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Fermilab

SOIL ACTIVATION CALCULATIONS FOR THE PROPOSED NEUTRINO FRONT HALL

J. D. COSSAIRT

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The proposed Neutrino Front Hall enclosure will consist of an enclosure constructed from precast sections. An impervious membrane located below the enclosure will be installed to protect against radionuclides migrating to the aquifer. A cross section of the proposed Front Hall is shown in Fig. 1. This TM is a report on calculations of the soil activation using the Monte Carlo code CASIM.[1]

In the Tevatron era it is likely that various configurations of target trains will be used in this new Front Hall. This TM examines several possible configurations in a schematic form not restricted to the specific details of a particular configuration. In general, the procedure used is quite similar to that discussed in Ref. 2.

The following parameters are common to all the configurations considered here:

Incident beam:	1000 GeV/c protons
Threshold momentum:	0.3 GeV/c
Beam spot size:	0.2 x 0.2 cm

Additionally, beam elements of standard sizes and materials were selected to be representative of those likely to be encountered in practice with the exception that rectangular objects have been approximated by cylinders with equivalent cross-sectional areas for reasons of computational efficiency. These beam elements are now defined:

Target:	Be, 2.86 cm diameter, 30 cm long
Dump:	Fe, 51.58 cm diameter, 305 cm long
Magnet:	Fe, 10 cm diameter bore, 51.58 cm outside diameter, lengths are varied to simulate strings of magnets

Now consider Fig. 1. Since the region beneath the enclosure is the most critical one for purposes of environmental protection, the enclosure was simulated by one having cylindrical walls with inner and outer radii equal to the r.m.s. values of those quantities as measured from the beam axis to the floor of the enclosure and here have the values of 128 cm and 171 cm, respectively. This was done to obtain an average distance of the wall surfaces from the beam axis. The regions protected by the bathtub and by the sumps were taken to be the regions bounded by the smallest radial distances of the bathtub and the lower underdrains from the beam axis; 445 cm and 597 cm, respectively. Three regions of interest are defined and have been included on Fig. 1:

Region 1: The region of soil protected by the bathtub from transport of radionuclides to the aquifer. Region 1 extends to the top of the berm.

Region 2: The region of soil below the bathtub but above the lower underdrains protected by the sumps from transport to the aquifer. This region subtends somewhat less than 180^0 in azimuth around the beam axis. In the calculations it was considered to subtend 180^o in azimuth.

Region 3: Unprotected soil not protected by the sumps or the bathtub.

The quantity of the radionuclides of interest produced in each region was obtained from the computer runs by summing the stars produced in each region and following the procedure of Ref. 2 to obtain radionuclide production and resulting transport to the aquifer.

Figures 2-5 contain plots of equal star density versus radius (R) and axial coordinate (Z) for the geometries considered here. Using the notation defined above, the configuration of the conceptualized beam elements are also shown on the 4 figures. In these figures, the designation of the 3 Regions are for the lower half-cylinder (below the beam axis) and do not change the above comments.

In a typical year, past experience indicates that 2×10^{19} protons would be targeted on the NO target. This is assumed to hold in the Tevatron era. Ref. 2 gives the following conversions for production of ^3H and ^{22}Na, the two principal radionuclides of interest:

^3H: 0.075 atoms (leachable)/star
^{22}Na: 0.003 atoms (leachable)/star

^{22}Na is approximately 15% leachable from soil so the numbers in what follows must be multiplied by 6.7 to obtain total ^{22}Na production. Only leachable ^{3}H production rates have been measured to date.

The formula for calculating activities in Curies from the number of stars/proton obtained from the code is then:

$$A = \frac{N_p\ S\ P}{T\ (3.7 \times 10^{10})} \qquad (1)$$

Where A is the activity in Curies (Ci)
N_p is the number of protons/year (here taken as 2×10^{19})
S is the number or stars/proton in the region of interest
P is the production rate in atoms/star of leachable radionuclide
T is the meanlife:
$T\ (^{3}H) = 17.7$ yr, 5.58×10^{8} sec
$T\ (^{22}Na) = 3.65$ yr, 1.18×10^{8} sec

The 3.7×10^{10} converts from disintegration/sec to Curies. Table I contains the star and radionuclide production for each case considered for each region.

Of course such radionuclides need to be transported to the Silurian aquifer (el. 677 ft) and transported off-site to present a problem. The time thus involved allows for some decay. Following Ref. 2 horizontal transput is neglected, while ^{3}H is transported vertically with a velocity of 7.2 ft/yr and ^{22}Na is transported with a velocity of 3.2 ft/yr. For our purposes here, all transport is presumed to start from el 728', the top of the unprotected soil, since the greatest activation in the unprotected soil will be in this vicinity.

Thus the ^{3}H requires, on average, 7.08 years and the ^{22}Na requires, on average, 15.9 years to reach the aquifer. Thus decay reduces the activities by the following factors:

$$^{3}H: \ \exp\ (^{-}7.08/17/7) = 0.67$$
$$^{22}Na: \ \exp\ (-15.9/3.75) = 0.0144$$

The EPA allows a maximum concentration of 20 pCi/mℓ ^{3}H and 0.2 pCi/mℓ of ^{22}Na in community water systems. A person using such water for residential purposes would receive an average internal exposure of 4 mrem/yr. The

Table 1

Star and Radionuclide Production
(Leachable Activities Only)

Case		Region 1 stars/proton	Region 1 A (Ci)	Region 2 stars/proton	Region 2 A (Ci)	Region 3 stars/proton	Region 3 A (Ci)
1.	^{3}H	14.7	1.07	2.20×10^{-2}	1.60×10^{-3}	6.4×10^{-4}	4.65×10^{-5}
	^{22}Na		0.202		3.02×10^{-4}		8.76×10^{-6}
2.	^{3}H	103.0	7.48	0.290	2.11×10^{-2}	1.00×10^{-2}	7.26×10^{-4}
	^{22}Na		1.42		3.98×10^{-3}		1.37×10^{-4}
3.	^{3}H	90.4	6.56	0.120	8.72×10^{-3}	5.40×10^{-3}	3.92×10^{-4}
	^{22}Na		1.24		1.65×10^{-3}		7.42×10^{-5}
4.	^{3}H	84.0	6.10	0.160	1.16×10^{-2}	9.10×10^{-3}	6.61×10^{-4}
	^{22}Na		1.15		2.20×10^{-3}		1.25×10^{-4}

Table II

Concentrations After Decay and Dilution

Case	^{3}H (pCi/mℓ)	^{22}Na (pCi/mℓ)
1	0.56	2.3×10^{-3}
2	8.8	3.6×10^{-2}
3	4.7	1.9×10^{-2}
4	8.0	3.2×10^{-2}

Figure Captions

1. Typical bathtub and enclosure cross section.

2. Case 1: Bare target with no downstream dump.

3. Case 2: Bare target with dump 305 cm downstream.

4. Case 3: Bare target with dump 305 cm downstream followed by a long string of magnets.

5. Case 4: Bare target followed by 305 cm of air, then a long magnet string with the dump 1600 cm downstream of the target followed by more magnets.

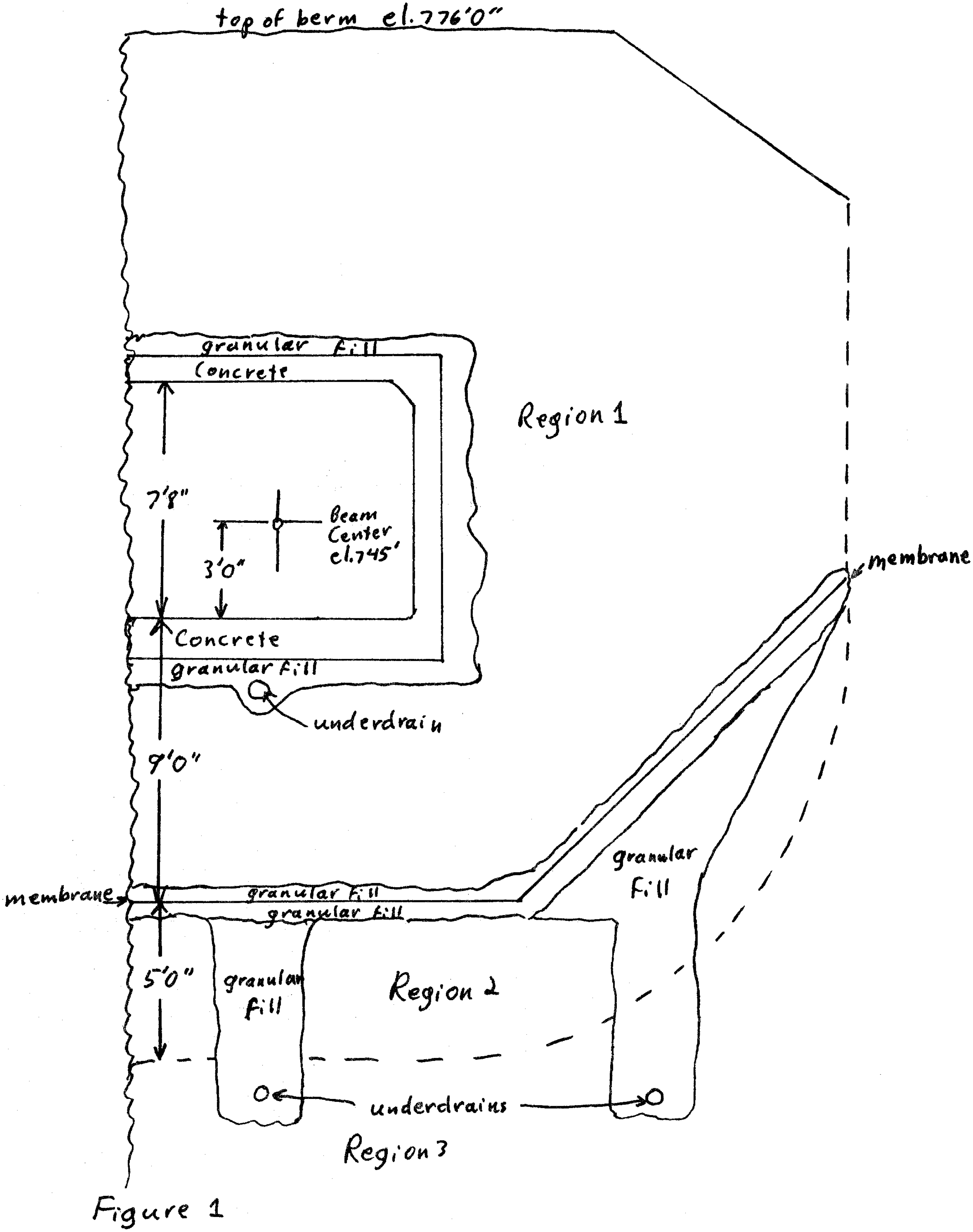
top of berm el. 776'0"
granular fill
Concrete
Region 1
7'8"
Beam Center el. 745'
3'0"
Concrete
granular fill
underdrain
9'0"
membrane
membrane
granular fill
granular fill
granular Fill
5'0"
granular fill
Region 2
underdrains
Region 3

Figure 1

CASE 1

Contours are of equal star density in units of Stars/(cm³ · incident particle)

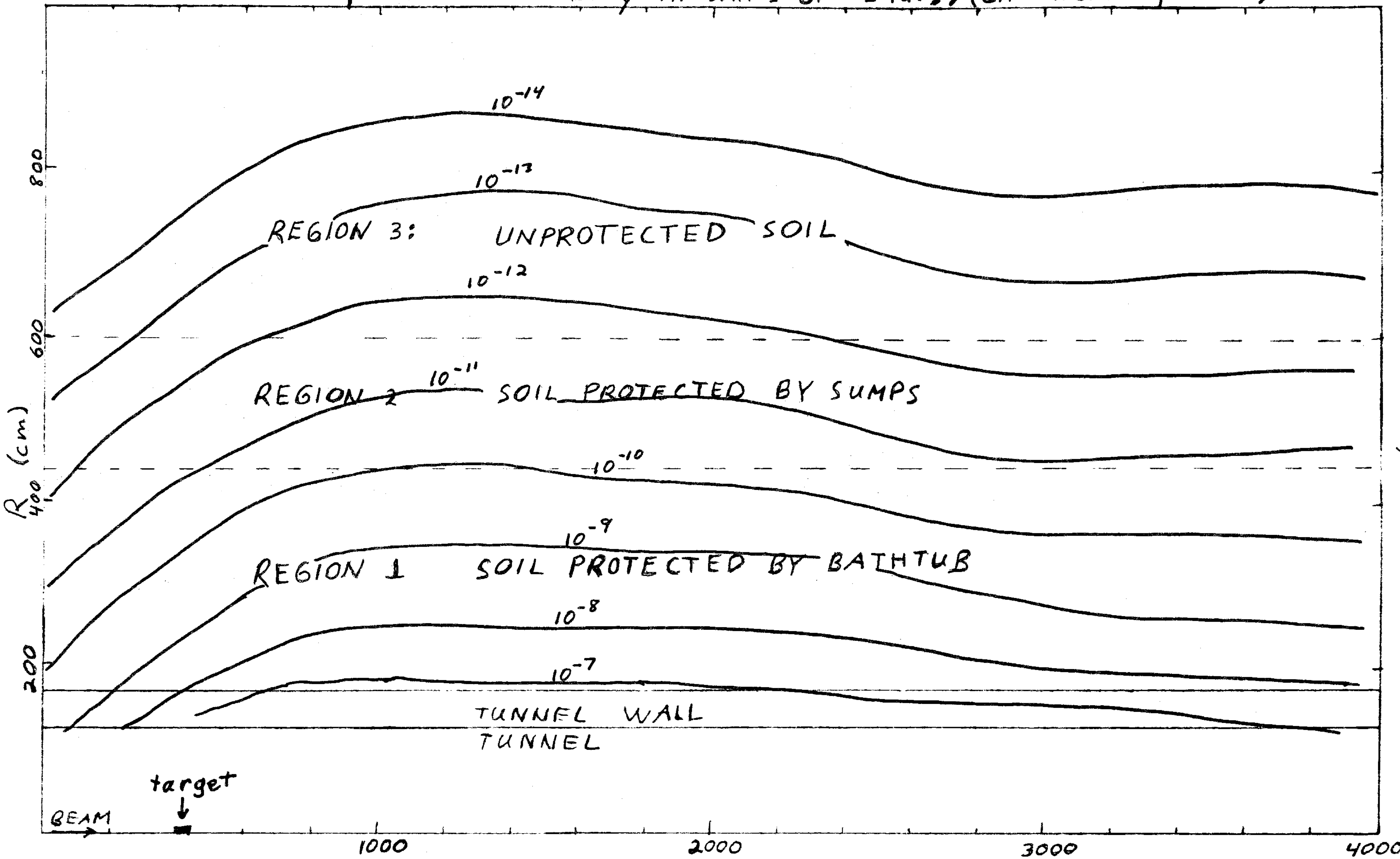

Figure 2: Target only, most activation Z (cm) will obviously be produced downstream in existing areas

CASE 2

Contours are of equal star density in units of Stars/(cm³ · incident particle)

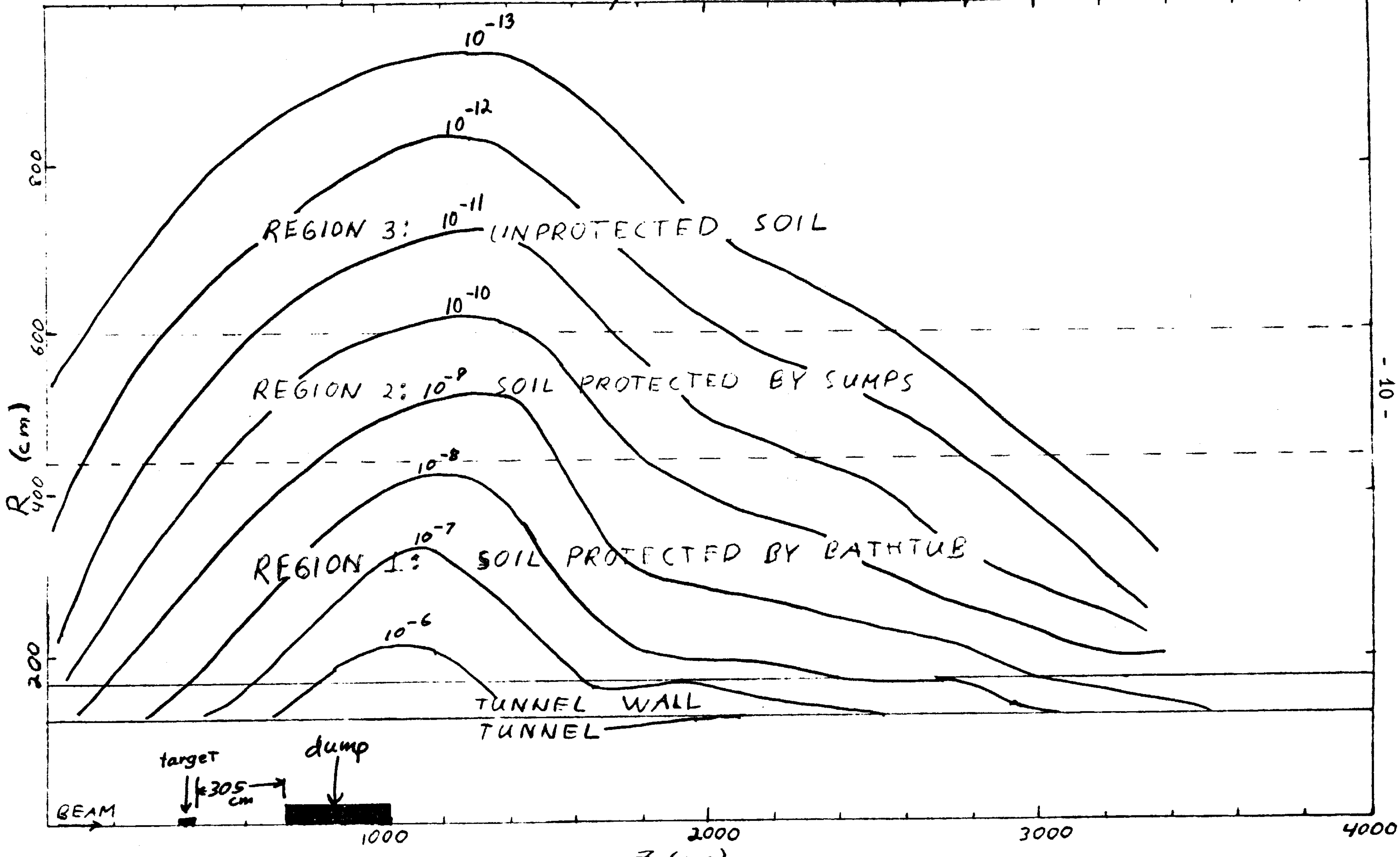

Figure 3: Target and dump

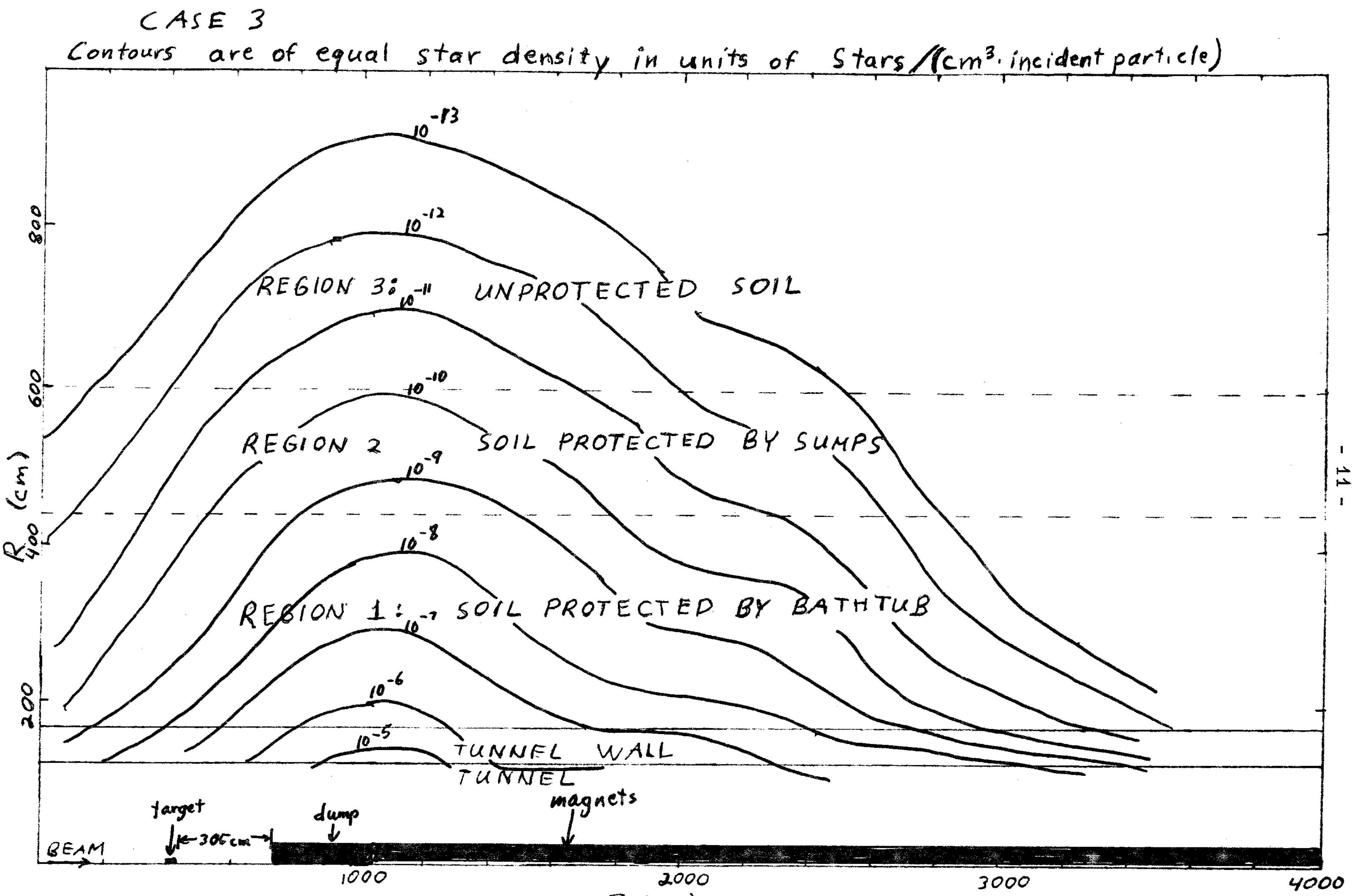

Figure 4: Target and dump with downstream magnets

Contours are of equal star density in units of Stars/(cm³·incident particle)

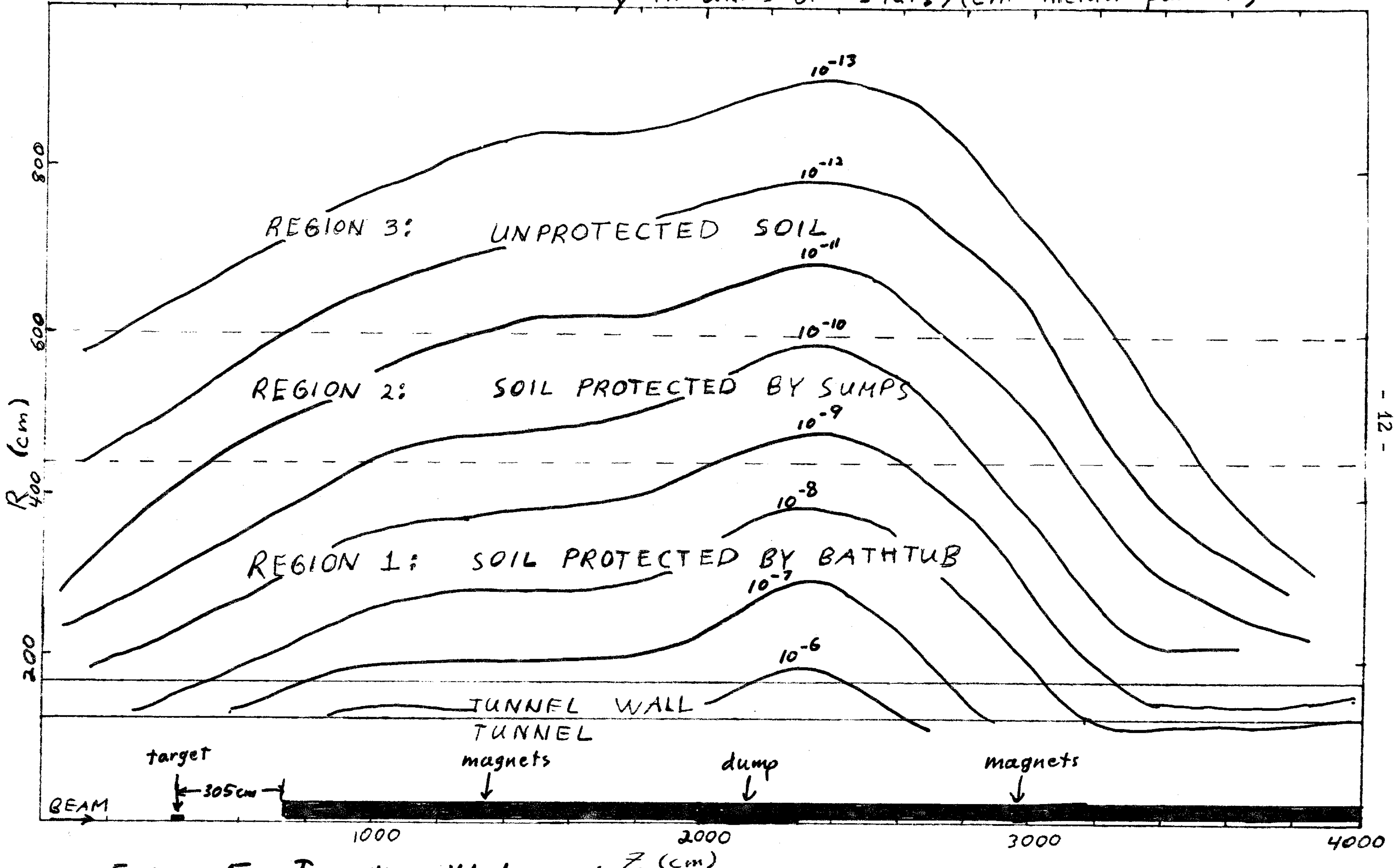

Figure 5 Target with dump downstream of one magnet string and upstream of another