THERMAL NEUTRON FLUX MAPPING ON A TARGET CAPSULE AT RABBIT FACILITY OF RSG-GAS REACTOR FOR USE IN k_0-INAA

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ABSTRACT

THERMAL NEUTRON FLUX MAPPING ON A TARGET CAPSULE AT RABBIT FACILITY OF RSG-GAS REACTOR FOR USE IN k_0-INAA. Instrumental neutron activation analysis based on the k_0 method (k_0-INAA) requires the availability of the accurate reactor parameter data, in particular a thermal neutron flux that interact with a targets inside the target capsule. This research aims to determine and map the thermal neutron flux inside the capsule and irradiation channels used for the elemental quantification using the k_0-AANI. Mapping of the thermal neutron flux (ϕ_{th}) on two type of irradiation capsule have been done for RS01 and RS02 facilities of RSG-GAS reactor. Thermal neutron flux determined using Al-0,1%Au alloy through $^{197}Au(n,\gamma)$ ^{198}Au nuclear reaction, while the flux mapping done using statistics R. Thermal neutron flux are calculated using k_0-IAEA software provided by IAEA. The results showed the average thermal neutron flux is $(5.6\pm0.3)\times10^{+13}$ n.cm^{-2}.s^{-1}; $(5.6\pm0.4)\times10^{+13}$ n.cm^{-2}.s^{-1}; $(5.2\pm0.4)\times10^{+13}$ n.cm^{-2}.s^{-1} and $(5.3\pm0.4)\times10^{+13}$ n.cm^{-2}.s^{-1} for Polyethylene capsule of 1st , 2nd, 3rd and 4th layer respectively. In the case of Aluminum capsule, the thermal neutron flux was lower compared to that on Polyethylene capsule. There were $(3.0\pm0.2)\times10^{+13}$ n.cm^{-2}.s^{-1}; $(2.8\pm0.1)\times10^{+13}$ n.cm^{-2}.s^{-1}; $(3.2\pm0.3)\times10^{+13}$ n.cm^{-2}.s^{-1} for 1st, 2nd and 3rd layers respectively. For each layer in the capsule, the thermal neutron flux is not uniform and it was no degradation flux in the axial direction, both for polyethylene and aluminum capsules. Contour map of eight layer on polyethylene capsule and six layers on aluminum capsule for RS01 and RS02 irradiation channels had a similar pattern with a small diversity for all type of the irradiation capsule.

Keywords: thermal neutron, flux, capsule, NAA

ABSTRAK

PEMETAAN FLUK NEUTRON TERMAL PADA KAPSUL TERGET DI FASILITAS RABBIT REAKTOR RSG-GAS UNTUK DIGUNAKAN DALAM k_0-AANI*.* *Analisis aktivasi neutron instrumental berbasis metode k_0 (k_0-AANI) memerlukan ketersediaan data parameter reaktor yang akurat, khususnya data fluks neutron termal yang berinteraksi dengan inti sasaran di dalam kapsul target. Penelitian ini bertujuan menentukan dan memetakan fluks neutron termal di dalam kapsul dan kanal iradiasi yang berbeda untuk kuantifikasi unsur-unsur menggunakan k_0-AANI. Pemetaan fluks neutron termal (ϕ_{th}) pada dua jenis kapsul iradiasi telah dilakukan untuk kanal RS01 dan RS02 di reaktor RSG-GAS. Fluks neutron termal ditentukan dengan menggunakan paduan Al - 0,1 % Au melalui reaksi nuklir ^{197}Au $(n,\gamma)^{198}Au$, sementara pemetaan fluks dilakukan menggunakan statistik R. Fluks neutron termal dihitung menggunakan perangkat lunak k_0-IAEA yang disediakan oleh IAEA. Hasil penelitian menunjukkan bawa rata-rata fluk neutron termal adalah $(5,6\pm0,3)\times10^{+13}$ n.cm^{-2}.s^{-1}; $(5,6\pm0,4)\times10^{+13}$ n.cm^{-2}.s^{-1}, $(5,2\pm 0,4)\times10^{+13}$n.cm^{-2}.s^{-1} dan $(5,3 \pm 0,4)\times10^{+13}$ n.cm^{-2}.s^{-1} masing-masing untuk lapisan 1, 2, 3 dan 4 pada kapsul polietilena. Dalam kasus kapsul aluminium, fluk neutron termal adalah lebih rendah dibandingkan dengan fluk neutron termal pada kapsul polietilena, yaitu $(3,0 \pm 0,2)$ $\times10^{+13}$ n.cm^{-2}.s^{-1}; $(2,8 \pm 0,1)\times10^{+13}$ n.cm^{-2}.s^{-1}; $(3,2 \pm 0,3)\times10^{+13}$ n.cm^{-2}.s^{-1} masing-masing untuk lapisan 1, 2 dan 3. Untuk setiap lapisan dalam kapsul, distribusi fluks neutron termal adalah tidak seragam dan tidak ada degradasi fluk dalam arah aksial, baik untuk kapsul polietilena maupun untuk kapsul aluminium. Peta kontur fluk neutron termal untuk delapan lapisan pada kapsul polietilena dan enam lapisan pada kapsul aluminium untuk kanal iradiasi RS01 dan RS02, memiliki pola yang sama dengan keragaman yang relatif kecil untuk semua jenis kapsul iradiasi.*

Kata kunci: neutron thermal, fluks, kapsul, AAN

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INTRODUCTION

Automation in Neutron Activation Analysis (NAA) will support the commercialization of research reactors regularly; thereby this automation will increase the efficiency of the time and other resource used. The NAA automation has been initiated by the IAEA since 2009 [1,2] and the Coordinated Research Program 2012-2015 (CRP1888)[3] regarding the integration between hardware and software in an effort to automate the NAA laboratory.

Among various methods used in neutron activation analysis, the method of k_0-Instrumental Neutron Activation Analysis (k_0-INAA) has a big opportunity to be applied on the automation system. Recently the utilization of k_0 method for quantification of elements in various samples trend to increase. This method is independent to the availability of standard comparator, based on numerical method and traceable to standard and a nuclear parameter data used. The use of single radioisotope as a neutron flux monitor is also very beneficial. However, this method requires an accurate data of reactor parameter and counting system.

Various laboratories have improved the counting automation as well as in the calculation process to increase the ability and effectiveness in the quantitative analysis of elements in the sample. For quantitative analysis, a commercial k_0-software packages were available, but the price is too high for most laboratory AAN.

In 2007, the IAEA has released a non-commercial software for IAEA member country that was free in-charge, which is known as the k_0-IAEA [4]. The k_0-INAA method used in the elemental determination is based on the concept of Hoghdahl. In this software, Blaauw removed all references to the cadmium cut-off energy from original k_0-formula [5]. In the k_0 - IAEA, the target is configured as group or layer and the thermal neutron received by target have to determine quantitatively using an appropriate thermal neutron flux monitor. Thus the monitoring parameters of thermal neutrons flux at the position of a target become very crucial, and must be known accurately.

So far, the thermal neutron flux distribution inside the target capsule has not yet available for all irradiation channels used for NAA at RSG-GAS reactor. Thermal neutron flux of RSG-GAS reactor have been determined and published by Amir Hamzah [6], Syaiful Bahri [7] and Jaka Iman [8]. However, this study did not specify for the type of irradiation capsule and the target distribution inside the capsule. In the k_0 method, matrices and materials of the capsule, were influential significantly in the quantitative calculations due to the interaction between a thermal neutrons with various materials have a different effects [4,8]. Therefore there is a need to determine of flux distribution accurately in the irradiation channels and at the target capsule in order to optimize the k_0-INAA method.

For the purposes of INAA based on k_0 method, the samples were irradiated at the irradiation channel of RS01 to RS04 at RSG-GAS reactor. Polyethylene capsule and Aluminum capsule normally used as container for short and long irradiation respectively [9,10]. Therefore, the mapping of the thermal neutron flux at the irradiation capsule is very important to be accurately determined

The aim of this paper is to investigate the distribution of thermal neutron flux inside the irradiation capsule for difference channel (RS01 and RS02) and map it for each layer and type of the irradiation capsule. For the long term, the use of the thermal neutron flux map on capsule irradiation and the corresponding channel will reduce a dependency on the use of alloy Al-0.1%Au as flux monitor.

MATERIALS AND METHODS

Utilization of $^{197}Au(n,\gamma)^{198}Au$ nuclear reaction to determine a thermal neutron flux has established and has been widely published [11,12]. This nuclear reaction is also recommended for k_0 method [5]. The Al-0.1% Au alloy of IRMM is designed to be used as a thermal neutron flux monitor in the development of k_0 INAA. However, the nuclear reactions of ^{68}Zn (n,γ)^{69m}Zn and ^{115}In (n,γ)^{116m}In have been also used as monitors for the thermal neutron flux [12, 13].

A number of 3 mg Al-0, 1% Au (IRMM 532RC, wire, purity 99.99%) were weighted and put into the 0.2 ml cleaned polyethylene micro-vial (Cole Parmer). Targets were than arranged to form a stack and layer inside irradiation capsule using a polyethylene tube, to fix a position at axial direction as shown in the Figure 1. For polyethylene capsule, 32 micro-vials (32 positions) formed four layers, while there were 24 micro-vials (24 positions) on aluminum capsule formed three layers.

Target then was irradiated in the rabbit facility of RS01 and RS02 at a reactor power of 15 MW. The results of the thermal neutron induced radiation, then were counted using a calibrated high-resolution HPGe detector (FWHM = 1.9 keV at E_γ = 1332.5 keV of ^{60}Co, P/T = 40) for 15 minutes after the cooling time of 1-2 days. Region of Interest (ROI) for energy peak of E_γ= 411.80 keV produced from a nuclear reaction of $^{197}Au(n,\gamma)$ ^{198}Au [11] were determined. Maximum accepted uncertainty was less than 1%. Calculation of thermal neutron flux was carried out using k_0 software provided by The International Atomic Energy Agency (k_0-IAEA) [4].

The open-source software of R statistics from CRAN have been used for statistical analysis and contour mapping. The positions of capsules 1 to 7 on the same layer were determined based on the flux calculation result. The high flux result was placed a position close to the reactor core, meanwhile the lowest flux course being away from the reactor core. Because the distance is quite short, it was estimated that the different on flux was very small.

The use of polyethylene tubes will helped to determine the location for both vertical direction (axial) and radial position. The axial position number 1 on layer one will correspond to the position number one on layer two, layer three and layer four respectively. Figure 1 below is configuration and position of vial target at irradiated capsule, both for polyethylene capsule and aluminum capsule respectively.

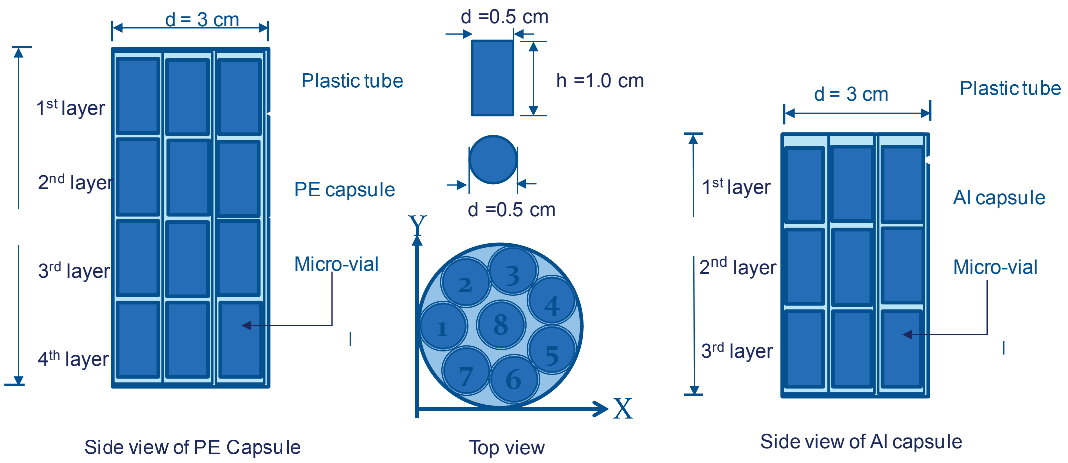

Figure 1. Configuration of the target for the thermal neutron flux mapping study.

RESULTS AND DISCUSSION

In the Neutron Activation Analysis (NAA) based on k_0 method, all used parameter should be determined accurately to give a result with uncertainty as small as possible. Because the variation of neutron thermal produced at reactor, the thermal neutron flux incident on the target should be

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monitored accurately at each capsule used, as well as, each layer of target position. Thus, the characteristic of thermal neutron flux at different capsule and difference irradiation channel is very important to determine for k_0 -NAA calculation. The statistical analyses of Box-Whisker have been used to compare the flux distribution, either at container capsule or irradiation channels. Figure 2 showed the Box-Whisker graphic for the distribution of average thermal neutron flux in aluminum and polyethylene capsule at the RS01 and RS02 channels respectively.

Average thermal neutron flux at the polyethylene capsule was relatively higher than that in the aluminum capsule, or about 1.5 times higher, at either RS01 channel or RS02 channel. Polyethylene capsule contained more H atom, on either capsule or micro vial, compared to the aluminum capsule. The existence of H atoms will moderate the fast neutrons to the thermal neutron through an inelastic collision of atoms. This thermal neutron will than contribute on the neutron flux coming from the reactor core. As a result, the number of thermal neutrons inside the irradiation capsule will increase. This could also mean that the impact of H is increase with increment of H atom on capsule [14]. In contrast, for aluminum capsule the contribution of H seemed very small. Because the polyethylene material contained in the aluminum capsule is relatively small compared to that in the polyethylene capsule. As a result, the contribution of H atoms in the neutron moderation inside aluminum capsule also small. Meanwhile, the aluminum atoms can capture the thermal neutrons, and it will contribute in the reduction of the thermal neutron flux inside the aluminum capsule.

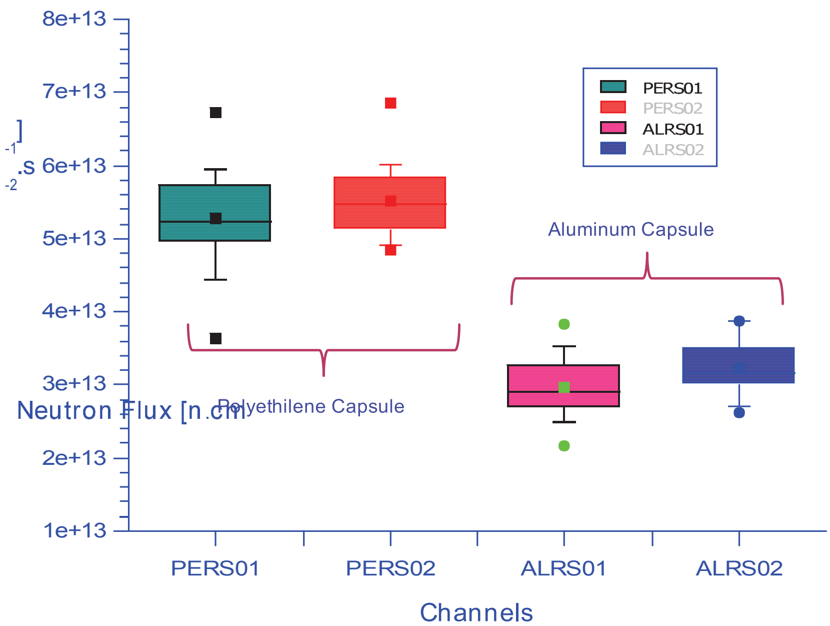


Figure 2. Box-Whisker for neutron flux distribution at polyethylene and aluminum capsule for RS-01 and RS-02 irradiation channels of RSG-GAS reactor.

The utilization of plastic tube helped us to locate a position at axial direction. Meanwhile it was difficult to locate at a radial direction. The degradation on axial direction was determined by average of all flux value obtained at same layer. Each target capsule has a different layer. The polyethylene capsule consist four layers, while aluminum capsule have three layers as shown in Figure 1, and each layer consisted of eight target. The flux measurement results at axial direction did not indicate any significant flux degradation, either polyethylene capsule or aluminum capsules, as shown at Figure 3. Irradiation position of rabbit capsule located at 30 cm above the ground, or in the middle position of fuel elements (60 cm), on the outside of the reactor core. High of irradiation capsule is 10 cm for aluminum and 12 cm for polyethylene. This is relatively small compare to the size of the fuel element.

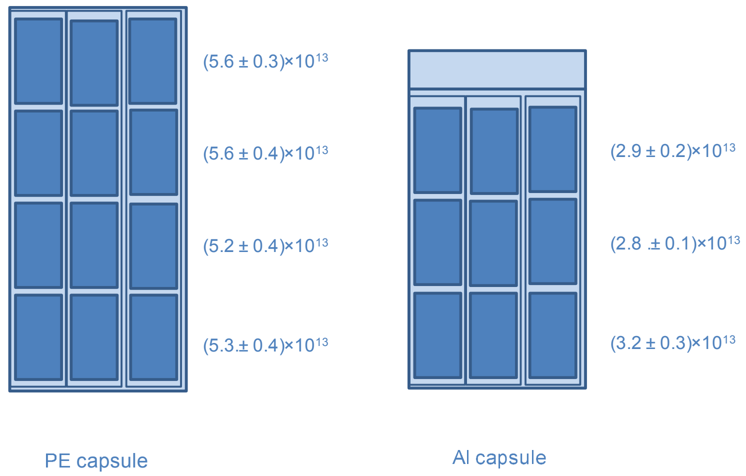
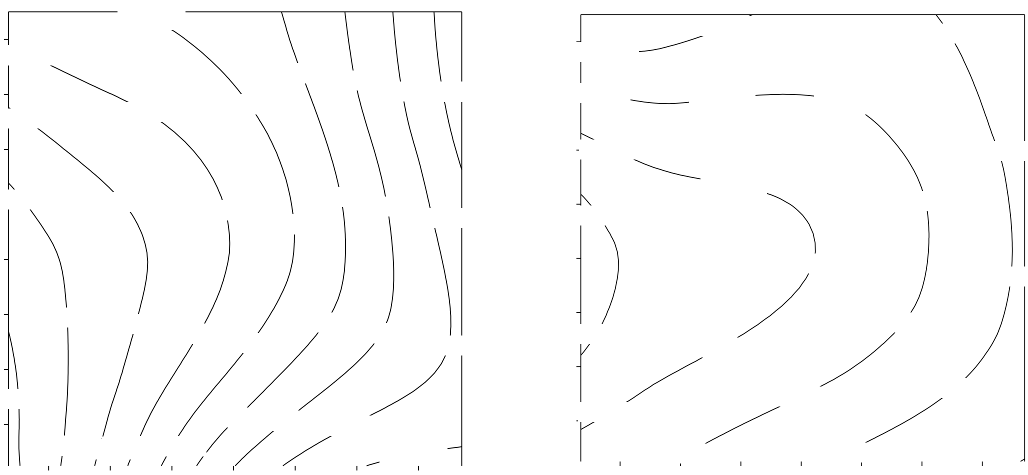


Figure 3. The average thermal neutron flux for each layer on the Polyethylene and Aluminum capsule [units given in $n.cm^{-2}.s^{-1}$].

An accurate result of neutron flux mapping is highly demanded in the k_0 method. The use of flux monitors can be reduced if the map of thermal neutron flux could be realized for each capsule type and irradiation channels. Mapping of thermal neutrons flux are presented in the form of contour map, as shown in Figure 4 to Figure 6.

Figure 4 and Figure 5 shows the contour map of thermal neutron flux on the polyethylene capsule at RS-01 and RS-02 channels, for layer one (Figure 4(a) to layer four (Figure 4 (d)) respectively. Contour map for the RS01 and RS02 on polyethylene capsule showed systematic pattern on each layer. The flux density of the left side is higher than that to the right side, from about 6.5×10^{13} $n.cm^{-2}s^{-1}$ to 4.0×10^{13} $n.cm^{-2}.s^{-1}$. This mean the left side indicated that the target position was close to the core. The capsule has a fix position at channels irradiation. Actually, it was not possible to determine an exact position at radial direction for each layer. The difference of flux on each layer was very small, of about 1.0-1.5 $n.cm^{-2}.s^{-1}$. In this condition, the capsule received a fluent neutron came from one direction. Thus the target inside the capsule was not possible to receive a homogenous neutron flux.



(a). Polyethylene capsule, channel RS01, 1st layer.

(b). Polyethylene capsule, channel RS01, 2nd layer.

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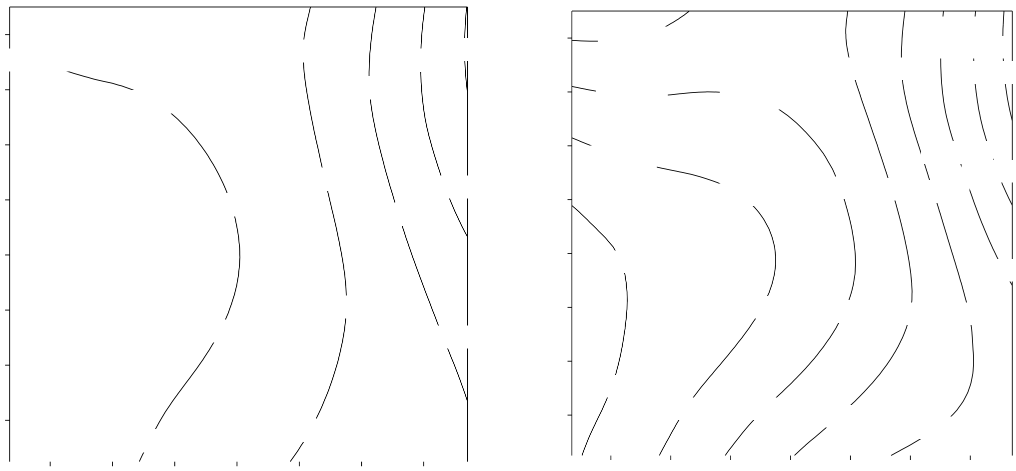
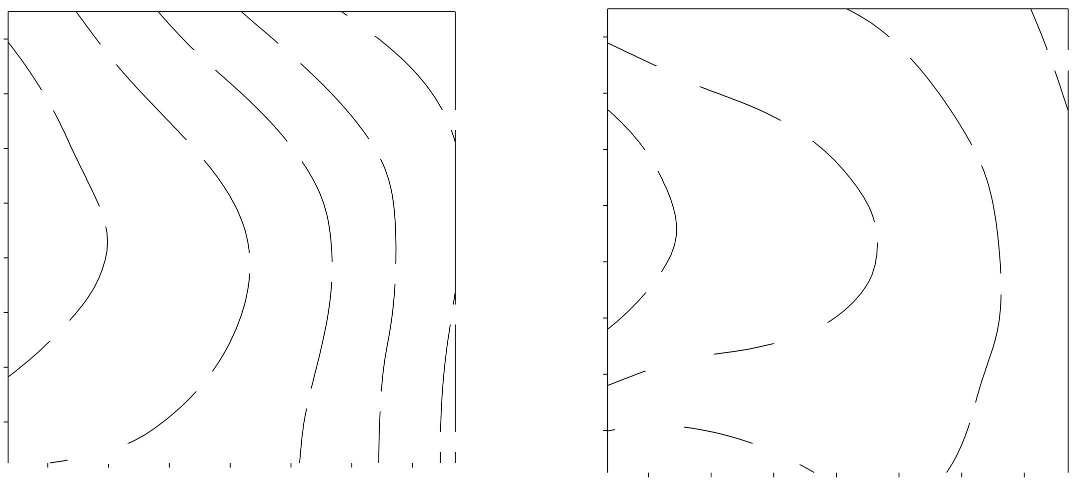


(c). Polyethylene capsule, channel RS01, 3rd layer.

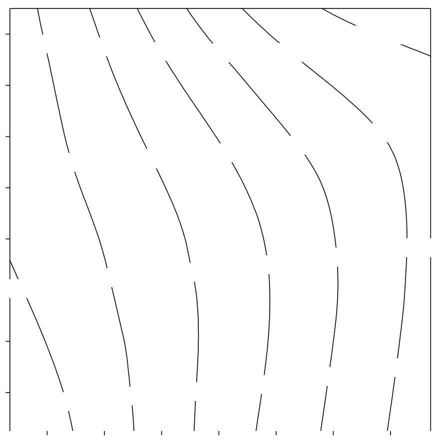
(d). Polyethylene capsule, channel RS01, 4th layer.

Figure 4. Contour map of the thermal neutron flux at the polyethylene capsule for RS01 channel, for 1st layer to 4th layer.

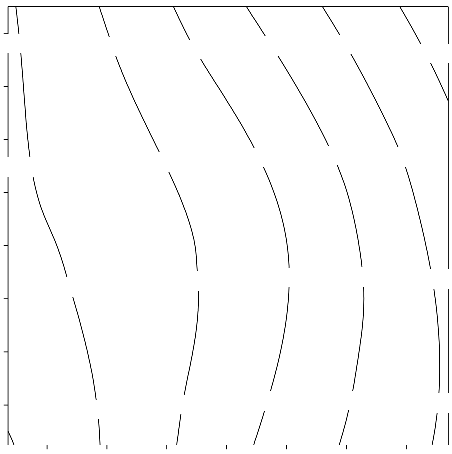


(a). Polyethylene capsule, channel RS02 1st layer.

(b). Polyethylene capsule, channel RS02, 2nd layer.



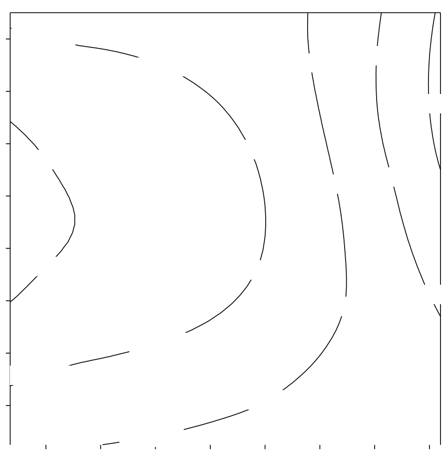
(c). Polyethylene capsule, channel RS02, 3rd layer.



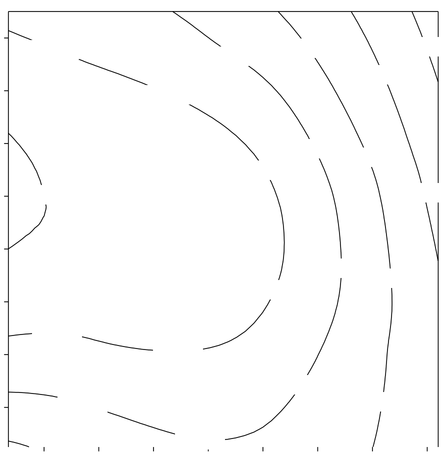
(d). Polyethylene capsule, channel RS02, 4th layer

Figure 5. Contour map of the thermal neutron flux at the polyethylene capsule at RS02 for 1st layer to 4th layer.

Figure 6 shown the contour map of thermal neutron flux inside aluminum capsule at RS01 and RS02 channel. The aluminum capsule provided three layers for vial target where each layer contains eight monitor of Au. The total was 24 points for mapping flux determination. The results of mapping flux showed a similar pattern with the pattern obtained in polyethylene capsule, except, of course, the amount of thermal of neutron flux was smaller. This suggested also that the capsules were in a fix position during irradiation taken place. For the RS-01, the thermal neutron flux moved significantly from 3.8×10^{13} n.cm^{-2}.s^{-1} at left side to 3.0×10^{13} n.cm^{-2}.s^{-1} at right side. In the case of RS-02 channel, the flux moved from 4.0×10^{13} n.cm^{-2}.s^{-1} at left side to 3.0×10^{13} n.cm^{-2}.s^{-1} at right side. Same with polyethylene capsule, the diversity was very small, of about 1.0×10^{13} n.cm^{-2}.s^{-1}.



(a). Aluminum capsule, channel RS01, 1st layer.



(b). Aluminum capsule, channel RS01, 2nd layer.

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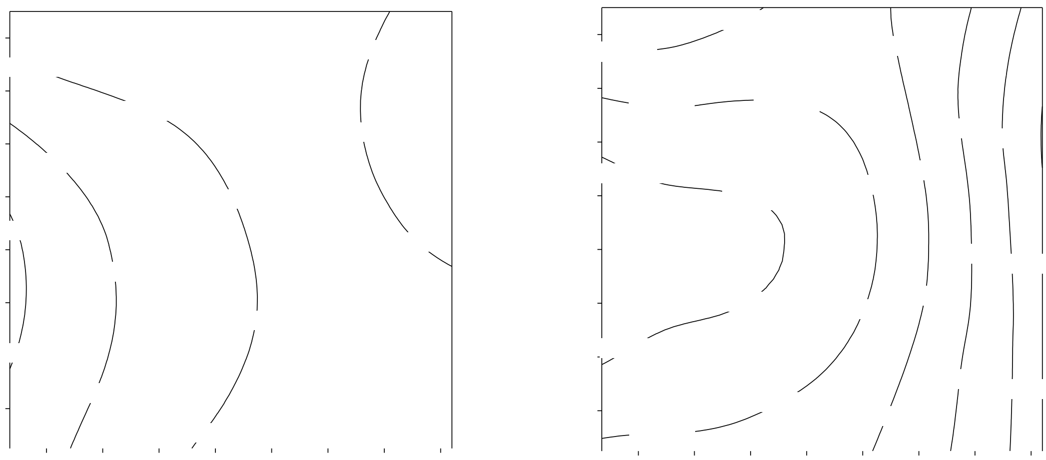
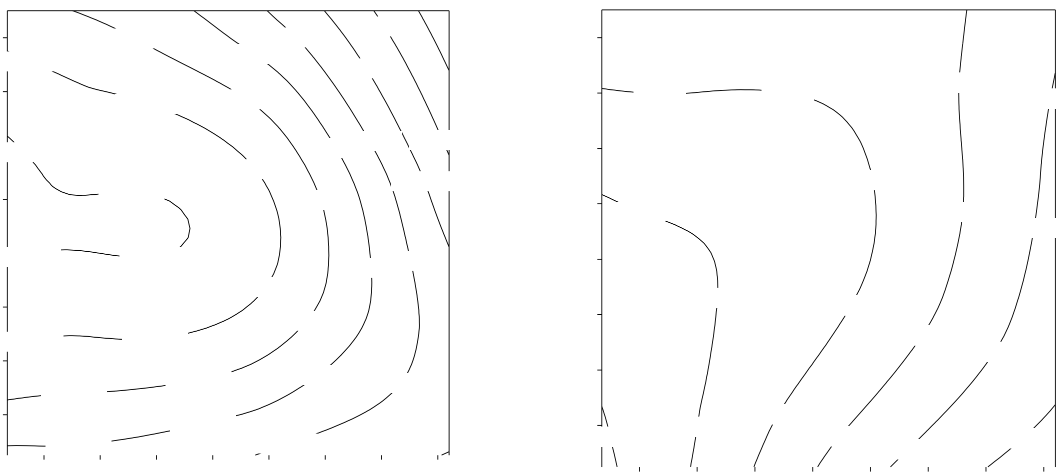


(c). Aluminum capsule, channel RS01, 3rd layer.

(d). Aluminum capsule, channel RS02, 1st layer.



(e). Aluminum capsule, channel RS02, 2nd layer.

(f). Aluminum capsule, channel RS01, 3rd layer.

Figure 6. Contour map of the thermal neutron flux at the aluminum capsule for RS01 channel and RS02 channel for 1st to 3rd layer respectively.

CONCLUSION

From the results of this research it could be concluded that the thermal neutron flux received by the target inside the capsule are dependence to the capsule type used. The average thermal neutron flux received by the target inside the polyethylene capsules are relatively higher than that inside the aluminum capsule at a reactor power of 15 MW. Thermal neutron flux distribution in the axial direction, for both polyethylene and aluminum capsules, show no degradation on flux. Meanwhile, the contour map of the thermal neutron flux for each layer had a similar pattern with a small diversity for all type of the irradiation capsule and irradiation position.

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