ANL/CSE-14/30

Bulk Shielding for NorthStar Production Facility

Chemical Sciences and Engineering Division

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Bulk Shielding for NorthStar Production Facility

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BULK SHIELDING FOR NORTHSTAR PRODUCTION FACILITY

1 INTRODUCTION

NorthStar Medical Technology is proposing to build a facility for the production of the medical isotope ^{99}Mo that uses electron linear accelerators to bombard targets of molybdenum metal enriched in the isotope ^{100}Mo. When the electron beam strikes the target, bremsstrahlung photons are produced and subsequently induce ^{100}Mo(γ,n)^{99}Mo reactions. The operation of the accelerator, the interaction of the electron beams with the targets, and the resulting activated materials all constitute radiological hazards that must be protected against by shielding those regions of the facility.

The facility will consist of a number of accelerator/target bays in which beams from two accelerators will be directed onto a single target from opposite directions (Figure 1). Four bulk shielding scenarios are to be considered:

1. Personnel should be able to access the target services area above the accelerator/target bays.

2. Personnel should be able to work in one bay while the accelerators in adjoining bays are operating.

3. The hallway outside the accelerator bays should be accessible during operation as non-radiation areas.

4. Areas outside the plant should also be accessible to the general public.

Plots of the facility are shown as Monte Carlo N-Particle Transport Code (MCNP) models in Figures 2 and 3.

The shielding shown in the figures consists of 18 in. (46 cm) of iron immediately surrounding a target region that is 12 in. (30 cm) high x 12 in. (30 cm) diameter. Outside of the iron is a concrete monolith with dimensions of 200 in. (508 cm) x 200 in. (508 cm). The overall height is to be determined by the need to keep the dose rate in the services area below 1 mrem/hr. The wall thickness between the accelerator bay and the hallway, and between one bay and those adjacent, will also be determined by the desired dose rates in the respective areas.

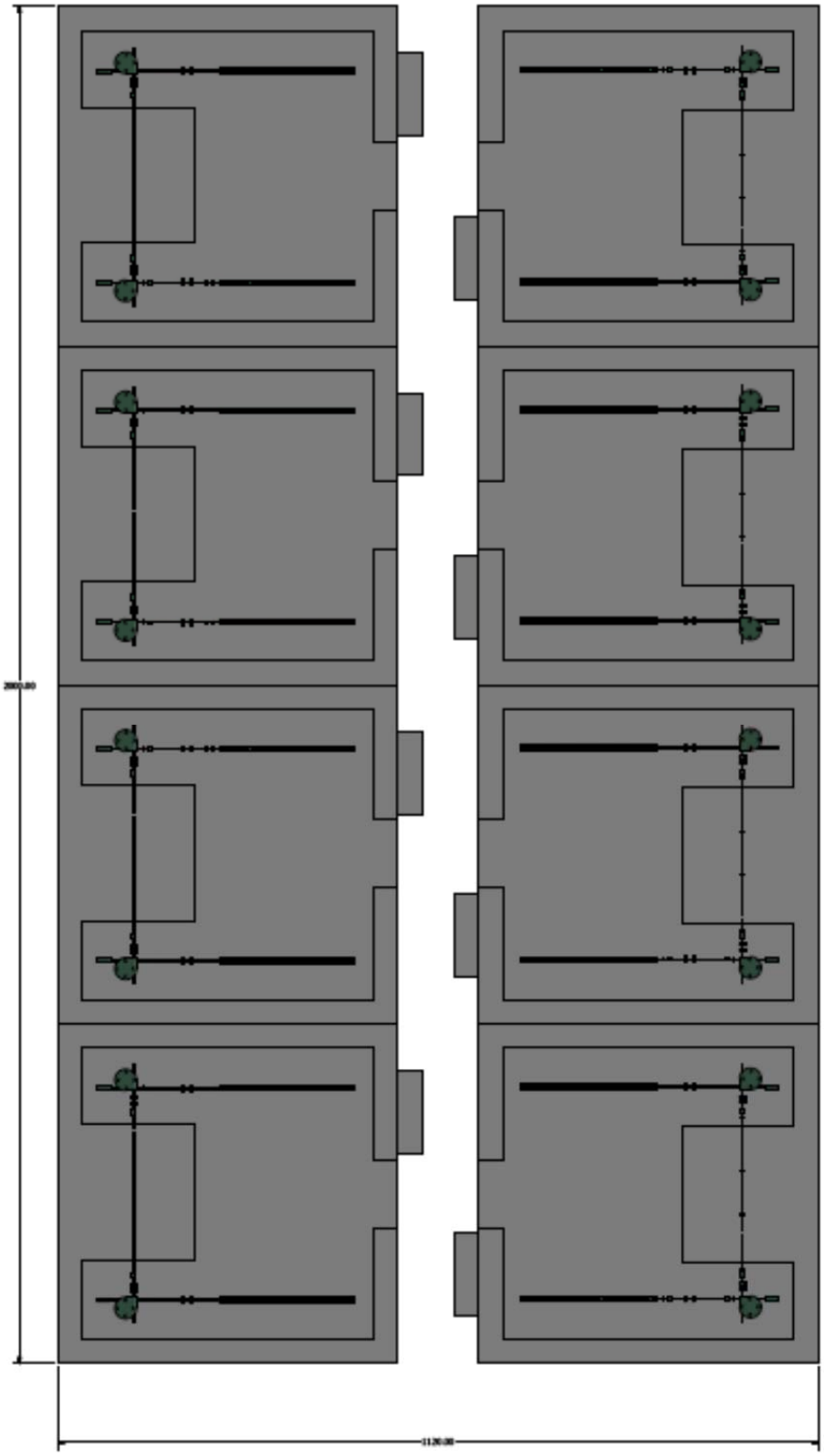

FIGURE 1 Proposed Facility Accelerator-Floor Arrangement for 16 Accelerators

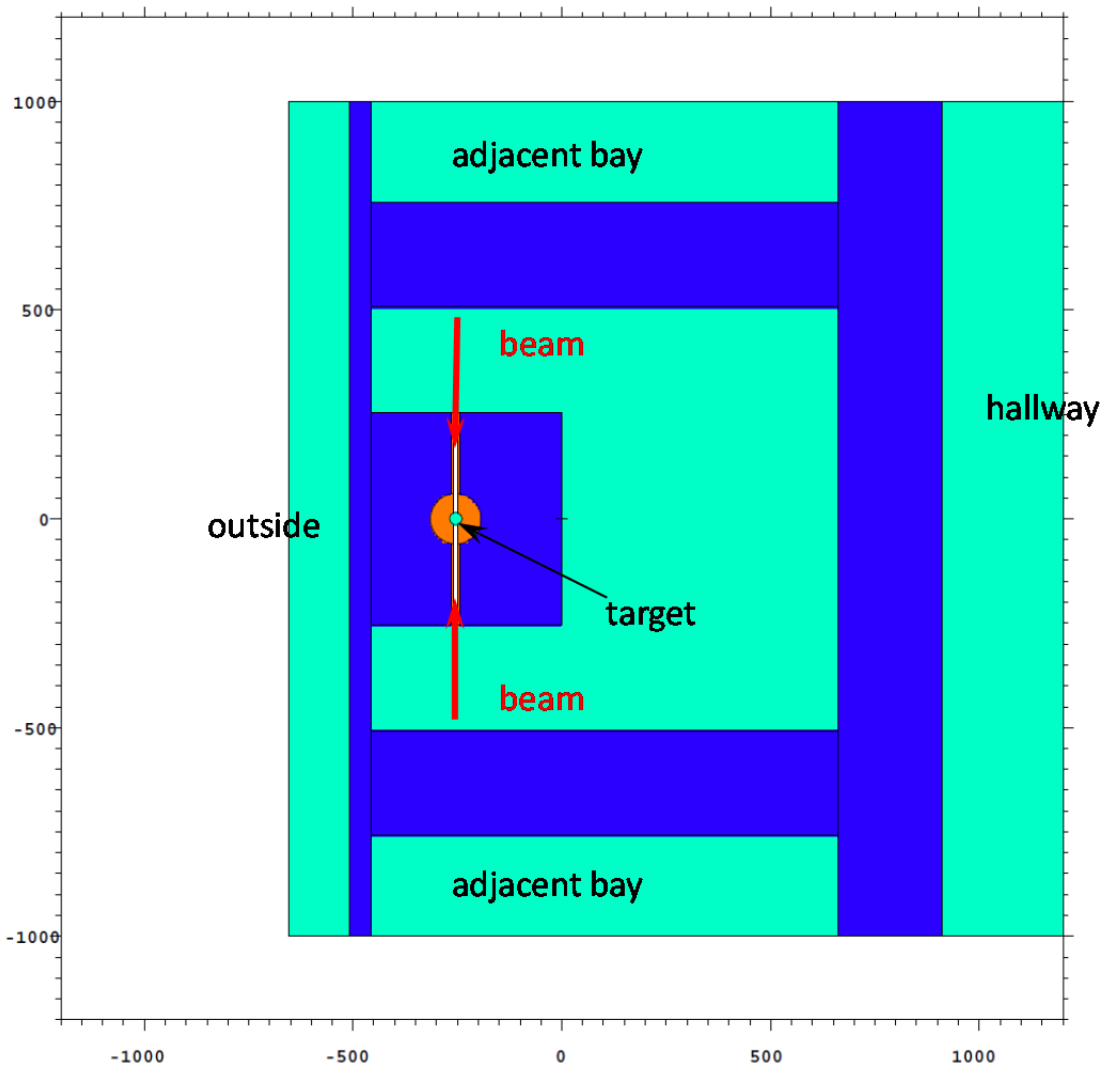

FIGURE 2 Top View of Accelerator-Based Production Facility (units of centimeters for axes)

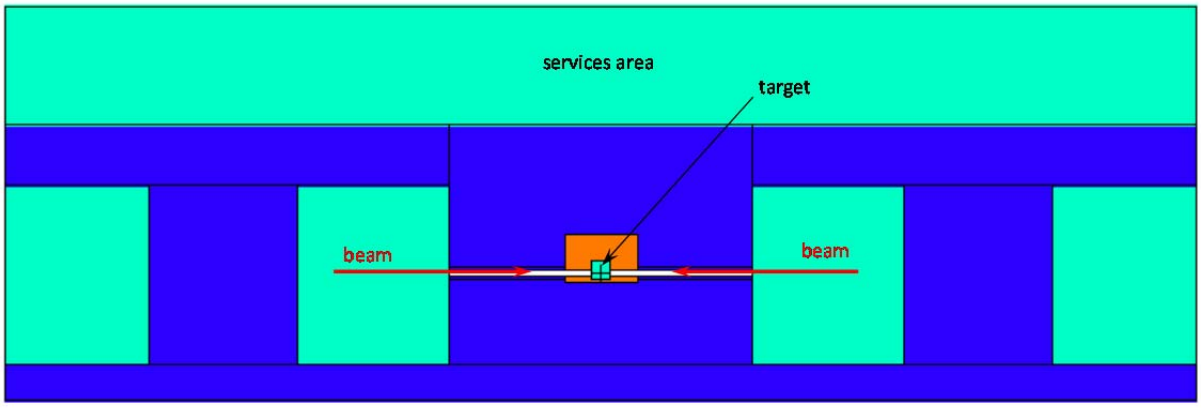

FIGURE 3 Side View of Accelerator-Based Production Facility

2 CALCULATION METHODS

Dose-rate calculations were performed using MCNPX v 2.7.0. The photon and neutron source terms were calculated in a separate run and then used in later shielding calculations. This allowed approximate solutions in which the source and shielding were spherically symmetric, leading to rapid convergence of the solutions. Each calculation used the correct source strength and energy spectrum for the direction considered i.e., at 0° to the beam for calculating the shielding needed for adjacent accelerator bays, and at 90° to the beam for dose rate calculations in the services area, the hallway, and outside the facility. The photon and neutron source terms were treated separately, with secondary radiations of all types considered, as it was easier to determine effective variance reduction parameters.

3 RESULTS AND DISCUSSION

3.1 SHIELDING FOR TARGET SERVICES AREA

The target services area is located directly above the target. Shielding thickness for this area was estimated using a spherically-symmetric target/shielding model (Figure 4) that leads to rapid convergence of the solution. Two concrete thicknesses were used to calculate an exponential attenuation coefficient for the dose rate through the concrete shield appropriate for the 90° photon energy spectrum. The results are shown in Figure 5.

A total concrete thickness of about 92 in. (232 cm) is estimated to be needed to reduce the dose rate to 1 mrem/hr at 12 in. (30 cm) above the floor, in a location directly above the target. In addition, shielding will be required in this area due to (a) radiation due to operation of the linear accelerators, (b) scattered and leakage radiation due to the electron beams incident on the target, and (c) the presence of activated components inside the accelerator/target bay. These considerations will determine the thickness required for the ceiling of the accelerator bays (which is also the floor of the services area).

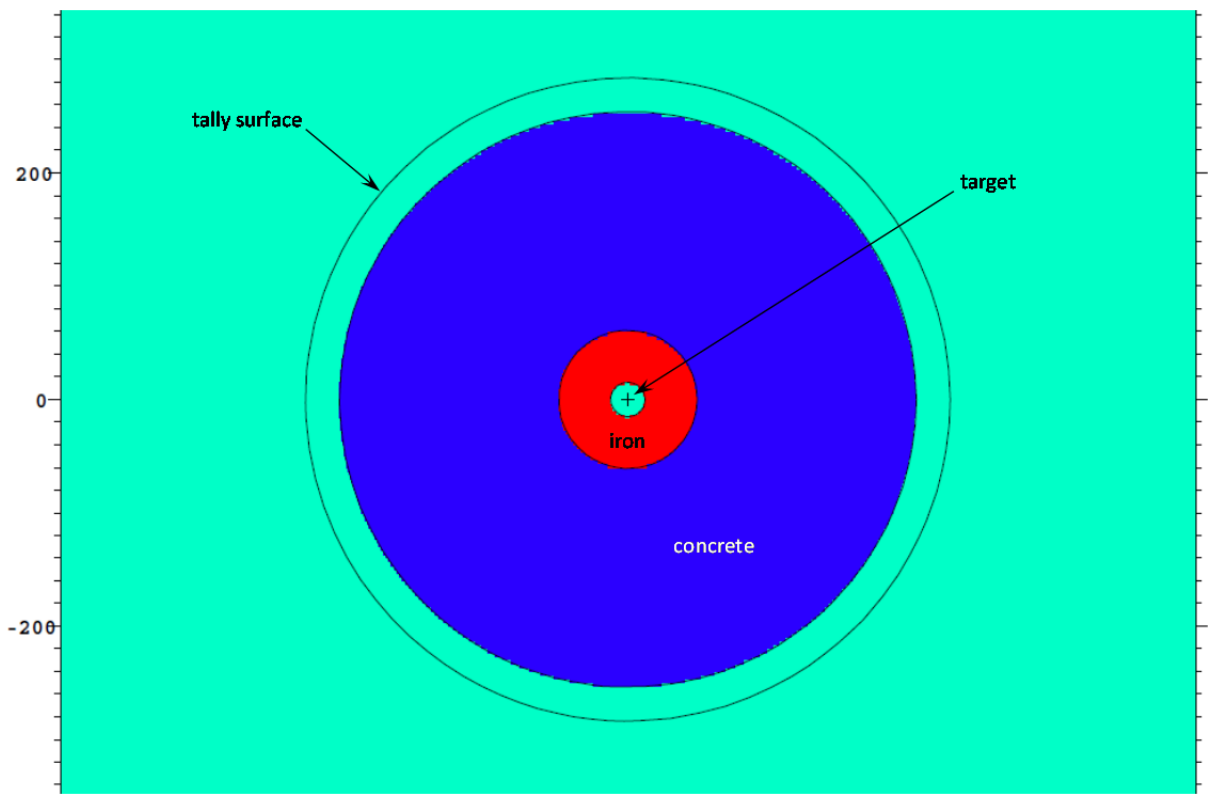

FIGURE 4 MCNP Geometry for Dose Rate Calculation in the Services Area (units of centimeters for axes).

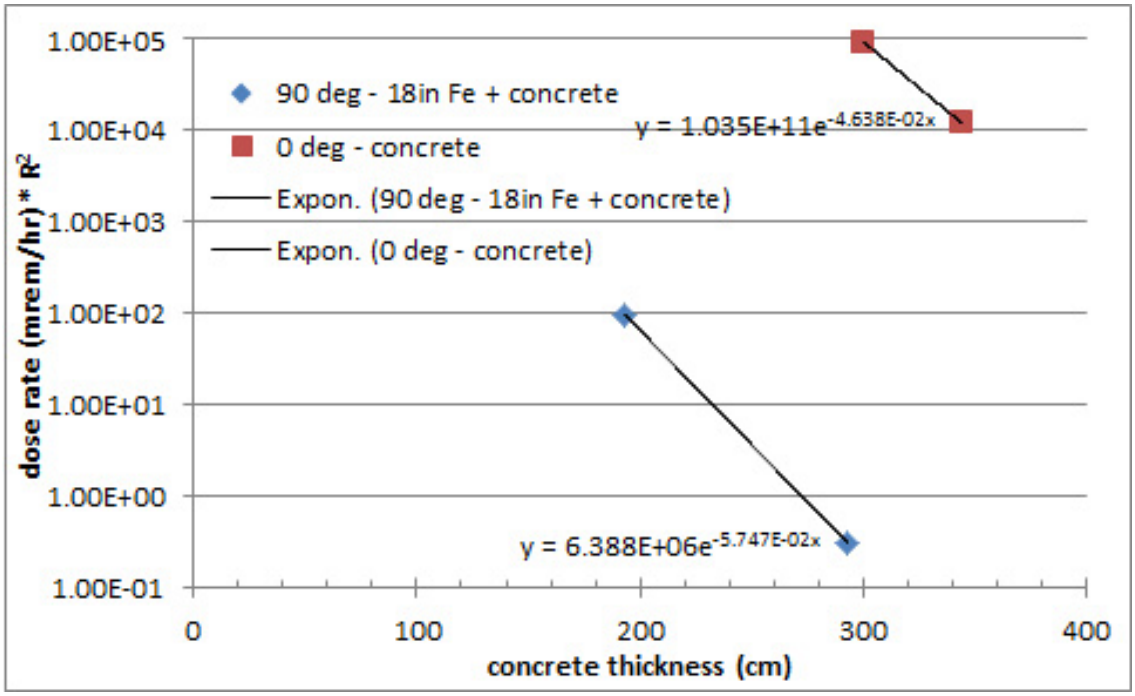

FIGURE 5 Dose Rates for Shielding Calculations

3.2 SHIELDING FOR HALLWAY

The hallway is located outside the accelerator bay (to the right in Figure 2) and would be accessible to non-rad workers. Besides the 18 in. (46 cm) iron and 76 in. (193 cm) concrete shielding immediately around the target, there will be an additional concrete wall that separates the accelerator bay from the hallway. The MCNP geometry for the dose rate calculation in the hallway is shown in Figure 6.

The dose rate 12 in. (30 cm) outside of a one-meter-thick wall would be about 3 µrem/hr. The shielding required at this location must also consider the effects of (a) radiation due to operation of the linear accelerators, (b) scattered and leakage radiation due to the electron beams incident on the target, and (c) the presence of activated components inside the accelerator/target bay. It seems likely that a shield sufficiently thick to protect against those radiation sources would also provide sufficient protection against direct radiation from the target (i.e., a dose rate no higher than 50 µrem/hr in the hallway).

3.3 ADJACENT ACCELERATOR BAYS

Accelerator bays can receive radiation from the targets in adjacent cells that is in the forward direction with respect to one of the electron beams. There is also backward-directed radiation from the second beam, which will have a much smaller photon source term. (Because the neutrons are emitted nearly isotropically, the neutron source term from the second beam can

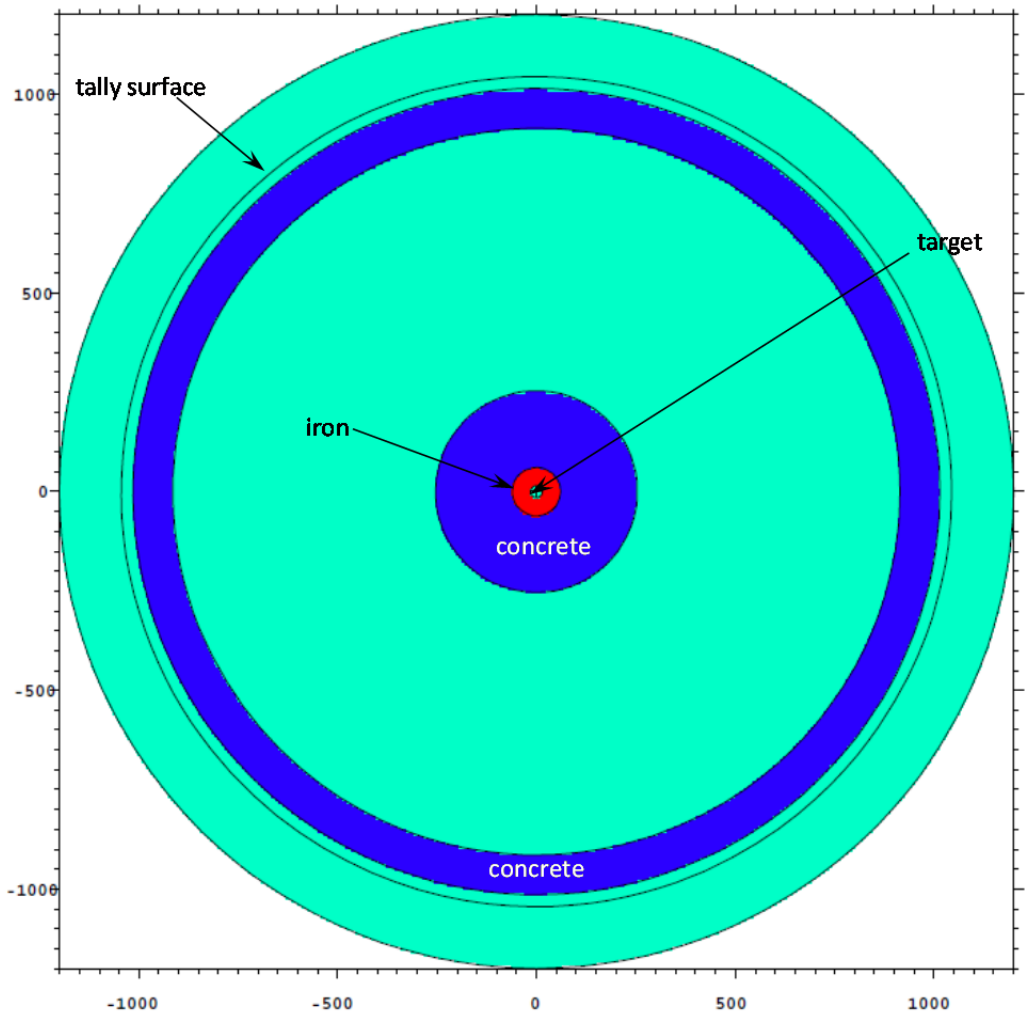

FIGURE 6 MCNP Geometry for Dose Rate Calculation in the Hallway (units of centimeters for axes).

be taken as equal to that from the first.) Previous work (internal report) has shown that for concrete shields the neutron source term contributes very little to the dose, so it is sufficient to consider only the source terms from the forward-directed beam.

To effectively attenuate the photons from the source, a lead shield block can be placed directly in line with the beamline opening into the target monolith. For a 12-in. (30-cm)-thick lead block, a concrete wall that is 100 in. (252 cm) thick will then attenuate the radiation dose to 1 mrem/hr at a point in the adjacent cell 12 in. (30 cm) away from the wall in line with the beamline. A larger iron block, perhaps 18 in. (46 cm) thick, could be used to avoid using lead. Figure 7 shows schematically the location of the photon source, lead block, and shield wall for the dose rate calculation in adjacent accelerator bay.

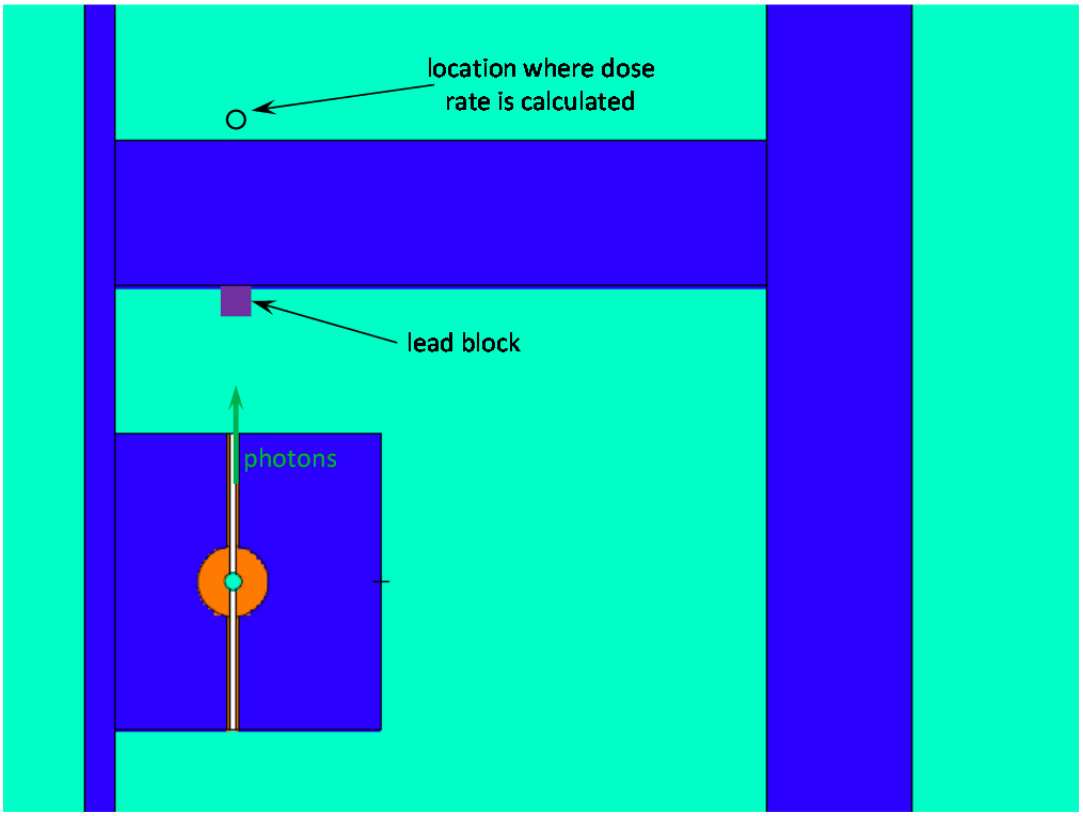

FIGURE 7 Location of Photon Source, Lead Block, and Shield Wall for Dose Rate Calculation in Adjacent Accelerator Bay

3.4 EXTERNAL TO FACILITY

The area external to the facility will be accessed by the general public and should be kept to a dose rate no higher than 50 µrem/hr. Assuming a density for soil that is one-half that of ordinary concrete, it would take about 63 in. (160 cm) of soil, in addition to the monolith shield of 18 in. (46 cm) steel and 76 in. (193 cm) concrete, to reduce the dose rate on the outside to 50 µrem/hr.

4 SUMMARY

Dose rates have been estimated for specific locations in a proposed production facility based on the $^{100}Mo(\gamma,n)^{99}Mo$ reaction using bremsstrahlung photons produced by an electron linear accelerator. The target dose rates were 1 mrem/hr for areas accessible by radiation workers (the service area above the target and accelerator bays adjacent to operating accelerators) and 50 µrem/hr for areas accessible by non-radiation workers (the hallway outside the accelerator bays and areas external to the facility). To achieve these dose rates, the following shielding can be used. These values could be optimized to reduce the total shielding volume through the use of different materials or geometry.

Target service area (above target):	18 in. (46 cm) iron + 92 in. (232 cm) concrete
Adjacent accelerator bay:	12 in. (30 cm) lead + 100 in. (252 cm) concrete
Hallway outside accelerators:	18 in. (46 cm) iron + 76 in. (193 cm) concrete (monolith) + 40 in. (100 cm) concrete (wall of accelerator bay)
	(dependent on sources inside bay)
External to facility:	18 in. (46 cm) iron + 76 in. (193 cm) concrete + 63 in. (160 cm) soil

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