

# NuMI Absorber Labyrinth Concept

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This document presents a conceptual design for the NuMI Absorber labyrinth. The design attempts to provide a simple labyrinth which provides a reasonable amount of radiation shielding for personnel and equipment that may be in the region where the Absorber Hall labyrinth corridor intersects the By-Pass Tunnel but would be relatively easy to construct. The labyrinth design must provide sufficient shielding to make the contribution to the dose from normal beam on dose penetrating the labyrinth similar in magnitude to dose that might be expected from the RAW systems that are located in the By-Pass Tunnel. With the proposed design, the anticipated dose range is expected to be in the 5 to 100 mrem/hour range. This would require "CAUTION -- RADIATION Area" signs and rigid barriers which are at least 4' high with locked gates. Access would be restricted to authorized personnel with the beam on.

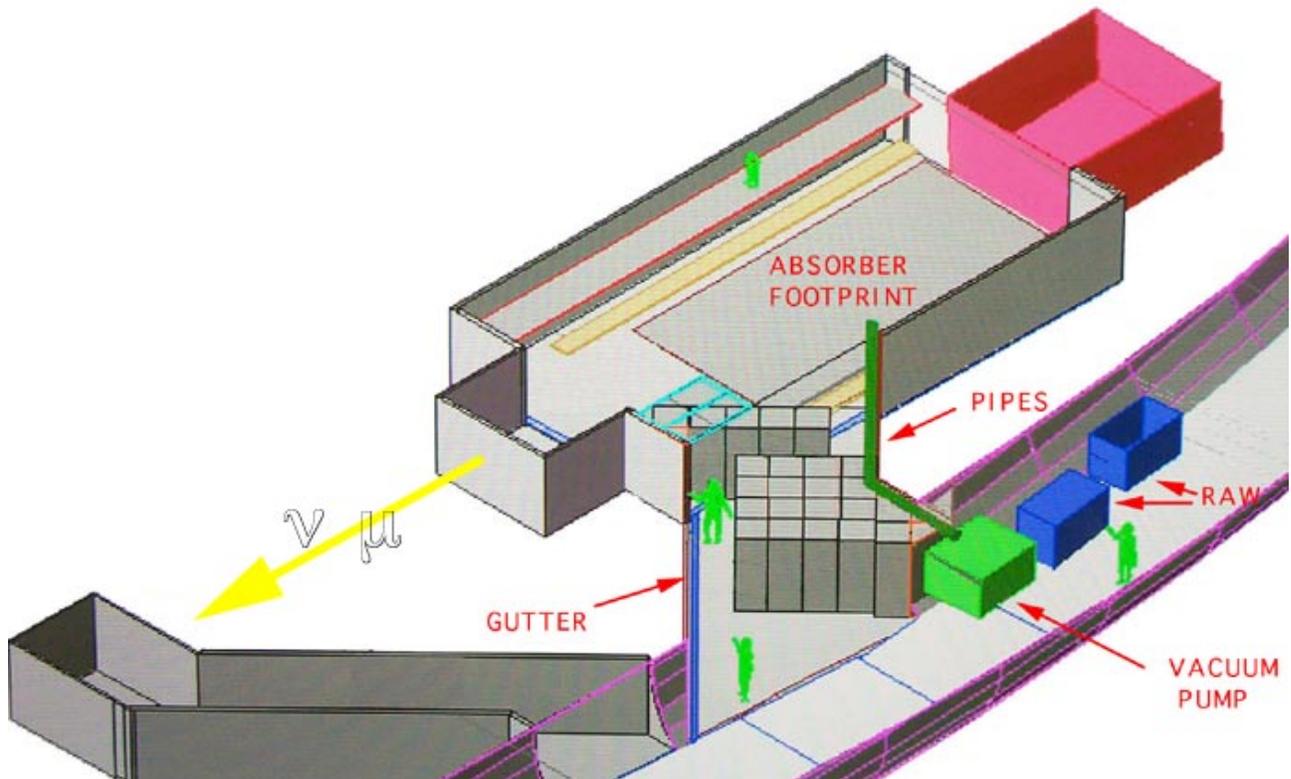


figure 1

Figure 1 is a cut away drawing. It shows some of the key features that were considered in the design of the labyrinth associated with the access corridor from the NuMI Bypass Tunnel to the NuMI Absorber Hall. These features include an access corridor that is 16' wide without the labyrinth and a minimum ceiling height of 8'. The actual height of the ceiling is unknown at this time until the construction of this corridor is completed. There are gutters built into the floor of the corridor that will reduce the effectiveness of the proposed labyrinth for this area. There will be a 10.75" outer diameter (o.d.) vacuum pipe, two 3.5" o.d. radioactive water (RAW) pipes, and two 2.125" o.d. RAW pipes running near the ceiling of the corridor in a common duct. One set of RAW pipes is for the absorber while the other set is for the decay pipe cooling. In addition, there will be some number of cables for power, controls and instrumentation that must be accommodated. It is assumed that most these cables will be routed adjacent to the vacuum and RAW pipes with the power cables separated from the controls and instrumentation cables as much as possible within the common duct. Any cables not routed

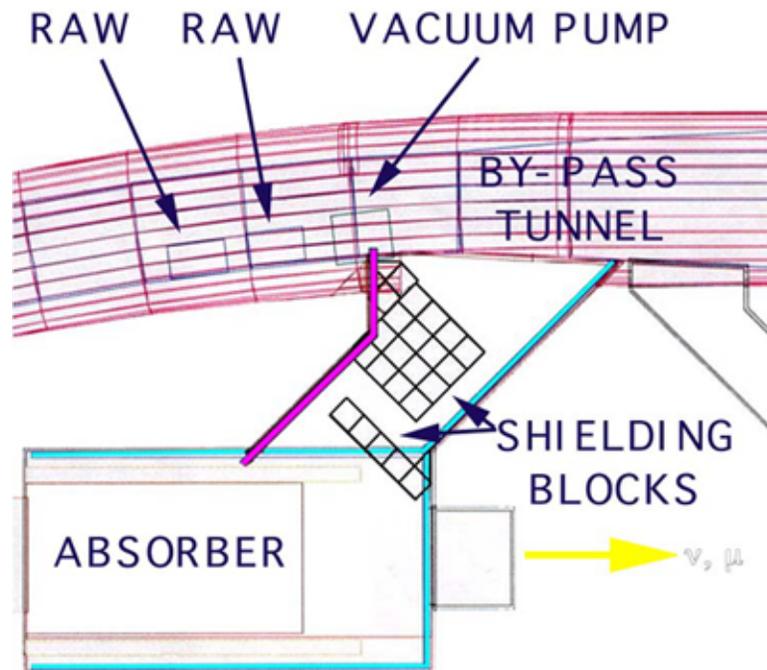


Figure 2

through this common duct will be ignored for the purposes of this document. Because of impedance concerns, the vacuum pipe within the corridor has been limited to one bend of 45 degrees. For purposes of

minimization of the impedance, the vacuum pump associated with this pipe has been placed as close as possible to the labyrinth in the By-Pass Tunnel. Since the RAW systems do not have as serious impedance concerns and since parts of the RAW systems will become significantly radioactive with use, the pumps, heat exchangers, etc. associated with the RAW systems have been located further away in the By-Pass Tunnel where unnecessary radiation exposure to personnel can be minimized. Figure 2 shows the same area of the NuMI beam line as in figure 1 but in plan view. Some of the key features in the area associated with shielding issues are shown in figure 2. Note that there are two sets of shielding blocks. The first set consists of a row of five square cross section shielding blocks and one triangular cross section shielding block. The second set of blocks consists of a footprint that is roughly square in cross section with 16 blocks in a square and an adjacent set of blocks with an approximately triangularly shaped footprint shown colored green in Figure 3.

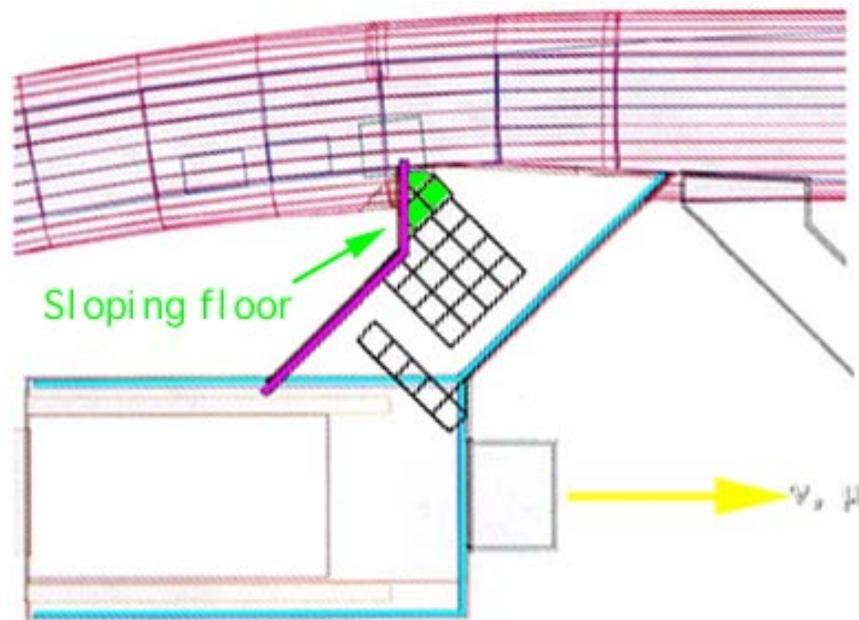


Figure 3

According to the NuMI Tunnels and Halls drawing<sup>1</sup>, the portion of the labyrinth corridor that is occupied by the shielding blocks colored green in figure 3 has a sloping floor. This section of the floor must be modified by the time of the installation of the labyrinth shielding.

<sup>1</sup> NuMI Tunnels and Halls Decay Tunnel Sta 24+40 to 31+70, Drawing No. 6-7-4, C-48, Rev. 1, 30 Nov. 2000

Otherwise there will be stability and perhaps gap problems for the shielding blocks located there. Plans are being made to have this portion of the floor leveled by the time the labyrinth blocks are to be installed<sup>2</sup>.

It should be noted that the vacuum pump, the RAW pumps, heat exchangers, etc. are located in the Bypass Tunnel along one side of the tunnel in this proposal. The region where these devices are located has a sloped floor. Using of legs of different lengths for the mounting of these devices, the mounting scheme should raise these devices high enough off the floor to try to take advantage of the increased transverse width of the tunnel above the sloped invert. By locating the vacuum and RAW related devices along the wall the amount of uncluttered invert space adjacent to these devices could be maximized. By maximizing the

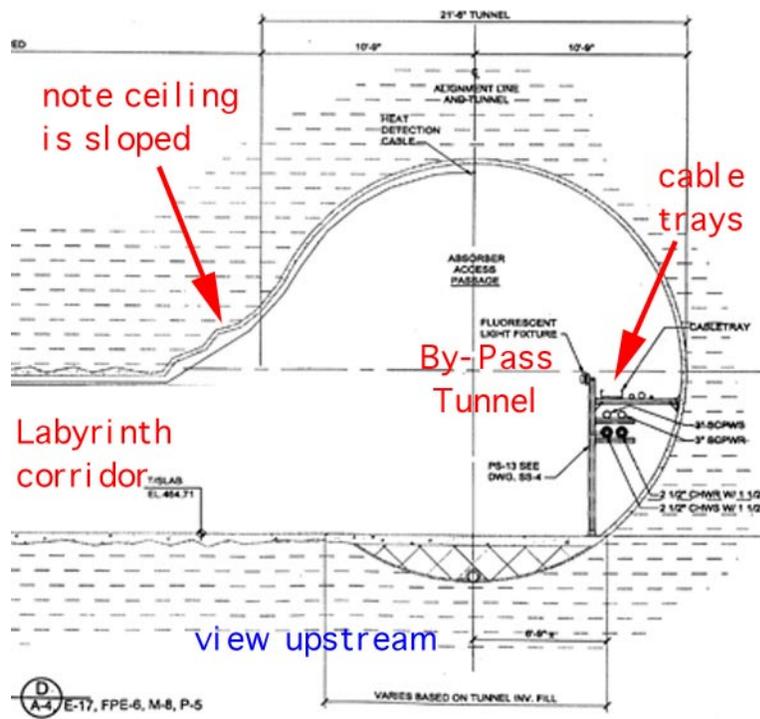


Figure 4

<sup>2</sup> D. Pushka, private communication, 7 June 2001.

uncluttered invert space, it should be possible to utilize the tunnel further upstream of the vacuum and RAW related devices as a storage area although the 50' limit to dead end rule must be still observed.

It should be pointed out that with the proposed locations for the vacuum pump and the RAW related devices in the By-Pass Tunnel, these devices will be located on the left side of the By-Pass Tunnel in Figure 4<sup>3</sup>, looking upstream. The utilities and their associated cable trays and supports coming from the downstream end of the By-Pass Tunnel are located on the right side of the tunnel looking upstream. It will be necessary to route the utilities and the cable trays from the right to the left side of the By-Pass tunnel just upstream of the Labyrinth corridor. The routing from the right to left side must be done high enough above any anticipated traffic that may require access to the portion of the By-Pass Tunnel upstream of the Labyrinth corridor.

Note also that the ceiling where the Labyrinth corridor joins the By-Pass Tunnel is sloped in figure 4. In locating the shielding blocks that constitute the labyrinth, consideration of this sloped ceiling shown in figure 4 played a part. At this time the extent of the sloped ceiling into the Labyrinth corridor is unknown. The extent will not be known until the actual construction of the tunnels in this area. It was hoped that by trying to locate as much of the shielding blocks as close to the

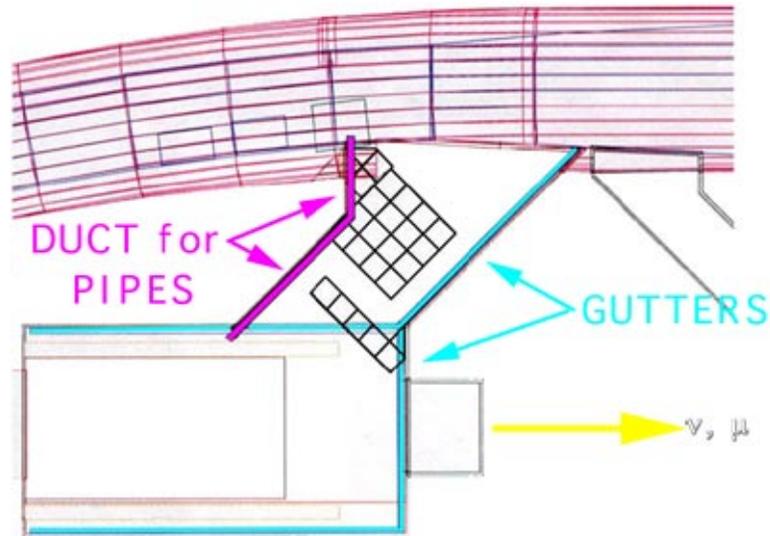


Figure 5

<sup>3</sup> This is an annotated version of drawing 6-7-6, A-14, 27 July 00, "NuMI Outfitting Architectural Sect. & Tet. Sht. 6"

Absorber Hall as possible, the impact of the sloped ceiling would be minimized. By trying to locate as much of the shielding blocks as close to the Absorber Hall as possible, it is hoped that the amount of additional shielding required to fill any voids above the shielding blocks in the sloped ceiling area would be minimized.

Figure 5 again shows the same area as previously. This time different items are labeled in the plan view. Note in particular that there are gutters in two places, shown in blue, below the first set of shield blocks. They traverse below the shielding blocks at an angle of 45 degrees relative to the orientation of the blocks. One of these gutters is parallel to the direction of the uninteracted primary proton beam but is offset by approximately 12' from the central beam axis. The other gutter is perpendicular to the beam direction and is located at the downstream end of the main part of the Absorber Hall.

In attempting to calculate the attenuation provided by the proposed labyrinth design, several factors must be considered. For the purposes of discussion, the legs of the labyrinth in figure 6 have been numbered as "0", "1", and "2". Each of these factors will now be considered. It is necessary to consider the effect of the gutters on the

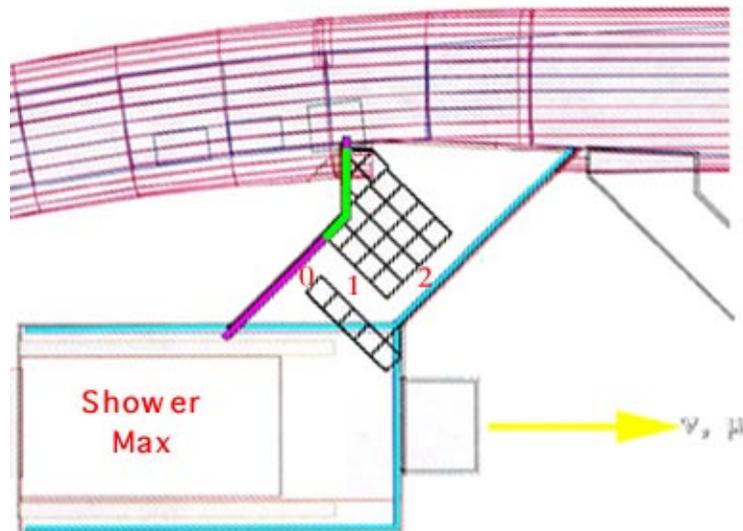


Figure 6

shielding capabilities of the proposed labyrinth. Since the square cross section shielding blocks are assumed to have sides that are 36" in length, the two gutters traverse a distance of 50.91" each under the first row of shielding blocks. Based on the information provided by drawing 6-7-4, C-49, Rev. 1 of 30 Nov. 2000, the depth of the gutter under the first row of shielding blocks was calculated to be approximately 12.5". The gutters are shown in drawing 6-7-4, C-68, detail 3, Rev. 0 of 7 Jan. 2000, to have a grating 8" wide and 1" deep while the gutter itself is 6" wide. For the purposes of shielding calculations, if one ignores the increase in the width to 8" for the top most 1" of the gutter (since some portion of that 1" is assumed to be occupied by a high density grate) and assumes a gutter with a cross section of 12.5" deep and 6" wide that is 50.91" in length, then using the R. Rameika shielding calculations methodology for ducts<sup>4</sup>, one gets  $50.91/\sqrt{12.5 * 6} = 5.88$ . This 5.88 value implies a dose attenuation of approximately  $6 \times 10^{-3}$  if one employs the "plane or point off axis" curve in figure 1a of the Rameika document. It is important to note that the curve employed is one of three curves shown in the Rameika document. The others are the "point" and "line" source curves that give significantly less attenuation values. Given the shielding that surrounds the NuMI Absorber core that would diffuse the source dose over a large volume, neither the "point" nor the "line" source seems to be appropriate. The most appropriate curve to use seems to be the "plane or point off axis". It is worth noting that neither the "plane or point off axis" curve chosen nor the "line" curves are employed in the J. D. Cossairt methodology<sup>5</sup> for labyrinth attenuation. Assuming that it is acceptable to employ the "plane or point off axis" curve in figure 1a of the Rameika document, the combined contribution of the gutters would be an attenuation factor of approximately  $2 * (6 \times 10^{-3}) = 1.2 \times 10^{-2}$ . The gutter contribution will come at the end of labyrinth leg numbered "1" in figure 6.

It is assumed that all of the legs of the labyrinth shown in figure 6 have basic cross sectional dimensions of 4' wide and 8' high if the contributions of the gutters or the presence of the duct containing pipes and cables are ignored. Any volume higher than 8' high in the Labyrinth corridor will be assumed to be filled with shielding. This ceiling shielding

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<sup>4</sup> R. Rameika, "Labyrinths and Penetration Methodology-Version 1.3", Fermilab Research Division Shielding Assessment (28 February 1991), private communication

<sup>5</sup> J. D. Cossairt, "Approximate Technique for Estimating Labyrinth Attenuation of Accelerator-Produced Neutrons", Fermilab E. S. & H. Section R. P. Note No. 118, 1 October 1995.

is assumed to be ribbed steel plates forming a support for bulk shielding consisting of small concrete blocks and/or sandbags. For the purposes of shielding calculations, the calculations for the ceiling ignores the presence of the steel plates. Standard Fermilab "B" type shielding blocks are 3 x 3 x 7.5' in size. If "B" blocks are employed for the construction, 0.5' plus whatever the distance to the ceiling that remains at a particular location must be filled with the bulk shielding. Depending upon the final ceiling height of the labyrinth corridor, it may be necessary to use some other shielding blocks besides the "B" type, e.g., the "C" type blocks that are 3x3x6', where the duct carrying the vacuum, RAW pipes and cables traverse. Again, whatever undesired voids that are left must be filled in with shielding. Note also that this document assumes the use of a few triangular cross section (with side of 3', 3' and 4.243') shielding blocks. These triangular blocks are not standard Fermilab shielding blocks and would require special fabrication or the use of some appropriate shielding that would fill the triangular voids.

There has been some discussion about placing the concrete shielding blocks that constitute the bulk of the labyrinth on steel bricks. The purpose for the steel bricks would be to raise the bottom of the concrete shielding blocks off the floor for easier installation and removal of the big concrete blocks. If this option is adopted, the voids created below the concrete blocks must be filled. It is assumed that the fill would be sand bags, poly beads, small concrete blocks or some combination of these items. The volume of the void above the ceiling would be consequently reduced. Regardless of what is used to fill the voids, their use must not significantly compromise the shielding capabilities of the labyrinth.

Several problems become apparent when one tries to apply the Cossairt methodology to calculate the labyrinth attenuation. First, the Cossairt methodology assumes that the losses occur at a point immediately in front of the entrance of the first leg of the labyrinth and that this first leg is in a direction that is perpendicular to the beam direction. The loss point in the case of the NuMI Hadron Absorber will be distributed and located at an angle centered roughly at 45 degrees from the beam direction rather than 90 degrees. Second, if leg "0" is considered to be the first leg of the labyrinth with 32 ft<sup>2</sup> cross section

and a length of 5 feet, then using the EXIT2 Microsoft Excel spreadsheet<sup>6</sup> that calculates labyrinth attenuation using the Cossairt methodology, one gets an attenuation of leg "0" of  $3.76 \times 10^{-1}$ . Given that leg "0" is not perpendicular to the beam direction but rather points back toward the loss point at approximately 45 degrees and that leg "0" is so short, to be conservative, it was decided to ignore any contributions that leg "0" might make to the total dose attenuation.

If leg "1" in figure 6 is assumed to be the first leg of the 32 ft<sup>2</sup> cross section labyrinth, using the EXIT2 spreadsheet one gets an attenuation of  $1.95 \times 10^{-1}$  at the end of leg "1".

It is necessary to take into consideration the problems associated with a short circuited labyrinth in a design proposed in figure 6. A labyrinth design may be deficient due to punch through of radiation through the bulk shielding that makes up the labyrinth rather than the penetration of radiation through voids. The Cossairt methodology makes no mention about short circuited labyrinths. To calculate whether the 3' thick concrete shield block wall is adequate, it was necessary to revert back to an updated version of the Rameika methodology. According to the Rameika methodology, radiation dose will be attenuated by  $10^{-(x/D)}$  where x is the thickness of the shielding material in feet and D is the thickness constant associated with that shielding material<sup>7</sup>. Since it will be necessary to fill in the gap between the top of the labyrinth shielding blocks and the tunnel ceiling with either sand bags or concrete blocks or both, the effective density of the labyrinth would likely be somewhat lower than that indicated by the shielding blocks. A 3' thick layer of sand bags attenuates dose by  $10^{-(3/2.8)} = 8.483 \times 10^{-2}$ . A 3' thick concrete block attenuates the dose by  $10^{-(3/2.6)} = 7.017 \times 10^{-2}$ . A 1.5' thick concrete shielding block which attenuates the dose by  $10^{-(1.5/2.6)} = 2.649 \times 10^{-1}$  would not be adequate. Attenuation of  $2.649 \times 10^{-1}$  is less than the attenuation of  $1.95 \times 10^{-1}$  at the end of leg "1" of the labyrinth although the  $1.2 \times 10^{-2}$  contribution from the gutters at the end of leg "1" must not be forgotten. Since both 3' thick layer of sand bags or 3' thick concrete block attenuate punch through dose better than the dose contribution through the labyrinth and the gutters, the wall facing the

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<sup>6</sup> J. D. Cossairt, EXIT2 Microsoft Excel spreadsheet, private communication

<sup>7</sup> M. Gerardi, private communication, e-mail of 31 May 2001, D = 2.8 feet for soil, 2.6 feet for concrete blocks. W. Higgins, private communication, e-mail of 31 May 2001, D=2.8 feet for sand bags.

NuMI Absorber Hall will be assumed to be constructed from 3' thick concrete blocks with small concrete blocks and sand bags filling in any voids that standard Fermilab shielding blocks cannot fill.

The second labyrinth leg, identified by the red "2" in figure 6, is 12' long and provides attenuation of  $2.95 \times 10^{-2}$  according to EXIT2. The second leg is assumed to have a gutter whose average cross section is 6 x 13.5" in addition to the 8 x 4' passageway. This additional gutter cross sectional area is incorporated into the passageway area in the attenuation calculation for the second labyrinth leg. Assuming that the attenuation of the pair of gutters under the shielding blocks that form leg "1" of the labyrinth can be simply added to the attenuation factor for leg "1" of the labyrinth itself, the total attenuation at the end of leg "2" would be  $(1.95 \times 10^{-1} + 1.2 \times 10^{-2}) * (2.95 \times 10^{-2}) = 6.1 \times 10^{-3}$ . Again, keep in mind that no credit is taken for any attenuation that might be contributed by leg "0" in this calculation.

12' of concrete blocks by itself gives an attenuation of  $2.4 \times 10^{-5}$  while 12' of sand bags by itself give an attenuation of  $5.2 \times 10^{-5}$ . Since it is assumed that the uneven ceiling of the Labyrinth corridor above the shielding blocks must be filled with sand bags, the attenuation will be assumed to be  $5.2 \times 10^{-5}$ . The dose due to punch through of 12' of shielding is negligible compared to the contribution of  $6.1 \times 10^{-3}$  from the labyrinth legs itself.

$6.1 \times 10^{-3}$  would be the dose attenuation starting at the end of leg "0" in figure 6 had there not been a duct for the utilities that penetrate this region of shielding. This utility penetration duct, shown in green in figure 6, is assumed to be 16 x 13" in cross section and is 144" long. While the duct actually makes a 45 degree bend about 1/3 of the way into the shielding, for the purposes of calculations the entire duct was assumed to be straight. Once again employing the Rameika methodology for ducts, one gets  $144/\sqrt{16 \times 13} = 9.98$  which corresponds in Rameika figure 1a to a dose attenuation factor between approximately  $1.5 \times 10^{-2}$  for a point source, approximately  $4.5 \times 10^{-3}$  for a line source, and approximately  $1.3 \times 10^{-3}$  for plane or point off axis. The dose attenuation factor of the labyrinth itself,  $6.1 \times 10^{-3}$ , is comparable to the attenuation factor through the duct if one assumes a non point source.

An up to date MARS simulation of the NuMI Absorber Hall has not been completed. For purposes of trying to arrive at some sort of estimate, if one uses the source dose estimates of  $1.25 \times 10^3$  mrem/hour used in late 1999 which assumed an accelerator cycle time of 1.9 seconds,  $2 \times 10^{13}$  protons/accelerator cycle, and thick concrete star densities to dose conversion factor<sup>8</sup> of  $9 \times 10^{-3}$  mrem/(stars  $\text{cm}^{-3}$ ), with an attenuation of  $6.1 \times 10^{-3}$ , one gets 7.6 mrem/hour under normal running conditions. A dose rate in the range of 5 to 100 mrem/hour for normal operating conditions requires "Signs (CAUTION -- Radiation Area) and rigid barriers (at least 4' high) with locked gates. For beam-on radiation, access restricted to authorized personnel."<sup>9</sup>

It should be kept in mind that RAW systems exist in the By-Pass Tunnel in the region near the Absorber labyrinth entrance (see figure 1). The RAW systems are used to cool the decay pipe and the Absorber. The RAW systems requires the use of deionizing bottles to clean the water. In the process of cleansing the water, these bottles become gamma emitters. Prior to their replacement, the bottles can emit doses in the

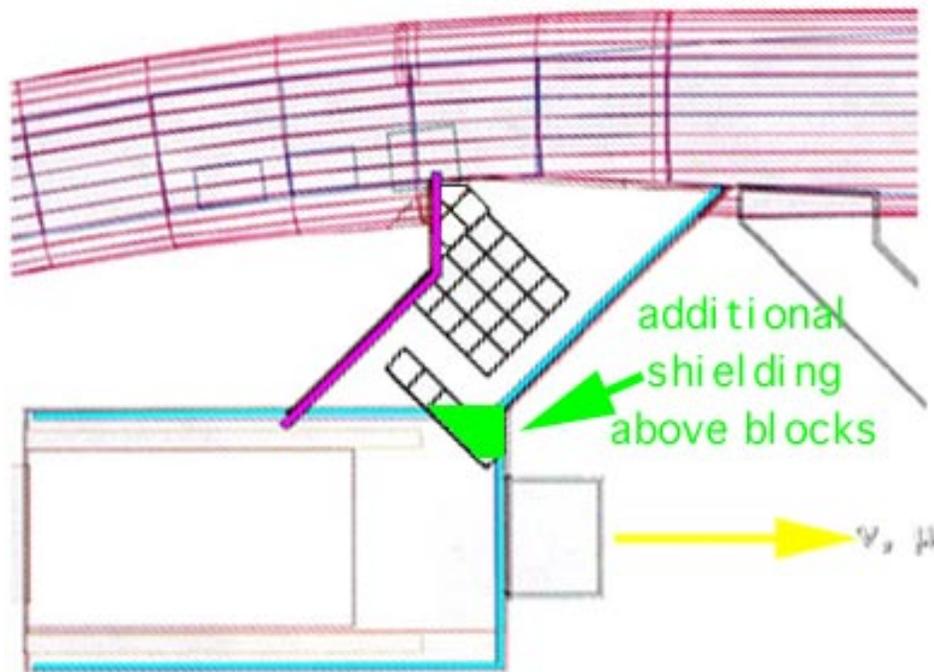


Figure 7

<sup>8</sup> Chapter 8, Fermilab Accelerator Shielding and Radioactivation, Appendix 8B Brief Summary of General Methods of Estimating Shielding, Rev. 1/98.

<sup>9</sup> Fermilab Radiological control Manual, Radiological Standards, Table 2-6, revised November 1997

range of 100 mrem/hour.<sup>10</sup> The half lives of the gamma emitters are measured in years so the potential for exposures to the gammas will remain even when the NuMI beam is off. Once you are several feet away from a deionizing bottle, the dose from the gamma emitting bottles acts as point source and the dose falls off as the inverse square of the distance. Therefore, the dose from the Absorber penetrating the labyrinth into the By-Pass Tunnel and the dose from the RAW systems are likely to be of similar magnitude in the vicinity of where the Absorber Access Corridor meets the By-Pass Tunnel when the beam is on and has been in use for some time.

It should be pointed out that with the proposed labyrinth design, it would be necessary to add some shielding inside the Absorber Hall. The location of the required addition is shown in green in figure 7. A small portion of the blocks that constitute the first part of the labyrinth protrudes into the Absorber Hall. At least 3' of shielding must be provided in that region to match the rest of the shielding that forms leg 1 (see figure 6) of the labyrinth.

The shielding block count for the labyrinth is approximately 25 full sized rectangular cross section blocks and the equivalent of 4 triangular cross section blocks. On 7 June 2001, there were approximately 328 "C" type and 423 "B" type shielding blocks available for use at Fermilab<sup>11</sup>.

Since the sloped ceiling in the labyrinth corridor presents an unknown volume, the amount of sandbags and or small concrete blocks can only be a rough estimate. At present about 400 cubic feet of sand bags and or concrete blocks is estimated to be the requirement.

The proposed labyrinth design attempts to provide sufficient shielding to make the DC beam on dose contribution penetrating the labyrinth similar in magnitude to dose that might be expected from the RAW systems that are located in the By-Pass Tunnel. With this design, the anticipated dose range is expected to be in the 5 to 100 mrem/hour

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<sup>10</sup> M. Gerardi, private communication, 1 June 2001.

<sup>11</sup> Dave Augustine, private communication on 7 June 2000.

range which would require "CAUTION -- RADIATION Area" signs and rigid barriers which are at least 4' high with locked gates. Access would be restricted to authorized personnel with beam on. A more accurate estimate of the dose in the area where the Absorber Hall access corridor meets the By-Pass Tunnel will have to wait the completion of the MARS runs that will provide an up to date source term for the dose at the entrance to the proposed labyrinth.