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Radiation Safety Review of the Modified Enclosure 103

J. D. Cossairt

June 18, 1980

In the Neutrino Area, a new N3 beamline has been designed[1] which will move the primary target from Enclosure 100 to a new extension of the present Enclosure 103.[2] The purpose of this TM is to investigate both the external dose rate and soil activation in the vicinity of this enclosure using the Monte-Carlo code CASIM[3]. An appendix includes an evaluation of the labyrinths for the Modified Enclosure 103. The beam line primarily considered in the present TM is being designed for 400 GeV operation. A slightly different target location (most likely further downstream) is envisioned for 1000 GeV operation and is also considered in considerably less detail in the present report.

Figure 1 shows a cross-sectional view of the proposed Enclosure 103 extension at the location of the target. The enclosure will be surrounded by a layer of granular material in order to provide a well drained zone of at least 5 feet radial extent. The underdrains thus protect the aquifer from migration of radionuclides produced in this zone. In this enclosure a 30 cm Be target 1 inch in diameter is followed 2 feet downstream by an EPB dipole and a 2 ft x 2 ft x 10 ft Fe beam dump with a rectangular aperture to pass the secondary beam (2 feet separate the dipole and the dump). Fifty four feet downstream of the target, the secondary beam passes through a standard EPB quadrupole. The dipole is a vertical bend appropriately energized so that a 400 GeV/c singly charged positive particle is bent 3.4 mrad upward. The new N3 beam line is presently being designed to view the target at 0 mrad in the vertical plane and at 3 mrad in the horizontal plane[2,4] with a beam spot having a full width of no more than 2 mm. The calculations are rather insensitive to the exact details of the targeting conditions.

In the present calculation, a rectangular beam spot 2 mm x 2 mm was used. A 1 mm x 1 mm spot was tested with no significant effect upon the results. The targeting was modeled as specified above. The actual rectangular apertures of the dipole, quadrupole, and dump were used while, as a concession to computational efficiency, all other radial dimensions were modeled as cylinders having cross sectional areas equal to the actual rectangular objects encountered.

The dipole, dump, and a region up to 2 feet upstream of the target were modeled as being shielded by a cylinder of steel with 1 ft thick walls. Such a shield is presently available in the form of the "coffins" used to shield the existing target configuration in Enclosure 100. In the calculation, the effect of the magnetic field was included within the gap of the dipole, although no significant differences were observed with the field set to zero. Also, a lower momentum cutoff of 0.3 GeV/c was used. Because of the crucial nature of the small targeting angle coupled with the aperture for the secondary beam, multiple scattering and nuclear diffraction effects were included in the calculation.

The results of the calculation for various cases are shown in Figs 2-5 as contour plots of equal star density as a function of depth and radius. The nature of each case is identified in the figure caption. All material external to the enclosure is calculated as if it were concrete. The conversion of concrete to soil for purposes of estimating external dose rates can conveniently be done by scaling by the ratio of densities to get the star density at desired shielding thicknesses. The density of concrete is 2.4 g/cm^3 while the density of soil for such "berms" is 2.1 g/cm^3. In the first 3 cases, which are all done for 400 GeV incident protons, 2 random member seeds were used and the contour plots in Figs 2-4 were drawn as the average of the 2 independent sequences of random numbers while for the other case a single random number seed was used, since the 1000 GeV design is not, at present, as well developed as the 400 GeV design. In each of the figures the region which is drained by the sumps is indicated as well as the region of unprotected soil.

It is quite easy to obtain external dose equivalent rates from these contour plots. One only needs to use the conversion 1×10^{-5} rem/(star $\cdot$ cm^3) so that at the 10^{-12} stars/($cm^3 \cdot$proton) contour we have:

$$10^{-12} \frac{\text{stars}}{\text{cm}^3 \cdot \text{proton}} \times 10^{-5} \frac{\text{rem}}{\text{star} \cdot \text{cm}^3} \times 10^{12} \frac{\text{protons}}{\text{pulse}} = 0.01 \frac{\text{mrem}}{\text{pulse}}$$

or 3.6 mrem/hr at the normally expected intensity of 10^{12} protons/pulse at 400 GeV. The accident condition of 2.5×10^{13} protons/pulse would thus create one pulse accidents of 0.25 mrem. This contour, at the worst point, is achieved (see Figs 1-3) with approximately 450 cm (15 ft) of concrete shield or 514 cm (16.8 ft) of soil shield for the 400 GeV cases. In Fig 1 there is 475 cm of shielding at all points so that the shielding is adequate for 400 GeV. Dose rates at other locations can be obtained in like manner.

This target station is at very nearly the same elevation as that studied in TM 945.[5)] This implies that many of the quantities evaluated concerning the migration of the principal activation products (^3H and ^{22}Na) will be valid here. From Ref. 5 it follows that 2.286 x 10^{16} stars in unprotected soil produce 1 pCi/mℓ of ^3H in the ground water and similarly 5.56 x 10^{18} stars produce 1 pCi/mℓ of ^{22}Na in the ground water. Both of these concentrations are at an off-site well using the model of Ref. 6. In the present work it is assumed that this target will be bombarded 2000 hrs/yr at 10^{12} protons/pulse, 12 sec cycle time which results in 6 x 10^{17} protons/yr. The results are shown in Table 1 for the 2 regions where Region 1 is that protected by sumps while Region 2 is surrounding unprotected soil. As one can see, the 400 GeV cases are comfortably within the present Laboratory limits.[7)] The consequences of a failure of the sumps to protect Region 1 in terms of concentrations presented to an off-site well is also shown on this table.

Downstream of the modified Enclosure 103 it is proposed to install 9 ft (274 cm) of soil shielding (equivalent to 8 ft concrete) around the beam pipe. In order to roughly estimate the adequacy of this a comparison was made using the roughly equivalent target and dump in Enclosure 100. To do this copper foils were placed in the present N5 beam at the downstream end of Enclosure 100 and the upstream end of Enclosure 101. In this study the Enclosure 100 location is roughly equivalent to the downstream end of the proposed Enclosure 103 while the Enclosure 101 location is equivalent to the upstream end of Enclosure 105 after the modification. During the 1 week irradiation period, 2.6 x 10^{16} 350 GeV protons hit the primary target. The Enclosure 100 foil was hit by 2.6 x 10^{14} hadrons in an approximately 3" diameter spot while the Enclosure 101 foil was hit be 0.2 x 10^{14} hadrons in a 3" diameter sample.[8)] The falloff between Enclosure 100 an Enclosure 101 is approximately that expected from the solid angle relative to the target. The bending magnets, beam dump, and EPB quadrupole put rather stringent limits upon the angular deviation of the beam from the center line. The dump and the quadrupole put a limit of 3 mrad on this devation. Such a 3 inch diameter beam, aside from its obvious divergence measured in the foil activation measurement could be lost over a minimum longitudinal distance of 83 ft (or 2540 cm). Experience with CASIM in both the present work and otherwise indicated that losses in segments of iron about 10' long will roughly be independent of each other so that under normal conditions of 10^{12} protons per pulse one could expect a secondary beam of about 10^{10} positive hadrons/pulse (when tuned for positives) and of these under accident loss conditions one could lose roughly 10^9/10 foot length. This is similar to the case shown in Fig. VIII. 20 of Ref 9. At the 8' shielding radius (concrete equivalent) a star density of 3 x 10^{-8} stars/proton$\cdot$cm^3 is obtained. This would result in 0.3 mrem/10^9 particles lost in a 10 ft length. This estimate is extremely conservative (by at least a factor of 10) because it neglects the divergence of the beam (2 mrad) and the large beam pipe (the ability to lose the beam in this location). This location is thus adequately shielded.

I would like to thank S. Baker, L. Coulson, and D. Theriot for their help with this report.

References

1. A. Malensek, "New N3 Beamline Design", TM-940.

2. J. Peoples and D. Theriot, "Neutrino Improvements for 500 GeV Operation," TM-950A.

3. A. Van Ginneken, "CASIM, Program to Simulate Transput of Radronic Cascades in Bulk Matter," FN272.

4. A. Malensek, Private Communication.

5. J. D. Cossairt, "Soil Activation Calculations for the Proposed Neutrino Front Hall," TM 945.

6. P. J. Gollon, "Soil Activation Calculations for the Anti-Proton Target Area," TM816.

7. Memo from A. L. Read to Division/Department Heads, April 5, 1979.

8. Memo from S. I. Baker to S. Butala and J. Grobe on 5/29/80.

9. A. Van Ginneken & M. Awschalom, High Energy Particle Interactions in Large Targets.

Table 1

Case No.	Integral Stars/proton		Concentrations (pCi/mℓ) at offsite well			
			Region 1		Region 2	
	Region 1	Region 2	^{3}H	^{22}Na	^{3}H	^{22}Na
Case 1 Seed 1	7.62	0.25	200	0.82	6.56	0.027
Case 1 Seed 2	9.10	0.35	238	0.98	9.18	0.038
Case 2 Seed 1	6.53	0.21	171	0.70	5.51	0.022
Case 2 Seed 2	5.79	0.40	152	0.62	10.5	0.04
Case 3 Seed 1	5.59	0.20	146	0.60	5.25	0.02
Case 3 Seed 2	6.51	0.31	171	0.70	8.14	0.03
Case 4 Seed 1	13.03	0.93	341	1.41	24.4	0.10
Laboratory Limit	N/A	N/A	N/A	N/A	20	0.2

Seed #1 = 17176372113526410561_8

Seed #2 = 17174213574632152361_8

Figure Captions

1. Cross Sectional view of the proposed Enclosure 103 at the target.

2. Case 1: The dump has a 1" x 1" aperture. The steel shield extends upstream of the dipole with 1' thickness throughout. The target is bombarded by 400 GeV protons.

3. Case 2: Same as Case 1 except that a ½" x ½" aperture is used in the dump.

4. Case 3: Same as Case 2 except that the region upstream of the dipole is shielded with just 6" of steel.

5. Case 4: Same as Case 2 only for bombardment by 1000 GeV protons.

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Figure 1

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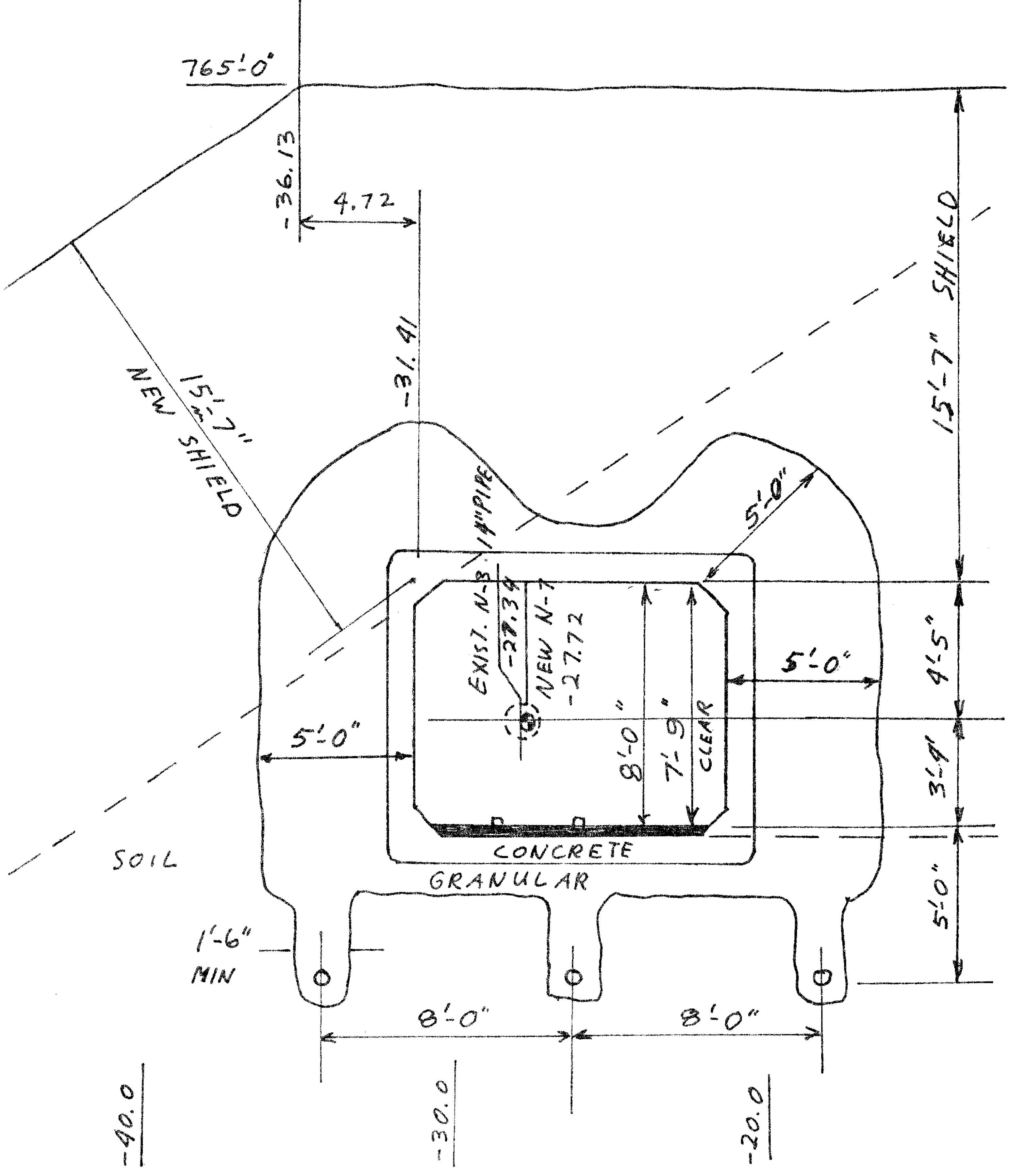
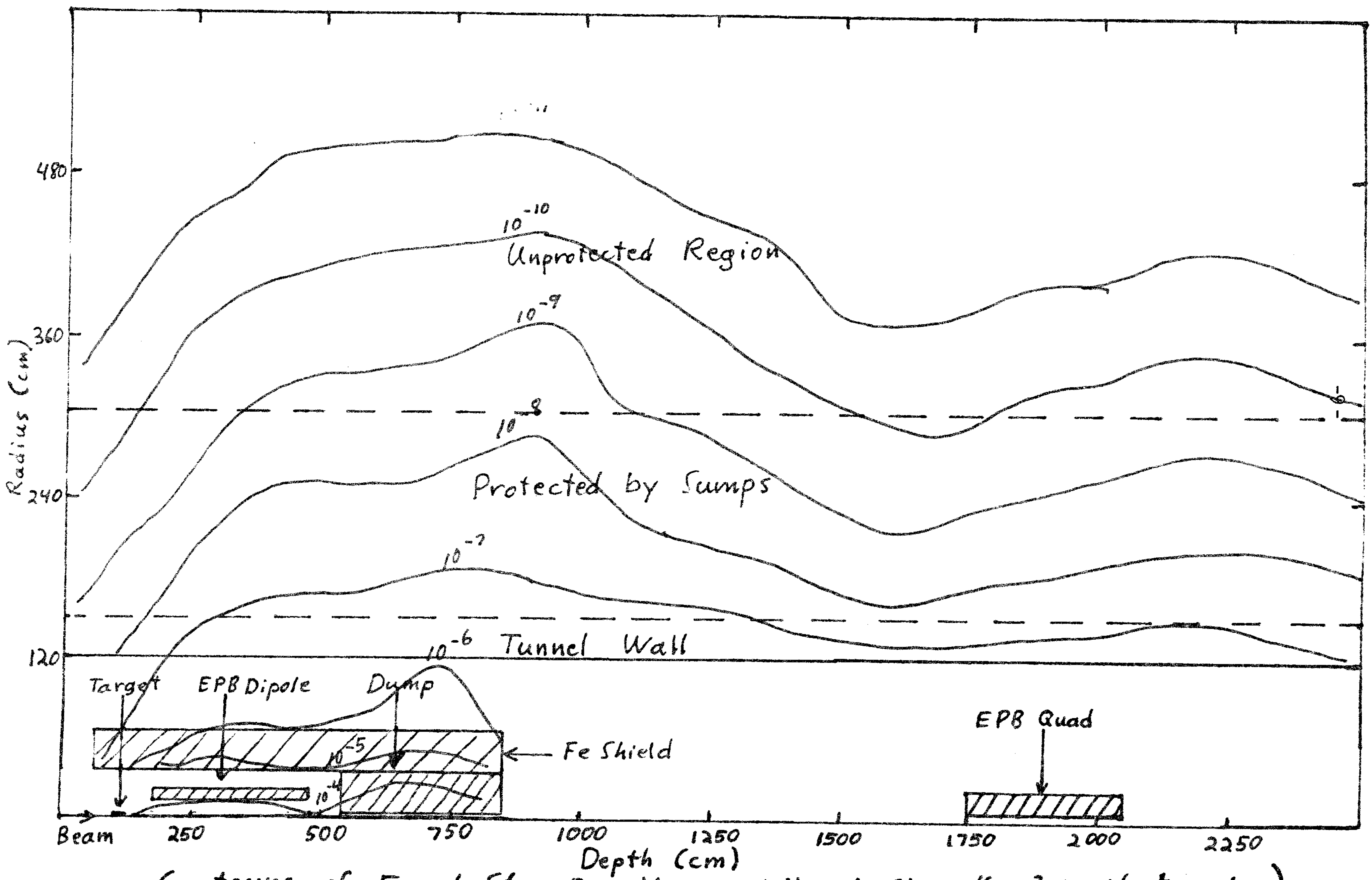
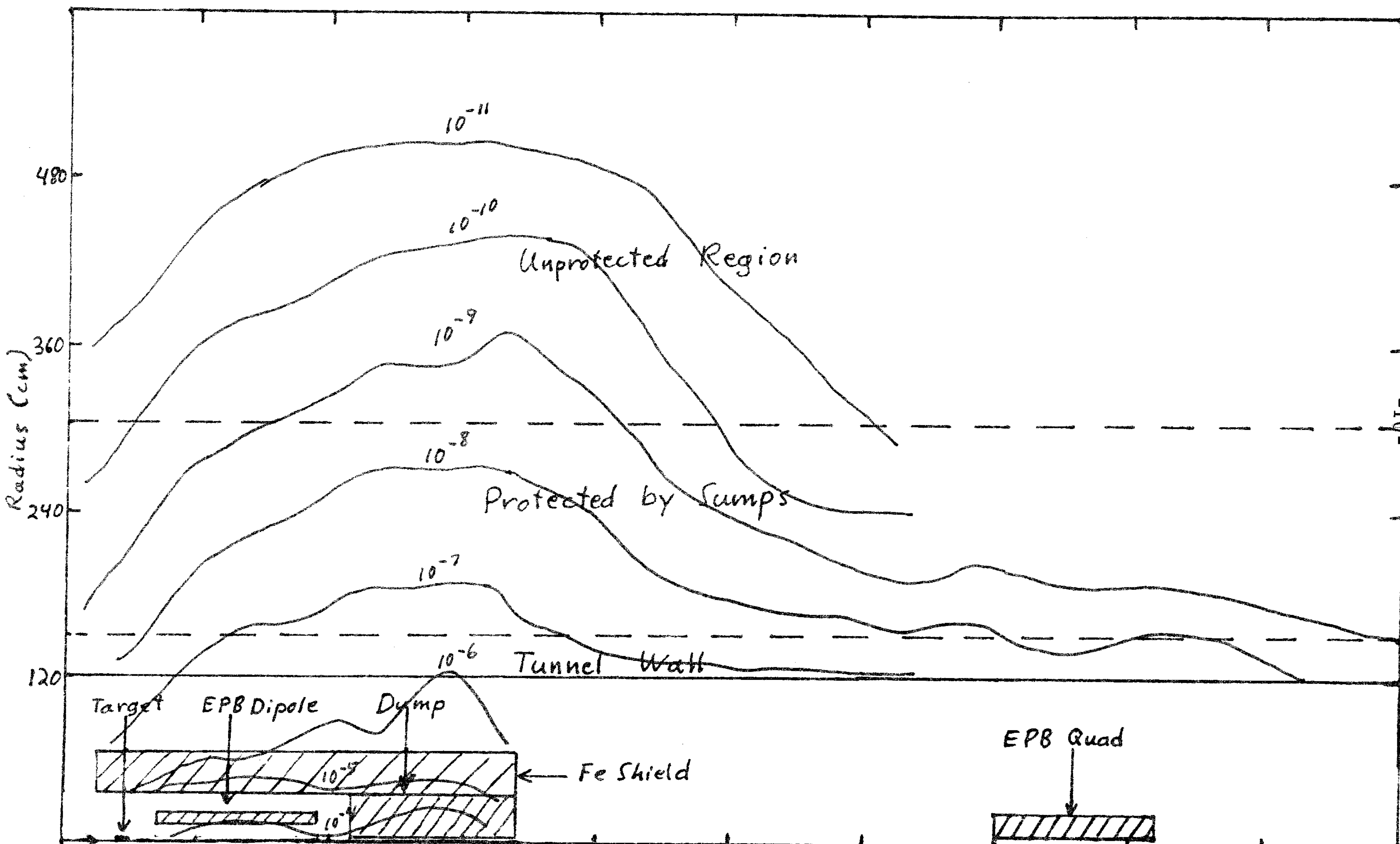
Wayne W. Nestander
5 June 80





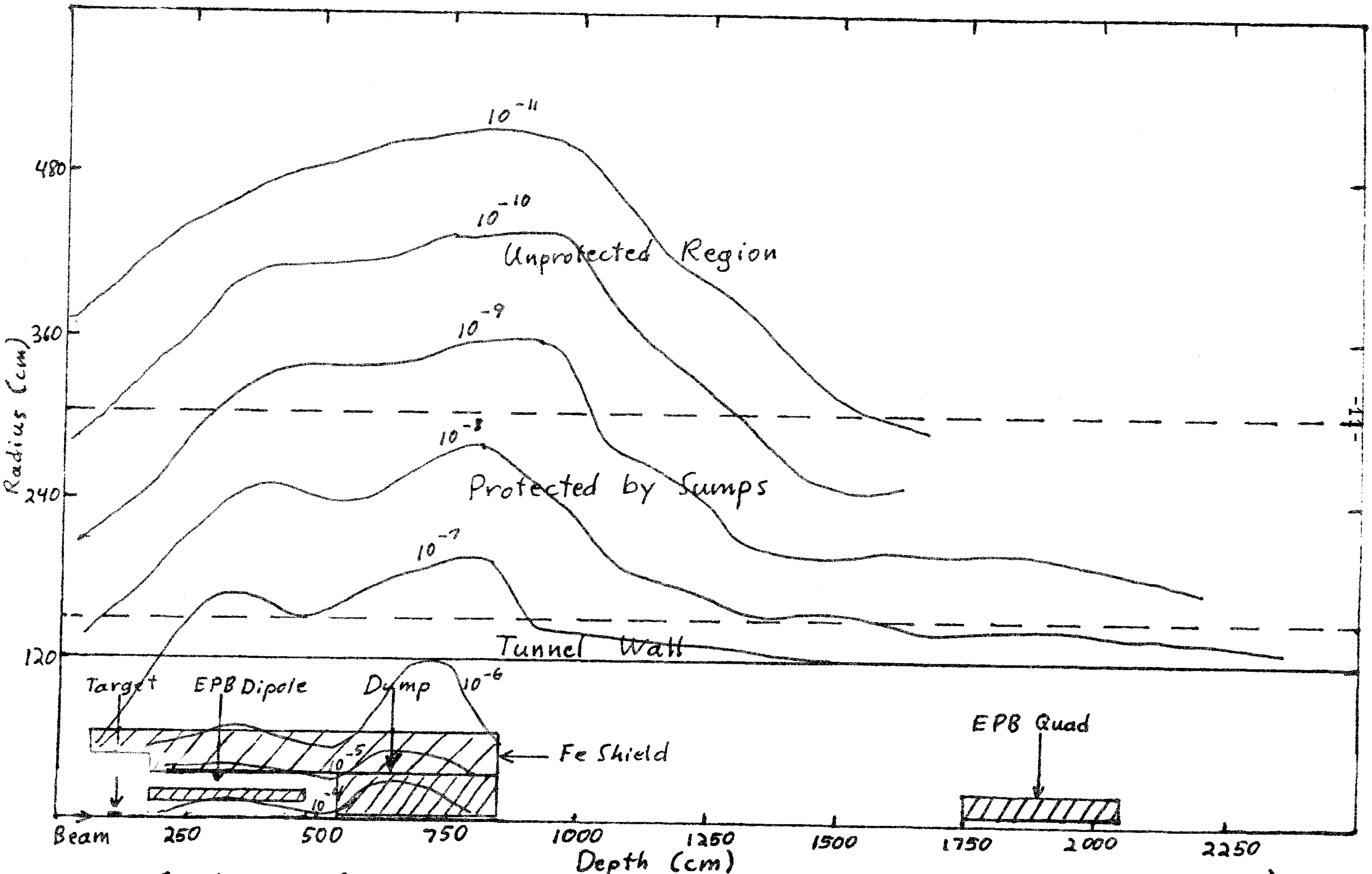
Contours of Equal Star Density in Units of Stars/(cm^3·incident proton)

Figure 2: Case 1 (E=400 GeV)



Contours of Equal Star Density in Units of Stars/(cm³·incident proton)

Figure 3: Case 2 (E = 400 GeV)



Contours of Equal Star Density in Units of Stars/(cm³·incident proton)

Figure 4: Case 3 (E=400 GeV)

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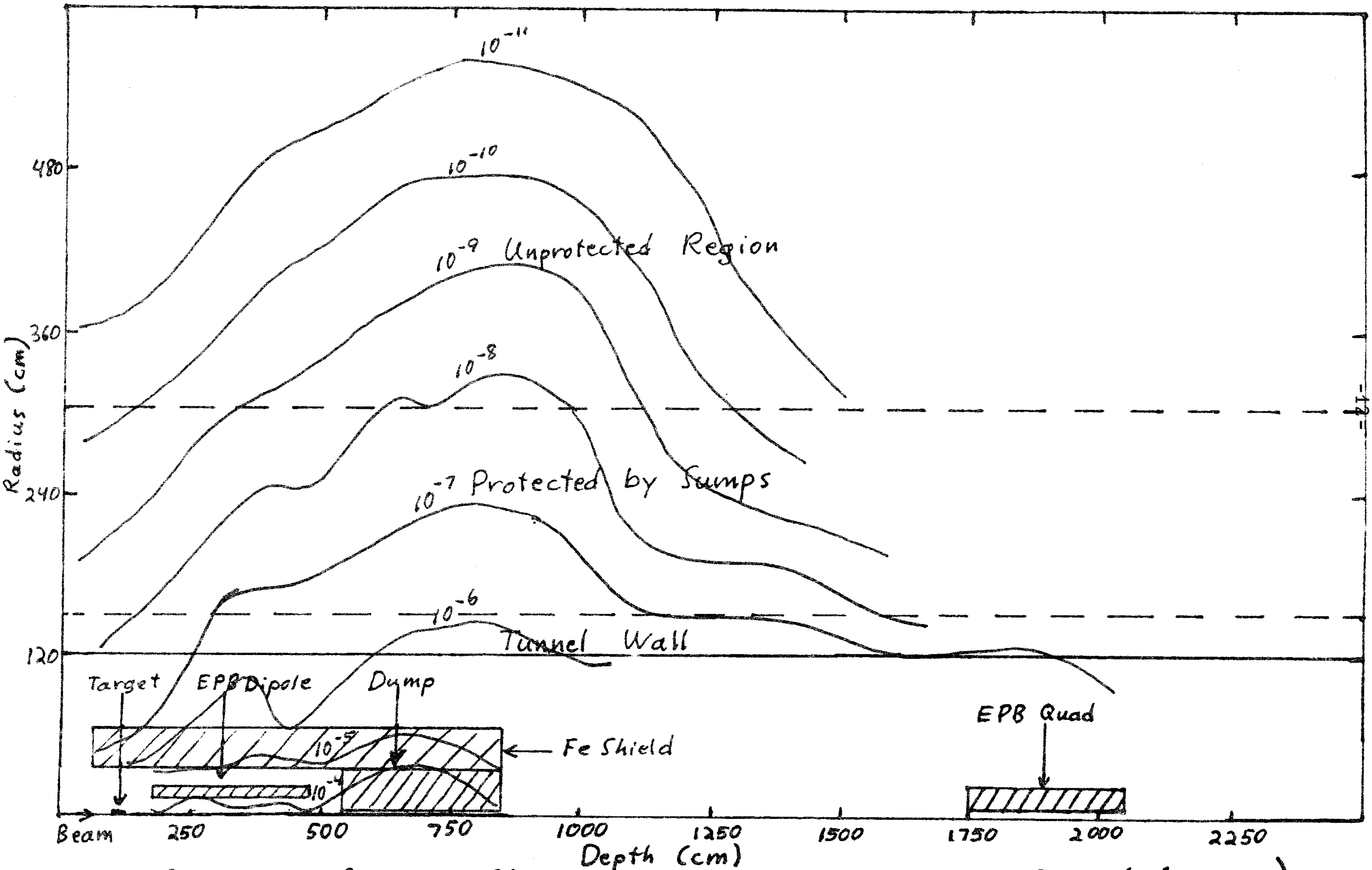

Contours of Equal Star Density in Units of Stars/(cm^3·incident proton)
Figure 5: Case 4 (E=1000 GeV)

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May 21, 1980

To: J. Grobe

From: D. Cossairt

Subject: Enclosure 103 Labyrinth Calculations

This memo follows the method used in my memos of 4/22/80 and 5/19/80 and uses the same reference for the labyrinths shown on the attached drawings as discussed with W. Nestander yesterday. Please note that I have shown the shield car installed on the downstream one and concrete shielding in the upstream one.

First consider the downstream one:

The mouth is 12' (366 cm) from the nearest beam center line making (at 400 GeV) the dose/2.5×10^{13} protons at that location:

$$\frac{2.5 \times 10^{13} \times 400}{4\pi\ (366)^2 \times 3 \times 10^7} = 198 \text{ rem}$$

In what follows, a "unit" is the square root of the cross section of the passageway. Using the references, quoted in the previous memos one can construct the following table at the end of each leg. The source is considered to be a point source, which represents the worst case situation. The slight vertical rise has been neglected here.

Location	Cross Section (ft x ft)	Length of leg in units	Attenuation of dose at mouth	Dose $\left(\frac{\text{mrem}}{2.5 \times 10^{13}}\right)$
mouth	---------	-----------	---------	198000
end of leg 1	6.2 x 8	4.3	0.04	7900
end of leg 2	3.5 x 7	4.4	8.0×10^{-5}	15.8
end of leg 3	3.5 x 7	3.7	8×10^{-8}	0.016

References: 1. P. J. Gollon & M. Awschalom, CERN 71-16, Vol 2, p 267.

2. P. Ruffin and C. Moore, Radiation Physics Note #9.

To get dose equivalent rates at 1% loss, 10 sec cycle, multiply the right hand column by 3.6. We thus see the labyrinth is quite adequate. Now considering the "straight - through" dose at the end of leg 1, the 12' of concrete in the shield car is worth a factor of 10^4, reducing the 7900 mrem/pulse to 0.79 mrem/2.5×10^{13}. Thus, this too is adequate.

Now considering the upstream labyrinth. In this case the mouth is only 6' (183 cm) from the nearest possible loss point and hence the dose/2.5×10^{13} protons at the mouth is:

$$\frac{2.5 \times 10^{13} \times 400}{4\pi\ (182)^2 \times 3 \times 10^7} = 792 \text{ rem}$$

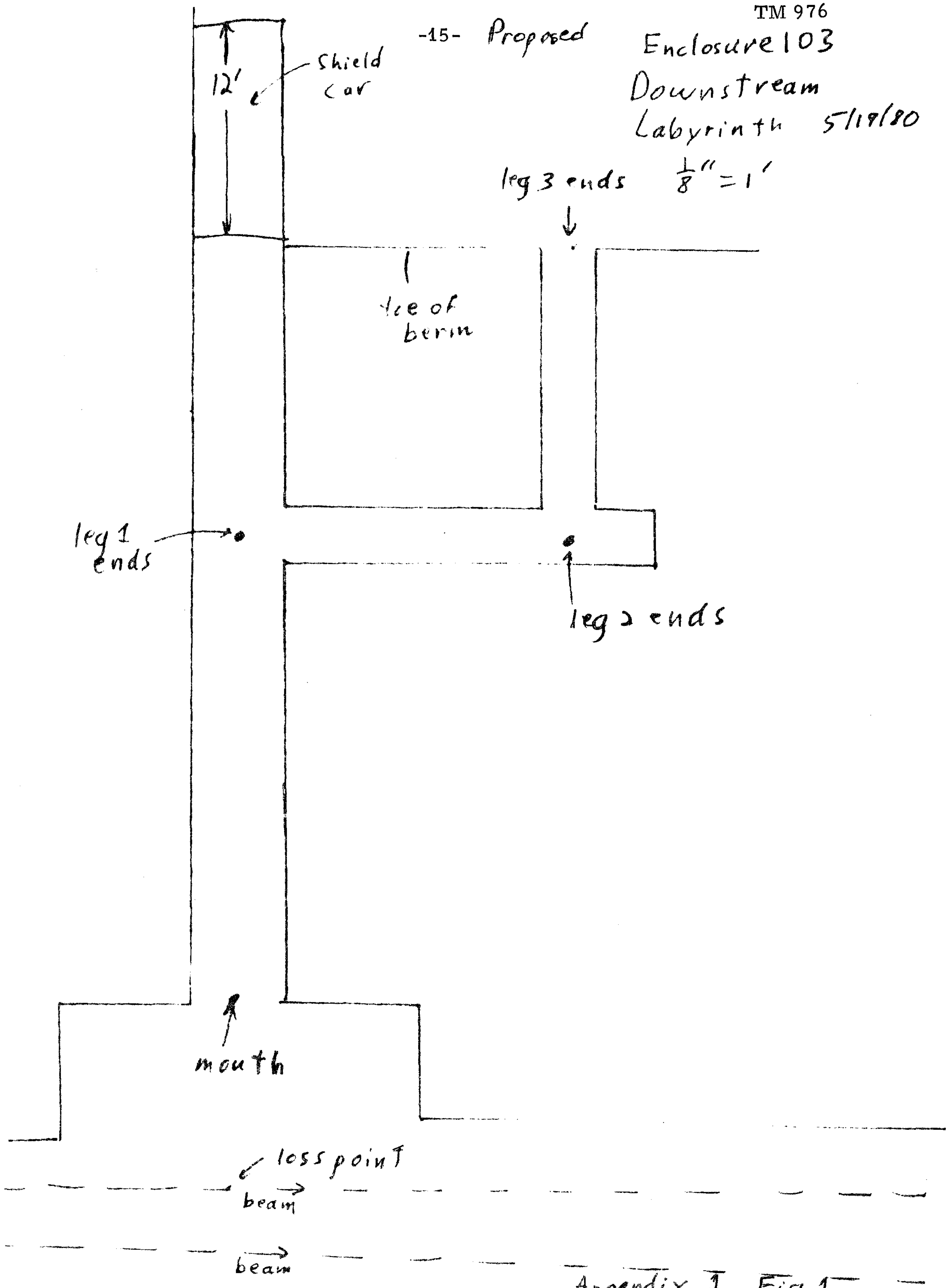
Again constructing a table:

Location	Cross Section (ft x ft)	Length of leg in units	Attenuation of dose at mouth	Dose $\left(\frac{\text{Mrem}}{2.5 \times 10^{13}}\right)$
mouth	------	------	-----	792000
end of leg 1	3 x 8	1.5	0.4	317000
end of leg 2	3 x 8	6.6	0.07	55400
end of leg 2	2 parts 3 x 8 then 6 x 8	6.6	3.5×10^{-5}	28
end of leg 4	3 x 8	2.1	8.8×10^{-6}	6.9
end of leg 5	3 x 8	0.7	1.1×10^{-6}	0.87

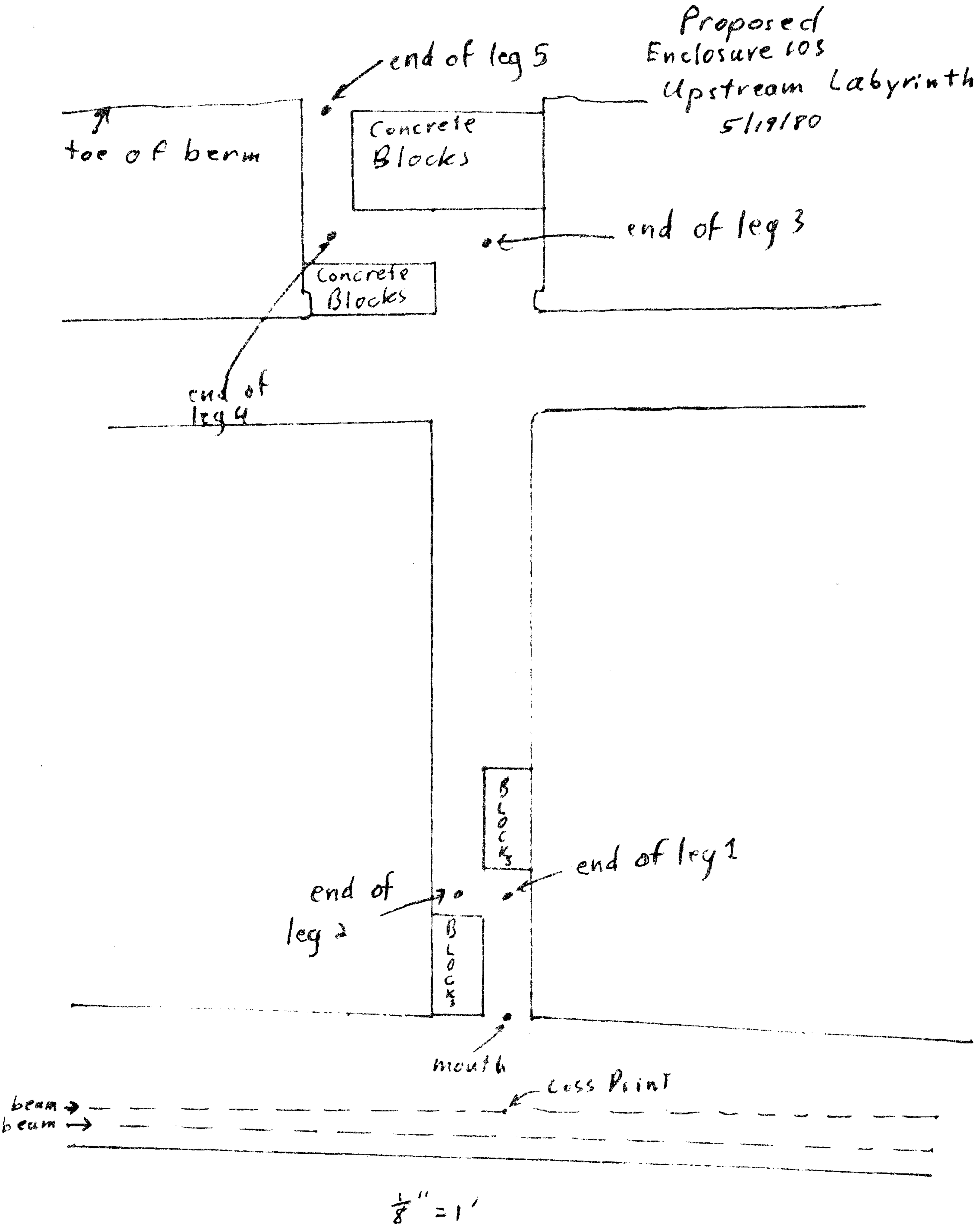
Again, the "straight through" dose must be considered. In all cases, the outside world is shielded by 12' of concrete. A straight leg without the blocks installed to form legs 1 and 2 would give a reduction factor of 0.03 or 24 rem/pulse at location designated "end of leg 3" on the drawing. However, 12' of concrete in the path would reduce this to at worst 2.4 mrem/pulse. However, it will be much (probably a factor of 5 or so) lower because of scatter into the berm in the gap between the 2 halves of the shield and spectrum softening in the gap. This labyrinth is thus also adequate. The roof of outer 2 legs of this labyrinth should be shielded by 6' of concrete (see 5/19/80 memo). The extra blocks near the mouth should overlap by several inches to prevent a problem with any crack.

DC/cm

cc: L. Coulson
S. Butala
D. Theriot
File



Appendix I Fig. 1



Appendix 1 Fig 2