national accelerator laboratory

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# PRELIMINARY DESIGN FOR PASSIVE MUON BACKSTOP FOR AREA II

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Enclosed are four figures showing the isoflux curves for solid muon backstops of soil and steel. The muon flux of $10^{-13}$ muons/$cm^2$ per interacting proton would give an exposure of about 20 mrem/week to the experimenters. The assumptions made to calculate these curves are as follows:

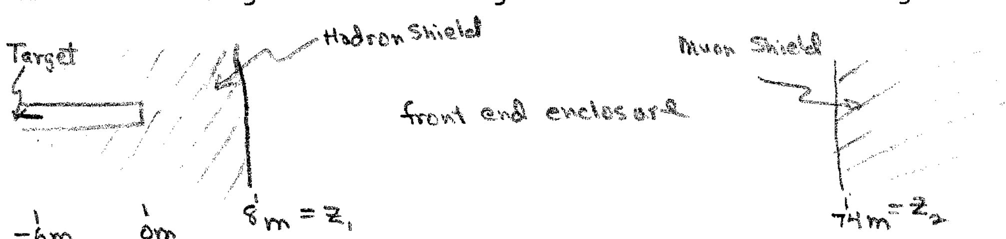
1) a Pb target in the Trilling formula for pion production[1] (the use of a Be target approximately doubles these fluxes);
2) a decay space in the target box 600 cm (20 ft) long and 15 cm (6 in) in radius;
3) multiple Coulomb scattering with energy loss taken into account according to the theory of Eyges[2]; and
4) dE/dx includes Sternheimer[3] density effect on ionization loss, bremsstrahlung[4], pair production and nuclear interactions[5].

The true width of the curves may be larger than shown because large angle Coulomb scattering and the momentum transfer associated with the radiative processes have been ignored. It is planned to look into these effects.

The results of the calculations are shown in Figures 1 and 2.

The isoflux curves are the shapes that the muon backstop would have if the target was surrounded by homogeneous shielding out to infinity. Hence, the use of these dimensions for the actual backstop include a small safety factor difficult to estimate. This is shown on Figures 7 through 9 of Reference 6.

In actual practice the target will be surrounded by just enough shielding to stop the hadrons. The beam transport front end will follow and then the main muon shield would begin. This produces considerable changes in the shape of the muon backstop. Two assumptions are used in estimating the new shape: 1) the flux falls off as $(Z_1/Z_2)^2$ when a part of shielding is moved from $Z_1$ to $Z_2$, where all Z's are measured from the beginning of the shield (not the target), and 2) the radius of shielding required at $Z_2$ increases as though the angle $\Theta = r_1/Z_1$ is preserved; therefore, $r_2 = \Theta Z_2$. This works as follows: The hadron shield is equivalent in thickness to about 8m of steel or 35m of soil. Assume that the muon shield begins at 80m from the target. The diagram below shows the geometry.




To get a flux of $10^{-13}$ muons/cm$^2$ per interacting proton at the outer surface of the muon shield, we look at a depth of 8m in steel for the radius at which the muon flux is $(Z_2/Z_1)^2 \times 10^{-13} = (74/8)^2 \times 10^{-13} = .855 \times 10^{11}$ muons/cm$^2$

per interacting proton. This occurs at a radius of 1.42m ($r_1$); therefore, the angle these muons have been scattered through in the shielding is $\Theta = r_1/Z_1 = 1.42/8.0 = 0.1775$ radians. The radius at position $Z_2$ where the flux is $1 \times 10^{-13}$ is $r_2 = \Theta Z_2 = 13.15$m. This process is continued throughout the shield. Thus, $Z_1 = 12$m is displaced to $Z_2 = 78$m, $r_1 = 1.53$m transforms to $r_2 = 9.8$m. The results for complete shields listed in Tables I and II and shown in Figures 3 and 4.

This design is very preliminary but should be useful to indicate the approximate size and shape of a passive shield. Later, better calculations will be made using an appropriate muon transport method.

It must be emphasized that the channeling effect of the beam transport magnets has been neglected. The effect of these magnets will be studied in the near future.

## ACKNOWLEDGEMENTS

I am very grateful to R. G. Alsmiller, Jr. and J. Barish of ORNL for providing the basic computer programs for these calculations and many useful discussions. The methods used in these programs is discussed in papers published by them[6].

I would also like to acknowledge many useful discussions with M. Awschalom of NAL.

## REFERENCES

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2. L. Eyges, Phys. Rev. 74, 1534 (1948).
3. R. M. Sternheimer, Phys. Rev. 88, 851 (1952); Phys. Rev. 103, 511 (1956); Phys. Rev. 115, 137 (1959); Phys. Rev. 124, 2051 (1961); Phys. Rev. 145, 245 (1966); and Phys. Rev. 164, 349 (1967).
4. P. J. Hayman, N. S. Palmer and A. W. Wolfendale, Proc. Roy. Soc. A275, 391 (1963).
5. P. M. Joseph, Nucl. Inst. & Meth. 75, 13 (1969).
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Table I:

Steel backstop for actual experimental area.

Target at 0m or 0ft followed by 6m decay space and 8m of steel.

Muon backstop begins at 80m or 262 ft from target.

| Distance from Target | | Radius | |
|---|---|---|---|
| 80m or | 262 ft | 13.15m or | 43.1 ft |
| 84 | 275 | 9.80 | 32.2 |
| 92 | 305 | 7.30 | 24.0 |
| 100 | 328 | 6.00 | 19.7 |
| 108 | 354 | 5.10 | 16.7 |
| 116 | 380 | 4.42 | 14.5 |
| 124 | 406 | 3.85 | 12.6 |
| 132 | 433 | 3.30 | 10.8 |
| 140 | 459 | 2.60 | 8.5 |
| 148 | 486 | 1.87 | 6.2 |
| 154 | 505 | 0.00 | 0.0 |

Table II:

Soil backstop for actual experimental area.

Target at 0.0m or 0.0ft followed by 6m decay space and 8m of steel.

Muon backstop begins at 80m or 262 ft.

| Distance from Target | | Radius | |
|---|---|---|---|
| 80m or | 262 ft | 15.10m or | 49.5 ft |
| 100 | 328 | 13.20 | 43.5 |
| 120 | 394 | 12.75 | 41.7 |
| 140 | 460 | 12.50 | 41.1 |
| 160 | 525 | 12.30 | 40.4 |
| 180 | 590 | 12.00 | 39.4 |
| 200 | 655 | 11.50 | 37.6 |
| 220 | 721 | 10.90 | 35.7 |
| 240 | 785 | 9.95 | 32.6 |
| 260 | 853 | 8.85 | 29.0 |
| 280 | 917 | 7.10 | 23.3 |
| 300 | 982 | 4.40 | 14.5 |
| 310 | 1015 | 0.00 | 0.0 |

Figure 1:

Muon Backstop

Isoflux Curves (muon $cm^{-2}$ $proton^{-1}$)

Material = Steel

Target to Backstop Distance = 600 cm

Target Enclosure Radius = 15 cm

Target Material = Pb

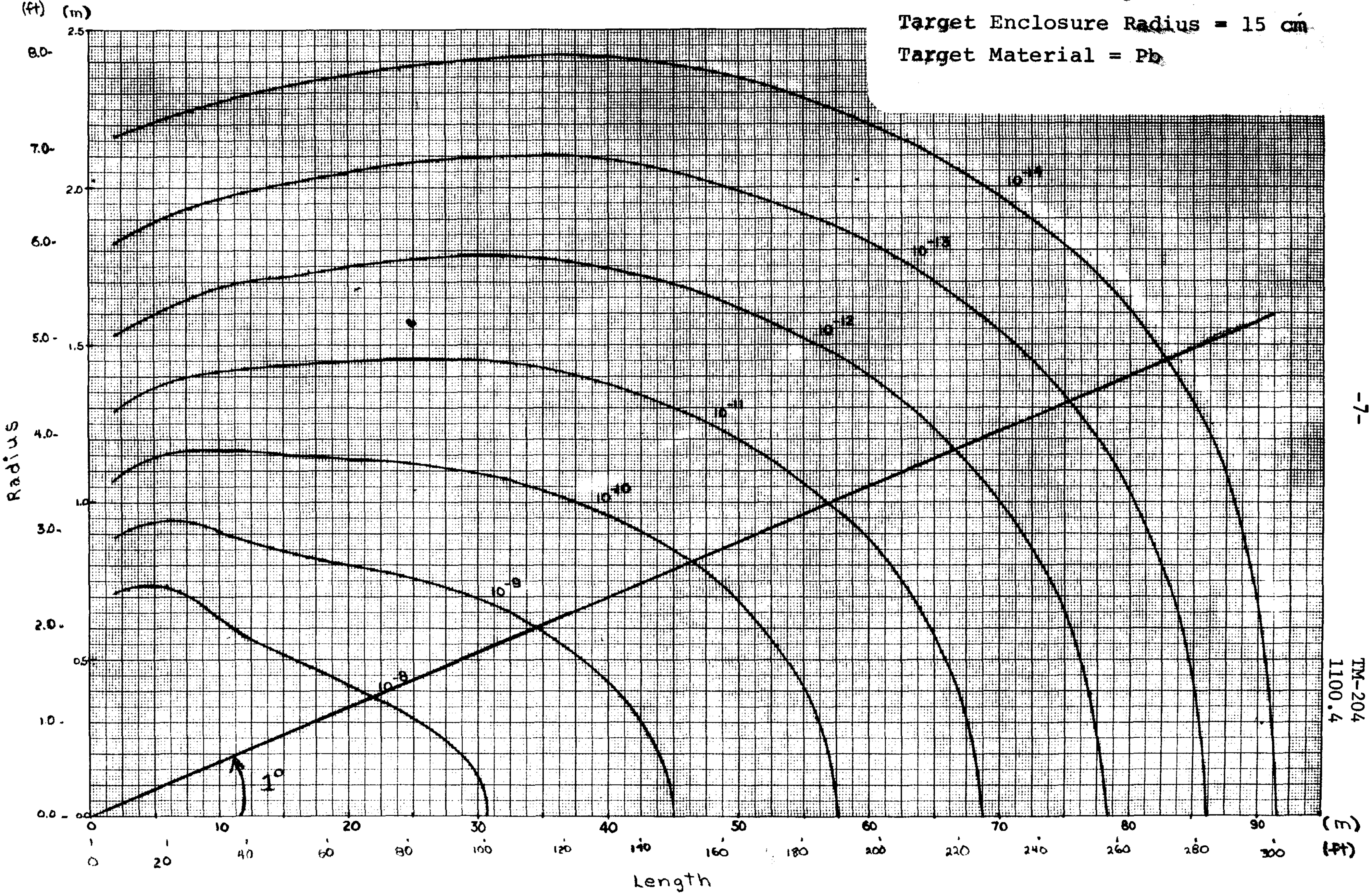




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Figure 2:

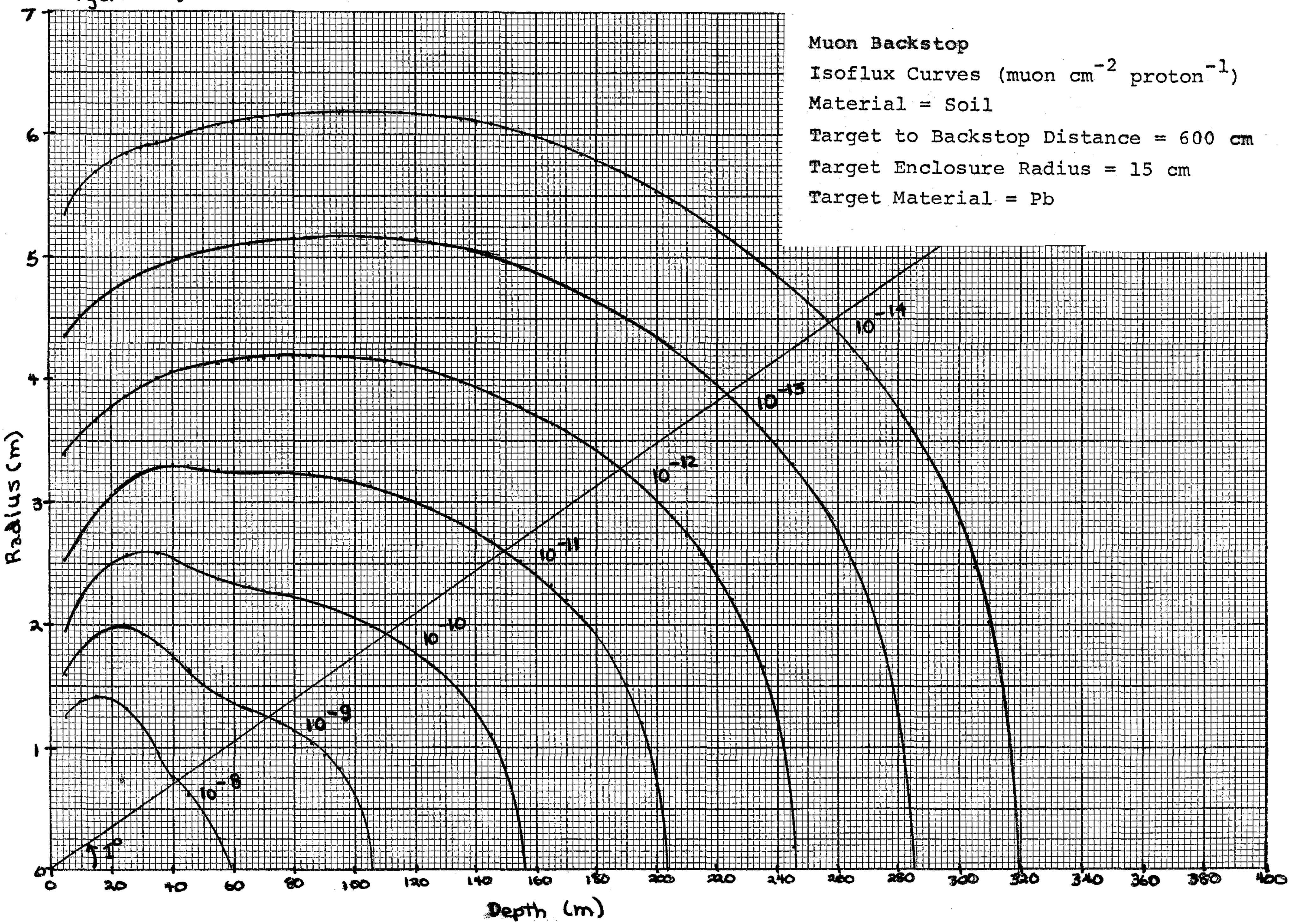

Muon Backstop
Isoflux Curves (muon cm$^{-2}$ proton$^{-1}$)
Material = Soil
Target to Backstop Distance = 600 cm
Target Enclosure Radius = 15 cm
Target Material = Pb
Radius (m)
Depth (m)
$10^{-8}$
$10^{-9}$
$10^{-10}$
$10^{-11}$
$10^{-12}$
$10^{-13}$
$10^{-14}$
1°
0
1
2
3
4
5
6
7
20
40
60
80
100
120
140
160
180
200
220
240
260
280
300
320
340
360
380
400

Figure 3:

Steel Backstop for experimental area

Target at 0 ft. followed by 20 ft. decay space and 26 ft. of steel

Muon Backstop begins at 262 ft.

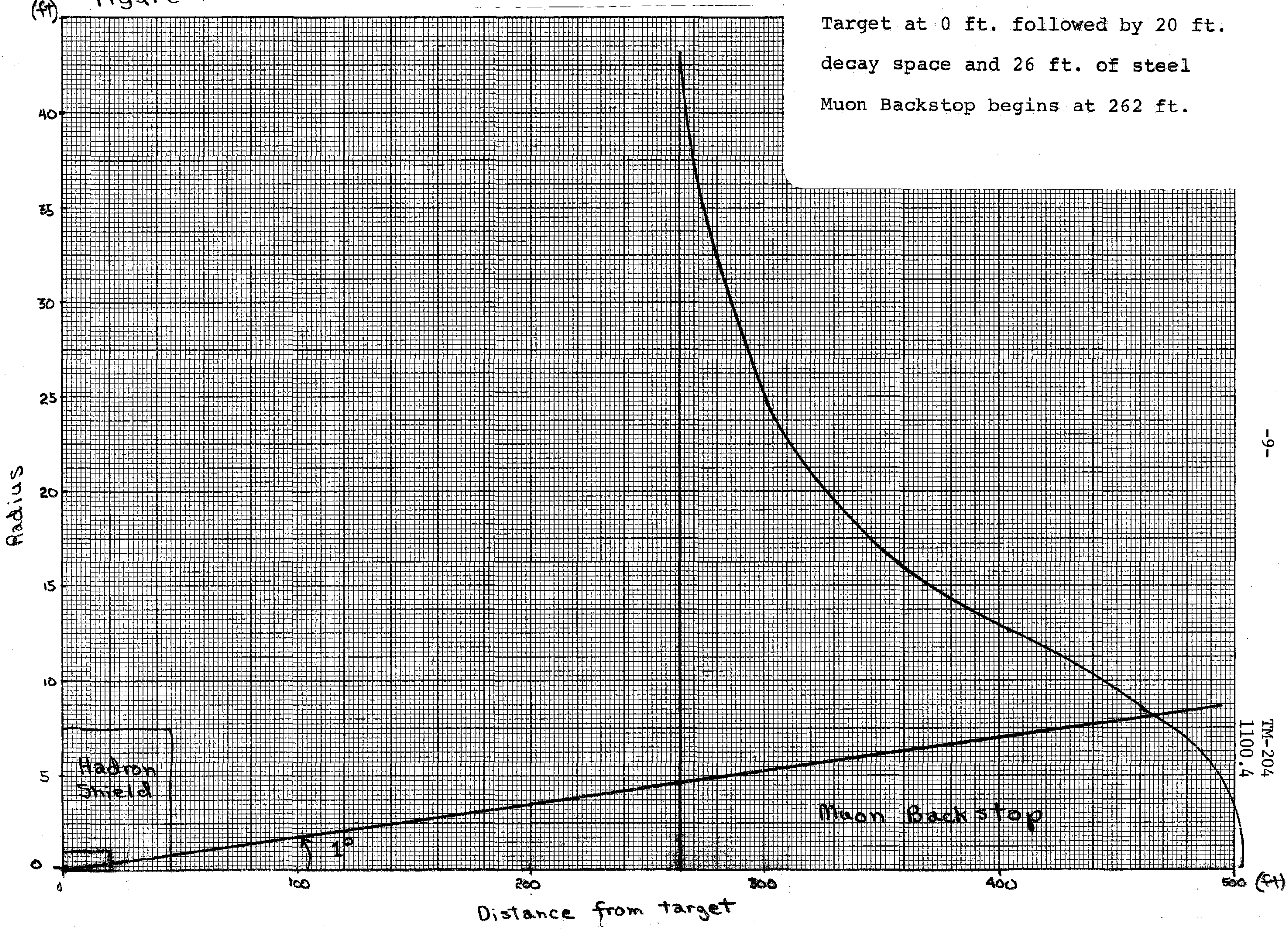
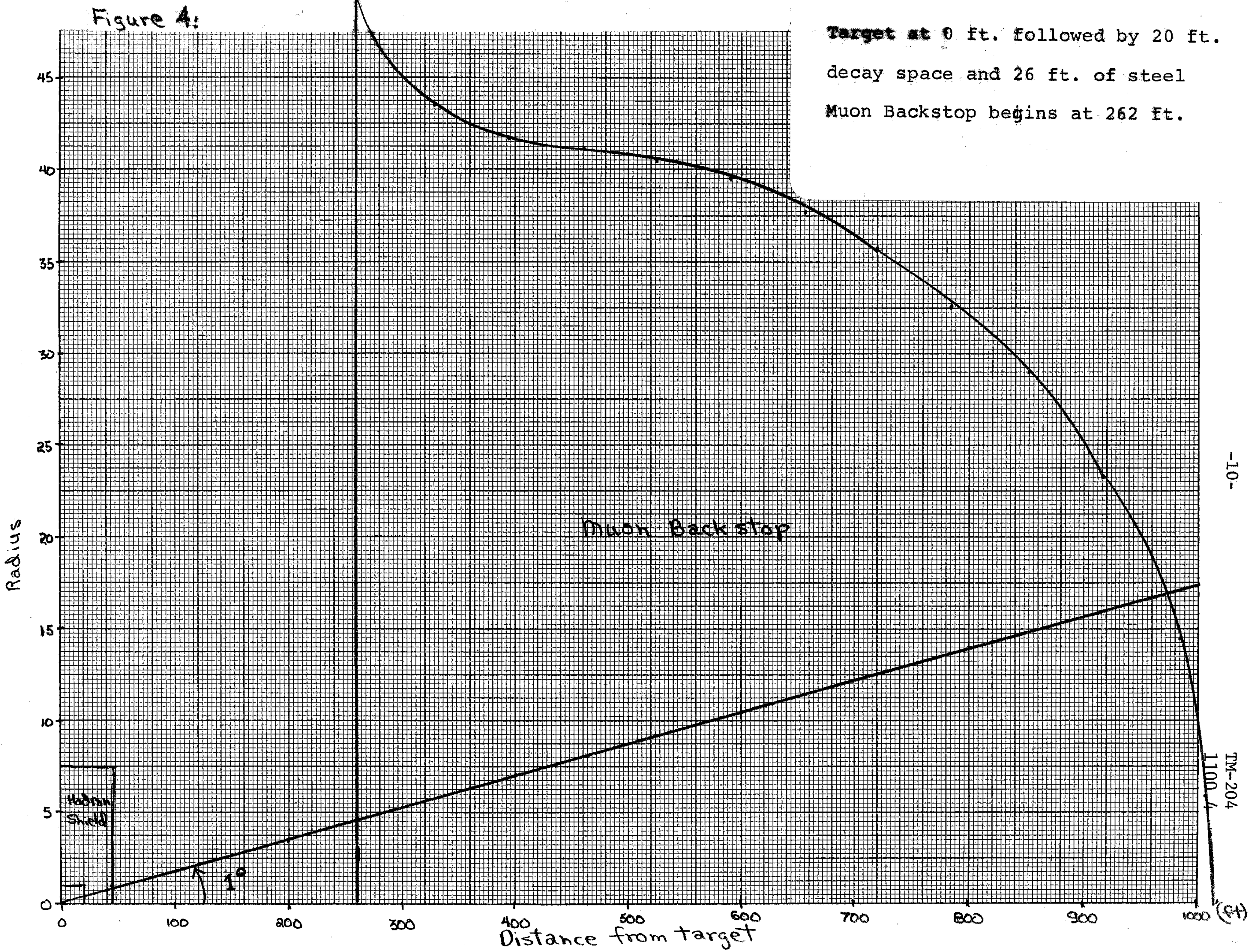


Figure 4:



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