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Memo

Date: *November 12, 2015*

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

From: *D. Beavis*

Subject: *Faults that Direct the CeCPoP Beam to the Side Wall Shielding*

This short report will examine the issue of magnet faults that can direct the CeCPoP electron beam to the side wall shielding made of concrete blocks. Magnet faults that can direct beam to the outside wall are not an issue for bulk shielding. The layout of CeCPoP is shown in Figure 1. Three dipoles can cause electron beam faults and are shown as blue triangles in Figure 1.

The following faults are considered:

1. Magnets in the wrong polarity
2. Magnets at the wrong bending power
3. Shorted magnets (from partial to full shorts)
4. Any combination of the above.

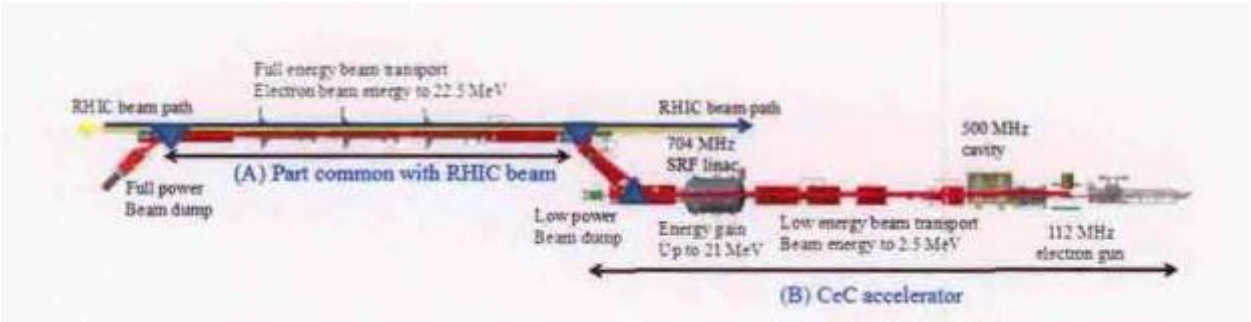

Figure 1: Layout of the CeCPoP in IR2. The three dipoles that bend the electron beam 45 degrees are shown as blue triangles.

Most of these are low probability events to very low probability events. Some of the cases considered may not be credible or may not be possible. There are usually magnet polarity checks before beam operations begin. This reduces the risk of item 1. Initial low power testing of the transport will not only determine mismatches of magnets due to any of the above reasons and decreases the risk of exposure. All the dipoles are in series so either they are all at the wrong bending power or there is a short in at least one magnet. This makes the analysis rather simple.

Case I: The first dipole is in the wrong polarity. This represents the worst case for exterior radiation since it is closer to the shield wall than the other two electron beam bending magnet. Issues of the magnet vacuum box will be ignored and it will be assumed that the magnet can bend 25 MeV beam 90°. The nominal magnet current to bend electrons 45° is 108 amperes[1] and the power supply can operate to 170 amperes[1]. At 170 amperes the electrons would strike the shielding wall at 20 degree off the normal. This would increase the effective thickness of the 8 foot thick shielding[2] to 8.5 feet. Lower energy beam can hit the wall perpendicular to the surface provided the orbit in the magnet is possible.

MCNPX was used to direct an electron beam to the shielding wall. It is assumed that the electrons go through the beam pipe and magnet without interaction. This is equivalent to starting the beam at the inside surface of the wall. The dose for neutrons, electrons and photons were tallied[3] every 30 cm through the wall inside cylindrical surfaces. The dose exiting the wall is $4.5*10^{-18}$ rem/e fot 25 MeV electrons. The calculation was repeated for 15 MeV electrons and the result was $2.4*10^{-19}$ rem/electron.

It will be assumed that the maximum beam current is fixed and equivalent to 8500 Watts at 25 MeV. This gives $2.125*10^{15}$ e/s or $7.65*10^{18}$ e/hr. Thick target formulas4 can be used to estimate the dose outside a shield using figures 3.5 and 4.1 of footnote 4. In using the thick target formulas[4] it is assumed the first foot of concrete is the target. Distance is then measured after the first foot. The calculations were repeated assuming that there was a shield wall one~ foot thick besides the dipole. A comparison of MCNPX with the thick target formula is given in Table 1.

Table 1: Comparison of MCNPX and Thick Target Formula

Energy (MeV}	MCNPX Direct hit mrem/hr	Formula Direct hit mrem/hr	MCNPX Indirect hit mrem/hr	Formula indirect hit mrem/hr
25	34,000	49,000	1,800	1,200
15	3,600	5,200		115
5		10		0.04

The agreement between the simple formula and the MCNPX results is reasonable. The analytic approach can be used to estimate how thick an inside shield wall should be to reduce the dose rate to acceptable levels. The outside area is a controlled area. Typically there is little occupancy near the shield wall. The laser building (1002C) and 1002B are 29 feet from the shielding providing a reduction of 0.18 of dose relative to being at the shield wall. Building 1002D is 60 feet from the shield wall and the increased distance provides a reduction of 0.067 of dose relative to that at the shield wall. It will be assumed that 100 mrads/fault will be the maximum allowed and that operations procedures will monitor for running condition and stop such a fault in 12 minutes. Then the one foot thick of concrete would allow 240 mrads, which is too high. Another foot of concrete would decrease the 25 MeV dose outside the shielding to 44 mrads in a 12 minute fault.

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[1] 1. Pinayev, footnote 6 of RSC Minutes of Oct. 16, 2015;
http://www.cad.bnl.gov/esfd/RSC/Minutes/10 16 15Minutes.pdf
[2] The shielding is actually 8.5 feet thick but has been rounded down to eight feet.
[3] As usual I have cheated and called a foot 30 cm.
[4] NCRP Report No. 144.

The extent of the inside concrete must extend far enough till the angle through the shielding increases the thickness enough to reduce the dose in 12 minutes to 100 mrads. This would require the shield to cover somewhat less than 45 degrees. With the increased distance the dose would actually be 50 mrads in 12 minutes.

It is expected that the Machine Protection System (MPS) will be operational for full power beam. The MPS would turn the beam off in a short time[5]. However, the RSC only gives modest credit for these types of systems. I recommend that the equivalent of two feet of light concrete be added to reduce the radiation levels as discussed above. (This assumes no credit for MPS and a lack of detailed analysis of possible beam orbits in the magnets.)

Case II: The first dipole has a large short and the experimenters tune the magnet current to get the beam into the dog-leg. This means the second magnet and all others are running at a higher current than needed to bend the beam 45°. This fault is covered by the analysis of case I other than the distance from the beam line to the shielding is slightly larger.

I recommend that the same shield design parameters be used as in case I.

Case III: The first two dipoles have large nearly identical shorts allowing the beam to be transported to the third electron dipole. The third dipole will have a field that will bend the beam greater than 45 degrees. Performing the analysis as before the dose rate out the truck door shielding[6] is 60 rem/hr for 15 MeV, which is the highest energy that can be bent to this angle. Placing two feet of light concrete to block the truck door and the transition in the shielding would reduce these levels to 60 mrem/hr. Coupled with appropriate administrative procedures and the MPS we would expect a fault dose of less than 12 mrem. There is a thin spot (see Figure 2) where the wall transitions inward allowing the radiation to penetrate only 5.6 feet of light concrete. The dose rate during a maximum fault would be 600 mrem/hr resulting in a dose of 120 mrem. Additional shielding should be added for these rays or additional analysis to decrease the estimated dose.

I recommend that the same shield design parameters be used as in case I except for the thin location where additional shielding should be used.

I recommend that the RSC consider if they want to establish a set of requirements for the MPS and then allow credit for a specified level of fault reduction.

I recommend that the RSC consider if any of these fault as not credible.

Additional analysis of the possible orbits that can be achieved in the dipole magnets would most likely reduce the beam fault expectations. If the Project conducts such analysis the RSC could consider reducing the energy and angles for beam faults.

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[5] The actual time for the system to respond to an undesired status and terminate the beam has not been provided to the RSC but should be less than 1 second. It is expected that in some or all cases it will be of the order of 0.001 seconds.

[6] The shielding is 7 foot 3 inches of light concrete and will be treated as 7 feet.

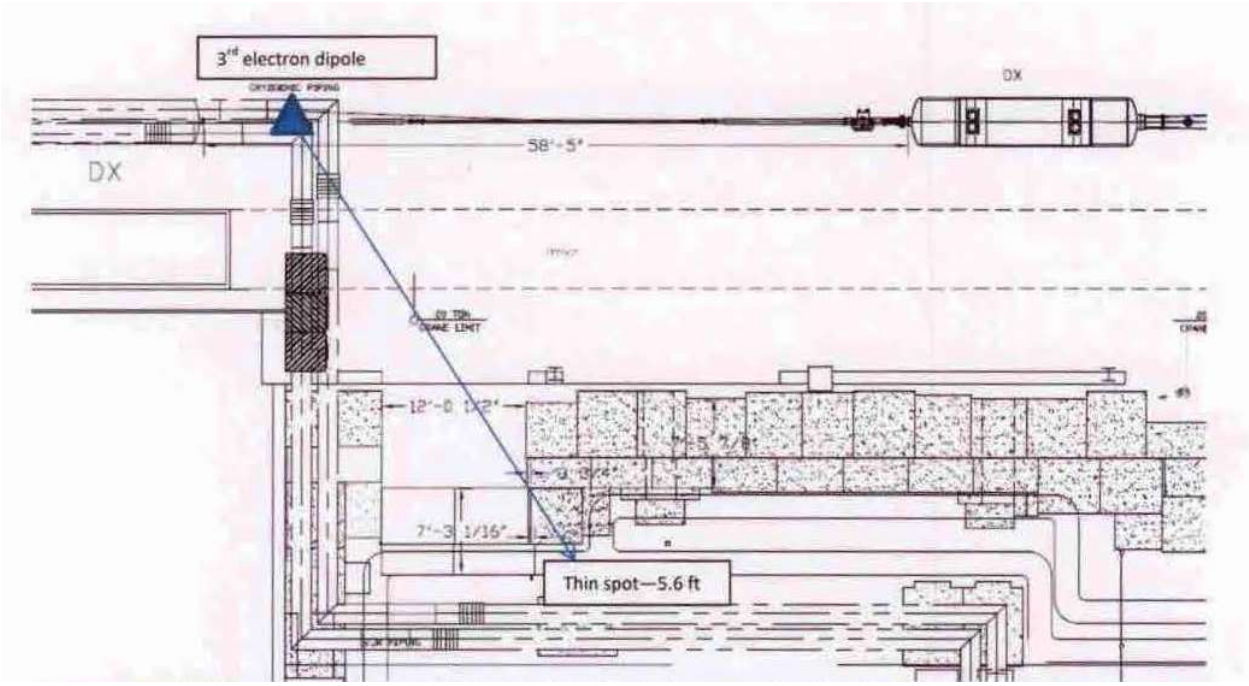

Figure 2: Truck door location relative to the third electron dipole. The arrow shows a location of a thin spot.

The dose presented in this report was for photons. The electron dose was about 10% of the photon dose after the radiation travels through several feet of concrete. The 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[7] 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. 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. Assuming the electrons directly hit the 8 foot thick concrete shield wall and create neutrons in the first foot of concrete then dose rate outside the shield wall is 0.8 mrem/hr. Since we are examining beam faults in the forward direction it is expected that the dose from photons will dominate.

The RSC needs to review and recommend the final implementation of this analysis. (CK-CEC-Nov. 20 2015-Karol & Beavis-1000)

[7] See P.K. Job and W.R. Casey, "Preliminary Radiological Condierations for the Design and Operation of NSLS II Storage Ring and Booster Synchrotron", NSLS II Tech. Note 13, July 15, 2006.