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CORE DESIGN OF TRIGA2000 BANDUNG USING U_3SI_2/AL FUEL ELEMENT MTR TYPE

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ABSTRACT

CORE DESIGN OF TRIGA2000 BANDUNG USING U_3SI_2/AL FUEL ELEMENT MTR TYPE. The TRIGA2000 Bandung reactor currently uses cylinders fuel type, but the fuel production has been discontinued. In order to operate continuously, it is planned that the TRIGA2000 reactor should change the fuel from cylinder type to U_3Si_2/Al MTR type since Indonesia has been able to produce such fuel element. In this research calculation of TRIGA2000 coreusing U_3Si_2/Al fuel MTR type of three different fuel densities has been done. This activity begins with performing neutron macroscopic cross section generation for all core materials as a function of temperature, burn up and xenon. The cross section generation was performed with the WIMSD5 code. The calculation of the core parameters were done with the Batan-FUEL code. Based on the calculation of neutronic parameters, there are three core configurations, i.e.core with 16 fuel elements and 4 control elements (Core 16/4), core with 14 fuel elements and 4 control elements (Core 14/4) and core with 12 fuel elements and 4 control elements (Core 12/4). The three cores meet the safety constraint but only the Core 16/4 that uses U3Si2/Al fuel with a density of 2.96 g/cm^3. The maximum thermal neutron flux in the core center is 5.874×10^{13} n/cm^{2}s with core cycle length is 245 days at 2 MW. The results show that the TRIGA2000 core can be converted from cylinder type fuel to silicide MTR type.

Keywords: cylinder fuel type, MTR type, Batan-FUEL, thermal neutron flux.

ABSTRAK

DESAIN TERAS REAKTOR TRIGA2000 BANDUNG MENGGUNAKAN TIPE ELEMEN BAKAR MTR U_3SI_2/AL. *Reaktor TRIGA2000 Bandung selama ini menggunakan bahan bakar jenis silinder tetapi bahan bakar tersebut tidak diproduksi lagi. Upaya yang dilakukan agar reaktor TRIGA2000 dapat beroperasi secara kontinu maka direncanakan pergantian bahan bakar jenis silinder ke U_3Si_2/Al jenis MTR karena Indonesia dapat memprodusi bahan bakar tersebut. Dalam penelitian ini telah dilakukan perhitungan desain teras reaktor TRIGA2000 menggunakan bahan bakar MTR jenis U_3Si_2/Al dengan tiga densitas bahan bakar yang berbeda. Kegiatan ini dimulai dengan melakukan generasi tampang lintang makroskopik neutron untuk semua bahan teras sebagai fungsi temperatur, fraksi bakar dan xenon. Generasi tampang lintang dilakukan dengan program WIMSD5. Perhitungan parameter teras reaktor dilakukan dengan program Batan-FUEL. Berdasarkan hasil perhitungan parameter neutronik ada tiga kemungkinan konfigurasi teras yaitu 16 elemen bakar dan 4 elemen kendali (Core 16/4), teras dengan 14 elemen bahan bakar dan 4 elemen kendali (Core 14/4) dan teras dengan 12 elemen bahan bakar dan 4 elemen kendali (Core 12/4). Ketiga konfigurasi teras ini memenuhi batasan keselamatan operasi tetapi hanya Core 16/4 yang dapat menggunakan bahan bakar U3Si2/Al dengan kepadatan 2,96 g/cm^3. Fluks neutron termal maksimum di pusat teras adalah 5,874 × 10^{13} n/cm^{2}s dan panjang siklus adalah 310 hari pada daya 2 MW. Hasil perhitungan menunjukkan bahwa teras TRIGA2000 dapat dikonversi dari bahan bakar jenis silinder menjadi bahan bakar silisida jenis MTR.*

Kata kunci*: bahan bakar jenis silinder, bahan bakar jenis MTR, Batan-FUEL, fluks neutron termal*

INTRODUCTION

Research reactors have been used for radioisotope production, education and research activities in the field of nuclear science and technology. Therefore, research reactors give great contribution to the development of industry, energy, health and environment, especially the application in radioisotopes[1–3]. Indonesia has three research reactors: RSG-GAS reactor at Serpong, TRIGA2000 reactor in Bandung and TRIGA Kartini reactor in Yogyakarta. The TRIGA2000 reactor in Bandung has operated since 1964 and the fuel has been supplied by General Atomic (GA). The GA as the standard fuel supplier of the TRIGA reactor has discontinued the production ofthe reactor fuel. Therefore, a replacement is planned for TRIGA fuels to use a plate type of silicide fuel which have the same dimensions as the RSG-GAS reactor fuel. RSG-GAS reactor fuel has been produced domestically by PT INUKI, so it is economically profitable.

Conversion of TRIGA-fueled cylinder loaded with high enriched uranium (HEU) based fuels to MTR fuels type, newly done, is to use low enriched uranium (LEU) based fuels to meet the rules set by the IAEA[4–6]. Basuki et al. has performed the initial calculation of TRIGA core using a plate type fuel with a configuration of 16 fuel and 4 control rod[7] and Anwar Ilmar Ramadhan has studied thermal-hydraulics aspects of the TRIGA research reactor using plate type fuel elements as replacement for cylinder fuel element[8].

The main objective in this research is to study the possibility of TRIGA core design using silicide plate type fuels with various densities. The results of the core design are expected to minimize the possibility of changing the current TRIGA system. For that reason, in the core design, the graphite material as reflector is used and the power of the reactor still remains 2 MW. With various types of configurations, it is expected that most optimal core configuration can be determined.

The core configuration to be determined is a reactor core which is in addition operated with fresh fuel as well as a core allowed to be operated with a equillibryum core. This paper only determines parameters of neutronic core with fresh fuel. The advantage of using fresh fuels is that it does not require a fuel management pattern in the core so the replacement of fuel is very easy. Some reactors with compact core use a fuel-loading pattern on the core with fresh fuels[6],[9].

The core calculations were performed using WIMSD5[10] and Batan-FUEL codes[11]. The later has been extensively validated using RSG-GAS reactor experimental data[12],[13] Design parameters such as exccess reactivity, shutdown margin, one stuck rod criteria and power peaking factor must meet the safety requirements of reactor operation. The core design is expected to produce high thermal neutron flux, more reliable and economical and has a high level of safety. Flux quantities are also used for absolute power determination, power distribution in the core, calculation of fuel fraction, power transients etc[14],[15].

METHODOLOGY

The diameter of TRIGA2000 core is 533.4 mm and if it is replaced with fuel/control element of 77.1 x 81 mm dimension (dimension of reactor RSG-GAS fuel/control element), then the core diameter is divided into 53 cm/8.1 cm, which is equal to 6 units. Since the cross-section of the core is a circle, the amount of fuel that can be placed into the core becomes 21 pieces with 5 x 5 lattice as shown in Figure 1. Based on the core configuration of Figure 1 then there are three possible configurations that are determined using the fresh fuel pattern and the equilibrium core. The first configuration is core configuration with 16 fuel elements and 4 control elements (Core

16/4) as shown in Figure 2(a) The Core 16/4 has 5 irradiation positions, where one position is in the centre (C-3) and the other 4 positions areat the edge of core (E-1, E-5, A1, A5 positions) but these positions are smaller because they are cut by the shape of the circle of the core. The second configuration is core configuration with 14 fuel and 4 control elements (Core 14/4) as shown in Figure 2(b). The Core 14/4 has 7 irradiation positions where 1 position is in the centre (C-3) and the other6 positions areat the edge (E-1, E-5, A1, A5, C-3 and C-5). The third configuration is core configuration with 12 fuels and 4 control elements (Core 12/4) as shown in Figure 2(c). The Core12/4 has 9 irradiation positions where 1 position is in the centre (C-3) and the other 8 positions are at the edge (E-1, E-5, E1, A5, C-3, C-5, E- 3 and E- 5).

Many design parameters can be variedly arranged to optimize the neutronic parameters. These include fuel density, number of fuel elements and control fuel elements, core cycle length, number of burn-ups and core configuration[16],[17]. Some design parameters are indeed dependent on each other such as number of burn-ups, cycle length and fuel density. Therefore, the main task in the procedure design is to determine the number of fuel elements, burn up classes as well as core configuration to maximize the core cycle length.

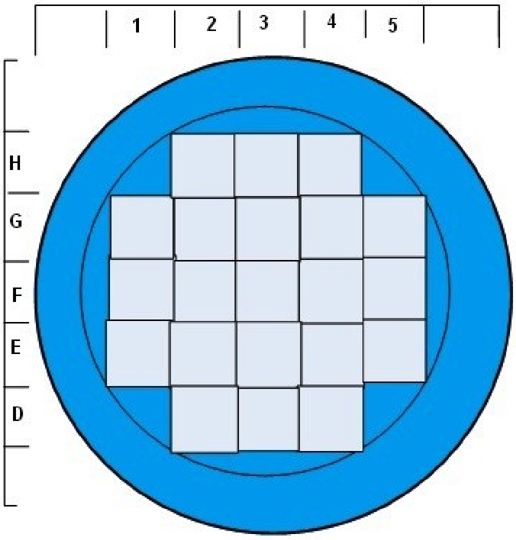
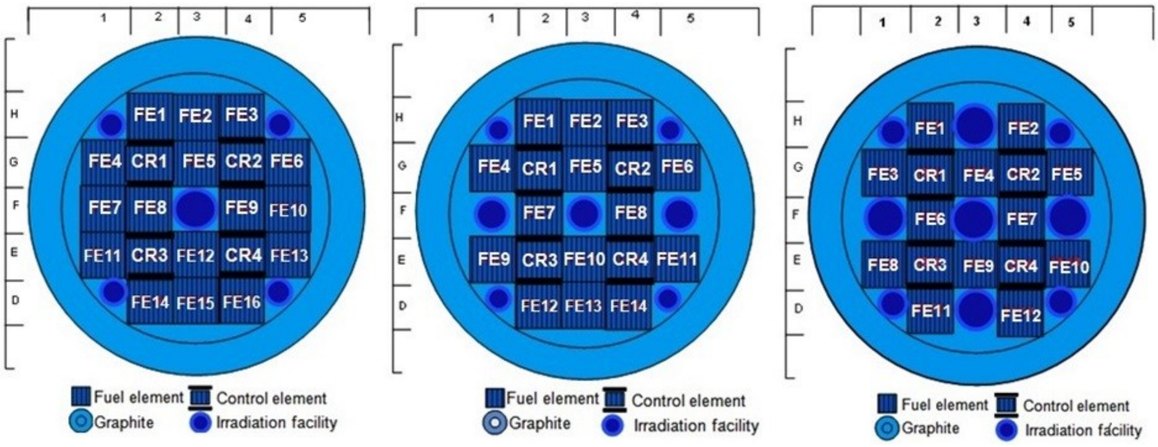


Figure1. Core configuration of TRIGA 2000



(a) (b) (c)

Figure 2. Core configuration with :
(a). 16 fuel elements and 4 control elements.
(b). 14 fuel elements and 4 control elements.
(c). 12 fuel elements and 4 control elements.

WIMS-D5 is a general reactor lattice cell calculation code, which has been used for nuclear computations in a wide range of reactor systems[10]. The 69 energy groups cross section were grouped to four energy groups diffusion constants with the upper and lower boundaries set. Four energy groups where the fast neutron region was $0.821<E\leq 10$ MeV, the slowing down region was $5.53<E\leq 0.821$ keV, the resonance region was $0.625<E\leq 5.53$ keV and the thermal region was $0.625<E\leq 0$ eV. The generated crosssection data is absorption cross-section, Σa, fission cross-section, $\nu\Sigma f$, scattering matrix, Σ_s, diffusion coefficient (D) and fission spectrum. Cross sections group of the standard fuel elements (Figure 3) are prepared by a 1-D model of a quarter of the fuel element (Figure 4) averaged by S_N method with multi plate option in the WIMS-D5 code, so that the 4-group effective cross section for one standard fuel element is obtained with this calculation.

Since the dimension of the active area (15 plates) in the control fuel element (Figure 5) is similar with the standard one, so the cross sections of the standard fuel element can be used for this area.

Figure 6 shows how to generate a few group cross sections for the Ag-In-Cd absorbers and this model is also applied for the other core materials. After the cross-section data is obtained, core calculations are performed using Batan-FUEL code.

The basic requirements which must be fulfilled in the nuclear design are standard fuel and control elements, domestically supplied by INUKI and nominal thermal power of 2 MW. From neutronic parameters aspect, the constrains are that thereactor must be subcriticality for one stuck rod condition and radial power peaking factor when all control rod inserted must be less than 1.4. The reactor core must be designed with sufficient excess reactivity so that reactor can be operated for limited period of time due to the availability of shutdown reactivity in the core.

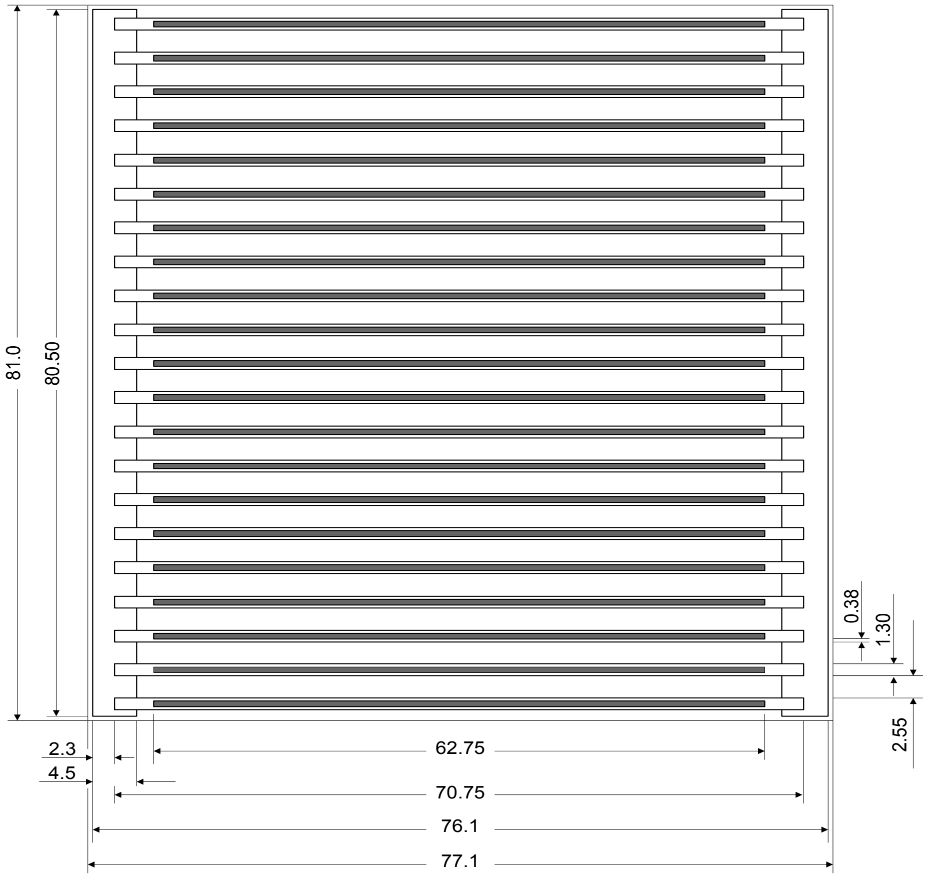


Figure 3. Standard fuel element of RSG-GAS reactor [11]

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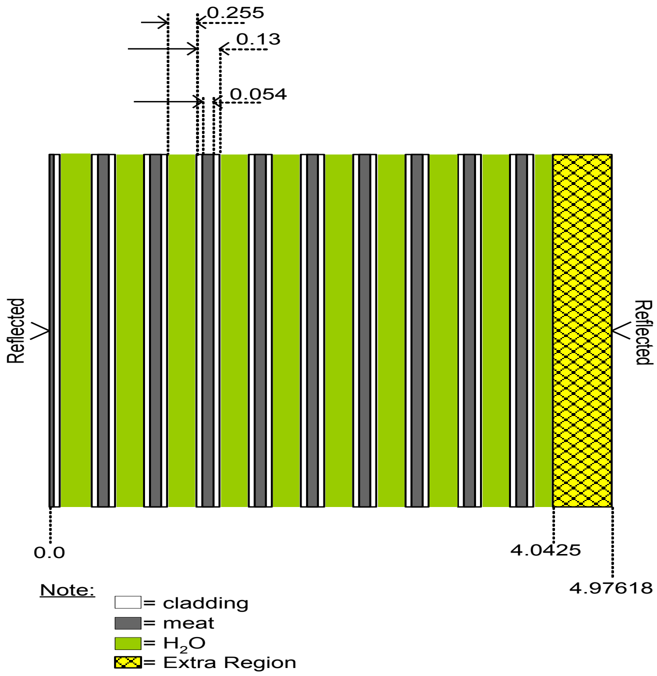

Figure 4. Fuel element cell model

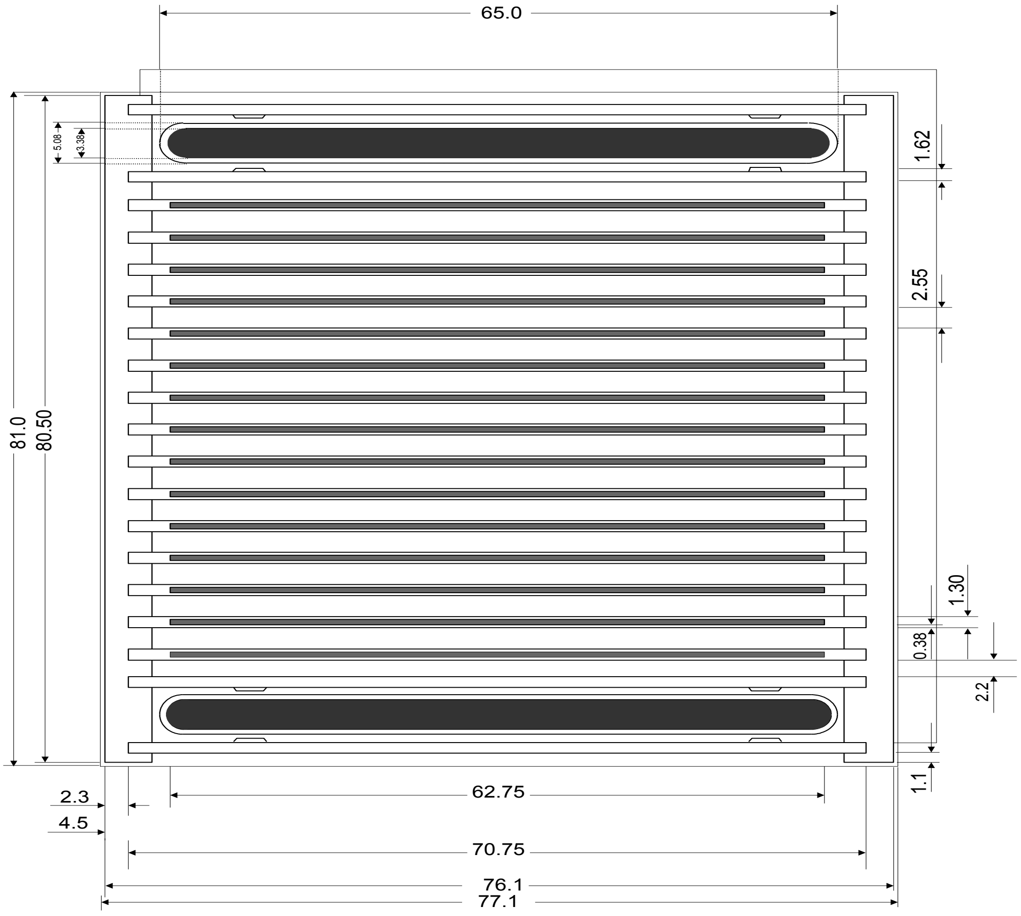

Figure 5. Control rod fuel element [11]

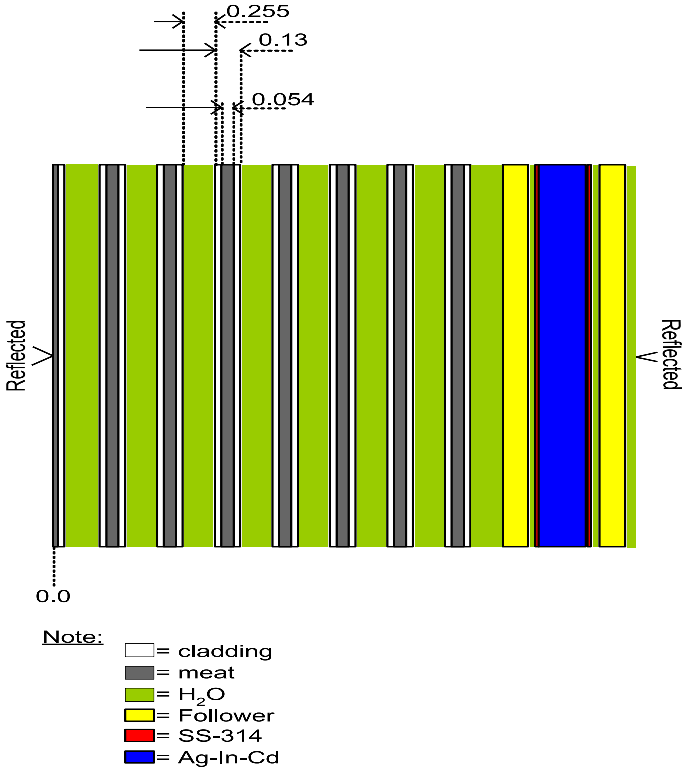

Figure 6. Ag-In-Cd absorber cell model

RESULT AND DISCUSSION

The results of neutronic parameter calculations for the three core configurations are shown in Table 1. Based on the calculation of Core 16/4, the neutronic parameters can be used for silicide fuel with meat density of 2.96 g/cm^3. Meanwhile, Core 14/4 and Core 12/4 must use fuel element with density of 3.55 g/cm^3 and 4.80 g/cm^3, respectively. Based on Table 1, the different parameter of the three configurations is the cycle length. Core 12/4 has a cycle length of 420 days because the meat density of fuel is4.80 g/cm^3. Burn up at the end of cycle for all three core configurations is similar and relatively small compared to the 56% burn up of the RSG-GAS reactor.

Table 1. Core parameters of the TRIGA2000 reactor using MTR fuel type

Core parameters	Core 16/4	Core 14/4	Core 12/4
Massa ^{235}U per standard fuel element (g)	250	300	400
Uranium density (g/cm^3)	2.96	3.550	4.800
Power (MWth) / cycle length (days)	2/245	2/270	2/420
Reactivity for one cycle (%Δ*k*/*k*)	4.5429	4.580	5.672
Reactivity xenon equilibrium (%Δ*k*/*k*)	6.8274	2.150	1.879
Reactivity cold to hot (%Δ*k*/*k*)	0.5012	0.471	0.437
Excess reactivity (%Δ*k*/*k*)	8.4046	8.204	9.135
Total control rod values (%Δ*k*/*k*)	-19.5737	-20.01	-18.42
Shutdown reactivity (stuck rod) (%Δ*k*/*k*)	-4.1719	-4.595	-2.850
Power density (W/cc)	28.305	31.663	34.882
Average radial power peaking factor	1.2971	1.338	1.256
Maximum discharged burn-up (%)	16.401	17.383	22.819

The maximum thermal neutron flux in the irradiation facility is shown in Table 2. Based on Table 2, Core 12/4 has a smallest thermal neutron flux compared to Core 16/4 and Core 14/4, due to the fuel density used in Core 12/4 is 4.8 g/cm^3 which reduce thermal neutron flux and increase the cycle length. The maximum thermal neutron flux is in CIP with a value of 5.923 × 10^{13} n/cm^{2}s. Thermal neutron flux is 1% larger than TRIGA2000 core, but interestingly there are some irradiation position facilities in the core with large thermal neutron flux.

The average radial power peaking factor distribution for Core 16/4, Core 14/4 and Core 12/4 configurations are shown in Figure 7, 8, 9 respectively. The highest radial power peaking factor of 1.283 (F-4)is for Core 16/4, 1.338 (F-4) is for Core 14/4, 1.256 (F-4) is for Core 12/2.All resultsare significant and power peaking factor is lower than the maximum limit value of 1.4 derived from the thermal hydraulic constraints. The results show that the power distribution is relatively flat since the power peaking factor is in the range of 0.8399 –1.3385.

Table 2. Neutron flux at the irradiation position and reflector

Neutron energy	**Maximum thermal neutron flux, E+13 n/cm^{2}s**		
	Core 16/4	Core 14/4	Core 12/4
Neutron flux at core centre region			
Fast neutron flux, > 0.821 MeV	1.191	1.252	1.480
Epithermal neutron flux, 0.625 eV<*E*<0.821 MeV	1.381	1.429	1.486
Thermal neutron flux, <0.625 eV	5.874	5.923	4.992
Flux at irradiation position at edge core position			
Fast neutron flux, > 0.821 MeV	0.498	0.499	0.537
Epithermal neutron flux, 0.625 eV<*E*<0.821 MeV	0.703	0.626	0.644
Thermal neutron flux, <0.625 eV	2.311	2.23	2.135
Flux at the reflector region			
Fast neutron flux, >0.821 MeV	0.385	0.376	0.372
Epithermal neutron flux, 0.625 eV<*E*<0.821 MeV	0.634	0.551	0..393
Thermal neutron flux, <0.625 eV	1.456	1.437	1.318

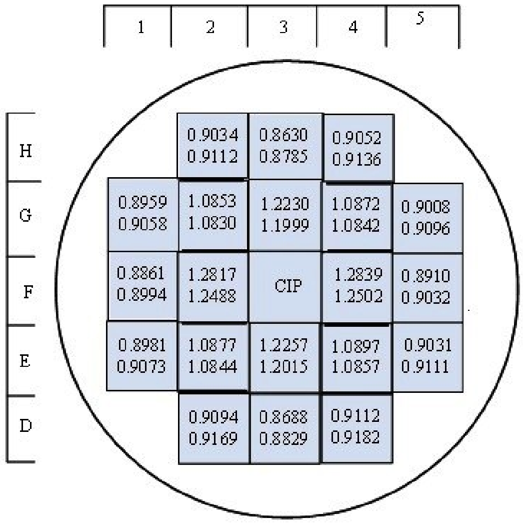

Figure 7. Radial power peaking factor distribution of the Core 16/4 at BOC/EOC.

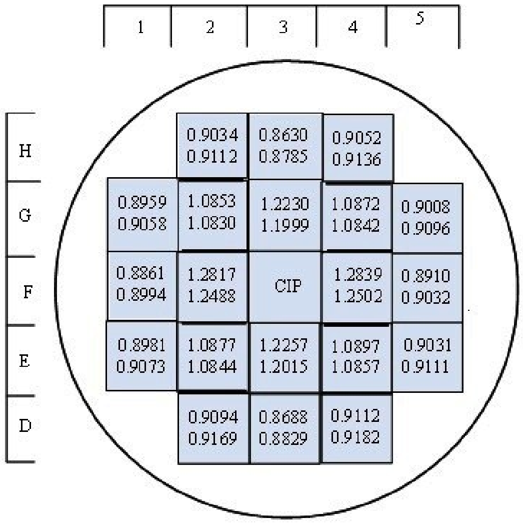

Figure 8. Radial power peaking factor distribution of the Core 14/4 at BOC/EOC.

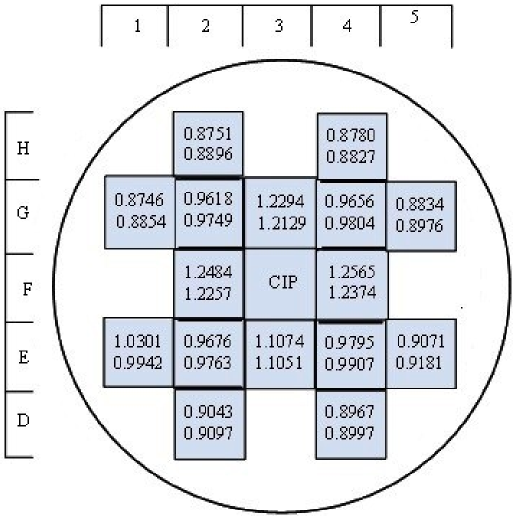

Figure 9. Radial power peaking factor distribution of the Core 12/4 at BOC/EOC.

The determination of the flux distribution in the core is very important for thereactordesign and safety analysis. The thermal neutron flux distribution for Core 16/4 is shown in Figure 10. Maximum thermal neutron flux occurs in the center of the core because neutron moderation.

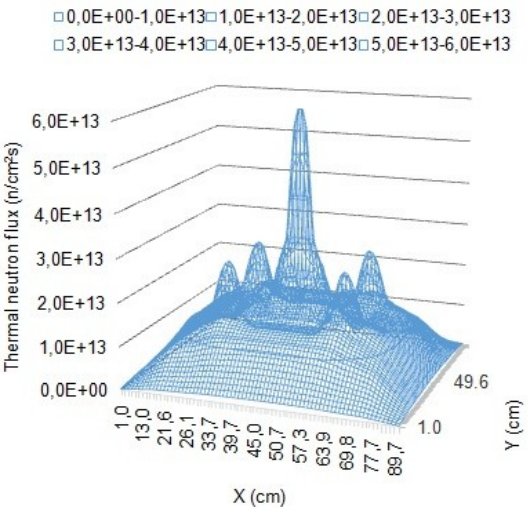

Figure 10. Distribution of thermal neutron flux at Core 14-4.

Fig. 11 shows the thermal neutron flux distribution of Core 14/4. There are 6 irradiation positions at the edge of the core. Other irradiation facilities are present in positions C-1 and C-5 as shown in Fig. 2(b). The average thermal neutron flux values in both positions is 3.992×10^{13} n/cm^{2}s.

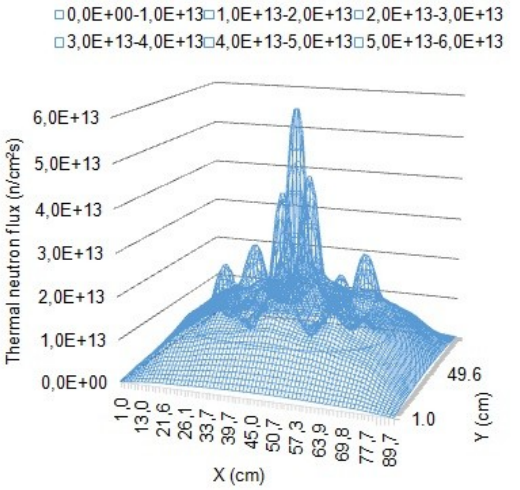

Figure 11. Distribution of thermal neutron flux at Core 14/4.

Figure 12 shows the distribution of thermal neutron flux of Core 12/4, where there are 8 irradiation positions at the edge of the core. In addition to irradiation facilities at the core center, there are four irradiated positions at the core of C-1, C-5, A-3 and E-3 as show in Figure 2(c). The average thermal neutron flux value in the four positions is 3.283×10^{13} n/cm^{2}s. The value of thermal neutron flux decreases with the increase in fuel density.

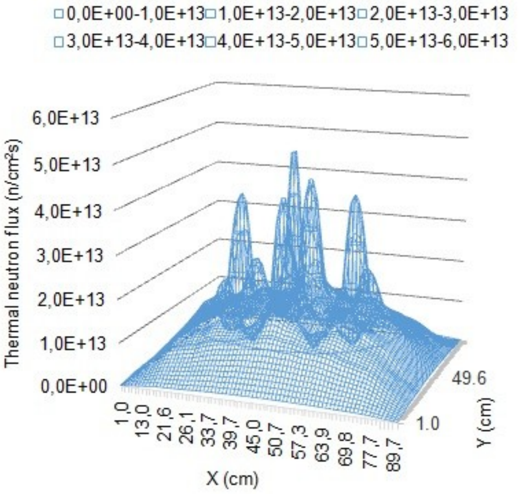

Figure 12. Distribution of thermal neutron flux at Core 12/4.

CONCLUSION

Based on the calculation of neutronic parameters, the TRIGA2000 reactor can be converted to plate type fuel.

Neutronic parameter calculations, such as criticality, excess reactivity, and neutron flux,have been performed. Based on the safety criteria, Core 16/4, Core 14/4, Core 12/4 can be used as core conversion but with different fuel density. Three configuration cores will selected as core conversion then performed optimized so that the core is more economical and remains within the safety limit.

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