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Fuel Fraction Analysis of 500 MWth Gas Cooled Fast Reactor with Nitride (UN-PuN) Fuel without Refueling

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Abstract. Nuclear Power Plant (NPP) is one of candidates which can support electricity demand in the world. The Generation IV NPP has fourth main objective, i.e. sustainability, economics competitiveness, safety and reliability, and proliferation and physical protection. One of Gen-IV reactor type is Gas Cooled Fast Reactor (GFR). In this study, the analysis of fuel fraction in small GFR with nitride fuel has been done. The calculation was performed by SRAC code, both Pij and CITATION calculation. SRAC2002 system is a code system applicable to analyze the neutronics of variety reactor type. And for the data library used JENDL-3.2. The step of SRAC calculation is fuel pin calculated by Pij calculation until the data homogenized, after it homogenized we calculate core reactor. The variation of fuel fraction is 40% up to 65%. The optimum design of 500MWth GFR without refueling with 10 years burn up time reach when radius F1:F2:F3 = 50cm:30cm:30cm and height F1:F2:F3 =50cm:40cm:30cm, variation percentage Plutonium in F1:F2:F3 = 7%:10%:13%. The optimum fuel fraction is 41% with addition 2% Plutonium weapon grade mix in the fuel. The excess reactivity value in this case 1.848% and the k-eff value is 1.01883. The high burn up reached when the fuel fraction is low. In this study 41% fuel fraction produce faster fissile fuel, so it has highest burn-up level than the other fuel fraction.

1. Introduction

Nuclear Power Plant (NPP) is one of candidate which can support electricity demand in the world. The country that have little fossil fuels or have chosen to use these for feedstock in the petro chemical industry, nuclear power is considered the source of choice for electricity generation. In the United State, nuclear power generates nearly 22,8% of the electricity. In other countries, notably France, the proportion nearly 80% [1]. In 1950s, early prototype reactors has been built, called Generation I of nuclear power. Now, the development of nuclear power is until Generation IV technologies.

In 2002, GIF (Generation-IV International Forum) selected six system from nearly 100 concepts as Generation IV technologies. There are 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). GIF defined four goals areas to advance nuclear energy, fourth generation. The goals are sustainability, safety and reliability, economic competitiveness, and proliferation resistance and physical protection [2,3].

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The GFR system is a high temperature helium cooled fast reactor with a closed fuel cycle. It combines the advantages of fast spectrum systems for long term sustainability of uranium resources and waste minimization (through fuel multiple reprocessing and fission of long-lived actinides), with those of high temperature systems (high thermal cycle efficiency and industrial use of the generated heat) [2,3]. Beforehand, the analyse of GFR with SRAC Code and modified CANDLE burn up scheme has been done [4,5,6,7,8]. In this research, we design 500MWth GFR with nitride (UN-PuN) fuel long life without refuelling.

2. Design Concept and Calculation Methods

The parameter design of the reactor is presented at Table 1. Determination of fuel, cladding, and coolant material in a reactor influence safety and economic factor of the reactor.

Table 1. Parameter design of the reactor

Parameter	Specification
Power	500 MWth
Fuel material	UN-PuN
Cladding material	Stainless Steel
Coolant material	Helium
Fuel volume fraction	40% - 65%
Cladding volume fraction	10%
Coolant volume fraction	30% - 50%
Active core diameter	220 cm
Active height core	110 cm
Reflector	50 cm
Pin pitch	1,45 cm
Reactor life	10 years

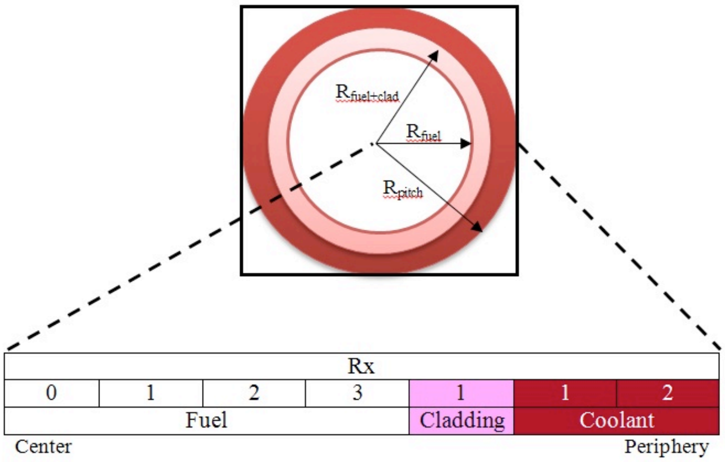

Figure 1. Cell geometry design (square cell) and distribution of region-X

In this study, we use square cell geometry design which presented in Fig. 1. This square cell fuel pin is divided by six regions, the first regions are fuel regions, the fourth region is cladding, and two last regions are coolant regions. A simple division of the region can be seen in fig. 1.

The reactor core use 2-D cylinder geometry design which divided by three regions for fuel. This reactor design will be focused on the optimization of fuel fraction analysis use nitride (UN-PuN) fuel for small GFR. We would like to find, the minimum value of excess reactivity. It means that, the k-eff value is near criticality value (reactor stable). Excess reactivity can be calculated with the equation below.

$$excess.reactivity(\%) = \frac{(k-1)}{k} x100\% \qquad (1)$$

Fig. 2 show Half heterogen core configuration with different width in variation fuel. There is three variation fuel, F1, F2 nad F3 which F1 is in the center, F2 in the middle and F3 in periphery, and after that there is a reflector. Percentage F1:F2:F3 = 7%:10%:13%. Table 2 show width of the radius and height in case a and case b which is show in Fig. 2. The calculation is use SRAC2006 code system and data libraries JENDL3.2 [9].

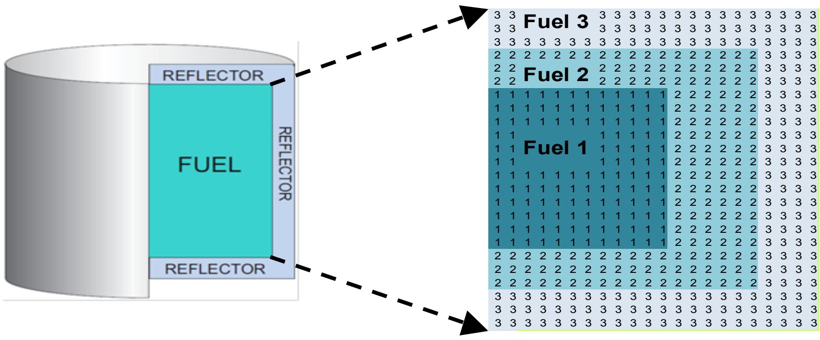

Figure 2. Half heterogeneous core configuration with different width in variation fuel

Table 2. Width of the radius and height in two case (case a and case b)

Parameter	Fuel type	Case a	Case b
Radius (cm)	Fuel 1	60	50
	Fuel 2	30	30
	Fuel 3	20	30
Height (cm)	Fuel 1	60	50
	Fuel 2	40	40
	Fuel 3	20	30

3. Results and Discussion

In the first step calculation, we calculate k-eff value for case a and case b (see Table 2). Fig. 4 show k-eff value of case comparation with three variation fuel. The k-eff value increase when the reactor use radius 50 cm for F1, 30 cm for F2 and 30 cm for F3. And after burn up time 2 years, k-eff value is stable. It means that when it decrease F1 volume, otomaticaly the volume of F2 and F3 increase, it make plus Plutonium in core reactor, so the k-eff value is increase.

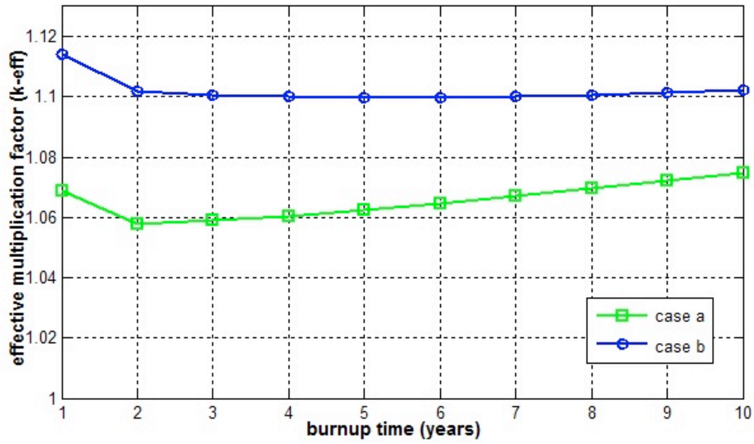

Figure 4. K-eff value of case comparation with three variation fuel F1:F2:F3=7%:10%:13%

Fig. 5 show k-eff value of fuel fraction comparation with three variation fuel. The fuel fraction variation is from 40% until 60% fuel fraction. Fig. 6 show the fuel fraction variation does not change the trend of the graph. The graph trend is similar, but it influence the k-eff value. When the fuel fraction is 40%, the k-eff value is subcritic. And when the fuel fraction is 45%, the k-eff value is around 1,03. It means that the excess reactivity still high. In this research, the objective of this research is to design the reactor which have 10 years burn up time and low excess reactivity value (less than 2%), so we must optimize the design.

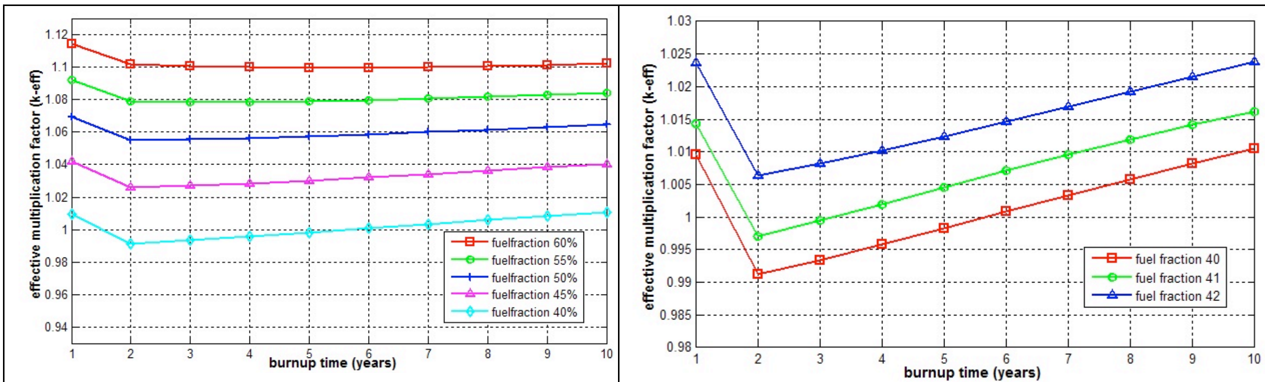

Figure 5 (a) K-eff value of fuel fraction comparation with three variation fuel F1:F2:F3=7%:10%:13% from fuel fraction 40% up to 60%, (b) K-eff value of fuel fraction 40%, 41% and 42%

Fig. 5 (b) show k-eff value of fuel fraction 40%, 41% and 42%. Due to the objective is to find excess reactivity value less than 2%, the fuel fraction calculation calculate more detail than before. From Fig. 6 show that excess reactivity value of fuel fraction 42% more than 2% or around 2,4%. Whereas, k-eff value in first and second burn up time for fuel fraction 41% is still subcritic. So, it take a weapon grade (Pu-239 pure) to increase the k-eff value. The philosophy take Pu weapon grade in the reactor is to decrease Pu-239 in the world, so it can't be used in nuclear weapon.

Fig. 4 and 5 show that there are always a peaking graph in the first until second years burn up time. The peaking value because the percentage of Pu-241 in the Plutonium isotope from waste PWR. Table 3 show plutonium percentage of total Plutonium in core from waste PWR. Percentage of Pu-241 is 11,4%, it is to much, because it absorb the neutron more than Pu-239. Because the cross section absorbtion value of Pu-241 bigger than cross section absorbtion value of Pu-239. So, the k-eff value is decrease greatly in the first step burn up.

Table 3. Plutonium percentage of total Plutonium from waste PWR (Waltar, 1981)

Isotope	PWR (U-fueled)
	Burn up 33 MWd/ton
Pu-238	1.8%
Pu-239	58.7%
Pu-240	24.2%
Pu-241	11.4%
Pu-242	3.9%

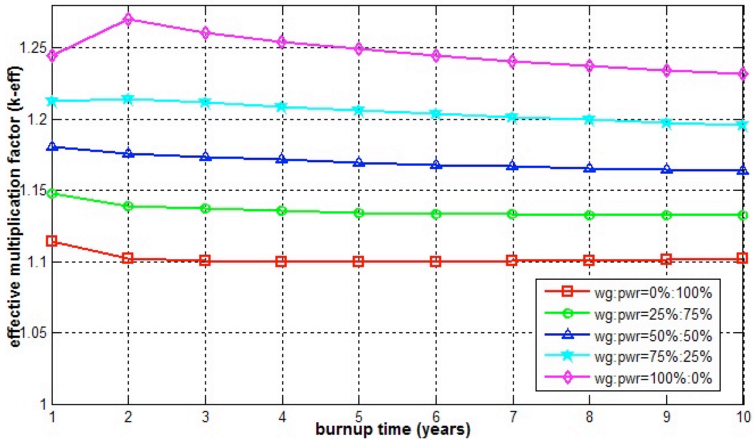

Figure 6. K-eff value of comparation Plutonium weapon grade (Pu-239 pure) and Plutonium from waste PWR fuel

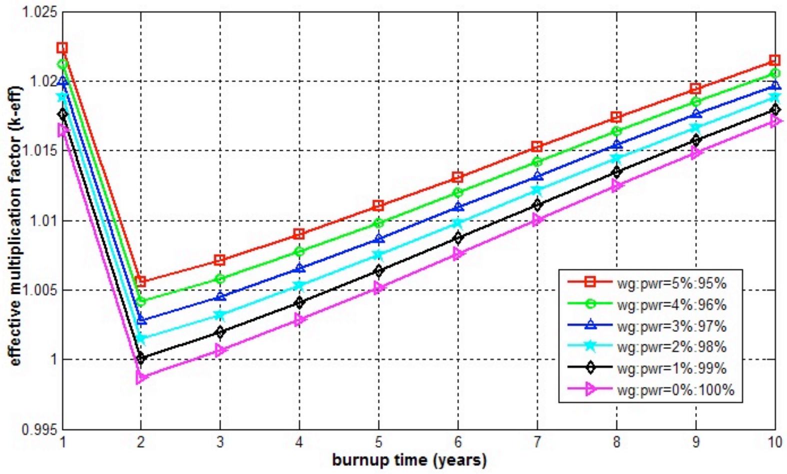

Figure 7. K-eff value of addition Pu weapon grade from 0% up to 5%

Due to, the k-eff value is decrease greatly, it take Plutonium weapon grade (pure Pu-239) mix into fuel. Fig. 6 show k-eff value of comparation Plutonium weapon grade and Plutonium from waste PWR. The variation is from 0%, 25%, 50%, 75% and 100%. Fig. 6 shows that the addition of Plutonium weapon grade change the trend of the graph in the first and second burn up time. Because Pu weapon grade can change the trend of the graph, we take Pu weapon grade in the calculation.

Figure 7 show k-eff value of addition Plutonium weapon grade from 0% up to 5%. From Figure 7, the optimum k-eff value when addition 2% of Pu weapon grade. The maximum excess reactivity value in this case 1.848% (less than 2%). And the maximum of k-eff value is 1.01883.

4. Conclusion

The optimum design of 500MWth GFR without refueling with 10 years burn up time reach when radius F1:F2:F3 = 50cm:30cm:30cm and height F1:F2:F3 =50cm:40cm:30cm, variation percentage Plutonium in F1:F2:F3 = 7%:10%:13%. The optimum fuel fraction is 41% with addition 2% Plutonium weapon grade mix in the fuel. The excess reactivity value in this case 1,848% and the k-eff value is 1,01883. The high burn up reached when the fuel fraction is low. In this study 41% fuel fraction produce faster fissile fuel, so it has highest burn-up level than the other fuel fraction.

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