ESH&Q DIVISION
RADIATION CONTROL DEPARTMENT

Shielding Requirement for 5 kW Isotope Project Target/Dump

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Thomas
Jefferson
National
Accelerator
Facility

Jefferson Lab
Thomas Jefferson National Accelerator Facility

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Author 9/24/19

Keith Welch, Manager Date[1]

Radiation Control Department

KBWelch for P.Degtiarenko
Reviewers E-Signature ON 4/25/19 9/24/19

Pavel Degtiarenko, Radiation Physicist Date

Radiation Control Department

9/25/19

Bob May, on behalf of the SCMB Date

Deputy Associate Director, ESH&Q

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The proposed isotope production test involves using the LERF to deliver up to 5 kW beam at up to 40 MeV on a tungsten radiator and gallium target. This document (covering only the basic shielding thickness requirements) is a brief analysis of the shielding needed for the target/dump. The target area is somewhat limited in space, so a compact design is useful. The final specifics of the shield design will include features to facilitate retrieval of the target.

The location of concern is in the upstairs service gallery area. Shielding of the vault in lateral directions is sufficient due to the earth berm (sideward shielding should still be applied to reduce radiation damage and activation in the vault, and the effect of the scattered sideward radiation field on the vault ceiling). CEBAF-TN-95-044 contains the original FEL shielding design calculations and gives an estimated dose rate upstairs (Fig. 8) from point beam loss of about 3 mrem/h photon and 2 mrem/h neutron per kW in a thick target (this is through about 8 feet of concrete/soil in the vault ceiling). At 5 kW, the corresponding dose rates are 15 mrem/h photon and 10 mrem/h neutron, well above radiation area threshold. The goal is to keep the total dose rate below 0.05 mrem/h.

The approach followed here is to maximize photon reduction ("over-shield") with conventional non-hydrogenous material, rather than to aim for proportional reduction in both fields. This facilitates a reduction in the use of hydrogenous material, which helps reduce the shield footprint and saves on cost. There is a trade-off in this approach in that using less hydrogenous material reduces the effectiveness of the conventional material for neutrons. Some iteration (not shown in detail) was used to arrive at an effective combination.

Calculations from Universal Tables

Shielding for photons

NCRP-51 Fig. E.13 gives a TVL for iron of about 85 g/cm^2 (11 cm) for the photons produced at 40 MeV (applying the correction in E.6 for 90 degree source term). Alternatively, the lead TVL is about 62 g/cm^2 (5.5 cm). However, lead is significantly less effective for neutron attenuation, so the approach used here will focus on iron (steel). Proportional reduction in the fields could be attained by reducing the photon field by 0.03/15, or 0.002 (about 2.7 TVL, or 30 cm iron). Assuming the possible use of S4 shield blocks, we "over-shield" this source with 13" (33 cm) thick steel. In addition, accounting for the need for some hydrogenous material, we add 15 cm of polyethylene. We assume poly to be water equivalent for this purpose, with a TVL for photons of about 100 cm (derived from Fig. E.12 for concrete, scaled to density). So we have a total of 33/11 + 15/100 = 3.15 TVL, giving a reduction of 0.0007 and a shielded gamma dose rate of 15 x 0.0007 = 0.012 mrem/h.

Shielding for neutrons

The dose rate "target" for neutrons based on the shielded gamma contribution is 0.05-0.012 = 0.038 mrem/h, giving a reduction of 0.038/10 = 0.0038, or about 2.4 TVL. Using NCRP-144 Fig. 4.10 (for a fission spectrum, comparable to the GDR spectrum here), we find a TVL for iron (without hydrogenous backing) of 300 g/cm^2 (38.46 cm). The 33 cm iron shield is then about 0.86 TVL. Then, using Fig. 4.11, we obtain a TVL for polyethylene of 10 cm, assuming an average energy of 1 MeV, which should be reasonably conservative for the spectrum. This value can be used instead of those suggested by Table 4.3, given the attenuation of the neutrons in the iron shield, and the conservative assumption of 1 MeV $\bar{E}_n$.

Alternatively, one could apply the modified iron TVL in Fig. 4.10 of 100 g/cm^2 (though caution should be used here, since the modified TVL assumes 20-30 cm of hydrogenous backing), then use the unadjusted TVL in Table 4.3, which yields a somewhat better overall result. This provides confirmation that the approach is fairly reasonable.

So with a total attenuation of 0.86 + 1.5 = 2.36 TVL, we are very close to the target of 2.4 TVL. Given the conservatism in this estimate, and the expected conservatism in the as-built shielding of the LERF (and considering the hydrogenous nature of the concrete structural shield), this result should be acceptable. It should be kept in mind that the poly shielding suggested here can be easily and cheaply augmented with a layer of water if needed. Indeed, if the final design configuration allows, the entire hydrogenous layer could be applied with water. In addition, the service gallery can (and should) be posted as an RCA as a precaution until dose rates are verified.

Note that other combinations of iron/poly (or water) are feasible. If the iron shield is constructed of something other than S4 block, and other specific thicknesses are used, it requires adjusting the hydrogenous layer accordingly. At a minimum, about 25 cm of steel is needed, which would then require at least 40 cm of hydrogenous shielding.

Monte Carlo Modeling

To validate the calculations above, the FLUKA code was used to simulate the conditions associated with the isotope target shielding. The model is a simplified geometry: the target is aligned parallel to the Linac rather than at the actual off-axis angle, but is at the correct height and approximate distance from the south and east walls of the vault. Correct dimensions are used for the vertical height of the vault and the ceiling shielding. The target shield is formed by 33 cm of iron and 20 cm water on all four sides and top (upstream side has less iron, consistent with probable constraints on use of S4 shield blocks). A top view of the shield model is shown in Figure 1 below.

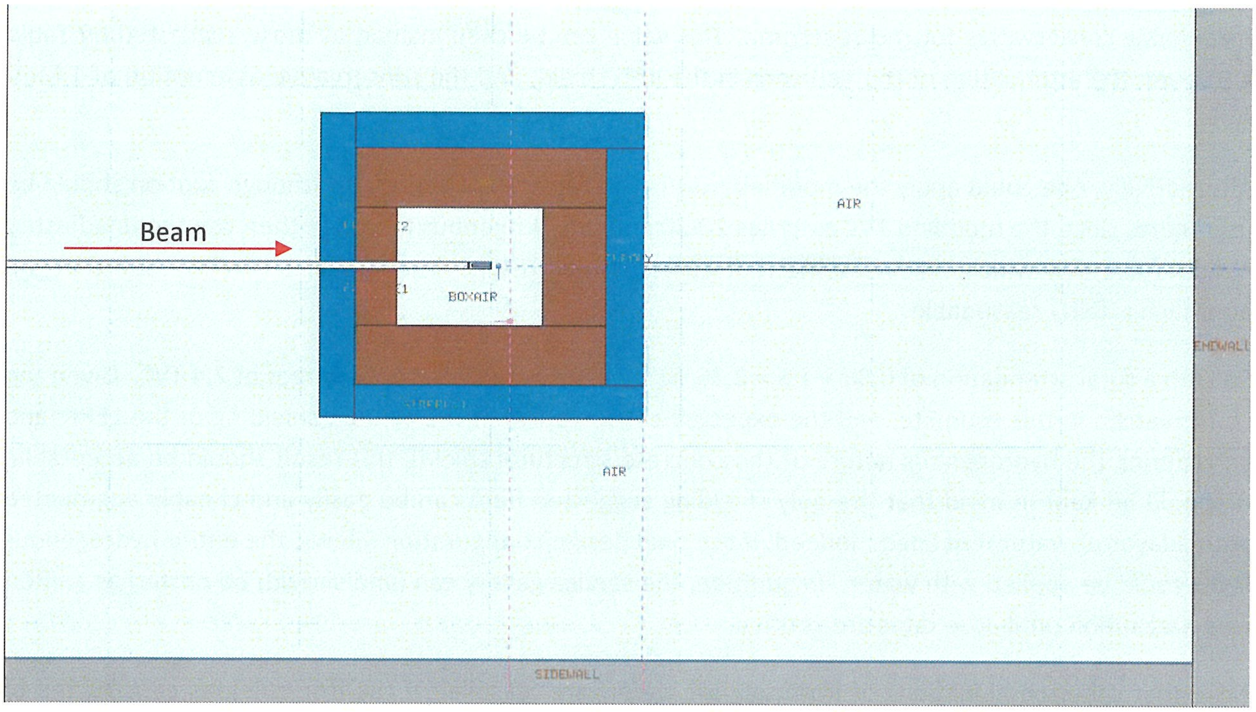

Figure 1: Plan view of the simplified model of isotope target shield

Figure 2 below shows the conceptual design developed using S4 shield blocks to meet the shielding thicknesses described above. The design calls for use of water shielding on the exterior of the block configuration shown. This configuration makes use of concrete blocks (shown in gray) to augment the steel blocks (green) due to incomplete overlap.

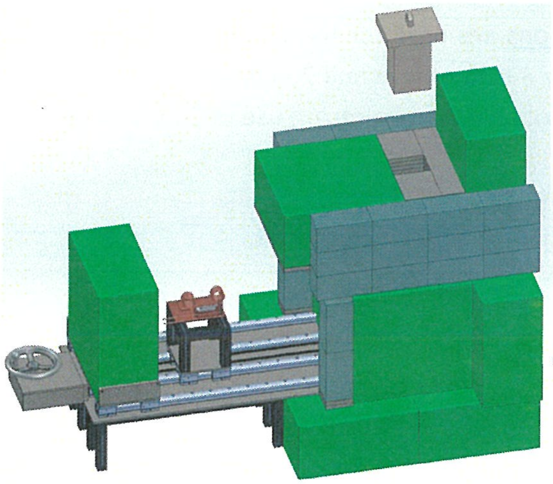

Figure 2a: Exploded view of shielding

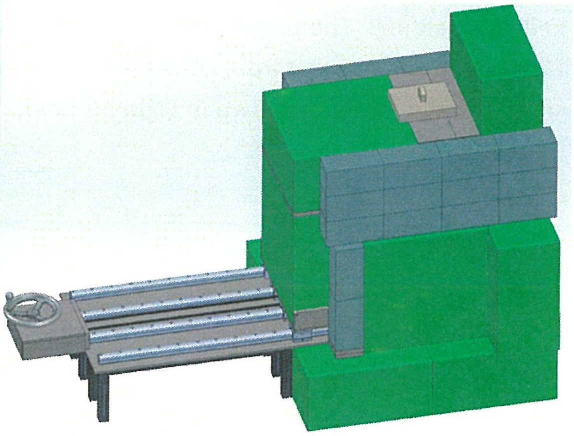

Figure 2b: Shielding with roll-out door closed

Figure 3 shows the dose equivalent rate resulting from operations at 40 µA at 5 kW power. Figure 4 shows a plot of the dose equivalent rate vertically, directly above the target, in the occupiable area of the RF gallery.

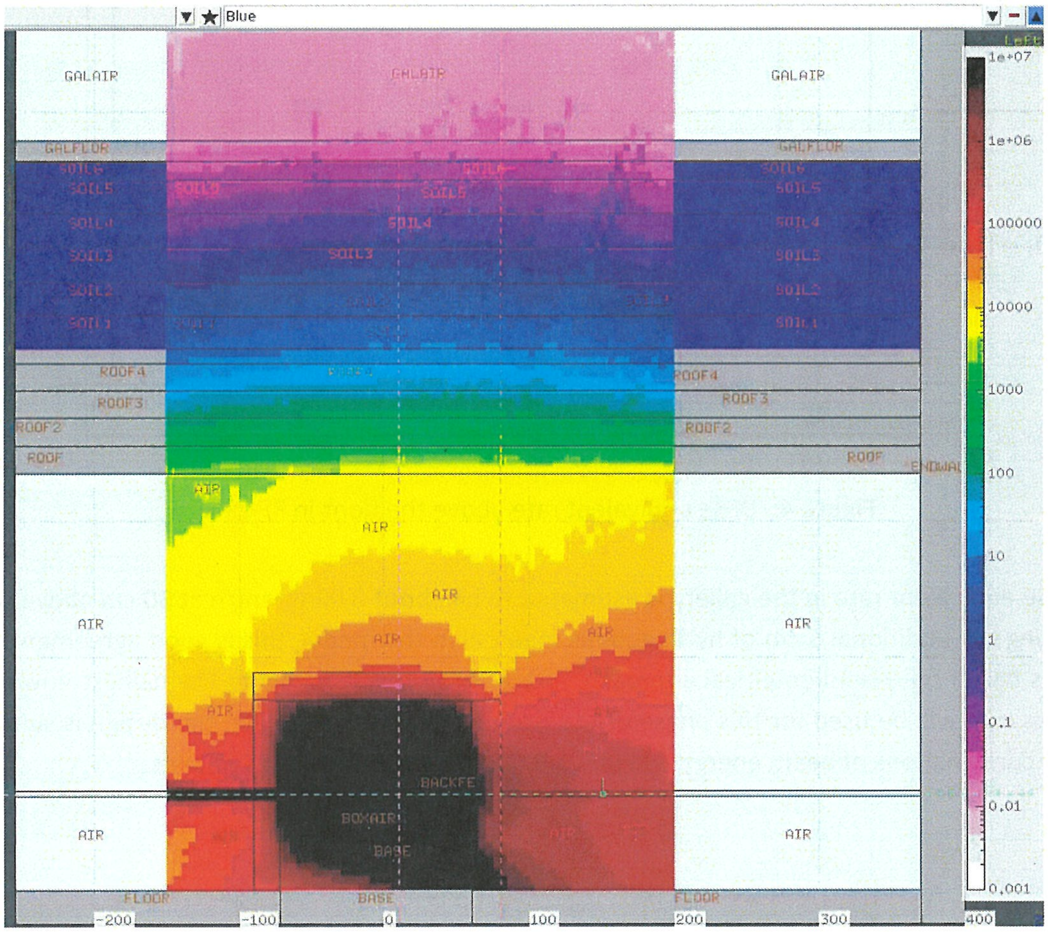

Figure 3: Dose equivalent rate, mrem/h

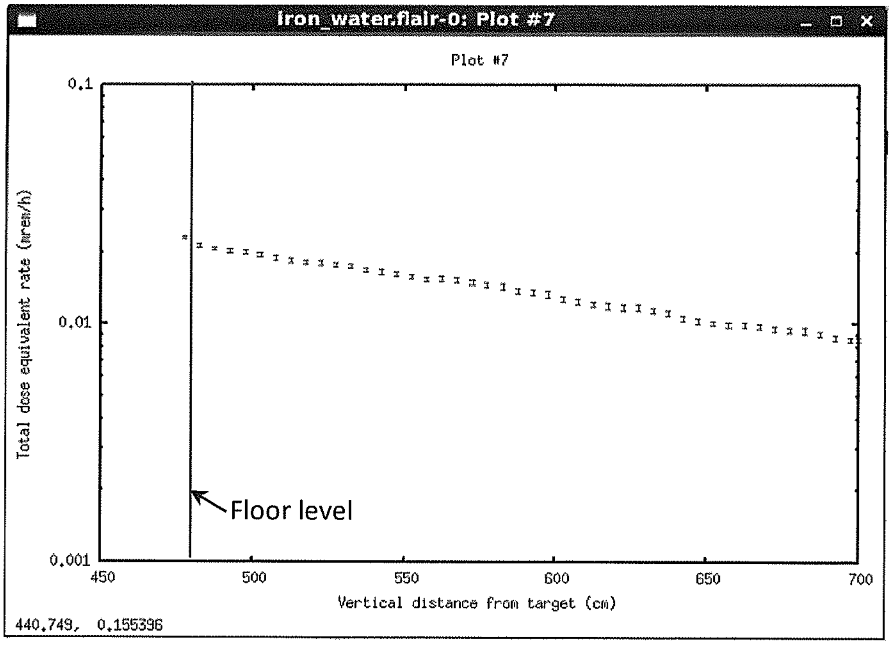

Figure 4: Dose equivalent rate above the floor in RF gallery

Total dose equivalent rate in the gallery is estimated to be about 0.02 mrem/h at 30 cm above the floor. Considering the additional 5 cm of hydrogenous material in the model, this is good agreement with the estimates based on a semi-empirical approach. Since these results apply to the highest power/energy conditions that will be used for this phase of the isotope production project, the design is sufficient for all of the combinations of beam energy and power envisioned for this series of tests.