Preliminary Shielding Estimates For The Proposed National ISOL Radioactive Ion Beam (RIB) Facility At Oak Ridge

CONF-960415--42

J. O. Johnson
T. A. Gabriel
R. A. Lillie

Oak Ridge National Laboratory
P. O. Box 2008
Oak Ridge, Tennessee 37831-6364

Oak Ridge National Laboratory, managed by Lockheed Martin Energy Research, Corp. for the U.S. Department of Energy under contract number DE-AC05-960R22464

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

J. O. Johnson, T. A. Gabriel, and R. A. Lillie
Oak Ridge National Laboratory
P. O. Box 2008, MS-6363
Oak Ridge, Tennessee 37831-6363
(423) 574-5262

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 Code[2] (HETC) Monte Carlo calculations and ANISN[3] 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.

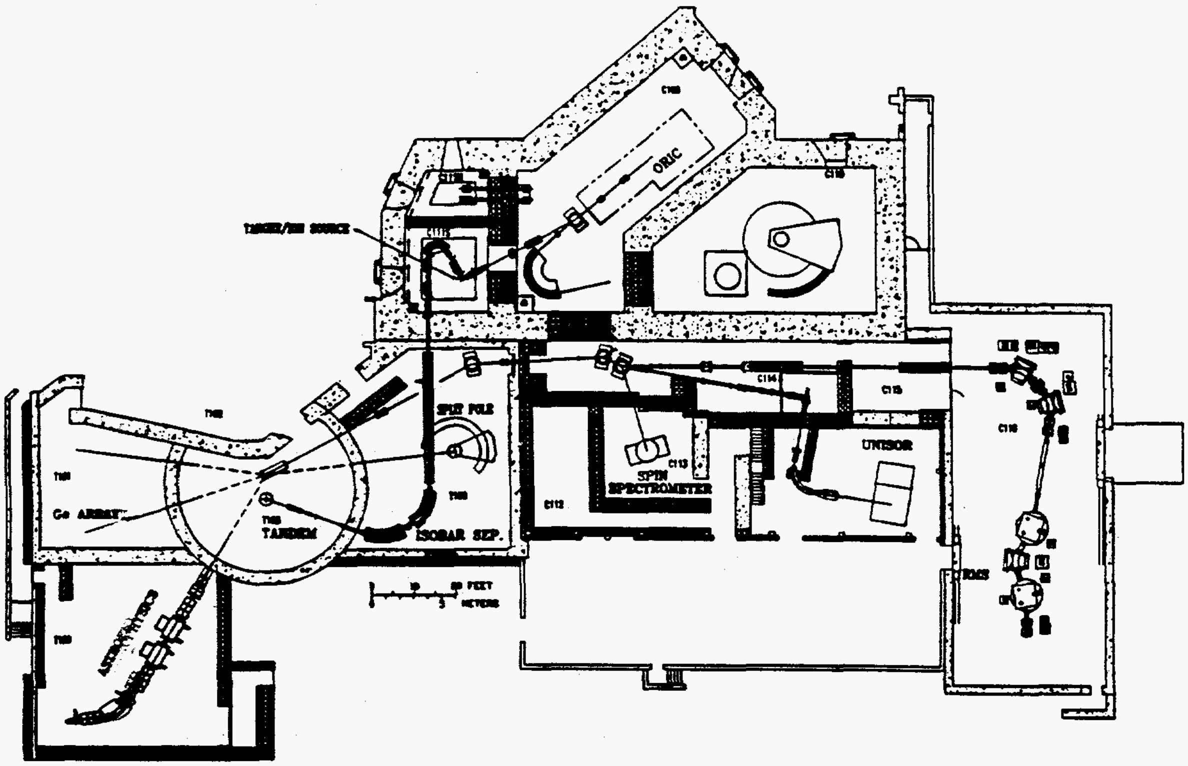


Figure 1. Existing HRIBF Building First Floor Plan and Initially Proposed Existing Target Room (Room C111).

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.

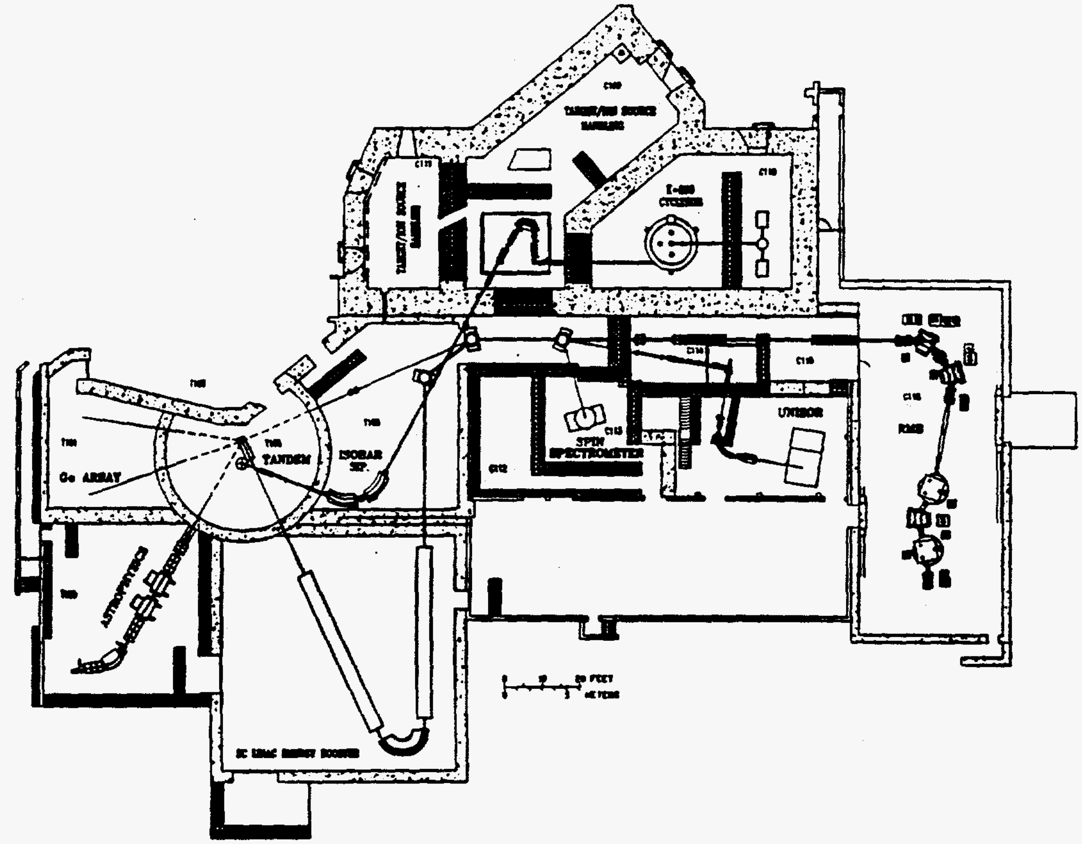


Figure 2. Upgraded HRIBF Building First Floor Plan and Proposed Alternate Placement of the Target Room (Room C109).

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.

ACKNOWLEDGMENTS

Prepared at the Oak Ridge National Laboratory, Oak Ridge, Tennessee 37831-6363. Managed by LOCKHEED MARTIN ENERGY RESEARCH CORPORATION for the U. S. DEPARTMENT OF ENERGY under contract DE-AC05-96OR22464.

REFERENCES

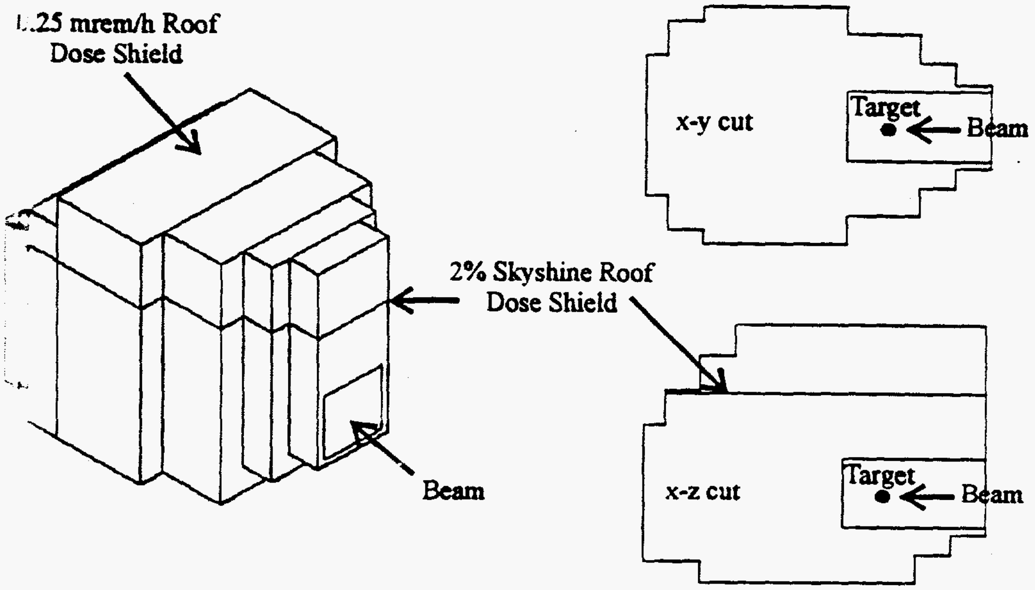
1. D. K. Olsen et. al., in "Production and Use of Intense Radioactive Beams at the Isospin Laboratory," ed., J. D. Garrett, CONF-9210121, pg. 385, (ORISE, Oak Ridge, 1992).

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).

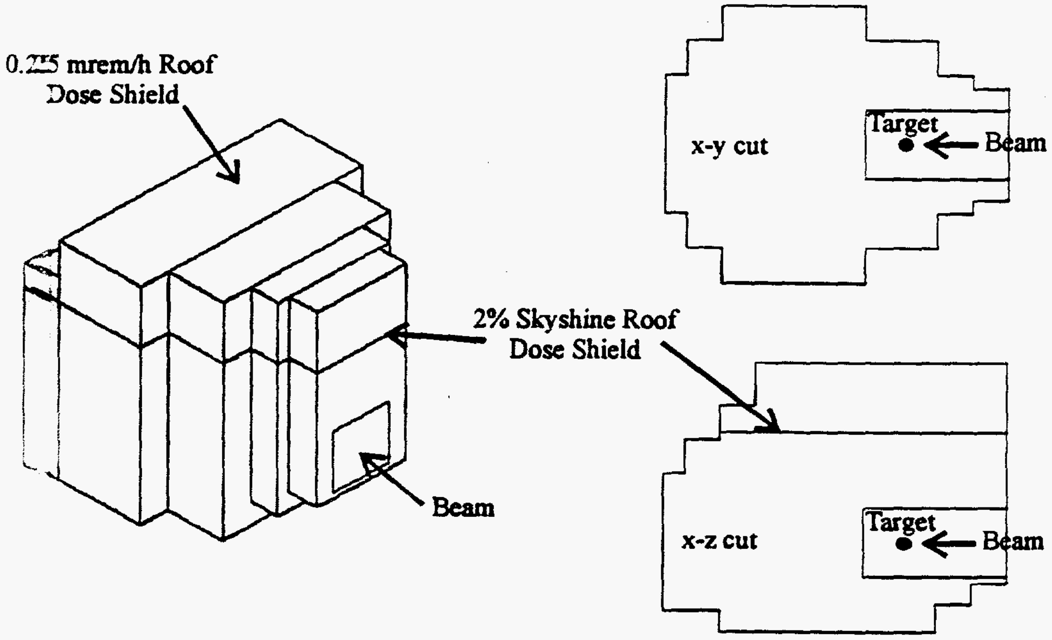
3. Ward W. Engle, Jr., "A User's Manual for ANISN, A One-Dimensional Discrete Ordinates Transport Code with Anisotropic Scattering," K-1693, Oak Ridge National Laboratory, (1967).

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.