Renovation status of neutron radiography facility at TRR-1/M1 reactor

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Abstract. Thai Research Reactor-1/Modification 1 (TRR-1/M1) at Thailand Institute of Nuclear Technology (TINT) has a beamline facility dedicated for neutron radiography (NR) research. The renovation has been ongoing to enhance the radiation safety and to facilitate research operations of the only reactor NR station in the country. The design of beam shutter and shielding walls has been conducted using Monte Carlo simulations along with attenuation measurements in the lab to ensure the shielding capability of the components and efficient operation. The progress and future plans TINT NR will be presented.

1. Introduction

Thai Research Reactor-1/Modification 1 (TRR-1/M1) is the only research reactor in Thailand. Operated at 1.2 MW, its main applications are radioisotope production, gemstone irradiation, and neutron activation analysis. There has recently been a plan to renovate the neutron radiography (NR) facility, which at current state can be used with a limited capacity due to a low L/D ratio (currently about 50), lack of automation, and a small working area. The details of the original NR setup can be found in [1].

NR facility at TRR-1/M1 has been in used for a long time and the original wall integrity has been compromised due to block dislocation. The initial improvement effort was to construct a new special concrete with barite and copper slag as aggregate, based on past literature. However, efforts to secure domestic supplier and contract were proven to be challenging. Therefore, the research team decided to take a more practical route, by using high-density concrete blocks from a hospital radiotherapy treatment room, which was recent decommissioned, to serve as components of the new NR wall. The NR upgrade is part of the large scale improvement of the neutron beam experimental facilities at TRR-1/M1, which includes the prompt gamma neutron activation analysis (PGNAA) facility [2].

Besides the new shielding, the ongoing renovation involve replacing the beam shutter with a larger volume and automated system, installing a frame for future collimators, and the digital imaging system. The content is organized in the following manner. In section 2, the methods of study are described. Section 3 goes through the results on concrete properties. The shutter description is given in Section 4. In the last section, the summary and conclusion are provided.

2. Materials and Methods

The NR system consists of six main parts: 1) the fission neutron source from the reactor core, 2) the beam shutter, 3) the collimator, 4) the sample stage, 5) the image capture system, and 6) the shielding walls. In the renovation plan, the beam shutter is designed based on [3] and the system is to be driven...
by a motor and placed on a sturdy table with tracks. The shutter also has a part where a collimator can be inserted in the future. This collimator will help focusing the beam and improve the image quality. The sample stage is currently being designed so that it can be remotely controlled via a computer. For the image capture system, the facility will mainly utilize a digital camera attached to an L-shaped light-tight box. Finally, shielding walls are planned to be built with leadite concrete. To design and evaluate the composition for the new shielding walls, the blocks were tested with a gamma radioisotope source.

In summary, the renovation plan timeline is as indicated in Fig. 1.

\textbf{Figure 1.} Radiography renovation plan.

2.1. \textit{Gamma-shielding concrete}
Ledite concrete blocks were acquired from a hospital. The dimensions of a block (Fig. 2) are roughly 15 cm x 15 cm x 30 cm. It has an interlock design. The current blocks have all flat surfaces.

![Figure 2. Ledite concrete block (top). Gamma shielding test of old (L) and new (R) concrete blocks.](image)

Gamma attenuation using a cobalt-60 source was measured and calculated using the Beer-Lambert law, \( I(x) = I(0)e^{-\mu x} \). The coefficients \( \mu \) will be calculated and compared between different concrete samples to evaluate gamma shielding effectiveness.

Dislocation which lead to gaps between blocks is one of the major problem at the current wall. The ridge design allows for an improved shielding capability than the flat block design currently used.

2.2. \textit{Beam shutter}
The new beam shutter design is shown in Figs. 3-4, and the actual pictures in Fig. 5. The outside walls are made of iron. Its size (approximately 50 x 50 x 50 cm\(^3\)) is appreciably larger than the current...
shutter (approximately 40 x 40 x 40 cm$^3$). The first layer is borated polyethylene, which will moderate and capture neutrons. The outside layers are lead, which will shield the gamma radiation.

Figure 3. Beam shutter design. Top: Current. Bottom left: New design, top view. Bottom right: New design, side view. New design has lead and borated polyethylene as shielding materials.
Figure 4. Shutter box configuration (left) and shielding materials (right). Bottom: Orientation with the reactor wall.

Figure 5. Shielding materials, consisting of BPE and lead, being assembled into the shutter box.
Radiation flux maps can be seen in Fig. 6. The fluxes are computed using PHITS Monte Carlo simulation software. It can be seen from the figures that the neutron dose is much reduced when using the new shutter. The gamma dose is comparably low in both cases.

![Image of radiation flux maps](image_url)

**Figure 6.** Radiation flux maps, comparing neutron and gamma fluxes of the old and the new shutters. The display is the top view, in which the left side of the figures is the reactor core and the right side is the NR area while the shutter is closed. The numbers inside the figures indicate different volumes. (Top-left) Neutron flux using old shutter; (Top-right) Neutron flux using new shutter; (Bottom-left) Gamma flux using old shutter; (Bottom-right) Gamma flux using new shutter.

Lanthanum bromide (LaBr$_3$(Ce)) scintillation detector (Canberra LABR-1.5x1.5) was used to measure gamma transmission. A linear setup with the Co-60 source and the detector separated by approximately 40 cm was used, along with partial collimation using lead blocks. Results are shown in Table 1.

**Table 1.** Gamma attenuation coefficients (μ) of different type of materials.

| Sample type | Thickness (cm) | 1.17 MeV | 1.33 MeV |
|-------------|---------------|----------|----------|
| Barite concrete (current) | 20 | 0.1904 ± 0.0001 | 0.1762 ± 0.0004 |
| hematite | 15 | 0.2661 ± 0.0005 | 0.2407 ± 0.0017 |
| Fe | 0.95 | 0.3991 ± 0.0051 | 0.3704 ± 0.0112 |
| Pb (1 block) | 0.3 | 0.7024 ± 0.0060 | 0.6356 ± 0.0059 |
| Pb (2 blocks) | 0.6 | 0.7176 ± 0.0066 | 0.6374 ± 0.0055 |
| Ledite (1 block) | 15 | 0.2318 ± 0.0016 | 0.2151 ± 0.0013 |
| Ledite (2 blocks) | 30 | 0.2431 ± 0.0001 | 0.2370 ± 0.0008 |
3. Results and Discussions

In combination with a new 3D imaging software and camera system, the new concrete wall and beam shutter setups for TRR-1/M1 neutron radiography should provide a better operation in terms of safety and imaging capability. From the gamma shielding tests, the ledite concrete blocks have higher gamma ray attenuation coefficients than that of the current barite concrete blocks. The shielding capability should also be further improved with an interlock connection. The new concrete blocks also serve as an effective option in terms of the gamma shielding property, availability, and the cost. Neutron radiography provides a unique probe into the physical structures of objects, which can be valuable for sample analyses and can be used in combination with other techniques such as X-ray radiography, X-ray fluorescence, X-ray diffraction, and neutron activation analysis. The new neutron beam shutter is considerably larger than the current one and can be operated automatically. The simulations also show that the new shutter can substantially confine the neutron dose in the surrounding area.

With the new upgrade, the neutron radiography facility should be able to construct 3D images of objects such as those from archeological, industrial, and other fields in Thailand [4].

4. Conclusions

The neutron radiography area at Thai research reactor TRR-1/M1 is one of the beam experiments being renovated. Ledite concrete blocks are used to construct the new shielding wall. A beam shutter consisting of borated polyethylene and lead and driven by a motor can improve safety and ease of operation. The new facility is expected to be complete before the end of 2016 and, when used along with an appropriate imaging software, should have a higher capacity to perform 3D neutron radiography.

References

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