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BRAHMS shield wall calculations

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I. Introduction

The initial calculations based on a preliminary design of the shield wall for the BRAHMS detector were presented to a sub-committee of the Radiation Safety Committee on 04/24/97. For completeness, those calculations are reproduced in this note as Appendix 1. Since that time, the design has evolved and additional calculations performed. This note describes the status of the design and calculations as of 09/22/97. The official shield design drawings corresponding to the calculations reported here have this date.

II. Solid Wall Calculations

One of the complexities of the shield wall is that its thickness decreases as the elevation increases. The nearest point of concern is for experimenters in a single story fast electronics "hut" a short distance outside the wall which is considered a high occupancy area. The thickest part of the wall extends somewhat over 12 ft. from the concrete pad floor, and is meant to shield people in this hut from "direct" radiation in the event of a fault in the area. Since the floor of this hut is elevated 2 ft. above the concrete pad level, this thick part of the wall has been called the "shielding below 10 ft. elevation." Its shadow is more than 4 ft. above the head of a 6 ft. person in the hut. Below we make separate estimates for the dose "below 10 ft. elevation" and at higher elevations for a solid shield wall using CASIM. Later in this note, additional dose due to the existence of penetrations is considered. **It will be of considerable importance that access to high elevations when the machine is running be forbidden.**

(A) *CASIM Calculations on Wall Below 10 ft. Elevation*

CASIM calculations were performed using the approximation of the wall shown in Fig. 1. This represents a close simulation of the geometry on the beam-line midplane, but "cylindricized" to a 2-dimensional geometry to achieve good statistical precision. For the beam going to the right in Fig. 1, calculations were done for beam loss on Q2, D0, and the first DX. For the beam going to the left, both DX magnets were considered as possible sources. In all cases, the beam was taken to be 250 GeV/c protons and the star density was calculated on the back of the wall shown. Since Q2 is a high β quad, it is assumed to be a location (given RHIC's design basis fault) where a 100% fault can occur which, at 4 times design intensity, is 2.28×10^{13} protons. The design basis fault on the remaining magnets is half of this number.

Table 1 below shows the maximum dose equivalent at the 4 locations indicated in Fig. 1. In this table twice the normal star density to dose conversion factor has been applied to anticipate a future doubling of the neutron quality factor. These locations represent relative "hot-spots."

The third column indicates worst case source location and beam direction in the orientation of Fig. 1.

Table 1. Dose at Selected Locations Below 10 ft. Elevation

Location (Fig. 1)	Dose Eq. @ 4 × Design (mrem.)	Source Magnet
1	77	D0, Beam L → R
2	182	Q2, Beam L → R
3	339	Q2, Beam L → R
4	320	DX (Upstream), Beam R → L

In addition to the star density in the shielding blocks, the star density was calculated in a small light concrete strip (dashed lines on the right hand side of Fig. 1) in order to estimate the entrance dose to a labyrinth which is not shown. The worst case here was from a source on the DX magnet, which gave an entrance dose of 28 rem. More will be said on this topic in Section IV below.

(B) *CASIM Calculations on Wall Above 10 ft. Elevation*

The CASIM approximation of the geometry at elevation 78 ft. 8 in. is shown in Fig. 2.[1] This is the elevation corresponding to the center of two cryogenics penetrations which are not shown in Fig. 2. Each of these penetrations (through blocks 2 and 10 in the figure) consist of two 25 inch diameter holes. Again, the geometry in the CASIM approximation is 2-dimensional.

Calculations were done for the same sources considered previously. Again, the "hot spot", whose location is shown in Fig. 2, is from a source on Q2, and has, in this case, the estimated value of 1.3 rem.

It is by no means clear to this author how "shine" from higher elevations should be estimated. However, a much larger source (through the holes represented by the cryogenic penetrations) exists which is estimated in the next section. The assumption is therefore made that the dose through these holes dominates the "excess" dose (i.e., anything other than the direct dose estimated in Section II (A) above) to people behind the shield in the fast electronics hut.

The thinnest shielding at higher elevations is where the shield wall overlaps the roof. At this point a line between the beam line and the exit of the wall goes through 4 ft. of concrete and exits the shield wall at a transverse distance of 35 ft. from the beam line. A simple scaling of the highest value shown in Table 1 (339 mrem) gives 2.63 rem. This is at an elevation assumed to be inaccessible, and is very far away from ground level.

III. LAHET Calculations

The methodology of making calculations using the LAHET Code System, and how such calculations compare with and complement the CASIM code, have been described elsewhere.[2,3] What is reported here is a series of calculations using "point detectors" to estimate the neutron dose outside the penetrations through block number 2 in Fig. 2. Referring to this figure, calculations were done assuming the source to be the D0 magnet for the beam going to the right and the DX magnet for the beam going to the left. The former was the worst case and only these results will be discussed. In this case the geometry is fully 3-dimensional. As mentioned above, each penetration consists of two 25 inch diameter holes. No attempt was made to simulate the pipes through these holes.

An plan slice (constant elevation view) of the approximation of the geometry near the shield wall is shown in Fig. 3.[4] In addition to the shielding (all of which is light concrete - the shading does not have the same meaning as Fig. 1) are numbered "point detectors." These are the locations where dose is estimated. A total of 8 such detectors were defined. The first detector was located between the two penetrations on the inside of block 2. Although this detector is nominally an estimator of the entrance dose, care must be taken with this interpretation as discussed below. The second detector was at a corresponding position on the outside of the (6 ft thick) shield block. The third and fourth detectors were 6 ft. and 12 ft. further outside the shield block. All these detectors are at 78 ft. 8 in. elevation. Point detectors 5 and 6 were positioned 7.2 ft. below detectors 3 and 4 respectively(i.e., at elevation 71.5 ft.). This is the elevation referred to at the beginning of Section II - the elevation of the top of a 6 ft. tall person standing in the electronics hut. Finally, point detectors 7 and 8 are at the same elevation as 5 and 6 but displaced 6 ft. toward the direction of the electronics hut.

In this case the calculations were done at 100 GeV and the incident particles assumed to be neutrons. A half beam fault at 4 times design intensity is 2.24×10^{13} neutrons. The results, which have been multiplied by 2 for possible increased neutron QF, are shown in Table 2 below.5 In this table the error is simply the rms. deviation of 4 runs with 800 incident particles each.

Table 2 Results of the LAHET Calculation

Detector No.	Fault Dose (rem)
1	169 ± 6
2	4.82 ± 0.27
3	0.94 ± 0.05
4	0.38 ± 0.02
5	0.062 ± 0.008
6	0.085 ± 0.004
7	0.090 ± 0.013
8	0.081 ± 0.011

Two aspects of these results must be discussed. First, it has been shown previously[3] that the dose estimate at the position of detector #1 contains a large contribution due to local albedo. In fact, if one takes the maximum CASIM entrance dose[6] from D0, it is a factor of 4.3 lower than the 169 rem given in Table 2 in exact agreement with the result in Ref. [3]. However, for the purposes of estimating dose transmission through labyrinths, as will be done Section V below, we multiply the CASIM entrance dose by a factor of 2 only.

The second point that must be discussed is the *interpretation* of the LAHET dose. In principle, it is the total dose. However, this author, at least at the current time, interprets the total dose as the CASIM + LAHET dose. The reason for this conservative interpretation is a concern that the (computer time) limited number of primary particles may result in an undersampling of the high energy (> 20 MeV) hadrons that interact in the shield wall. Now in fact, the point detectors chosen are all in low occupancy regions where the criteria for the design basis fault is 1000 mrem. However, even if the greater distance to the electronics hut is ignored, then the ~ 90 mrem in Table 2 (at occupied elevations) added to about 200 mrem, which is the worst case fault in back of the shield wall at lower elevations from a fault on D0, is safely below the high occupancy criteria of 500 mrem.

Before leaving this section, comments should be made on calculations that have **not** been made. Several blocks, all above elevation 73.5 ft., have small holes for cable penetrations. None of these are close to the high occupancy electronics hut. It is not clear to this author whether even part time occupancy near these blocks is required when the machine is running. The other cryogenics penetration has also not yet been calculated. There are several reasons for believing that this penetration is less of a problem than the one that was treated here: (1) the entrance is partially shadowed by internal steel shielding as shown in Fig. 2, (2) the electronics hut is farther from the exit of the penetration (39 ft. vs. 30.5 ft.), and (3) the hut is mostly screened from the penetration exit by the roof over the truck access way, i.e., the roof over the heavy concrete shown on the right hand side of Fig. 1. Finally the heavy concrete blocks which block the truck access way are single layered and therefore have (vertical) cracks. There is no direct source for "shine" through these cracks (other than the beam pipe, backwalls etc.) so that there is no reason to believe the excess dose through these cracks is as large as computed for the STAR detector[7] with the exception that the distance is closer. Scaling the STAR excess of 50 mrem for a 3/8 inch by R^2 would give 82 mrem which would not be a problem.

IV. Labyrinths

Three labyrinths are planned through the shield blocks. One is a personnel labyrinth whose entrance is indicated by the dashed lines on the right hand side of Fig. 1. This is a 3-leg labyrinth whose parameters[8] are shown in Table 3. The other two are (nearly identical) two-leg cable labyrinths which, in fact, are not finalized. Here I assume the second leg is 3 ft long which implies 4 foot long blocks forming the second leg which is outside the main shield wall. The parameters of the cable labyrinths are given in Table 4.

Table 3 Parameters of the Personnel Labyrinth

Leg	Length (ft.)	Area (ft.^{2})
1	5.2	19.5
2	18.2	19.5
3	1.0	23.4

Table 4 Parameters of the Cable Labyrinths

Leg	Length (ft.)	Area (ft.^{2})
1	8.4	2.5
2	3.0	2.5

As mentioned in the preceding sections, the entrance dose will be taken as twice the worst case dose using the CASIM calculations. For the personnel labyrinth this is from the DX source (see Fig. 1 - beam going to the right) and is 56 rem. For the cable labyrinths twice the maximum entrance dose anywhere on the wall from Q2 is used which is 225 rem. (As usual, these numbers also contain the ×2 QF for low energy neutrons). For attenuation the formula of Goebel is used which is:

$$A = \frac{1}{1 + 2.5\sqrt{d} + 0.17d^{1.7} + 0.79d^3} \quad \textit{for leg}\ 1$$

and

$$A = \frac{1}{1 + 2.8d(1.57)^{d+2}} \quad \textit{for subsequent legs}$$

where d is the "universal" leg length = $L/\sqrt{A}$. The results are 23 mrem for the personnel labyrinth and 55 mrem for the cable labyrinths. Again, these values are no cause for concern when considered as incremental to the solid wall dose given in Table 1.

In principle, of course, these penetrations could have been done using LAHET. However LAHET calculations are quite time consuming. The calculation which *was* done with LAHET was motivated in part because of uncertainty in choosing the correct "entrance dose" caused by the fact that the entrance to the cryogenics pipes are in a recess and the disagreement between the two codes on beam line position dependence. If one uses the maximum dose "anywhere" from D0,[6] then twice the maximum CASIM entrance dose would be, as discussed immediately following Table 2 in Section III above, (2/4.3) × 169 rem = 78.6 rem. If one now treats the two side-by-side circular holes as a single hole with radius √2 × 12.5" and applies the first leg formula of Goebel,[9] the exit dose estimate is 3.54 rem, in reasonable agreement with the LAHET result of 4.82 rem given above. Using twice the actual CASIM entrance dose, which is not well justified in this author's opinion, would have given 2.2 rem.

The estimates made in this section using twice the CASIM values for the entrance dose estimate do not suffer from the problem of "close sources" which motivated the actual LAHET calculation. In the case of the personnel labyrinth the source (the DX magnet "pointing at" the labyrinth entrance in Fig. 1) is far enough away for the CASIM dose to be greater than the LAHET dose as shown in Ref. [3]. In the case of the cable labyrinths, the maximum CASIM dose was used without regard to the actual location of the labyrinths with respect to the position of that maximum.

Footnotes/References

1. The distances and thicknesses shown in Fig. 2 result from dividing the lateral distances in the actual shielding configuration by cos. $\theta = 0.9393$. In creating a 2-dimensional approximation at higher elevations, some angle is defined by the beam line and a point on the inside of the shield wall at elevation 78 ft., 8 inches. The value chosen represents a compromise between the angles at each of the two cryogenic pipe positions on the inside of the shield wall at this elevation.

2. .E. Prael and H. Lichtenstein, "User Guide to LCS: The LAHET Code System," Los Alamos National Laboratory Report LA-UR-89-3014, September, 1989.

3. A.J. Stevens, "Comparison of CASIM with the LAHET Code System," AD/RHIC/RD-115, August, 1997.

4. The approximation in Fig. 3 is thinner than the actual shielding immediately to the right of the penetrations for X > 940 cm. This is conservative for locations to the "right" of the penetrations in Fig. 3 which is the direction of the electronics hut.

5. The LAHET results have also been multiplied by 1.15 to approximate the effect of the magnetic field in the aperture of D0. LAHET does not have to ability to incorporate directly the effects of an external magnetic field; the 1.15 is what CASIM would estimate at this angle for a midplane enhancement which is conservative since the cryo pipes are above the midplane.

6. CASIM and LAHET do not agree on the beam direction dependence of "tunnel wall" dose as shown in Ref. [3], the dose maximum in LAHET being closer to the source position than in CASIM. The CASIM dose in the text is the maximum on the entrance wall in Fig. 2 scaled ($1/R_T^2$) to the transverse distance of the cryo pipe entrance.

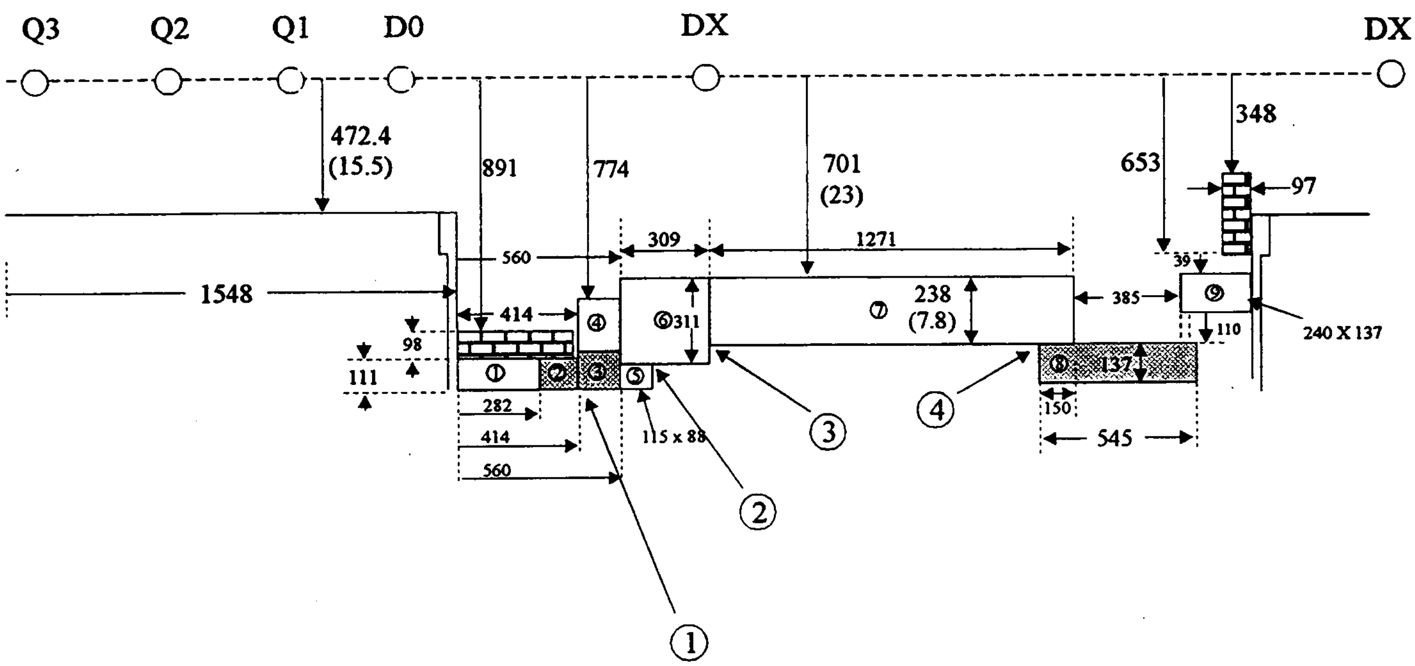
7. A.J. Stevens, "Estimate of Dose Through Cracks in the STAR Shield Wall," RHIC/DET Note 23, August, 1997.

8. The height of all legs was taken as the height of the Berkeley doorway blocks which is 6.5 ft.

9. The universal leg length is 2.733.

Scale: .1505 inches = 100 cm.

Dimension in cm. (ft.)



This drawing is the CASIM approximation of the BRAHMS shield wall at elevations below 10 ft. Engineering drawings dated April 25 1997.

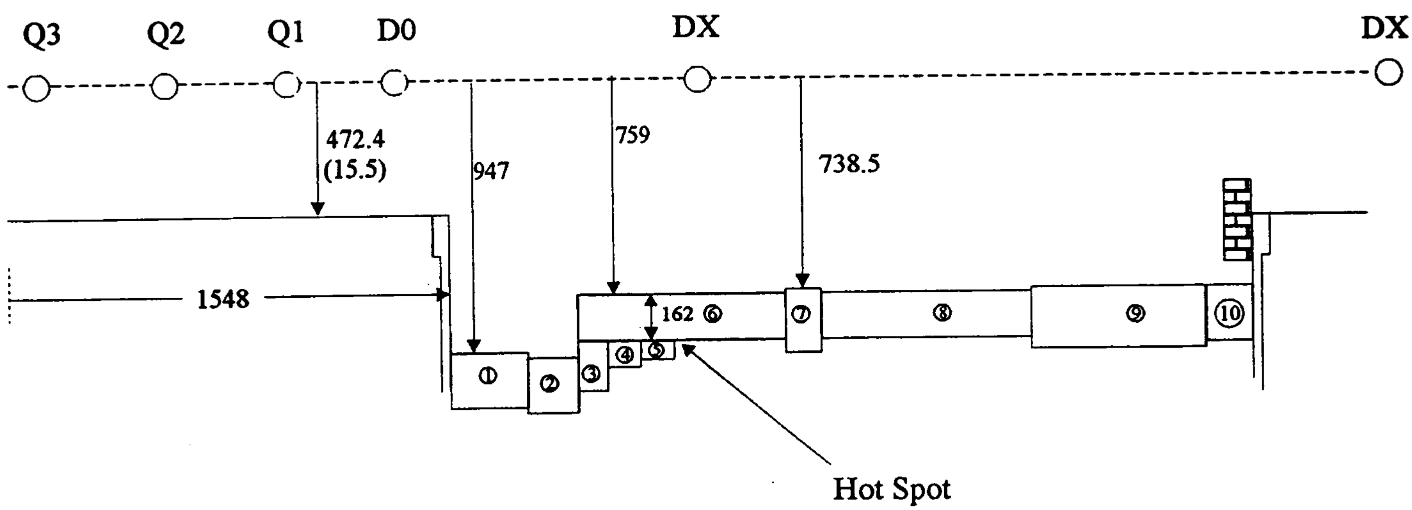
(The April drawings do not differ significantly from the Sept., 97 drawings).

"Brick" pattern indicates steel. Shaded indicates heavy concrete.

Fig. 1

Scale: .1505 inches = 100 cm.

Dimension in cm. (ft.)



This drawing is the CASIM approximation of the BRAHMS shield wall at elevation 78 ft. 8 in.. Engineering drawing Sept. 1997.

Note: Cryo. Penetrations are in Blocks 2 and 10

Fig. 2

Approximation of Shield at Y = 78 ft. 8 in.

(Position coordinates in cm.)

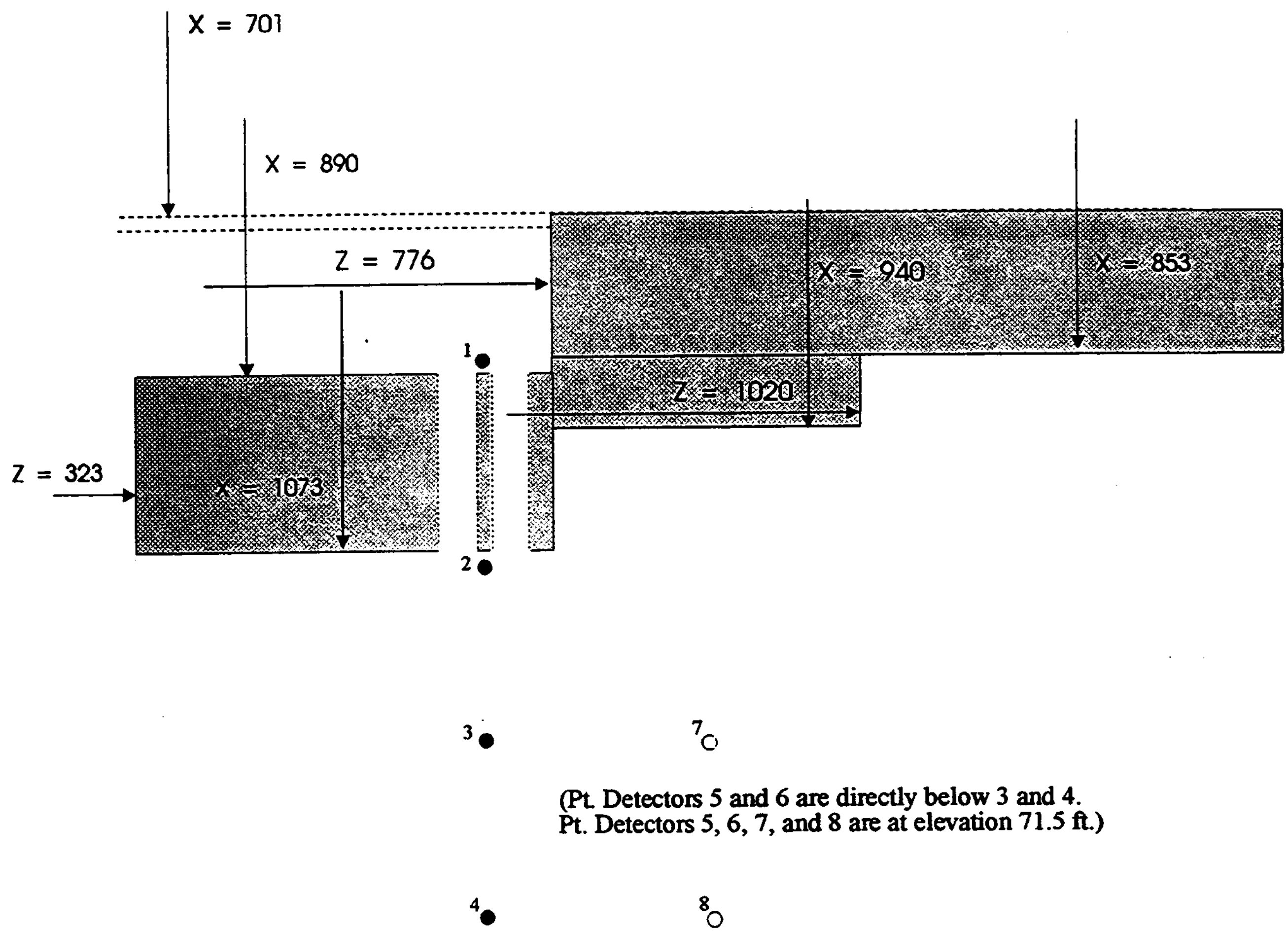


Fig. 3

Appendix 1

Calculations Relevant to BRAHMS Shield Wall Design
Status as of 04/23/97
A. Stevens

1. CASIM Calculations on Basic Wall at Below 10 ft. Elevation

A. See Sketch. (Direction Reversed from Engineering Drawings).

Note: The sketch is close to the actual design on this date with the exceptions of (1) an added block near location 2 of sketch and (2) thicker Fe in recess.

B. Results

Max Doses in Fault (X 2 Q.F. Included)

Location (Sketch)	**Source**	**Result**
1	DX	48 mrem
2	Q2	440 (~270)* mrem
3	Q2	266 mrem
4	DX	111 mrem
5	DX	31.6 rem**

* Last Calculation Done (440 mrem) does not Include Added Block. 270 is approximately result with added block.

** This is the source term for the Labyrinth.

2. Other Topics Below 10 ft. Elevation

A. Cracks

Only cracks are location 4 on sketch. No analysis done, as the approximation to date needs a direct source in front of crack. None exists here. [There is great margin].

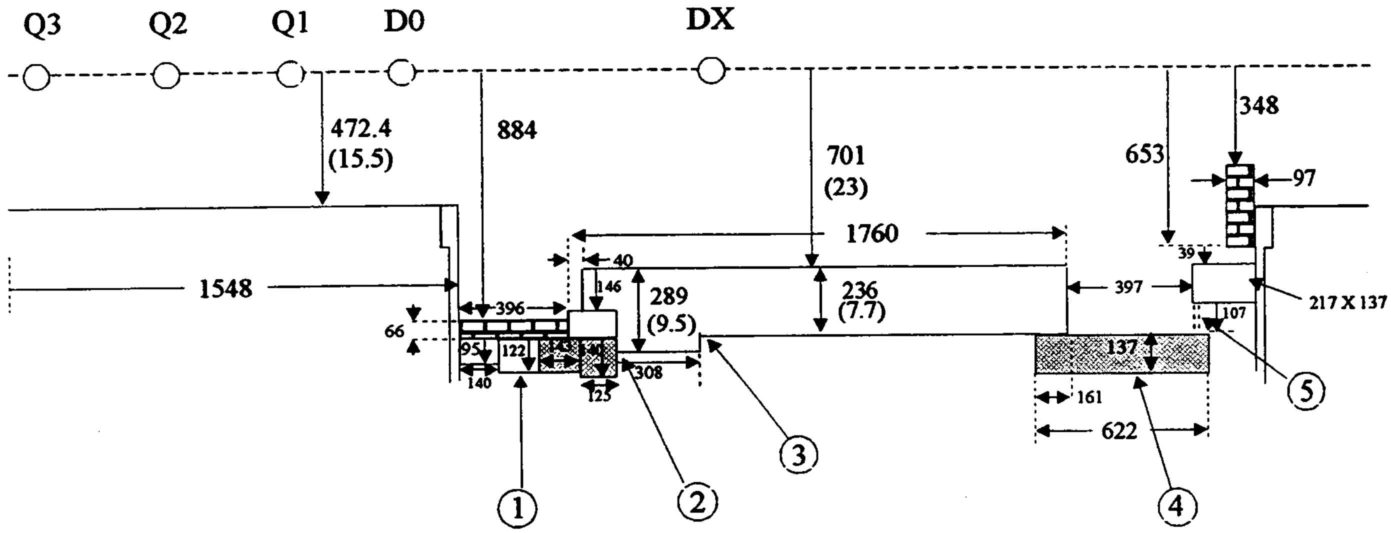
B. Labyrinth

Two legs (plus stubby 3rd). Parameters: L1 = 5.6 ft, L2 = 18.4 ft., Opening = 3 X 9 ft.

Atten (leg 1) = .2183, (leg2) = 8.217×10^{-3} . Total Attenuation = 1.79×10^{-3}
Dose = **57 mrem**.

Scale: .1493 inches = 100 cm.

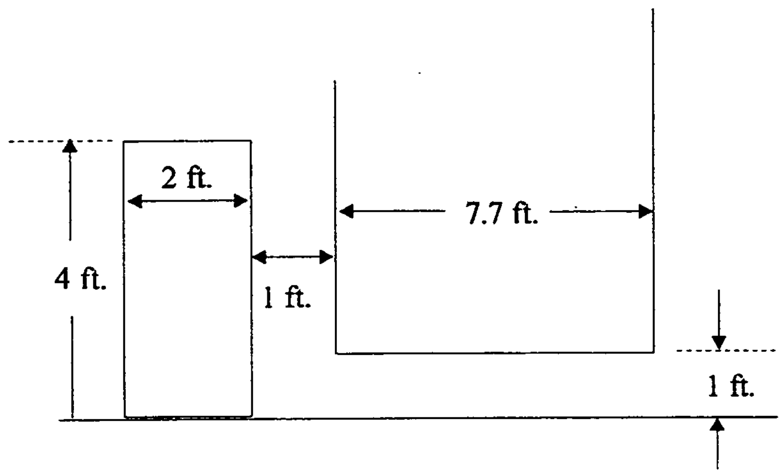
Dimension in cm. (ft.)



04/23/97 This Sketch is NOT The Latest Design

Also worry about low energy punch-through after short distance (5.2 ft.) in second leg. Guestimate conservative attenuation length in heavy concrete is 23.4 cm. (Probably VERY conservative.) If 1/2 of dose is candidate for punch-through, get attuation of 2.51×10^{-3}

C. Penetration at Floor Level for Cables



The CASIM Entrance Dose is 127 rem (Q2)

Width (dimension along beam line) is 2.5 ft. Goebel formula give attenuation in first leg of 9.97×10^{-3} and in second leg of 3.14×10^{-2} **Total = 40 mrem**. Same punch-through believed to be overestimate (exp(-60.96/23.4)) gives **94 mrem**.

Concern (on my part - in this geometry) of low energy entrance dose in excess of CASIM entrance dose leads to a recommendation to construct a small block enclosure on the inside of the wall.

3. Topics Above 10 ft. Elevation

A. Personnel Exclusion Assumed

B. Roof Overlap

For a 3 ft. Overlap CASIM gives 8.2 rem. (Q2, Worst case) Current Design Unknown Prior to Review. (See “Shine” Below)

C. Last Design Estimated has Thick Section Near Recess and 5 ft. the rest of the way. **Last Estimate of "hot spot"** (corner alalogous to hot spot position 2 in sketch) is **2.83 rem. Highest dose in 5 ft. section is 1.94 rem** (plus whatever from cracks).

D. Cryogenics Penetrations (2 20 inch diameter holes)

Entrance dose in Cryo penetration in recess is 19.4 rem. On Opposite side is 65.7 rem.

Assume Encased in 6 ft. blocks. Dose through opening is Low energy plus "Dosexit" plus dose as if penetration did not exist. Estimate as a function of distance for the "hot" penetration is:

Position	**Dose Estimate**
Exit	3.62 rem
Exit + 6 ft.	1.20 rem
Exit + 12 ft.	0.70 rem

[This should be re-estimated. One component, the low energy, actually falls off faster than assumed when this calculation was done.]

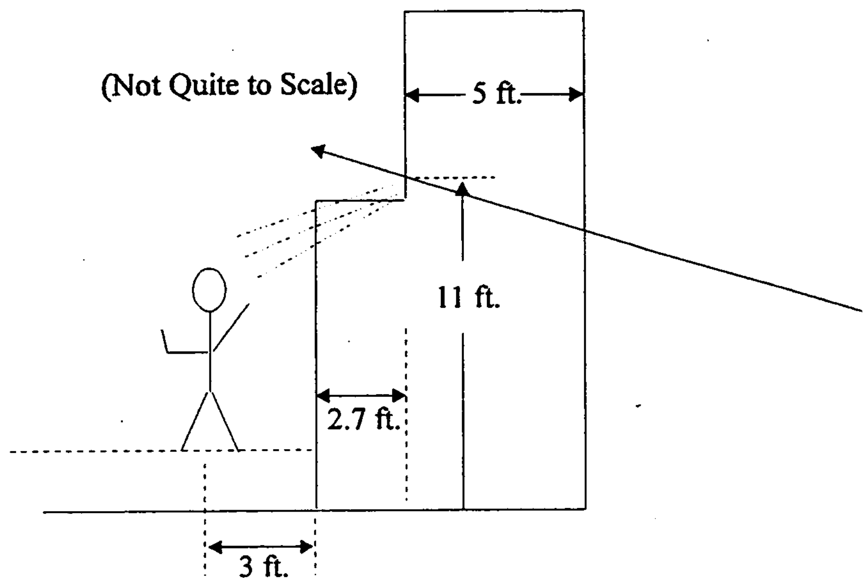
E. "Shine"

The dose above 10 ft. does not meet the low-occupancy criteria. As mentioned above, exclusion is assumed. Some dose from higher elevations will "shine" on a person at low elevation, adding to the dose calculated above. I assume that (1) only low energy dose will do this (high energy being directional and headed "up") and (2) that the fall-off found for dose from MCNP calculations is conservative. The fall-off there is well fit by:

$$\textit{Fall Off} = \frac{5.712}{(2.39 + d)^2}$$

where d is in feet.

Example Calculation: Next Page



d = Sqrt((3 + 2.7)**2 + (11 - 8)**2) = 6.4 ft.

Fall Off = .074

Total Dose = 2.83 rem × .074 + 266 mrem = 475 mrem (Just made it!)