PRELIMINARY SHIELDING ESTIMATES FOR THE PROPOSED OAK RIDGE NATIONAL LABORATORY (ORNL) RADIOACTIVE ION BEAM FACILITY (RIBF)

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Preliminary Shielding Estimates For The Proposed Oak Ridge National Laboratory (ORNL) Radioactive Ion Beam Facility (RIBF)

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The Oak Ridge National Laboratory (ORNL) has proposed designing and implementing a new target-ion source for production and injection of negative radioactive ion beams into the Hollifield tandem accelerator. This new facility, referred to as the Radioactive Ion Beam Facility (RIBF), will primarily be used to advance the scientific communities' capabilities for performing state-of-the-art cross-section measurements. Beams of protons or other light, stable ions from the Oak Ridge Isochronous Cyclotron (ORIC) will be stopped in the RIBF target ion source and the resulting radioactive atoms will be ionized, charge exchanged, accelerated, and injected into the tandem accelerator. The ORIC currently operates with proton energies up to 60 MeV and beam currents up to 100 microamps with a maximum beam power less than 2.0 kW. The proposed RIBF will require upgrading the ORIC to generate proton energies up to 200 MeV and beam currents up to 200 microamps for optimum performance. This report summarizes the results of a preliminary one-dimensional shielding analysis of the proposed upgrade to the ORIC and design of the RIBF. The principal objective of the shielding analysis was to determine the feasibility of such an upgrade with respect to existing shielding from the facility structure, and additional shielding requirements for the 200 MeV ORIC machine and RIBF target room.

To address this problem, a series of High Energy Transport Code[1] (HETC) Monte Carlo calculations and ANISN[2] one-dimensional discrete ordinates calculations were initiated to determine the shielding requirements for a 0.25 mrem/h dose rate on the external surface of the shield, i.e. the target room walls, ceiling, and floor. HETC was used to determine the angular and energy dependent neutron leakage spectrum from a ^{238}U target assembly for input into ANISN. One-dimensional spherical models of the RIBF target room and surrounding structure were analyzed in ANISN to determine the dose rates on the exterior shield surfaces. The 88 group HILO cross-section library,[3] which includes 66 neutron and 22 gamma-ray groups, was used in the ANISN calculations to mix the different materials present in the RIBF target room and surrounding building. The HILO cross section library extends up to 400 MeV in energy.

Within the scope of this investigation, several parameter studies were performed to aid in quantifying the feasibility of upgrading the ORIC and building the RIBF. In particular, proton energies of 50, 100, 150, and 200 MeV were analyzed in HETC to calculate the neutron leakage spectrum for input into ANISN. The target size was adjusted for each proton beam energy to maximize the number of neutrons leaking from the target. Parameter studies were performed in the ANISN calculations with respect to the RIBF target neutron leakage spectra angular dependence, concrete wall thickness and material composition, additional shielding placement and thickness, and RIBF target room location within the existing building. The ANISN calculations, for each proton beam energy and shielding configuration analyzed, were performed to determine the maximum beam current allowable for a 0.25 mrem/h dose rate on the external surface of the shield (i.e. the target room walls, ceiling, and floor).

The analysis of the initial placement of the RIBF in the existing ORIC building indicated maximum proton beam currents ranging in the nanoamp to picoamp range for the 200 MeV proton beam. These currents were well below the desired design current of 200 microamps. To increase the maximum beam current to a minimum of 200 microamps, a 2.30-meter-thick steel shield would be required around the target, offset from the target by approximately 0.3 meters. A symmetrical spherical shield of this dimension would weigh approximately 572 metric tons. This weight was deemed prohibitive, and consequently, the RIBF designers reconfigured the facility and relocated the target room deeper into the internal structure of the ORIC building to take advantage of additional concrete wall shielding offered by the building support structure.

The ANISN analyses of the initial target room location used an isotropic source distribution. To analyze the anisotropy of the neutron leakage source, the angular distribution (heavily peaked forward) of the neutron leakage out of the target was accounted for in the next generation of ANISN calculations. Therefore, HETC-generated ANISN source distributions were determined for a 0-degree source (the forward direction), a 45-degree source, a 90-degree source, and a 180-degree source. The general floor plan of the building was studied and ten different ANISN cases were setup to characterize the shielding requirements for the new RIBF target room. ANISN calculations were executed for each of the cases, and where required, additional cases were run with increasing steel shadow-shield thicknesses until the maximum operating current was well above the 200 microamp design limit.

Two scenarios were modeled from the results of the ANISN cases. The first scenario (Scenario A) assumed the HETC-generated angular distributions of the target neutron and gamma-ray emissions were correct. Therefore, for the 0-, 45-, and 90-degree sources, the steel thicknesses were designed for a 200 microamp current. The second scenario (Scenario B) assumed the HETC-generated angular distributions underestimated the target neutron emissions as the source direction increased from the straight ahead direction. Therefore, the steel thickness was designed for a 200 microamp current in the 0-degree direction, a 300 microamp current in the 45-degree direction (50% HETC under-estimation), and a 400 microamp current in the 90-degree direction (100% HETC under-estimation). Finally, the ANISN model for the ceiling and roof was calculated for both the 0.25 mrem/h dose rate on the roof of the building, and for a skyshine dose of 0.25 mrem/h (approximately equivalent to 2% of the dose rate on the roof of the building).

Utilizing the results from the ANISN calculations, and taking a conservative approach with respect to shield design, generalized steel shields were designed for both scenarios. The shields were designed symmetrically with the direction requiring the most shielding material driving the design. The new shield design weights ranged from 75 metric tons (Scenario A) and 95 metric tons (Scenario B) for the case where the dose rate on the roof is 0.25 mrem/h, to 57 metric tons (Scenario A) and 75 metric tons (Scenario B) for the 2% skyshine return dose of 0.25 mrem/h. These shield weights are much more manageable for the ORIC upgrade to 200 MeV protons at 200 microamps beam current. Furthermore, suggestions to the RIBF designers resulting from the shielding analysis, could further reduce the additional steel shielding weight by a factor of two to three.

These results are not optimized. A three dimensional shield design requires a three-dimensional analysis. The thicknesses will vary for given directions and the shape may vary a little. However, with the conservatism built into the Scenario B shield, the shield analysts believe this shield is a fairly good approximation in terms of size and shape of what would eventually be required for the proposed configuration and orientation of the RIBF.

References

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