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A 3-D Model of the Beam Line Shield for the HIPPO Instrument at the Lujan Center and Comparisons with 2-D Results

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Abstract

We have examined the differences between a 2-D model and a 3-D model for designing the beam-line shield for the HIPPO instrument at the Lujan Center at the Los Alamos National Laboratory. We have calculated the total (neutron and gamma ray) dose equivalent rate coming out of the personal access ports from the HIPPO instrument experiment cave. In order to answer this question, we have investigated two possible worst-case scenarios: a) failure of the T_0-chopper and no sample at the sample position; and b) failure of the T_0-chopper with a thick sample (a piece of Inconel-718, 10 cm diam by 30 cm long) at the sample position.

1. Introduction

We have compared the calculated total dose equivalent rate using 2-D model and 3-D models of the neutron beam-line shielding above the T_0-chopper [1,2,3] for the HIPPO instrument at the Manuel Lujan Jr., Neutron Scattering Center (Lujan Center).
Furthermore, we used the 3-D model to solve one of the issues for the HIPPO instrument shielding design, namely, the radiation level at the personnel access ports into the HIPPO experiment cave (so called "manholes").
For this situation, the total (neutron plus gamma-ray) dose equivalent rate at the entrance of the manholes must be 1 mrem/hr or less. This radiation level must be attained with the Lujan Center operating at 200 μA.

We have calculated the total dose equivalent rate leaking out the manholes of the HIPPO instrument for two possible worst-case scenarios. The scenarios and results are as follows:

- Failure of the T_0-chopper and no sample at the sample position. In this case, the entire neutron beam strikes the beam stop.
- Failure of the T_0-chopper but with a thick sample located at the sample position. The thick sample was assumed to be a piece of Inconel-718 with a diameter of 10 cm and a length of 30 cm.

2. The 3-D Model

We built a 3-dimensional MCNPX model of the HIPPO beam line, beam-line shielding, experiment-cave shielding, and beam stop using the latest available drawings. This model included the full collimation system, bulk shielding, mercury reservoir, T_0-chopper, T_0-chopper motor, T_0-chopper cavity, beam-line shielding, experiment-cave shielding, a cylindrical approximation of the snout shielding, and beam stop. We also modeled the manholes explicitly and used this 3-dimensional model to calculate the total dose equivalent rate coming out of the manholes. The Monte Carlo model is shown in Figures 1 and 2, and does not have any flex-boral on the floor of the experiment cave.

To decrease the necessary computer runtime we did not run the whole problem with protons as the starting particle, but with a source term, calculated by Gary Russell, which describes the neutron current in HIPPO flight path at a position ~4 meters away from the proton beam centerline. This source term was used to design the beam-line shielding, experiment-cave shielding, and beam stop shielding for the HIPPO instrument.

3. Results

3.1 Comparison between the 2-D and the 3-D models

For the design of the beamline shielding for the HIPPO instrument Gary Russell used a 2-D model, which allowed him to change the geometry very easily and to minimize computer running time. When we built our 3-D model for HIPPO, we were interested how good Russell's model matches with the new 3-D model. In order to do that we calculated the total equivalent dose rate just above the T_0-chopper and compared the 2-D and 3-D results. The calculated total equivalent dose for the 2-D model is *1.1 mrem/h* ± *5%*. In comparison, the total equivalent dose rate for the 3-D model is *1.4 mrem/h* ± *13%*. If we separate the total dose into the two individual (neutron and gamma-ray) components, we see some subtle differences between the 2-D and 3-D models. The neutron dose equivalent rate for the 2-D model is 0.67 mrem/h ± 5%, whereas for the 3-D model the neutron dose equivalent rate is 1.3 mrem/h ± 13%, the calculated neutron dose equivalent rate is for the 3-D model about twice as high as for the 2D model. For gamma rays, the total dose equivalent rate for the 3-D model (0.1 mrem/h ± 7%) is much lower than for the 2-D model (0.41 ± 1%). These differences can be explained by the fact, that the 3D model is no longer cylindrical symmetrical and therefore the neutrons hit the polyethylene at a different point in the scattering process. Overall we can say that the 2-D model is a reasonable first approximation for neutron beam-line shielding calculations.

3.2 T_0-chopper failure and no thick target at the sample position

The first possible worst-case scenario is a failure of the T_0-chopper and no sample at the sample position. In this case the major part of the neutron flux coming down the HIPPO beam line hits the center of the beam stop. Therefore, this calculation is a quality test for the beam stop. It can be seen from the results presented in Table 1, that the total dose equivalent rate is less than 1.33 mrem/hr. We have also analyzed which parts of the geometry contribute the most to the total dose equivalent rate. As it can be seen in Table 2, the ceiling, wall, and floor of the HIPPO experiment cave are the largest contributors to the total dose equivalent rate exiting the manholes. In order to make sure that this statement is not misleading, one needs to understand how these contributions are calculated.

To be able to even perform this calculation, one needs to use the variance reduction method of the DXTRAN sphere. This method calculates the probability that a particle can make it from its current position directly to the DXTRAN sphere. As mentioned above, most of the neutrons will hit the beam stop in this case. If one calculates the direct contribution of these particles to the DXTRAN sphere, their probability will be rather low because they are well shielded by the beam stop per se. The iron beam stop is covered (except for the top) by a polyethylene laminate composed of 1 inch of 5% borated polyethylene followed by 4 inches of regular polyethylene and finally 1 inch of 5% borated polyethylene.

However, in these simulations, there was no polyethylene on top of the iron beam stop. Also the concrete base on with the beam stop was placed is not covered with polyethylene. This means that neutrons and gamma rays have a better chance to escape from the top of the beam stop and the concrete base, scatter, and make a contribution to the DXTRAN spheres.

We have recommended to cover the top of the beam stop and the sides of the concrete beam-stop base with at least 2 inches of 5% borated polyethylene. This should help reduce experiment backgrounds as well.

3.3 T_0-chopper failure and a thick sample at the sample position

The second possible worst-case scenario is a failure of the T_0-chopper and a thick sample (as described above) at the sample position. In this case, the HIPPO neutron beam strikes the thick sample. The neutrons can be scattered in the thick sample and not directly strike the beam stop. These scattered neutrons partly contribute directly to the total dose at the manholes and partly go into the walls, ceiling, and floor of the experiment cave to interact further and make contributions to the total dose equivalent rate exiting the manholes. In this scenario, the calculated total dose equivalent rate at the open manhole position is ~7.4 mrem/hr (see Table I). This is significantly more than the ER-1 calculated design goal of 1.0 mrem/hr. Also, in this case, the improvements to the beam stop discussed above will not help because the neutrons are already getting scattered in the thick sample and those striking the beam stop are diminished from the situation where there is no thick sample present. Therefore, we had to consider covering the manhole openings.

We have performed two calculations where we covered the manholes with either 2 inches or 3 inches of 5% borated polyethylene. The result for the calculation with 2 inches of polyethylene (see Table I) shows that it is possible to reduce the neutron dose equivalent rate by nearly an order of magnitude (to ~0.80 mrem/hr), but with the cost of increasing the gamma-ray dose equivalent rate by 10% (to ~0.65 mrem/h). This increased gamma-ray dose equivalent rate is due to the (n,γ) reaction in polyethylene. The total dose equivalent rate for this calculation is 1.45 mrem/hr, which is still ~50% above the ER-1 calculational beam-line shielding design goal. Therefore, we investigated increasing the polyethylene thickness to 3 inches. The results are shown in Table I. It can be seen that (for manhole cover of 3 inches of 5% borated polyethylene), the total dose equivalent rate is 0.95 mrem/hr, which meets the calculated ER-1 design goal of 1 mrem/hr or less.

3.4 Conclusions

The comparison between a 2-D model and a 3-D beam-line shielding models for the HIPPO instrument shows, that, for a first approximation of the beam-line shield, a 2-D model gives reasonable results.

We have investigated the two possible worst-case scenarios for the dose equivalent rate coming up the manholes used for access into the HIPPO experiment cave. We have discovered that the worst-case scenario with a T0-chopper failure and a thick sample at the sample location gives a total dose equivalent rate exiting the manholes of ~7.4 mrem/hr. In order to achieve the ER-1 calculated total dose equivalent rate design goal of 1 mrem/hr exiting the manholes, we have recommended covering the manholes with 3 inches of 5% borated polyethylene.

Acknowledgements

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References

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Table I: Dose equivalent rate coming out of the HIPPO manholes for the Lujan Center running at 200 μA.

	Neutron Dose Equivalent Rate [mrem/hr]	Gamma Ray Dose Equivalent Rate [mrem/hr]	Total Dose Equivalent Rate [mrem/hr]
no T_0-chopper, no thick target	1.21 ± 7.3%	0.113 ± 3.9%	1.33 ± 7.0%
no T_0-chopper, with thick target	6.8 ± 3.1%	0.60 ± 2.4%	7.4 ± 3.0%
manholes closed with 2 inches of 5% boron polyethylene, with thick target	0.80 ± 3.5%	0.65 ± 3.0%	1.45 ± 3.2%
manholes closed with 3 inches of 5% boron polyethylene, with thick target	0.41 ± 5.7%	0.53 ± 2.2%	0.95 ± 3.7%

Table II: Contributions of the various parts of the HIPPO instrument shielding to the dose equivalent rate coming out of the manholes.

	floor	wall	ceiling	beam-stop	snout	thick target
no T_0-chopper, no thick target; neutron dose	19.8%	25.5%	47.1%	3.2%	3.7%	
no T_0-chopper, no thick target; gamma dose	10.5%	40.7%	30.0%	11.4%	7.4%	
no T_0-chopper, with thick target; neutron dose	24.6%	22.1%	46.6%	2.5%	2.1%	4.2%
no T_0-chopper, with thick target; gamma dose	12.0%	41.9%	34.0%	7.7%	3.1%	0.8%

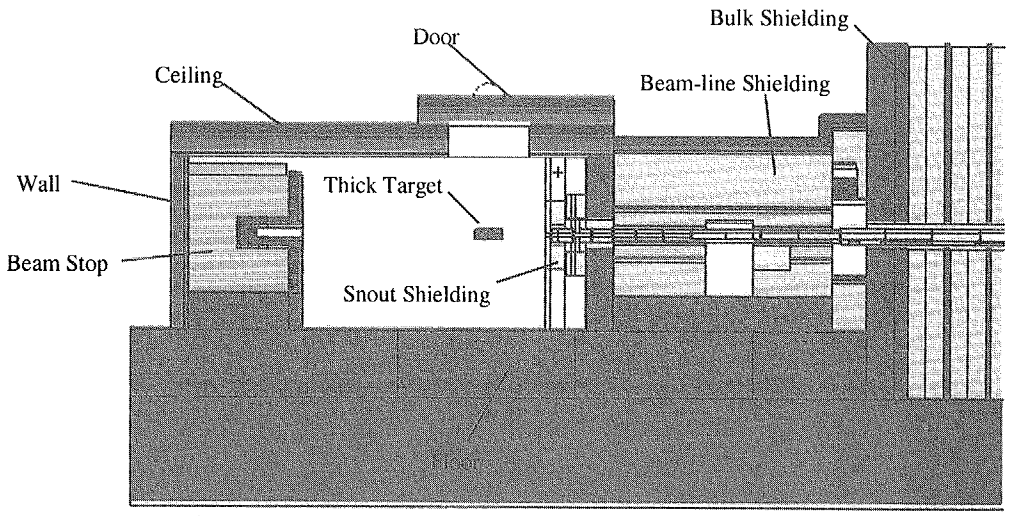

Figure 1: MCNPX model for the HIPPO instrument shielding.

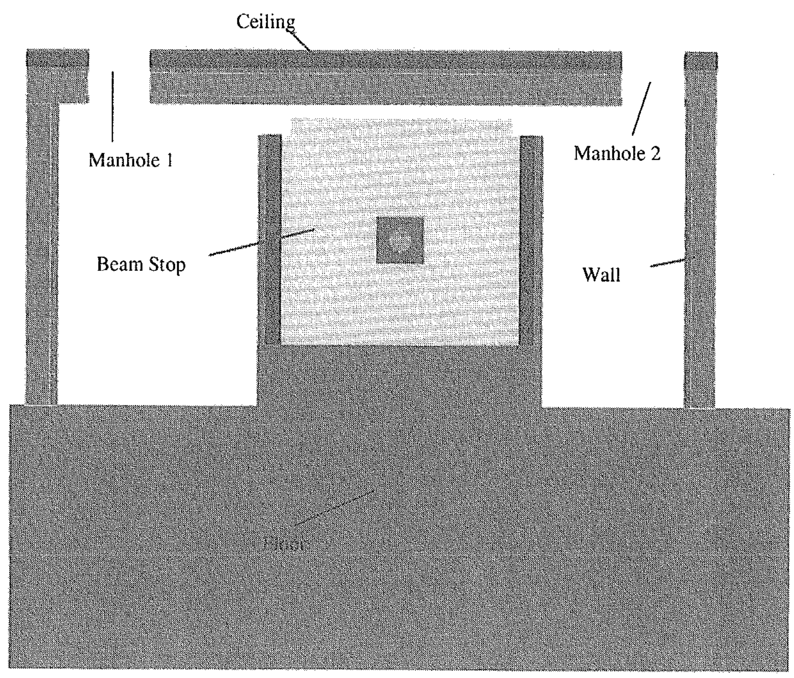

Figure 2: MCNPX model for the HIPPO instrument beam stop and its manholes.