Optimization of Gamma Shielding for the Neutron Radiography Facility at TRR-1/M1 Using PHITS Simulation

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EXTENDED ABSTRACT

Neutron radiography (NR) is a widely utilized non-destructive evaluation technique used for the analysis and characterization of various materials. In two-dimensional neutron radiography, which is commonly applied in many testing scenarios, samples are often exchanged while the nuclear reactor is in operation. This process results in elevated background levels of gamma radiation, potentially exposing operators to unnecessary radiation doses. Therefore, in accordance with the ALARA (As Low As Reasonably Achievable) [1] principle, appropriate shielding materials must be implemented to enhance radiation safety for personnel.

In this work, the study focuses on the optimization of a gamma shielding to be installed in the neutron radiography room of Thai research reactor, TRR-1/M1, Thailand Institute of Nuclear Technology (Public Organization) [2]. Particle and Heavy Ion Transport code System (PHITS) Version 3.30 [3] simulation was employed to investigate the effectiveness of lead shielding in attenuating gamma radiation.

Lead gamma shielding, measuring 40×70 cm^2, was installed at the end of the extended collimator with a thickness ranging from 1 to 3 inches. The simulation was performed under the condition of a closed shutter with the reactor in operation.[4] The number of simulated particles was 10^7 particles per batch, with a total of 10 batches. The detector was an air-filled sphere with a radius of 1 cm (volume of 4.189 cm^3). Two detectors, located at a height of approximately 115 cm from the floor of the NR room, representing the height of the beam axis, were positioned within the extended collimator and behind the gamma shielding for flux determination shown in Fig 1, expressed in the unit of 1/cm^2·s.

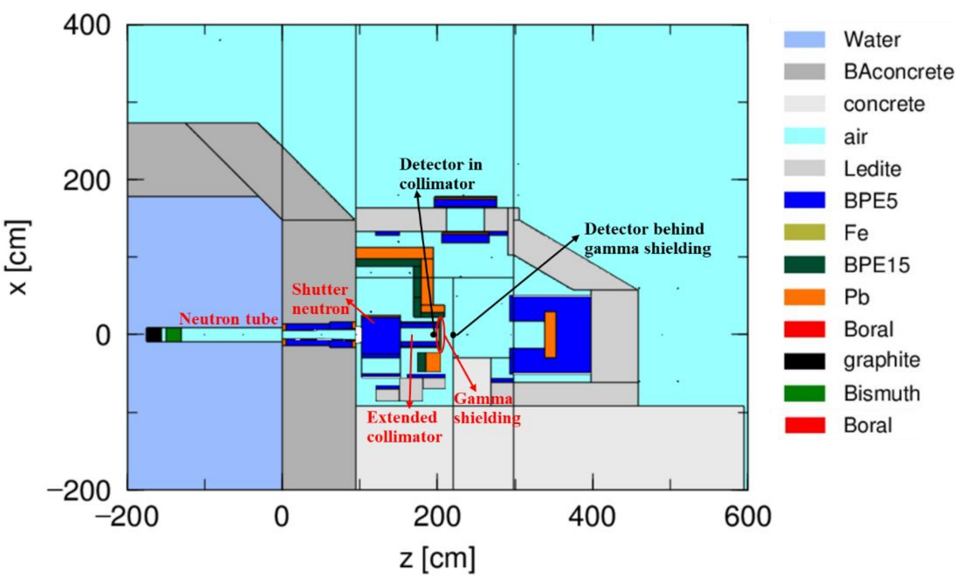

FIGURE 1. Schematic diagram of the NR facility with the existing shielding design from PHITS simulation.

Gamma shielding effectiveness using lead was evaluated by comparing neutron and photon fluxes at two positions: the collimator outlet and behind the lead shielding. The simulation results are shown in Table 1, For the neutron results, it was found that in the absence of lead shielding, the neutron fluence behind the collimator was relatively high. This might be due to neutron scattering caused by surrounding materials in the room. However, when the lead gamma shield was installed, it helped reduce such scattering, resulting in a lower neutron fluence behind the collimator. Nevertheless, increasing the lead shielding thickness had no significant impact on the neutron fluence. The ratio of flux between the collimator outlet and the post-shielding position significantly decreased. The photon flux was reduced by approximately 99% following the addition of lead shielding. These results indicate that lead is an effective material for gamma radiation attenuation, with shielding efficiency increasing as thickness increases. Consequently, the design of the gamma shielding complies with the ALARA principle, thereby enhancing radiation safety for operational.

TABLE I. The simulated neutron and photon fluxes when adding gamma shielding (unit of 1/cm^{2}s.)

Gamma shielding thickness (inch)	Detector in collimator		Detector behind gamma shielding		Ratio of radiation fluxes after to before shielding	
	Neutron	Photon	Neutron	Photon	Neutron	Photon
0	1.4742E+02	2.4963E+03	5.0779E+02	1.5177E+03	3.44	0.61
1	3.1462E+02	2.7611E+03	1.4582E+02	5.2098E+01	0.46	0.02
2	3.2810E+02	2.7684E+03	2.1858E+02	1.4171E+01	0.67	0.01
3	3.2810E+02	2.7036E+03	1.4315E+02	7.2337E+00	0.44	0.00

The shielding design result, a gamma radiation shield was installed within the neutron radiography room using lead with a thickness of only 1 inch. This thickness was determined to be sufficient to ensure radiation levels remain within safe limits for occupational exposure. Furthermore, the selection was influenced by spatial constraints within the facility, which limited the feasibility of installing more extensive shielding. The installation is expected to be completed in the near future.

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