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Criticality analysis of Kartini Reactor connected to test facility of subcritical assembly Molybdenum-99 production (SAMOP)

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Abstract. Criticality Analysis of the Kartini Reactor as an external neutron source for the test facility of the Subcritical Assembly Molybdenum-99 Production (SAMOP) connected via its radial beamport is presented using The Monte Carlo N-Particle Six Version (MCNP6) software. The reactor was simulated at 100 kW operating power and the fuel of the SAMOP was a solution of uranyl nitrate with a concentration of 300 gU/L. The criticality values obtained from this research was 1.00749 ± 0.00045 and 0.99 ± 0.00041 for the Kartini and SAMOP respectively. When the both reactors were connected, criticality value was 1.01536 ± 0.00009 . It could be concluded that the Kartini reactor remains critical although it was used as the neutron source for the SAMOP facility.

1. Introduction

The Kartini reactor is a TRIGA-MARK II reactor currently designed for education and training, for nuclear analysis techniques, and as a medium of Nuclear Training Center (NTC) [1]. The reactor has various experimental facilities for neutron activation analysts (AANs) commonly called irradiation facilities and for the development plan of *Prompt Gamma Neutron Activation Neutron* (PGNAA). The PGNAA experimental facility uses a neutron source derived from the available beamport.

One of the PGNAA plan is of the Subcritical Assembly Molybdenum-99 Production (SAMOP) test facility [2]. Nuclide Mo-99 decays into technetium-99 metastable (^{99m}Tc) by emitting 140 keV gamma rays with short half-life of 6 hours [3]. The ^{99m}Tc radiopharmaca mainly is used for internal disease diagnostics, about 85% of nuclear medicine clinics around the world use it. Accordingly, the SAMOP facility will be useful to advance the nation of Indonesia in developing of the nuclear technology. SAMOP is one type of Aqueous Homogenous Reactor system but with subcritical design in order to work safety [4].

The criticality of a reactor is expressed by the amount of *keff* that is the ratio of the number of neutrons in one generation to the number of neutrons in the previous generation. The reactor is in a critical condition when possesses the value of *keff* = 1, in other words the number of neutrons in each generation is constant [5]. In the previous research, it was reported that the *keff* value of the Kartini reactor was 1.00749 ± 0.00045 [6]. Other author reported that the critical value of the SAMOP facility fueled with concentration of 300 gU / L uranyl nitrate solution in another study was 0.99 ± 0.00041 [7]. But the *keff*



value of the SAMOP depends on the concentration of uranyl nitrate. It has been reported when the concentration was 108 gU/L, the value of k_{eff} was 1.0517 [8]. All researchs mentioned previously use Monte Carlo method by means of MCNP code [6,7,8].

Design of the SAMOP is subcritical, in order to be operated for a long time, an outside a neutron source is needed. One possibility of the neutron source is the Kartini reactor. In this study, the safety aspect of the Kartini reactor as the a neutron source for the SAMOP was reported.

2. Numerical Methods

The top view scheme of the Kartini reactor core is presented in Figure 1. It can be seen there are 4 neutron beamports namely the tangential, 2 radials, and radial piercing. The Kartini reactor core model can be seen in Figure 2 [9]. The core model has been validated by Octa et al [6]. The SAMOP facility reactor will be connected to the radial beamport.

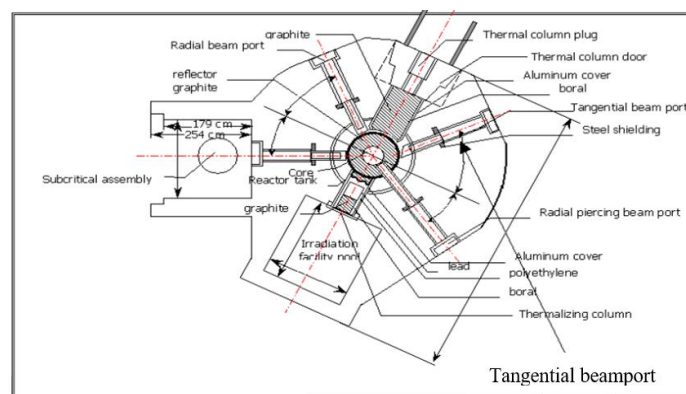


Figure 1. Top view scheme of Kartini Reactor

In this study, k_{eff} value calculation is done using MCNP6 software, input is written with Notepad ++, the geometry is displayed by Visual Editor. The first stage is Kartini reactor input published by Budi Rohman modeled [9].

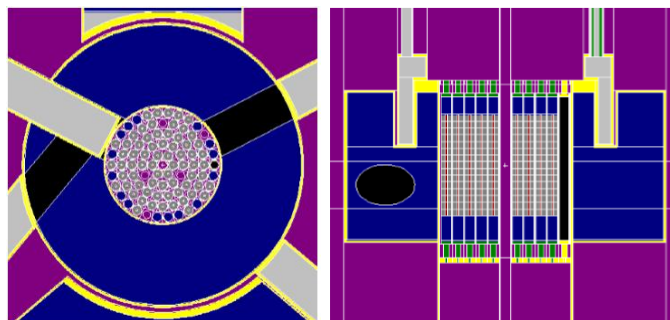


Figure 2. Representation of Kartini Reactor Core in MCNP, top (left) side (right) view [9].

The Kartini reactor is simulated at 100 kW operating power using fresh fuel assumption. And then the Kartini reactor input was modified by adding a cell card. The addition of a cell card is performed on one of the radial beamport of the Kartini reactor to connect to the SAMOP facility. The addition will form into the geometry of the samop facility. Before it has to add material on the cell card using the material card.

In the MCNP, the definition of a chemical element is called Zaid i.e. the identity (id) element represented by the atomic number (Z) and the mass number (A). Since a material can be composed of more than one element, Zaid is written with the atomic fraction. Zaid The nuclide identification number with the form ZZZAAA.abx where ZZZ is the atomic number, AAA is the mass number (000 for naturally occurring elements), ab is the unique alphanumeric table identifier, x=C for continuous-energy neutron tables, x=D for discrete-reaction tables. Since in simulation used Neutron continuous-energy reactions, so code

used in writing material card $ab = 60$, $x = c$. The example is 92235.60c [10]. Here's the geometry scheme of samop facility:

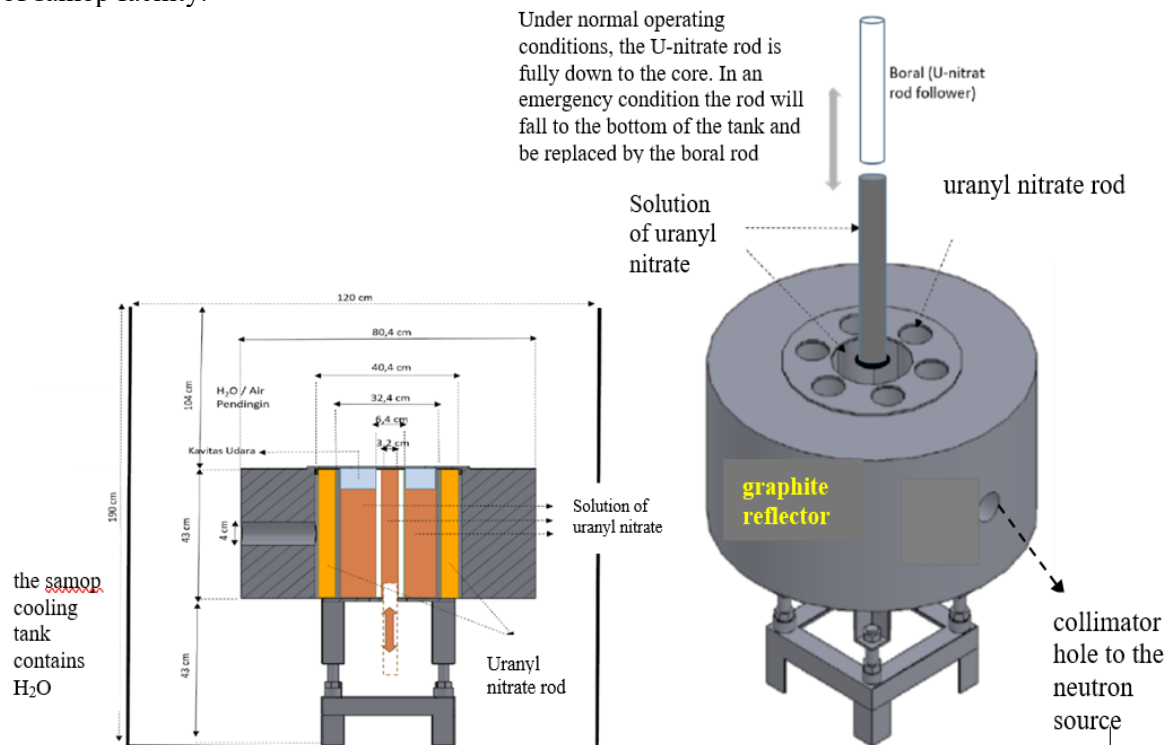


Figure 3. The core design scheme of the SAMOP facility

SAMOP facility uses fuel in the form of a 19.75% enriched uranyl nitrate solution and a 300gU / L uranium concentration. In this study used KCODE card to calculate the criticality or k_{eff} on Kartini reactor connected with SAMOP facility. In this KCODE card, the number of neutrons simulated for each cycle is 400000 with the initial critical criterion being 1.0. The number of cycles skipped 50 while the number of calculated iterations is 250 so the total number of iterations is 300. In addition to the above code, a position is required for the initial neutron source to trigger a chain reaction. The position is defined in the following KSRC code. KSRC using the coordinates of the neutron source and is defined on the core of each Kartini reactor and SAMOP. After that in running the program to get the results. Time to running program is 25 hours.

3. Results and Discussion

The k_{eff} value represents the criticality condition of a reactor. From the results studied, the value of k_{eff} on only the Kartini reactor is 1.00749 ± 0.00045 [6]. From these results the condition on the Kartini reactor when not used as a neutron source is critical. And when used as a neutron source for SAMOP test facility we get k_{eff} result from simulation of 1.01536 ± 0.00009 . So from the results of the reactor is still critical although used as a source of neutrons. Both of these results have a difference of 0.00787. This is due to the addition of the samop test facility, which also contains uranyl nitrate fuel where the chain fission reaction occurs. So the results of the fission reaction produce more neutrons because in the simulation results obtained the average value of the number of neutrons produced per fission of 2.434. Then the k_{eff} value also increases with the addition of SAMOP. While only for SAMOP has been simulated in previous research, the value of k_{eff} is 0.99 ± 0.00041 [7]. The results say the condition of SAMOP is subcritical because the facility is indeed subcritically designed to achieve work safety.

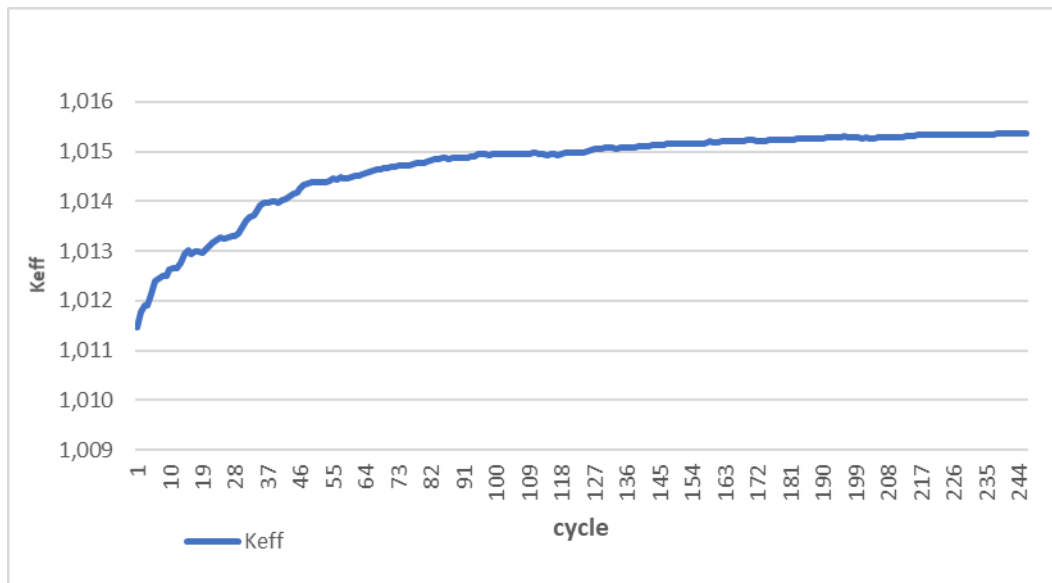


Figure 4. Reaktor criticality during operation

The calculated $keff$ is presented on Figure 4. It can be seen starting from cycle 53 to end, $keff$ value is stable. there is no $keff$ value sharp increase. Because inside the kcode card, the $keff$ value starts to be calculated on cycle 51. So the previous cycle will be skipped.

The following figure shows the geometry of the results of the Kartini reactor connected with the samop:

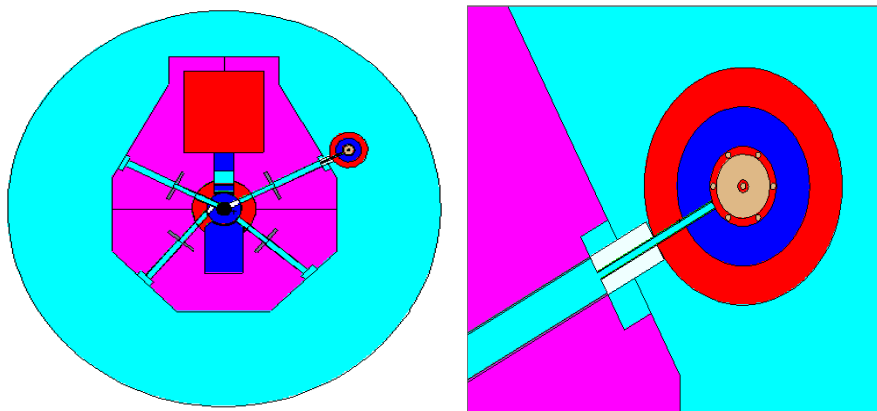


Figure 5. Geometry of the Kartini reactor connected to SAMOP in MCNP

4. Conclusion

In this study, it shows the difference in $keff$ values when only the Kartini reactor and when the Kartini reactor is connected to the samop reactor. There is an increase of 0.78% when it is connected with samop but the value is still critical. So in conclusion the Kartini reactor is still a critical condition although some of its neutron products are taken for the samop facility.

5. References

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