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Neutronic analysis of comparation UN-PuN fuel and ThN fuel for 300MWth Gas Cooled Fast Reactor long life without refueling

Ratna Dewi Syarifah, Artoto Arkundato, Dwi Irwanto and Zaki Su'ud

Physics Department, Faculty of Mathematics and Natural Science, Jember University
Jalan Kalimantan no.37 Jember, East Java, Indonesia

Nuclear Physics and Biophysics Research Division, Physics Department, Faculty of Mathematics and Natural Science, Bandung Institute of Technology Indonesia,
Jalan Ganesha 10 Bandung 40132, Indonesia
E-mail: rdsyarifah.fmipa@unej.ac.id

Abstract. *Neutronic analysis of comparation UN-PuN fuel and ThN fuel for 300MWth Gas Cooled Fast Reactor long life without refueling has been done. Gas Cooled Fast Reactor is a Generation IV reactor with gas coolant (i.e. helium) and using fast spectrum neutron. The neutronic calculation was carried out using SRAC (Standard Reactor Analysis Code) version 2006 under the Linux Operating System with nuclear data library JENDL4.0. The first calculation is fuel pin cell calculation (PIJ-method) by using a hexagonal cell and then followed by the calculation of the core reactor (CITATION-method). The calculation of the core reactor used homogeneous and heterogeneous core configuration. The UN-PuN fuel use plutonium as a fissile material and natural uranium as a fertile material and the ThN fuel use U233 as a fissile material and natural thorium as a fertile material. The percentages of fissile material are varied in heterogeneous core configuration. It is used to decrease the peaking power in the center of the core. The heterogeneous core configuration contains of Fuel 1 (F1) 8% fissile materials, Fuel 2 (F2) 10% fissile materials, and Fuel 3 (F3) 12% fissile materials. F1 is located in the central core, F2 middle core and F3 outer core. The diameter and height active core are 240 cm and 100 cm. The reflector radial-axial width is 50 cm. All of the calculations can reach burn up time more than 20 years with excess reactivity less than 1 percent ($\Delta k/k <1\%$) both UN-PuN fuel and ThN fuel. It means that the reactor stable in 20 years. The average of power density both of UN-PuN fuel and ThN fuel are around 66 Watt/cc. The maximum power density of UN-PuN fuel is 94Watt/cc and ThN fule is 129Watt/cc. The UN-PuN fuel has lower maximum power density value than ThN fuel. So, for fast neutron spectrum reactor especially Gas Cooled Fast Reactor type, it is better used UN-PuN fuel than ThN fuel.*

1. Introduction

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Gas-Cooled Fast Reactor (GFR) is a Generation IV reactor with gas coolant (i.e. helium). GFR used fast spectrum neutron. The GFR is a high-temperature with a closed fuel cycle. It combines the advantages of fast-spectrum systems with those of high-temperature systems. The fast spectrum affords more sustainable use of uranium resources and wastes minimization through fuel recycling and burning of long-lived actinides, and the high temperature affords high-thermal-cycle efficiency and industrial use of the generated heat, e.g., for hydrogen production [1], [2].

The neutronic analysis for Gas-Cooled Fast Reactor using nitride fuel (UN-PuN) is already studied before [3-10]. In this article, the study of the neutronic analysis of comparation UN-PuN fuel and ThN fuel GFR will be reported. The studied are about the modular GFR long life without refueling. The calculation was carried out using SRAC (Standard Reactor Analysis Code) version 2006 under the Linux Operating System with nuclear data library JENDL4.0 [11].

2. Design Concept and Calculation Methods

The neutronic calculation was calculated by SRAC (Standard Reactor Analysis Code) version 2006 under the Linux Operating System with nuclear data library JENDL4.0. SRAC calculates static cell and core calculation including burn-up analysis and also covers the production of effective microscopic and macroscopic group cross-section. First, it calculates fuel pin cell PIJ with Collision Probability Method (CPM) and continues to calculate core reactor with CITATION [11]. The first calculation is fuel pin cell calculation (PIJ-method) by using a hexagonal cell. Figure 1 shows hexagonal geometries for fuel pin calculation (PIJ) by SRAC2006. It is divided into six regions, the first three regions are fuel regions, the next two regions are cladding areas and the next two regions are coolant areas.

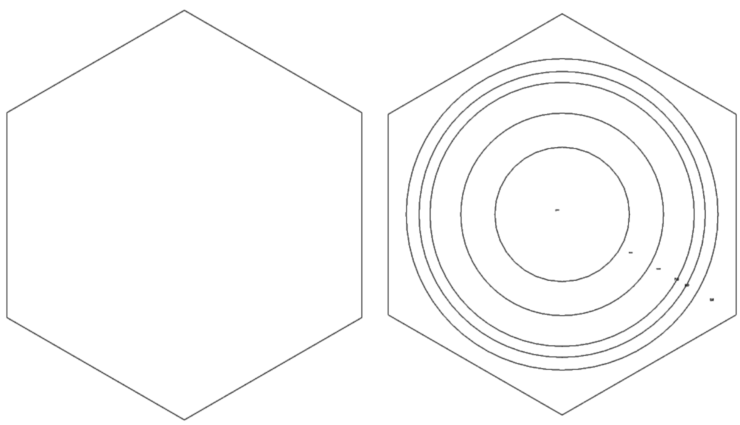

Figure 1. Hexagonal geometries for fuel pin calculation (PIJ) by SRAC2006

After calculated fuel pin calculation, then followed by the calculation of the core reactor (CITATION-calculation). The calculation of the core reactor used homogeneous and heterogeneous core configuration. The homogeneous core configuration used one type percentage of fuel in the core reactor, and then the heterogeneous core configuration used different (three types) a percentage of fuel in core calculation. Figure 2 shows a heterogeneous core configuration with three type percentage of fuel

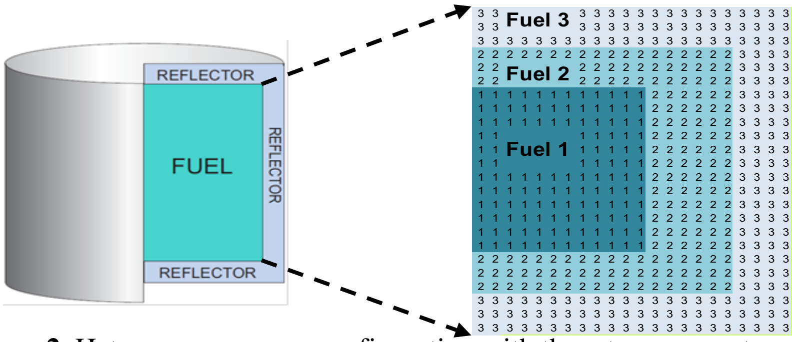

Figure 2. Heterogeneous core configuration with three type percentage of fuel

Table 1 shows the design parameter of the fuel pin with UN-PuN fuel and ThN-U233N fuel. There are fissile material percentages, the addition of minor actinide material, volume fraction, diameter and height of the active core. The UN-PuN fuel use Plutonium as a fissile material and natural uranium as a fertile material and the ThN fuel use U233 as a fissile material and natural thorium as a fertile material. The percentages of fissile material are varied in heterogeneous core configuration. It is used to decrease the peaking power in the center of the core. The heterogeneous core configuration contains of Fuel 1 (F1) 8% fissile materials, Fuel 2 (F2) 10% fissile materials, and Fuel 3 (F3) 12% fissile materials. F1 is located in the central core, F2 middle core and F3 outer core. The diameter and height active cores are 240 cm and 100 cm. The reflector radial-axial width is 50 cm.

Table 1. Design parameter of fuel pin with UN-PuN fuel and ThN-U233N fuel

Specification	Fuel	
	UN-PuN	ThN-U233N
Percentage of Plutonium:		
a. *Fuel* 1 (F1)	8.0%	-
b. *Fuel* 2 (F2)	10.0%	-
c. *Fuel* 3 (F3)	12.0%	-
Percentage of Uranium		
233:	-	8.0%
a. *Fuel* 1 (F1)	-	10.0%
b. *Fuel* 2 (F2)	-	12.0%
c. *Fuel* 3 (F3)		
Addition of Am	0.3%	-
Addition of Np-237	0.3%	-
Addition of Pa-231	4.5%	5%
Fuel volume fraction F1	57.5%	57.5%
Fuel volume fraction F2	60%	60%
Fuel volume fraction F3	60%	60%
Diameter active core	240 cm	240 cm
Height active core	100 cm	100 cm

3. Results and Discussion

The optimum results can be reached if the reactor has effective multiplication factor (k_{eff}) around one ($k_{eff} \geq 1$), which means the reactor has excess reactivity less than 2% %Δk/k. The multiplication factor is the number of fission in one generation divide by the number of fission in the preceding generation.

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(1)

Table 2 shows k_{eff} value of comparison UN-PuN fuel and ThN-U233N fuel. All of the calculations show that the fuel can reach burn up time more than 20 years with excess reactivity around 1 % ($\Delta k/k$ <1%) both UN-PuN fuel and ThN fuel. It means that the reactor will be stable in 20 years.

Table 2. Effective multiplication (k_{eff}) value of comparison UN-PuN fuel and ThN-U233N fuel

Years	UN-PuN + Pa 4.5%, Am 0.3%, Np 0.3%	(Th-U233)N + Pa 4.5%	(Th-U233)N + Pa 5%
0	1.00681	1.01096	1.0032
1	1.00219	1.00761	1.00039
2	1.00113	1.0072	1.0005
3	1.00044	1.00695	1.00073
4	1.00009	1.00678	1.00102
5	1.00002	1.00666	1.00133
6	1.00017	1.00656	1.00163
7	1.00049	1.00645	1.00191
8	1.00096	1.00633	1.00215
9	1.00155	1.00617	1.00236
10	1.00222	1.00598	1.0025
11	1.00295	1.00575	1.00259
12	1.00372	1.00548	1.00262
13	1.00452	1.00516	1.00259
14	1.00532	1.00479	1.00249
15	1.00613	1.00436	1.00233
16	1.00691	1.00388	1.00211
17	1.00768	1.00335	1.00182
18	1.00841	1.00277	1.00146
19	1.0091	1.00213	1.00105
20	1.00975	1.00145	1.00057

Figure 3 shows k k_{eff} value of comparison UN-PuN fuel and ThN-U233N fuel. All of the graphs, in the beginning of burn up time, the k k_{eff} value decreased sharply. The declining graph explains that the reactor is burning. For UN-PuN fuel after a burn up time of 5 years, the graph is increasing, which means that the reactor is breeding. The breeding step means the fertile material becomes fissile material because of capturing or absorbing neutron in the reactor. For examples in UN-PuN fuel is U-238 (fertile material) become Pu-239 (fissile material) by absorbing a neutron and emitting beta decay (see Figure 4).

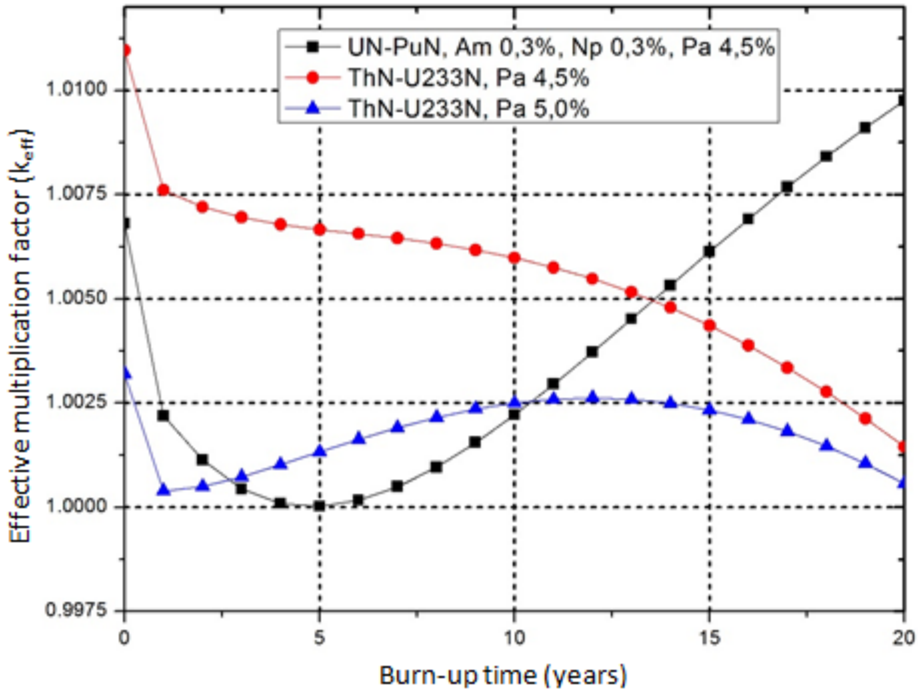

Figure 3. Comparison of effective multiplication factor (k_{eff}) of UN-PuN fuel and ThN-U233N fuel

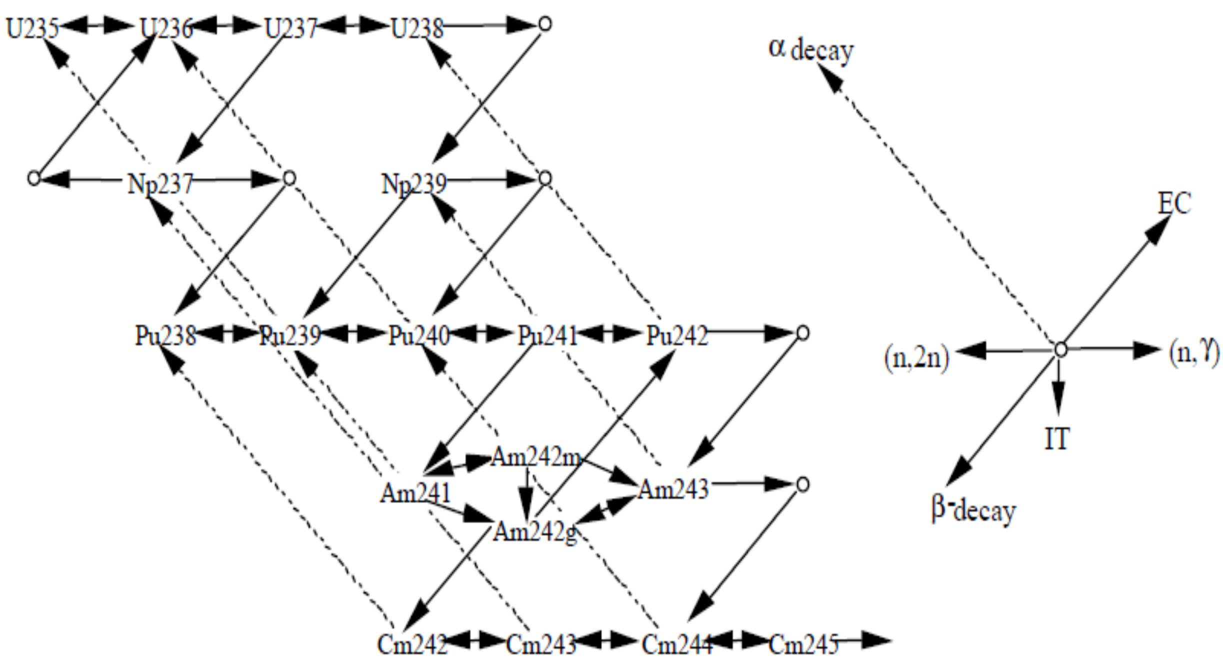

Figure 4. Burn-up chain Uranium from SRAC Code ver 2002

Table 3 shows the comparison of the average and maximum power density of UN-PuN fuel and ThN-U233N. The average of power density both of UN-PuN fuel and ThN fuel are around 66 Watt/cc. The maximum power density of UN-PuN fuel is 94Watt/cc and ThN fuel is 129Watt/cc. The UN-PuN fuel has a lower maximum power density value than ThN fuel. So, for fast neutron spectrum reactor especially Gas-Cooled Fast Reactor type, it is better to use UN-PuN fuel than ThN fuel.

Table 3. Comparison of the average and maximum power density of UN-PuN fuel and ThN-U233N

Fuel Type	Average power density (Watt/cc)	Maximum power density (Watt/cc)
UN-PuN, Am 0,3%, Np 0,3%, Pa 4,5%	66.31	94.66
ThN-U233N, Pa 5,0%	66.31	129.68
ThN-U233N, Pa 4,5%	66.31	131.00

4. Conclusion

Neutronic analysis of comparison UN-PuN fuel and ThN fuel for 300MWth Gas-Cooled Fast Reactor long life without refueling has been done. There are three types of fuel used in this comparison, i.e. UN-PuN fuel and ThN fuel. The UN-PuN fuel uses plutonium as a fissile material and the ThN fuel use U233 as a fissile material. Both UN-PuN fuel and ThN fuel have the same average power density value. The UN-PuN fuel has a lower maximum power density value than ThN fuel. So, for a fast neutron spectrum reactor especially Gas-Cooled Fast Reactor type, it is better to use UN-PuN fuel than ThN fuel because the peaking factor of UN-PuN fuel is lower than ThN fuel.

Acknowledgment

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