Date: August 26, 2016

To: RSC, D. Phillips, J. Tuozzolo, and A. Fedotov

From: D. Beavis

Subject: Penetration Dose Rates due to LEReC and other Changes at IR2

The LEReC will operate with electron beam energies from 0.4 MeV to 3.0 MeV. Several existing and new penetrations were evaluated for LEReC beam faults. For new penetrations the dose rates were calculated for RHIC beam faults and CeCPoP beam faults. For LEReC gun losses it was assumed that 100 mA at 0.5 MeV is continuously lost. The accelerated LEReC beam will be assumed to have 130 kW of beam power at 3.0 MeV or 2.5 MeV (nominal maximum operation energy is 2.6 MeV). The dose rate for any beam energy can be scaled to appropriate energies.

CeCPoP beam losses will be assumed to be 8.5 kW at an energy of 25 MeV. For RHIC beam the dose rates were evaluated for a of loss $2.5 \times 10^{13}$ protons at 250 GeV.

The eight locations evaluated were:

- 2GE1 Labyrinth
- Survey Shaft to Berm
- Ventilation Shafts
- LEReC Horizontal Utility Penetrations
- Cryogenic Pipe Penetration
- LEReC Laser Port
- North Cableway
- 704 MHz coaxial Waveguide Port

2GE1 Labyrinth

The LEReC gun and accelerated beam can create x-rays that shine onto the wall adjacent to the 2GE1 labyrinth. Figure 1 shows the layout of the LEReC and the shielding near the labyrinth. Photons produced by the gun or beam losses in the transport can illuminate the shielding wall. The higher energy beam will dominate the potential dose through the labyrinth to the gate. The wall adjacent to the labyrinth opening was divided into four sections to estimate the dose entering the first leg of the Labyrinth. The labyrinth is treated as having three legs and a reflection coefficient of 0.03 was used for each scattering. The dose rate at the wall was estimated from curves\(^1\) with a value $7 \times 10^3 \text{R-m}^2/(\text{hr-kW})$. The distance from the beamline to the

\(^1\) See NCRP Report No. 144. Figure 3.5 was used for the dose rate estimate.
The dose rate at the wall is $8.99 \times 10^3$ rad/hr for 130 kW loss of 3.0 MeV electrons. This creates a dose rate of 270 mrads/hr at the gate\(^2\).

The same analysis was conducted for 0.5 MeV electrons at the maximum gun current of 0.1 Amps. The dose rate at gate 2GE1 is 9 mrads/hr. It is expected that this is a conservative estimate and if calculated in MCNPX would be substantially lower. In addition, the beam pipe and vacuum system would likely cause the beam to stop within a short amount of time.

The external chipmunk at IR2, NMO265, will be moved into the Labyrinth. The chipmunk will be located on the end wall of the labyrinth and monitor dose at the end of the labyrinth. An alarm level will be established to alert operators that there are high beam losses. The dose rate at the chipmunk will be about twice that of the gate. An alarm level of 5-10 mrem/hr would be an appropriate alarm level.

---

\(^2\) The bolded results are the ones that are used in the summary table at the end of this report.
Survey Shaft to Berm

There is a 22-inch diameter survey shaft located just downstream of the LEReC bending magnet that deflects the electron beam towards RHIC. The exit of the shaft is inside a locked fence which is swept before beam operations of RHIC, CeCPoP, and LEReC. There are occasions when requests are made to enter the locked fence during beam operations. This work is allowed via the OPM with an appropriate work permit and if the work is performed away from the weak locations where exposure could occur. It is useful to estimate the dose rate out the survey shaft and the ventilation shaft should such an occasion arise in the future with LEReC operations.

The survey shaft is inside the 20-foot diameter tunnel section. Similar shafts have been modeled\(^3\) for hadron beam losses for the 16-foot diameter tunnel sections where the shafts exit onto the berm and access is not prevented by a locked fence. Changes were made to the model to make it appropriate for the estimation of the dose outside the shaft due to 2.5 MeV electrons striking a copper target.

![Model from footnote 3 that has been modified for the LEReC calculations. The RHIC magnet string has been removed and air placed inside the tunnel, shaft, and above the shaft. The photon source is shown as the circle number 39 and is 58 cm from the shaft axis. A one-foot thick layer of concrete has been placed to represent the tunnel floor.](http://www.c-ad.bnl.gov/esfd/RSC/Memos/Survey_Shift_07132012.pdf)

---

The analysis was conducted with electrons striking at target and tracking the electrons and photons through the model. The calculations were repeated with a photon distribution with a restricted angular distribution centered about the shaft entrance in the tunnel. The results were in agreement\(^4\) except that the second method is much more efficient allowing better statistics. The results are given in Table 1. The dose rates around the survey shaft are evaluated at distances of one and two feet from the shaft. If a person is two or more feet away the fault dose rates are “reasonable”.

The Department should determine if these shafts are needed in the future. A plan for reducing the potential dose out survey shafts could be developed to match the future use of the machine. The shaft near LEReC could have additional shielding added inside or outside the shaft. For other shafts around the ring do not presently have a risk of photon dose but it may be wise to consider additional shielding to reduce neutron dose.

<table>
<thead>
<tr>
<th>Height above exit (cm)</th>
<th>Radius (cm)</th>
<th>Dose Rate (R/hr)</th>
<th>comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0-28</td>
<td>236.</td>
<td>RHIC beam 0.9 R/fault</td>
</tr>
<tr>
<td>100</td>
<td>0-28</td>
<td>36.</td>
<td>RHIC beam 0.2 R/fault</td>
</tr>
<tr>
<td>200</td>
<td>0-28</td>
<td>14.</td>
<td>RHIC beam .12 R/fault</td>
</tr>
<tr>
<td>0-100</td>
<td>58</td>
<td>10.5</td>
<td>High</td>
</tr>
<tr>
<td>100-200</td>
<td>58</td>
<td>11</td>
<td>High</td>
</tr>
<tr>
<td>0-100</td>
<td>88</td>
<td>2.3</td>
<td>Reasonable</td>
</tr>
<tr>
<td>100-200</td>
<td>88</td>
<td>3.3</td>
<td>Reasonable</td>
</tr>
</tbody>
</table>

The angle of incidence of the radiation into the shaft coupled with the ratio of the shaft diameter to the shaft length allows photons be directed up most of the shaft and then penetrate the soil for a short distance. Figure 3 displays the 2-dimensional dose distribution 80-100 cm above the ground level. The peak dose is five times the dose over the shaft, about 200 rads/hr. The six-inch poly disc near the top of the shaft is not effective for photons. The poly was replaced with six inches of steel to examine the effect of adding shielding. The peak dose was reduced in area and had a maximum of 60-70 R/hr. The dose directly over the shaft was reduced to 13 R/hr. The shielding is too high in the shaft to have optimum effectiveness. The calculation was conducted with the poly but with the source moved an additional 100 cm away from the shaft axis. The peak is then well centered on the survey shaft with a peak dose of 5 R/hr. This would suggest that placing a shield over the portion of the beam line near the survey port would be an effective means of reducing external dose from a large electron beam losses.

\(^4\) This was conducted to provide a simple check on the normalization factor and distribution used for the second method.
Figure 3: Photon dose tallied 80 to 100 cm above the ground. The peak dose is 200 R/hr and the dose above the survey shaft is 30-40 R/hr.

The need for additional shielding is not necessary to protect personnel from beam faults if they are not allowed into locked fence or it is deemed that other controls including administrative practices to keep personnel away from the survey shaft is sufficient. This would need to be decided by either the RSC or a subcommittee.

The chronic loss of electrons in the vicinity of the survey shaft should be measured when the machine becomes operational. The dose rates for a 0.1% loss near the port would produce a areal dose rate of the order of 200 mrad-m⁻²/hr. For 2000 hours per year the yearly dose at the closest location of the site boundary⁵ would be 0.017 mrad. The closest non-C-AD facility is farther away.

Ventilation Shafts

The LEReC beam transport passes directly in front of ventilation shaft, 1EF3, in the beginning of the twenty foot diameter tunnel section. The tunnel has two ventilations shafts on opposite sides of the tunnel. The one on the inside of the ring is farther away from the LEReC beam transport but has a three foot shorter vertical shaft. The results for ventilation shaft 1EF4 were scaled from results for 1EF3. An elevation view of the ventilation shafts are shown in Figure 4. The MCNPX model has a tunnel diameter of 20 feet and the top of the shaft is 24 feet above the beam height. The MCNPX model⁶ is shown Figure 5. The photon distribution for 2.5 MeV electrons striking a copper target was used to illuminate the shaft opening and the adjacent soil. The photon dose was tallied on surfaces inside the shaft and above the exit of the shaft on the berm. Portions of the tunnel soil not relevant for the calculation are not in the model.

---

⁵ A distance to the site boundary of 780 meters was used.
⁶ In the MCNPX model the floor is soil and is higher than in the actual geometry. This is not expected to change the results.
The elevation at which the shaft penetrates the berm is 94 feet (24 feet above beam height. The source of photons is at beam height and 120 cm from the tunnel wall. The floor is higher than the actual geometry.
The dose rates were tallied at the exit of the shaft at ground level and 50 and 100 cm above ground level. Dose rates were tallied at the interface of the shaft surface, and distances of 30 and 60 cm from the shaft. As can be seen in Figure 4 there is no access\(^7\) over the shaft.

### Table 2: Dose rates for a 130 kW beam loss of 2.5 MeV Electrons at Ventilation shaft 1EF3

<table>
<thead>
<tr>
<th>Height above exit (cm)</th>
<th>Radius (cm)</th>
<th>Dose Rate (R/hr)</th>
<th>comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0-60</td>
<td>12.2</td>
<td>No access possible</td>
</tr>
<tr>
<td>50</td>
<td>0-60</td>
<td>8.9</td>
<td>No access possible</td>
</tr>
<tr>
<td>100</td>
<td>0-60</td>
<td>7.4</td>
<td>No access possible</td>
</tr>
<tr>
<td>0-50</td>
<td>60</td>
<td>11.8</td>
<td>High</td>
</tr>
<tr>
<td>50-100</td>
<td>60</td>
<td>6.7</td>
<td>High</td>
</tr>
<tr>
<td>0-50</td>
<td>90</td>
<td>0.180</td>
<td>reasonable</td>
</tr>
<tr>
<td>50-100</td>
<td>90</td>
<td><strong>0.350</strong></td>
<td><strong>reasonable</strong></td>
</tr>
<tr>
<td>0-50</td>
<td>120</td>
<td>0.040</td>
<td>reasonable</td>
</tr>
<tr>
<td>50-100</td>
<td>120</td>
<td>0.135</td>
<td>reasonable</td>
</tr>
</tbody>
</table>

Ventilation shaft 1EF4 is on the opposite side of the tunnel. The distance from LEReC beam transport to the vent opening is four times greater than for 1EF3. This reduces the entrance dose by a factor of 16. Ventilation shaft 1EF4 exits the berm at an elevation of about 3 feet lower than 1EF3. The dose rate from the shorter shaft would have an attenuation of one-half that of the longer one. The net result would be that the dose rates out 1EF4 are eight times lower than 1EF3 for LEReC beam losses.

The areal dose rate out ventilation shaft 1EF3 is ten to twenty times smaller than that of the survey shaft. Provided beam loss is small near the ventilation shaft the skyshine will not be an issue.

**LEReC Horizontal Utility Penetrations**

The RHIC tunnel has four 16-inch diameter utility ports that were installed for LEReC. The ports were discussed in a previous memo\(^8\) but the final positions are now available. The ports enter the tunnel in the twenty-foot diameter section with varying elevations due to the construction technique. Figure 6 shows an elevation view of the first of the four utility pipes. The first port has an eight-inch diameter entry into the tunnel due to the proximity of a retaining wall. The other ports are 16-inch diameters for the entire length. The plan view of the pipes is shown in Figure 7. The lowest 16-inch diameter port has its center 104 cm above beam height. The LEReC beam is 490 cm from the ports in the horizontal plane. Beam losses at various locations in the LEReC transport can illuminate the port openings without RHIC transport components providing shielding.

The pipes exit the berm inside the locked fence. The pipe axes are perpendicular to the fence with the pipe ends about 7 feet from the fence. The pipes become exposed on the top side about 5

---

\(^7\) It would require a ladder to climb on top of the shaft hood. This is a locked area and access while beam is on would require reviews and it is therefore considered not credible that a person would climb onto the ventilation shaft hood.

\(^8\) D. Beavis, Oct. 9, 2015; [http://www.c-ad.bnl.gov/esfd/RSC/Memos/10_09_15_LEReC.pdf](http://www.c-ad.bnl.gov/esfd/RSC/Memos/10_09_15_LEReC.pdf)
The dose rate along the utility penetration was calculated using a source 136 cm below the pipe axis. The dose rate is shown in Figure 8. The dose rate along the pipe behaves similar to that of a point source displaced inside the front portion of the penetration. The dose rate at the fence is 90 mrad/hr. The calculations were performed for a source 104 cm below the utility port axis. The dose rate at the fence is 180 mrad/hr. Although the 180 mrads in one hour is within the criteria established for RHIC beam faults by the RHIC Project, it is not a desirable dose rate unless one is confident that the beam faults have a limited duration. The area outside the fence is a Controlled Area. The source term used for the calculations is an extreme case and is likely to have a duration of much less than an hour.

Figure 6: Elevation view of the first of four utility penetrations. This penetration has an eight-inch diameter tube for the last few feet due to an interference with a retaining wall.

The penetrations will be loaded with steel conduit which will add substantial mass to the penetration, independent of the cables. The conduits will be welded in place inside the utility pipe and can be considered permanent. A simplified model of the conduits was placed into MCNPX as seen Figure 9. The steel pipes have wall thicknesses of 0.34 cm and 0.30 cm for the 5 and 4 inch diameter pipes, respectively. Since the radiation is scattered down the pipe at a relatively shallow angle to the walls, it would be expected that the dose rate should drop like the diameter of the conduits. The conduits were placed in the first portion of the utility port, from z=490 cm to z= 1170 cm, and the dose rate compared to the calculation without conduits. At 780 cm into the utility port (z=1270 cm) the conduits decreased the dose rate by a factor of ten, faster than expected for a 5 inch diameter pipe. Another factor of 8 would be expected to the fence. Accounting for the attenuation caused by the presence of the conduit the dose rate at the fence for a 130 kW beam loss of 2.5 MeV electrons will be 2 mrad/hr.

---

9 One foot from where the top of the pipe is exposed is where the dose evaluations are conducted. The bottom of the pipe is not exposed until another 2-3 feet.
Figure 7: Plan view of the four utility pipes for LEReC. The transition from the 26-foot diameter tunnel to the 20-foot diameter tunnel is on the right hand side. The fence and power supply building (1002D) are at the bottom of the figure.
Figure 8: The dose rate as a function of distance from the source for LEReC. The green points are for the source 134 cm below the port axis and no conduits. The red curve displays a function of the form amp/(z-d)**2 representing a displaced point source. The blue points are for the LEReC loss 104 cm below the port axis and conduits in a portion of the port, 490 to 1170. The red triangles are for RHIC fault doses with conduit in a portion of the port.

The utility port immediately north of the ventilation shaft could have a contribution from photons that enter the horizontal or vertical portions of the ventilation shaft. The effective length of the utility will be shortened by 200 cm. Figure 8 demonstrates that this change to the length of the penetration will have an impact of less than a factor of 2. The minimum soil between the utility penetration and the horizontal shaft is 53 cm and the minimum distance between the vertical shaft and the utility port is 30 cm. The transverse TVL for soil for 2.5 MeV electron produced photons is 25 cm. The photons travel at an angle of approximately 45 degrees relative to the axis of the utility port, which increases the path length of the soil. The horizontal shaft has at least three TVLs of soil shielding and does not contribute to the exit dose. The vertical shaft has more than 1 TVL of soil and a small area. It should not contribute an appreciable amount to the exit dose rate of the utility port.
Figure 9: A section view of the utility pipe with conduits. This is a modified version of the actual conduit layout. The conduit wall thicknesses were used in the model.

Figure 10: Plan view of the 20-foot diameter tunnel with the LEReC. The end of the transport has the beam dump from ERL without any shielding. The blue arrow shows the location of the closest utility penetration to the beam dump.

The LEReC beam dump can provide chronic radiation to the utility port. Figure 10 displays the layout of LEReC in the tunnel and the position of the beam dump relative to the closest utility
port. The angle between the axis of the utility port and radiation from the beam dump is 82°.
Figure 2.28 of Sullivan\textsuperscript{10} can be used to estimate the transmission of photons through the utility port. The pipe length of 56.5 feet and radius of .667 feet give a length to square root of the area of 48. The curve for a ratio of 50 gives a transmission of less than $10^{-6}$. The dose rate from the dump was estimated\textsuperscript{11} using $2 \times 10^4 \text{ Rads-m}^2/(\text{hr-kW}) \times 130\text{kW} = 2.6 \times 10^6 \text{ rads/hr}$ at one meter. The dose rate at the entrance of the utility port is $2.7 \times 10^4 \text{ rads/hr}$. This would produce a chronic dose rate of $27 \text{ mrad/hr}$ at the exit of the utility port on the berm\textsuperscript{12}. With the presence of the conduits the exit dose would be reduced to 0.3 mrad/hr.

It has been recommended that shielding be placed around the beam dump\textsuperscript{13} to protect equipment and reduce ozone production. If this shielding is added then the chronic dose rates will be small out the utility ports even without taking credit for the attenuation caused by the conduits.

The dose rate for neutrons was calculated for the utility penetrations. The penetrations are far enough from the high-beta quadrupoles that it will be assumed that half the proton beam interacts in dipole D0. A loss of $2.5 \times 10^{13}$ protons at 250 GeV will be used directly across from the utility port. The hadron source was approximated by examining the hadron absorbed dose 4 meters from a proton beam striking a steel cylinder with a radius of 10cm and a length of 60 cm. The absorbed dose for all hadrons was 2.1 times higher than that due to neutrons. The neutron energy distribution was used for the analysis with twice the intensity to account for other hadrons. Neutrons were then emitted from the desired source location with a solid angle encompassing the penetration. The dose due to neutrons is shown in Figure 8 as a function of $Z$. The dose at the fence for a RHIC MCI would be 0.3 mrem.

**Cryogenic Pipe Penetrations**

There was substantial discussion and analysis of the cryogenic pipe penetrations above the entrance labyrinth for IR2 for CeCPoP beam losses\textsuperscript{14}. The same model was used with the source displaced to the location of the LEReC beam transport and the energy distribution of photons for 2.5 MeV electron losses was used. The beam is assumed to have 130 kW at 2.5 MeV. The peak dose\textsuperscript{15} at $z=1200\text{cm}$ is nearly $5 \text{ rads/hr}$. However, the dose rates at a person’s head would be $10 \text{ mrad/hr}$. The peak of the distribution is similar to CeCPoP results but the dose rates are smaller for LEReC away from the peak. The RSC will need to make recommendations as to the controls to prevent access to the peak.

\textsuperscript{11} NCRP Report 144, see figure 3.5. The numbers are for 2.5 MeV electrons creating radiation in the forward direction.
\textsuperscript{12} It is expected that there is a fair amount of conservatism built into this number. The curves of footnote 11 assume a high-Z target material. Self-shielding from the beam dump has been ignored.
\textsuperscript{13} D. Beavis, May 23, 2016; \url{http://www.c-ad.bnl.gov/esfd/RSC/Memos/5_23_16_LEReC.pdf}
\textsuperscript{14} See D. Beavis, April 2, 2016; \url{http://www.c-ad.bnl.gov/esfd/RSC/Memos/4_02_16_25MeV.pdf}
\textsuperscript{15} This $z$ location is about half-way down the labyrinth where a person standing on the ground has a direct view of one of the cryogenic ports. A persons head would be at a $y$ of about 300cm and with $x$ of 100 cm.
Figure 11: Lego plot of the photon dose distribution in x (horizontal) and y (vertical). The distribution is at z=1200 cm.

The gun will be tested to the diagnostic beam dump. The diagnostic beam dump is the copper CeCPoP beam dump, which will be relocated for LEReC. The beam dump will be the routine location where a majority of the beam is lost. It will be assumed that there is no shielding around the diagnostic beam dump and that the entire beam could be lost there or on the beam pipe upstream of the dump. The same model was used to calculate the dose rate outside the cryogenics port for 0.1 Amps of 0.5 MeV beam. The 2-dimensional distribution of the photon dose rate is shown in Figure 13. The punch-through peak is no longer dominate as in the case at 2.5 MeV. **The peak dose rate is 1.5 mrad/hr.** This is an area that cannot be accessed without a violation of the posting for no elevated work.
Figure 12: Layout of LEReC inside IR2. The diagnostic beam dump is shown in the upper left-hand corner of the layout. The blue box after the gun is the location of the booster cavity.

![Layout of LEReC inside IR2](image)

<table>
<thead>
<tr>
<th>Photon dose in mrad/hr for 0.5 MeV</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Dose</strong></td>
</tr>
<tr>
<td>Entries: 400</td>
</tr>
<tr>
<td>Mean x: -1.139</td>
</tr>
<tr>
<td>Mean y: 27.74</td>
</tr>
<tr>
<td>RMS x: 93.3</td>
</tr>
<tr>
<td>RMS y: 113.6</td>
</tr>
</tbody>
</table>

Figure 13: Lego plot of the photon distribution at z=1200 cm. The two peaks are from the leakage out the penetration and the punch-through above it.

![Lego plot of photon distribution](image)
LEReC Laser Port

A penetration will be bored through the side wall concrete shielding to allow the LEReC laser to be directed into the IR. The laser light is inside a vacuum tube which is shown as the purple tube in Figure 1. The elevation of the penetration is 30 cm above the beam elevation. The laser pipe will have an outer diameter of 2 inches and the port will have a 3 inch diameter. The penetration can be illuminated by the RHIC beam, CeCPoP beam, and the LEReC beam. The laser transport will have a mirror box inside the IR2 shielding to bend the beam 90° upwards. A shadow wall will be located between the radiation sources and the penetrations. The close proximity of the laser port, coaxial port, and the cable way will require a common shadow wall.

---

![Photon dose in mrad/hr](image)

**Figure 14: 2-dimensional distribution of the photon dose rate outside the laser port. The dose rate was tallied 30 cm from the shielding. The peak occurs from 3 cm to 9 cm above the center of the 4 cm radius port. There is no shadow shield present in the IR.**

The CeCoP beam has a maximum energy of 25 MeV with a power of 8.5 kW. The dose rate outside the laser penetration is shown in Figure 14. The peak is over 4 R/hr for a full beam fault. Contours of the photon dose rate for a full beam loss of LEReC gun beam is shown in Figure 15. There is no “punch-through” peak for the lower energy. The distribution is centered on the penetration axis. The peak dose rate for the 0.5 MeV beam is 11 mrad/hr. However, this exposure rate is inside the laser transport tube. The average dose rate from a radius of 4 cm to 10 cm is 1 mrad/hr. This is still a small area to use full body exposure criteria. To reduce the dose rate for CeCPoP beam losses or RHIC beam losses a shadow shield will be required. The TVL for light concrete is 16.9 cm. The plan is to place 45 cm of heavy concrete in front of the port providing a reduction of $10^3$. The expected dose rate is less than 0.001 mrad/hr from 0.5 MeV beam losses.
Figure 15: Contour plot of the photon dose rate outside the laser port. The LEReC gun beam is assumed to have a loss of 0.1 Amps at 0.5 MeV. The dose rate averaged over the 4 cm radius penetration is 11 mrad/hr. There is no shadow wall present in the IR.

A 45 cm thick heavy concrete shield was placed four feet in front of the laser port. The analysis for CeCPoP was repeated to determine the effectiveness of the shielding. The dose rate has a peak of 70 mrad/hr above the laser port due to the punch-through photons. The 45 cm of heavy concrete reduced the dose rate by a factor of 60. This dose rate is not a full body dose and is very unlikely to have a duration that is longer than five minutes. The dose rate averaged over a diameter of 40 cm is 2 mrad/hr.

Figure 16: Contours of the photon dose rate for a electron beam loss of 8500 Watts at 25 MeV beam. The peak dose of 70 mrad/hr is above the penetration and due to punch-through photons. This calculation has 45 cm thick heavy concrete shadow shield inside IR2.
The dose from RHIC beam was computed assuming that the loss was $2.5 \times 10^{13}$ 250 GeV protons. The methods discussed for the utility ports were used for the laser port and the coaxial waveguide port. A fault dose of 77 mrem was obtained when averaged over the 8 cm diameter port. **This is reduced to 20 mrem when averaged over a 40 cm diameter area.** Radiation at 45 degrees was assumed to miss the shadow shield. The dose calculated was 0.9 mrem averaged over a 20 cm diameter.

**North Cableway**

The North cable way has a shadow shield that has been designed\textsuperscript{14} for CeCPoP beam losses. The gun (0.5 MeV) is presently sited upstream of the cableway and the Booster cavity (2.5 MeV). The cableway was examined for photon dose rates external to the shielding. The shadow wall is effective for the low energy photons. The dose rate at the exit of the cableway into the light concrete chimney was 0.4 mrad/hr. The two feet of light concrete will provide another three orders of reduction. The albedo from the main shield contributes to the dose rate but should not be an issue for external dose.

The present layout of LEReC as shown in Figure 12 has the 2.5 MeV beam downstream of the cable penetration. The cableway was examined for 2.5 MeV beam losses at the peak of the dose rate distribution\textsuperscript{16}. The 45 cm of heavy concrete provides an attenuation of $9 \times 10^{-4}$. For 130 kW of 2.5 MeV beam lost the dose rate out the cableway into the base of the vertical chimney is 200 mrad/hr. The dose rate outside the chimney at the base will be reduced by two feet of light concrete to 0.2 mrad/hr. The dose rate four feet up using one reflection will be 1 mrad/hr. The albedo off the interior shield wall will contribute to the external dose. A factor of two should provide a reasonable estimate for the combined dose rate, 0.4 mrad/hr at the base and 2 mrad/hr over the top of the chimney.

\textsuperscript{16} This would make the photon spectrum “harder” and more intense.
Figure 17: Updated isometric view of the area near the north cableway with the main IR2 shielding removed. The purple lines are the laser transport tube and the light blue tube is the coaxial waveguide for the 704 cavity in the tunnel.

704 MHz Coax Port

The Project is planning a port for a 15 cm diameter coaxial waveguide for the 704 cavity in the tunnel. Figure 17 shows the area where a port will be drilled through the shielding for a coaxial waveguide. The port will have a diameter of 23 cm to allow the installation of the waveguide. The outer and inner shield walls will be modified to accommodate the waveguides that use the cableway and the new port. The center of the port will be approximately 60 cm above the ground. The waveguide is modeled as an Al tube with an OD of 15.8 cm and a wall thickness of 0.3 cm. The inner copper conductor has been ignored. This geometry has been modeled in MCNPX to examine the potential radiation leakage. The light concrete is assumed to be two feet from the main shielding walls\textsuperscript{17}.

\textsuperscript{17} It will be demonstrated that the electron losses do not require the exterior shielding for the coaxial port. However, the shielding is required for the cableway and the coaxial waveguide is too close to place the side shield for the cableway. Therefore, the port will be inside the concrete chimney.
Figure 18: Two-dimensional plot of the photon dose rate for a 8.5 kW of CeCPoP beam loss. The dose rate is tallied 30 cm from the main shield wall, which would be inside the light concrete chimney. The center of the port is at x=y=0.

X-rays produced from beam losses for LEReC and CeCPoP are examined. The present location of the port is upstream of the Booster cavity but to be conservative we will assume that it is downstream and use the 2.5 MeV beam for LEReC beam faults and the 25 MeV beam for CeCPoP beam faults. The peak of the distribution is slightly below the port with a value of 10 mrad/hr. The distribution has a slight vertical asymmetry due to direct punch-through. The average over the port diameter is 6 mrad/hr. For 130 kW of 2.5 MeV beam losses the average over the port diameter is 2 mrad/hr. These faults are sufficiently extreme that no shielding is required on the outside of the port.

The dose rates for the two sources were compared along the penetration. The shield wall in front of the port is more effective in reducing the x-ray dose from the 2.5 MeV beam loss. After 1.5 meters into the port the radiation for each source has a similar z-dependence.
Figure 19: Photon dose rate as a function of the distance along the penetration. The 25 MeV source is at \( z=0 \) and the 2.5 MeV source is at \( z=-200 \). There is 45 cm of heavy concrete 120 cm before the port opening in the IR.

The fault dose was averaged over the 11.5 cm radius of the coaxial port one foot from the exit of the penetration resulting in 100 mrem. The dose is higher than the photon dose since the concrete shadow wall inside the IR is much less effective in reducing the neutron dose. Figure 20 shows that the peak of the distribution is below the port due to punch-through neutrons. **The average dose over a diameter of 40 cm is 60 mrem.** This is inside a two foot thick light concrete chimney, which will reduce the dose further.

Figure 20: The neutron dose outside the coaxial waveguide port. The peak dose is below the port and has a value of almost 200 mrem.
Figure 17 shows the shadow wall with a side wall. The shadow wall was removed and radiation from RHIC beam faults directed at the coaxial port at 45 degrees. The resultant dose outside the shielding was 40 mrem compared to 100 mrem with the beam fault directly across from the port with a shadow shield. The shadow shield inside the ring does not need a side wall for dose reduction outside the IR shielding. The shadow wall should cover to 45 degrees unless a calculation is conducted for other angles.

**Recommendations and Summary**

The following recommendations have been made:

- Move the chipmunk, MON265, into the labyrinth
- Set a chipmunk alarm level of 5-10 mrem/hr
- Place a monitor TLD on the survey shaft
- Determine the future plans for the survey shafts at RHIC
- Place monitor TLD outside the laser port
- Shadow shield required to 45 degrees for coaxial waveguide port
- Review exterior Cableway chimney for height

The results of the calculations presented in this report summarized in the Table 3.

<table>
<thead>
<tr>
<th>Location</th>
<th>LEReC (0.5 MeV) Mrem/hr</th>
<th>LEReC (2.5 MeV) mrem/hr</th>
<th>CeCPO (25 MeV) mrem/hr</th>
<th>RHIC 250 GeV mrem/fault</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gate 2GE1</td>
<td>9</td>
<td>270</td>
<td>NR</td>
<td></td>
</tr>
<tr>
<td>Survey Shaft</td>
<td>NR</td>
<td>14,000</td>
<td>NR</td>
<td></td>
</tr>
<tr>
<td>Ventilation shaft 1EF1</td>
<td>NR</td>
<td>350</td>
<td>NR</td>
<td></td>
</tr>
<tr>
<td>Utility pipes 1EF1</td>
<td>NR</td>
<td>2</td>
<td>NR</td>
<td></td>
</tr>
<tr>
<td>Cryogenic pipes</td>
<td>[1.5]</td>
<td>10 [5000]</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Laser Port</td>
<td>0.001</td>
<td>NR</td>
<td>2</td>
<td>20</td>
</tr>
<tr>
<td>Cableway</td>
<td>.0004</td>
<td>0.4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Coaxial waveguide port</td>
<td>NR</td>
<td>[2]</td>
<td>[6]</td>
<td>60</td>
</tr>
<tr>
<td>Fault</td>
<td>50 kW</td>
<td>130 kW</td>
<td>8.5 kW</td>
<td>2.5*10^{13}</td>
</tr>
</tbody>
</table>

NR-> Implies Not Relevant. Either the geometry is such that it is not an issue or a larger fault has been shown to be acceptable.

Empty cells -> These cells were calculated in other reports.

[ ]-> These numbers in at locations that are not accessible.