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**Shielding Assessment for the
Proposed HRIBF Upgrade to
the National ISOL Facility**

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Computational Physics & Engineering Division

**SHIELDING ASSESSMENT FOR THE PROPOSED HRIBF UPGRADE
TO THE NATIONAL ISOL FACILITY**

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ABSTRACT

An upgrade of the existing ORNL Holifield Radioactive Ion Beam Facility (HRIBF) to the National Radioactive Ion Beam Isotope Separator On Line (RIB ISOL) Facility is being proposed. Part of the upgrade involves increasing the source proton energy and current, resulting in more intense, higher energy radiation. Shielding requirements for the proposed upgrade to the HRIBF have been assessed with respect to weight, space, and dose-rate constraints. Shielding assessments were made for operating, shutdown, and accident conditions. The results indicate reasonable shielding solutions for the target room except for the marginal dose rate on the roof. Shielding requirements in the target room were greatly reduced by decisions to move the target to a more interior room and to direct the proton beam downward into the target. A slightly more difficult shielding problem arises for proton beam extraction losses from the cyclotron. Here, the assumed isotropic beam losses (hence, neutron emissions) mean higher roof dose rates than those over the target room unless substantial localized shielding is placed over the cyclotron. Shutdown dose rates were found to present no problems. While dose rates through the sides of the facility during accident conditions will probably satisfy the accident dose-rate constraints, dose rates above the roof will be well above the constraints unless a solution is devised to shield the locations where beam losses are likely to occur. Ground activation analysis was postponed for this study.

SHIELDING ASSESSMENT FOR THE PROPOSED HRIBF UPGRADE TO THE NATIONAL ISOL FACILITY

1.0 INTRODUCTION

The Holifield Radioactive Ion Beam Facility (HRIBF) was developed at the Oak Ridge National Laboratory to produce radioactive beams for astrophysics and nuclear physics research.¹ This first-generation facility is based on the Isotope Separator On Line (ISOL) technique and uses beams of protons or other stable light ions from the Oak Ridge Isochronous Cyclotron (ORIC) to produce radioactive atoms from nuclear reactions in a thick target material in a target-ion source assembly. The radioactive ions produced are then ionized, charge exchanged, accelerated to 300 keV, mass separated, and injected into the 25-MV tandem accelerator to increase the RIB energy to ranges of interest for nuclear and astrophysics research.

An upgrade of the HRIBF to a second-generation facility, the National Radioactive Ion Beam Isotope Separator On Line (RIB ISOL) Facility at Oak Ridge, is being planned. This facility will use many of the existing components and shielded areas of the HRIBF. The proposed upgrades include: (1) adding a superconducting booster for the tandem accelerator, (2) boosting the proton source from the 50- μ A, 60-MeV beam produced by ORIC to a 200- μ A, 235-MeV beam produced by a replacement cyclotron, and (3) building a high-power ^{238}U fission target to accept the more intense proton beam. A preliminary shielding analysis was performed on an earlier layout of the facility to determine the feasibility of the upgrade² (See Appendix A). As a result of this preliminary analysis, modifications were made to the facility design, including (1) directing the proton beam downward into the target and (2) moving the target to an interior room to take advantage of the additional walls for shielding. The results of the analysis of shielding for the revised facility design are presented in this report.

2.0 OBJECTIVES

The main objective of the shielding analysis is to determine what shielding is required to maintain dose rates below a dose-rate criterion of 0.25 mrem/h in areas where access is allowed during operation. Figure 1 shows a preliminary first-floor layout of the heavily-shielded part of the facility containing the cyclotron and target rooms. This part of the facility is called the ORIC shielded area. Figure 2 shows a first-floor layout which contains the ORIC shielded area shown in Figure 1. The major concerns were: (1) the amount of extra shielding required along the south wall of room C109 to protect the second-floor offices, (2) the amount of iron needed on the target-ion source (TIS) platform to meet the dose-rate criterion while minimizing the iron on the platform, (3) shielding requirements for the TIS handling area during shutdown and in particular the dose rates due to neutron activation, (4) ground activation due to a strong neutron source directed into the ground, (5) the dose rate above the roof and associated skyshine problems, (6) transient dose rates due to accidents and in particular the loss of magnet power where the protons stop in structural materials, and (7) shielding requirements for radiation sources created by the continuous beam-extraction proton losses within the cyclotron structure. In the case of a loss of magnet power, the dose rate outside the building should be no more than 100 mrem/h (See Appendix B).

3.0 CROSS-SECTION DATA, MATERIALS, AND DOSE FACTORS

For these calculations, neutron energies could range up to the 235-MeV energy of the source protons. Therefore, the HILO cross-section library³ was used as data for the calculations, since it was the only available library that contained data for neutrons at those energies. This library has an energy structure consisting of 66 neutron groups ($0.0001 \text{ eV} < E < 400 \text{ MeV}$) and 22 gamma-ray groups ($0.01 \text{ MeV} < E < 20.0 \text{ MeV}$). Data are included for 18 of approximately 30 nuclides commonly found in shielding materials, and six scattering cross-section moments (P_5 order) are present for each nuclide. Materials of interest for the shielding calculations are: ordinary concrete, heavy concrete, and iron (i.e., 1020 steel). Compositions for these materials are shown in Table 1. The heavy concrete is ordinary concrete at 2.35 g/cm^3 with enough iron at 7.9 g/cm^3 added to produce a mixture with a density of 3.71 g/cm^3 , a specification used for heavy concrete at the Argonne National Laboratory's ^{60}Co Facility⁴. The mixture contains 75.5 volume percent of ordinary concrete and 24.5 volume percent of iron. The composition of ordinary concrete was obtained from the ANL 5800 document.⁵

Dose factors for the HILO group structure were derived from ICRP Publication 51 (ICRP-51)⁶ tabular data. These tables include Table 6 (PAR column), Table 21 (10 mm column), and Table 23 (10 mm column normalized to the Table 21 data at 20.0 MeV). Log-log interpolation and standard weighting spectra were used to convert the data to group constants for the HILO structure. Data from the VELM61 cross-section library⁷ were also converted to the HILO structure and compared to the data derived from ICRP-51. These comparisons are shown in Figure 3 for neutrons and Figure 4 for gamma rays. The comparisons show the converted ICRP-51 data to be reasonable, although there are large differences at low energies for both neutrons and gamma rays. The large difference at thermal-neutron energies is probably due to differences in weighting spectra used in the data conversion. Because high-energy neutrons are the dominant contributors to the dose rate, the dose rates obtained using these two response functions should be nearly equal.

All the ANISN and DORT calculations were performed using P_5 expansions of the scattering cross sections. However, the ANISN calculations used a rather fine S_{32} quadrature, while the DORT calculations used a coarser symmetric S_{12} quadrature with 96 directions.

4.0 SOURCE CALCULATION

Dose rates around the proposed facility result mainly from high-energy neutrons produced in the target material and secondary gamma rays generated in the target and shielding materials. The neutrons are produced from interactions of the source protons with the $^{238}\text{UC}_2$ target material, those interactions being determined by the HETC computer code.⁸ The proton beam is directed downward onto the 2-cm-diameter by 8-cm-long cylindrical $^{238}\text{UC}_2$ target, and the protons are normally incident and uniformly distributed over a 1.5-cm-dia. disk. HETC creates and tracks the neutrons until they escape or leak from the target or until they reach an energy cutoff. All the particle events are stored on a collision file that is analyzed to obtain (1) the high-energy ($E > 20.0 \text{ MeV}$) neutron leakage from the target and (2) a low-energy ($E < 20.0 \text{ MeV}$) neutron source for the MORSE Monte Carlo radiation transport code.⁹ The energy, position (x,y,z), direction (u,v,w), and weight parameters for the high-energy neutron leakages from the HETC code and the low-energy neutron and gamma-ray leakages from the MORSE code were written to files that were then processed by an in-house code to create volumetric sources for ANISN¹⁰ 1-D shielding calculations. Treating the target as a point, the code collected all particle directions lying within a specified cone about the beam's forward direction, summed the associated weights, renormalized the source over the 4π solid angle, and scaled the results by the number of protons per second ($1.25 \times 10^{15} \text{ s}^{-1}$ for 200 μA). Neutron and gamma-ray source spectra ($\text{MeV}^{-1} \cdot \text{s}^{-1} \cdot \text{sr}^{-1}$) are

shown in Figures 5-10 as a function of angular bin. In the ANISN calculations, the source was distributed over a small volume, since a true point source is not an option. Therefore, the source values were also divided by the volume over which they were distributed. The above-mentioned in-house code was also modified to create an angular-dependent source for GRTUNCL¹¹, which generates a 2-D R-Z first-collision source for the DORT two-dimensional discrete ordinates radiation transport code.¹² The point source is located 221 cm (87 in.) above the floor, 381 cm (12.5 ft) from the south wall, and 274 cm (9.0 ft) from the east wall.

5.0 SHIELDING ANALYSIS

5.1 TARGET ROOM (C109) -- OPERATIONAL

During operation, the source leakage from the target would ideally be azimuthally symmetric, varying only as a function of the polar angle measured from the -z axis along which the proton beam is directed when it impinges on the target. Hence, as a first approximation, the amount of side shielding required at a given height may be determined by using a 1-D source based on the angle between the -z axis and a line between the source and a representative point on the wall. Initially, such 1-D sources were used to scope shielding requirements at various heights for the south wall of room C109, the most vulnerable wall, and for the ceiling. These shielding estimates were then put in DORT 2-D R-Z calculations to verify the 1-D models. The DORT calculations for the south wall of room C109 were performed for three target shield designs. These designs were steel inverted cylindrical shells that were (1) uniformly 60.96-cm thick, (2) uniformly 30.48-cm thick, or (3) 15.24 cm on side and 60.96 cm on top. The weights of these shields, 50.6, 17.7, and 11.5 metric tons, respectively, are all probably allowable on the TIS platform. Isodose rate contours plotted on the 2-D geometry model are shown in Figures 11-13. It is seen that for each of the cases, the dose-rate constraint is satisfied at the exclusion boundary, although barely so for the latter target shield. The weakest point in the shielding is at the floor or lower wall of the walkway between the south wall of room C109 and the second floor computing room.

Results from the DORT calculation with the 60.96-cm-thick target shield were compared with ANISN results to determine which angular bins yielded the sources that most nearly reproduced the 2-D results. The data are plotted in Figures 14-16. For a horizontal traverse through the south wall on the first floor (Figures 14 and 15), the 50° to 70° source is the best fit, while the 75° to 90° source is a better fit for the 12.8° elevation traverse to the second floor. These sources were used to determine shielding requirements for the north, east, and west walls of the room. Note that initial 2-D X-Y calculations indicated that streaming would be too much of a problem with the maze design as shown in Figure 1. Hence, the north wall to the target area would have to be a solid shield during operation with a movable door to allow access during shutdown.

Figure 17 is a cross section through the ORIC shielded area of the facility. It shows areas where extra concrete shielding would need to be installed to keep operating and shutdown dose rates below regulatory limits. Figure 18 shows paths through the shielding for which 1-D calculations were performed to determine shielding requirements. For each of the three target side shield thicknesses (0.0, 30.48, and 60.96 cm), Table 2 shows dose rates as a function of the thicknesses of the various heavy concrete shields. Table 3 summarizes these results and shows the shielding thicknesses required to satisfy the dose-rate constraint. It was assumed that the 1-D to 2-D comparisons shown in Figures 14 and 15 remained valid for all the target shield thicknesses.

From the 1-D and 2-D results, the uniformly 60.96-cm-thick target shield and the corresponding heavy concrete shields shown in Table 3 appear to be the best shield system. If the TIS platform will not support this nearly 51-metric-ton target shield, then the system having the uniformly 30.48-cm-thick target shield is recommended. Systems having no target shield or having one with

a 60.96-cm-thick top and a 15.24-cm-thick side are less desirable because of the higher roof dose rates.

5.2 CYCLOTRON ROOM (C110) -- OPERATIONAL

During operation of the cyclotron, protons will be continuously lost from the beam during extraction and stopped in cyclotron structure. Like the protons that are stopped in the target, these protons lost during extraction cause the production of energetic neutrons and gamma rays that must be shielded against. For the shielding calculations associated with extraction losses, it was assumed that: (1) about 7% of the beam is lost at a point near the center of the room, (2) the protons are stopped in iron, and (3) about 61 cm (2 ft) of iron is integral with the cyclotron and will serve as shielding. In addition to the above assumptions, the emitted radiation was assumed to have an isotropic distribution. Similar to procedures used for the target calculation, the neutron and gamma-ray sources were generated using the HETC and MORSE codes. Since the stopping distance for 256 MeV protons is about 8 cm in iron,¹³ the protons were placed at the center of a 17-cm-diameter iron sphere for the source calculation. Low-energy ($E < 20$ MeV) neutrons produced by HETC were tracked by MORSE, and high- and low-energy neutrons and gamma rays leaking from the sphere were then used to create an isotropic source for the 1-D shielding calculations performed with ANISN. The total number of protons per second for a 14- μ A beam loss is $8.74 \times 10^{13} \text{ s}^{-1}$.

The most stringent shielding requirements were determined by performing the calculations along a path through the nearest wall adjacent to an accessible area (i.e., the east wall of room C110). Results from the calculation are shown in Table 4, indicating that beyond the 61 cm of self-shielding iron integral with the cyclotron, an additional 130 cm (4.3 ft)^a of iron would be required to meet the dose-rate criterion. Alternatively, an additional 39 cm (1.3 ft) of iron along with 183 cm of heavy concrete may be used to bring the dose rate down. Of course, the farther the shielding is placed away from the cyclotron, the greater the total amount of shielding that would be required. For the alternative shielding, the dose rate above the roof would likely be much higher than the allowable limit. Clearly, a continuous 7% beam loss from the cyclotron during extraction would be a serious shielding concern, and very substantial local shielding around the cyclotron would be required.

5.3 TARGET ROOM (C109) -- SHUTDOWN

During operation, the steel and concrete shielding will become activated through neutron interactions. Determining that activation over a fine spatial grid would be difficult. Therefore, ORIGEN¹⁴ calculations were performed for neutron spectra inside the steel shield and inside the ordinary and heavy concrete shields, and gamma-ray spectra in the HILO structure after one day of radioactive decay were extracted (only the last 11 groups have significant source). In addition, a 2-D X-Y DORT calculation was performed on a 2-D X-Y model of the ORIC shielded area and the added shielding shown in Figure 17. Dose rates along a south traverse from the target were found to differ from the 2-D R-Z results by a factor of 1/r. Therefore, thermal-neutron fluxes at each location were computed by summing the appropriate group flux fractions and dividing the result by r if r was greater than 1.0 cm. The fluxes were unchanged for $r \leq 1.0$ cm. The activation

^aThis value was obtained by adding the 8.5 cm iron thickness used in the source calculation to the 183 cm required shield thickness shown in Table 4 and subtracting the 61 cm of iron integral with the cyclotron.

gamma-ray sources for each mesh were then computed by ratioing the thermal-neutron flux for the mesh to the thermal-neutron flux for the appropriate spectrum (steel, ordinary concrete, or heavy concrete) and scaling the appropriate ORIGEN activation gamma-ray spectrum by that ratio. Where void appears in the geometry, there is no source. A DORT source file was written for the same X-Y geometry, and an eleven-group gamma-ray DORT calculation was performed. Like the neutron fluxes calculated for this geometry, the calculated decay gamma-ray fluxes are also likely to be conservative throughout the system. Hence, if the dose-rate criterion is satisfied at these flux levels, the shielding is probably conservative and no additional margin need be applied to the calculated shielding thicknesses.

Isodose rate contours are plotted over the geometry in Figure 19. It is seen that the dose rate in the target handling area is well below the criterion, particularly since there is no opening in the north wall of the target area. The dose rates in the target handling area are likely to increase with decreasing target shield thickness and decrease with increasing target shield thickness. For the range of target shield thicknesses considered, the shutdown dose rate does not appear to present a problem.

5.4 LOSS-OF-MAGNET-POWER ACCIDENT

There are many accident possibilities for the proton beam. A common accident would be the loss of electrical power in a dipole magnet, in which case the proton beam would not be bent, but the protons would stop in the magnet yoke. For loss-of-magnet-power accidents, the beam was assumed to be lost at one of the three bends in the beam line shown in Figure 20. As in the analysis in section 5.2, the beam was considered lost in iron and neutrons were emitted isotropically. Only a few cases were considered here. For a beam loss at position 1, the dose rate outside the southmost part of the building was calculated for the path shown in Figure 21 with the corresponding label. The dose rates at the floor and above the roof of the equipment room were calculated for positions 2 and 3. Locations where the dose rates were calculated are shown as "2A" and "2B" in Figure 20 (the dose rates for a beam loss at position 3 are the same as those due to a loss at position 2). Also for position 3, the dose rate in the west hallway was calculated for the corresponding path shown in Figure 21. Table 5 shows the results. For locations around the sides of the facility, the results indicate that because of the extra shielding in the target room, a beam loss at the bend in the target room (position 3) would lead to a direct dose rate well below the 100 mrem/h accident dose rate limit. However, the roof dose rate would be so high that the skyshine dose rate would exceed the 100 mrem/h criterion. The same conclusion is true for a loss at position 2. For the southside dose rate, added shielding for protecting against proton losses from the cyclotron were not included in the calculations. If heavy concrete shielding were added around the room, the direct dose rate outside the south wall of the facility would be less than the 100 mrem/h criterion. Skyshine dose rates could again be problematic.

If neutron emission were considered angular dependent, then a loss of beam at positions 1 or 3 would yield a smaller dose rate to the roof, although probably not enough to bring the dose rate there within compliance. Additionally, the dose rate outside the south wall of the building would fall within the criterion. The roof dose rate for a beam loss at position 2 would be worse than that calculated based on isotropic emission. Thus, the roof with its resulting skyshine would likely be the only problem area if angular dependence of neutron emission were strongly forward directed (i.e., along the direction of the incident proton beam). Skyshine dose rates could be a very serious problem for loss-of-magnet-power accidents.

5.5 GROUND ACTIVATION

Because the proton beam is directed downward into the target and towards the earth, the strongest neutron source will also be directed downward into the earth. This led to concerns that the ground could be activated and that groundwater could spread that activity. The task to determine the level of this activity and, based on regulatory limits on groundwater contamination, to determine whether a removable shield plug in the floor would be needed was not completed.

6.0 UNCERTAINTIES

The calculated dose rates are not exact and may be quite uncertain if there are large uncertainties in the data and methods used to calculate them. Thus, a calculated dose rate a few percent below the dose-rate criterion cannot with certainty be said to satisfy the criterion. The results may be uncertain due to (1) method uncertainties, (2) cross-section data uncertainties, (3) quadratures that are too coarse, (4) insufficient scattering cross-section moments to adequately represent forward scattering, (5) uncertainties in material compositions, and (6) uncertainties in high-energy physics modeling. The discrete ordinates method, the quadratures, and the material compositions are thought to contribute little to the uncertainties. If there are insufficient scattering cross-section moments, the straight-ahead flux will be underestimated and the flux in other directions will be overestimated. When fluxes are overestimated, there is less uncertainty as to the adequacy of the shield design. Thus, the number of cross-section moments has greater significance for the ground activation calculation. Unless there are substantially-deep windows in the cross-section data, the low-energy cross-section data will not contribute much to the uncertainty. Uncertainties at high energies ($E > 20.0$ MeV) are combinations of uncertainties in the modeling and in the cross-section data. High-energy and moderate-energy uncertainties were quantified by comparing measured neutron emission data with HETC-calculated data.² It was found that calculated yields underpredicted measured yields by about a factor of 1.5 at 90° and about a factor of 2.0 at 180° . Since the roof dose rate for the case with a target shield having a 61-cm-thick top and 15.2-cm-thick sides was higher than that for the case of a target shield having 30.5-cm-thick top and side walls as shown in Figures 12 and 13, the dose rate above the roof appears to be controlled by neutrons initially emitted in more forward directions. Therefore, it would seem that the smaller factor of 1.5 underprediction should apply to all dose rates. Hence, the shield design should be such that the controlling calculated dose rate is a factor of 1.5 less than the dose-rate criterion. An additional 11 cm of heavy concrete beyond that which yields the criterion dose rate would be required to achieve the desired dose-rate margin.

7.0 UNRESOLVED ISSUES AND CONCLUSIONS

Several issues with regard to shielding for the proposed upgrade to the Holifield Radioactive Ion Beam Facility were examined to determine the feasibility of the proposed upgrade. Satisfactory solutions for some of the issues may not have been achieved. For example, the dose rate on the roof during operation is borderline with respect to skyshine. Also, the roof dose rate for accident conditions far exceeds the criterion. Some type of shielding on the floor of the equipment room may be required to reduce the dose rate. In addition, the shielding arrangement for Room C110 needs to be resolved. Placing extra shielding along the walls helps to keep the dose rate below the criterion for both the continuous loss of protons from the cyclotron and the accidental loss of beam, while placing shielding only around the cyclotron leaves other areas vulnerable in the event of a loss-of-magnet-power accident in that room.

The proposed shield design for the target room during operation and shutdown does reduce the dose rate below the criterion at the side boundaries of the exclusion area. However, the dose rate

above the roof during operation is marginal. Likewise, shielding the side regions against continuous beam-extraction losses in the cyclotron is feasible, while shielding the roof presents difficulties. Similarly, the lack of adequate shielding for the roof is the biggest problem for the "loss-of-magnet-power" accident. While there may be several meters of side shielding to penetrate to reach the outside of the facility, there are only about 2.2 meters to penetrate to reach the outside through the roof. The shielding requirements related to ground activation remain to be examined.

Finally, it should be noted that the shields in this study have no penetrations, so the effects of those penetrations on dose rates outside the shields have not been factored into the analysis. The locations of these penetrations depend on the detailed design of the facility, and that design has not been completed. The inclusion of the effects of shield penetrations can significantly alter the conclusions of this study.

9.0 REFERENCES

1. D. K. Olsen, et al., "The ORNL Radioactive Ion Beam Project," in *Proceedings of the Workshop on the Production and Use of Intense Radioactive Beams at the ISOSPIN Laboratory*, J. D. Garrett, ed., pp. 375-416, Joint Institute for Heavy Ion Research, Oak Ridge, Tennessee, October 7-10, 1992.
2. J. O. Johnson, T. A. Gabriel, and R. A. Lillie, "Preliminary Shielding Estimates for the Proposed National ISOL Radioactive Ion Beam (RIB) Facility at Oak Ridge," in *Proceedings of the 1996 Topical Meeting: Radiation Protection & Shielding*, Volume 1, pp. 94-101, American Nuclear Society, North Falmouth, Massachusetts, April 21-25, 1996.
3. R. G. Alsmiller, Jr. and J. Barish, "HILO Neutron-Photon Multigroup Cross Sections for Neutron Energies < 400 MeV," Oak Ridge National Laboratory, ORNL/TM-7818 (June 1981).
4. C. O. Slater, "Analysis of the ANL ^{60}Co Facility TORT Code Verification Experiment," Oak Ridge National Laboratory, ORNL/TM-11931 (June 1992).
5. *Reactor Physics Constants*, ANL-5800, Argonne National Laboratory, U. S. Atomic Energy Commission, Washington, D. C. (July 1963).
6. The International Commission on Radiological Protection, *ICRP Publication 51: Data for Use in Protection Against External Radiation*, Pergamon Press, New York, 1987.
7. C. Y. Fu and D. T. Ingersoll, "VELM61 and VELM22: Multigroup Cross-Section Libraries for Sodium-Cooled Reactor Shield Analysis," Oak Ridge National Laboratory, ORNL/TM-10302 (April 1987).
8. T. A. Gabriel, et al., "CALOR: A Monte Carlo Program Package for the Design and Analysis of Calorimeter Systems," Oak Ridge National Laboratory, ORNL/TM-5619 (1977).
9. M. B. Emmett, "The MORSE Monte Carlo Radiation Transport Code System," Oak Ridge National Laboratory, ORNL-4972 (1975), ORNL-4972/R1 (1983), ORNL-4972/R2 (1984).
10. W. W. Engle, Jr., "A User's Manual for ANISN: A One-Dimensional Discrete Ordinates Transport Code with Anisotropic Scattering," Union Carbide Nuclear Division Report K-1693 (1967).
11. R. L. Childs and J. V. Pace, "GRTUNCL: First Collision Source Program," Unpublished Documentation (1982) now documented as "GRTUNCL: An Analytic First Collision Source Code," in *A User's Manual for MASH 1.0 - A Monte Carlo Adjoint Shielding Code System*, J. O. Johnson, ed., Oak Ridge National Laboratory, ORNL/TM-11778 (March 1992).
12. W. A. Rhoades and R. L. Childs, "The DORT Two-Dimensional Discrete Ordinates Transport Code," *Nucl. Sci. & Eng.* **99**, (1), 88-89 (May 1988).
13. M. M. Meier, C. A. Goulding, G. L. Morgan, and J. L. Ullmann, "Neutron Yields From Stopping-Length and Near-Stopping-Length Targets for 256-MeV Protons," *Nucl. Sci. & Eng.* **104** (4) 339-363 (April 1990).
14. A. G. Croff, "ORIGEN2 — A Revised and Updated Version of the Oak Ridge Isotope Generation and Depletion Code," Oak Ridge National Laboratory, ORNL-5621 (July 1980).

Table 1. Compositions of Materials Used in the Shielding Calculations for the Proposed HRIBF Upgrade.

Nuclide	Materials			
	Uranium Carbide	1020 Steel	Ordinary Concrete	Heavy Concrete
	Atomic Density ($b^{-1} \cdot cm^{-1}$)			
H			7.768-3	5.864-3
C	5.1848-2 ^a	7.8228-4		
O			4.386-2	3.311-2
Na			1.336-3	1.009-3
Mg			1.486-4	1.122-4
Al			2.389-3	1.804-3
Si		4.2140-4	1.580-2	1.193-2
K			6.931-4	5.233-4
Ca			2.915-3	2.201-3
Mn		3.8777-4 ^b		
Fe		8.4006-2	3.128-4	2.111-2
U	2.5924-2			

^aRead as 5.1848×10^{-2} .

^bCr was used in place of Mn for which no cross sections were available.

Table 2. Dose Rates (mrem/h) at the Exclusion Boundary for Various Paths Through the Geometry of the Proposed HRIBF Upgrade.

Path ^a	Shield ^b	Shield Thickness (cm)	Target Shield Thickness (cm)		
			0.0	30.48	60.96
			Dose Rates (mrem/h)		
1	D	121.92	68.8	12.02	1.97
1	D	182.88	6.87	1.21	0.20
1	D	243.84	0.68	0.12	0.02
2	C	60.96	0.30	0.053	0.009
2	C	91.44	0.10	0.018	0.003
2	C	121.92	0.034	0.006	0.001
3	C	60.96	4.57	0.80	0.14
3	C	91.44	1.63	0.29	0.049
3	C	121.92	0.59	0.10	0.018
4	H	0.0	0.011	0.00256	4.04-4 ^c
4	H	60.96	0.0005	7.58-5	1.21-5
5	E	0.0	16.9	2.94	0.49
5	E	30.48	6.01 ^d	1.05 ^d	0.18 ^d
5	E	60.96	2.14 ^d	0.38 ^d	0.06 ^d
5	E	91.44	0.76 ^d	0.13 ^d	0.023 ^d
5	E	121.92	0.27	0.048	0.008
6	D	121.92	12.0	2.1	0.35
6	D	182.88	1.57	0.28	0.046
6	D	243.84	0.20	0.036	0.006
7	C	60.96	2.53	0.44	0.075
7	C	91.44	0.81	0.14	0.024
7	C	121.92	0.26	0.047	0.008
8	F	0.0	2.72	0.48	0.079
8	F	60.96	0.34	0.06	0.010
9	G	0.0	-	1.0 ^e	0.23
9	G	60.96	0.99	0.16	0.024

^aSee Fig. 6.

^bSee Fig. 5.

^cRead as 4.04×10^{-4} .

^dInterpolated values. ^eFrom 2-D dose plot.

Table 3. Thicknesses (cm) of Heavy Concrete Needed to Reduce Dose Rates From the Target to Less Than 0.25 mrem/h Outside the Exclusion Areas When the Steel Around the Target (A) is a Given Thickness.

Shield	Target Shield (A) Thickness (cm)		
	0.0	30.48	60.96
	Heavy Concrete Shield Thicknesses (cm)		
B	182.88	182.88	182.88
C	152.4	121.92	60.96
D	274.32	243.84	182.88
E	152.4	91.44	30.48
F	91.44	30.48	0.0
G	-	0.0	0.0
H	0.0	0.0	0.0

Table 4. Maximum Dose Rates Outside the Exclusion Area Due to 7% (14 mA) Beam Extraction Losses From the Cyclotron in Room C110 as a Function of Shield Design. The cyclotron would be shielded with about 61 cm of steel.

Case	Shield Description ^a	Dose Rate (mrem/h)
1	91 cm Steel	30.1
2	122 cm Steel	5.70
3	152 cm Steel	1.06
4	183 cm Steel	0.19
5	61 cm Steel/183 cm Heavy Concrete	0.54
6	91 cm Steel/183 cm Heavy Concrete	0.10

^aThe 8.5 cm of steel used in the HETC source calculation should be added to these thicknesses.

Table 5. Dose Rates Due To Loss of Magnet Power Accidents.

Loss Position	Dose Location	Dose Rate (mrem/h)
1	Outside South Wall	265
2 or 3	Equipment Room Floor	680,000
2 or 3	Equipment Room Roof	70,600
3	West Hallway (outside room C111)	3.1

Figure 1. Preliminary Layout of the Heavily-Shielded Area, the ORIC Shielded Area, Containing the Target and Cyclotron Rooms of the Proposed HRIBF Upgrade to the National RIB ISOL Facility.

Figure 2. Preliminary Layout of the First Floor of the Proposed HRIBF Upgrade to the National RIB ISOL Facility

Figure 3. Comparison of HILO Neutron Dose Factors Converted From ICRP-51 Data to Those Converted From VELM61 Data.

Figure 4. Comparison of HILO Gamma-Ray Dose Factors Converted From ICRP-51 Data to Those Converted From VELM61 Data.

Figure 5. Target Neutron Leakage Spectra in 0° to 15°, 15° to 30°, and 30° to 45° Angular Bins for a 200-mA Beam of 235-MeV Protons Incident on the $^{238}\text{UC}_2$ Target.

Figure 6. Target Gamma-Ray Leakage Spectra in 0° to 15°, 15° to 30°, and 30° to 45° Angular Bins for a 200-mA Beam of 235-MeV Protons Incident on the $^{238}\text{UC}_2$ Target.

Figure 7. Target Neutron Leakage Spectra in 45° to 60°, 60° to 75°, and 75° to 90° Angular Bins for a 200-mA Beam of 235-MeV Protons Incident on the $^{238}\text{UC}_2$ Target.

Figure 8. Target Gamma-Ray Leakage Spectra in 45° to 60°, 60° to 75°, and 75° to 90° Angular Bins for a 200-mA Beam of 235-MeV Protons Incident on the $^{238}\text{UC}_2$ Target.

Figure 9. Target Neutron Leakage Spectra in 90° to 105°, 105° to 135°, and 150° to 180° Angular Bins for a 200-mA Beam of 235-MeV Protons Incident on the $^{238}\text{UC}_2$ Target.

Figure 10. Target Gamma-Ray Leakage Spectra in 90° to 105°, 105° to 135°, and 150° to 180° Angular Bins for a 200-mA Beam of 235-MeV Protons Incident on the $^{238}\text{UC}_2$ Target.

Figure 11. Dose Rates (mrem/h) for a 2-D R-Z Model of the Proposed HRIBF Upgrade for the Case of an Inverted Cylindrical Cup Target Shield Having a 60.96-cm-Thick Top and a 60.96-cm-Thick Side Wall.

Figure 12. Dose Rates (mrem/h) for a 2-D R-Z Model of the Proposed HRIBF Upgrade for the Case of an Inverted Cylindrical Cup Target Shield Having a 30.48-cm-Thick Top and a 30.48-cm-Thick Side Wall.

Figure 13. Dose Rates (mrem/h) for a 2-D R-Z Model of the Proposed HRIBF Upgrade for the Case of an Inverted Cylindrical Cup Target Shield Having a 60.96-cm-Thick Top and a 15.24-cm-Thick Side Wall.

Figure 14. Comparison of DORT Dose Rates for a First-Floor Radial Traverse From the Source Through a 2-D R-Z Mockup of the South Regions of the Proposed HRIBF Upgrade With ANISN Dose Rates for Sources in Angular Bins Between 60° and 90

Figure 15. Comparison of DORT Dose Rates for a First-Floor Radial Traverse From the Source Through a 2-D R-Z Mockup of the South Regions of the Proposed HRIBF Upgrade With ANISN Dose Rates for Sources in Angular Bins Between 50° and 70°.

Figure 16. Comparison of DORT Dose Rates for a 12.8° Elevation Radial Traverse From the Source to the Second Floor Through a 2-D R-Z Mockup of the South Regions of the Proposed HRIBF Upgrade With ANISN Dose Rates for Sources in Angular Bins Between 45° and 90°.

Figure 17. Identification of Added Heavy Concrete Shields Around the Target Room of the ORIC Shielded Area of the Proposed HRIBF Upgrade.

Figure 18. Paths in the Proposed HRIBF Upgrade Geometry Along Which 1-D Calculations Were Performed.

Figure 19. Activation Gamma-Ray Dose Rates (mrem/h) for a DORT Calculation on an X-Y Geometry Mockup of the Proposed HRIBF Upgrade.

Figure 20. Elevation View of the Proton Beam in Rooms C110 and C109 of the HRIBF Upgrade. (Circled numbers show bends in the line where the beam may be lost in a Loss-of-Magnet-Power accident. Also shown are the locations where accident dose rates above the target room were calculated.)

Figure 21. First-Floor Layout of the Proposed HRIBF Upgrade, Showing Paths Along Which Accident Dose Rates Were Calculated.

APPENDIX A

**PRELIMINARY SHIELDING ANALYSIS FOR THE
PROPOSED HRIBF UPGRADE**

PRELIMINARY SHIELDING ESTIMATES FOR THE PROPOSED NATIONAL
ISOL RADIOACTIVE ION BEAM (RIB) FACILITY AT OAK RIDGE

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ABSTRACT

The Oak Ridge National Laboratory (ORNL) has built a first-generation Radioactive Ion Beam (RIB) facility to produce radioactive beams for astrophysics and nuclear physics research. This existing facility is named the Holifield Radioactive Ion Beam Facility (HRIBF) and is based on the Isotope Separator On Line (ISOL) technique. In addition to developing this first-generation facility, planning is underway for a second-generation facility, the National ISOL RIB Facility at Oak Ridge. The preliminary upgrade plan for the new facility includes; 1) adding a superconducting booster for the tandem accelerator, 2) replacing the 1960-vintage, 60 MeV proton, 50 microamp ORIC with a modern 200 MeV proton, 200 microamp cyclotron, and 3) building a high power ^{238}U fission target to accept the 200 MeV proton beam. This report summarizes the results of a preliminary one-dimensional shielding analysis to determine the feasibility of such an upgrade with respect to existing shielding from the facility structure, and additional shielding requirements for the high-power 200 MeV proton, 200 microamp ^{238}U target-ion source.

A calculational strategy was initiated utilizing High Energy Transport Code (HETC) Monte Carlo calculations and ANISN one-dimensional discrete ordinates calculations to determine the shielding requirements for a 0.25 mrem/h dose rate at the external surface of the exclusion area. HETC was used to determine the angular and energy dependent neutron leakage spectrum from a ^{238}U target assembly for input into ANISN. Multiple directionally dependent one-dimensional spherical models of the target room and surrounding facility structure were analyzed in ANISN to determine the dose rates on the exterior surfaces of the exclusion area.

Steel shields were designed for several dose rate scenarios and modeling assumptions utilizing the results from the ANISN calculations, and taking a conservative approach with respect to shield design. The shield weights ranged from 60 to 100 metric tons depending on the assumptions in the calculational model and dose assessment parameters. These shield weights were considered manageable for the upgrade, and furthermore, suggestions resulting from the shielding analysis could further reduce the additional steel shielding weight by a factor of two to three if the orientation of the proposed target station was changed.

I. INTRODUCTION

The Oak Ridge National Laboratory (ORNL) has built a first-generation Radioactive Ion Beam (RIB) facility to produce radioactive beams for astrophysics and nuclear physics research.¹ This existing facility is named the Holifield Radioactive Ion Beam Facility (HRIBF) and is based on the Isotope Separator On Line (ISOL) technique. The HRIBF utilizes beams of protons or other stable light ions from the Oak Ridge Isochronous Cyclotron (ORIC) to produce radioactive atoms from nuclear reactions in thick target material in a target-ion source assembly. The resulting radioactive atoms are ionized, charge exchanged, accelerated to 300 keV, mass separated, and injected into the 25 MV tandem accelerator for acceleration to energies of interest for nuclear and astrophysics research.

In addition to developing this first-generation facility, planning is underway for a second-generation facility, the National ISOL RIB Facility at Oak Ridge. This second-generation facility will build on the existing HRIBF and may utilize many existing components and shielded areas. The preliminary upgrade plan for the new facility includes; 1) adding a superconducting booster for the tandem accelerator, 2) replacing the 1960-vintage, 60 MeV proton, 50 microamp ORIC with a modern 200 MeV proton, 200 microamp cyclotron, and 3) building a high power ^{238}U fission target to accept the 200 MeV proton beam. This report summarizes the results of a preliminary one-dimensional shielding analysis of the proposed upgrade. 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 high-power 200 MeV proton, 200 microamp ^{238}U target-ion source.

II. CALCULATIONAL PROCEDURE

To address this problem, a series of High Energy Transport Code² (HETC) Monte Carlo calculations and ANISN³ 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 target exclusion area. HETC was used to determine the angular and energy dependent neutron leakage spectrum from a proton source incident on a ^{238}U target assembly for input into ANISN. Multiple directionally dependent one-dimensional spherical models of the target room and surrounding structure were analyzed in ANISN to determine the dose rates on the exterior of the exclusion area. The 88 group HILO cross-section library,⁴ which includes 66 neutron and 22 gamma-ray groups, was used in the ANISN calculations to represent the different materials present in the 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 facility. 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 target neutron leakage spectra angular dependence, concrete wall thickness and material composition, additional shielding placement and thickness, and 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 exclusion area.

III. RESULTS

A first-floor layout of the existing HRIBF with the initially proposed existing target room (Room C111) is illustrated in Figure 1. The analysis of the initial placement of the target in the existing target room indicated maximum proton beam currents ranging in the nanoamp to picoamp range for the 200 MeV proton beam and an allowable dose rate of 0.25 mrem/h. 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 proposed facility was reconfigured and the target room relocated deeper into the internal structure of the building to take advantage of additional concrete wall shielding offered by the building support structure.

Figure 1. Existing HRIBF Building First Floor Plan and Initially Proposed Existing Target Room (Room C111).

The ANISN analyses of the initial target room location used an isotropic source distribution. The true angular distribution of the target neutron leakage source is highly anisotropic (heavily peaked forward). Consequently, the angular distribution of the neutron leakage out of the target was accounted for in the next generation of ANISN spherical calculations. HETC-generated ANISN source distributions were determined for a 0-degree source (the forward direction) averaged over a cone from 0 to 15 degrees, a 45-degree source averaged over a cone from 30 to 45 degrees, a 90-degree source averaged over a cone from 75 to 90 degrees, and a 180-degree source averaged over a cone from 150 to 180 degrees.

The alternate placement of the target room configuration (Room C109), along with other upgrades to the facility, is illustrated in Figure 2. The general floor plan of the building was studied and ten different ANISN cases were setup to characterize the shielding requirements for the new target room. Nine calculational models were setup to analyze the shielding requirements on the first floor, and one case was setup to analyze the shielding requirements for the leakage out of the ceiling and roof of the facility. Case 1 modeled the forward directed source; Case 2 modeled a forward direction at approximately 45 degrees and penetrated a cut through one of the concrete walls; Cases 3 and 8 modeled the 90-degree directions; Case 6 modeled the 180-degree direction; and Case 10 modeled the 90-degree source penetrating the roof. Cases 4, 5, and 9 were designed to investigate directions of minimal shielding when considering only the walls of the building structure. ANISN calculations were executed for each of the cases, and in some cases, the effects of two different directional sources were calculated. 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. Complete descriptions of the HETC-generated ANISN source distributions and ANISN spherical models for all cases can be found in an ORNL Technical Memorandum (TM) to be published later.

Figure 2. Upgraded HRIBF Building First Floor Plan and Proposed Alternate Placement of the Target Room (Room C109).

The results of the ANISN analyses of the new target location using the appropriate directional sources are given in Table 1. In some cases, the results were obtained for two different HETC-generated directional sources. From these results, Cases 5, 6, and 7 indicate adequate shielding for the proposed design current, and Cases 4 and 9 indicate maximum operating currents close to the

design limit of 200 microamps. Additional ANISN cases were setup to include steel shielding around the target assembly using the results in Table 1. The steel shield was offset from the target approximately 0.3 meters. Cases 1 through 4 and 8 through 10 were analyzed for various steel thicknesses. For each case, the steel thickness was increased until the maximum operating current was well above the design limit. From these results, the minimum additional steel shielding could be determined for the different sources and directions utilized in the ANISN models.

Table 1. Dose Rate and Maximum Current Results for the Alternate Target Position in Room C109.

Directional Neutron And Gamma-Ray Emissions From Target			
Case Number	Directional Source (Degrees)	Dose Rate (mrem/h)	Maximum Current (Amps)
1	0	1.868-12	2.144-08
2	0	1.999-12	2.004-08
2	45	2.335-13	1.715-07
3	90	4.240-15	9.446-06
4	90	2.723-16	1.471-04
5	90	1.942-19	2.062-01
5	180	1.693-23	2.366+03
6	180	1.902-21	2.106+01
7	90	6.424-24	6.235+03
7	180	0.000+00	-----
8	90	8.528-16	4.697-05
9	45	3.605-16	1.111-04
9	90	2.237-18	1.790-02
10	90	4.295-13	9.325-08

Read 1.234-05 as 1.234×10^{-5}

Results are per source proton per second

Maximum Current Results are for a 0.25 mrem/h Dose Rate

Outside the Exclusion Area Walls.

The uranium target experiment utilizing 256 MeV protons, performed by M. M. Meier et. al.,⁵ was calculated using HETC to determine the accuracy of the HETC-generated angular distributions of the target neutron and gamma-ray emissions. The results of the comparisons to the experimental measurements indicated HETC compared well in the forward direction, but increasingly underestimated the source as the source angle increased from the straight ahead direction. Consequently, 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- and 180-degree sources, the additional steel shield 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 additional steel shield 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- and 180-degree directions (100% HETC under-estimation). Finally, the ANISN model for the ceiling and roof (Case 10) was calculated for both a 0.25 mrem/h dose rate on the roof of the building, and for a 12.50 mrem/h (50 times 0.25 mrem/h) dose rate on the roof. This latter quantity represents a skyshine dose return equivalent to 0.25 mrem/h (i.e., equivalent to 2% of the 12.50 mrem/h dose rate on the roof of the building [Case 10*]). The results for these two scenarios are given in Table 2.

Table 2. Additional Steel Shielding Material Required for the Alternate Target Position in Room C109.

Scenario A		Scenario B	
Case Number	Steel Thickness (m)	Case Number	Steel Thickness (m)
1	1.69	1	1.69
2	1.23	2	1.31
3	0.49	3	0.61
4	0.06	4	0.17
8	0.24	8	0.35
9	0.11	9	0.18
10	1.19	10	1.23
10*	0.58	10*	0.69

Case 10* assumes a 2% skyshine return equivalent to the 0.25 mrem/h dose rate outside the roof of the building.

Steel shields were designed for both scenarios utilizing the results from the ANISN calculations presented in Table 2, and taking a conservative approach with respect to shield design. A shield was placed below the target to minimize the floor and ground activation; however, this shield thickness was not determined by calculation, but rather through intuition from the other 90-degree source analyses. In both scenarios, the shields were designed symmetrically with the direction requiring the most shielding material determining the thickness of the steel. Isometric, X-Y, and X-Z cut views of the composite designs are presented in Figure 3a for the Scenario A calculations, and Figure 3b for the Scenario B calculations. The separate section on top, indicated in each view, represents the additional shielding required if the dose exiting the roof must be less than 0.25 mrem/h. If the dose requirements are set for a skyshine dose of 0.25 mrem/h, then this top portion of the shield would not be required.

From the initial analysis, a shield weighing approximately 572 metric tons was required for the target positioned in room C111 using the HETC-generated isotropic source distribution. Fine tuning the design of the shield configurations presented in Scenario's A and B yielded a considerable reduction in required shielding size and weight. The results indicate shield weights of

75 metric tons (Scenario A) or 95 metric tons (Scenario B) for the case where the dose rate on the roof is 0.25 mrem/h, and shield weights of 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 were considered much more manageable for the proposed upgrade to 200 MeV protons at 200 microamps beam current.

In viewing the results in Table 2 and composite shield designs in Figure 3, it was apparent that the two areas requiring the most additional shielding were the forward direction (Cases 1 and 2), and the roof (Case 10). Consequently, the shielding analysts suggested that the orientation of the target station be changed such that the incident proton beam is directed vertically downward into the target. This orientation could then utilize the ground for the bulk of the forward direction shielding and beam stop. Furthermore, the least intense source, i.e., the HETC-generated 180-degree source, would be directed upward toward the roof and consequently reduce the amount of required shielding in that direction. Incorporation of this design change (if feasible) would probably further reduce the required additional steel shielding weight by a factor of two to three.

IV. CONCLUSIONS AND RECOMMENDATIONS

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 from the designs presented in Figure 3. 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, shape, and weight of what would eventually be required for the proposed configuration and orientation of the HRIBF upgrade. A configuration with the proton beam directed vertically into the ground should be investigated.

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REFERENCES

1. D. K. Olsen et. al., in "Production and Use of Intense Radioactive Beams at the Isospin Laboratory," ed., J. D. Garrett, CONF-9210121, pg. 385, (ORISE, Oak Ridge, 1992).
2. T. A. Gabriel et. al., "CALOR; A Monte Carlo Program Package for the Design and Analysis of Calorimeter Systems," ORNL/TM 5619, Oak Ridge National Laboratory, (1977).
3. Ward W. Engle, Jr., "A User's Manual for ANISN, A One-Dimensional Discrete Ordinates Transport Code with Anisotropic Scattering," K-1693, Oak Ridge National Laboratory, (1967).
4. R. G. Alsmiller, Jr. and J. Barish, "HILO Neutron-Photon Multigroup Cross Sections for Neutron Energies < 400 MeV," ORNL/TM-7818, Oak Ridge National Laboratory, (June 1981).

5. M. M. Meier, C. A. Goulding, G. L. Morgan, and J. L. Ullmann, "Neutron Yields From Stopping-Length and Near-Stopping-Length Targets for 256 MeV Protons," Nuclear Science and Engineering, (1989)

3a. Scenario A Steel Shield

3b. Scenario B Steel Shield

Figure 3. Isometric, X-Y, and X-Z Cut Views of the Required Additional Steel Shields for Scenario A and Scenario B.

APPENDIX B:
DOSE-RATE CONSTRAINTS FOR A LOSS-OF-MAGNET-POWER ACCIDENT

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Date: March 29, 1996
To: J. O. Johnson, 6025, MS-6363
cc: G. D. Alton, J. R. Beene, J. D. Garrett, F. Plasil
From: D. K. Olsen, 6000, MS-6368, 4-6122 (RC) *DKO*
Subject: Total Dose for Accelerator Accidents

The total dose and dose rate limits for various situations for the operation of accelerators is contained in DOE Order 5480.25 "Safety of Accelerators" dated 11/3/92. The main issue in the past has been the hazard class of the accelerator facility. Almost all accelerator facilities are in the low-hazard class. The 5480.25 Guidance document, dated 9/1/93, has the following accident dose requirements for a low-hazard facility:

1) "Off-site," outside Building 6000	Dose = 1.0 Rem
2) "On-site," inside Building 6000	Dose = 25.0 Rem

These doses can occur over a one-hour period and one can assume the shielding remains intact and the doors and gates are secured. No active mitigation of the accident is allowed.

These requirements are fairly well defined. The requirement of an off-site accident for the SSC giving a dose of 0.1 Rem, 1/10 of the above value, which we discussed, seems reasonable in terms of this guidance. The confusion occurs because a letter dated 1/2/96 on the Clarification of Guidance to 5480.25 withdrew the above requirements. This leaves everything to be decided on a case-by-case basis.

What shall we do? Surely a loss of magnet power accident will occur from time to time, so we need to be conservative. It seems that a dose rate of 0.100 Rem/hr is a reasonable level in an accident mode, both in and outside Building 6000. It is 1/10 of the previous guidance value for off-site accidents. In addition, 0.100 Rem/hr is the boundary between Radiation areas and High-Radiation areas, so this limit makes sense in terms of radiation protection. I suggest we perform dose rate calculations for magnet failures in which the full beam stops in an iron target. Calculate the dose rates outside the shielding and then decide what to do from these results. If the dose rate is less than 0.100 Rem/hr, we probably have completed the accident analysis.

DKO:jm

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