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Memo

date: *December 30, 2009*

to: *RSC*

from: *D. Beavis*

subject: *Potential Dose on the RHIC Berm*

Introduction

The potential dose on the RHIC berm will be examined using a simple empirical formula. The numbers will be compared to the RHIC SAD to demonstrate consistency. The simple formulation will then be used to examine the issue of potential dose on the RHIC berm for low energy operations and for future beam upgrades.

It is concluded that the potential for dose on the RHIC berm is not a serious issue for a short period of low energy running (4-8 weeks). Minor improvements may be required for long low energy runs. The planning of these improvements will benefit from knowledge gained from a short run.

For beam energy and intensity upgrades the dose on the berm for MCI is approaching values that may be a concern, especially for the road over the berm. A combination of better understanding of MCIs would be helpful for typical ring location to ensure that the scenario is not overly conservative. Neutron skyshine to the site boundary, muons penetrating the berm, and shield walls at the IRs have been identified as areas that require additional analysis for beam upgrades.

An approach to integrate all planned upgrades and new modes of operations may provide the most efficient means to address all the radiological issues for RHIC.

Intensity and Energy Upgrades

Simple upgrades in beam intensity and energy are under consideration. The beam intensity may be increased by a factor of two. For the calculations presented in this note only the total beam in the machine (a ring) is relevant and not the bunch structures. Machine protection issues may need additional considerations including the time structure of the beam. Increases in beam energy are being considered. A maximum of a 30% increase is considered possible without a major reconfiguration of the magnets. Using the usual energy scaling[1] a total increase of 2.47 in transverse radiation would result from the combined improvements compared to the present operating conditions. A factor of 2.5 will be used when considering the potential dose on the berm.

Low Energy Operations

The heavy ion program would like to operate with beam energies well below the present injection energy of 10.4 GeV gold. At present the lowest energy proposed is 2.5 GeV per nucleon gold. The berm shielding will be examined down to this energy. The potential dose on the berm can be more problematic for low energy operation because of the larger number of ions injected per hour and the increased distributed losses around the RHIC ring compared to normal energy injection and stores of gold.

Method for Estimation of Dose on the RHIC Berm

The potential dose to a person on top of the RHIC berm can be estimated[2] using a simple empirical formula. The dose on the berm for a localized full beam fault of $2.28*10^{13}$ protons at 250 GeV is

$D = (38{,}800 \text{ rem})* e^{-(d/att)}/(r_t*r_t)$ where,

D is the dose in rem, r_t is the transverse distance in feet, d is the berm thickness in feet, and att is the attenuation length of the shielding in feet. For a composite shield the exponential can be broken into products of the attenuation terms for the various components of the shield. This formula incorporates the factor of 2 that the RHIC project used for increased neutron dose equivalence. This increase is now required in the near future by an updated version of 10CFR835. The dose can be scaled to the amount of lost beam and can be energy scaled using $E^{0.8}$ where E is the kinetic energy per nucleon of the beam. The value of attenuation length, att, will depend on factors of soil density and composition. An attenuation length[2] of two feet will be used for soil in this note.

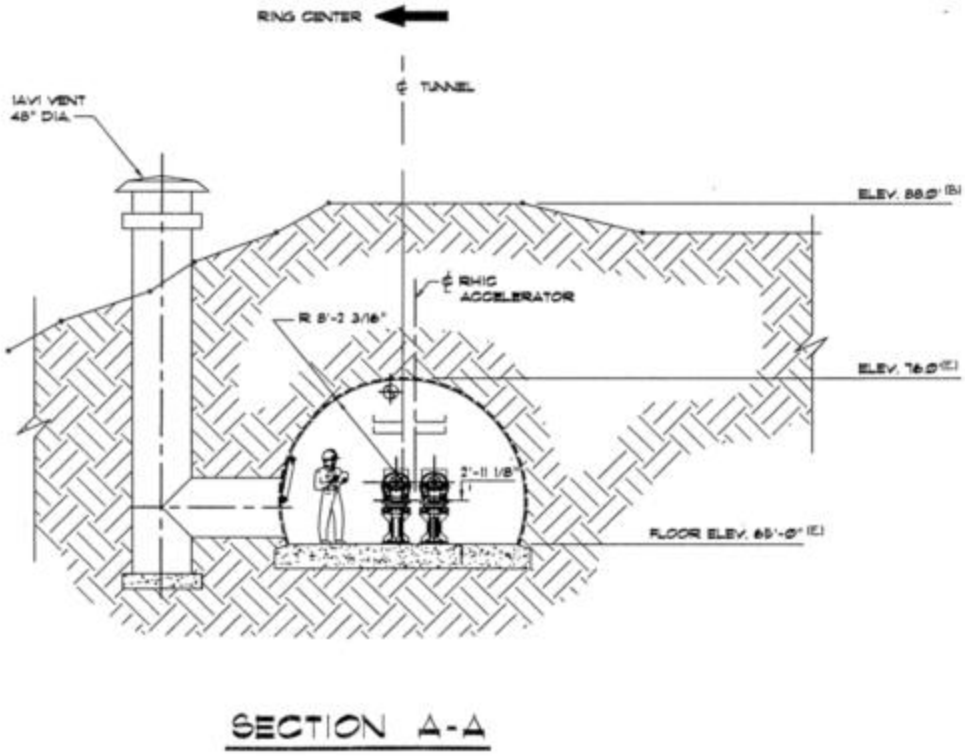

Figure I. Elevation view of the RHIC tunnel in sector 1 at 1AV1.

Archived drawings of the berm were examined to determine the typical berm conditions and non typical areas. Most of the archived drawings display areas where there are changes in the tunnel structure such as exits, alcoves, and change in tunnel diameter. In addition a topological map of the berm was examined to further aid the review. The topological map provides details of the entire berm with two-foot contour lines obtained by fly-over techniques. The survey group[3] has overlaid their elevations for reference. The topological map is quite accurate, but there are a few locations that were upgraded after the topological map was generated.

The typical RHIC berm has 12 feet of soil coverage. Fig. I shows a typical cross-sectional view of the RHIC tunnel. Most of the RHIC collider has the ring magnets inside a 16-foot diameter corrugated steel tunnel with the top of the tunnel being at elevation 76 feet, the beam at 69 feet 2 inches, and the tunnel floor at 65 feet.

Maximum Credible Incidents (MCI)

A Maximum Credible Incident (MCI) for radiation is assumed[4] to be a full beam fault at special locations such as limiting apertures and half the beam faults at typical locations. Most of the areas around the ring are typical and therefore would have a source term one-half of that given in the formula above. The dose to a person on a typical section of the RHIC berm would be 135 mrem. If one extends this to three feet above the berm for a standing adult then a value of 99 mrem is obtained. The RHIC SAD[5] quotes a value of 114 mrem. We see that the values are consistent.

There are several special areas of interest around the RHIC ring. Renaissance Road crosses over the berm at a location east of building 1005 and is the only section of the berm that is not a Controlled Area. This section has been left uncontrolled to allow access to building 1005, which in also Uncontrolled. The tunnel under the road is a typical section with 16 foot diameter steel arch-plate. There are no elevation views of the road in the archived drawings. The portion of the topological map for the road is shown in Fig. II and demonstrates that the crown of the road is between 88 and 90 feet of elevation. Using visual landmarks such as the top of section 1005R the best estimate without survey is an elevation of 89 feet. An MCI at the road would produce a maximum dose on the surface of the road of 74 mrem and if one scales to three feet above the road's surface then the dose would be 56 mrem.

A monitor TLD is placed several feet east of Renaissance Road. This TLD has always seen yearly integrated dose consistent with zero. A chipmunk is placed on the west side of the road to measure and high dose rates. No high dose rates have been seen on this chipmunk.

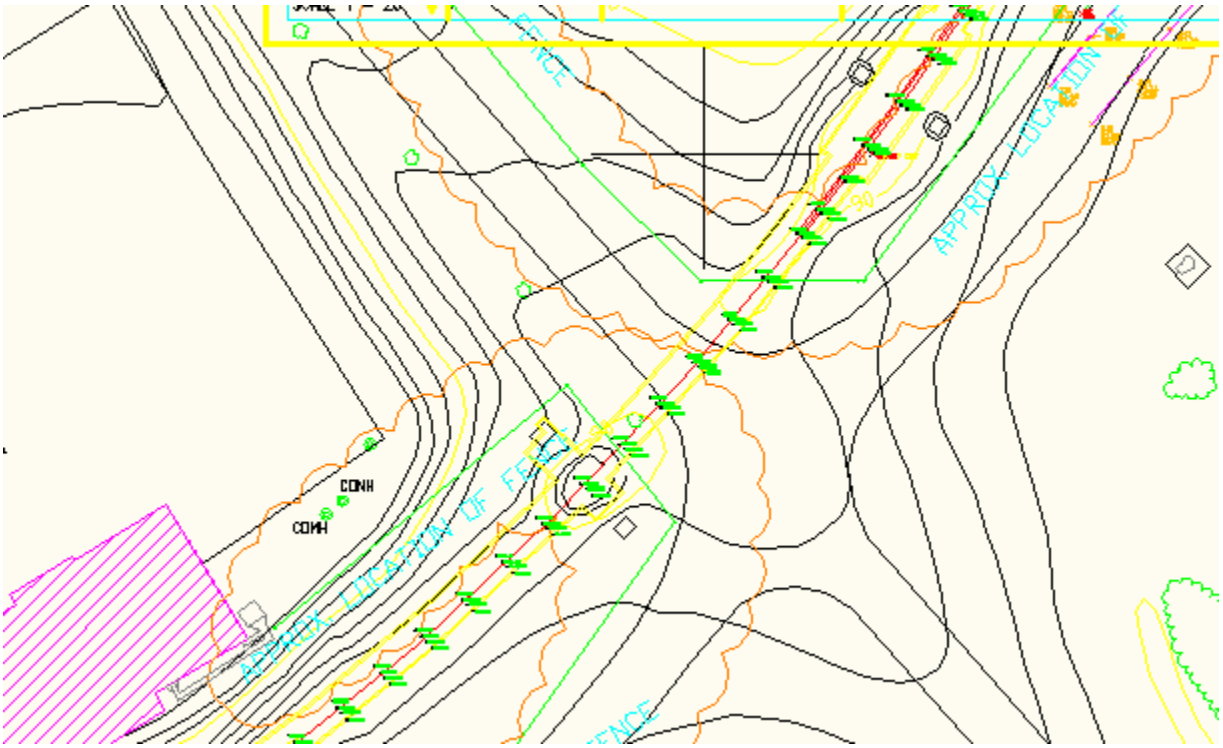

Figure II: Topological Map of the road over the RHIC ring.

The area over the injection transport is another berm area of interest. Fig. III shows a cross-sectional view of the injection area at 6 O'clock. The soil is 11 feet thick and the light concrete is 2 feet thick. An MCI at full energy would be 34 mrem. This area was not considered as special for full energy beam faults. For low energy operations it would be possible to have an MCI at this location with the full beam. In that case the dose would be 68 mrem at full energy (250 GeV) but is only credible at low energies.

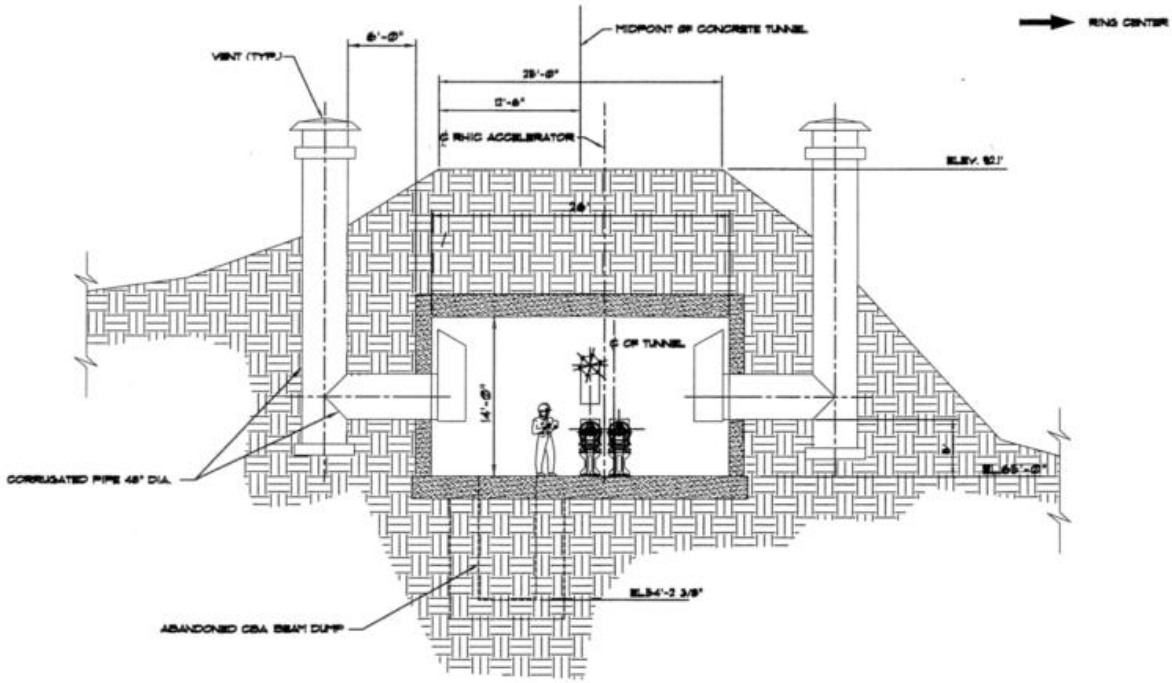

Figure III: Cross-section of the Injection area near the ventilation shafts 6EF1 and 6EF2.

Building 1005 is shown in the lower left corner of Fig. II. The berm height was increased near building 1005 after the data for the topological map was created. This area is of interest since it is the only occupied area that is not a Controlled Area.

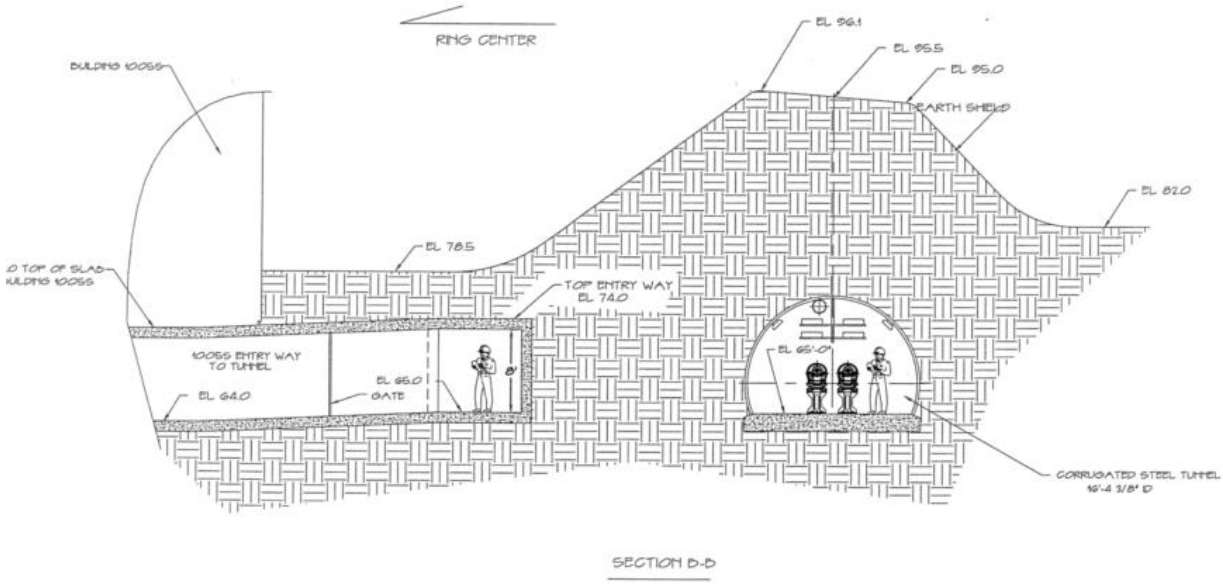

Figure III: Cross-sectional view of RHIC ring near Building 1005.

Figure IV shows a cross-sectional view of the RHIC berm near building 1005. The higher elevations of 1005 have direct shine from the side of the RHIC berm. Examination of Fig. II

shows a minimum distance of 70 feet and a soil thickness of 19.5 feet. The estimate for an MCI would be 0.25 mrem. If a more conservative attenuation length were used than up to 0.60 mrem could be expected. The shield design near the collider center and potential weaknesses were discussed[2] in appendix 15 of the RHIC SAD.

The ring near the Intersection Regions (IRs) often have increased tunnel diameter and shield thickness. Fig. IV shows a cross-sectional view of the triplets at 1 O'clock. Typically the high-beta quads have 13 feet of soil shielding. Except for the 10 O'clock area these areas are inside fences so the dose to personnel could only occur with a granted exception to the access procedure. The dose for a person standing above the triplet shown in fig. IV is estimated to be 80 mrem. The berm areas above the triplets are fenced to prevent exposure to chronic dose and not dose in an MCI, although they are one of the most likely locations for an MCI to occur. Chronic dose will be discussed later.

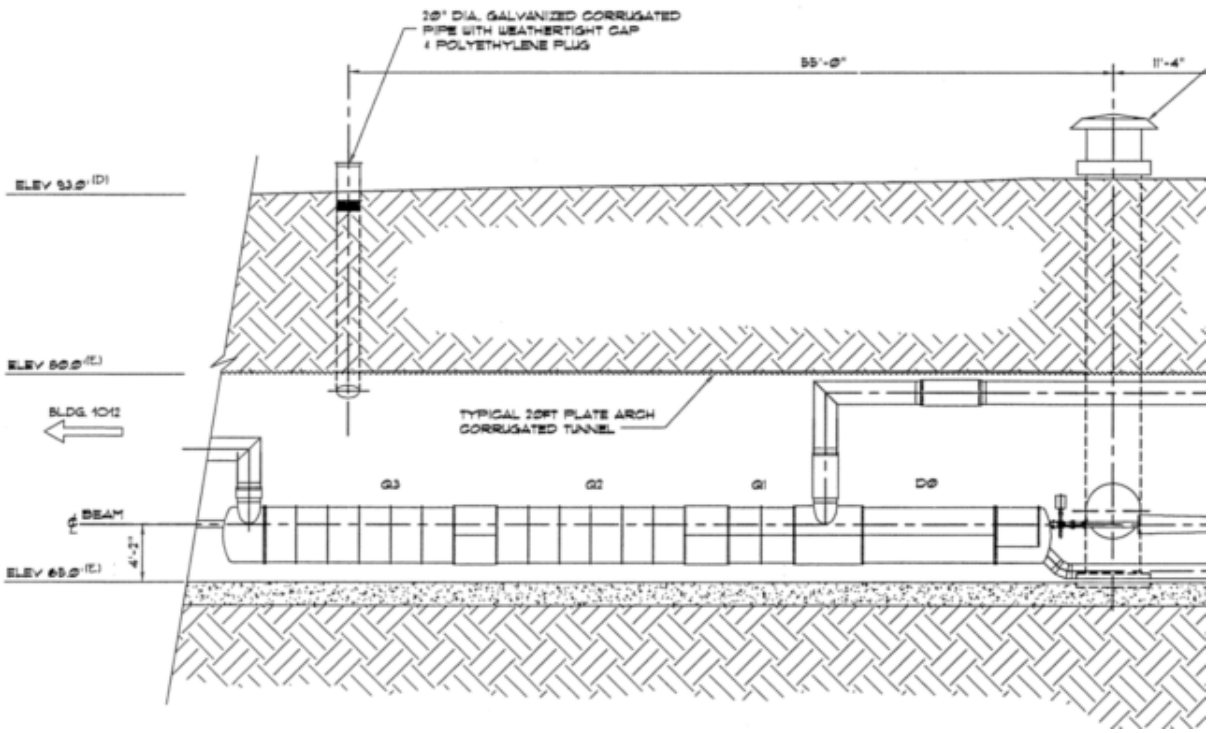

Figure IV: 1 O'clock triplet area.

The primary beam collimators at RHIC are locations where MCIs are likely to occur. The collimators are located in the warm sections on each side of the PHENIX IR. The berm above the collimators is fenced to reduce the potential for exposure. There is 13.5 feet of soil over the blue primary collimator and the distance to a person standing is 27.5 feet. A person allowed in this secured area could receive 60 mrem from an MCI. The original RHIC analysis[6] assumed 13 feet of soil with an estimated dose of 80 mrem. Scaling the 60 mrem with distance gives 77 mrem consistent with the RHIC analysis. The collimators have already been considered[7] for low energy

operations and are not a concern. The intensity upgrades could cause the estimated skyshine to the site boundary to increase to 2.5 mrem in a year. This increase is close to the 5 mrem limit and should be examined more carefully. It may be that a re-evaluation of the amount of nucleon-GeV placed into the collimators per year would be sufficient for full operations with the energy and intensity upgrades. The conditions assumed by the RHIC Project were conservative.

The beam dumps have been previously examined[8] for potential dose on the berm. The low energy operations should not be an issue for MCI analysis or chronic losses. The area directly over the beam dumps are inside a secured fence. Fig. V displays the berm section where the beam dumps are located. Similar to the collimators, the high energy operations with the beam dumps will increase the possible off-site exposure from the beam dumps to 2 mrem per year. Again, an administrative limit to the amount of GeV-nucleons placed into the beam dump may be sufficient. It should be noted that the RHIC SAD quotes a soil thickness of 17.5 feet of soil over the beam dumps. Indication from the topological map and the drawings suggest this is actually 22 feet of soil. This would suggest the dose associated with beam into the beam dumps is an order of magnitude lower than quoted in the documentation.

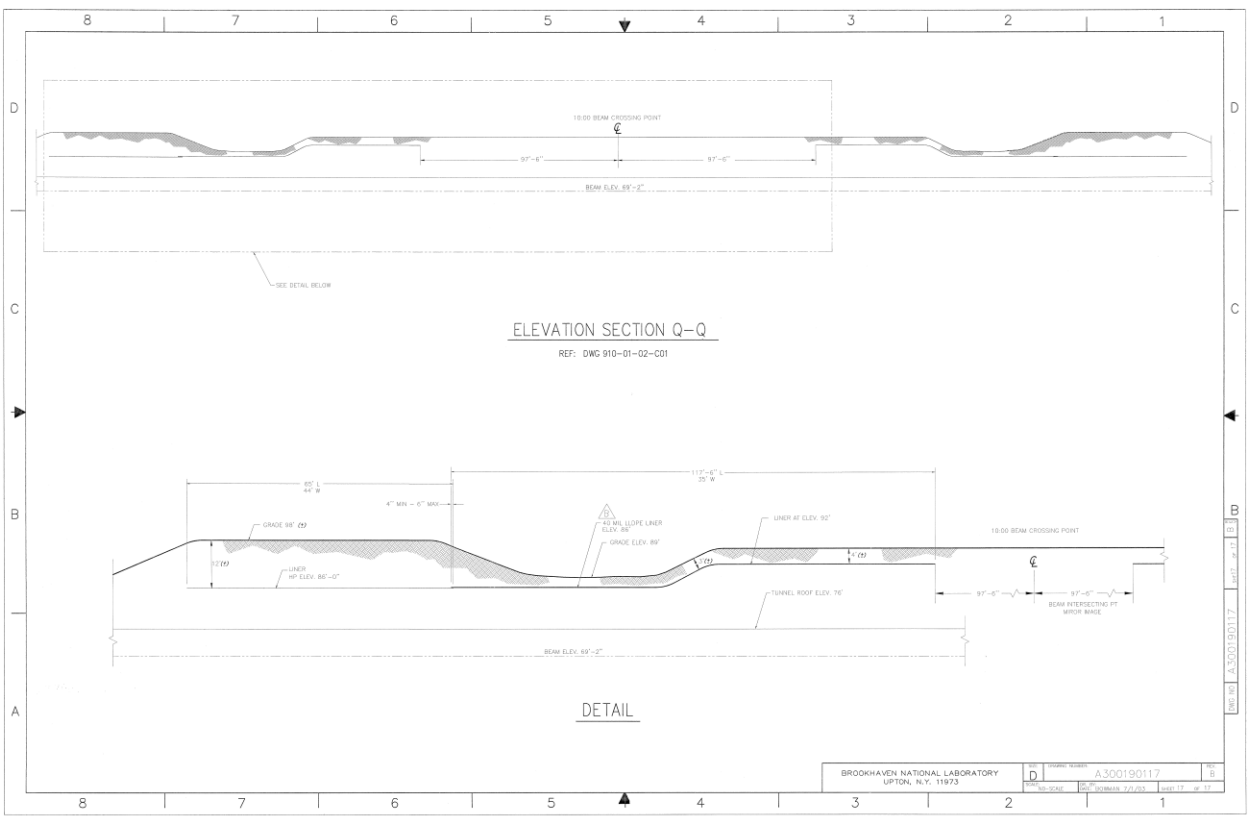

Figure V: Elevation view of the berm where the dumps and abort kickers are located.

The abort kickers are in the warm section starting after the triplet. They were not considered as a special location in the RHIC analysis since they were not expected to have large beam losses. For low energy operations they could be a location for MCI or chronic losses. For the purposes here we will assume that all of the high energy beam can interact in the kicker. It is difficult to determine the soil thickness over the kickers from the documentation but in a small region it may

be as thin as 13 feet, i.e. a berm elevation of 89 feet as seen in Fig. V. This area is assessable and a person standing at the thinnest section could receive a dose of 55 mrem for a full beam fault.

The potential dose from an MCI can now be summarized for full energy operations, low energy operations, and beam intensity and energy upgraded. The low energy numbers[9] will assume that the injected beam is 3.85 GeV and that the injection intensity is $1*10^9$ Au ions. The dose will be scaled with the factor of $E^{.8}$, where E is the kinetic energy per nucleon.

MCI Dose to a person standing on RHIC berm in mrem.

Location	Full Energy	Upgrade	Low Energy (3.85 GeV inj.)	Comment
Typical	100	250	1.8	RHIC SAD had 114 mrem
Renaissance Road	56	140	1.	Only uncontrolled area
Injection	34	85	1.2	Assumes all low energy can fault
Triplet	80	200	1.4	Secure area
Dump calculated based on 22 feet	0.16	0.4	0.003	Used methods presented
Dump (SAD)	3.8	9.5	0.07	Used SAD info Secure area
Collimator	60	150	1.1	Secure Area
Abort kicker	55	150	2.	Open area

The levels for an MCI are not an issue for low energy operations. For energy upgrades a typical berm area may have 250 mrem for an maximum credible incident (MCI). The road over the berm could have 140 mrem during an MCI. Except for the road, these levels are probably acceptable when one considers the likelihood of the berm being occupied.

Chronic Doses on the RHIC Berm

The RHIC project did not address the issue of chronic doses on the berm. The collider by design has low losses for typical operations that were planned by the Project. All indications are that this judgment was correct. The MCI above will be scaled assuming a chronic loss for a week of operations so that a comparison can be made between potential existing dose and that which may exist for low energy running operations or for beam upgrades.

The RHIC Project assumed[10] a distribution of beam loss points. The loss scenario will be approximated here as 38 weeks of uniform operations with a total of 2400 fills. The Project assumed that 82% of the beam ends up in the beam dumps for each ring and that 14% of the beam is lost on the collimators. In addition, 2.3% of the beam would be lost in “other places”. We will assume that 1% of this (.023%) is lost at an arbitrary typical location and that 2.3% is lost equally in four sets of high beta quads. However, since both rings in this case have a loss that is geometrically close we will assume a total of 1.14% lost at each triplet. The project also

assumed that 0.5% would be lost on the injection septum at injection energy. These numbers will be used to estimate the weekly dose on the berm assuming 63 fills a week.

Chronic losses for the upgrades will assume the same percentages for full energy operations. Thus the full energy numbers will be scaled by a factor of 2.5. In reality the losses in some locations would be expect to decrease.

T. Satogata[9] has provided an estimate for the losses during low energy operations. The beam energy of 3.85 provides a good conservative estimate for the maximum chronic doses to expect on the RHIC berm. Since the actual losses and distribution is not well know it will assumed that 25% of the beam is lost at locations with restrictions, 25% goes into the beam dump, and a typical chronic hot spot of 10% of the beam exists somewhere. Since the triplets for all IR will be operated at the same value it is assume that the 25% loss will be distributed over all twelve locations of the triplets. The low energy operations at 3.85 GeV assumes 3 fills per hour[9] and 168 hours of operations per week.

Chronic dose to a person standing on the RHIC berm in mrem per week.

Location	Full Energy	Upgrade	Low Energy (3.85 GeV inj.)	Comment
Typical	3.	7.5	180	Assumes a 10% hot spot for low E
Renaissance Road	1.6	4.	100	Low E with 10% hot spot
Injection	1.	2.5	150	Assumes 25% for Low Energy
Triplet	58	144	30	Secure area
Dump calculated based on 22 feet	8	20	0.4	Used methods presented here
Dump (SAD)	200	500	10	Used SAD info Secure area
Collimator	1100	2800	135	Secure area
Abort kicker			246	Open area

The estimate for Renaissance Road is 1.6 mrem/week during full energy operations with a chronic loss of 0.00023 of the beam. The monitor TLD has shown values consistent with background for past RHIC runs integrated over the entire period of operations. This illustrates the conservative nature of the calculations for typical areas of the berm including the road. The actual beam loss in typical ring locations is probably 10 to 1000 times lower than the value used here. None of the numbers in the table take into account occupancy factors.

For the low energy operations a 10% hot spot is also probably very conservative for most locations around the RHIC ring. This very conservative assumption is what makes the road and typical berm location appear so high. More realistic is probably a number 10-100 times lower.

The injection area and the area above the abort kickers are accessible and if these are high loss locations may require additional measures to reduce the potential dose to personnel.

The locations over the abort kickers and injection magnets may have chronic levels above that for normal high energy operations.

The chronic high loss locations for low energy operations have weekly doses well below similar locations for normal operations. They are not expected to cause an increase in the skyshine dose to off site locations. For example the abort kickers are near the beam dumps. The SAD had a similar dose per week from the beam dumps and based on location the chronic dose from the kickers should not present a skyshine issue.

Recommendations and Comments

Some simple recommendations and comments will be made regarding low energy operations and the potential upgrades in energy and intensity. Some of the recommendations will be entered into the Radiation Safety Committee's (RSC) check-off database prior to review.

The issue of muons penetrating[11] the berm was not evaluated for beam upgrades. This is not a concern for ion running but only for protons. The muons were estimated to produce a contribution to the off-site dose. The energy increase could substantially increase the muon penetration of the berm. **(CK-RHIC-upgrades-P-652).**

End walls for areas were not examined. This is expected to be a potential issue for high energy upgrades. **(CK-RHIC-upgrades-653)**

Survey numbers for the elevations of the road over the ring should be provided to remove any uncertainty in the berm thickness. **(CK-RHIC-FY2009-654)**

Visual observation suggests that the berm is probably thicker over the abort kickers than depicted in the drawings, especially for the blue beam kicker. Survey of the elevations over the kickers should be generated before any long duration low energy runs. **(CK-RHIC-FY2010-655)**

The elevation of the berm over the beam dumps should be surveyed. (**CK-RHIC-FY2010-656)**

Updates loss estimates for all modes of operations should be provided to the RSC. **(CK-RHIC-FY2010-657)**

A series of monitor TLDs should be placed around the facility to monitor berm doses. **(CK-RHIC-FY2010-658)**

The injection areas and abort kickers should be posted to have personnel excluded pending surveys by HP and the determination of the loss levels for low energy operations. **(CK-RHIC-FY2009-659)**

The final recommendations for the berm require both a better understanding of the operating conditions and the integration of other items such as ventilation shafts and personnel access ways.

The fences over areas of the berm may require adjustment for beam upgrades. Most of the fence locations were chosen based on the berm being an uncontrolled area. **(CK-upgrades-RHIC-660)**

The chronic dose at IR shield walls is expected to be smaller than that of normal operations based on the weekly losses at the triplets. These areas should be surveyed early in the commissioning of the low energy beams.

The IRs will need to have the shielding evaluated for an MCI with beam upgrades. Doses at the shield walls and entrance ways of the two operating experiments already exceed the criteria established[12] for machine upgrades. **(CK-RHIC-upgrades-P-661)**

References

1. A.H. Sullivan, A Guide to Radiation and radioactivity Levels Near High Energy Particle Accelerators, Nuclear Technology publishing, 1992
2. A.J. Stevens, "Radiation Field in the Vicinity of the Collider Center", AD/RHIC/RD-77, Oct. 1994. Values ranging from 2.2 to 1.8 have been used at BNL for the attenuation length. A value of 2 has been chosen in this report for soil. An attenuation length of 1.61 feet will be used for light concrete.
3. The head of the survey group, F. Karl, provided some understanding into the details of the topological map.
4. M. Harrison and A.J. Stevens, "Beam Loss Scenario in RHIC", AD/RHIC/RD-52, Jan. 1993. It assumes that only the beam in one ring needs to be considered.
5. RHIC SAD. See section 4.F. Note that if the 135 mrem calculated in this note is evaluated at 3 feet above ground level than a dose of 100 mrem would be received.
6. A.J. Stevens, "Radiation Safety Considerations near Collimators", AD/RHIC/RD-113, April 1997.
7. D Beavis, "Low Energy RHIC Operations: External Dose from Collimators", Nov. 20, 2009.
8. D. Beavis, "Low Energy RHIC Operations: External Dose from the Beam Dumps", Nov. 20, 2009.
9. T. Satogata, "RHIC Low Energy Beam Loss Projections", Sept. 9, 2005.
10. M. Harrison and A. J. Stevens, "Beam Loss Scenario in RHIC", AD/RHIC/RD-52, January 1993.
11. A.J. Stevens, "Radiation of Muons at RHIC", AD/RHIC-46, Feb. 1989.
12. RSC Minutes of August 25, 2009, "Fault Dose design Criteria for RHIC upgrades".

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