Collimator design for neutron radiography station using Monte Carlo simulation

S Wonglee*, T Liamsuwan, W Pornroongruengchok, J Channuie, R Picha, and S Khaweerat

Thailand Institute of Nuclear Technology, 9/9 Moo 7 Tambon Saimoon, Amphur Ongkharak, Nakhon Nayok 26120, Thailand

* Email: sarinratwl@gmail.com

Abstract. In this research, neutrons and gamma rays at the neutron radiography station of Thai Research Reactor, TRR-1/M1, at Thailand Institute of Nuclear Technology (Public Organization) were characterized. The aim was to design an appropriate outer neutron collimator at the neutron radiography station for collimating neutron beam to the radiographic position, by reducing radiation scattering and reducing dose rate around the radiography station. Beam characteristics of 3 different designs of collimators were studied at the reactor power of 1.2 MWth by using Monte Carlo simulation. From the results, the outer collimator assembled from 5.5 cm-thick of borated polyethylene (5% boron) which was covered by 1 cm-thick lead and 0.5 cm-thick iron, respectively, and the length of 50 cm could reduce the gamma ray scattering most effectively. Moreover, the neutron fluence at the radiographic position of 100 cm and 140 cm were increased by 22% and 8%, respectively, when compared with the condition without an outer collimator. Therefore, the exposure time and also the dose rate around the radiographic station could be reduced. In the future, the outer collimator will be constructed and will be installed based on this appropriate design.

1. Introduction

The external collimator installation is a part of the development of neutron tomography (NT) system at Thai Research Reactor (TRR-1/M1). The neutron radiography (NR) station was renovated [1] and the radiographic position was set away from the reactor beam port of 140 cm to slightly increase the L to D ratio. Therefore, the aim of this work was to design the appropriate external collimator for decreasing the loss of neutron intensity from scattering in the atmosphere. Moreover, by reducing the radiation scattering, the dose rate around NR station can be decreased. Borated polyethylene (BPE) with 5% boron content by weight was used as a shielding material. BPE effectively reduced the dose of neutrons from $^{10}B(n, \alpha)^{7}Li$ reaction. To design the external collimator for NR station, Monte Carlo simulation was performed to study the neutron and gamma ray characteristics after passing through the external collimator.

2. Methodology

The external collimator was composed of two parts: the first part was the in-shutter collimator and the second part was the extended collimator, which were installed in a neutron shutter box and behind the neutron shutter, respectively, as shown in figure 1. In this work, Monte Carlo PHITS code version 2.88 [2] was used to simulate the characteristic of neutrons and gamma rays after passing through the designed collimators. The neutron energy spectrum (figure 2) at the south beam tube of the TRR-1/M1 was used as the input source. The low energy up to 100 MeV of neutrons and gamma rays at 1.2 MWth-reactor power were observed. In this study, the gap between the reactor wall and the neutron shutter was set to 0.5 cm and the neutron beam aperture was 16 cm × 14 cm. The external collimator was designed to have BPE (5% boron) with the thickness of 5.5 cm. The length of the in-shutter collimator and extended collimator were 50 cm. The intensity of neutrons and gamma rays (fluence per source neutron, $cm^{-2}s^{-1}n^{-1}$) at the radiographic position of 100 cm and 140 cm away from the reactor wall were characterized. The simulation was performed with 4 different configurations which are described below:

Case 1: Simulation without the external collimator.

Case 2: Simulation with the BPE in-shutter collimator and the BPE extended collimator with the aperture of 16 cm × 14 cm.

Case 3: Simulation with the BPE in-shutter collimator and the BPE extended collimator covered by 1 cm-thick of lead and 0.5 cm-thick of steel, respectively and the aperture of 16 cm × 14 cm.

Case 4: Simulation with the BPE in-shutter collimator and the BPE extended collimator covered by 1 cm-thick of lead and 0.5 cm-thick of steel, respectively and the aperture of 19 cm × 19 cm.

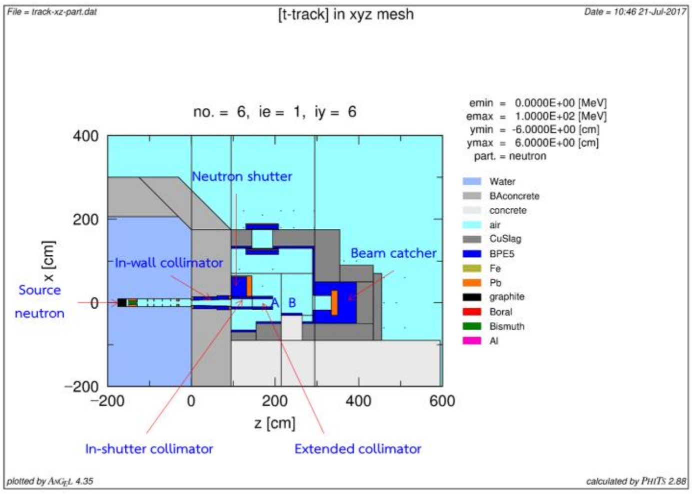

Figure 1. Schematic diagram of neutron radiography room at TRR-1/M1.

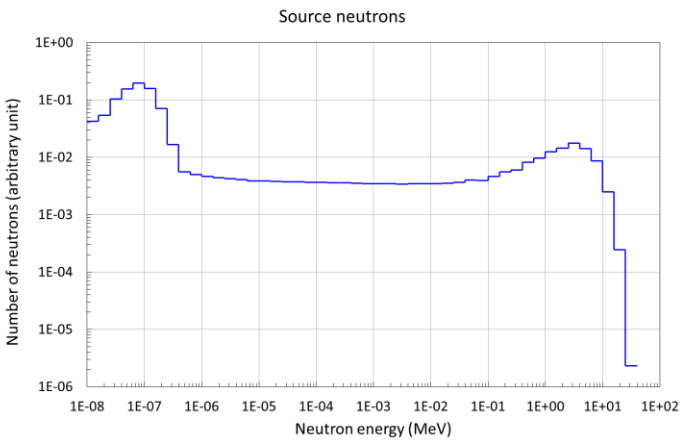

Figure 2. Neutron spectrum of the TRR-1/M1 south beam tube.

3. Results and discussion

Monte Carlo simulation was used to calculate the neutron and gamma ray characteristics at the radiographic position of 100 cm (A) and 140 cm (B) as shown in figures 3 - 6 and table 1. Figure 3 shows the neutron and gamma ray profiles without the external collimator. Radiation from the beam port was only collimated by the iron frame of the neutron shutter with the aperture of 20 cm×20 cm. The profiles showed high neutron and gamma scattering at the NR station and the beam shape was expanded and became larger than the cavity of the beam catcher. Therefore, the radiation level around the NR station was relatively high. From the calculation, neutron and gamma fluences at 100-cm distance were 4.13×10^{-9} $cm^{-2}s^{-1}$ n^{-1} and 2.44×10^{-9} $cm^{-2}s^{-1}$ n^{-1}, respectively. At the 140-cm distance, neutron and gamma fluences were 2.59×10^{-9} $cm^{-2}s^{-1}$ n^{-1} and 1.94×10^{-9} $cm^{-2}s^{-1}$ n^{-1}, respectively, as shown in table 1.

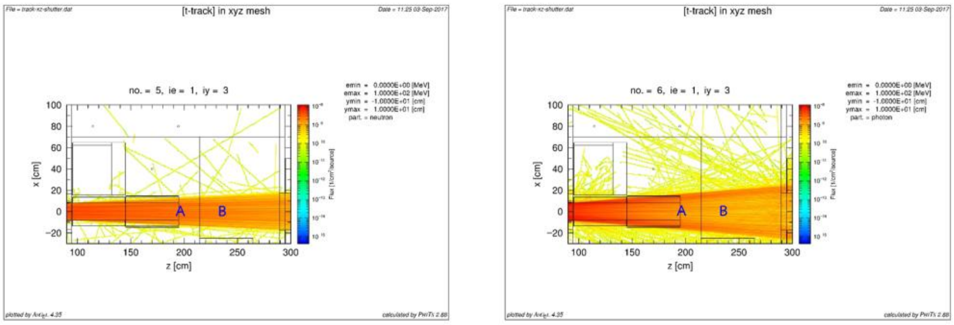

Figure 3. Neutron profile (left) and gamma ray profile (right) without the external collimator.

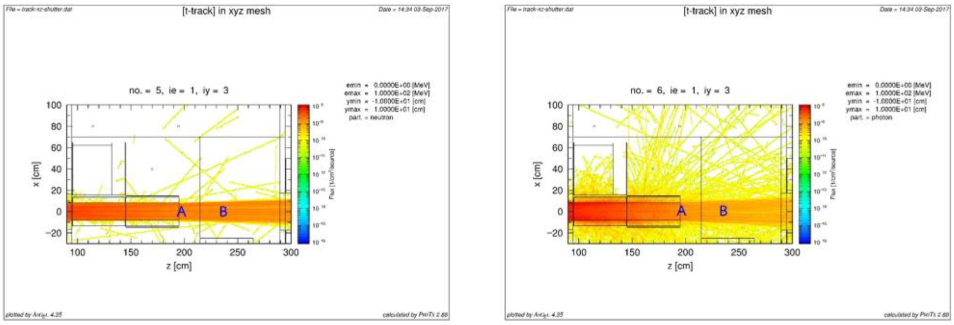

Figure 4. Neutron profile (left) and gamma ray profile (right) with the BPE in-shutter collimator and the BPE extended collimator with the aperture of 16 cm × 14 cm.

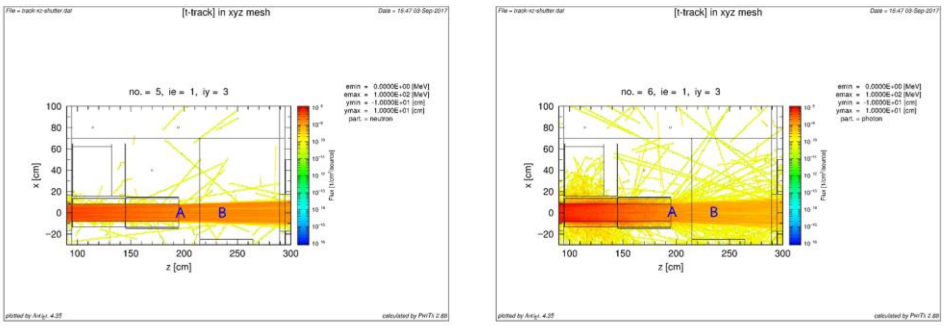

Figure 5. Neutron profile (left) and gamma ray profile (right) with the BPE in-shutter collimator and the BPE extended collimator covered by lead and steel with the aperture of 16 cm × 14 cm.

Figure 4 - 5 shows the neutron and gamma ray profiles with the BPE external collimator and the aperture of 16 cm × 14 cm. Neutron and gamma ray beams became smaller because of the collimation in both cases. Moreover, the scattering of gamma rays was decreased as shown in figure 5. It was due to the covering of lead and steel at the extended collimator. From the calculation, neutron and gamma fluences at the radiographic positions were not different from the without collimator condition.

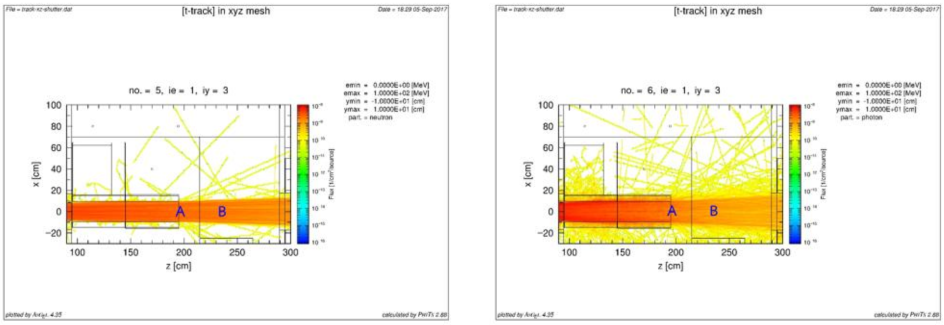

Figure 6. Neutron profile (left) and gamma ray profile (right) with the BPE in-shutter collimator and the BPE extended collimator covered by lead and steel with the aperture of 19 cm × 19 cm.

Figure 6 shows the neutron and gamma ray profiles with the external collimator and the aperture of 19 cm × 19 cm. Radiation scattering was decreased when compared with the case without the collimator. Due to the larger aperture, neutron fluence increased to 22% and 8% at radiographic position of 100 cm and 140 cm, respectively. By increasing of neutron fluence with this collimator design, the exposure time for NT can be decreased.

Table 1. Fluence per source neutron ($cm^{-2}s^{-1}n^{-1}$) of the different collimation designs.

Position	Case 1		Case 2		Case 3		Case 4	
	N_fluence	G_fluence	N_fluence	G_fluence	N_fluence	G_fluence	N_fluence	G_fluence
A	4.13E-09	2.44E-09	4.13E-09	2.68E-09	4.13E-09	2.68E-09	5.03E-09	2.44E-09
B	2.59E-09	1.94E-09	2.59E-09	1.94E-09	2.59E-09	1.94E-09	2.80E-09	2.37E-09

4. Conclusion

The characteristics of neutron beams and gamma rays at the NR station of TRR-1/M1 research reactor with the different collimator designs were carried out by using the Monte Carlo simulation code PHITS. The simulation indicated that the collimator installation could reduce the radiation scattering significantly, especially for neutrons. The appropriate design based on this study was the BPE in-shutter collimator and the BPE the extended collimator covered by lead and iron with the length of 50 cm and the aperture of 19 cm × 19 cm. This design enhanced the neutron and gamma fluences at the radiographic position and the benefit for the development of the NT system. In the near future, the external collimator will be built and installed at the NR station.

References

[1] Picha R, Channuie J, Liamsuwan T, Promping J, Ratanatongchai W, and Wonglee S 2017 *J. Phys. Conf. Ser.* **860** 012036

[2] Japan Atomic Energy Agency. PHITS Ver. 2.88 User’s manual [Internet]. 2016 Jan 29 [cited 2017 September 12]. Available from: http://phits.jaea.go.jp/manual/manualE-phits288.pdf