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Design of Irradiation Facilities at Central Irradiation Position of Plate Type Research Reactor Bandung

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A B S T R A C T

One of the results from Plate Type Research Reactor Bandung (PTRRB) research program is PTRRB core design. Previous study on PTRRB has not calculated neutron flux distribution at its central irradiation position (CIP). Distribution of neutron flux at CIP is of high importance especially in radioisotope production. In this study, CIP was modeled as a stack of four to five aluminum tubes (AT), each filled by four aluminum irradiation capsules (AIC). Considering AIC dimension and geometry, there are three possibilities of AT configuration. For irradiation sample, 1.45 gr of molybdenum (Mo) was put into AIC. Neutron flux distribution at Mo sample was calculated using TRIGA MCNP and MCNP software. The calculation was simulated at condition when fresh fuel is loaded into reactor core. Analyses of excess reactivity show that, after installing irradiation AT and Mo sample was put into each configuration, the excess reactivity is less than 10.9 %. The highest calculated thermal neutron flux at Mo sample is 5.08×10^{13} n/cm^2.s at configuration 1. Meanwhile, the highest total neutron flux at Mo sample is located at capsule no. II and III. Thermal neutron flux profile is the same for all configurations. This result will be used as a basic data for PTRRB utilization.

1. INTRODUCTION

TRIGA 2000, a General Atomic-built nuclear research reactor located in Bandung, is one of research reactors owned and operated by Indonesian National Nuclear Energy Agency (BATAN). During its fifty-three years of operation, TRIGA 2000 has been uprated successfully twice. The first uprate was at 1971, increasing the power from 250 kW to 1000 kW. Second uprate was at year 2000, the power is increased from 1000 kW to 2000 kW. Another successful TRIGA 2000 project is control rod replacement in 2015. Control rod produced by General Atomic was replaced by indigenous control rod made by BATAN.

One of the main problems of TRIGA 2000 operation is that General Atomic has stopped producing cylindrical fuel for TRIGA reactors. This will have an impact on the continuation of TRIGA 2000 operation, since its fuel was imported from General Atomic. To maintain the TRIGA 2000 operation, BATAN is planning to replace the cylindrical fuel element with plate-type fuel element. The latter is chosen because BATAN have been successfully producing plate-type fuel element for research reactor. It was also successfully applied to RSG-GAS, another research reactor owned by BATAN.

Neutronic, thermal hydraulic, and safety analysis of Plate-Type Research Reactor Bandung (PTRRB) conceptual design have been reported.

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Previous studies by Basuki [1,2] have analyzed core configuration, safety, and fuel management. However, those studies are yet to calculate neutron flux distribution at central irradiation position (CIP) of the proposed new core. The purpose of this study is to calculate neutron flux distribution at CIP without and with Mo sample put into aluminum irradiation capsule (AIC), based on the conceptual design.

Data of neutron flux distribution at CIP is of great significance for designing irradiation facilities of PTRRB. Among its application is for producing radioisotope, as demonstrated in various reactors [3-7]. Examples of radioisotope produced in a research reactor are Mo-99/Tc-99m, Pm-149, Tb-161, and I-131 [8-12]. MCNP program is employed for the purpose of calculating neutron flux distribution. The result could be used as basic data for designing radioisotope irradiation facilities and radioisotope production.

2. METHODOLOGY

The first procedure to calculate neutron flux distribution at CIP of PTRRB is to determine PTRRB core model in MCNP. This is done to ensure that the CIP is absent from fuel element or any irradiation facility. Another reason is to obtain geometrical dimension of CIP.

The following procedure is to examine the geometry and dimension of AIC. This informations is needed since the material irradiated in the reactor core is usually put into the AIC. The geometrical and dimensional data are also required to design AIC configuration at the CIP. Since MCNP is used to perform the calculation, MCNP model of PTRRB is then designed. The model is made both before AIC installed and when material sample, in this case molybdenum (Mo), put into AIC at CIP [13,14].

Then, multiplication factor (k_{eff}) of the reactor core before installing AIC is calculated. MCNP calculate k_{eff} by comparing the ratio of neutron in successive generations [13,14]. K_{eff} data before installing AIC is an indication that reactor is at critical condition and will be the base to study the excess reactivity when installing AIC.

Lastly, calculation is performed for k_{eff} and neutron flux distribution with Mo sample is placed at various positions at CIP. The neutron flux is calculated using surface tally detector [13,14]. K_{eff} data after Mo sample is put into AIC will be treated as a base to study excess reactivity analysis of the reactor. Meanwhile, neutron flux distribution data of Mo sample at various position will be a basis to design material irradiation experiment at CIP.

3. RESULTS AND DISCUSSION

MCNP model of PTRRB core configuration at (x,y) axis is depicted at Fig. 1 [1,2]. In Fig. 1, reactor core modeled in a square grid, each grid labeled alphabetically A-2, A-3, A-4, etc. Code U3Si2 in several grids at Fig. 1 refers to U3Si2-Al nuclear fuel element. Grid A2, A3, A4, B1, B3, B5, C1, C2, C4, C5, D1, D3, D5, E2, E3, and E4 filled by fuel element. Grid B2, B4, C3, D2, and D4 filled by fuel element and control rod. Meanwhile, grid C3 is planned for CIP. Data of PTRRB listed at Table 1.

Fig. 2 is an MCNP model of PTRRB core configuration at (x,z) axis generated by TRIGA MCNP computer package and visualized by VISED [13]. TRIGA MCNP is a computer code dedicated for simulating PTRRB. TRIGA MCNP possesses a database of PTRRB, consisting of biological shielding, geometrical dimension, and material composition of the reactor core, as well as geometry, dimension, and material composition of neutron beam tube. Fig. 1 and 2 showed that grid C3 is vacant from fuel element and irradiation facility.

Fig. 2 show the z-axis position of C3. The bottom fuel element is at 5.0 cm while top fuel element is at 73.3 cm. Fig. 3 showed geometrical dimension at C3. The width of C3 is 7.74 cm and its length C3 is 8.12 cm.

Table 1. Data of PTRRB

Reactor thermal power	2 MWt
Active reactor core diameter	53.3 cm
Fuel	U_3Si_2Al
Enrichment	20%
Control element	Ag-In-Cd and U_3Si_2-Al
Number of fuel element	16
Number of control rod	4
Reflector	Graphite
Moderator	H_2O

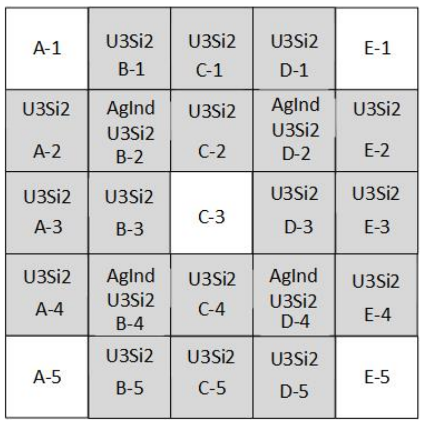


Fig. 1. PTRRB reactor core model [1,2]

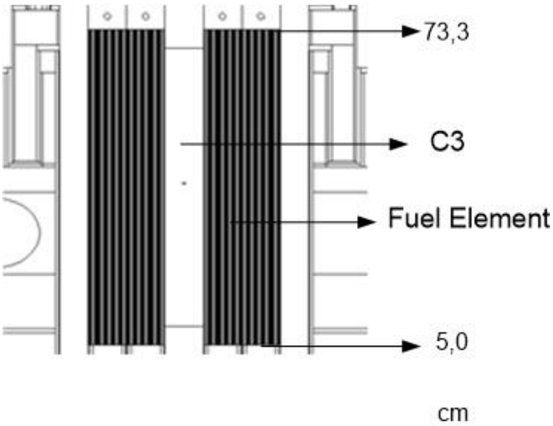


Fig. 2. PTRRB reactor core model at (x,z) axis

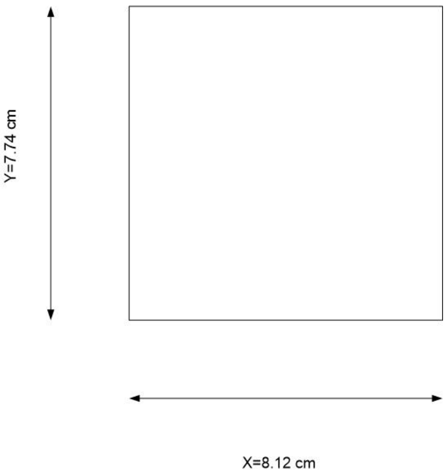


Fig. 3. Geometrical and dimensional of C3 at xy axis

Currently, material to be irradiated at TRIGA 2000 is placed into AIC as shown by Fig. 4 and 5. Fig. 4 is cross section of AIC at xz-axis and Fig. 5 is cross section of AIC at xy-axis. AIC is divided into two sides, bottom side and upside. Bottom side is where the sample is placed. Upside is intended as capsule seal. AIC is made from hollow aluminum filled by air, with diameter and thickness of 25 mm and 0.3 mm, respectively. Upside and bottom side height of AIC are 4 cm and 10.5 cm, respectively.

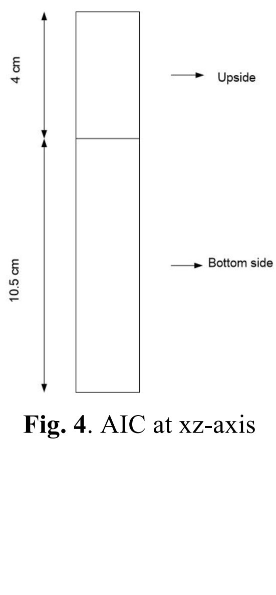


Fig. 4. AIC at xz-axis

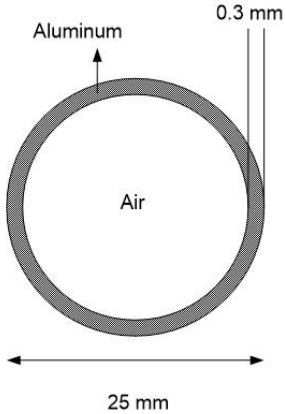


Fig. 5. AIC at xy-axis

Considering AIC material and dimension, it will be difficult to insert AIC one by one to the CIP. In this study, we propose that the AIC is contained within an aluminum tube (AT). Aluminum is chosen for tube material due to material similarity with AIC, easily fabricated, and low neutron-absorbing. It was designed is such a way so that not only AIC placement is made simpler but also coolant flow in the irradiation position is smoother.

Design of AT at xy-axis is shown by Fig. 6. Its diameter and thickness are 28 mm and 0.5 mm, respectively. There is 1 mm air gap between AIC and AT. Because fuel element height at C3 is 68.3 cm as illustrated in Fig. 2, there can only be four AIC at AT. The height of AT is 58.1 cm, as shown at Fig. 7.

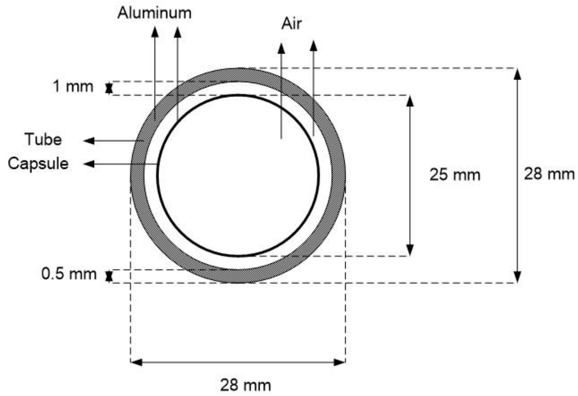


Fig. 6. Design of AT at xy axis

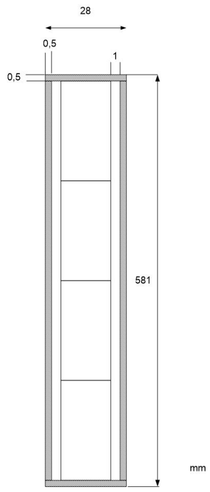
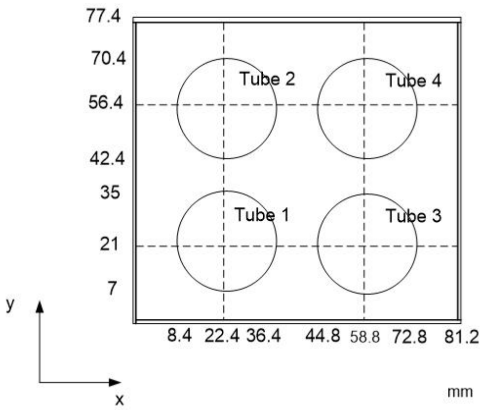
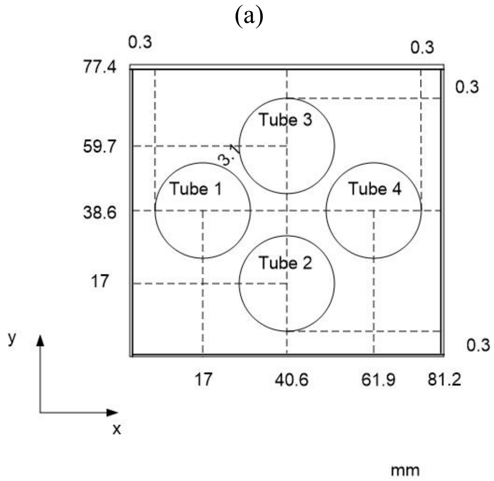


Fig. 7. Dimension of AT at xy-axis

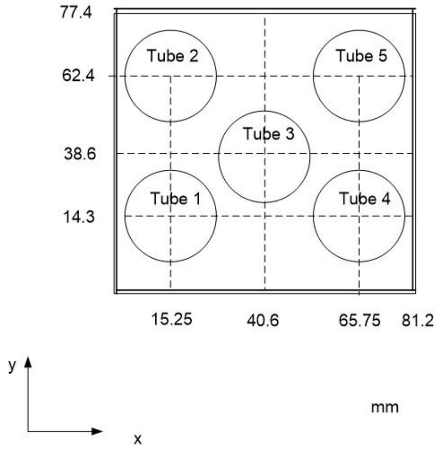
Based on the geometries and dimensions of C3 and AT as shown by Fig. 2, 6, and 7, there are three geometrical AT configuration possibilities, as shown in xy-axis at Fig 8.



(a)



(b)



(c)

Fig. 8. Possible configurations of AT; (a) Configuration 1, (b) Configuration 2, (c) Configuration 3

Another consideration is there are 10.3 cm of difference between AT height and fuel element height at C3. That condition caused bottom part of irradiated AT is shifted upward at 10.1 cm above the bottom as shown at Fig. 9. The other reason is that the neutron flux is higher in the center of the core. Z-axis position of each AT is the same for all three configurations. The differences are at xy-position of capsule, depending to configuration as illustrated at Fig. 8.

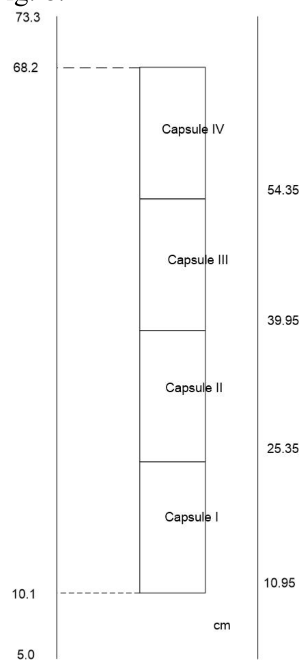


Fig. 9. AT position at z-axis

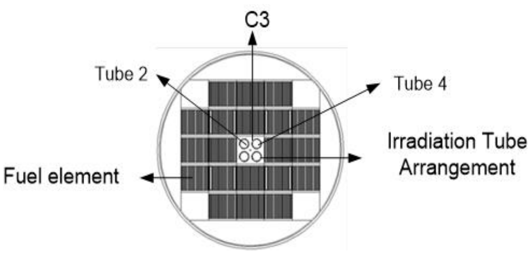
Mo sample is put into AIC in all configurations, and then full MCNP model of reactor core is created. Figure 10-12 visualize the MCNP reactor model of three AT configurations. Each configuration is numbered by 1, 2, and 3. Fig.

10-12 show cross section of MCNP reactor core model at xy-axis and xz-axis. If the core model as figured at Fig. 1 and 2 and MCNP reactor core model as figured at Fig. 10-12 are compared, the former has no AT configuration put into the design. In these studies, the core is simulated when Mo sample put into each configuration. The amount of Mo is 1.45 gr each and put in such a way as figured at Fig. 13. The AIC is stacked within AT as figured at Fig 14.

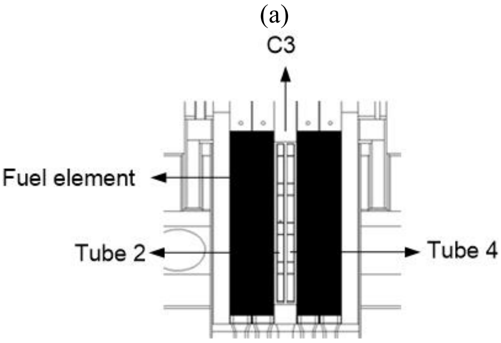
Calculation of neutron flux is performed at condition when fresh fuel loaded to reactor core and Ag-In-Cd neutron absorber is inserted 3 cm into the top fuel grid. The first calculation is to calculate k_{eff}. The k_{eff} value both before installing AT (configuration 0) and after installing AT (configuration 1, 2, and 3) are listed in Table 2. Based on those values, all four core configurations are in critical conditions.

Excess reactivity of four configurations are also listed in Table 2. Excess reactivity is calculated using Equation 1 shown below. The value of excess reactivity of four configurations is less than 10.9 %. The mentioned value is the excess reactivity limit for neutronic safety criteria of PTRRB basic design [15]. Configuration 1, 2, and 3 each has excess reactivity less than 10.9%. Thus, installation of AT at CIP satisfies the neutronic safety criteria.

$$Excess\ Reactivity = \frac{k_{eff-1}}{k_{eff}} x100\% \qquad (1)$$

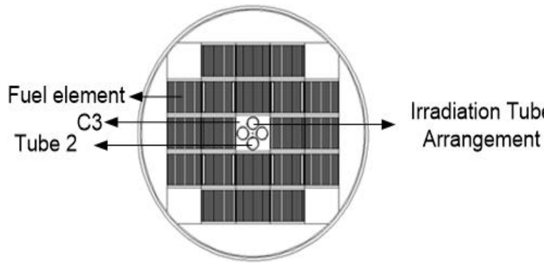


(a)

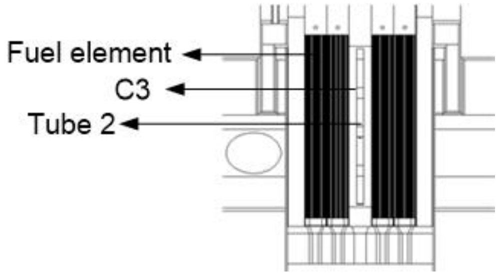


(b)

Fig. 10. Reactor core model configuration 1; (a) Cross section at xy axis, (b) Cross section at xz-axis

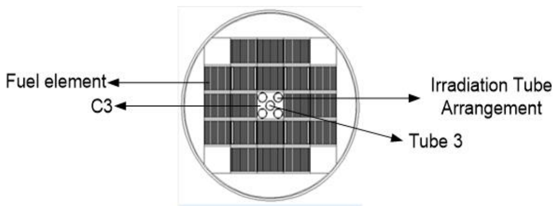


(a)

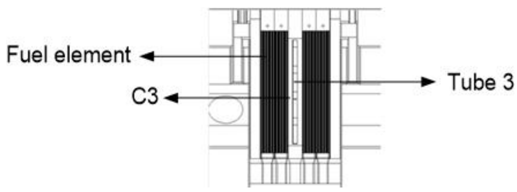


(b)

Fig. 11. Reactor core model configuration 2; (a) Cross section at xy-axis, (b) Cross section at xz-axis



(a)



(b)

Fig. 12. Reactor core model configuration 3 (Cross section at xy axis (a), Cross section at xz axis (b))

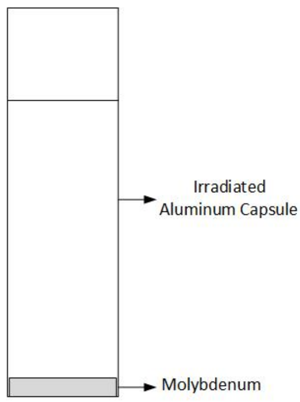


Fig. 13. Position of Mo sample

Table 2. Multiplication factor (k_{eff}) and Excess reactivity of configuration 0,1,2,3

	(k_{eff})	Excess reactivity (%)
Configuration 0	1.08618	7.93
Configuration 1	1.09833	8.95
Configuration 2	1.09858	8.97
Configuration 3	1.09946	9.04

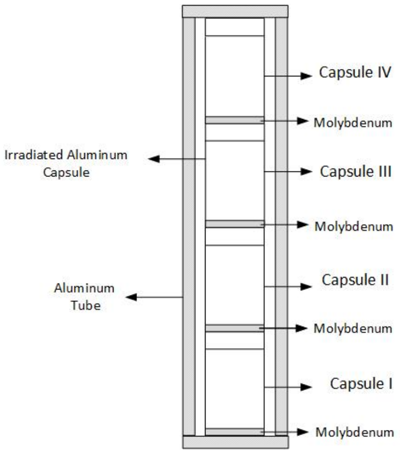


Fig. 14. Stacking irradiated aluminum capsule in aluminum tube

Thermal neutron flux at Mo sample at each AIC and each AT of three configurations are listed in Table 3. The flux at Mo sample with the same capsule number of the three configurations are similar. Highest thermal neutron flux at Mo sample are found at AIC number II and III, while the rest are lower. Highest thermal neutron flux of Mo sample recorded is 5.08 × 10^{13} n/cm^2.s at configuration 1.

Table 3. Thermal neutron flux of Mo sample

Configuration	Tube Number	Thermal Neutron Flux (n/cm^2.s) x 10^{13} Capsule Number I	II	III	IV
	1	2.8	4.31	4.95	4.01
1	2	2.85	4.35	5.03	4.07
	3	2.85	4.34	4.97	3.96
	4	2.88	4.39	5.08	4.02
	1	2.75	4.14	4.82	3.89
2	2	2.83	4.19	4.83	3.8
	3	2.84	4.26	4.90	3.94
	4	2.87	4.34	4.87	3.97
	1	2.45	3.57	4.10	3.32
	2	2.44	3.56	4.13	3.41
3	3	2.93	4.10	4.80	3.91
	4	2.53	3.60	4.10	3.30
	5	2.41	3.56	4.15	3.28

While the previous core design has no AT in the CIP design, it was used as a basis to study thermal hydraulics of PTRRB [16-18]. Installation of AT for irradiation at CIP will affect coolant flow. Further study should be performed to analyze the effect of AT installation to PTRRB coolant system.

4. CONCLUSION

Irradiation facilities at CIP of Plate Type Research Reactor Bandung have been designed. There are three possible designs of irradiation facilities. In this study, simulation is performed when 1.45 g of Mo is put into AIC. Analyses of excess reactivity after the Mo is put into AIC show that its value less than 10.9% for all configurations. Based on the value, installation of AT at CIP is accepted based on neutronic safety criteria. The highest thermal neutron flux are found at AIC no II and III. Meanwhile, highest thermal neutron flux at Mo sample is 5.08 × 10^{13} n/cm^2.s is found at configuration 1.

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