Thermal neutron flux measurement using self-powered neutron detector (SPND) at out-core locations of TRIGA PUSPATI Reactor (RTP)

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Abstract. The thermal neutron flux measurement has been conducted at the out-core location using self-powered neutron detectors (SPNDs). This work represents the first attempt to study SPNDs as neutron flux sensor for developing the fault detection system (FDS) focusing on neutron flux parameters. The study was conducted to test the reliability of the SPND’s signal by measuring the neutron flux through the interaction between neutrons and emitter materials of the SPNDs. Three SPNDs were used to measure the flux at four different radial locations which located at the fission chamber cylinder, 10cm above graphite reflector, between graphite reflector and tank liner and fuel rack. The measurements were conducted at 750 kW reactor power. The outputs from SPNDs were collected through data acquisition system and were corrected to obtained the actual neutron flux due to delayed responses from SPNDs. The measurements showed that thermal neutron flux between fission chamber location near to the tank liner and fuel rack were between $5.18 \times 10^{11}$ n/s to $8.45 \times 10^9$ n/s. The average thermal neutron flux showed a good agreement with those from previous studies that has been made using simulation at the same core configuration at the nearest irradiation facilities with detector locations.

1. Introduction

Neutron flux can be classified as safety parameter used to analyse the neutronic and thermal hydraulic parameters and also convey the neutron behavior during fission reactions. The flux was used to determine the reactor states through neutron production and its evolution as its supplies the information to the reactor protection system and reactor power regulating [1]. This flux can be measured using detectors such as fission chamber (FC), self-powered neutron detectors (SPND), local power range monitors and others. The principal for all neutron detectors applies the activation of the main components materials which produce the electrical signals that are proportionate to the neutron flux at the detector locations.
The benefit of such the neutron detectors is that it can be used as sensors to develop a fault detection system (FDS) for safety improvement, reliability, and availability during reactor operations [2]. The FDS mainly focuses on the neutron flux parameters to detect any abnormal events such as sudden increases in number of neutrons during reactor operations. RTP has implement safety procedure which automatically will trip the reactor when operating limit is exceeded. By implementing the FDS, it will help along diagnose and overcome the sources of failure in real-time mode which prevents the reactor from tripping and allow the reactor to continues is operation in safe manners.

Generally in research reactors, wide range FC detectors were used as safety instruments to measure the neutron flux and also to monitor the neutron behavior in the reactor core. The measurements carried out were the leakage flux that is proportional to the linear power level calculation, period time calculation and as a reactor trip parameters. These parameters were able to determine the reactor states during operations from start-up to full power level [3]. FC was usually located in fixed positions around the reactor core with leak-tight instruments port so that the detectors were not subjected to moisture [4]. To prevent any build-up of corrosive substances on the detector, an inert gas is provided in this port.

At RTP, the neutron detectors that are currently used are FC which is responsible for detecting the signal changes during reactor operations. However, the prompt response from FC limits the signals output to study the neutronic and thermal hydraulic parameters. The signals measured need to undergo interpretation which requires a precise knowledge of the mass and isotopic composition of the fissile coating materials [5]. FC can only display the fluctuation of the signal from the detectors which difficult to be used as the FDS sensors. The actual flux value at certain power level is unknown. The signal also cannot be manipulated to obtain the flux and power. Therefore, by utilizing the SPNDs, the experiment was conducted with the aims to measure the thermal flux and to estimate the reliability of the output for developing the FDS at RTP core. The FDS method will not discuss further in this paper.

2. Materials and methods

2.1. TRIGA PUSPATI Reactor (RTP)
Malaysia has the one and only research reactor namely TRIGA PUSPATI (RTP) since 1982 where it has been operated safely by Malaysian Nuclear Agency (Nuklear Malaysia) and licensed by Atomic Energy Licensing Board of Malaysia (AELB). The RTP reactor is a TRIGA MARK II, pool type reactor with 1 MW thermal power and has achieved its first criticality on 28 June 1982. The cylindrical core consists of fuel elements from solid Uranium Zirconium-Hydride (UZrH\(_{1.6}\)) with 8.5 wt. %, 12.0 wt. %, and 20.0 wt. % of uranium fuel (U) and 19.7% of Uranium-235 enrichment. The purpose of this homogenous mixture of the ZrH\(_{1.6}\) in the fuel is to moderate neutrons of energy above 0.14eV [6]. There are 4 boron carbide (B\(_4\)C) control rods whereby one of them is an air follower type and the rest are fuel follower type which composed of 8.5 wt. % of U and B\(_4\)C absorber on top of fuel section. The core were surrounded with graphite as reflector and cooled by natural convection. As for protecting purposes, the core biological shield is made of high density concrete of 2.5m thick wall to attenuate radiation and shield its surrounding from radiological contamination. Recently, the RTP core is on it 15\(^{th}\) configuration as shown in figure 1 below.
2.2. Self-Powered Neutron Detector (SPND)
SPND has been used widely to measure the flux behavior and as a monitoring devices in core of research and power reactors. The unique characteristics of SPND make it favorable to be used in harsh radiation field associates with high pressure and temperature conditions [7]. It also does not need any external power supply and can be fitted in the in-core locations. The SPNDs consists of three major components and connected to the insulated coaxial cables, centered with emitter surrounded with insulator and collector as shown in figure 2 below. The emitter consists of materials that has high absorption cross-section and capable to react with neutrons through radiative capture like vanadium, rhodium, cobalt and others [8]. Insulators are solid dielectric materials that are capable to retain the high electrical resistivity and high radiation fields. The collector is of made conducting materials like aluminum oxide and magnesium oxide.

Figure 1. RTP core15th configuration [6].

Figure 2. Schematic views of general SPNDs [8]

In this paper, the vanadium SPNDs were used to measure the neutron flux at out-core locations. These SPNDs have been chosen because of the emitter depletion rates were longer but suffer from the delay responses. These SPNDs are desirable to be used because of its high accuracy on detecting the neutrons [9]. The interaction happen when the neutron is being absorbed then emits the energetic electrons after a few minutes due to induction of the beta activity in the emitter [10]. The electrons then travelled and passed through the insulator and were deposited at the collector. This phenomenon
will create the collector as negative side and the emitter as positive side thus allow for small currents to flow through the insulated coaxial cable. The observed signal were said to be directly proportional to the rate of neutron absorption in the emitter which represents the neutron flux at the detector locations.

The measurement has been done at the out-core location where the three detectors were coupled and located together at the same locations. Since the vanadium SPNDs suffered from delay responses, each measurement were recorded within 30 minutes at four different locations with full reactor power level at 750 kW. The SPNDs were connected to the data acquisition system to record the signals from the detectors. All the data were then reconstructed to determine the flux using the correction factors in equations 1 and 2 below [11].

\[
\psi_i = CI \\
\psi_{i+1} = C \left[ I_{i+1} - \exp\left(-\frac{\Delta I}{\tau}\right) \right] + \exp\left(-\frac{\Delta \psi_i}{M \tau}\right)
\]

\(\psi\), \(C\) and \(I\) are neutron flux, normalisation constant and detector current respectively, whereas \(\tau\) and \(\Delta\) are characteristic time decay of \(V^{52}\) and sampling time.

The SPNDs position were located at the fission chamber cylinder, at the above graphite reflector, between graphite reflector and tank liner and at the fuel rack as shown in figure 3. The data obtained were used to plot the flux and calculate the responses corrected using correction factors to study the signal’s reliability for developing FDS.

![Top view of RTP](image)

**Figure 3.** SPNDs location for flux measurements.

3. Data analysis

The outputs from the SPNDs are in current unit which are related proportionately to the flux by using correction factors to calculate the actual flux values. Figure 4 shows the flux and corrected flux calculated using correction factors for each location against the sampling time for all three SPNDs. The flux varied due to the varied distance between the detector and the core. As this measurement were conducted at the out-core locations, the predicted thermal flux was assumed to be less than 3.78 x10^{12} nv and was obtained from previous simulation at the nearest irradiation facilities (PTS-G20) with fission chamber locations [12]. Based on figure 3 below, the maximum thermal neutron flux recorded in SPND#3 was approximately 4.5x10^{11} nv while the corrected flux calculated was 5.5x10^{11} nv at the location above graphite reflector. The detectors were moving out from fission chamber channel which increases the signals slightly. Besides the detectors movement, the signals may be affected by gamma ray and neutrons which comes from the reflector and also from the core. The minimum flux was located at the fuel rack which less neutrons available in this area.
The measurements were conducted by coupling all three SPNDs together. Figure 4 illustrates the average signals obtained directly from SPNDs and average signal obtained from responses corrected. Based on the graph below in figure 5, the flux started to increase as the power level rises. At 750kW reactor power, the SPNDs were allowed to record the data for 30 minutes at each location to obtain the equilibrium flux. The flux were approximately 3.07x10^{11} nv at fission chamber location, 5.18x10^{11} nv at the above graphite reflector, 4.55x10^{11} nv between the graphite reflector and tank liner and 8.45x10^{09}nv at the fuel rack for both data. By comparing with previous study, the average thermal neutron flux in this work has shown a good agreement, with the assumption which the flux obtained must be less than 3.78x10^{12} nv due to the locations has less neutrons and less gamma radiations to study the reliability of the SPNDs signals.

Based on the result, the signals can be used further to develop a fault detection system in RTP core. However, to ensure the detection system works efficiently, the delayed responses needs to undergo some improvement in real time mode so that the signals produces will promptly transfer to a system for any abnormal events in neutron flux.

![Diagram showing neutron flux at different locations](image)

**Figure 4.** Neutron flux obtained directly from measurements and from responses corrected.
Figure 5. Neutron flux obtained directly from measurements and from responses corrected.

4. Conclusion
Out-core thermal neutron flux measurements has been recorded and compared with previous simulation to study the reliability of the SPNDs signal for preliminary test of FDS development at RTP. The average thermal neutron flux showing a good agreement with those from previous studies that has been made using simulation at the same core configuration at the nearest irradiation facilities with detector locations. The flux obtained from the simulations was $3.78 \times 10^{12}$ nV while from this work the average flux measured were in the range of $5.18 \times 10^{11}$ nV to $8.45 \times 10^9$ nV. The results has shown that the signals are reliable and capable to be used as a sensor for developing FDS.

5. References
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