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Actinide Minor Addition on Uranium Plutonium Nitride Fuel for Modular Gas Cooled Fast Reactor

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Abstract. This study has made a calculation of Actinide Minor Addition on Uranium Plutonium Nitride Fuel for Modular Gas Cooled Fast Reactor. The purpose of this study was to determine the characteristics of minor actinides when incorporated into plutonium nitride uranium fuel. Neutronics calculation was design by using SRAC Code version 2006 (Standard Reactor Analysis Code) with the data nuclides from JENDL-4.0 under the Linux Operating System with nuclear data library JENDL4.0. Neutronic calculations were done through some steps of parameter survey to obtain the ultimate optimization results. The initial calculation was calculation of fuel cell (PIJ calculation) by using hexagonal cell and then followed by calculation of core reactor (CITATION calculation) by using program code SRAC2006. The addition of minor actinide has been calculated in this research. The minor actinides which were added were americium (Am-241 and Am-243) and neptunium 237. They were put into the uranium plutonium nitride material to decrease the k-eff value. The addition of minor actinide into the reactor aimed to reduce the number of minor actinides in the world. Minor actinide is a nuclear waste fuel or often called spent nuclear fuel (SNF) which has high toxicity. Neptunium 237 is a minor actinide with the highest percentage of SNF.

1. Introduction

Nuclear Reactor Generation IV has four goals areas, i.e., sustainability, economics, safety and reliability, and proliferation resistance and physical protection. Six systems of Generation IV reactor technologies, i.e. Gas Cooled Fast Reactor (GFR), Lead Cooled Fast Reactor (LFR), Molten Salt Reactor (MSR), Sodium Cooled Fast Reactor (SFR), Supercritical Water Cooled Reactor (SCWR), and Very High Temperature Reactor (VHTR) [1-2]. This study has made a calculation of Actinide Minor Addition on Uranium Plutonium Nitride Fuel for Modular Gas Cooled Fast Reactor. The purpose of this study was to determine the characteristics of minor actinides when incorporated into plutonium nitride uranium fuel. The addition of minor actinide into the reactor aimed to reduce the number of minor actinides in the world. Minor actinide is a nuclear waste fuel or often called spent nuclear fuel (SNF) which has high toxicity.

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Neutronics calculation was performed by using Standard Reactor Analysis Code (SRAC) ver 2006 with JENDL-4.0 as nuclear data libraries. Neutronic calculations were done through some parameter surveys to obtain the optimal results. The first step was calculation of fuel cell (PIJ-method) by using hexagonal cell and then followed by calculation of core reactor (CITATION -method) [3]. The neutronic analysis for Gas Cooled Fast Reactor using nitride fuel (UN-PuN) is already studied before [4-11]. In this study, we add actinide minor into nitride fuel to reduce the the number of minor actinides in the world.

2. Design Concept and Calculation Methods

The parameter design of fuel pin and core reactor shown in Table 1.

Table 1. Parameter design of fuel pin and core reactor

Parameter	Specification
Fuel/Cladding/Coolant	UN-PuN/SiC/He
Fuel volume fraction	40% - 65%
Cladding volume fraction	10%
Coolant volume fraction	30% - 50%
Pin pitch	1.45 cm
Minor actinide	Americium, Neptunium-237
Burnable poison	Protactinium 231
Percentage Plutonium	5 % – 15 %
Percentage Americium	0% - 5%
Percentage Neptunium-237	0% - 5%
Percentage Protactinium	0% - 5%
Power	300 MWth
Burn-up time	>20 year
Core geometry	*Cylinder Pancake*
Fuel pin cell	Hexagonal cell
Pin pitch/diameter	1.45 cm
Height active core	100 cm
Diameter Active Core	240 cm
Reflector	50 cm

The hexagonal cell geometry in this study 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. The division of the region can be seen in Figure 1. And Figure 2 shows Hexagonal geometries cell for fuel pin calculation (PIJ).

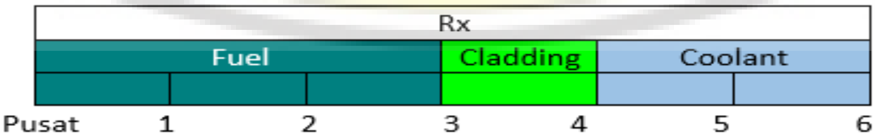

Figure 1. Hexagonal geometries for fuel pin calculation (PIJ)

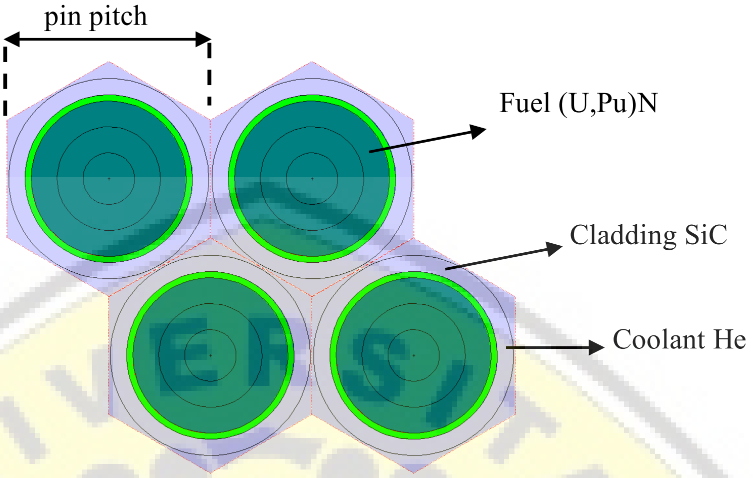

Figure 2. Hexagonal geometries cell for fuel pin calculation (PIJ)

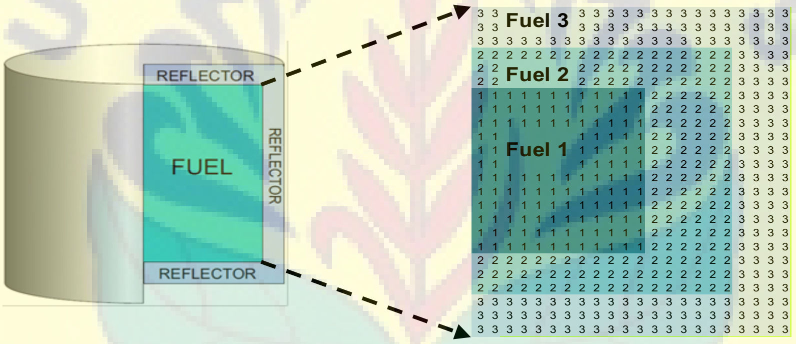

Figure 3. Half core configuration with different width in variation fuel

Fig. 2 show hexagonal geometries for fuel pin calculation (PIJ). Fig. 3 shows half configuration with different width in variation fuel. There are fuel F1, F2 and F3 from center to periphery, and after that there is a reflector. Percentage F1:F2:F3 = 8%:10%:12%.

The calculation method use SRAC 2006 and JENDL 4.0 as libraries. It is designed to permit neutronics calculation for various type reactors. SRAC covers production of effective microscopic and macroscopic group cross section, and static cell and core calculation including burn-up analysis. First, it calculate fuel pin cell PIJ. In PIJ calculation, we get k-inf, burn-up analysis and more. After that, it continues to calculate core reactor with CITATION, with various core configuration [16].

3. Results and Discussion

There are three types of minor actinides produced in nuclear reactors, namely Neptunium (Np-237), Americium (Am-241 and Am-243) and Curium (Cm-242, Cm-244, and Cm-245). The addition of minor actinides in the reactor is often referred to as the transmutation process. This transmutation process is carried out because it remembers the accumulation of the number of minor actinides. Minor actinides are used LWR waste or often called spent nuclear fuel (SNF) which has a relatively long half-life and high toxicity.

Calculation that considering addition of minor actinide was performed. The minor actinides which were added were americium (Am-241 and Am-243) and neptunium 237. They were put into the uranium plutonium nitride material in order to decrease the k-eff value. The addition of minor actinide into the reactor aimed to reduce the number of minor actinides in the world. Minor actinide is a nuclear waste fuel or often called spent nuclear fuel (SNF) which has high toxicity. Neptunium 237 is a minor actinide with the highest percentage of SNF.

Table 2. Actinide minor composition from spent fuel of LWR* (Arai, 2012)

No.	Nuclide	Composition (%)	Half life/T$\frac{1}{2}$
1.	Np-237	49,14	2,14 x 10^6 years
2.	Am-241	29,98	4,32 x 10^2 years
3.	Am-242m	0,08	1,52 x 10^2 years
4.	Am-243	15,5	7,38 x 10^3 years
5.	Cm-242	0,0	163 days
6.	Cm-243	0,05	
7.	Cm-244	4,99	18,1 years
8.	Cm-245	0,26	8,5 x 10^3 years

*after being removed from PWR (35 GWd/t) and has been cooled for 5 years before being reprocessed

Table 2 shows that Neptunium and Americium have a large percentage in LWR used fuel. Even neptunium 237 has the most amount when compared to the others. Curium 244 has a percentage of about 5%, Cu-244 has a half-life of only a dozen years so that it decays rapidly when compared with Neptune and America which has a half-life of hundreds to millions of years.

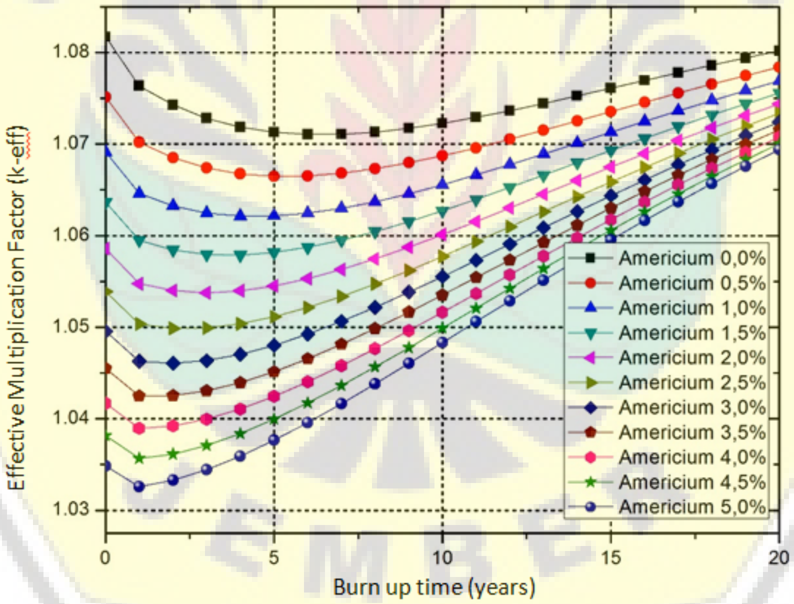

Figure 4. Value of effective multiplication factor (k-eff) for the addition of americium to the reactor from the percentage of 0% to 5%

Figure 4 shows the k-eff value of the addition americium in the reactor from 0% to 5%. Figure 4 shows that the addition of the percentage of americium to the reactor causes a decrease in the value of k-eff at the beginning of the burn-up year, but does not affect in the end of burn-up. It happened because at the beginning of the burn-up years, the number of americium was still relatively large. This Americium captures neutrons, causing the k-eff value at the beginning of the burn-up to decrease significantly. As the burn-up time increases, the number of the americium decreases, so that the k-eff rises again. It can be concluded that the addition of americium cannot reduce the k-eff value as a whole (at the beginning and at the end of burn-up). For this reason, the next calculation will add another minor actinide, neptunium 237 to reduce the overall k-eff value. Neptunium 237 is the most minor actinide in SNF and has the longest half-life of around millions of years.

Figure 5 shows the k-eff value of addition neptunium 237 in the reactor from 0% to 5%. In the figure, the more addition of Np-237 in the reactor will reduce the k-eff value at the beginning of the burn-up year, but this applies otherwise to the end of the burn-up year. This is because, at the beginning of the year burn-up the amount of neptunium in the reactor is still relatively large, the neptunium absorbs neutrons causing the k-eff value to decrease. After some time, the N-237 which absorbs the neutrons will turn into Pu-239 (fissile material), so that at the end of the burn-up year, with the increase in Np-237 will add to the value of k-eff.

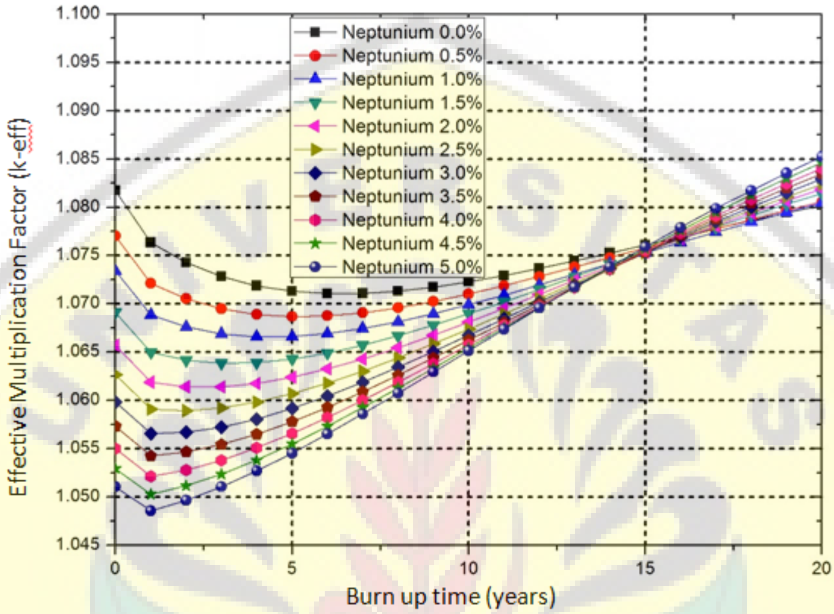

Figure 5. The value of the effective multiplication factor (k-eff) for adding neptunium 237 to the reactor from the percentage of 0% to 5%

The next calculation was the addition of protactinium 231 as the neutron toxin. The addition of Pa-231 was performed to decrease the overall k-eff value without significantly increase the mean power density and maximum power density.

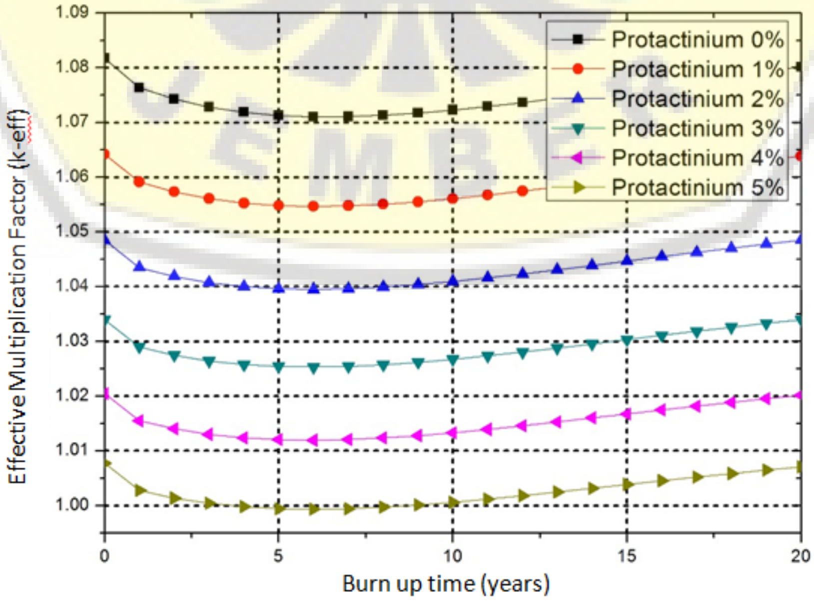

Figure 6. The value of effective multiplication factor (k-eff) with various variations in the percentage of protactinium 231

Table 3. Maximum power density value with percentage variation of Protactinium

No.	Percentage Pa-231	Max power density (Watt/cc)
1.	0%	93,09
2.	1%	91,17
3.	2%	91,95
4.	3%	92,58
5.	4%	93,11
6.	5%	93,58

Table 3 shows that the addition of Pa-231 changes the maximum power density but is not significant. The maximum power density generated from the addition of Pa-231 is still below the maximum power density which is set at 100 Watt / cc. Therefore, Pa-231 can be used as an additional material as burnable poison, a material that can absorb neutrons, causing k-eff value to decrease both at the beginning of the burn-up year and at the end of the burn-up year.

4. Conclusion

Actinide Minor Addition on Uranium Plutonium Nitride Fuel for Modular Gas Cooled Fast Reactor is has been done. There are three type of nuclide has been add in the fuel i.e., Neptunium 237, Americium 241, and Americium 243. The addition minor actinide can decrease the k-eff value in the beginning of burn-up. And the addition of protactinium can decrease the k-eff value in the beginning of burn-up until in the end of burn up.

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