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Memo

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

From: *D. Beavis*

Subject: *Dose Rates Out the Lateral Shielding of IR2 from CeCPoP Beam Losses*

This short report examines the dose rate through the lateral shielding at IR2 for CeCPoP beam losses. The estimates for the dose rates will be obtained by scaling 25 MeV calculations[2] conducted for ERL. The dose rates are dominated[3] by losses of the 25 MeV beam. Both routine and fault losses will be considered. However, the beam losses are expected to be close to the intended transport of the electron beams. Large miss-steering of the beam due to magnet failures has already been considered.

Section views of the IR2 shielding were given in an earlier memorandum[4] on CeCPoP. The side wall is 14 feet from the CeCPoP beam line before the first dipole. The common portion with RHIC is another 7 feet further away but this change will be ignored for the side wall shielding. Based on footnote 2 the dose for beam losses of 25 MeV electrons outside four feet of light concrete is $2*10^{-19}$ rem/e at a total distance of 4.2 meters. The side wall at IR2 is 8 feet thick and a total distance of 6.7 meters. The TVL for light concrete is 110 gm/cm^2 so the additional four feet of light concrete provides a reduction of $10^{-(120*2.35/110)}$, which is 0.0027. The increased distance provides a factor of $(4.2/6.7)^2$, which is 0.39. The dose outside the side wall shielding is expected to be $2*10^{-19}$rad/e*($7.65*10^{18}$e/hr)*0.0027*0.39, which is 1.6 mrad/hr for a loss of 8500 watts of 25 MeV beam. The expected routine loss[5] is 5 micro-amperes of beam, which is a 0.0147 reduction to a full beam loss. The routine dose rate through the IR2 side wall shielding would be 0.023 mrads/hr.

The truck door shielding is one foot thinner than the other portions of the side wall. However, the distance from the common beam transport to outside the truck door shielding is 70% larger than the distance used above. The loss of one foot of light concrete coupled with the increased

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[1] There were some TVLs written as e^{-d} rather than 10^{-d} in the text but the numbers were correct. In addition the dose rate through the roof from the dump had a math error the created a very large incorrect value including for the skyshine. These were discovered while writing and checking the RSC minutes of Dec. 9, 2015.
[2] D. Beavis, "ERL Roof Transition", Jan. 13, 2014; http://www.c-ad.bnl.gov/esfd/RSC/Memos/ERL_1_13_14.pdf
[3] From Figure 3 of footnote 2 the photon dose from 2.5 MeV beam losses are 10^{-4} the dose rate from 25 MeV beam losses after four feet of light concrete.
[4] D. Beavis, "CeCPoP Beam Test", March 20, 2015; http://www.c-ad.bnl.gov/esfd/RSC/Memos/CeCPoP_3_20_14.pdf
[5] I. Pinayev, RSC Minutes of Oct 16, 2015; http://www.c-ad.bnl.gov/esfd/RSC/Minutes/10_16_15Minutes.pdf

distance would result in the routine dose being 0.023mrads/hr*$(22/37.6)^2$*$10^{(30*2.35/110)}$. The routine dose rate[6] is 0.034 mrad/hr and the fault dose rate of 2.3 mrad/hr.

The side wall is sufficient for these losses and this will be confirmed by routine surveys and monitor TLDs during commissioning and operations.

The dose rate out the IR roof can be estimated with the same technique. The beam is 5.67 feet above the concrete floor. The ceiling is 27.67 feet from the floor, or 22 feet above the beam. The light concrete roof is 3.75 feet thick. The adjustment for the 0.25 feet of missing concrete is $10^{(30*2.35*.25/110)}$ or 1.45. The distance to the outside of the roof is 25.75 feet. This provides a reduction of $(4.2/7.85)^2$ or 0.286. A full beam loss of 8500 watts creates a dose rate out the roof of $2*10^{-19}$ rem/e *($7.65*10^{18}$ e/hr)*0.286*1.45 or 634 mrads/hr. The roof area is swept of personnel and locked as part of the operations procedures for RHIC beam or CeCPoP beam. The routine dose would be 9 mrads/hr.

The dose rate on the berm over the beam dump can be estimated by assuming that 100% of the beam goes into the beam dump during operations to the beam dump. Under routine operations a few percent may not arrive at the beam dump. The beam dump is inside the front portion of 26 foot diameter tunnel covered with soil. The distance to the outside is the same as the IR concrete roof, which is 7.85 meters. The tunnel is covered with 13 feet of soil, which is equivalent to 10 feet on light concrete. The routine dose rate out the top of the berm is 10^{-2} that of the roof or 0.09 mrads/hr .

The side wall shielding of the IR is shadowed from the beam dump by the steel buoy anchors which were put in RHIC to shadow the side wall from the radiation caused by RHIC beam losses in the high-beta quadrupoles. This steel shielding prevents the beam dump from directly shining onto the truck door or the weak location to the right of the truck door.

The beam dump can also illuminate the IR roof. The dump is approximately 8 feet into the tunnel away from the IR structure. The dump shines on the ceiling at an angle of 30 degrees or greater. This angle provides an increased effective thickness of the roof and an increased distance. The maximum dose rate out the IR roof from the beam dump will be 170 mrads/hr, assuming no self-shielding or additional shielding. This dose rate is conservative but quite large for a routine dose. Although the area is swept and locked it is posted as a Controlled Area. The portion of the IR roof over 100 mrem/hr would require being posted as a High Radiation Area. If 2 TVLs of shielding is added near the beam dump to shadow the IR roof then the roof area can be classified as a Radiation Area. It would require 3.3 TVLs of shielding to reduce the dose rate to Controlled area. The addition of shielding near the beam dump should consider the issue of potential skyshine dose.

The dose out the IR roof creates skyshine that can cause people offsite or at adjacent facilities to receive dose. The off-site dose is computed for all operations assuming a person lives 24 hours a day at the closest location of the site boundary. For on-site facilities occupancy factors can be

[6] Note that the routine loss is the total routine loss distributed about the transport. As such it can be expected that it may not occur so that the peak in the radiation pattern occurs at the truck door.

used. Based on the site map the closest location to the site boundary is 590 meters. The closest adjacent facility not part of C-AD is the sewage treatment facility which is 1240 meters. The site boundary is closer than the nearest facility and the off-site dose limits are much lower than on-site exposure limits so only the off-site exposure needs to be examined.

The skyshine is estimated by calculating the total areal dose through the roof and using empirical formulas or Monte Carlo programs to calculate the transport of the radiation to the distance location. The skyshine photon dose through the roof can be estimated by using

$$H(d) = 2.5*10^{-2}*HO/(d^2),$$

where H is the dose at a distance d in meters and HO is the area integrated dose out the surface. A simple estimate of HO can be obtained by multiplying the peak dose by the area where the dose is 1/3 of the peak value. Using Figure 2 of footnote 2 an area[7] of 88 m^2 is obtained. An estimate[8] for FY2016 operations is 1225 hours of CeCPoP beam to the final beam dump at 1W and 175 hours of beam at 6 kW. The skyshine dose at the site boundary is dominated by high power operations and is 0.007 mrads/yr for routine losses in the transport. The skyshine dose from the beam dump is 0.12 mrads/yr. These estimates are conservative and calculated with 8.5 kW rather than 6 kW.

The empirical formula does not have attenuation due to the air and should become very conservative for distances beyond a distance of 250 meters, which is the recommended limit for distance. The attenuation length appropriate for the scattered x-rays would be less than or about 100 meters. This would reduce the site boundary yearly dose to 1 mrad/yr. It is suggested that additional conservatism in the calculations may reduce this to 0.5 to 0.1 mrad/yr. This is sufficiently small that it would be a small contribution to the boundary dose, which must be less than 5 mrem/yr per facility. There are other contributions from the RHIC facility[9] so one should not think there is plenty of margin.

Two options for the RSC to consider are:

1. Add additional shielding to reduce the beam dump shine onto the IR roof
2. During low power operations make radiation measurements on the IR roof and use that for a shielding design as needed. The advantage of this scheme is to avoid over shielding in a location where there is no crane coverage.

For option 2 to be implemented in a timely fashion there needs to be a base in place that can support the shielding, if necessary. Some additional shielding may be required to reduce the dose rate from the beam dump from residual activity.

The dose presented in this report was calculated for photons. The electron dose was found to be about 10% of the photon dose after the radiation travels through several feet of concrete. The

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[7] An area of 25.2 m^2 is obtained at 4.2 meters. This must be increased by the solid angle to the increased distance of 7.85 meters.

[8] E-mail from I. Pinayev to D. Beavis and D. Phillips, Nov. 10, 2015. There are an additional 320 hours of 1 W operations to the low power beam dump that are ignored in this analysis. No division in energy for the time is given so to be conservative it is assumed that all the beam time is at 25 MeV.

[9] Monitor TLDs have been placed on near the ring road to monitor the potential neutron skyshine dose from the RHIC beam dumps and collimators. There has been no dose measured above background at these locations which are much closer than the site boundary.

neutron statistics were too low in MCNPX to compute the external dose through the thick shields without more biasing techniques and computer time. The dose rate from neutrons can be estimated[10] using simple techniques. There are $3.06*10^7$ J/hr of electrons. Giant Dipole Resonance (GDR) neutron dose is 0.27 mrem*m^2/J. This value is for high energy electrons when the neutron production is essentially saturated. Based[11] on Figure 3.12 of NCRP Report 144 the neutron production should be at least a factor of 4 lower. The neutron production used here will be 0.0675mrem*m^2/J. High Energy Neutron (HEN) dose is usually considered for neutrons above 25 MeV so it will not be computed for CeCPoP beam losses. The attenuation length for GDR neutrons in light concrete is 17 cm.

The routine dose rate out the side wall can now be calculated as was conducted for the photons except the neutron source term and attenuation is used. The dose rate is $H = 0.0675*3.06*10^7 J*(0.0147=\text{routine loss})*e^{-(8*30/17)}*(1/6.7m)^2 = 0.0005$ mrem/hr. The fault dose rate is 0.034 mrem/hr and is expected to be limited to less than 12 minutes or .007 mrem. The routine dose rate out the roof from transport losses is 0.7 mrem/hr and a fault dose rate of 45 mrem/hr but limited in time to a dose of 9 mrem. The beam dump will generate a dose rate out the top of the berm of 0.0005 mrem/hr. The beam dump at full power will generate a peak dose rate out the IR roof of 13 mrem/hr. Shielding used to reduce the photon dose rate from the beam dump will likely be ineffective for neutrons.

The skyshine dose for neutrons is calculated in a slightly different manner than the photons. The skyshine dose[12] $H(d) = HO*\exp-(d/att)*(1./(40+d)^2)$, where H0 is the area integrated and time integrated dose out the IR roof, d is the distance to the location of interest and att is the attenuation length in air based on the upper energy of the neutron spectrum. HO is estimated to be 572mrem-m^2*175 = $1.0*10^5$ mrem.m^2 . H is then given by $1.0*10^5$mrem.m^2*$(1./630m)^2$*exp(-590/210) = 0.014 mrem/yr. This dose should be sufficiently low as to not warrant additional shielding. If shielding is placed near the dump to shadow the IR roof for photons then there will be an additional reduction.

The results outside bulk shielding are summarized in Table 1 below.

Table 1: Summary of dose rates for 8500 Watts of CeCPoP beam

	Routine dose rate mrad/hr, mrem/hr	Fault dose rate mrads/hr, mrem/hr	Fault dose mrads, mrem
Transport-sidewall	0.023, 0.0005	1.6, 0.034	0.3, 0.007
Transport-roof	9, 0.7	634, 45	130, 9
Transport-truck door	0.034, 0.002[13]	2.3, 0.16	.5, 0.03
Beam dump-roof	170, 13	170, 13	na
Beam dump-berm	0.09, .0005	0.09, .0005	na

[10] See P.K. Job and W.R. Casey, "Preliminary Radiological Considerations for the Design and Operation of NSLS II Storage Ring and Booster Synchrotron", NSLS II Tech. Note 13, July 15, 2006.
[11] NCRP Report No. 144.
[12] See section 6.2.1 of footnote 11.
[13] Updated

The results for skyshine to the site boundary are summarized in Table 2.

Table 2: Summary of Skyshine Dose at the site boundary.

Source	Gamma (mrad/yr)	Neutron (mrem/yr)	comments
Dump	0.12	0.014	updated
Transport	0.007	nc[14]	

[14] Not calculate since it is so small.