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MUON SHIELDING: STUDIES OF HOMOGENEOUS SHIELDING FOR A NEUTRINO FACILITY

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The explicit problem considered is the "shape" of homogeneous muon shielding for a stopping 500 GeV proton beam in a geometry suitable for a neutrino facility such as proposed for Area I. The same pions and kaons whose decay produces neutrinos also produce high energy muons. In order to reduce the muon flux to tolerable levels a massive shield is required. This muon flux at a point outside the shielding is reduced by ranging out muons, solid angle and scattering.

Muon transport programs have been developed for NAL[1] which allow us to calculate the shape of homogeneous shields. This report gives the results of some studies made on the design of such shields for a neutrino facility.

The calculations were made with the following assumptions:

1. a cylindrical decay space 600m in length and 1m in diameter,
2. pion production using the Trilling[2] formula with parameters to fit p-Be π-production,

3. small angle multiple Coulomb scattering with energy loss[3],
4. dE/dx for collision losses only using the Sternheimer[4] density effect correction,
5. no focusing device in the tunnel,
6. homogeneous shielding material of various kinds,
7. straggling has not been included,
8. muons of both charges.

Figure 1. shows the geometry used in all calculations. a cylindrical decay space 600m long and 1m in diameter is located in a semi-infinite medium of shielding material. The pions are produced in a beryllium target located at 0,0 and allowed to decay anywhere in the cylindrical void. The pion is absorbed when it hits the wall of the void. Muons from a decay travel in the same direction as the parent pion.

The first calculation was made at 200 GeV incident proton energy and iron as a shielding material. The results are shown in figure 2. The isoflux curves have the units of muons per square centimeter per interacting proton. The amount of shielding required for radiation safety purposes lies between the 10^{-12} and 10^{-13} isoflux curves, approximately 110m thick from the end of the decay space with a radius of slightly over 2m. Since these shields are homogeneous, this iron would extend all the way back to the target with an approximate radius of 2m. Calculations for this lateral shielding were not carried out for the case of iron but were for other materials and will be discussed later.

Figure 3 shows the same calculation for an incident proton energy of 500 GeV and iron shielding. The backstop now required for radiation safety purposes is 270m thick and slightly over 3m in radius an increase of about 5.5 for the backstop alone over the 200 GeV incident proton energy case.

Since such massive iron shields are prohibitively expensive, pure soil as well as heavy concrete as shielding were also studied. Figure 4 shows the calculation for a muon backstop at 500 GeV using heavy concrete as a shielding material. The backstop required for radiation safety of heavy concrete is 500m thick with a radius of approximately 5m.

Figure 5 shows isoflux curves for lateral shielding of heavy concrete around the decay tunnel. Generally a radius of 5m is necessary except in the region near the target. These calculations assumed no focusing of the pions. Any device which focuses one sign of particle and defocuses the other will change these curves mostly in the region near the target.

The results for soil are shown in figures 6 and 7. The radiation safety shield dimensions require a backstop 850m thick with a radius of 6.5m. The lateral shielding of the tunnel requires a radius of approximately 6.5m also.

Throughout we have referred to the requirements for radiation safety. Since it is proposed to locate a large bubble chamber in the neutrino facility, a comment should be made about the shielding for the bubble chamber. The bubble chamber requires shielding roughly four orders of magnitude better than that required for radiation safety purposes alone (1 muon m^{-2} as opposed to 1 muon cm^{-2}) For this purpose we have included a 10^{-17} isoflux curve in all of our figures. It is necessary to increase the thickness of the backstop above that required for radiation safety alone in order to achieve such shielding. Also additional length must be added to protect against straggling. It is not so clear that additional shielding must be added in the lateral dimensions unless the lateral dimension of the shield is comparable to the lateral dimensions of the bubble chamber such as in the case of the iron shield. For the heavy concrete and soil shields the lateral dimensions of the radiation safety shields are larger than the dimensions of the bubble chamber and may be adequate. A qualification should be made however. "Muon skyshine" (the scattering of muons in the air around the long shield) may make it necessary to increase the lateral dimensions of even the heavy concrete or soil shields to achieve sufficient shielding. This increase would be certainly less than that indicated by the 10^{-17} isoflux curve.

In order to study such effects as,

1. heavy shielding along the decay path
2. heavy absorbers at the end of the decay enclosure
3. ground-shine
4. skyshine
5. focusing devices.

Monte Carlo calculations are needed and the appropriate program is now under development.

ACKNOWLEDGEMENT

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REFERENCES

1. R. G. Alsmiller, Jr., M. Leimdorfer, and J. Barish, High Energy Muon Transport and the Muon Backstop for a 200 GeV Proton Accelerator, ORNL-4322 (November, 1968).
2. J. Ranft and T. Borak, Improved Nucleon Muon Cascade Calculations, NAL FN 193, p. 9 (November, 1969).
3. L. Eyges, Phy Rev 74, 1534 (1948).
4. 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).

Figure 1: Geometry used in calculations of homogeneous shielding for a neutrino beam facility.

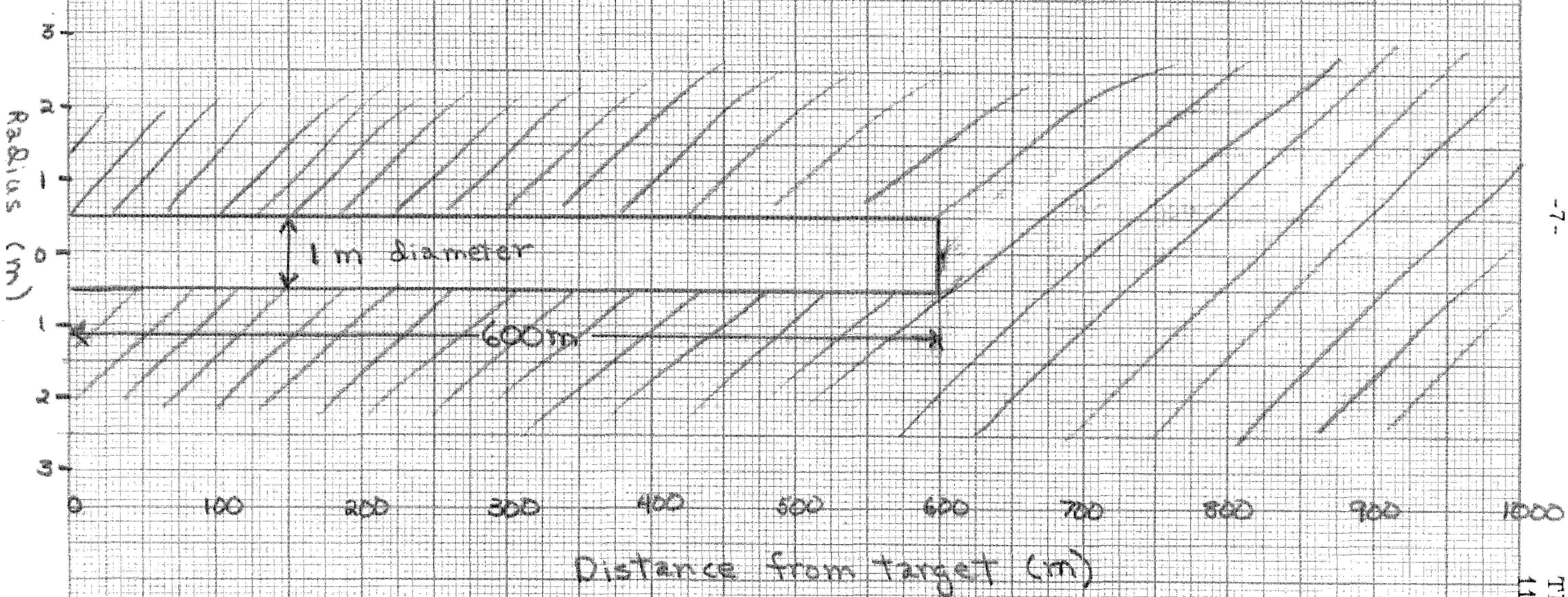

Figure 2:

Area I Muon Backstop - 200 GeV
Isoflux Curves (muon cm^{-2} $(int\ prot)^{-1}$)
Shielding Material: Iron, density 7.87
Target Material: Be
Decay Space: 600 m length x 1m diameter
$(dE/dx)_{coll.}$ used to calculate ranges

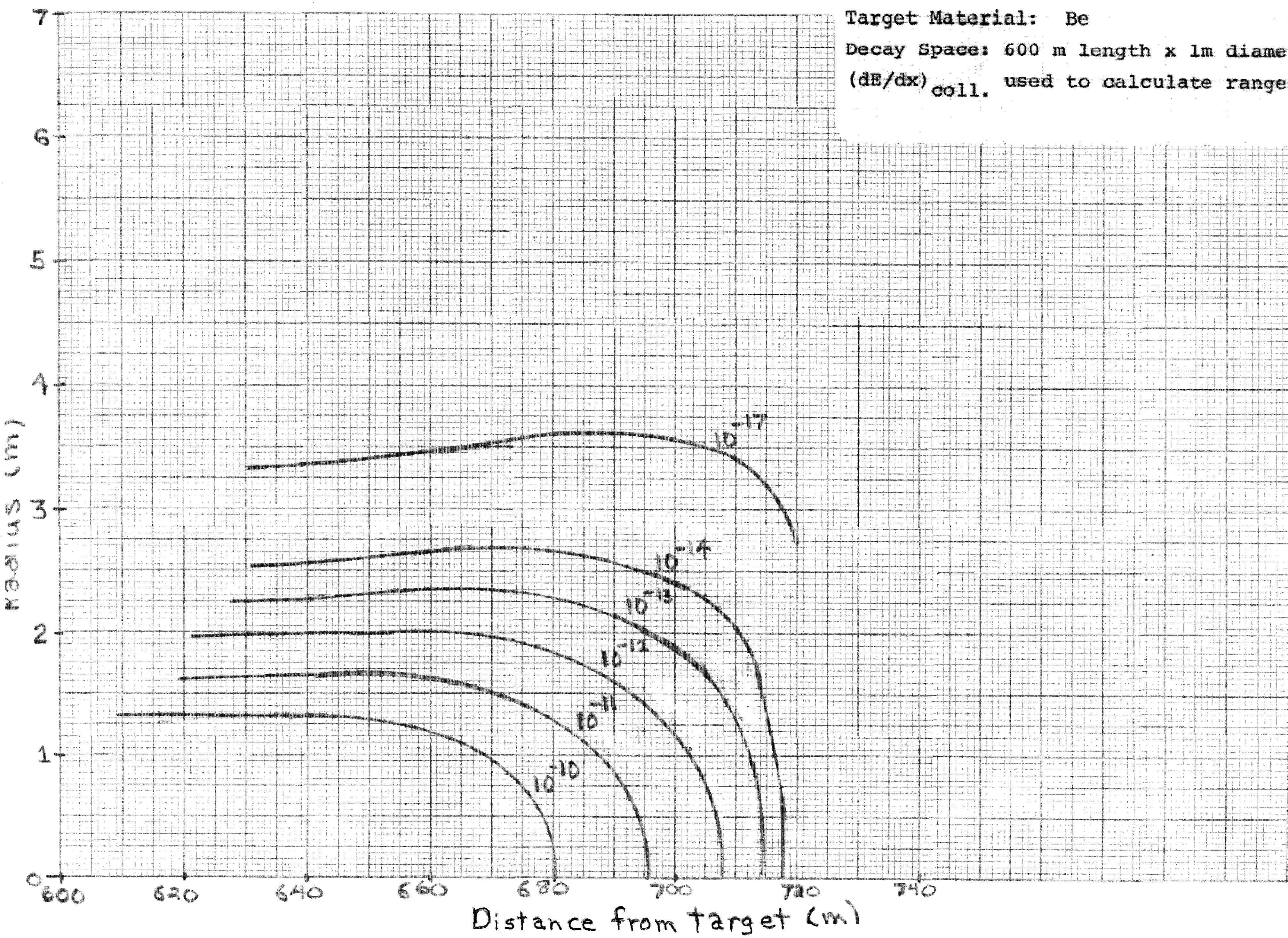

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Figure 3:

Area I muon Backstop - 500 GeV

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

Shielding Material: Iron, density 7.87

Target Material: Be

Decay Space: 600 m length x 1m diameter

$(dE/dx)_{coll.}$ used to calculate ranges

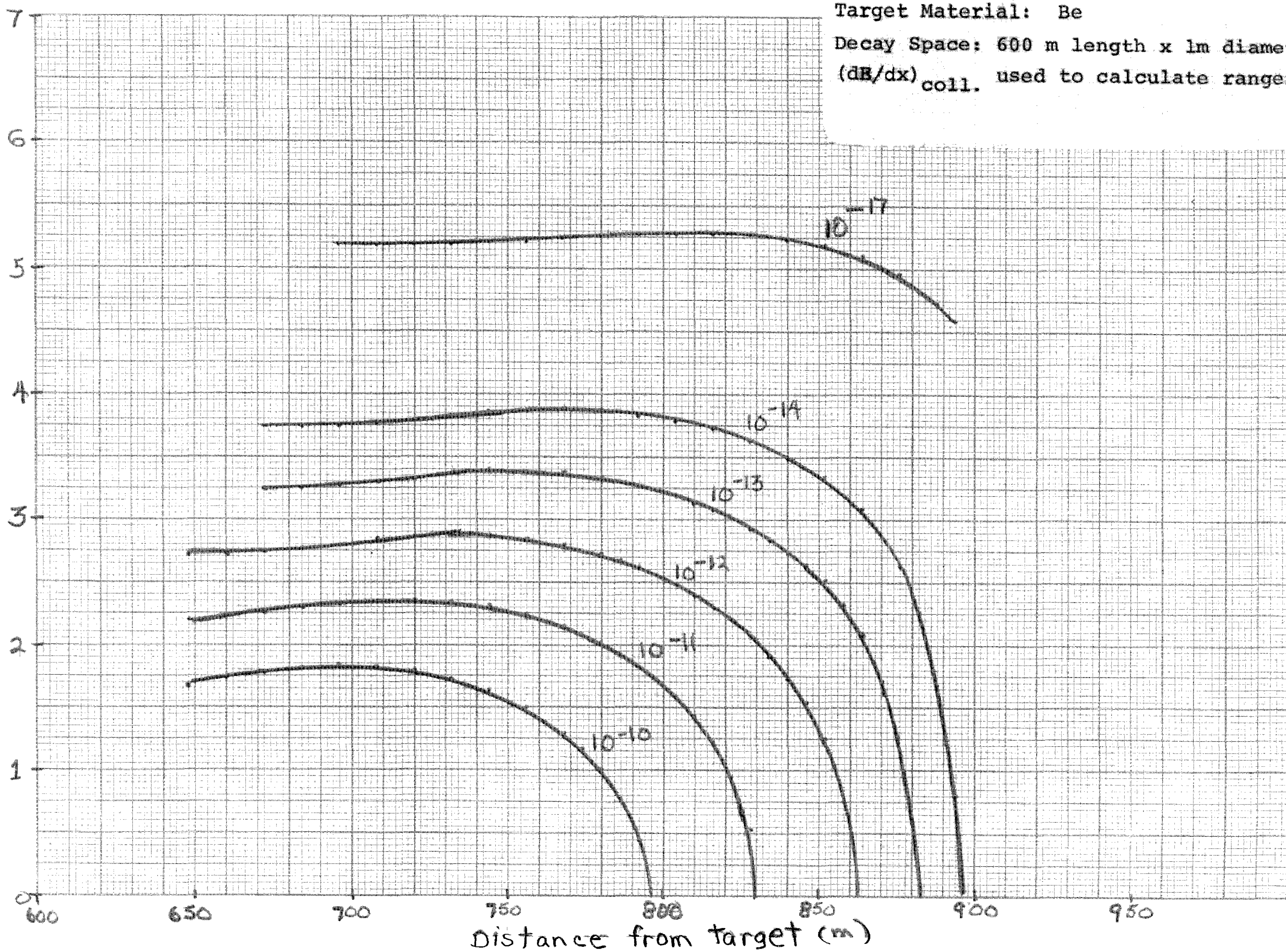

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Figure 4:

Area I Muon Lateral Shielding - 500 GeV
Isoflux Curves (muon cm^{-2} (int prot)$^{-1}$)
Shielding Material: Heavy Concrete, density 3.84
Target Material: Be
Decay Space: 600 m length x 1m diameter
$(dE/dx)_{coll.}$ used to calculate range

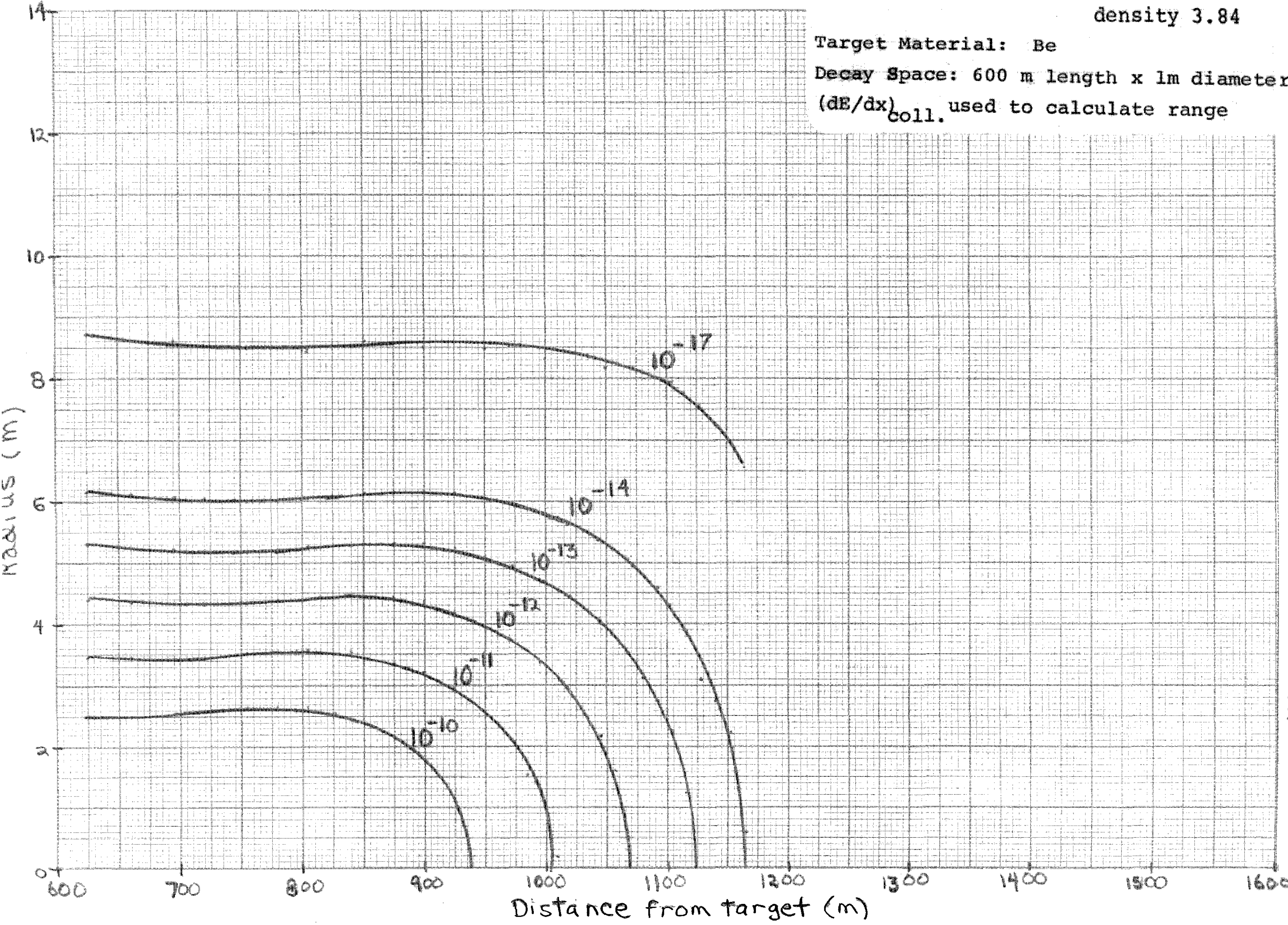

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Figure 5:

Area I Muon Backstop - 500 GeV

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

Shielding Material: Heavy Concrete, density 3.84

Target Material: Be

Decay Space: 600 m length x 1m diameter

$(dE/dx)_{Coll.}$ used to calculate ranges

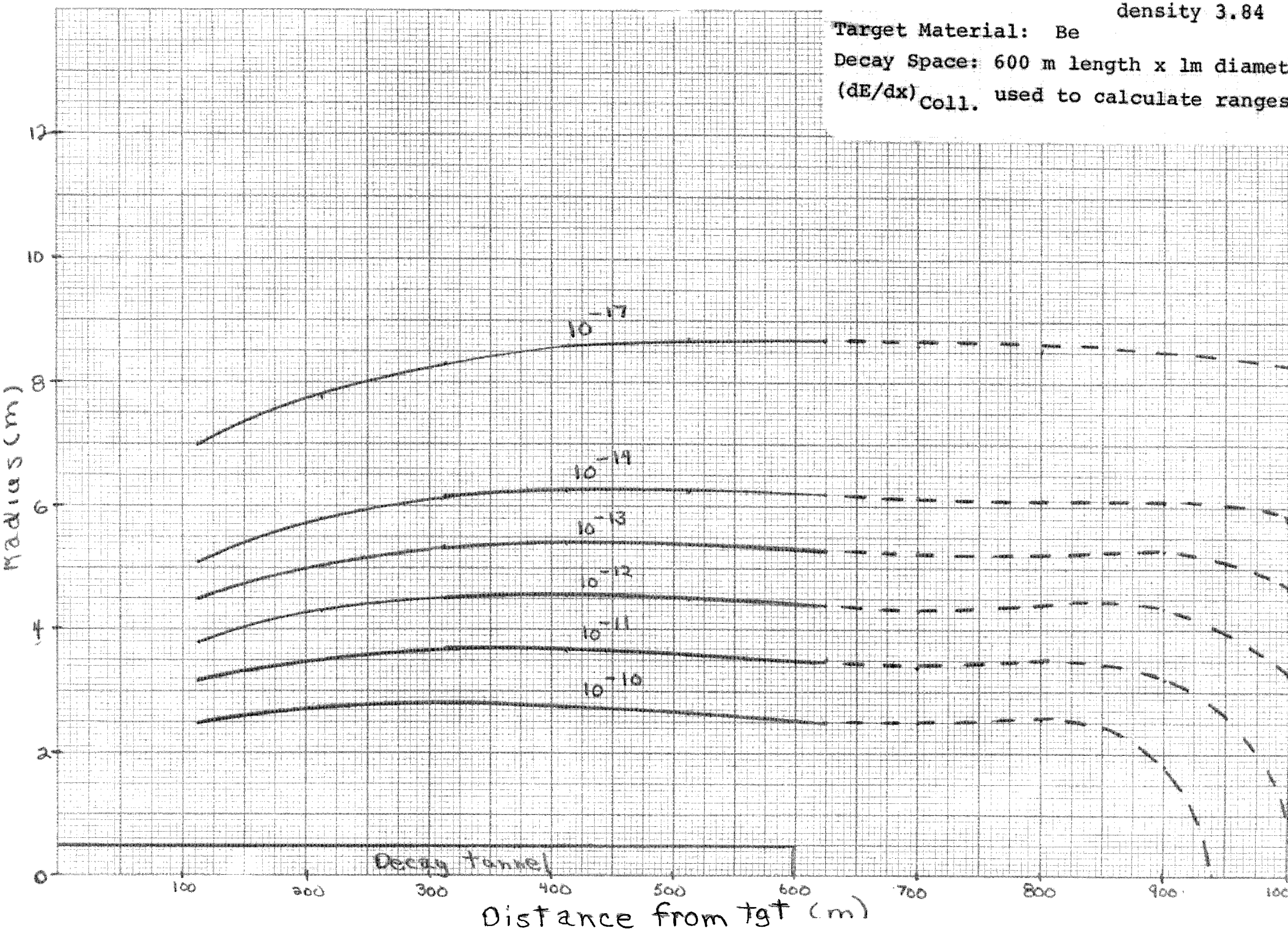

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Figure 6:

Area I muon Backstop - 500 GeV

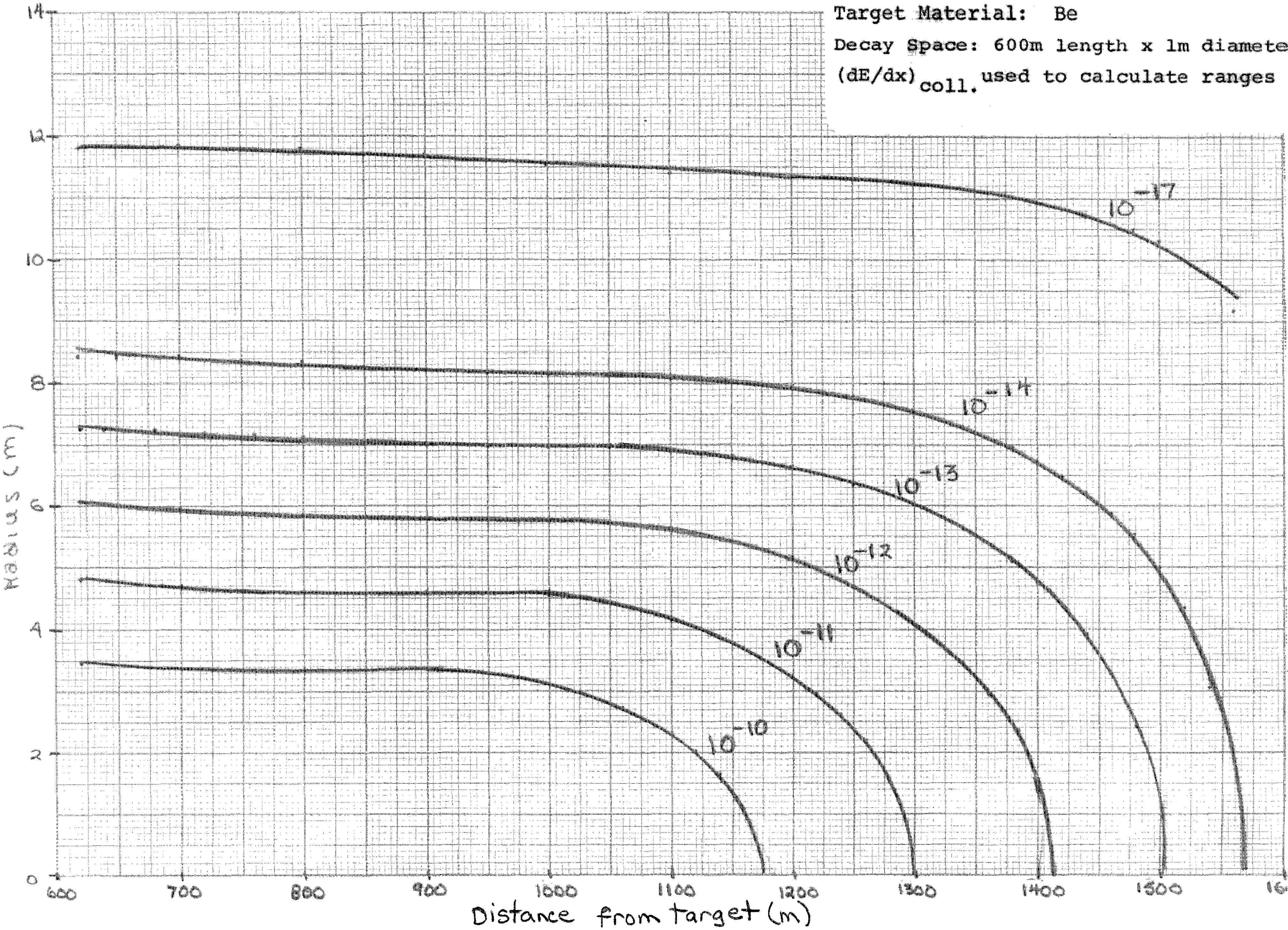
Isoflux Curves (muon cm^{-2} (int prot)$^{-1}$)

Shielding Material: Soil, density 2.00

Target Material: Be

Decay Space: 600m length x 1m diameter

$(dE/dx)_{coll.}$ used to calculate ranges



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Area I muon Lateral Shielding - 500 GeV

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

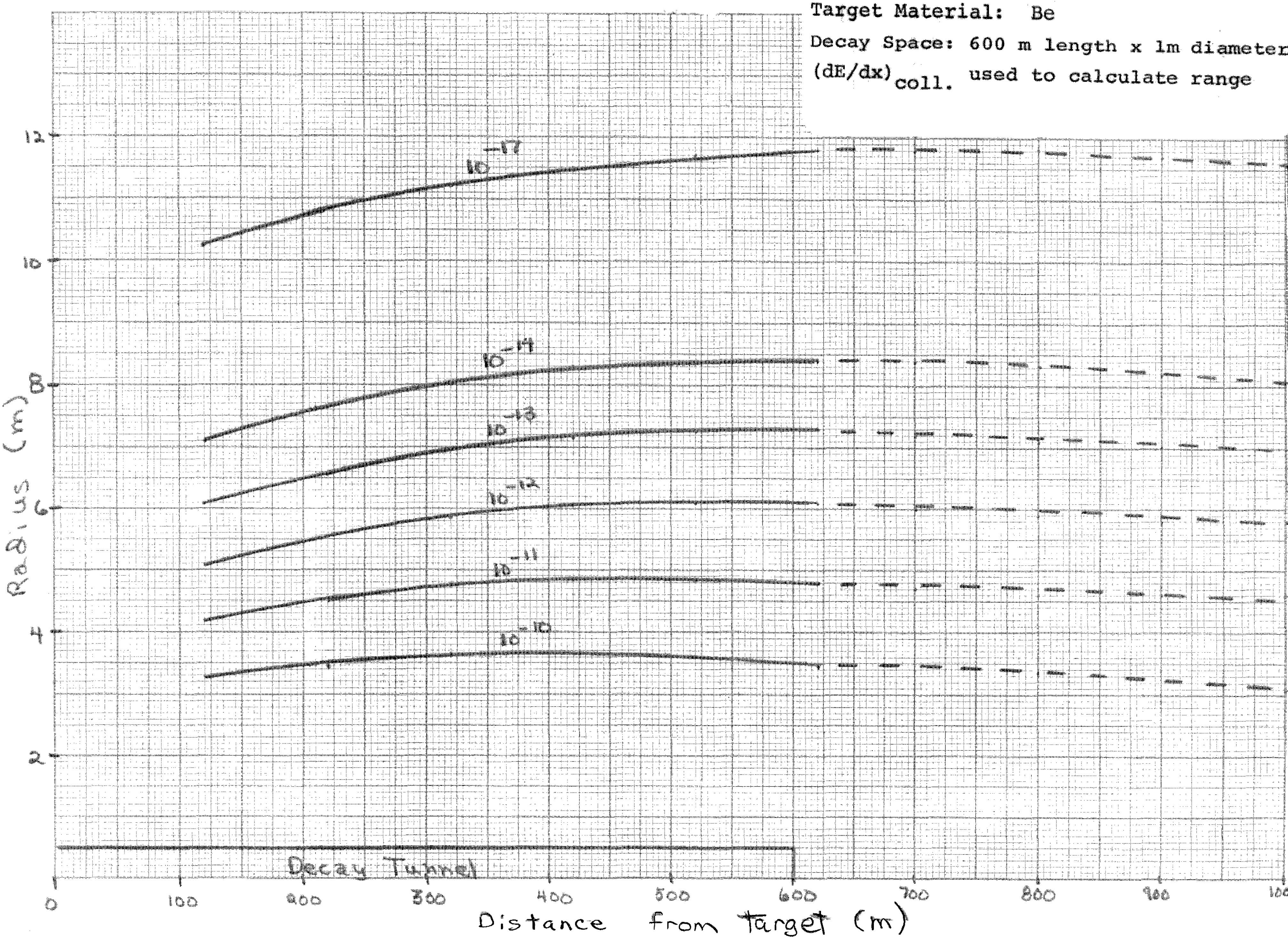
Shielding Material: Soil, density 2.0

Target Material: Be

Decay Space: 600 m length x 1m diameter

$(dE/dx)_{coll.}$ used to calculate range

Figure 7



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