Neutronic Analysis of UN-PuN Fuel use FI-ITB-CHI Code for 500MWth GFR Long Life Without Refueling

Ratna Dewi Syarifah¹,², Zaki Su'ud, Khairul Basar and Dwi Irwanto

¹Nuclear Physics and Biophysics Research Division, Physics Department, Faculty of Mathematics and Natural Science, Bandung Institute of Technology Indonesia, Jalan Ganesha 10 Bandung 40132, INDONESIA
²Sekolah Tinggi Teknologi Nuklir, Badan Tenaga Nuklir Nasional (National Nuclear Energy Agency), Jalan Babarsari, Caturtunggal, Kec. Depok, Kabupaten Sleman, Daerah Istimewa Yogyakarta 55281, INDONESIA

E-mail: syarifah.physics@gmail.com

Abstract. Neutronic analysis of UN-PuN fuel use FI-ITB-CHI code for 500MWth GFR long-life without refuelling has been done. The reactor use fast neutron spectrum, helium coolant and stainless steel for the cladding. The FI-ITB-CHI is code to calculate the neutronic analysis both fuel pin and core calculation. The parametric survey of various Plutonium percentages with homogeneous core configuration and variation of fuel volume fraction has been done. The variation is from 8% percentage of Pu up to 15% percentage of Pu. The 11% percentage of Plutonium has k-eff value more stable than the others, or we can say that it has critical condition. And the variation of fuel volume fraction is from 40% up to 60%. When the fuel volume fraction is increase, the reactor can be operated longer than small fuel volume fraction. The 60% of fuel volume fraction has optimum value in this case. For heterogeneous core configuration, there is three type of fuel, i.e. fuel 1 (F1), fuel 2 (F2) and fuel 3 (F3). The percentage plutonium of F3 is varied from 13%, 13.5% and 14%. The optimum value for heterogeneous core configuration is use case 1 which is use 8% percentage of plutonium for F1, 10% for F2 and 14% for F3. The reactor can be operated almost 25 years without refueling.

1. Introduction
Gas Cooled Fast Reactor is one of Generation-IV reactor used high temperature helium coolant and fast neutron spectrum. The fast spectrum affords more sustainable use of uranium resources and waste minimization. GFR can operate with an outlet temperature up to 850°C. In this temperature, it is possible to use as hydrogen production [1].

Neutronic analysis can be calculated with some of neutronic calculation code such as SRAC, SCALE, MCNP, FI-ITB-CHI etc. FI-ITB-CHI code has been patent and has been benchmarking in IAEA-tecdoc-1652 with little small reactors without on-site refuelling: neutronic characteristics, emergency planning and development scenarios [2].

Neutronic analysis of UN-PuN fuel use FI-ITB-CHI code for 500MWth GFR long-life without refuelling has been done. Beforehand, the research of GFR with nitride fuel use SRAC Code has been
calculated before [3-7]. The neutronic analysis use FI-ITB-CHI code also has been calculated to Pb-Bi cooled reactor [1,8-10]. In this research, we want to calculate analyse GFR used FI-ITB-CHI code.

2. Design Concept and Calculation Methods
Table 1 show the parameter design of gas cooled fast reactor. The fuel use uranium plutonium nitride fuel. The uranium is uranium natural and the plutonium is spent fuel from light water reactor. The percentage of Plutonium is taken from spent fuel PWR (U-fueled) with burn up 33 MWd/ton. The percentage of Pu-238 is 1.8%, Pu-239 is 58.7%, Pu-240 is 24.2%, Pu-241 is 11.4% and Pu-242 is 3.9% [11].

Nitride fuel has high melting point so it can be operated in high temperature. The cladding use stainless steel, it oftentimes uses to be cladding material. The core reactor dimension use balance core, means the diameter active core as same as height active core.

| Parameter                  | Specification                     |
|----------------------------|-----------------------------------|
| Power (MWth)               | 500                               |
| Fuel material              | Uranium Plutonium Nitride         |
| Cladding material          | Stainless Steel                   |
| Coolant material           | Helium                            |
| Fuel volume fraction (%)   | 40% - 60%                         |
| Cladding volume fraction (%)| 10%                               |
| Coolant volume fraction (%)| 30% - 50%                         |
| Active core diameter & height (cm) | 250                         |
| Reflector radial & axial width (cm) | 50                              |
| Pin pitch (cm)             | 1.45                              |
| Reactor life (years)       | 25                                |

The calculation use FI-ITB-CHI code both fuel cell calculation and core calculation. The fuel cell calculation varied the fuel volume fraction from 40% up to 60%. The core calculation, there are two calculation, i.e. homogeneous calculation and heterogeneous calculation. Figure 1 show half heterogeneous core configuration with different width in variation fuel.

Fig. 1 show hexagonal geometries for fuel pin calculation (PIJ) by SRAC2006 results calculation. Fig. 2 show half heterogeneous core configuration with different width in variation fuel. There is three variation fuel, i.e. fuel 1 (F1), fuel 2 (F2) and fuel 3 (F3). For each fuel there is a width for each. The F1 is located in the centre of the core, after F2, and last F3.
FI-ITB-CHI has been benchmarking with six participant team in IAEA-tecdoc-1652 [2]. The calculation uses two dimensional R-Z geometry calculations. The energy group neutron is divided by 8 energy group. Figure 2 show FI-ITB-CHI calculation scheme. For iteration, we can take amount of time depend on how many burn up time that we needed in the calculation.

Fuel pin calculation
With input
sracgen1m.sh,
sracgen2m.sh,
sracgen3m.sh,
Core calculation
With input spinnor.sh
26th iteration
FINISH
Output
K-eff, power distribution

Figure 2. The FI-ITB-CHI calculation scheme

3. Results and Discussion
Figure 3 shows effective multiplication factor (k-eff) value of gas cooled fast reactor with variation percentage of Plutonium. The cell and core calculation use FI-ITB-CHI code. The variation of Plutonium is from 8% up to 15% use homogeneous core configuration, it means in core reactor there is one type of percentage plutonium of fuel. The homogeneous configuration fuel is used to calculate the parametric survey value for the next calculation.

![Figure 3](image)

Figure 3. Effective multiplication factor (k-eff) value of gas cooled fast reactor with variation percentage of Pu

When the percentage of Plutonium 8% up to 10%, k-eff value in the subcritic value (k-eff<1). The graphics of percentage 8%, 9% and 10% is increasing. It shows there is breeding, means there is increasing of Plutonium amount in the reactor from fast neutron which absorb by U-238.

Percentage of Plutonium is 11% has k-eff value more stable than the others, or we can say that it has critical condition. Whereas the percentage of Plutonium 12% up to 15% have k-eff value more than one (k-eff>1) or we can say that they have supercritical condition. The k-eff value of percentage plutonium 12% - 15% is decreasing. From that case show that there is burning continuously in the
reactor. Burning means that the number of fuel (fissile contain, in here Plutonium) is decrease continuously.

![Figure 4](image)

**Figure 4.** Effective multiplication factor ($k_{\text{eff}}$) value of gas cooled fast reactor with variation of fuel volume fraction (homogeneous core)

Figure 4 show $k_{\text{eff}}$ value homogeneous core configuration with variation of fuel volume fraction. From Figure 3 or parametric survey, we know that the stable $k_{\text{eff}}$ value is when the percentage of Plutonium 11%. From that case, we take 11% Pu as a standard to calculate fuel fraction variation. In this case, the volume fuel fraction is varied from 40% up to 60%. From Figure 4, the black graph use 60% fuel volume fraction, the blue graph 55% continuously up to the green one 40% fuel volume fraction. When the fuel volume fraction is increase, the reactor can be operated longer than small fuel volume fraction.

Figure 5 shows $k_{\text{eff}}$ value use heterogeneous core configuration. Heterogeneous core configuration means in one core there is more than one type of percentage plutonium in fuel. In here we use three type of fuel, i.e. fuel 1 (F1), fuel 2 (F2) and fuel 3 (F3). F1 located in the central of the core, after that F2, than F3. The radius of F1 is 35 cm from centre, radius F2 is 25 cm from F1 and radius F3 is 35 cm from F2. There are three variation fuels that has been done (see Table 2), we call it case 1, case 2 and case 3. For all variation Plutonium percentage for F1 and F2 are unchanged (constant). The percentage plutonium of F3 is varied from 13%, 13.5% and 14%.

| Type | F1 | F2 | F3 |
|------|----|----|----|
| Case 1 | 8% | 10% | 14% |
| Case 2 | 8% | 10% | 13.5% |
| Case 3 | 8% | 10% | 13% |

Figure 5 shows $k_{\text{eff}}$ value for heterogeneous core configuration. The green line is case 1, the blue one is case 2 and the red one is case 3. For all case use 60% fuel volume fraction. From the graph, we can see that for case 1 and 2 has similar graphic trend, and case 3 different. From figure 3, if we use case 1, the reactor can be operated until almost 25 years without refueling, because the $k_{\text{eff}}$ value is more than one. And for case 2 and case 3 the reactor is subcritical because they have $k_{\text{eff}}$ value less than one. In this case, the optimum value is use case 1 which is use 8% percentage of plutonium for F1, 10% for F2 and 14% for F3.
4. Conclusion
Parametric survey with various percentage of plutonium show the critical condition reach when 11% percentage of Pu and 60% fuel volume fraction. When the fuel volume fraction is increase, the reactor can be operated longer. The optimum value of heterogeneous core configuration when use 8% percentage of plutonium for F1, 10% for F2 and 14% for F3. The reactor can be operated almost 25 years without refueling.

Acknowledgment
The authors express their gratitude for the support from The Ministry of Research Technology and Higher Education of The Republic of Indonesia through the scheme of Penelitian Unggulan Perguruan Tinggi (PUPT) RISTEKDIKTI.

References
[1] GIF (The Generation IV International Forum) 2002 A technology Roadmap for Generation IV Nuclear Energy System (U.S DOE Nuclear Energy Research Advisory Committee) p 1-22
[2] IAEA-TECDOC-1652 2010 Small Reactors Without On-site Refuelling: Neutronic Characteristics, Emergency Planning and Development Scenarios (International Atomic Energy Agency) p 62
[3] Ratna D S, Yacobus Y, Zaki S, Khairul B and Dwi Irwanto 2016 Matec Web Conferences 82 03008
[4] Ratna D S, Zaki S, Khairul B, Dwi Irwanto 2017 IOP Conf. Series: Journal of Physics: Conf. Series 799 012022
[5] Ratna D S, Zaki S, Khairul B, Dwi Irwanto 2017 Key Engineering Materials 733 47-50
[6] Ratna D S, Zaki S, Khairul B, Dwi Irwanto 2016 IOP Conf. Series: Journal of Physics: Conf. Series 776 012103
[7] Ratna D S, Zaki S, Khairul B, Dwi Irwanto 2017 IOP Conf. Series: Journal of Physics: Conf. Series 877 012064
[8] Zaki S and Hiroshi S 1993 Nuclear Engineering and Design 140 251-260
[9] Zaki S 1998 Progress in Nuclear Energy 32 571-577
[10] Zaki S and Hiroshi S 1996 Nuclear Engineering and Design 162 205-222
[11] Alan E W Albert B R 1939 Fast Breeder Reactors (Pergamon Press) p 243