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Memo

Date: *April 2, 2016*

To: *RSC, A. Drees, D. Phillips, I. Pinayev, and V. Litvinenko*

From: *D. Beavis*

Subject: *Accessible Penetrations and the Photon Dose from 25 MeV Beam Losses*

Introduction and Conclusions

The dose rate exiting penetrations caused by 25 MeV beam losses are examined. The IR2 shielding has several penetrations which are accessible and the dose rates are estimated in this report. Penetrations that are not accessible such as the vent fans inside the locked berm fence are not estimated. In several cases the exit of the penetration is not directly accessible but personnel may be able to access the shine at some distance from the penetration. The penetrations are the cryogenics penetrations, the two cable ways that are at ground level, access in the tunnel to the B alcove gate in sector 1, and the labyrinth. The dose rates for these and other penetrations were previously estimated[1] for losses of the gun beam at 2 MeV.

Several methods will be used to estimate the dose rate. MCNPX has been used to estimate the neutron and photon energy spectrum and intensity which is then transported in a separate model to and through the penetration. In addition simple empirical formulas using albedo coefficient or labyrinth formulas have been used. The primary goal is not high accuracy but to establish conservative estimates which establish the design satisfies the C-AD shield policy and is ALARA.

The maximum energy of 25 MeV beam will be used for the dose rate estimates. The maximum beam power at full energy is 8500 Watts. The project has noted that the machine protection system will be set to prevent routine losses of greater than 5 micro-amps corresponding to a maximum routine loss of 125 Watts of electron beam at 25 MeV. Typically, it would be expected that the routine loss will be less than this value. The penetrations will be examined for both routine loss rates and full beam loss rates[2] of 8500 Watts.

Table 1 summarizes the results for the penetrations at IR2 where personnel can receive exposure from losses of the 25 MeV beam. The areas have a minimum posting as Controlled Areas. The

[1] RSC Minutes of March 24, 2014; http://www.c-ad.bnl.gov/esfd/RSC/Minutes/03_24_14Minutes.pdf . These minutes have the losses restricted to the low energy beam line.

[2] Localized loss rates of 8500 Watts are not expected to be sustainable. For the total dose in an incident a maximum time of 12 minutes will be used. It is expected that the most likely beam faults will cause machine damage if a short time. Other faults that can last for longer duration are expected to be terminated by either personnel procedures for operating CeCPoP or the machine protection system.

dose rates and potential fault doses are low and satisfy the C-AD shielding policy. The numbers are expected to be conservative. The errors in these results are not expected to be large enough for any area to have conditions that could exceed the shielding policy. Some limited fault studies will be conducted to examine the validity of the design including the bulk shielding. The fault studies are likely to be conducted for beam power from 10-100 Watts. Based on Table 1 it will be difficult to measure any dose rates at the penetrations. If this is the case the minimum detectable level will be scaled to full beam power and determined if the design meets the shielding policy.

Table 1: Dose rates and fault dose from 25 MeV Electron Beam Losses of 8500 Watts

Location	**Routine rate (mrem/hr)**		**Fault Dose (mrem)**	
	photon	**neutron**	**photon**	**neutron**
B Alcove Gate	1	.0006	14	.001
Labyrinth gate	0.7	0.03	10	0.3
Cryogenics pipe	0.7-1.1	0.06	10-15	0.8
North cableway	0.06	0.0003	0.8	0.004
South cableway	0.2	0.0008	2.2	0.01

B Alcove Gate

Personnel can access the gate at the 1 O'clock B alcove from IR12 while CeCPoP is operating with beam. The forward photon dose rate[3] from 25 MeV electrons is $8*10^5$ rad/hr at a meter per kW. The B-alcove gate is located 300 meters from IR2 and the tunnel curves 30 degrees. There is no direct line of sight from the IR to the gate. Forward photons need to be scattered 30 degrees to reach the gate and to be conservative it will be assumed that this is achieved with one scattering[4] halfway down the tunnel. The tunnel is assumed to be uniformily filled with photons which have a albedo coefficient of 0.03. The dose rate at the gate would be 1 mrad/hr for a 125 Watt loss and 70 mrads/hr for 8500 W of beam loss. A chipmunk has been installed on the sector isolation barrier near the gate and would warn any personnel of elevated levels. The maximum estimated dose in an incident would be 14 mrads if personnel ignored the chipmunk. Personnel are trained to move away from radiation monitors that indicate an elevated radiation level and report it to MCR.

The dose rate due to neutrons can be estimated in a similar manner. The 25 MeV electrons will create[5] 1000 rem/hr at a meter for 8500 watts of beam. Using an albedo factor of 0.1 and assuming one scatter with an area of 18.7 m^2 provides an estimated neutron dose rate of 0.004 mrem/hr. In the forward direction the photon dose rate from high energy electron interactions will dominate the neutron dose rate.

Cryogenic Pipe Penetrations

[3] Radiation Protection for Particle Accelerator Facilities, NCRP Report No. 144, National Council on Radiation Protection and Measurements (2003); See Figure 3.5

[4] It is most likely that for CeCPoP at least two scattering are need. However, with LEReC following close behind in schedule and having transport much farther down the tunnel it was decide to be very conservative for now and capture any requirements for LEReC.

[5] This dose rate is estimated using MCNPX with a copper target.

The cryogenic pipes exit the shielding at an elevation of 9.5 feet above the beam, which is more than 14.5 feet above the ground. The pipes exit the tunnel in pairs with a small distance between the penetrations. The holes in the six foot thick light concrete shielding are 60 cm in diameter to accommodate the stainless steel cryogenic pipes which have a diameter of 50 cm and a 0.6 cm wall thickness. Additional pipes are contained inside the main pipe along with other materials. The cryogenic pipes will be approximated as outer pipe of diameter 50 cm and a wall thickness of 0.6 cm with the inner material approximated by a pipe with a diameter of 30 cm and a wall thickness of 0.3 cm. The layout[6] is shown if Figure 1 and depicts the geometry for the cryogenic pipes over the entrance labyrinth. The cryogenic pipes on the other side or the IR exit into a fenced and locked area between the shielding and building 1002B. This penetration can only be illuminated by 25 MeV in the backwards direction and is not an issue for the high energy electrons. The focus will be put on the penetration over the labyrinth.

Direct access is not allowed to the area where the cryogenic pipes exit the shielding. Elevated work in allowed along the labyrinth shielding and the entire area along the shield wall is posted as no ladders or climbing. The closest point of access with line of sight to the penetration exiting the shielding on the 1 O'clock side is about 14 feet along the axis of the pipe and approximately 10 feet in the transverse direction. The dose rate external to the penetrations is estimated by illuminating the area around the penetration with a photon distribution consistent with 25 MeV electrons striking a copper target. The photons are tallied along the penetration and outside the shielding. The dose is then calculated by normalizing the incident photon distribution to the dose expected at the penetration.

The photon dose was tallied at 30 cm increments along the penetration and at several points of interest outside the shielding. The tallied dose rate along the penetration axis is shown in Figure 2. The dose rate at z=1600 cm is at the end of the concrete block that forms the end wall of the IR entrance labyrinth. This location is approximately 15 feet above ground elevation. The dose rate for a continuous full beam loss would be 25 mrads/hr. The two cryogenic pipe penetrations are close to each other, which would make the total dose rate[7] 50 to 75 mrads/hr. The dose in such an incident would be 10 to 15 mrads. This is a Controlled Area and the C-AD shielding policy limits are satisfied.

[6] This is for one cryogenics pipe which is used in the MCNPX model. The result for one pipe will be multiplied later by a factor to account for the second pipe.

[7] The upper limit of 75 is obtained by assuming a single penetration of twice the area and that the dose rate goes as the area to the 3/2 power.

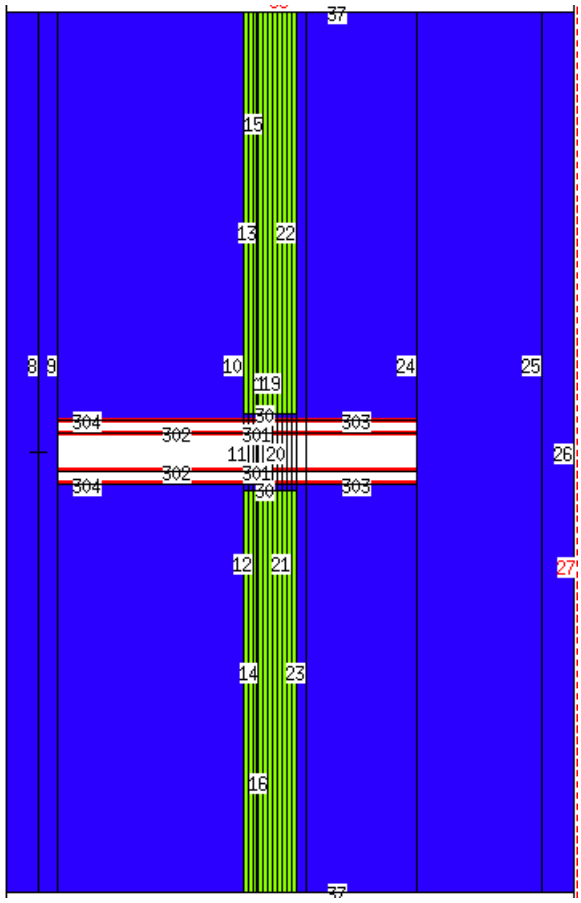

Figure 1: Top view of the model to calculate the dose through a cryogenic pipe port. The cryogenic pipe is approximated as two stainless steel co-axial pipes with an outer diameter of 50 cm inside a 60 cm diameter hole in the light concrete.

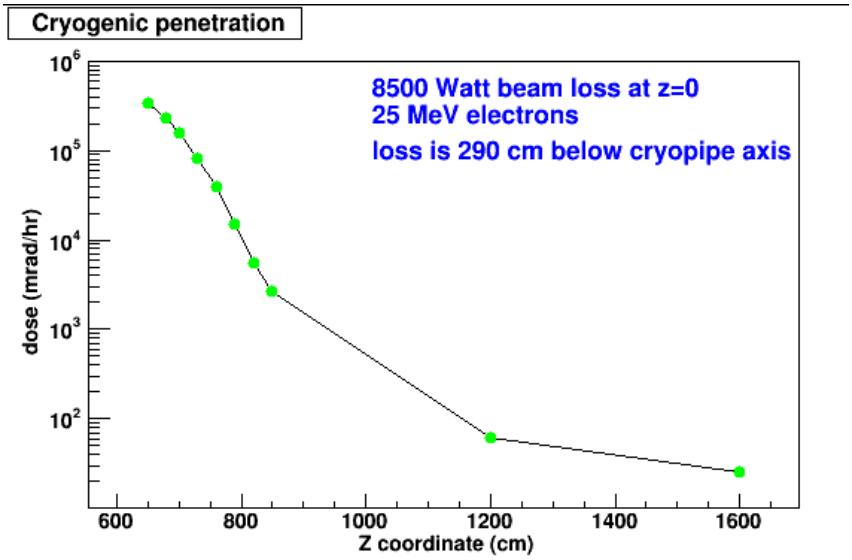

Figure 2: Photon dose rate for a loss of 25 MeV electrons with a beam power of 8500 Watts. The loss occurs at z=0 and at an elevation 290 cm below the penetration axis. The location of z=1600 is at the end of the concrete block which terminates the labyrinth into the IR.

The dose rates at z=1200 cm and Z=1600 were integrated over radial bins to obtain the dose rate as a function of transverse distance. The labyrinth structure[8] prevents access at small transverse distances until one get to the end of the labyrinth structure. The area near the labyrinth is posted to notify personnel that climbing and ladders are not to be used. Z=1200cm was selected since it is the closest location where a person standing on the ground has direct line of sight to one of the cryogenic pipes exiting the shielding. z=1600 cm is the end of the labyrinth structure.

The increase seen in the radial average away from zero is due to a localized hot spot over the top of the cryogenic pipes, which causes an increase in the azimuthally averaged dose rate. A two-dimensional contour plot has been generated from a two-dimensional tally of the dose rate. Figure 4 shows the hot spot which is 180 cm above the cryogenic pipes. This is easily understood since this is a direction that direct photons see the least material when penetrating the shield. The photon dose rate has a peak[9] of 3,000 mrads/hr for 8500 Watts of beam loss. The routine loss of 125 Watts would result in a dose rate of 50 mrads/hr . The photons can create such a peak only if the beam loss occurs in a short section[10] of the beam line almost directly across from the cryogenic pipe penetration. Most of the additional dose in the peak comes from photons in the energy range 1 MeV to 25 MeV.

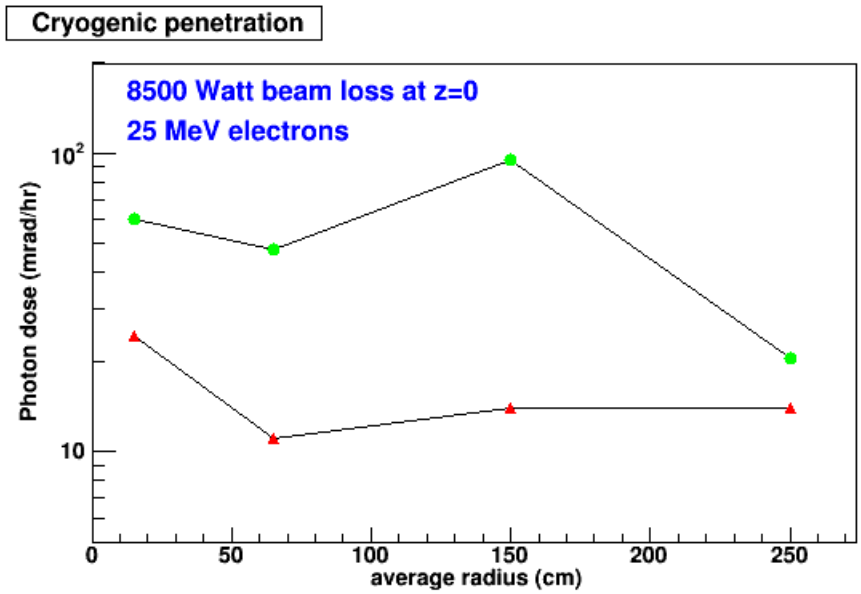

Figure 3: The radially averaged dose rates for photons in four bins with outer radii of 30, 100, 200, 300 cm. The points are plotted at the average radial value.

[8] The concrete forming the labyrinth and the retaining wall are ignored in the calculation other than to determine the location where the closest line-of-sight to the penetration.

[9] The peak at the end of the labyrinth structure would be 8 meters above the ground and assuming reduction with distance from the target of $(12/16)^2$ the dose rate for routine losses would be 25 mrads/hr.

[10] Estimated to be less than 3 meters in length.

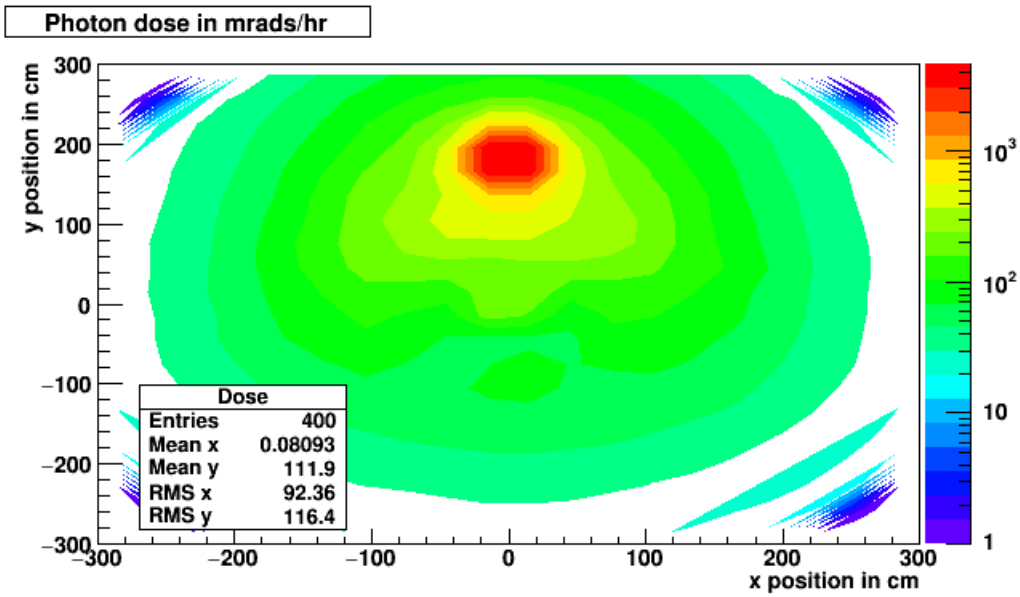

Figure 4: Contour plot of the photon dose rate for 8500 Watt loss of electrons. The center of the cryogenic pipe is x=y=0. The large bin size of 30cm on a side creates the geometric shape to the circular cryogenic penetration. This contour plot is on surface 24, which is 380 cm after the cryogenic pipes exit the shield wall.

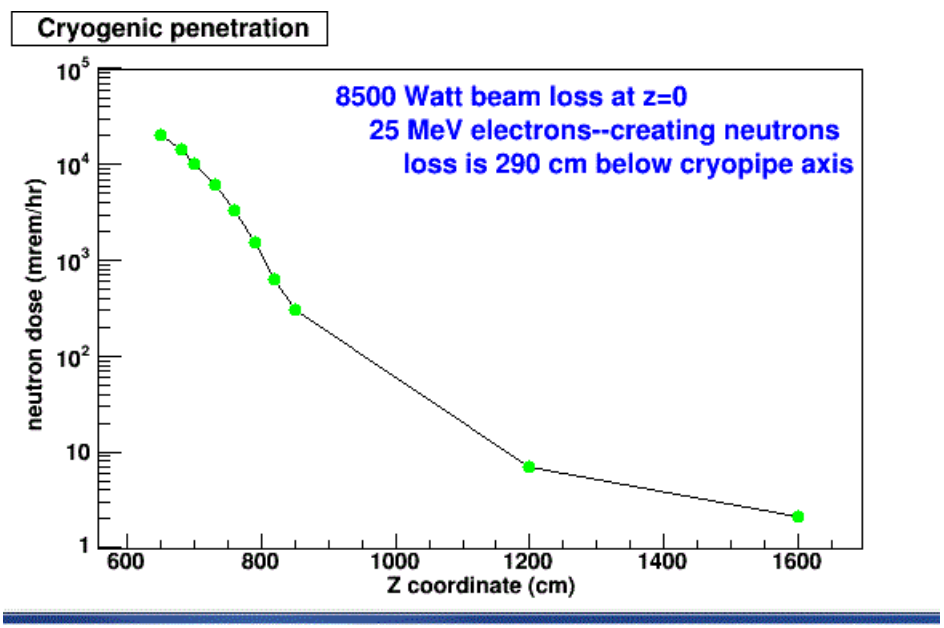

Figure 5: Neutron dose rate as a function of z along the cryopipe axis. The beam loss is for 25 MeV electrons with a beam power of 8500 Watts. The point at z=1600cm is at the end of the labyrinth shielding.

The dose rate for neutrons created by beam losses can be estimated with the same methods used for photons. Figure 5 displays the dose along the axis of the cryogenic pipe penetration. The distribution is similar to the photon dose rate given in Figure 2, but about a factor of 10 lower.

Cableways

The IR has two cables tray penetrations that are at floor level. There are some differences between the two penetrations but both will be assumed to have a width of 80 cm, a height of 30 cm, and a length of 240 cm. Outside the IR the cableway has a vertical shaft made with light concrete shielding blocks. The height is four feet and the back wall has a thickness of two feet. Heavy concrete[11] blocks have been stacked inside the IR to shadow the entrance of the cableway from photons. The blocks form a "shadow" wall 3 feet high, 6 feet wide and 1.5 feet thick that is centered in front of the cableways. A plan view of the north cableway is shown in Figure 6 and an elevation view in Figure 7.

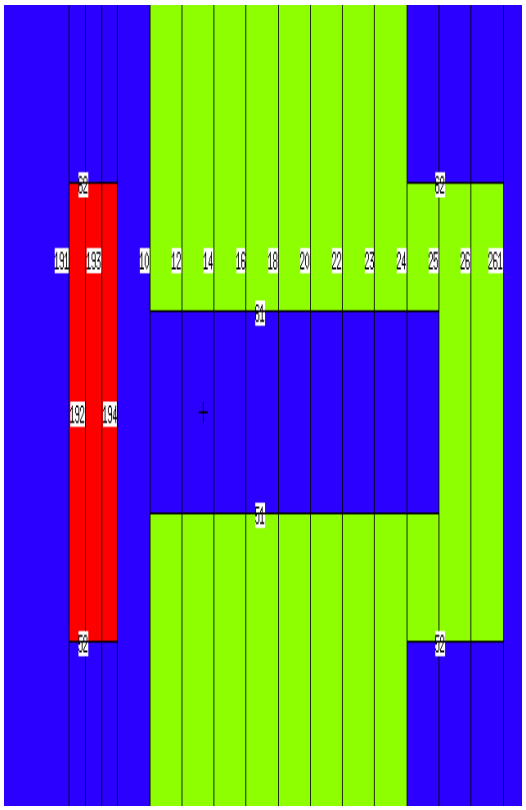

Figure 6: Plan view of the north cableway. The red material is the heavy concrete shadow wall inside the IR, he green material is the light concrete shielding including the four foot high chimney on the outside, and the blue material is air. The plan view is at an elevation of 15 cm above the floor.

[11] In this report heavy concrete has the same composition as light concrete but a density of 3.5 gm/cm^2 rather than 2.35 gm/cm^2. This approximation was considered sufficient for these calculations.

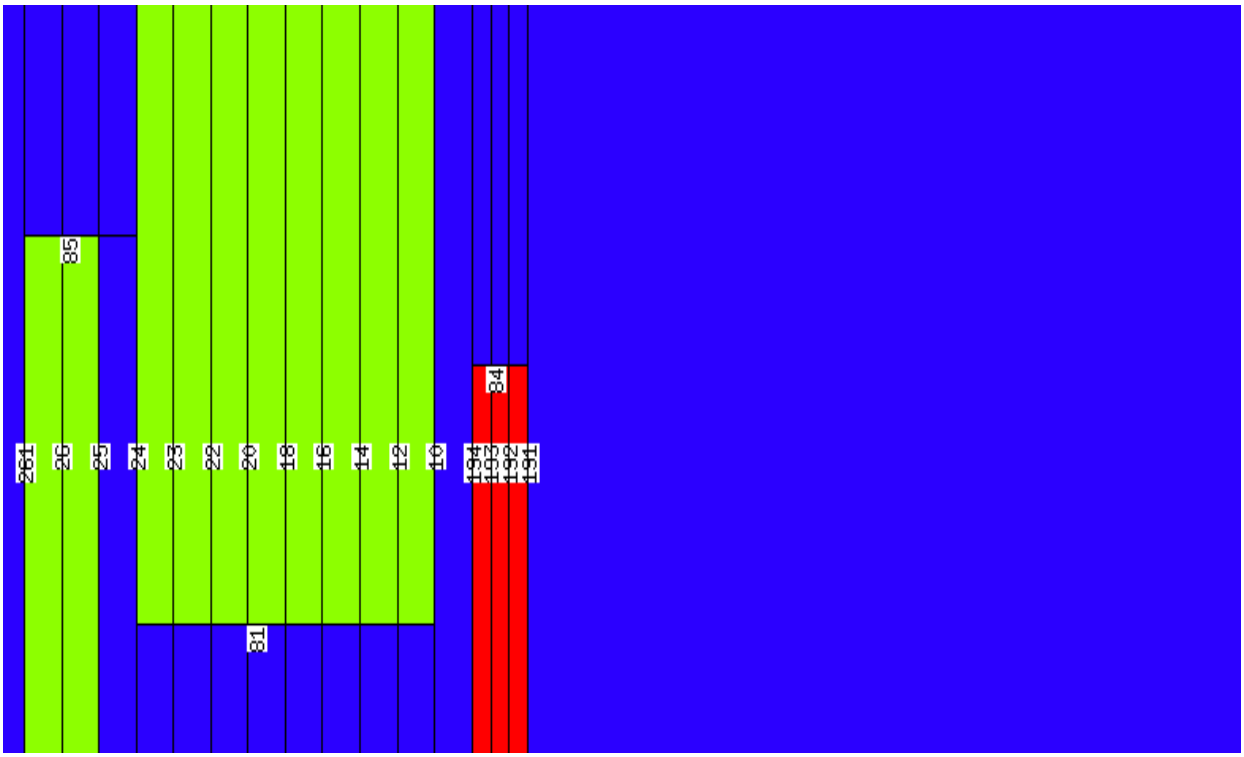

Figure 7: Elevation view of the north cableway. The outside chimney is four feet high and the inside shadow wall is 3 feet high. The source point is in the upper right-hand corner of the plot.

The photon dose rate was tallied in 30 cm increments through the penetration and then one foot outside the back block of the chimney shielding. Three loss points were used to investigate the change with position. A loss directly transverse to the cableway, a loss point 300 cm upstream of the cableway, and a loss point 600 cm upstream of the cableway. The results are shown in Figure 8. The bump in the radiation (blue points) is from the photons missing the side shield and emerging in the penetration a few feet inside. The errors in the last points of the data are quite large but consistent with the data trend as a function of z and the two feet of light concrete. Two feet of light concrete would be expected to reduce the x-rays by a factor of 100. The dose rate is estimated to be 4 mr/hr. With a routine loss of 125 Watts the dose rate would be 0.06 mrads/hr. The dose for a fault lasting 12 minutes would be less than 1 mrad. The dose 1 foot higher above the ground was 50% lower.

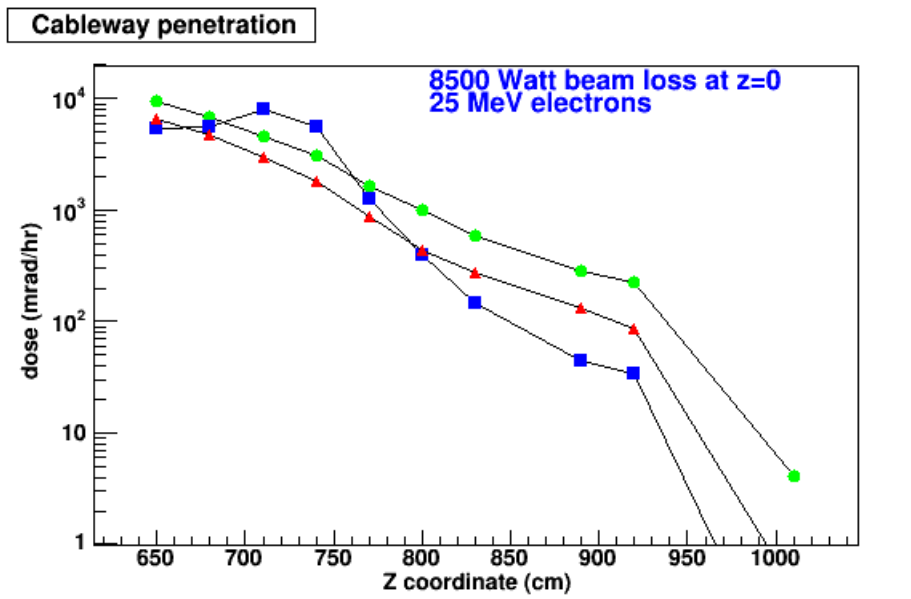

Figure 8: Dose at various locations along the cable way. The source is at z=0cm, the light concrete shielding wall starts at z=650 cm with the main shield wall ending at 890 cm. The green points are for the radiation transverse to the penetration but at an elevation of 150 cm. The red points and blue point are at the same elevation but 300 and 600 cm upstream of the penetration axis.

The geometry of the overlapping blocks on the outside has locations to the side of the penetration where there is less than the two feet of shielding as used in the analysis. The minimum shielding is 30 cm thick and allows the fault dose to be 6 mrad for a small area. These dose and dose rates are essentially at ground level (15 cm above the ground) and are about a factor of two lower at 60 cm above the ground.

The main shield wall was illuminated with photons at several elevations to examine the contribution of albedo from the wall relative to radiation striking the shadow shield. The dose rate at 90 cm into the penetration was nearly 100 times lower for photon striking the wall 150cm above the penetration. The dose into the penetration drops faster than the area of the wall away from the penetration increases. At 300 cm the dose was four orders of magnitude lower. It is not expected that this will contribute a dominate share of the photon dose exiting the shielding.

The dose rate due to neutrons can also be calculated. Figure 9 displays the neutron dose rate as a function of the coordinate along the penetration axis. Z=0 is the location of the RHIC and CeCPoP beam in the common beam transport. The green points are for the source of neutrons at the correct beam elevation and the blue points have the source artificially low at 15 cm above the floor to be in line with the penetration. There is essentially no difference between the two treatments and the errors for the green data point are very large at high z. The z-dependence has three component; the attenuation in the shadow shield (575-620cm), a decrease dominated by the fluence decrease with distance, and finally another attenuation term created by the outside shielding. The direction of the neutron radiation to the port does not have an impact[12] on the

[12] This remark applies to neutrons that strike the shadow shield.

neutron dose rate leaking out. This is due to the low energy of the neutrons and the large scattering that occurs in the shadow shield. The neutron dose rate outside the penetration is about 100 times lower than the photon dose rate.

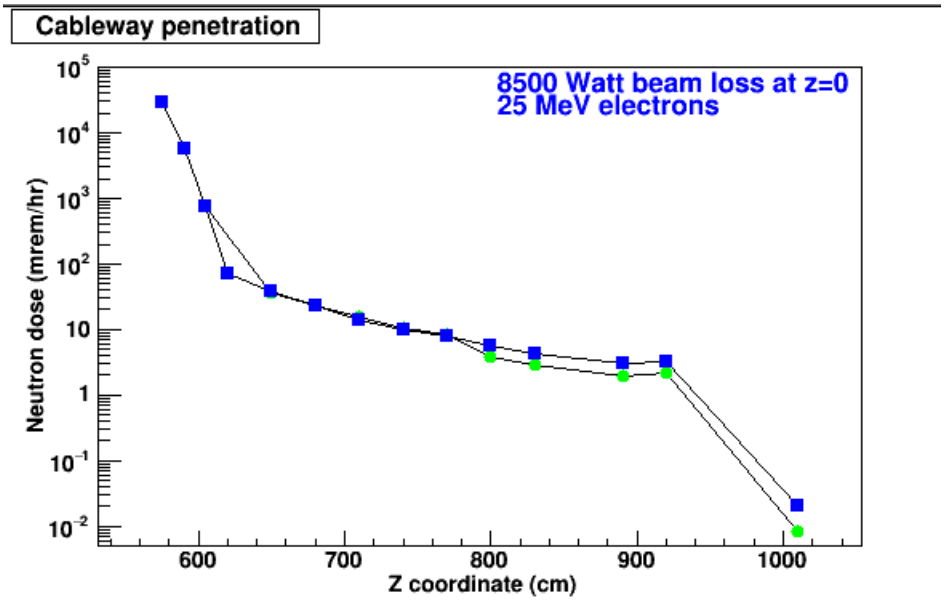

Figure 9: Neutron dose rate as a function of the coordinate along the penetration axis. The green circles are for the standard geometry and the blue squares are if the source is at the same elevation above the floor as the north cable way penetration. The green points are missing a data point at z=620 cm.

The south cable way penetration is almost directly across from the Linac. Based on the discussion above it is not expect that there will be much difference between the north and south penetration due to radiation hitting the shadow blocks. The larger distance between the shadow blocks and the main shield wall may change the attenuation for radiation coming at angle to the penetration. The plan view of the geometry is shown in Figure 10. The penetration was examined as if the 25 MeV can interact at several meters upstream of the penetration, which it cannot do. This provides an overestimate for potential backward radiation from the downstream losses of the 25 MeV beam.

The photon dose rates along the penetration are shown in Figure 11. The two loss locations are 300 and 600 cm upstream of the penetration axis. The statistics are poor for large z points and a factor of 100 was used to account for the two feet of light concrete for the last point rather than the output from MCNPX. The south cable way dose rates are somewhat higher than the north cable way due to the reduced distance from the source. The dose rates are similar and since the highest external dose rate is caused by losses essentially across from the penetration a simple scaling factor can be used based on the change in fluence to the penetration. This should be sufficiently accurate and the scaling factor is 2.8 for converting the north cableway numbers for the south cable way.

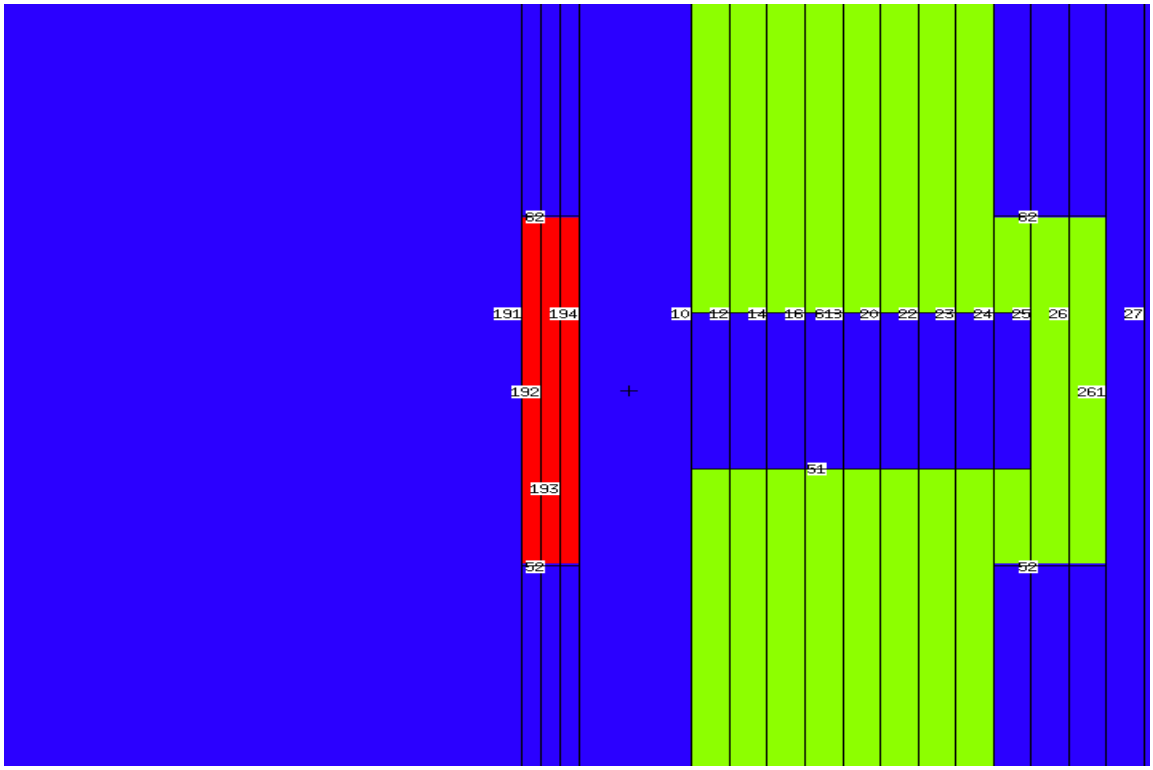

Figure 10: Plan view of the south cableway penetration. The shadow wall in the IR is 90 cm in front of the penetration through the main shield wall.

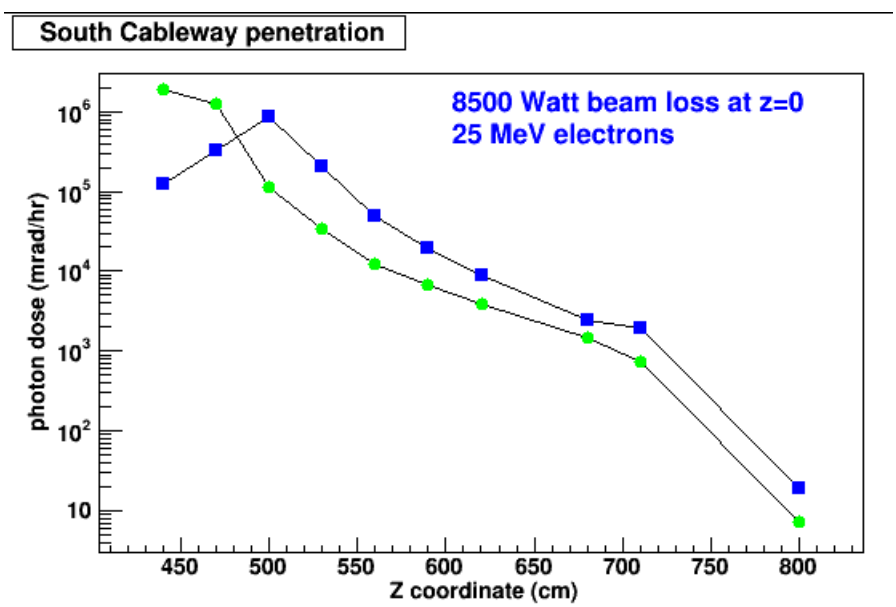

Figure 11: Photon dose as a function of distance along the south cable way penetration. The statistics of the last points become poor. The last point of each curve has been set to 0.01 of the previous point based on data from the north cable penetration. The blue points are for a source 300 cm upstream of the penetration axis and the green circles are for a source 600 cm upstream.

Labyrinth—Gate 2GE1

The dose rate out the access labyrinth to gate 2GE1 can be estimated using labyrinth formulas for the neutrons and albedo coefficients for the photons. There is a limited segment of the electron transport that can illuminate directly into the long leg of the labyrinth, which mean it is treated as two bounces. The other locations along the transport require three bounce for radiation to reach the gate. It will be shown that the two bounce condition creates the highest possible dose rates for both neutrons and photons.

The labyrinth geometry will be approximated with parameters given in Table 2.

Table 2: Approximated Labyrinth Geometry for Gate 2GE1

	Length (ft)	Width (ft)	Height (ft)
First leg	7	3	7
Second leg	20.75	3	7
Third leg	1	4.25	7

The dose rate for photons from a thick target is $8*10^3$ rads/hr at one meter per kW. For a loss of 8.5 kW the dose rate is 68,000 rads/hr. The distance for the locations that can directly shine into the long leg of the labyrinth are approximately sixty feet away. The dose rate at the beginning long leg would be 200 rads/hr. The effective area is approximately 1 foot by 7 feet. Using an albedo formalism with a coefficient of 0.3 provides a dose rate of 50 mrads/hr at the gate. Using a shorter distance appropriate for losses in the common beam transport but three lreflections gives a photon dose rate of 5 mrads/hr. A routine loss of 125 Watts creates a photon dose rate of 0.7 mrad/hr with two bounce conditions. An 8500 Watt beam fault would produce a photon dose of 10 mrads.

The dose rate due to neutrons can be estimated using the neutron dose rate given by MCNPX of 1020 rads/hr at a meter and the universal labyrinth formula given[13] by Goebel et. al. The two bounce condition results in a neutron dose rate of1.7 mrem/hr at the gate. The three bounce condition creates a maximum neutron dose rate at the gate of 0.5 mrem/hr. The maximum estimated neutron dose for an 8500 Watt beam loss is 0.3 mrem. The dose at the gate is dominated by photon dose.

[13] K. Goebel, G.R. Stevenson, J.T. Routti, and H.G. Vogt, “Evaluating Dose Rates Due to Neutron Leakage Through Access Tunnels of the SPS”,CERN-LABII-RA-Note-75-10,1975.