

Memo

Date: *October 9, 2015*

To: *RSC, D Phillips, A. Fedotov, C. Folz, I. Pinayev, and A. Drees*

From: *D. Beavis* 

Subject: *LEReC Utility Ports near IR2*

The Low Energy RHIC electron Cooling (LEReC) project needs utility ports on the north side of intersection region at 2 O'clock (IR2). A request to place four 16 inch diameter steel pipes for the utilities through the berm has been made. The route has been chosen to reduce cable length from the devices in the tunnel to the instrumentation in 1002D.

The pipe locations may change to accommodate the installation technique. It is not expected that this will substantially impact the results reported below unless the vertical position is much lower. The as built will need to be examined to determine if there are any concerns due to possible changes. It is concluded that only minor shielding may be needed for any beam dumps in the vicinity of the DX magnet such as the CeCPoP beam dump or any LEReC tuning beam dump. The shielding could be either near the dumps or external to the utility pipes on the berm. However, the pipes are expected to be heavily utilized and most likely no shielding is necessary.

An elevation view of the proposed layout is shown in **Figure 1**. The penetrations enter the ring well above the beam height, more than eight feet above beam elevation. It has been requested that the pipes have no bends in them to make installing utilities easier. A plan view of the utility pipes is shown in Figure 2. The pipes exit into a locked fence area at RHIC which is classed as a Controlled Area. The area is swept and locked along with the IR roof and the area on the south side of the IR. The routine dose rates in the fenced area are less than 5 mrem/hr but there are locations with potential high dose from beam faults. The fence is located between the exit of the pipes and building 1002D. The area between the utility ports can be prepared to support shadow shielding if needed to reduce dose outside the fence. If the routine dose rate exiting the ports is above 5 mrem/hr then either the posting will need to be changed or a small area around the utility ports will need to be posted as a Radiation Area. Access to the fenced area while beam is operational is only allowed by exception to OPM 4.56.ca.

There are several potential sources of radiation that challenge the entrance of the port in the RHIC tunnel. These are:

- Routine losses of RHIC Beam
- Fault losses of RHIC beam
- Dose from the CeCPoP beam dump
- Routine losses from CeCPoP transport
- Dose from the LERec beam dump (Phase I)
- Dose from the LERec routine losses and fault losses in transport.
- Dose from the LERec gun

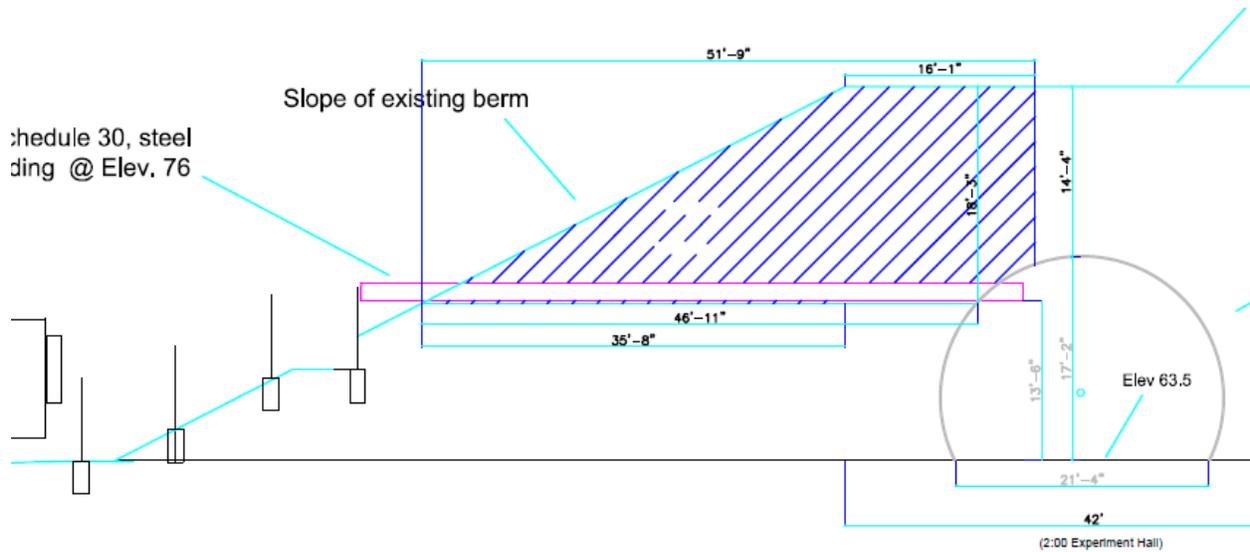


Figure 1: Elevation view of the utility ports on the north side of IR 2 at RHIC. Building 1002D is on the far left. The pipes enter the tunnel near the top of the 26 foot diameter section and exit the berm in the locked fenced area.

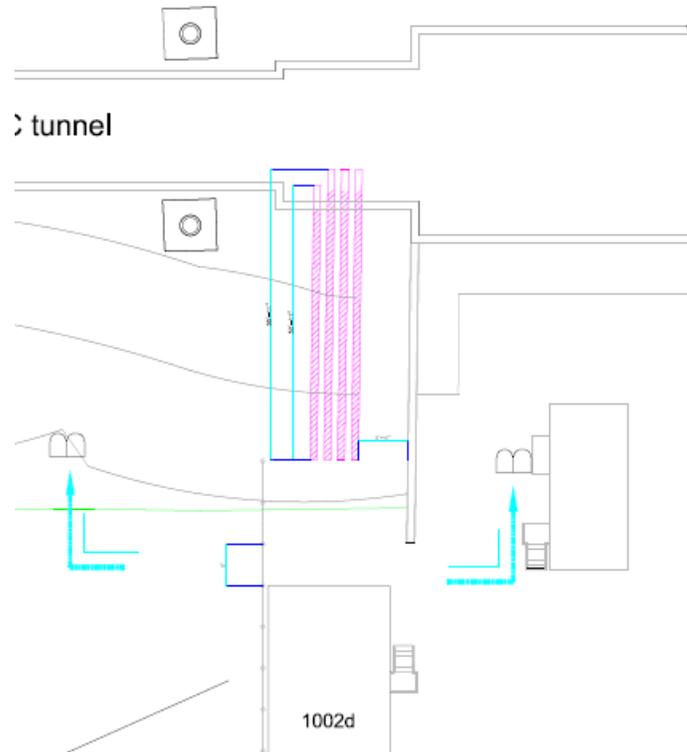


Figure 2: Plan view of the utility ports. There is one pipe diameter between the pipes. There is space between the pipe ends and the fence to install shielding if needed to decrease the dose exiting the pipes or the fenced area.

RHIC Beam Losses

The TLD monitor data from RHIC over the past 15 years has demonstrated that the routine losses¹ at RHIC are negligible. The issue for RHIC beam is the loss in a Maximum Credible Incident (MCI). The utility ports are across from the DX magnet in the tunnel. An MCI on a DX magnet is considered to be 50% of the beam in one ring. Assuming 5×10^{13} protons at 255 GeV gives a dose rate² at the utility port entrance of 137 rem. Attenuation curves for straight penetrations³ suggest that an empty port would have an attenuation of 4×10^{-5} . The method⁴ of Goebel et. al. can be used and a value of 1.4×10^{-5} is obtained for the attenuation. The dose at the exit of the port on the berm would be 5 mrem. This is sufficiently low as to not be a concern for inside the fence or outside the fence.

¹ The initial RHIC Project assumed the losses would be negligible and distributed active radiation detectors (chipmunks) and TLDs to monitor the external radiation environment.

² D. Beavis; http://www.c-ad.bnl.gov/esfd/RSC/Memos/RHIC_labys.pdf

³ A.H. Sullivan, A Guide to Radiation and Radioactivity Levels near High Energy Particle Accelerators, 1992.

⁴ Goebel et al.; 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).

LEReC Radiation Sources

The LEReC effort has two Phases. The details of Phase I layout are nearing completion and are sufficient to make estimates for the penetrations. The details of Phase II layout are not as complete so the potential dose rate into the ports will not be addressed in this report. The beam parameters of the two phases are:

LEReC Phase	electron energy (MeV)	Beam Power (kW)
Phase I	2	60
Phase II	5	250

During routine operations the entire 60 kW of beam will be deposited into the water cooled beam dump⁵. The beam dump is located near the Q3 quadrupole in the 20 foot diameter tunnel section. The proposed layout of the beam transport and beam dump in this area is shown in Figure 1. Radiation created in the beam dump can illuminate⁶ the utility ports. From measurements the distance to the ports is estimated to be 23.1 meters and the angle the radiation makes to the port axis is approximately 80 degrees. Ignoring either self-shielding from the beam dump or shielding around the beam dump the dose rate⁷ at the port is $10^4 \text{ rads/hr} * (1/23.1)^2 = 1100 \text{ rads/hr}$. The attenuation of the photons in an empty pipe can be estimated from Figure 2.26 of Footnote 3 to be $2 * 10^{-5}$. The dose rate exiting the utility pipes will be 2 mrad/hr. It is expected that 60% of the area of the utility port will be filled with conduits and cables. This should reduce the dose rate to negligible levels from the beam dump.

Routine losses have not been estimated for the beam transport from the gun to the beam dump. Electron machines typically have small losses. Use of intrusive instrumentation is usually conducted at low beam intensity to avoid damage to the instrumentation. The beam gun is located in the IR before the 26 foot diameter tunnel begins. The beam transport is opposite the utility penetration on the outside of the RHIC ring. It is reasonable to assume that a routine 1% loss will occur in this section of transport. Based on the geometry a distance of 5.9 meters from the beam loss to the penetrations will be used and the angle of the radiation to the pipe axis is 50 degrees. The dose rate would be $3.5 * 10^5 \text{ rad/hr} * (1/5.9)^{-2} * 2 * 10^{-5} * 0.01 = 2 \text{ mrad/hr}$. Materials in the pipes should reduce the dose rate on the berm should be negligible.

⁵ The present planning has the beam dump from the ERL project moved into the tunnel. This beam dump is rated for over 1 MW of electrons at 3.5 MeV.

⁶ The transition from the 20 foot diameter tunnel to the 26 foot diameter tunnel may shadow some or all of the beam ports from direct radiation. For this estimate it is assume that the ports can receive direct radiation.

⁷ NCRP 144; see Figure 3.5

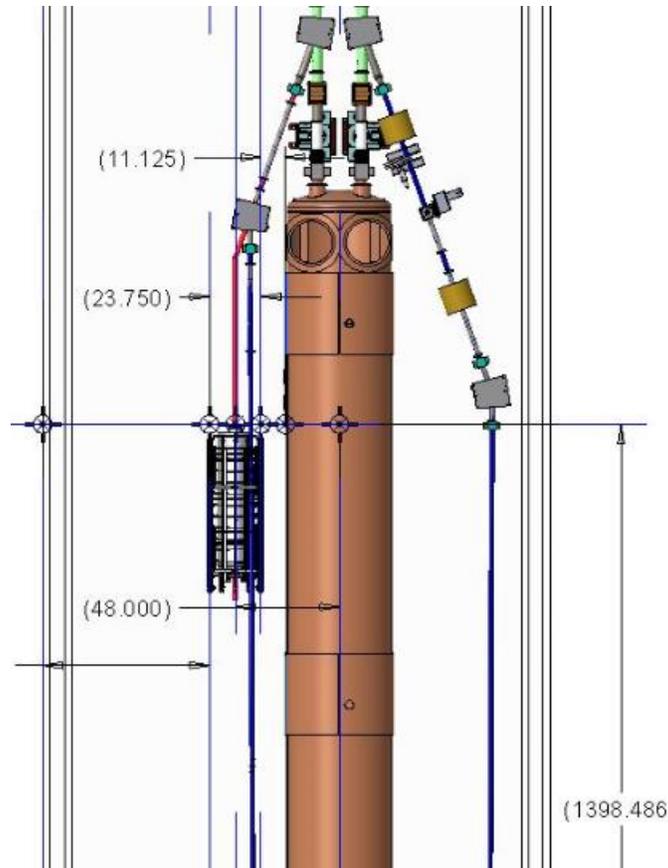


Figure 3: Layout of the LEReC beam line and beam dump at the downstream end of the D0-Q1-3 cryostat. The beaming of the beam into the yellow beam line and the extraction out of the blue beam line to the dump is shown.

The LEReC gun is located in IR2. Figure 4 shows the power supply on the side of the 500kV warm electron gun. The gun is not expected to generate many x-rays while the machine is operating. During the conditioning process⁸ the gun may generate x-rays up to 1000 mrad/hr. Downstream of the gun is the ERL gun cavity which will be used to boost the beam to 2 MeV. The 2 MeV beam system may be tuned to small beam stops, which have not yet been located and their beam-power rating established. To estimate the potential radiation for the penetrations it will be assumed that a tuning dump will operate with 60kW of 2 MeV beam 8.3 feet downstream of the ERL cavity. Most likely only a fraction of the beam will be used for tuning. Based on the plan view the distance from the dump to the penetration is 9.75 meters and the angle to the penetration axis 50 degrees. The estimated exit dose rate from the penetration is $10^4 \text{ rads-m}^2/(\text{hr-kW}) * 60 \text{ kW} * (1/9.75)^2 * 2 * 10^{-5} = 125 \text{ mrad/hr}$. It would be easy to shield the beam dump and reduce this dose rate to acceptable levels. The gun and the cavity are expected to emit several orders of magnitude lower radiation and will not be an issue for the penetrations.

⁸ E-mail from B.M. Dunham to D. Beavis and J. Tuozzolo, Oct. 8, 2015

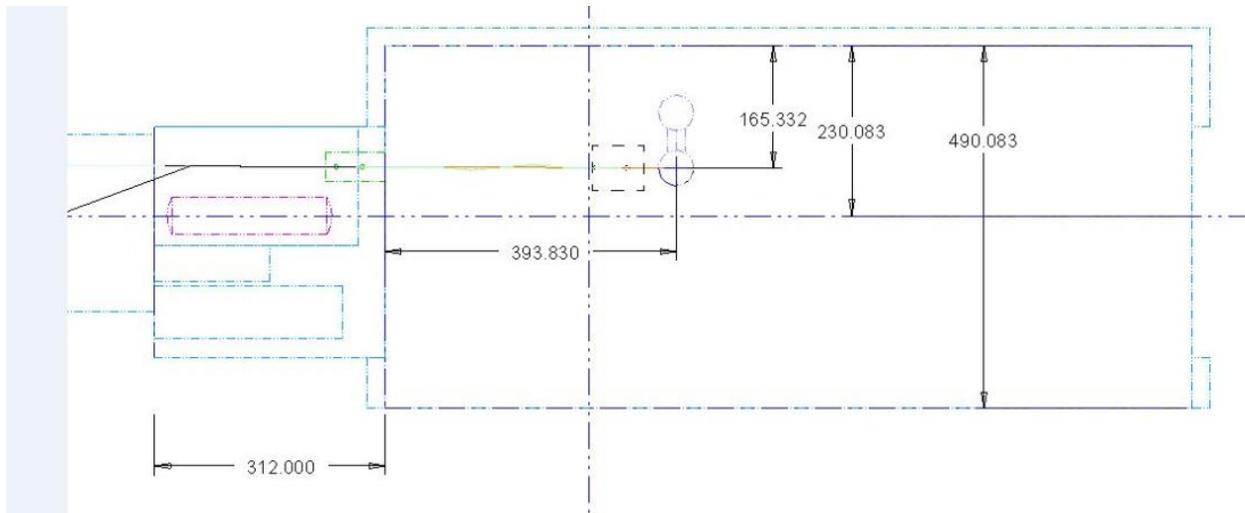


Figure 4: Plan view of the LEReC gun in IR2. The device in the transport across from the DX magnet is the proposed location of the cavity for Phase II.

CeCPoP Radiation Sources

The CeCPoP 22 MeV beam at 8.5 kW has the potential to generate copious gamma rays. Several potential sources of radiation from the CeCPoP beam will be examined. The largest routine source will be the beam dump where 8.5 kW of electron beam will be stopped. Figure 5 shows the beam dump near across from the DX magnet and ending near the tunnel under the IR floor. The beam line and forward radiation points underneath the penetrations which are 11.6 feet above the CeCPoP beam elevation. The dose rates out the penetrations will be estimated using the established layout.

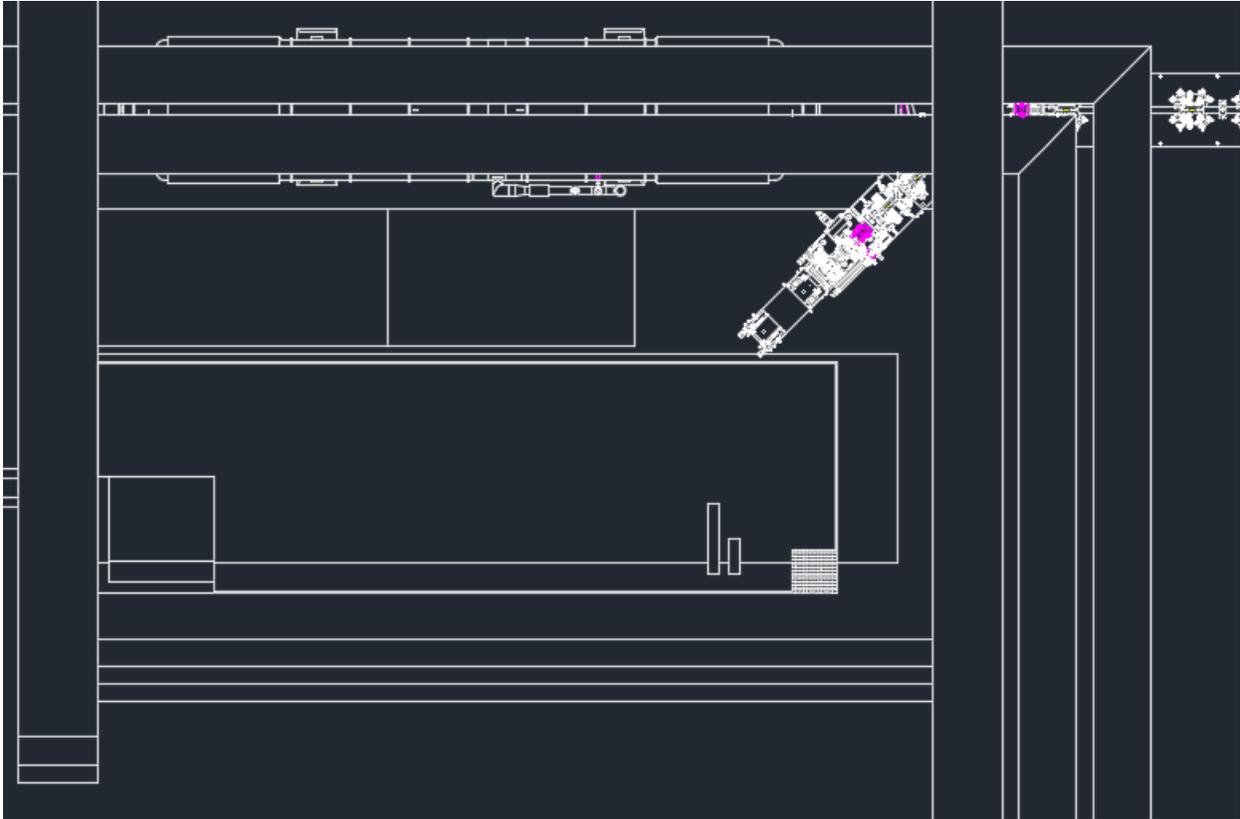


Figure 5: Plan view of the CeCPoP beam dump at the end of the beam line in the 26 foot diameter tunnel. The beam has a 45 degree angle relative to the tunnel axis.

The 8.5 kW of 22 MeV beam into the beam dump will generate $7 \cdot 10^5$ rad-m²/(hr-kW) at zero degrees. The radiation makes a 50 degree angle to the axis of the penetration and angle of 40 degrees and a reduction factor of 0.03 can be used. The penetration openings are 5.3 meters from the beam dump. The dose rate at the penetration opening is $7 \cdot 10^5$ rad-m²/(hr-kW)

* $8.5\text{kW} * 0.03 * (1/5.3)^2 = 6350$ rad/hr. The reduction in dose to the exit of the utility pipe is $2 \cdot 10^{-5}$, which results in an exit dose rate of 130 mrad/hr. Shielding at the beam stop, shielding external to the penetrations, of the material in the penetrations can reduce this to acceptable levels. Any beam fault along the transport would be expected to be smaller than this number due to the increased distance and expected lower sustained power loss at a fixed location.

The beam dump will also generate neutrons. The neutron flux⁹ at a foot is $2.25 \cdot 10^8$ n/cm² per second. The peak of the distribution is at a few MeV and the equivalent dose¹⁰ rate is 32,400 rem/hr at a foot. The neutron equivalent dose rate at the opening of the utility port is 107 rem/hr. The neutron dose rate exiting the pipe on the berm is 1.5 mrem/hr.

⁹ See Fig. 3.18 of footnote 7.

¹⁰ A conservative fluence to dose conversion factor of $4 \cdot 10^{-8}$ rem/(n/cm²) has been used.

The CeCPoP is expected to use multiple devices to monitor the machine performance and keep beam losses for both 22 MeV and 2 MeV to a minimum. These devices will provide defense in depth in preventing large beam losses. Routine losses along the beam line at 22 MeV are expected to be at less than 1% of the beam. Therefore, the maximum expected dose rate out the penetrations would be less than 1 mrad/hr. Losses in the 2 MeV transport are also expected to be less than 1% and have a substantial distance to the penetrations.