ii. Shielding

The design basis for earth shielding surrounding RHIC is shown in Figs. 10-2 and 10-3. Figure 10-2 shows the radial "lobes" of earth which are required to extend outward to a maximum distance of 90 m from the tunnel center line at the center of each arc and to present a minimum thickness of 4 m in the vertical direction as measured from the beam elevation. These lobes were designed to attenuate radiation from (penetrating) muons to a level of less than 5 mrem/yr at the nearest site boundary.[1] The "typical section" through the shielding shown in Fig. 10-3 shows two thicknesses of earth above the tunnel enclosure. Most of the ring has a 4 m vertical earth cover, but in the region of the Collider Center, where non-radiation workers are present and where occupancy is high, the vertical cover

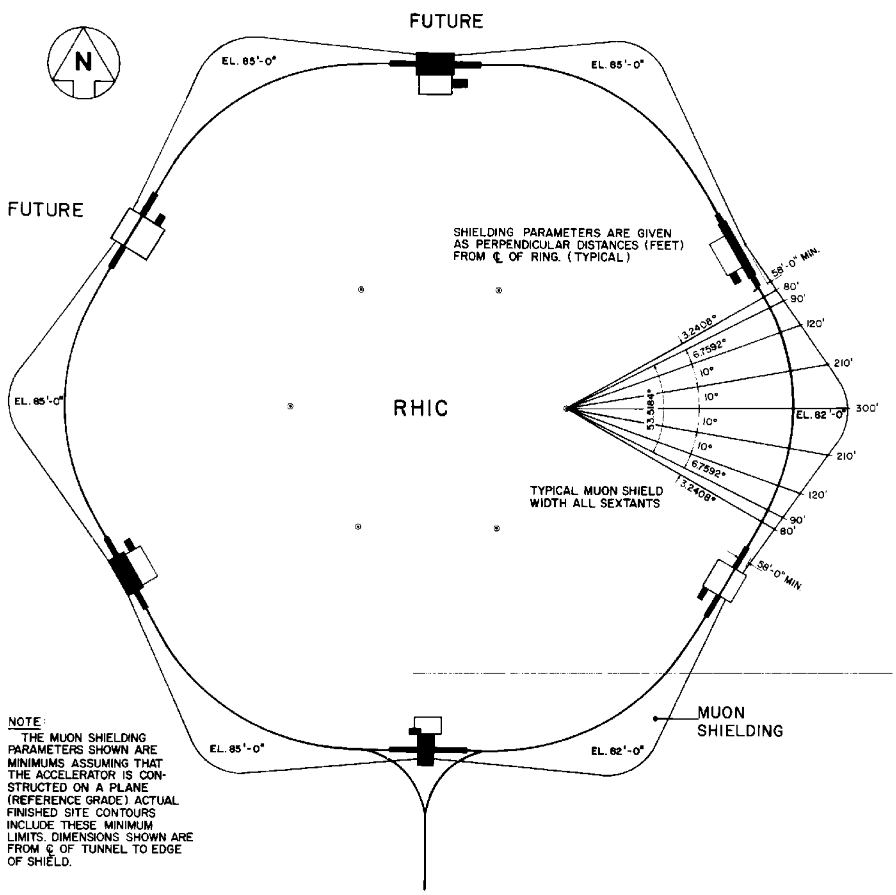

Fig. 10-2.

Plan of accelerator ring.

[1] P. J. Gollon and W. R. Casey, *ISABELLE Shielding Criteria and Design*, Health Phys. 46, 123-131, (1984).

has been increased to 6 m. The berm cover will also be increased over the locations of the internal dumps, where beam "loss" is expected to be high, in accordance with basic ALARA principles.

Because the existing shielding was designed for the ISABELLE project, it is necessary to compare anticipated loss between ISABELLE and RHIC. ISABELLE was designed to accelerate 3×10^{17} protons per ring per year to 400 GeV, or 2.4×10^{20} GeV/yr. Although RHIC is designed to operate with many species and energies, a conservative estimate of the annual accelerated energy has been placed at the equivalent of 5.5×10^{14} Au ions per ring per year at 100 GeV/nucleon,[2] or 2.2×10^{19} GeV/yr. The radiation burden of RHIC will therefore be approximately one order of magnitude less than that for which the shielding was designed.

A variety of calculations have been performed to verify the adequacy of the RHIC shielding. These calculations rely on the computer code CASIM[3,4] to simulate the intra-nuclear cascade.

Radiation at the site boundary is dominated by neutron skyshine, airborne radioactive emissions, and muons escaping the shielding lobes. Using the (conservative) scenario for "normal" beam loss given in Ref. 2, together with CASIM results and the methodology of Stevenson and Thomas,[5] a skyshine dose of 0.5 mrem/yr is predicted[6], while airborne emissions should contribute only 0.02 mrem/yr.[6] Muon dose at the site boundary has been calculated to be ~0.3 mrem/yr.[7]

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[2] M. Harrison and A. J. Stevens, *Beam Loss Scenario in RHIC*, AD/RHIC/RD-52 (1993). This reference assumes an "upgraded" RHIC with 4 times the initial design beam intensities.

[3] A. Van Ginneken, *High Energy Interactions in Large Targets*, Fermilab, Batavia, Il, (1975) and *CASIM. Program to Simulate Hadronic Cascades in Bulk Matter*, Fermilab, FN-272 (1975).

[4] A. J. Stevens, *Improvements in CASIM; Comparison with Data*, AGS/AD/Tech Note No. 296, (1988).

[5] G. R. Stevenson and R. H. Thomas, *A simple Procedure for the Estimation of Neutron Skyshine from Proton Accelerators*, Health Phys. 46 115-122, (1984).

[6] *RHIC Preliminary Safety Analysis Report* (1991).

[7] A. J. Stevens, *Radiation from Muons at RHIC*, AD/RHIC-49 (1989).

As mentioned above, the collider center is a special location because of high occupancy and the presence of non-radiation workers. The combination of direct radiation (from beam-gas interactions and aperture-limiting collimators assumed to exist near the entrance to each arc) and skyshine amounts to less than 6 mrem/yr, well below the laboratory guideline limit of 25 mrem/yr for on-site non-radiation workers.

The maximum dose rate near the collider is expected to occur directly over the dump location and is calculated to be ~75 mrem/hr during periods of beam studies at the 4 m berm cover. Although additional berm will be added here, it will still be necessary to designate this location as a "controlled area" and to restrict access appropriately.

In addition to "normal" loss, the possibility of fault conditions must also be considered. An example of a "credible fault" would be failure of the beam dump kicker coincident with a magnet quench. Such a fault would likely result in ~20% of the beam interacting at a single point and would require considerable accelerator downtime to repair the resulting damage. We define a "Design Basis Accident" (DBA) fault as loss of the entire full energy beam on any magnet near the limiting aperture or loss of one-half of the full energy beam on any other magnet. A DBA fault would result in a dose at the top of the

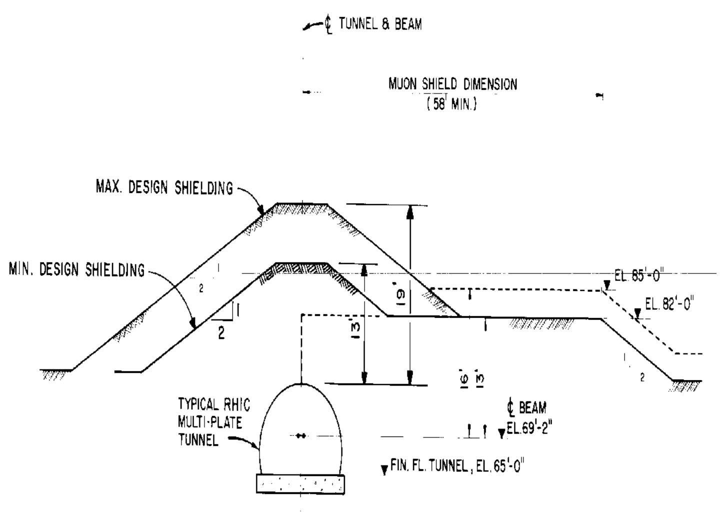

Fig. 10-3. Typical section through RHIC tunnel showing maximum and minimum earth cover.

4 m shielding berm in the 100 - 200 mrem range. One DBA fault per year (in the worst possible location) would increase the annual dose in the Collider Center by up to 1.7 mrem and at the site boundary by <0.01 mrem (due to skyshine). These levels are much less than the dose from normal operation and are therefore of no concern.

An aerial photogrammetric survey of the terrain cover of the RHIC and AGS regions of Brookhaven National Laboratory has been made.[8] Topographic contour curves were determined at 0.6 m (2-foot) elevation intervals which allows the design berm cover to be verified and/or "low points" to be discovered and corrected.

A detailed analysis of radiation dose levels exterior to the transfer line between the AGS and RHIC has been made.[9] Although dose resulting from normal beam loss is expected to be very small, $\lesssim$300 mrem/yr on top of the berm in the worst case, the (warm) transfer line magnets do not intrinsically limit fault conditions as is the case in the collider. For this reason, a combination of access restrictions and interlocking radiation monitors must be employed to limit potential fault dose. Access restriction will also be required around limited regions of the transfer line where beam shaving or beam dumping for diagnostic studies are planned.

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[8] Aerial survey of April 3, 1992 prepared by Chas. H. Sells, Inc.

[9] A. J. Stevens, *Analysis of Radiation Levels Associated with Operation of the RHIC Transfer Line*, Draft Version 6 (1992).