Preliminary validation of computational model for neutron flux prediction of Thai Research Reactor (TRR-1/M1)

S Sabaibang[1,3], S Lekchaum[1] and C Tipayakul[2]
[1] Department of Applied Physics, Faculty of Science , King Mongkut's Institute of Technology Ladkrabang, Latkrabang, Bangkok, Thailand,
[2] Thailand Institute of Nuclear Technology (Public Organization), Ongkharak, Nakhon Nayok, Thailand

E-mail: nemoshow2531@gmail.com

Abstract. This study is a part of an on-going work to develop a computational model of Thai Research Reactor (TRR-1/M1) which is capable of accurately predicting the neutron flux level and spectrum. The computational model was created by MCNPX program and the CT (Central Thimble) in-core irradiation facility was selected as the location for validation. The comparison was performed with the typical flux measurement method routinely practiced at TRR-1/M1, that is, the foil activation technique. In this technique, gold foil is irradiated for a certain period of time and the activity of the irradiated target is measured to derive the thermal neutron flux. Additionally, the flux measurement with SPND (self-powered neutron detector) was also performed for comparison. The thermal neutron flux from the MCNPX simulation was found to be 1.79×10^{13} neutron/cm^{2}s while that from the foil activation measurement was 4.68×10^{13} neutron/cm^{2}s. On the other hand, the thermal neutron flux from the measurement using SPND was 2.47×10^{13} neutron/cm^{2}s. An assessment of the differences among the three methods was done. The difference of the MCNPX with the foil activation technique was found to be 67.8% and the difference of the MCNPX with the SPND was found to be 27.8%.

1. Introduction

To utilize nuclear research reactors efficiently, neutron flux is generally an important parameter for the reactor users. In Thailand, there is a research reactor named “Thai Research Reactor–1/Modification 1 (TRR-1/M1)” which is a TRIGA Mark III swimming pool type. The operational power of the reactor power is 1.2 MW. It is used for training, research, isotope production and neutron activation analysis (NAA) [1]. The thermal neutron flux measurement at TRR-1/M1 adopts the gold foil activation technique. The measurement is conducted, at minimum, annually to monitor the flux changes within the irradiation facility. During the recent years, there have been efforts to develop and improve the computational model of Thai Research Reactor (TRR-1/M1). This model is expected to be capable of accurately predicting the neutron flux level and spectrum. In this research, the preliminary validation of the computational model was performed. The computational method of an in-core irradiation facility called CT (Central Thimble) was created. figure 1 shows the configuration of the TRR-1/M1 core including the location of CT irradiation facility within the core. The neutron flux result obtained by the computation model was compared with the results from two actual measurement methods to assess the

[3] To whom all correspondence should be addressed.

accuracy of the model. The first measurement method used the typical gold foil activation technique. The second measurement method employed SPND (self-powered neutron detector).

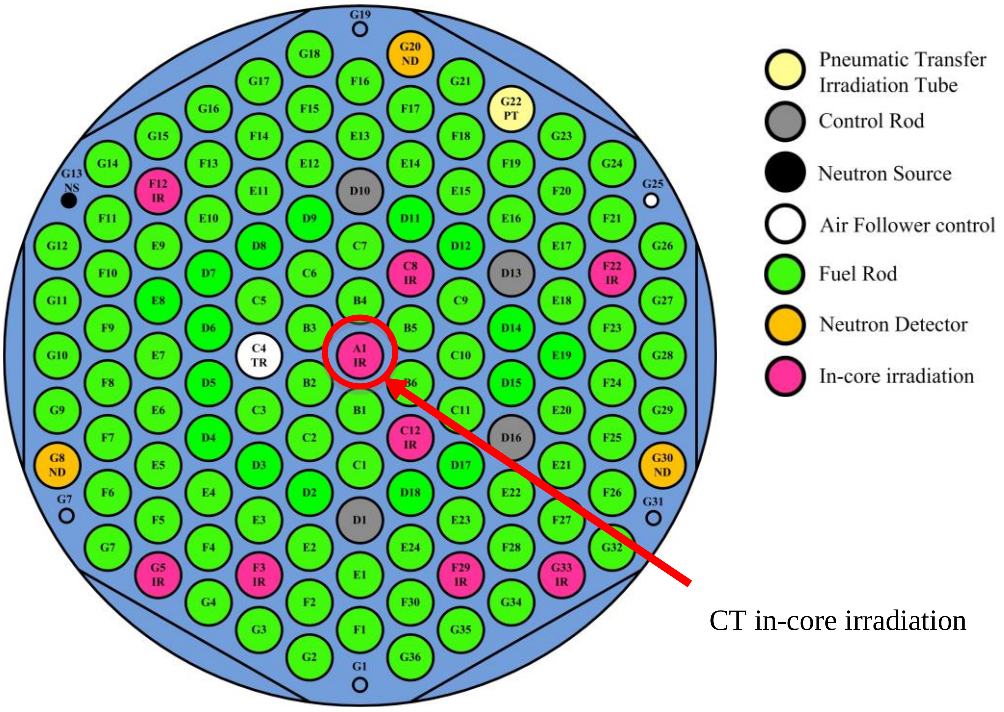


Figure 1. Configuration of TRR-1/M1 Core

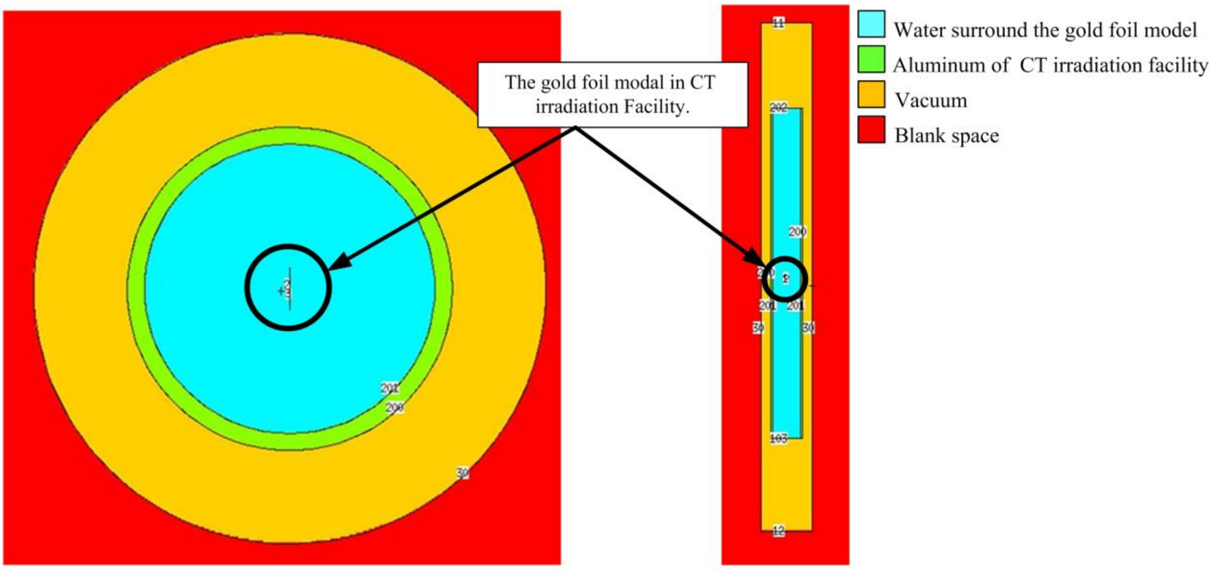
2. Method

2.1. Computational Model

The computational model was created using MCNPX (Monte Carlo N-Particle Extended) computer code version 2.6 [2]. This computer code uses Monte Carlo method to simulate and calculate radiation transport. The model was expanded from the computational prototype [3], that is, the model of the CT irradiation facility was set up in two stages in order to save computational time. First, the model of the whole TRR-1/M1 core was created and the source distribution is set to be $5x10^8$ nps (number of particles) around the CT irradiation facility was recorded by SSR card of MCNPX [3]. In the second stage, the CT in-core irradiation facility was modeled in detail as shown in figure 2. This model uses the source distribution recorded from the previous stage as the source definition by SSW card of MCNPX [3]. By setting up the model in this two-stage scheme, the second stage requires much less computational time and therefore is easier to detect errors or make modeling adjustments. In this model, the size of the gold foil in the model was 0.25 cm in radius and 422.2 µm in thickness which is to mimic the size of the gold foil used in the foil activation measurement. The tally F4 card, the e0 and FM4 card [4] were used together in the simulation model in order to obtain thermal neutron flux spectrum and the reaction rate in different energy groups.

2.2. The gold foil activation method

In this experiment, the thermal neutron flux of the CT irradiation facility was measured by gold foil activation method. The gold foil measurement was performed according to the typical measurement procedure at TRR-1/M1. The dimensions of gold foil are shown in figure 3. To determine thermal neutron flux, two foils were irradiated. The first was a bare foil which was to measure the neutron flux in thermal and epithermal ranges while the second was covered with cadmium to measure the neutron flux only in the epithermal range. With these two foils, the thermal neutron flux can be calculated. The gold foil was loaded in the CT in-core irradiation facility for 20-minute irradiation. It was then left to decay for approximately 5 days. Finally, the radioactivity of the gold foil was measured to estimate the thermal neutron flux by a gamma spectrometer.



(a) (b)

Figure 2. The MCNPX model of CT irradiation model
(a) XY plane view.
(b) YZ plane view.

(a) (b) (c)

Figure 3. The preparation of gold foils for foil activation measurement
(a) The dimensions of the gold foil.
(b) The bare gold foil for thermal neutron measurement.
(c) The gold foil covered with cadmium for epithermal neutron measurement.

2.3. The SPND method

The SPND (self-powered neutron detector) was used for the measurement of the thermal neutron flux at the CT in-core irradiation facility for this research as well. The SPND is basically Rh based material which emits beta particles while being irradiated by thermal neutrons. The measurement of emitted beta particles is done in term of electrical current (A) which is proportional to the thermal neutron flux. As shown in figure 4, the SPND was attached to an aluminum stick and loaded into the CT irradiation position. The experiment of SPND was operated at the reactor powers of 10 kW, 100 kW, 500 kW, 1,000 kW and 1,300 kW respectively. The electrical current measured from the SPND was recorded and used for the estimation of the thermal neutron flux.

Figure 4. The preparation of SPND and the picoammeter setup.

3. Results

3.1. Result of MCNPX method

The thermal neutron flux in the gold foil model for the energy less than 0.025 eV (assuming this is the energy cutoff for thermal neutron flux) obtained by tally F4 of MCNPX was $4.29270\times10^{-4}(1/cm^2)$ per source. Then, the absolute thermal neutron flux (ϕ_{th}) at 1.2 MW was calculated from equation (1). The results of the thermal neutron flux at different reactor powers are shown in table 1.

$$\phi_{th(MCNPX)} = Reactor\ Power \times fission\ constant \times \phi_{TallyF4} \quad (1)$$

where $Reactor\ Power$ is in the unit of MW,
$fission\ constant$ = 3.467×10^{10} fissions/watt – sec [4, p5-102],
$\phi_{TallyF4}$ = Neutron flux as calculated from MCNPX, unit $1/cm^2$.

3.2. Result of the gold foil activation experiment

The thermal neutron flux was calculated for the gold foil activation by equation (2). The calculation of the thermal neutron flux at reactor power 1,200 kW is shown in table 1.

$$\phi_{th} = \frac{1}{Eff * f * \sigma_{th}}\left[\frac{CPS_{(bare)}}{N_{Au1}\left(1-e^{-\lambda t_{r1}}\right)e^{-\lambda t_{d1}}} - \frac{CPS_{(Cd)}}{N_{Au2}\left(1-e^{-\lambda t_{r2}}\right)e^{-\lambda t_{d2}}}\right] \quad (2)$$

where

ϕ_{th}	Thermal neutron flux (neutron/cm^{2}s)
Eff	The efficiency of gamma spectrometer
f	Decay fraction
σ_{th}	Microscopic activation cross section of $^{197}Au\ (n,\gamma)^{198}Au$
N_{Au1}	Number of atoms in the gold foil
N_{Au2}	Number of atoms in the cadmium-covered gold foil
CPS	Count per seconds. (for bare and cadmium-covered foils)

λ	Decay constant
tr	Irradiation time
td	Decay time

3.3. Result of the SPND

The constant of the SPND used in this experiment was 9.42×10^{-21} A/(neutron/cm^{2}s) and the thermal neutron flux was converted from the measured current by equation (3). The results of the thermal neutron flux measured by SPND at the reactor powers of 10, 100, 500, 1,000 and 1,200 kW respectively are shown in table 1.

$$\phi_{th(SPND)} = current\,(nA)\,/\,constant\,detector \tag{3}$$

where constant detector = 9.42×10^{-21} A/(neutron/cm^{2}s) (from SPND calibration)

Table 1. The result of the thermal neutron flux.

Reactor power (kW)	ϕ (neutron/cm^{2}s)		
	MCNPX	Gold foil activation	SPND
10	1.488×10^{11}	-	2.200×10^{11}
100	1.488×10^{12}	-	2.266×10^{12}
500	7.441×10^{12}	-	1.089×10^{13}
1,000	1.488×10^{13}	-	2.200×10^{13}
1,200	1.786×10^{13}	4.684×10^{13}	2.472×10^{13}

At 1,200 kW which is the typical operating power level, the thermal neutron flux from the MCNPX was found to be 1.79x10^{13} neutron/cm^{2}s. The thermal neutron flux from the gold foil activation measurement was 4.68x10^{13} neutron/cm^{2}s and the thermal neutron flux of SPND was 2.47x10^{13} neutron/cm^{2}s. The comparison of the thermal neutron fluxes between the MCNPX with the gold foil activation technique were found to be 67.8% and the difference of the MCNPX with the SPND was found to be 27.8% calculated from equation (4).

$$Percentage\,difference = \frac{|E-S|}{S}\times100\% \tag{4}$$

where E = the thermal neutron from the gold foil activation or the thermal neutron flux of SPND
S = the thermal neutron from the MCNPX

The MCNPX model gave a result closer to the SPND than the gold foil activation technique. The causes of discrepancies among the three methods are to be verified. It is believed that the major difference between the results from MCNPX model and those from other methods is due to the selected energy cutoff which could not be a good representation to the experiment. Moreover, the two experiment methods should be validated against each other as well. It is expected that the foil activation method should have higher measurement uncertainty because there are more steps requiring different types of measuring activities and hence each can contribute to the overall uncertainty. This foil activation experiment shall be repeated in the future with the uncertainty estimation. The SPND is believed to be the best reference method since it is more straightforward and measures the quantity which is directly proportional to the neutron flux.

4. Conclusion

Three methods, which are a computational model, foil activation technique and SPND, to obtain the thermal neutron fluxes were conducted at TRR-1/M1. The results from these methods were compared in this work. It was found that the computational model results were closer to the SPND method than the foil activation technique. It still cannot be concluded at the moment that the computational model is adequately accurate because the difference between the foil activation technique and SPND was not negligible. The foil activation and the SPND measurements may be subject to various statistical and systematic uncertainties which would affect the accuracy of the thermal neutron flux measurement. It is believed, however, the energy cutoff in the computational model could be the main cause of the large difference. More work is needed to make the thermal neutron fluxes measured by the foil activation technique and the SPND agree before making the final assessment of the accuracy of the MCNPX model.

Acknowledgements

The authors would like to thank the Department of Physics, King Mongkut's Institute of Technology Ladkrabang and the Reactor Operation Group, Thailand Institute of Nuclear Technology.

References

[1] Thailand Institute of Nuclear Technology 2010 *Safety Analysis Report for Thai Research Reactor - 1/Modification 1 (TRR-1/M1)* Revision 03 Chapter 5
[2] Pelowitz D B 2008 *MCNPX User's Manual, Version 2.6.0*, Los Alamos National Laboratory report LA-CP-07-1473
[3] Sabaibang S, Tipayakul C and Lekchaum S 2013 Analysis of neutron flux measurement in Thai Research Reactor-1/Modification 1 using the Monte Carlo Method *International Science, Social Science, Engineering and Energy Conference* **5** 402-405
[4] x-5 Monte Carlo Team 2008 *MCNP-A general Monte Carlo N-particle Transport code* Version 5 LA-UR-03-1987