Collider-Accelerator Department

BROOKHAVEN NATIONAL LABORATORY

Building 911B – P.O. Box 5000
Upton, NY 11973-5000
Phone 631 344 7124
Fax 631 344 5568
beavis@bnl.gov
www.bnl.gov

managed by Brookhaven Science Associates
for the U.S. Department of Energy

Memo

date: *July 31, 2012*

to: *RSC*

from: *D. Beavis*

subject: *Dose near 22-inch Diameter RHIC Survey Shafts during an MCI*

The RHIC beam intensity and energy may soon be increased provided the machine upgrades are completed and the analysis and any appropriate modifications of the RHIC areas are completed to provide adequate radiation protection. In many cases the RHIC Project results can be scaled. In addition, some areas have been recalculated to check the results. More up-to-date Monte Carlo programs are available to simulate the radiation then used by the RHIC Project. In this note the equivalent dose exiting the largest diameter survey shafts that penetrate the RHIC shield are examined.

The Maximum Credible Incident (MCI) for radiation will be considered to occur with half the beam in one ring striking a magnet. This is the original RHIC Project assumption and has also been accepted by present C-AD Management. Special locations such as the primary collimators and high-beta quads are assumed to have the potential for 100% of the beam to interact. The special locations are typically underneath fenced areas of the berm where access is prohibited without special permission.

The large survey shafts were discussed[1,2] in RSC meetings in the late 1990's. For an MCI it was determined that the dose outside a shaft would be 2.2 rem. This dose would be reduced[3] to 255 mrem if a six-inch thick polyethylene plug was placed into the shaft. These large shafts have the poly plugs in them. Smaller diameter shafts have thinner disks of poly in them.

Calculations and Results

The calculations conducted in this note are essentially the same as the calculations conducted for the RHIC ventilation shafts (B1 and B2), which use the Monte Carlo program MCNPX. For details on the method of calculations the reader should refer to reference 4. The changes in the geometry are taken into account when simulating the problem. The ventilation shafts are two-legged penetrations while the survey shafts are a single straight penetration. The survey shafts do not have cables or other utilities routed in them, which might provide additional attenuation.

The techniques discussed by the RHIC Project in RSC minutes should have provided a reasonable estimate of the potential exposure. The RHIC project[5] used the old neutron quality factor multiplied by a factor of two. After examining the energy distribution of neutrons that exit the ventilation shafts the author thought it might be worthwhile to re-examine the large reduction

achieved by the poly in the survey shafts. This was the motivation to check the survey shafts rather than scale the RHIC Project numbers.

Figure 1 has depicts the model used in MCNPX. The axis of the shaft is displaced in x by 160 cm from the center of the RHIC ring; the ring magnet is displaced in x by 50 cm. The top of the shaft penetrates the berm at a height of 730 cm above the centerline of the tunnel. Figure 2 displays the same shaft as figure one except it is enlarged and has six-inches of poly inside. The top of the poly is six inches below the berm surface[6] and has a one inch gap around the perimeter. The ploy is treated as C_2H_4 with a density of 0.94 grams/cc.

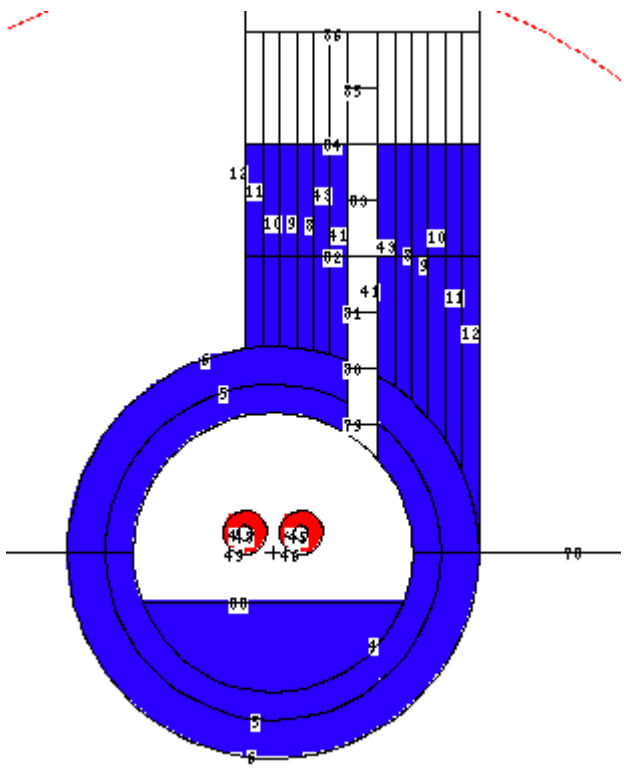

Figure 1: A 22-inch diameter survey shaft at RHIC used in the MCNPX program. The equivalent dose is calculated on surfaces inside and outside the shaft.

The equivalent dose will be averaged over surfaces concentric with the shaft diameter or perpendicular to the shaft diameter. Typically the dose is estimated 3 feet above a surface that personnel stand on. The surfaces perpendicular to the shaft axis are averaged over the diameter of the shaft and calculated at berm elevation, 1 meter above the berm and 2 meters above the berm. The results are given in Table I.

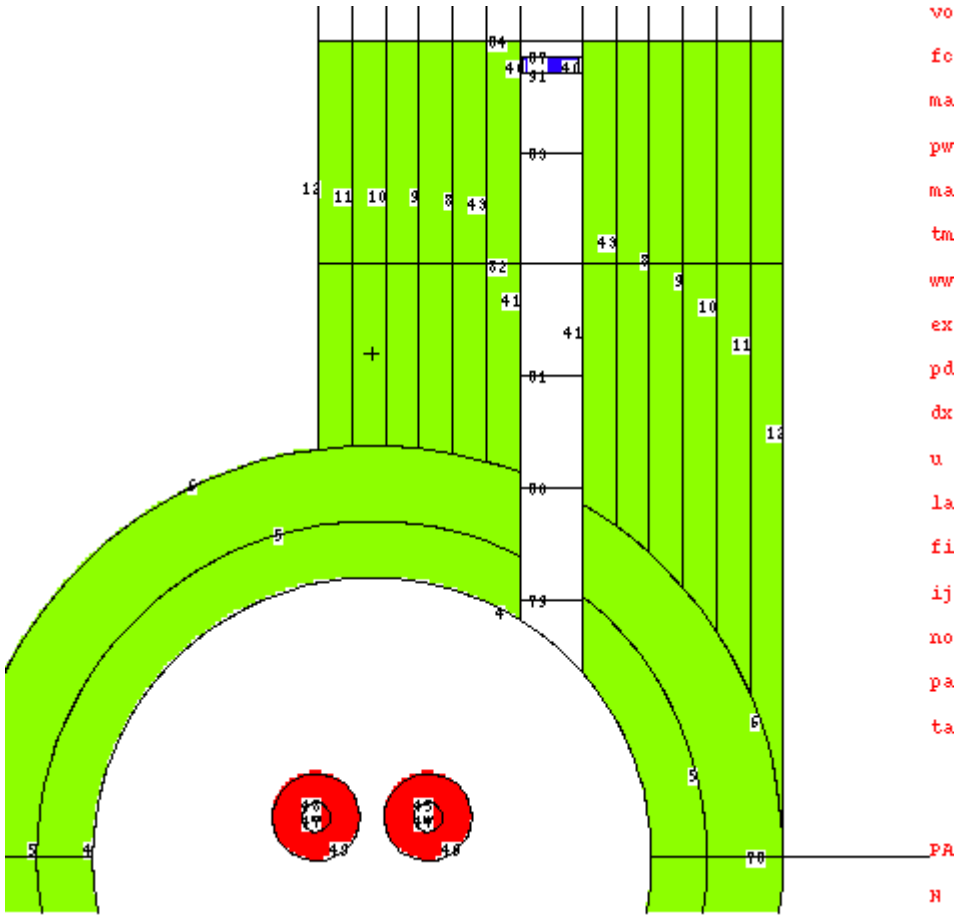

Figure 2: A blow-up of the geometry shown in figure 1 except that a piece of six-inch thick poly is inside the shaft close to where it exits the berm.

The equivalent doses given[7] in Table I are consistent with the results reported in the RSC minutes. At a height of one meter (3 feet) above the survey shaft the equivalent dose is a factor of ten times smaller when six inches of poly is in the shaft compared to none. During an MCI a person will not receive more than 1000 mrem of exposure. Several of the large survey shafts have been examined on the berm. They have survey towers over them, which make it difficult to stand directly over the shaft.

Table I: Equivalent Dose average over shaft diameter for MCI

Elevation (cm)	No Poly Dose (mrem)	Six inches of Poly Dose (mrem)
730	3,700	920
830	2,000	200
930	1,300	120

The two concentric surfaces used for tallies have the equivalent dose calculated by averaging over the surface. One surface has a radius (28cm) equal to the shaft radius and the other has a radius that is 30 cm larger (58cm), representing one foot away from the shaft. The equivalent

doses for the surfaces concentric to the shaft will be averaged around the complete circumstance and integrated over a vertical distance of 100 cm. The results[7] are given in Table II. A person standing at least one foot from the edge of the shaft would receive a equivalent dose of about 100 mrem.

Table II: Equivalent Dose averaged over concentric surface for MCI

Radius of surface (cm)	Elev. above berm (cm)	No Poly Dose (mrem)	Six-inches of Poly Dose (mrem)
28	0-100	2,400	800
28	100-200	1,760	200
58	0-100	140	90
58	100-200	110	60

The dose averaged over the shaft diameter was calculated for the survey shaft in one meter vertical increments. It is useful to compare this dose to the first leg universal labyrinth formula of Goebel[8] et. al. The results are shown in Table III where the labyrinth formula and the MCNPX calculation have been forced to be equal at the first location. The labyrinth formula predicts 60% more dose at the exit of the shaft, but provides a reasonable estimate when considering the ease of using the formula verses the Monte Carlo methods.

Table III: Comparison of MCNPX to Labyrinth Formula

Elevation (cm)	Poly Dose (mrem)	No Poly Dose (mrem)	Labyrinth Formula Dose(mrem)
230	2,040,000	2,040,000	2,040,000
330	290,000	290,000	324,000
430	57,000	57,000	70,400
530	17,000	17,800	24,000
630	7,700	7,500	11,000
730	920	3,700	5,900

The energy spectrum of the equivalent dose has been tabulated at each surface. The equivalent dose for energy bins is tabulated in Table IV for the neutrons that exit the shaft at the berm surface. 62% of the neutron equivalent dose is from neutrons with energy from 1-1000 MeV. The contribution of other particles to the dose is not given in table IV, but over 95% of the exit equivalent dose is from neutrons. As noted a substantial portion of the energy spectrum is above 1 MeV.

Table IV: Equivalent dose for neutrons is energy bins at the shaft exit.

Lower energy (MeV)	Upper energy (MeV)	Equivalent Dose (mrem/proton)
0	10^{-8}	$2.3*10^{-16}$
10^{-8}	10^{-7}	$3.5*10^{-15}$
10^{-7}	10^{-6}	$1.4*10^{-15}$

10^{-6}	10^{-5}	$7.0*10^{-16}$
10^{-5}	10^{-4}	$8.1*10^{-16}$
10^{-4}	10^{-3}	$1.1*10^{-15}$
10^{-3}	10^{-2}	$1.8*10^{-15}$
10^{-2}	10^{-1}	$4.3*10^{-15}$
10^{-1}	1	$3.9*10^{-15}$
1	10	$4.2*10^{-14}$
10	100	$2.3*10^{-14}$
100	1000	$1.2*10^{-14}$
Total		**$1.24*10^{-13}$**

Conclusions and Recommendations

The equivalent dose 1 meter above a 22-inch survey shafts is estimated to be 200 mrem for a maximal MCI. This is approximately a factor of two higher than the dose exiting the berm. The results for potential exposure are consistent with the values calculated by the RHIC Project when changes in intensity, energy, and neutron weighting factors are taken into account. The potential risk for exposure decreases quickly to the sides of the shafts.

The RSC should revisit the protection for the survey shafts. Both the posting and potential barriers to prevent access should be considered. The hazard should be considered relative to the other potential exposures that can occur during an MCI. **(Ck-fy2013-RHIC-808)**

The RSC should obtain an inventory of all survey shafts for the RHIC ring and the injection arcs. **(Ck-fy2013-RHIC-809)**

At least one survey shaft of each type should be examined for the size and location of the poly discs. **(Ck-fy2013-RHIC-810)**

References

1. RSC minutes of Sept. 17, 1997; http://www.c-ad.bnl.gov/esfd/RSC/Minutes/17_Sept_97Minutes.pdf
2. RSC Minutes of Nov. 25 and Nov. 30 1998; http://www.c-ad.bnl.gov/esfd/RSC/Minutes/11_25_98Minutes.pdf
3. The reduction has a one inch gap around the perimeter. The elevation of the quoted dose was not stated in the minutes but often the dose berm was quoted at three feet above the surface being considered.

4. D. Beavis memorandum dated June 25, 2012; http://www.c-ad.bnl.gov/esfd/RSC/Memos/RHIC_vent_B2_061412.pdf
5. See RHIC SAD Appendix 5; http://www.c-ad.bnl.gov/ESSHQ/SND/RHICSAD/appendices/app19.pdf
6. The actual location of the poly in elevation was not known at the time this note was written. The vertical position should not have a large impact on the dose if the surface being considered is not close to the ground level.
7. The highlighted results are only accurate to a factor of a few. However, all numbers trend as expected so additional computation time to improve the statistics was not pursued.
8. 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).

CC:

A. Pendzick
W. Fischer
A. Dress