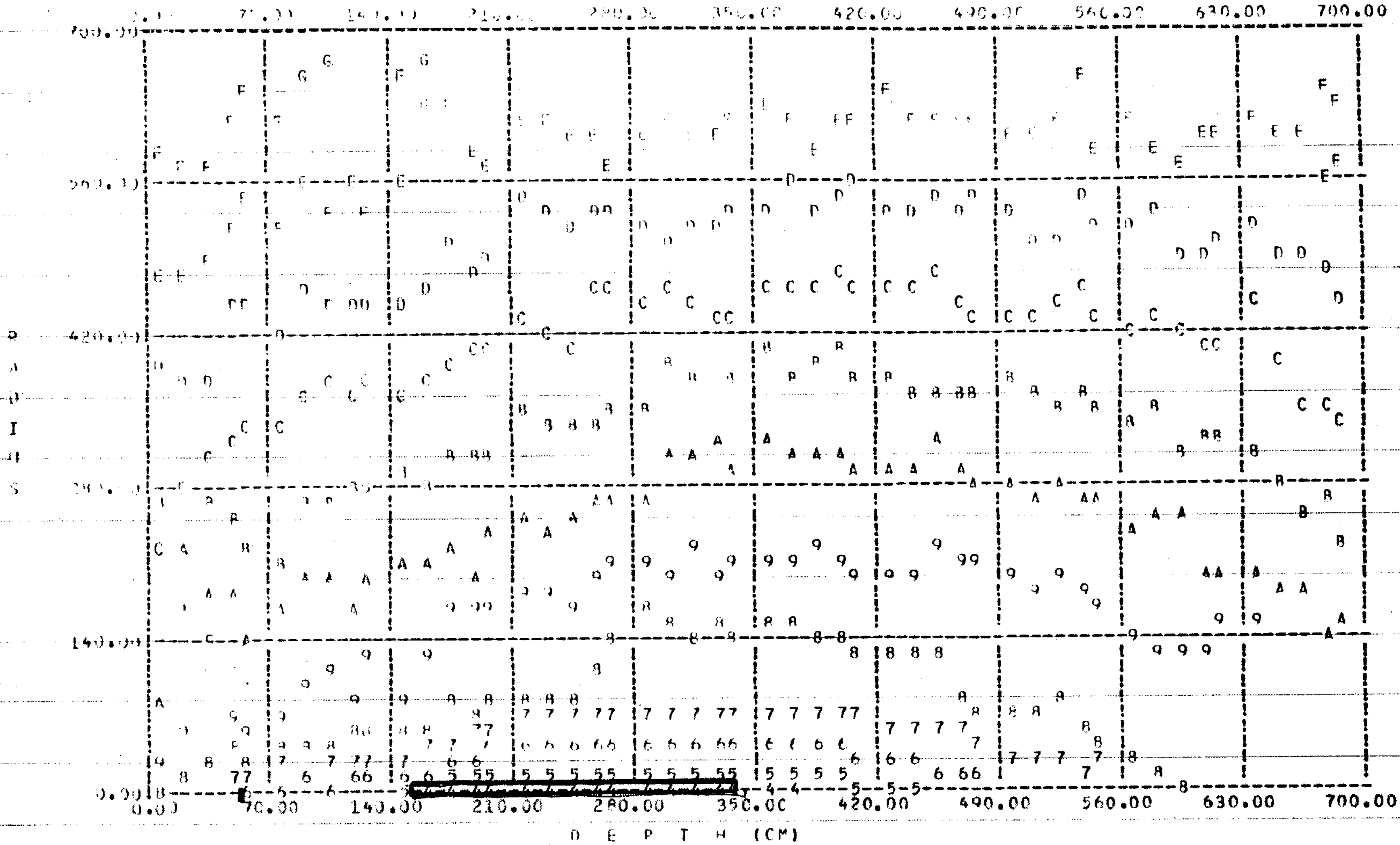
Transverse Cross section



Longitudinal Cross section

FIG. 4

CONTOURS OF FINAL STAR DENSITY (STARS/CM**3*INC.PTCLE)
CONTOURS ARE SHOWN [illegible] INTEGRAL POWERS OF 10

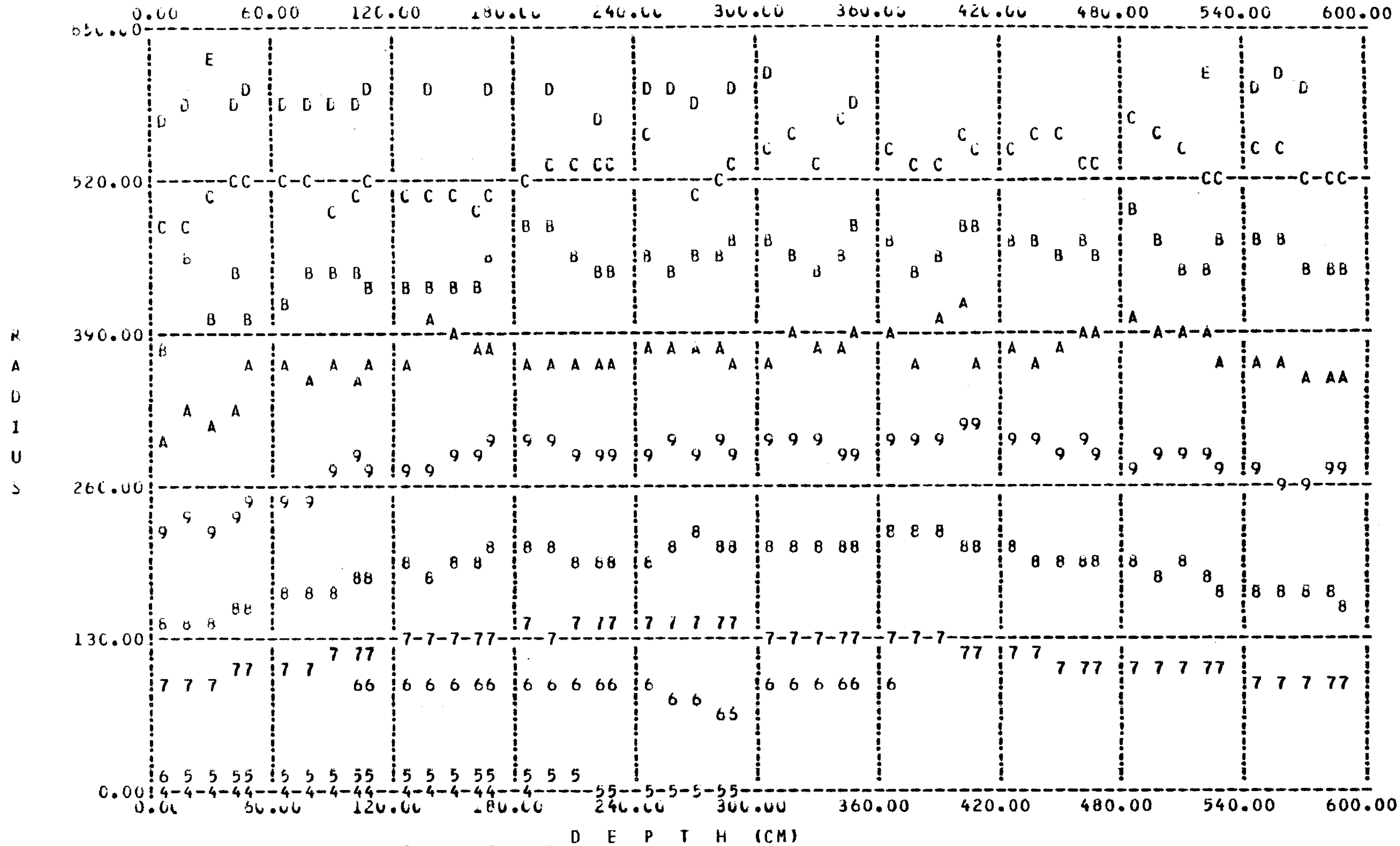


B-LABELS REFER TO SMALLER VALUES OF CORRESPONDING AXIS
LEGEND : NUMERICAL SYMBOLS REFER TO THE NEGATIVE POWER OF 10 OF THE STAR(ENERGY) DENSITY E.G., 5 REFERS TO THE 10**-5 CONTOUR
OTHER POWERS OF 10(SYMBOLS) -10(A),-11(B),-12(C),-13(D),-14(E),-15(F),-16(G),-17(H),-18(I),-19(J)
1(Z),2(Y),3(X),4(W),5(V),6(U),7(T),8(S),9(R),10(Q)

MAXIM run ρMYOCHS

FIG 5

CONTOURS 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(L),-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)

MAXIM run PMYOGYB

FIG 6