Fermilab
ES&H Section

RP. NOTE 147

Radiation Dose Rates from the NuMI Labyrinths and Penetrations

Kamran Vaziri

(March 2004)

Author: [signature] Date: 3/23/'04
K. Vaziri

Reviewed: [signature] Date: 3/23/04
N. Grossman

Reviewed: [signature] Date: 3/23/04
D. Cossairt

Approved: [signature] Date: 3/23/04
D. Cossairt
Associate Head, Radiation Protection

Approved: [signature] Date: 3/23/04
Bill Griffing
Head, ES&H Section

Distribution via Electronic Mail*

RP. NOTE 147

Radiation Dose Rates from the NuMI Labyrinths and Penetrations

Kamran Vaziri

March 2004

Introduction

There are several labyrinths and penetrations in the NuMI tunnels and halls for personnel access, connection to equipment, air inlets and exhausts, survey risers and an air-cooling labyrinth. This note describes the results of the radiation attenuation calculations for these labyrinths and penetrations.

Methodology

The general methodology for calculation of the attenuations is described in ref. 1. The source terms are either from MARS simulations[2] when available, or directly calculated[1] using the proton beam parameters[3]. Most of the particle fluences from MARS are calculated right at the entrance to the penetrations, which makes the estimation of the source shape and location unnecessary. At locations where full beam is not normally lost, an average beam loss rate of 0.01% is assumed based on groundwater and residual activation concerns. Accidental beam loss is assumed to be five full intensity pulses. For the calculation of the attenuations of Survey Riser plugs and radiation short circuits attenuation lengths of 2.6 ft. for concrete and 1 ft. for iron are assumed. Polyethylene shielding is only suggested when the MARS results show that most of the neutrons have energies less than 2 MeV. Further information on the neutron spectrum out of MARS can be used to refine these estimates[2]. All dimensions are obtained from the NuMI Radiation Safety Drawings 9-6-7-4[4].

Results

The results are summarized in Table 1. Different penetrations and labyrinths are discussed in the rest of this document.

I. Survey Risers 1,2 and 3

The accident dose rate at the exit of SR-1 is 90 mrem/hr. A combined 3 ft. iron and 1 ft. concrete plug will reduce the accident dose rate to below 50 micro-rem/hr. This reduced dose rate does not require any radiological postings. The plug will also reduce the dose rate due to normal losses to the same classification.

For SR-2 and SR-3 a combined 2 ft. iron and 1 ft. concrete plug will reduce the exit dose rates from accidents and normal beam losses to below 50 micro-rem/hr, that do not require radiological posting.

II. Air Exhaust stacks EAV-1, EAV-2 and EAV-3

Figure 1 shows EAV-1, EAV-2 and EAV-3, and their dimensions. The middle leg at EAV-1 is at 45^o to the other two legs. For EAV-2 and 3 only the vertical part is used in the calculations. The location and direction of the first short leg make their contribution to the source of radiation at the ground level insignificant.

The dose rates at the exit of EAV-1 are insignificant both under the accident conditions and normal loss rates. For EAV-2 and EAV-3 the source term calculated with MARS is due to the interaction of the full beam with the target. Based on the combined dose rates from EAV-2 and EAV-3, the areas around these stacks do not need to be posted. However, because of the possibility of significant radioactive air emissions from these three stacks the area around them will be fenced and posted as Controlled Area and locked.

III.a. Target Hall Labyrinth

The radiation source is strong enough that there is an additional contribution to the radiation field in the second leg due to leakage through the wall (the so called short circuit). This leakage dose rate is calculated as an additional source term. The leakage source is assumed to be in the middle of the second leg of this labyrinth (an averaged location). The leakage term is then propagated through the half of the second leg and remaining legs. The resulting dose at the exit is added to that originated at the entrance to the first leg.

$$S = S_1 [A_{L1} A_{L2} + 10^{(-t/2.6)} \boldsymbol{A_{L2'}}] A_{L3} A_{L4}$$

Where S_1 is the source term, A_{Li} is the attenuation due to leg "i". $\boldsymbol{A_{L2'}}$ is the attenuation of the half of the second leg. The term $10^{[-t/2.6]}$ corrects the source component due to leakage through the concrete. The dose rates under both the normal and accident conditions are low enough that the exit of this labyrinth requires no posting.

III.b. Target Hall Access Door

Target hall is not accessible during the beam operations. There is a 10 ft. concrete door blocking the direct access to the hall. Based on the MARS source term behind the door and attenuation of the concrete, the dose rate immediately outside the door is 0.74 mrem/hr. The classification for this area would be Controlled Area with limited occupancy. Given the location of this area, it is naturally a limited occupancy area.

IV. Horn Strip-line Penetration

The section of the penetration between the horn and the top of the module is not considered here, since the target hall is not accessible during the beam operation. Only the section of penetration between the target hall and the power supply room is needed to calculate the dose to personnel in the power supply room. The source term is calculated at the entrance to this penetration using MARS. The neutron spectrum at the entrance to this penetration is mainly composed of neutrons of energy less than 1 MeV (ref. 2). Polyethylene is an effective absorber of these neutrons. The penetration is modeled as empty, but it is partially filled with the strip-line, which material occupies about 10% of the cross sectional area. Since the rest of the penetration cannot be filled completely, at least six inches of polyethylene sheets may be used near the entrance and exit of this penetration to shadow the penetration to reduce the 136 mrem/hr dose significantly.

V. RAW Systems Penetration

MARS calculations provided the source term at the entrance to this penetration. Similar to the horn strip-line, the section of penetration between the target hall and the RAW room is used to calculate the dose to personnel in the RAW room. This penetration is 95% filled with RAW pipes filled with water, which cuts the amount of radiation leakage greatly. Water is a much more effective shield against low energy neutrons than concrete. As Table 1 shows, the dose rate from the filled penetration is small.

VI. Hadron Absorber Access Labyrinth

The design of this labyrinth is given in ref. 5 and Figure 2. Since access to this area is controlled at the fire door the dose rates are calculated at the door.

In addition to the labyrinth, there are two possible short circuit paths; through the 6 ft. concrete section and the 9 ft. section. The leakages through these two pathways are added to the dose from the labyrinth. The resulting dose rate is 5 micro-rem/hr. This calculation was done assuming the labyrinth is made of ordinary concrete with a density of 2.35 g-cm^2. Some of the concrete bricks used on top of the blocks or along the walls have a density of 1.44 g-cm^2. To check the effects of this lower density, the calculation was repeated assuming the whole labyrinth is constructed with the lower density concrete. The exit dose rate increased to 13 micro-rem/hr, which is still insignificant. However, the dose rate from the shielded RAW system skid near the exit will require that this section of the bypass tunnel to be posted as a minimal occupancy Controlled Area.

VII. Beam-on Dose Rate at the Gate to the Muon-Alcoves 2,3 and 4

The source terms for the NuMI muon-alcoves (see reference 4, drawings A4, A5 and A16) are given in the NuMI note 845[5], which describes calculations done with both MARS and GEANT MonteCarlo codes.

NuMI note 845 gives the muon and neutron fluences at alcoves 1,2 and 3. The neutron fluence in alcove 4 is obtained by using the attenuation in the neutron fluences going from alcove 2 to alcove 3. As the Monte Carlo simulations show these fluences do not scale with attenuation in soil and solid angle for different reasons. Therefore soil thickness and distance was not used for extrapolation from alcove 3 to 4. Alcove 4 is further from 3 than alcove 2 is from 3. As a conservative assumption, the neutron flux attenuation from alcove 3 to 4 is assumed to be the same as that going from 2 to 3.

Alcoves 2,3 and 4 have no direct opening (first leg) to the source of radiation. Therefore, the transport calculations used are those for second and further legs. Figure 3 shows an example of a two-leg approximation to a curved alcove. The angle between the two legs is the angle of curvature of the alcove as given on the drawings.

Most of the muons are in a forward going cone. Being weakly interacting and relatively high energy very few of the muons entering the alcove will scatter at large angles to reach the alcove gate. The insignificant contribution of the muons to the dose rates at the alcove gates are ignored in these calculations. The fluence to dose conversion factor for neutrons behind a thick soil shield from FRCM Table 8-3 is used. Table 2. shows the input parameters used for the calculations.

The results of calculations are given in Table 3. The dose rates are calculated for both the MARS and the GEANT predictions, which are a factor of 30 higher. According to the MARS results the area outside the alcove gates are at most classified as Controlled Area (see Table 2-6 of FRCM). Based on the GEANT predictions the area outside the Alcove 2 is a Radiation Area. If this turned out to be the case, as the drawings show, it is possible to extend the alcove gate by three feet. This extension will reduce the dose rate by 30%, which will reduce the classification to Limited Occupancy.

Regarding the differences between the MARS and GEANT predictions, it is known that MARS dose rate predictions has been extensively benchmarked. However, here is another opportunity to measure the dose rates in the alcoves in front of the muon monitors to compare the prediction power of these two codes.

VIII. Target Hall Air Cooling Labyrinth

Based on the dimensions of the target chase down stream air-cooling labyrinth[7], and the particles fluxes at the entrance to the decay pipe[2], the radiation attenuation through the labyrinth and the subsequent activation of the air handling system were calculated. Using these results and the Barbier Danger Parameters[8] for aluminum and iron, the resulting dose rate on contact from the air-cooling system was calculated. The dose rate calculated is due to the activation by the neutrons passing through the labyrinth and interacting with the air handling system. This is a very conservative assumption, since most of the remaining neutrons will be in the thermal energies range. At this range cross sections for interacting with iron or aluminum are very small.

Table 4 shows the results. The first column shows the four different scenarios of irradiation and cooling times (d=day, w=week, M=month, Y=year). The second and the third columns show the flux to activity conversions for aluminum and iron. The last two columns show the resultant dose rate on contact, from the activated air handling equipment. Note the worst case is one-year irradiation and one-day cooling, which results in 0.23 mrem/hr dose rate on contact.

Radiation leaking through the iron shielding above the grill (see Figure 4) will constitute a short circuit pathway. The current configuration allows for three layers of 9.125-inch thick Continuous Cast Stainless Steel (CCSS). However, only two layers of CCSS are installed. Table 5 shows the dose rates from the induced residual activity in the air handling equipment for two layers of CCSS. The worst case, irradiation of iron equipment for one year and one day of cooling is highlighted in cyan. Tables 4 and 5 show the radiation leaking through two layers of CCSS is a little higher than that coming through the labyrinth.

MARS calculations[2] show that the residual dose rate from the repair-cell is less than 1 mrem/hr. If the ambient dose rates are a few times higher than this, local shielding and planning of the radiological work may be needed.

IX. MINOS Access Shaft and EAV-4

The dose rates at the base of the MINOS access shaft and in the MINOS hall are negligible. No measurable radiation dose rates due to the NuMI beam operations is expected at the top of the MINOS access shaft or the EAV-4.

References

1. K. Vaziri “Dose Attenuation Methodology for NuMI Labyrinth, Penetrations and Tunnels”, Radiation Physics Note. 140, May 2003.

2. B. Lundberg "NuMI Secondary Beam MARS Modeling", NuMI NOTE 1010, March 2004.

3. NuMI Design Parameter Book http://www-numi.fnal.gov:8875/numwork/tdh/TDH_V2_3_DesignParameters.pdf

4. NuMI Radiation Safety drawings 9-6-7-4.

5. Hadron Absorber Labyrinth drawing (2004 version) 8875.114-ME-427796.

6. D. Harris and N. Grossman, “Radiation Dose Estimates for the Monitoring System”, NUMI-NOTE-BEAM-845, 7/8/2002.

7. Fermilab drawings 8875.126-ME-406830, 8875.126-ME-431511.

8. M. Barbier, *Induced Radioactivity*, (North-Holand Publishing Company, Amsterdam and London, Wiley Interscience Division, John Wiley and Sons, Inc. NewYork, 1969).

Region	Normal Loss			Accidental Loss		
	Source	Exit Dose Rate		Source	Exit Dose Rate	
	(mrem/hr)		Comment	(mrem/hr)		Comment
Survey Riser SR-1	3.98E+04	3.42	Needs plug (see text)	1.05E+06	90.12	Needs plug (see text)
Air Vent EAV-1	78832	0.00	OK (loss rate 1E-4)	4.16E+05	0.00	OK
Survey Riser SR-2	3.98E+04	0.21	Needs plug (see text)	1.05E+06	5.53	Needs plug (see text)
Target Hall labyrinth	1.73E+03	0.004	OK	4.56E+04	0.10	OK
Target Hall Equipment Door	5168	0.74	Post as Controlled Area			
Stripline Penetration	16979	136	Needs shielding and posting (see text)			
RAW Penetration	4124	0.06	Pipes will fill voids (see text)			OK
Survey Riser SR-3	497	0.004	OK	1.05E+06	7.60	Needs plug (see text)
Vent EAV-2	400	0.001	OK (locked gate for air emissions)			
Vent EAV-3	400	0.001	OK (locked gate for air emissions)			
Absorber Labyrinth	994	0.013	Post as Controlled Area (see text)			
Downstream air cooling labyrinth			Not accessible during beam on			
* Source term is obtained from MARS calculations for full beam on target. (4E13 ppp, 1.87 sec/pulse)						

Table 1. Source terms, dose rates at the exit and mitigation where needed for the NuMI labyrinths and penetrations.

Protons/spill = 4.00E+13	Spills/hr=1895		
	Neutrons/cm^2/p	mrem/p	mrem/hr
Source- Alcove 2=	1.00E-09	1.60E-15	121.28
Source- Alcove 3=	5.00E-11	8.00E-17	6.06
Source- Alcove 4=	2.50E-12	4.00E-18	0.30

Table 2. Fluxes and their corresponding dose equivalent rates used for the three alcoves.

	MARS	GEANT
Location	DE rate (mrem/hr)	DE rate (mrem/hr)
Alcove 2 gate	0.18	5.43
Alcove 3 gate	0.01	0.30
Alcove 4 gate	9.50E-05	0.003

Table 3. Dose equivalent rates at the gate to alcoves 2,3 and 4.

		With 9.125" wide slots			
Ti , Tc	Barbier D#s(Al)	Barbier D#s(Fe)	Contact Res. Activity Dose rate		
	(mrad/hr)/(h/(s-cm^2))		mrad/hr (Al)		mrad/hr (Fe)
Md	1.50E-05	2.30E-05	1.02E-01		1.57E-01
Mw	4.00E-07	1.10E-05	2.73E-03		7.51E-02
Yd	1.80E-05	3.30E-05	1.23E-01		2.25E-01
Yw	3.00E-06	2.00E-05	2.05E-02		1.37E-01

Table 4. Dose rates from the air handling equipment made of aluminum or iron for different irradiation and cooling times.

	Short circuit with 2 layers of CCSS	
	mrad/hr (Al)	mrad/hr (Fe)
Md	6.24E-01	9.57E-01
Mw	1.66E-02	4.58E-01
Yd	7.49E-01	1.37E+00
Yw	1.25E-01	8.32E-01

Table 5. Dose rate due to air handling equipment residual activity induced by radiation leakage through the CCSS shielding, for two iron shielding thicknesses.

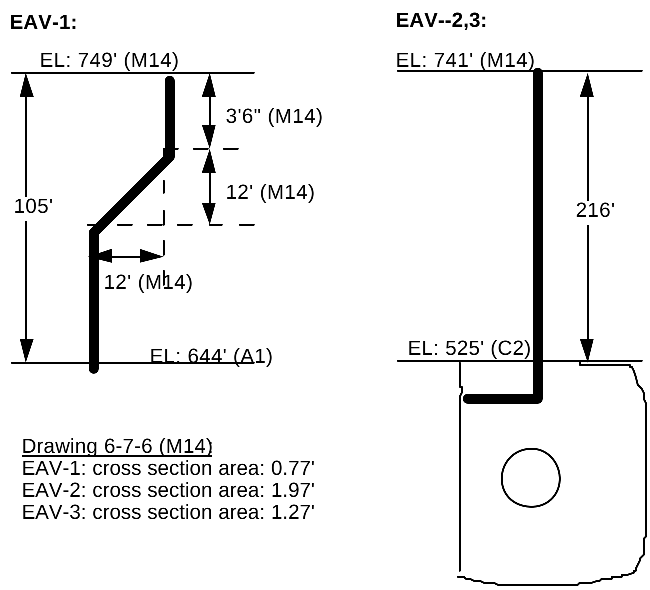

Figure.1. Schematic drawings of EAV1, 2 and 3 with dimensions.

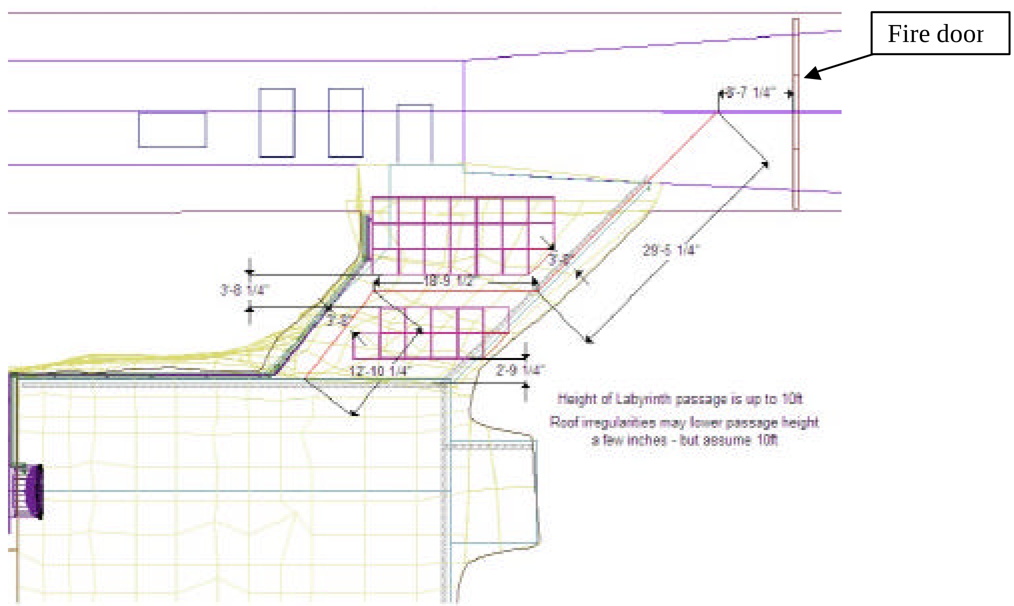

Figure 2. Schematic drawing of the hadron absorber, access labyrinth and the bypass tunnel.

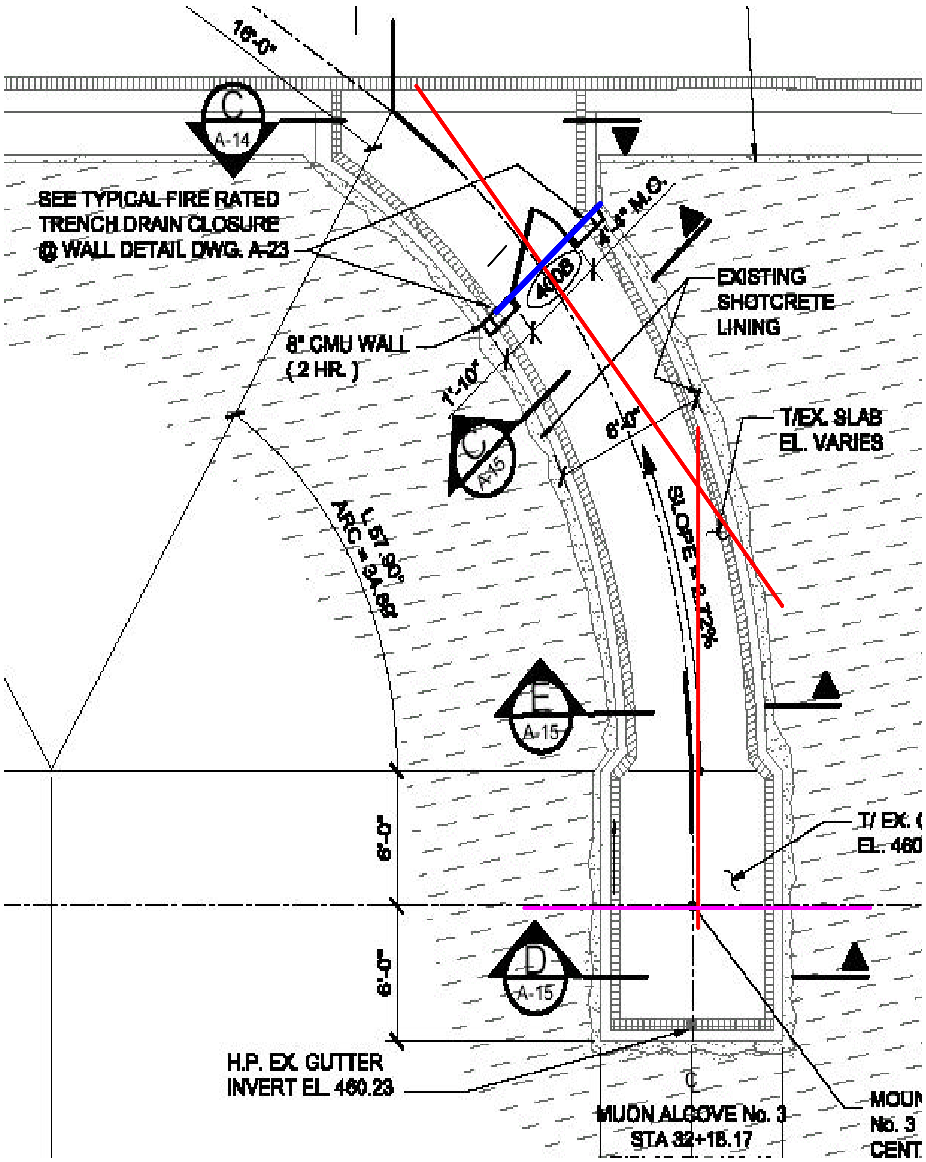

Figure 3. An example of two-leg approximation to a curved labyrinth. The red lines show the straight leg approximation. Leg 1 started at center of the alcove to where it crosses the second leg (red line). Leg 2 is defined from the intersection to the gate of the alcove.

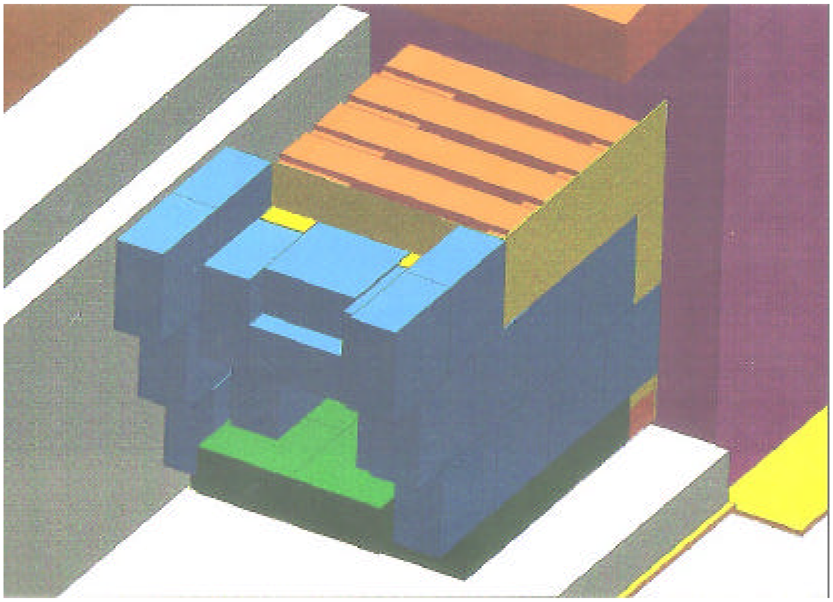

Figure 4. Cut away picture of the NuMI target hall and chase, showing the air passageway through the grills.