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Memo

date: *May 26, 2011*

to: *RSC*

from: *D. Beavis*

subject: *Scaling Muon Doses from 250 GeV to 300 GeV*

RHIC would like to be able to operate with the highest energy protons that the machine can accelerate and store. The present limit on proton energy has been set at 250 GeV. 300 GeV is believed to be beyond the physical limit that the machine can reach and 275 GeV is a more likely practical upper limit. The dose from muons at the site boundary is the only external radiological issue that the higher energy proton beam substantially changes.

The RHIC Project estimated the dose to the nearest site boundary for the blue beam dump and the blue collimator. These are the two dominate potential sources for muon dose at the site boundary. The results were estimated for 2345 full energy stores at 250 GeV. The results were:

Source	RHIC SAD mrem/yr	Intensity upgrade mrem/yr	References
Blue beam dump	0.15-0.42	0.3-1.5	1
Blue collimator	0.13-0.7	0.3-0.9	1,2,3

An intensity upgrade will increase the proton beam per ring to $5*10^{13}$ protons and the muon doses for this upgrade are given in the table above. These numbers are well within the DOE requirements and are below the BNL requirement of less than 5 mrem/yr per facility. The muon dose to non-C-AD facilities is small and was addressed in the RHIC Project SAD.

The muons exiting the RHIC berm are high energy muons that are produced in the forward direction from pion and kaon decay. The muons are deflected by the magnetic field in the RHIC magnets and travel a substantial length in steel before traveling an even greater distance in the soil shield that is known as the muon spurs. The Monte Carlo program CASIM was used to estimate[1] the muon flux exiting the RHIC berm and then the distance was used to scale the result to the site boundary. The calculations were conducted with approximations to the magnetic field both in the magnet gaps and cold mass. Reasonable scaling could be done if sufficient details were given in the RHIC Project analysis. Unfortunately this is not the case.

Estimates with less accuracy can be achieved from reference 1. The uncertainties of these estimates are large but still lead to the conclusion that initial operations between 250 to 300 GeV could begin while details calculations[4] are completed or empirical measurements are made of the

muons. The highest energy muons travel nearly in a straight line through the magnets and soil shield. Using a cold mass diameter[5] of 11 inches and assuming that the muons transverse 75% of the blue ring cold mass diameter, it is estimated that the muons travel through 8.5 meters of iron (including 2.5 meters for the beam dump iron). The muons then travel through 225 meters of soil to exit the muon spur.

The approximation[6] of Sullivan for muon flux can be used to scale the results from one energy to another once the shield thickness has been estimated. Using the shielding parameters[6,7] for muons and the shield thickness given above it is estimated that the integrated muon flux through the shield increases by a factor of 3.9 when the energy goes from 250 GeV to 300 GeV. Doubling the estimated length of steel the muons transverse in the magnets increases the factor to 4.2. This factor is for the entire energy spectrum penetrating the shield and therefore should be an upper limit since the muons penetrating the shield are momentum dispersed.

Figure 4.27 of reference 6 can be used to estimate the decrease due to the dispersion. The variable X=E(muon)/E(proton) where E(muon) is the lowest energy muon escaping the shield and E(proton) is the proton energy is about 0.55 for RHIC at 250 GeV and 0.50 for 300 GeV. A segment of dX maps into a longitudinal segment of muon flux external to the berm. At either energy the same dX will occupy the same area external to the berm. The estimated increase in dose is less than a factor of two.

The dose due to muons at the site boundary is estimated to be less than 3 mrem/yr if the machine operates with 300 GeV protons. In case the muons trajectories are more complicated it is recommended that the detailed calculations be completed. The RHIC muon estimates have never been checked so that ensuring that the dose at the site boundary is sufficiently low is a worthwhile investment in effort.

References

1. A.J. Stevens memorandum, Jan 06, 1993 (see appendix 18 of RHIC SAD).
2. The numbers from reference 1 have been scaled to account for the move of the collimator to 8 O'clock.
3. There may be a higher percentage of protons scrapped on the blue collimator than used in the RHIC project estimate. However, there has been substantially fewer fills to 500 GeV than used in the estimate. See http://www.c-ad.bnl.gov/esfd/RSC/Memos/coll_history_final.pdf
4. K. Yip has begun detailed Monte Carlo simulations with the program MARS.
5. See RHIC Design Manual, August 31, 1992. Both the dipoles and quadrupoles have a cold mass with an O.D. of about 11 inches.
6. J. Donald Cossiart, "Radiation Protection for Personnel and Environmental Protection", Fermilab Report TM-1834 revision 7, April 7, 2004.
7. D.E. Groom, N. Mokhov, and S. I. Striganov, "Muon Stopping Power and range Tables 10 MeV-100TeV, Atomic data and Nuclear Data Tables, **78**, 183-356 (2001).

CC: W. Fischer
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