R. P. Note No. 74

Shielding for the Loma Linda Accelerator in IB1 - Experimental Area

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I. Introduction

Following the methods outlined in R. P. Note 71, calculations were done to specify the required shielding for the experimental area of the Loma Linda accelerator in IB1.

II. Description of Experimental Area

The experimental area is located to the west of the accelerator, immediately outside of the IB1 building. It consists of a single horizontal beam line approximately three feet above ground and 26 feet in length surrounded by concrete shielding. Beam is extracted at a 10^0 downward angle from the accelerator then bent upward through a 20^0 angle after clearing the downstream dipole magnets in the northwest quadrant of the accelerator. The beam is then brought back to the horizontal by a 10^0 downward bend just outside the IB1 west wall. There is a 20 foot long section of beam line after the last quadrupole magnet. This space will be fitted with various detectors, collimators, and beam diagnostic equipment under development. A beam stop/target will be installed at the end of this beam line. Thick targets of various materials (e. g. graphite, aluminum, iron, copper) will be inserted at the target position, and the dose attenuation will be measured at several depths in the concrete shielding. The measurements will be made at three angles (0^0, 45^0, 90^0) by inserting detectors into vertical holes created in the shielding. Concrete plugs will be inserted into the unused holes to prevent neutrons streaming out, and to provide solid shielding in front of and behind the detectors.

If the 20^0 bend magnet is turned off, then the extracted beam continues downward at a 10^0 angle through the footing of the building into a graphite beam stop. The beam stop will be about1.5 feet below grade in the parking lot area. It will be long enough to stop 250 MeV protons. Note that no special precautions for cooling the dump or targets are required since the average beam power is only 1 watt (2.5×10^{10} protons/sec at 250 MeV).

For initial running, the shielding configuration will be simplified. In the initial arrangement there will be a simple shield downstream of the beam stop, without the provisions for the more elaborate shielding experiment.

III. Results

Dose Rates - Initial Configuration

Figures 1 through 4 show different views of the initial shielding configuration, together with calculated dose rates at various locations outside the shield. Losses are assumed to occur only in the beam dump, located 1.5 feet below grade. For comparison, dose rates are shown for both 150 MeV and 250 Mev operation. In both cases the dose rates are calculated based on an assumed interaction rate of 2.5×10^{10} protons per second. Dose rates outside the shield are everywhere less than 2.7 mrem per hour so that the area will not be considered a radiation area. Note that these results are affected by the depth of the dump, since the additional transverse shielding that results from being below grade is considered in the calculations. A significantly shallower dump will result in higher dose rates and probably require additional shielding. For simplicity, the effect of the 10^{0} downward angle of the beam was not considered. Including this would result in *lower* dose rates in the forward direction due to the strong angular dependence of the dose rate.

I recommend that a minimum of 6 feet of shielding block be installed in the transverse direction (side walls and roof) and 7.5 feet in the end wall region as shown in figures 1 through 4. Note that I have not considered in these calculations the presence of any local steel shielding over the dump. The inclusion of such a cover would be one option if dose rate prove higher than anticipated.

Dose Rates - Shielding Experiment Configuration

Figures 5 through 7 show dose rates calculated in the same way as discussed above. In this case, the dump/target is nominally three feet *above* grade, and no benefit is derived from earth shielding. Therefore, the calculated dose rates are higher and substantial additional shielding is required.

Dose rates for 250 and 150 MeV operation are shown. For both energies, the interaction rate in the target is assumed to be 2.5×10^{10} per second. For dose rates resulting from losses on the upstream beam line elements, the assumed loss rate is 2.5×10^{8} protons per second (1% of full intensity). The loss points for each calculated dose rate are illustrated by the tails of the arrows in the Figures.

Note the strong energy dependence of the dose rates. For operation at 150 MeV, for example, the shielding as currently configured (12 feet in the end wall, 6 feet in the transverse direction) would result in a maximum dose rate immediately outside the shield of about 0.9 mrem per hour. On the other hand, at 250 MeV dose rates will be about ten times higher. A particular problem area is near the northwest corner opposite the entrance to the trailers where dose rates could approach 10 mrem per hour at 250 MeV. Some additional shielding will probably be required here in order to reduce rates in the trailer to less than 0.25 mrem per hour when operating near maximum energy. In addition, there may be small areas on the roof on the enclosure with dose rates of about 6 mrem per hour. This will require posting with radiation area signs. Small areas in the forward direction may also require signs and ropes when operating at maximum energy since dose rates there will be over 2.5 mrem per hour.

In general a minimum of 15 feet in the end wall area and 9 feet in the transverse direction would be needed for operation at maximum energy and intensity in order to reduce dose rates everywhere to less than 2.5 mrem per hour. Thinner shields can be accomodated if running at lower energy or intensity. Alternatively, additional barriers (rope, fences) can be placed outside the shield at appropriate distances if dose rates are too high adjacent to the shield. The only potential problem area is the trailers, which are not minimally occupied and must therefore be below 0.25 mrem per hour. Adding shielding along the north wall in this area may obstruct access to the pathway between the trailers and the wall and make use of the south trailer entrance impossible.

Doses in the Backward Direction

There is little shielding in the far backward direction, other than the 1 to 2 foot thick concrete west wall of the IB1 building. In addition, this wall does not completely fill the opening from the experimental area back into the accelerator. It is useful to calculate expected dose rates in the backward direction in order to obtain some estimate of shielding requirements. Unfortunately, the SAIC calcualtions on which the dose rate calulations are based only describe dose attenuation *averaged* over the backward hemisphere. This average value represents the dose at 120^{0}, which is somewhat forward of the angles that are relevant in the IB1 case. Thus it should be considered only an upper limit on the dose. To estimate the dose, I assume the arrangement shown in figure 8. I assume a 2 foot thick shield located at an angle of 120^{0} and a distance of 10 feet. This distance corresponds to the distance from the dump to the IB1 West wall. The calculated dose rate outside the shield is 15.3 mrem per hour for an assumed loss of 2.5×10^{10} protons per second at 250 MeV.

An important consideration is whether there is a direct line of sight from the mezzanine over the east accelerator shield wall along the extraction beam line into the experimental area. The geometry is shown in figure 9. A line projected from the beam dump over the 12 foot high east accelerator shield wall strikes the mezzanine at an elevation of 21.5 feet above the main floor. The angle is about 161^0, considerably larger than the 120^0 assumed in the dose rate calculation. Assuming this direct line of site (looking through the 2 foot thick west wall of IB1) gives a dose rate of

$$15.3 \text{ mrem/hour} * (10'/73.7')^2 = 0.29 \text{ mrem/hr}$$

at the mezzanine (assumming r^{-2} scaling). The rapid decrease in dose rate with increasing angle means that the mezzanine dose rate will almost certainly be less than 0.25 mrem per hour from losses on the below ground beam dump, provided at least two feet of shielding is present in the backward direction. It would be advisable to add at least this amount across the full opening. Alternatively, a steel or concrete cover (at least 0.5 feet thick if steel, 2 feet if concrete) over the dump might be a more efficient way to reduce the dose, but it would have to extend rather far upstream in oreder to intercept the line of sight.

Losses at the target position present a slightly different situation, since the line-of-sight angle is much shallower due to the longer distance and higher elevation of the target. Using the same procedure as for the dump calculation, the line-of-sight strikes the mezzanine at an elevation of 16.7 feet above the floor and in this case passes *over* the the concrete west wall of IB1 (see figure 10). This makes a dose estimate difficult but it seems likely that dose rates will be higher than for the beam dump case. There are two competing factors that affect the dose in this case - (1) the target is farther away from the mezzanine than in the beam dump case (2) there is essentially no shielding along the line of sight. The additional distance from the mezzanine results in only a factor of 0.7 reduction in the dose compared to the beam dump case, assumming a r^{-2} dependence. A two foot thick wall provides an attenuation factor of about 0.15 in the backward hemisphere so it seems likely that the increase in dose rate with no shielding will be at least a factor of 0.7/0.15=4.7 as compared to the dump case. The is would give a dose rate of about 1.4 mrem per hour at the mezzanine. Note that a significantly higher dose than this could occur since the SAIC calculations neglected lower energy neutrons (E_n<20MeV). These cannot be neglected for the case where no shielding is present.

If the mezzanine is not a minimally occuppied area then additional shielding of the opening is required to reduce the dose to less than 0.25 mrem per hour for operation at 250 MeV. A two foot thick shield wall (or extension of the existing IB1 wall to fill the opening) would be sufficient. As an alternative, lowering the ceiling height from 9 feet to 6 feet at the upstream end of the experimental enclosure would eliminate the line-of-sight to the mezzanine although it would still leave a small (~1 foot) gap at the IB1 window level which could result in some neutrons entering the accelerator area.

IV. Summary

- The initial shielding configuration (for the dump) is sufficient to keep the dose rates less than 2.5 mrem per hour at the highest beam energy and intensity, provided that the dump is at least 1.5 feet below grade. Six feet of shielding for the side walls and roof and 7.5 feet for the end walls should be adequate.

- The dose rates outside the experimental area when in the "shielding experiment" configuration are strongly dependent on the beam energy. For operation near 250 MeV and 2.5×10^{10} protons per second, dose rates along the north wall may approach 10 mrem per hour unless additional shielding can be installed. The dose rates are expected to be less than 2.5 mrem per hour everywhere else, except for two very localized regions along the end wall and a small area on the roof.

- It would be advisable to fill as completely as possible the opening between the accelerator enclosure and the experimental area to reduce the dose rate at the mezzanine to less than 0.25 mrem per hour. A total of two feet of concrete (including the existing IB1 west wall) should be adequate. An alternative is to lower the ceiling height at the upstream end of the beamline from nine feet to six feet to remove the direct line of sight. This will still leave about a one foot opening which may allow "backstreaming" of neutrons into IB1.

Figure Captions

1. Plan view of dose rates for 150 MeV operation in initial shielding configuration. Beam delivered to below-grade dump. Intensity is $2.5x10^{10}$ protons per second.

2. Plan view of dose rates for 250 MeV operation in initial shielding configuration. Beam delivered to below-grade dump. Intensity is $2.5x10^{10}$ protons per second.

3. Elevation view (looking south) of dose rates for 150 MeV and 250 MeV operation in initial shielding configuration. Beam delivered to below-grade dump. Intensity is $2.5x10^{10}$ protons per second.

4. Elevation view (looking east) of dose rates for 150 MeV and 250 MeV operation in initial shielding configuration. Beam delivered to below-grade dump. Intensity is $2.5x10^{10}$ protons per second.

5. Plan view of dose rates for 150 MeV operation in "shielding experiment" configuration. Beam delivered to target located three feet above grade. Intensity is $2.5x10^{10}$ protons per second for losses on the target and $2.5x10^{8}$ protons per second for losses on the upstream beamlines elements.

6. Plan view of dose rates for 250 MeV operation in "shielding experiment" configuration. Beam delivered to target located three feet above grade. Intensity is $2.5x10^{10}$ protons per second for losses on the target and $2.5x10^{8}$ protons per second for losses on the upstream beamlines elements.

7. Elevation view (looking south) of dose rates over the target for 150 and 250 MeV operation. Dose rates are given assumming 3 feet and 6 feet of roof shielding.

8. Idealized geometry for calculating doses in the backward direction from losses on the beam dump. A 2 foot thick wall at a distance of 10 feet is assumed. The effective angle relative to the incident beam is 120^{o} in this figure. The angle in the true shielding arrangement is larger, resulting in a lower dose rate.

9. Elevation view (looking south) of the line-of-sight from the beam dump to the mezzanine area in IB1.

10. Elevation view (looking south) of the line-of-sight from the target to the mezzanine area in IB1.

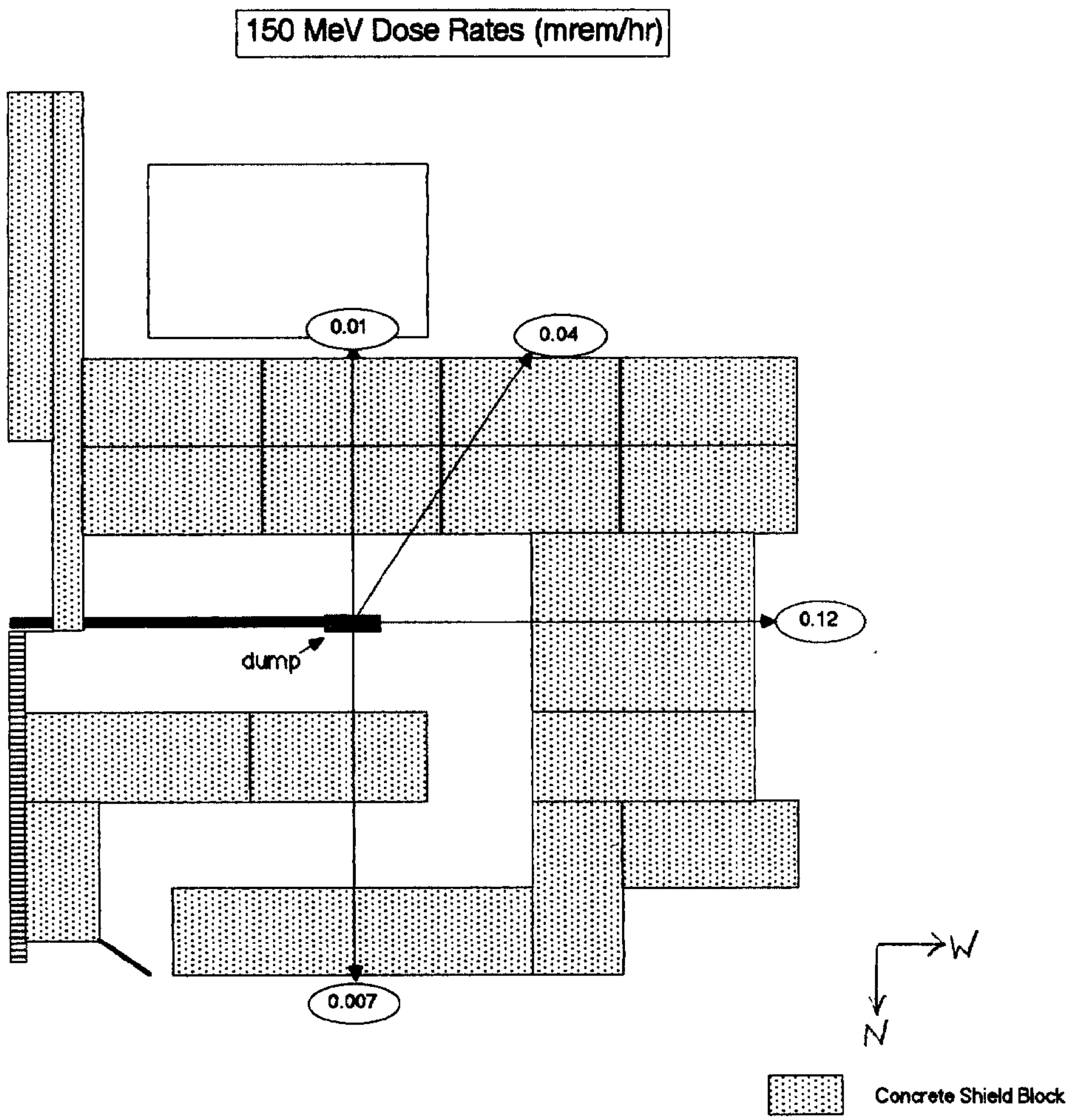
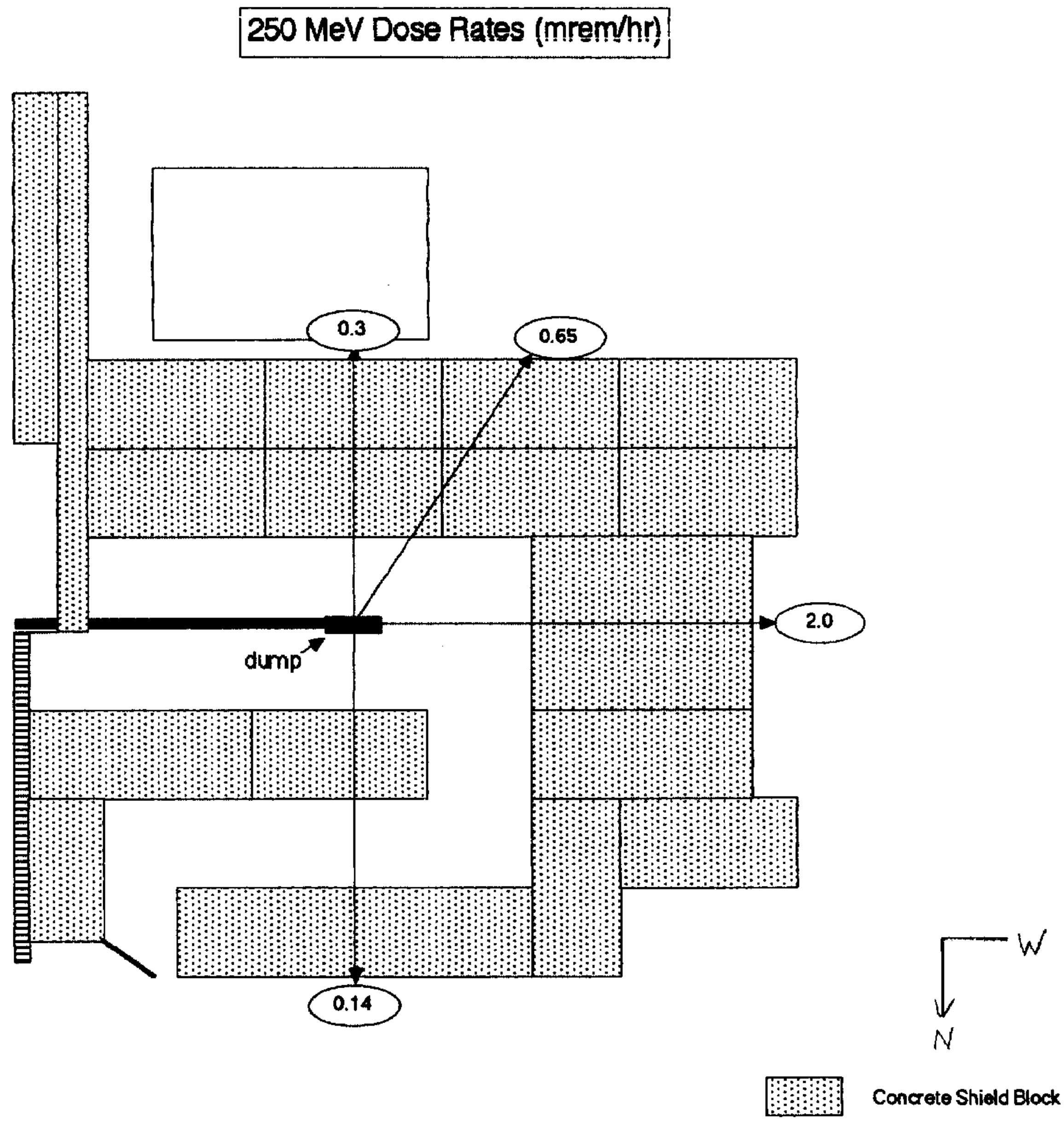
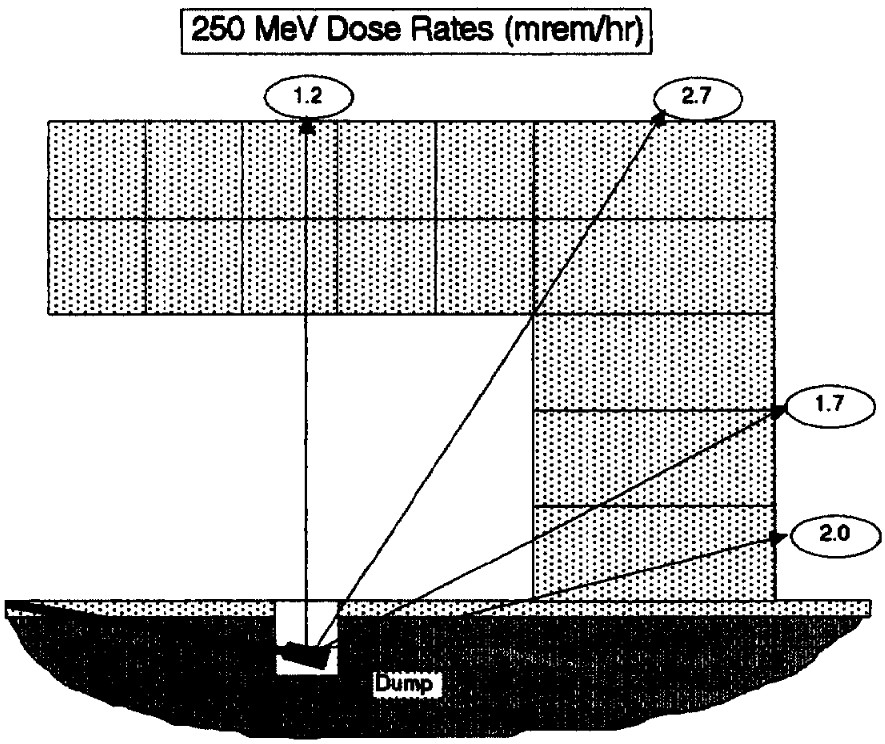

150 MeV Dose Rates (mrem/hr)
0.01
0.04
0.12
dump
0.007
W
N
Concrete Shield Block

Figure 1



250 MeV Dose Rates (mrem/hr)
0.3
0.65
2.0
dump
0.14
W
N
Concrete Shield Block

Figure 2


250 MeV Dose Rates (mrem/hr)
1.2
2.7
1.7
2.0
Dump

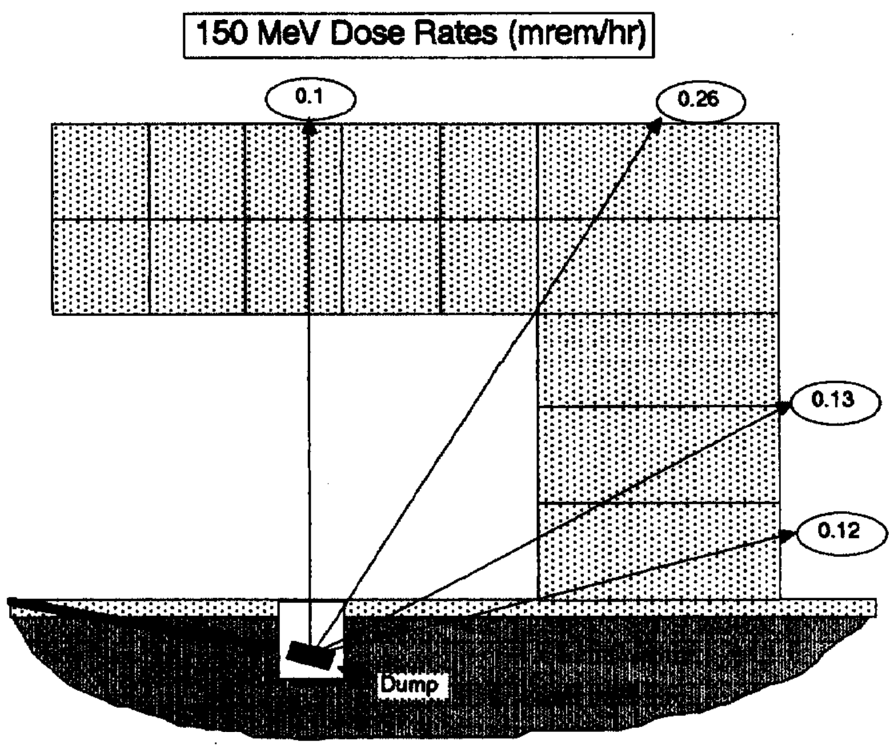
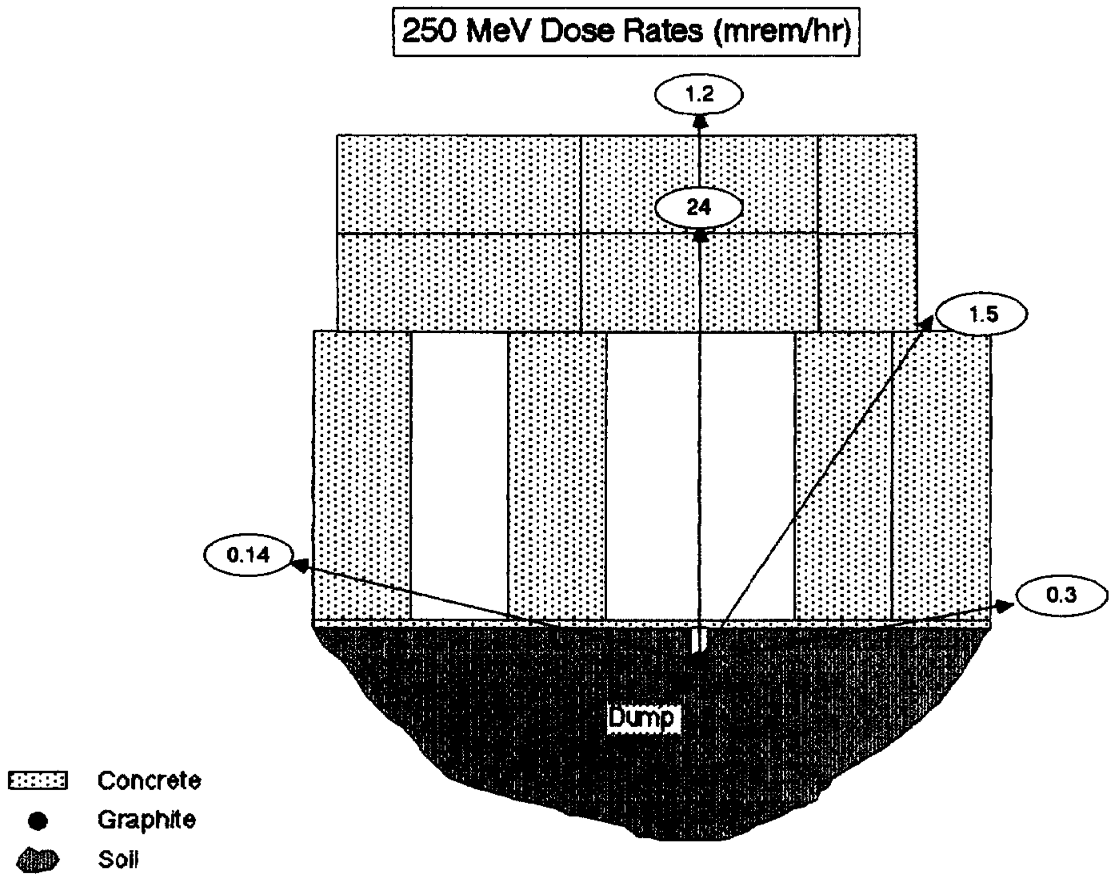

150 MeV Dose Rates (mrem/hr)
0.1
0.26
0.13
0.12
Dump

Figure 3


250 MeV Dose Rates (mrem/hr)
1.2
24
1.5
0.14
0.3
Dump
Concrete
Graphite
Soil

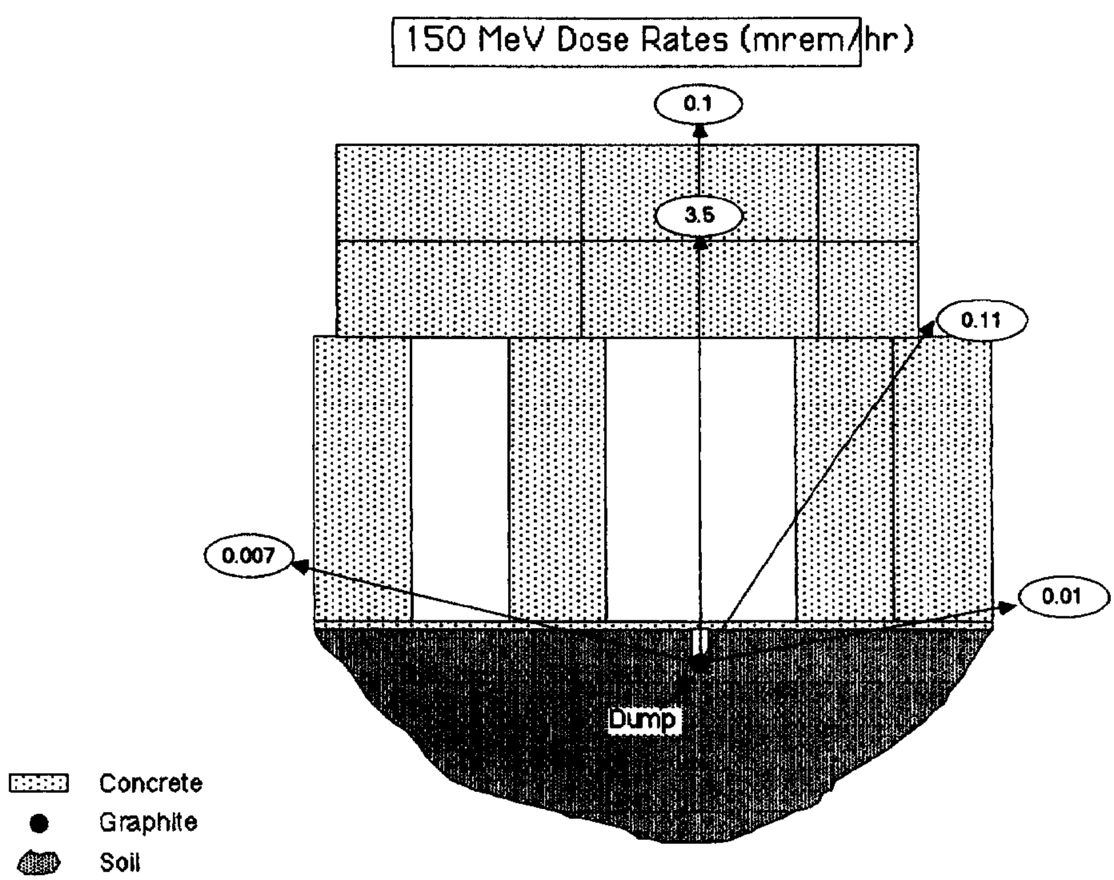

150 MeV Dose Rates (mrem/hr)
0.1
3.5
0.11
0.007
0.01
Dump
Concrete
Graphite
Soil

Figure 4

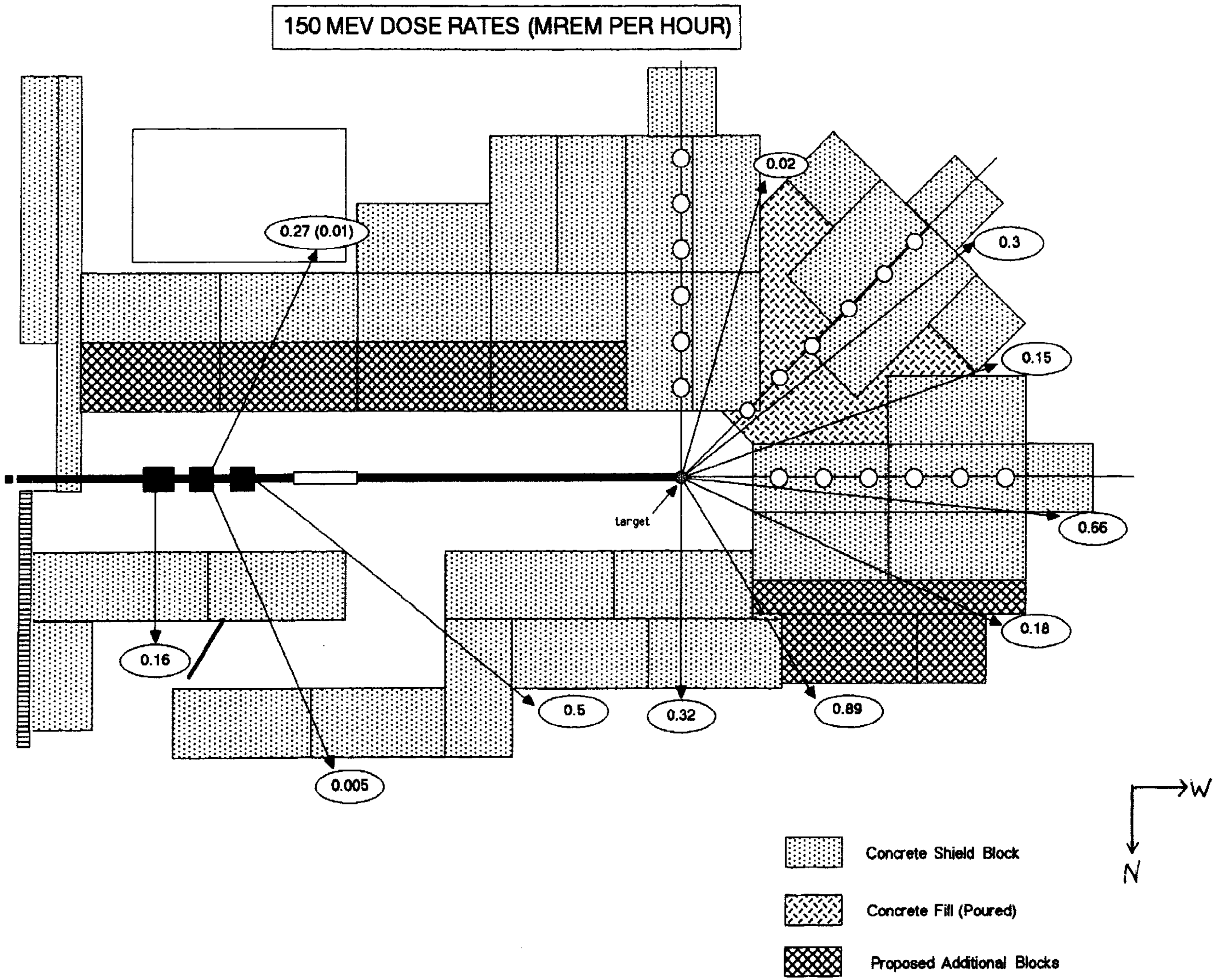

150 MEV DOSE RATES (MREM PER HOUR)
0.02
0.3
0.15
0.27 (0.01)
target
0.66
0.18
0.16
0.5
0.32
0.89
0.005
W
N
Concrete Shield Block
Concrete Fill (Poured)
Proposed Additional Blocks

Figure 5

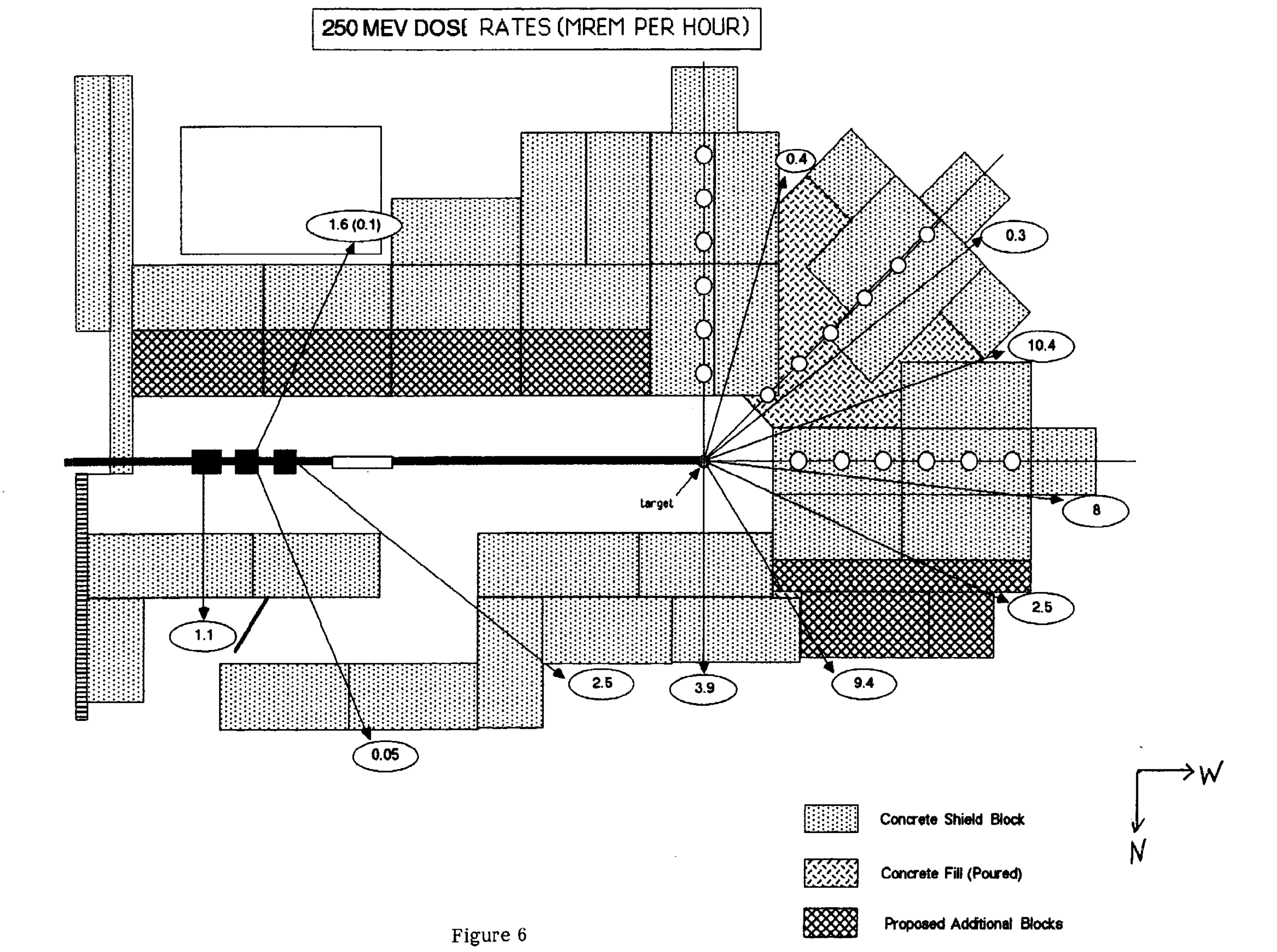

250 MEV DOSI RATES (MREM PER HOUR)
0.4
0.3
1.6 (0.1)
10.4
target
8
1.1
2.5
3.9
9.4
2.5
0.05
W
N
Concrete Shield Block
Concrete Fill (Poured)
Proposed Additional Blocks

Figure 6

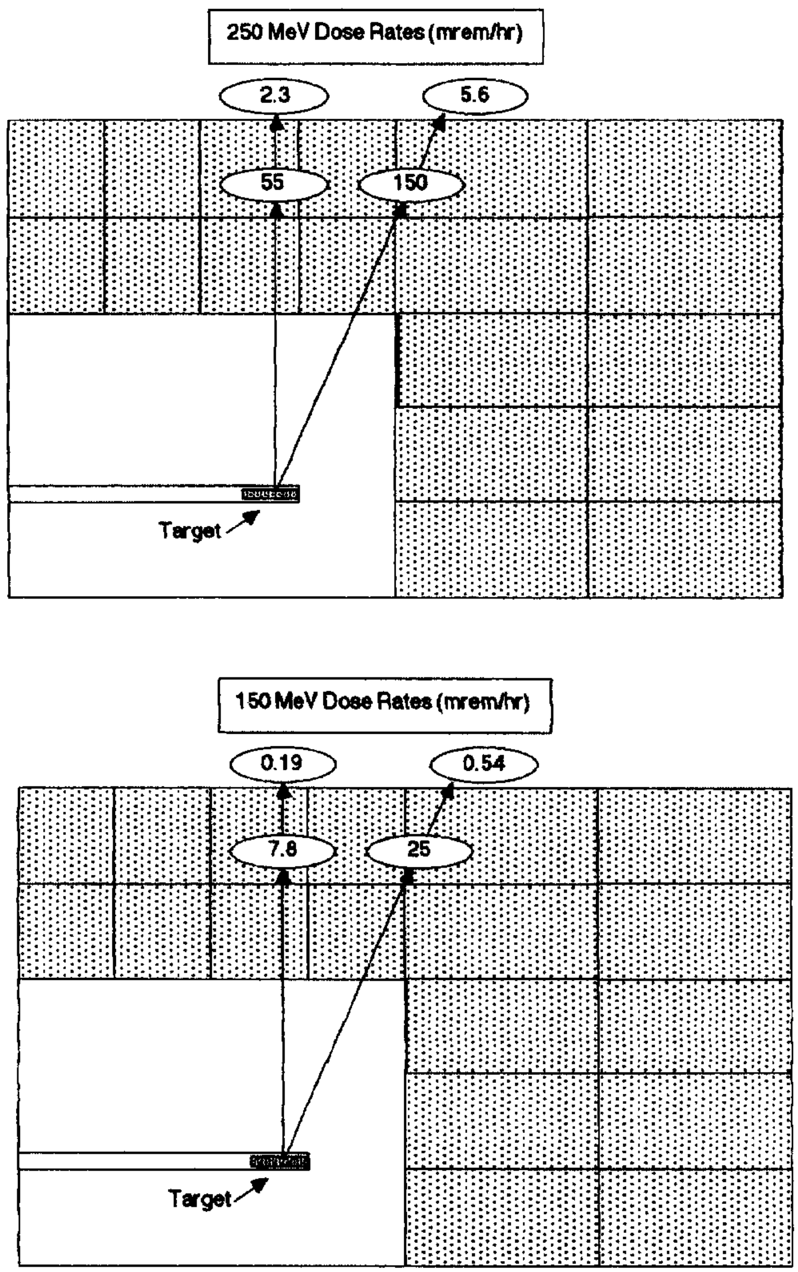

250 MeV Dose Rates (mrem/hr)
2.3
5.6
55
150
Target
150 MeV Dose Rates (mrem/hr)
0.19
0.54
7.8
25
Target

Figure 7

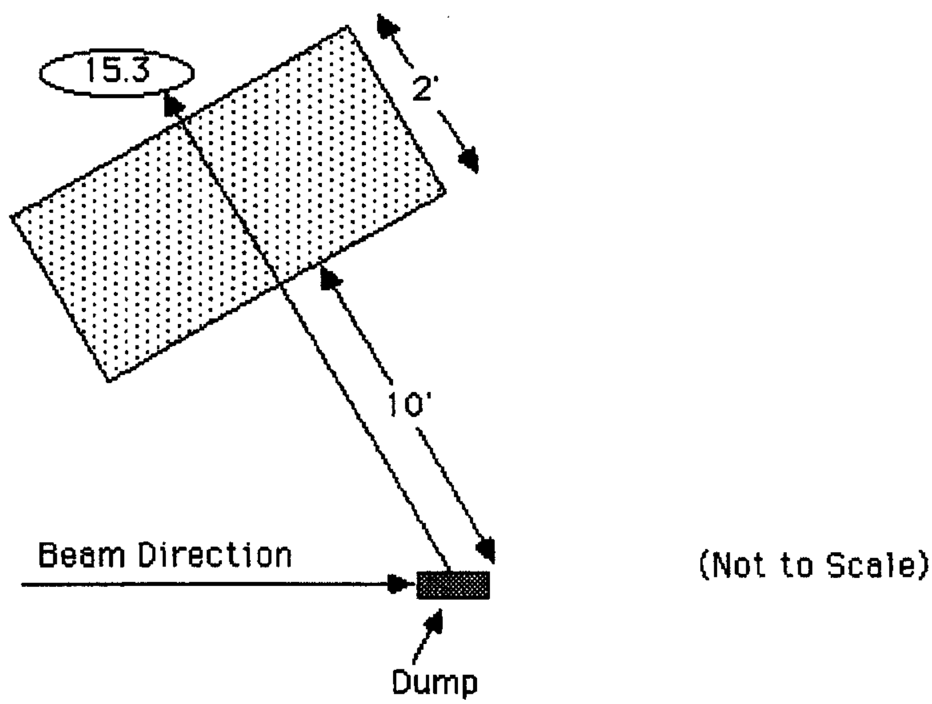


Figure 8

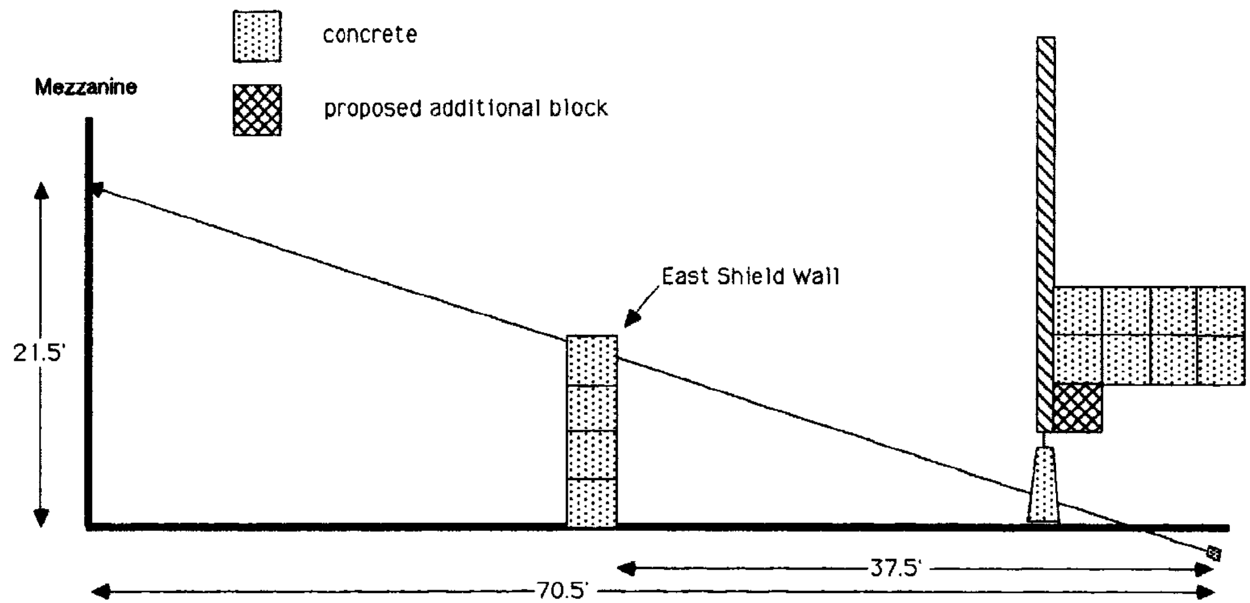

concrete
proposed additional block
Mezzanine
21.5'
East Shield Wall
37.5'
70.5'

Figure 9

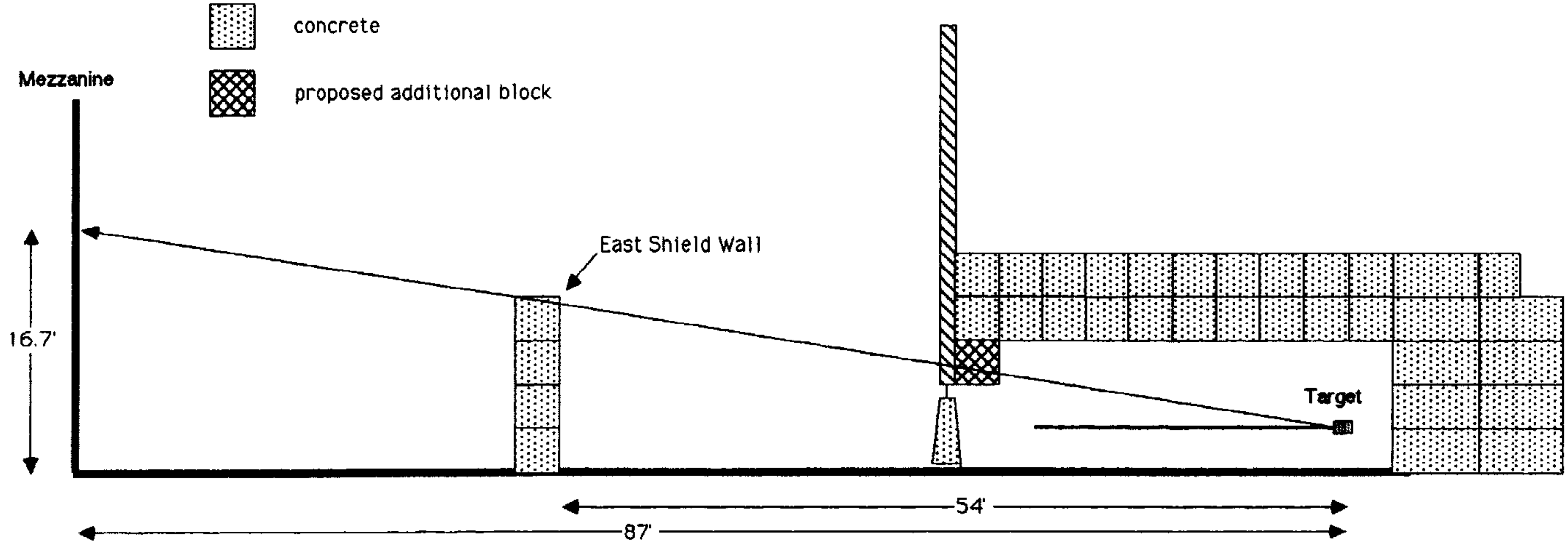

concrete
proposed additional block
Mezzanine
East Shield Wall
Target
16.7'
54'
87'

Figure 10