Determination Of First Criticality In TRIGA 2000 Reactor Modified Using Plate Type Fuel With MCNP6

I S Hardiyanti¹, Riyatun¹, Suharyana¹ and A Khakim²
¹Physics Department, Faculty Mathematics and Natural Science, Sebelas Maret University, Jl. Ir. Sutami 36A Kentingan, Jebres, Surakarta 57126, Indonesia
²P2STPIBN, Nuclear Energy Regulatory Agency (BAPETEN), Jl. Gajah Mada No.8 Jakarta 10120 Indonesia

E-mail: iza@student.uns.ac.id

Abstract. This research offers a fuel conversion from cylinder type to plate type for solving the operation problems as a solution when the TRIGA reactor fuel production run out. The research has been implemented utilizing MCNP6 software to model and simulate the core of the TRIGA 2000 reactor plate type fuel. The geometry of the simulated reactor consists of a reflector, a moderator and a reactor tank. The fuel was U₃Si₂Al with 19.75% enrichment and the density was 2.96 gU/cm³, the reflector was graphite and the control rod was AgInCd. The first criticality value with 15 fuel assemblies and the 4 control rods position at 11.97cm from the top surface of the reactor core was (1.00000 ± 0.00016) in agreement with the reference value for initial configuration of TRIGA reactor core was (1.00 ± 0.01).

1. Introduction
Reactors TRIGA (Training, Research, Isotope Production by General Atomic) are still used today by several countries to support their nuclear science and technology research. Indonesia has two TRIGA reactors, namely the TRIGA 2000 Bandung and the Kartini TRIGA MARK II. Their power are 2 MW and 250 kW, respectively. The numbers of the TRIGA reactors around the world at 2015 are 69 reactors, there are 38 reactors are operated whereas the rest, 31 reactors, are not operated or under decommissioning conditions [1]. General Atomic as the producer TRIGA reactors, plans not to supply UZrH fuel with cylindrical cladding [2]. This is not good for the sustainability of TRIGA operations in Indonesia. In other words, the TRIGA reactor fuel element should be replaced with another type.

Another reactor operated by BATAN is the RSG-GAS (Reaktor Serba Guna- GA Siwabessy). This reactor equiped plate type fuel produced by PT. INUKI for 25 years without problems. The plate type fuel element is U₃Si₂Al with an enrichment of 19.75%. On this basis, it was proposed to replace the cylinder type TRIGA 2000 into the plate type fuel. The use of domestic-made fuels if applied can increase independence in Indonesia's nuclear science [3].

Regarding the level of save and safety of the reactor, before the reactor is built all the components related to the reactor must be carefully tested. The testing or modelling carried out included neutronic, thermal-hydraulics and mechanical aspects.

Neutronic calculations can be performed using two methods, namely deterministic and statistical method. Monte Carlo is an example of the statistical method. The process simulated in Monte Carlo is...
a trace of neutron particles beginning when neutrons are born until they disappear. The simulation is done by selecting neutrons randomly by taking into account every possible interaction with the material [4].

The reactor is always designed with a certain safety criteria. It is intended that the safety of the reactor is guaranteed, so that the reactor can be operated according to its benefits and the impact or risk posed as small as possible. One of the safety parameters of reactor design that can be studied from the neutronic aspect is the first criticality. In this work, we report our study on the first criticality in the TRIGA 2000 reactor using plate type fuel with MCNP6 software.

2. Experimental
The parameters used to model the TRIGA 2000 core are presented in Table 1. The reactor core model is based on the TRIGA 2000 reactor core geometry. The modeled TRIGA 2000 reactor geometry is the core, graphite reflector, light water moderator and reactor tank. The core geometry and fuel input arrangement are shown in Figure 1 and 2, respectively.

| Parameter                                    | Value                      |
|----------------------------------------------|----------------------------|
| Fuel element dimension and control element   | 77.1 x 81 x 600 mm         |
| Thickness of the fuel plate                  | 1.3 mm                     |
| Width of the cooling channel                 | 2.55 mm                    |
| Total of U₃Si₂Al plate per fuel assemblies   | 21                         |
| Total of U₃Si₂Al plate per control assemblies| 15                         |
| Thickness of the fuel cladding               | 0.38 mm                    |
| Fuel material                                | U₃Si₂Al                    |
| Density                                      | 2.96 gU/cm³                |
| Neutron absorber                             | AgInCd                     |
| Material absorbent cladding                  | SS-321                     |
| Thickness absorbent cladding                 | 0.85 mm                    |

Figure 1. The side view of TRIGA 2000 reactor
In this research, the number of simulated neutrons for each cycle is 100,000 with an initial criticality value is 1. The number of cycles passed is 50 (assuming that the 51th iteration has been convergent and deserves to be simulated statistically in subsequent iterations) while the number of iterations is 200. The position of the initial neutron source to trigger a chain reaction on each fuel assembly is 21 pieces while for each control rod assembly is 15 pieces.

3. Results and Discussion

Previously, we published our research with the maximum number of assemblies namely 20 fuel assemblies. The resulting value of the $k_{\text{eff}}$ was $(1.07100 \pm 0.00017)$ [6]. The value is considerable higher than of the reference criticality. Accordingly, we carried out on the amount of fuel 14 and 15 assemblies in order to reduce the $k_{\text{eff}}$ values. The results are written in Table 2.

| Number of assemblies | $k_{\text{eff}}$ | Standard deviation |
|----------------------|------------------|--------------------|
| 14                   | 0.99022          | 0.00017            |
| 15                   | 1.01377          | 0.00016            |

From these results it can be seen that the critical core configuration can be achieved with a minimum amount of 15 assemblies. However, the criticality value produced is still quite high so the next step is to change the position of the compensation control rods which were originally fully up to partially down. The reactor core geometry for the determination of the first criticality with 15 fuels is displayed in the visual editor MCNP6 as shown in Figure 3, while the results of criticality testing with changes in the position of the control rod are shown in Table 3.
The simulation results show that with 15 fuels and the condition of the compensation control rod fully down at 11.97 cm from the top surface of the core, the first criticality is $(1.00000 \pm 0.00016)$. That means, chain fission reactions on the core can be maintained. Also it does mean the reactor are in a safe condition from the point view of neutronic [7, 8, 9, 10].

4. Conclusion
The first critical value in the TRIGA 2000 reactor type plate was obtained with 15 fuel assemblies with the compensation control rod position at 11.97 cm from the top core surface. The calculation value $k_{\text{eff}}$ is $(1.00000 \pm 0.00016)$ so that the calculation results have met the required standards. In subsequent studies the design of the reactor model will be added to be supported, thermalizing column and thermal column to get a more accurate criticality value.

References
[1] IAEA 2015 Safety Standard Series No.SSR 3-5: Safety of Research Reactor (Vienna, Austria: International Atomic Energy Agency).
[2] Hampel G 2010 The Importance of TRIGA Reactors Behalf of the European TRIGA community Johannes Gutenberg : Universitat Mainz D-55099
[3] Setiyanto and Surbakti T 2016 Conference Proceedings PTKRN Batan 3
[4] MCNP Team 2010 MCNP - A General Monte Carlo N- Particle Transport Code Version 5 (United States: University of California, Los Alamos National Laboratory)
[5] Purwadi 2017 Conference Proceedings PRSG BATAN 21 87
[6] Hardiyanti I S, Riyatun, Suharyana and Khakim A 2019 J. Phys. Conf. Ser. 1153 012104
[7] Salam M A, Soner M A M, Sarder M A, Haque A, Uddin M M, Sarker M M and Islam S M A 2014 Ann. Nucl. Energy 68 257
[8] Wu Z, Williams R E, Rowe M, Newton T H and O’Kelly 2017 Nucl Technol 199 67.
[9] Manowogbor V C, Odoi H C and Abrefah R G 2018 Research & Reviews: Journal of Pure and Applied Physics 6 7

[10] Ravnik M, Zagar T and Persic A 1999 Nucl Technol 128 35