



Design Study of Gas Cooled Fast Reactor (GFR) with Uranium Plutonium Carbide (UC-PuC) as Fuel with Addition Protactinium (Pa-231)

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Abstract. Analysis performance of uranium plutonium carbide (UC-PuC) as fuel in gas cooled fast reactor (GFR) with addition of protactinium as a burnable poisons has been done. Neutronic analysis in this research was carried out using the SRAC code from JAERI with a nuclear library based on JENDL 4.0. The calculation is carried out by two steps, the first step is the PIJ calculation which calculates the fuel cell and the second step is the CITATION calculation which calculates the various configurations of the reactor core. The first calculation determines the k-eff value in a homogeneous core configuration. The results obtained show that the percentage of 10% is the sloping result with a k-eff value of 1%. The second calculation determines the k-eff value in the heterogeneous core configuration. The results obtained indicate that the fuel variation 8% -10% -12% is the most critical percentage with a peak power density value of less than 100 Watt/cc. Furthermore, the addition of protactinium with a variation of 0% to 5%. At a protactinium 4% percentage and 63% fuel fraction, the excess reactivity value is 1.02% or close to 1% which indicates that the reactor is in a critical condition.

Keywords: GFR, Uranium Plutonium Carbide, Protactinium

Introduction

Generation IV reactors consist of six types of reactors, 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]. One of the advantages of generation IV reactors is the inherent safety, sustainability, non-proliferation, and is more economical than other power plants. Research on GFR has been done previously by Syarifah et al. Research on the design study of 200MWth gas cooled fast reactor with nitride (UN-PuN) fuel long life without refueling using PIJ dan CITATION calculation with data library JENDL 3.2 has been carried out, optimum result k-eff value is 1.10142 with excess reactivity value 1.403% [2]. Other research has also been carried out regarding neutronic analysis of thorium nitide (Th, U233) N fuel for 500MWth gas cooled fast reactor (GFR) long life without refueling with PIJ dan CITATION calculation and data library JENDL 4.0, the resulting k-eff value is 1,01229 with excess reactivity value 1.21% [3]. And other studies on GFR with UN-PuN fuel have been carried out by Syarifah [4-7]. Design study GFR 300 MWth was carried out with variations fuel fraction with uranium plutonium carbide and variations addition of protactinium as a burnable poison.

Theoretical Background

Nuclear power plant (PLTN) is an alternative energy that can be used to support the world's electricity needs. Nuclear power is considered the best source of choice for electricity generation [8]. Further development of nuclear power is needed to meet future energy demands on demand. Designing a nuclear system needs to emphasize a highest level of safety. Generation IV reactors include a future nuclear system which has four goals, namely economy, sustainability, safety, reliability and proliferation. One of the generation IV reactors is the GFR, which is a helium gas cooled fast reactor using the fast neutron spectrum. The function of the cooling gas is an inert chemical capable of operating at high temperatures without corrosion and toxicity and a single phase that eliminates boiling [9].

The reaction that occurs in the reactor is called a nuclear reaction, where the nuclear reaction is the collision of two nuclei or two particles which produce a nucleus or particle that is different from its origin [5]. Nuclear reactors in the process require a fuel that is used to produce nuclear energy. Fuel is divided into two, namely fissile material and fertile material [10]. The fuel used is plutonium uranium carbide with the addition of protactinium 231 as a burnable poison. Protactinium has a large catch section and is used to reduce excess reactivity at the start of combustion. The use of protactinium is also used to reduce the world's waste fuel [11]. This research was conducted by varying the fuel fraction from 60% to 65% and varying the protactinium 0% to 5%.

Materials and Methods

Determination of fuel, cladding, and coolant in the reactor can affect the safety factor and reactor economy. In this study, the pin design geometry uses the hexagonal cell geometry as shown in Figure 1. The geometry is divided into six regions, where the first three areas are the fuel area, the next one is the cladding area, and the next two are the coolant areas. The active core diameter is 240 cm and the active core height is 100 cm. Table 1 shows the reactor design parameters that have been designed.

Table 1. Reactor design parameter

Design parameters	Specification
Power	300 MWth
Fuel material	Uranium Plutonium Carbide (UC)
Cladding material	Silicon Carbide (SiC)
Coolant material	Helium (He)
Fuel fraction	60% - 65%
Cladding fraction	10%
Coolant fraction	25% - 30%
Active core diameter	240 cm
Active core height	100 cm
Reflector axial & radial width	50 cm
Burn-up time	20 years

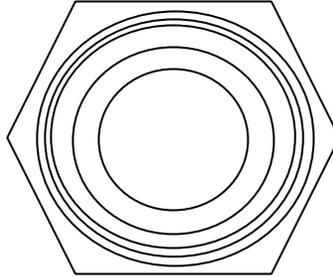


Figure 1. Cell geometry

In this study the calculations were carried out using the SRAC Code. SRAC (Standard Reactor Analysis Code) is a code developed by JAERI (Japan Atomic Energy Agency). The SRAC is designed for neutronic calculations of various types of reactors. The nuclear data library used is JENDL 4.0 which is the latest nuclear database developed by Japan. SRAC includes effective microscopic and macroscopic production, and static cell and core calculations including burn-up analysis. First, the PIJ calculation which calculates fuel cells in the form of hexagonal cells using the Collision probability methods (CPM) method. In the PIJ calculation we get the k-inf value, burn-up analysis and others. After that, proceed with the calculation of the reactor core using CITATION calculations with various core configurations [12].

Results and Discussion

Analysis performance of uranium plutonium carbide (UC-PuC) as fuel in gas cooled fast reactor (GFR) with addition of protactinium as a burnable poisons has been done. The first step in the calculation is to determine the k-eff value based on the variation of homogeneous and heterogeneous fuels with a fuel fraction of 60%, cladding 10%, and coolant 30%. Figure 2. is a graph of the k-eff value in a homogeneous core configuration with a fuel value variation of 5% to 15%. The graph of the k-eff value in the homogeneous core configuration shows that 10% fuel variation is the most sloping result, with a delta k-eff value of 0.007638 or equal to 1%.

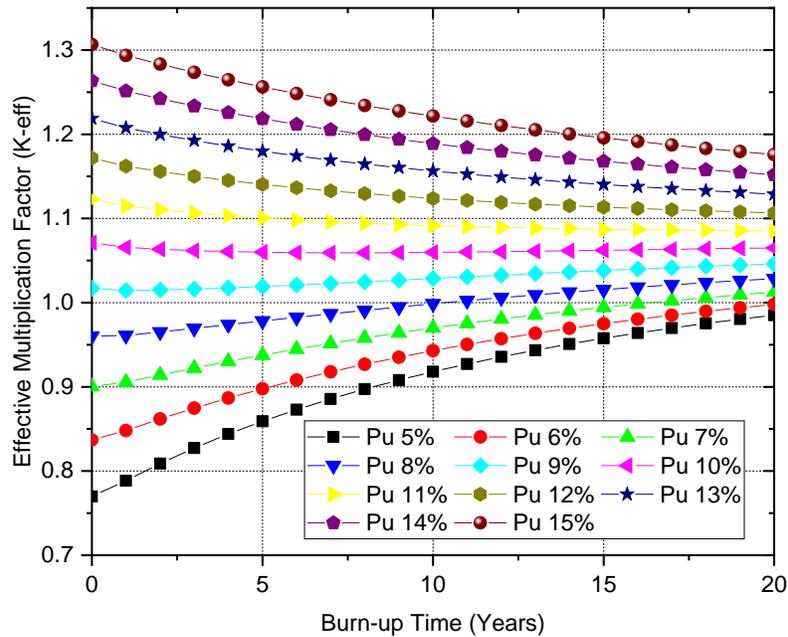


Figure 2. The k-eff value in a homogeneous core configuration

The next calculation uses a heterogeneous core configuration, where the fuel used has three variations in value with an average of 10%. Figure 3. is the result of calculating the k-eff value obtained in the heterogeneous core configuration. Fuel variation with a value of 8% -10% -12% is the variation that shows the most critical results, with a peak power density value less than 100 watt/cc. The power distribution to the radial direction of the mesh in the homogeneous and heterogeneous core configurations in the reactor core can be seen in Figure 4.

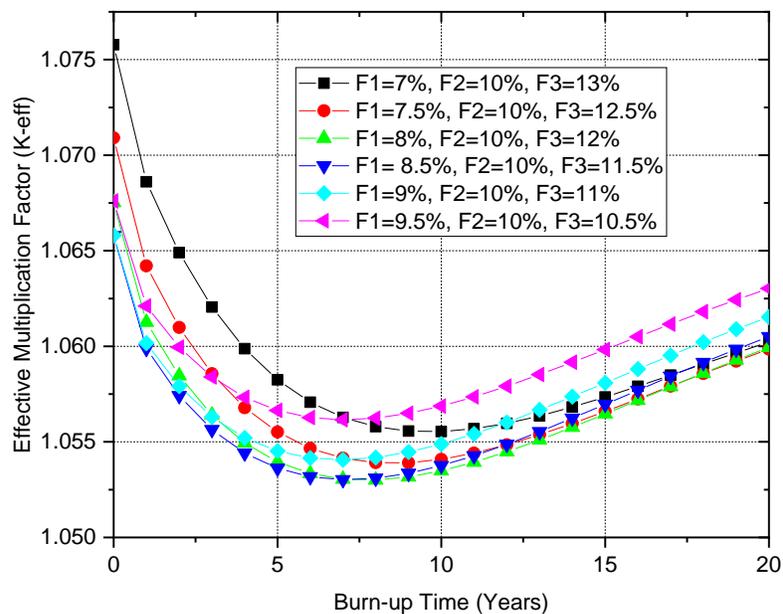


Figure 3. The k-eff value in a heterogeneous core configuration

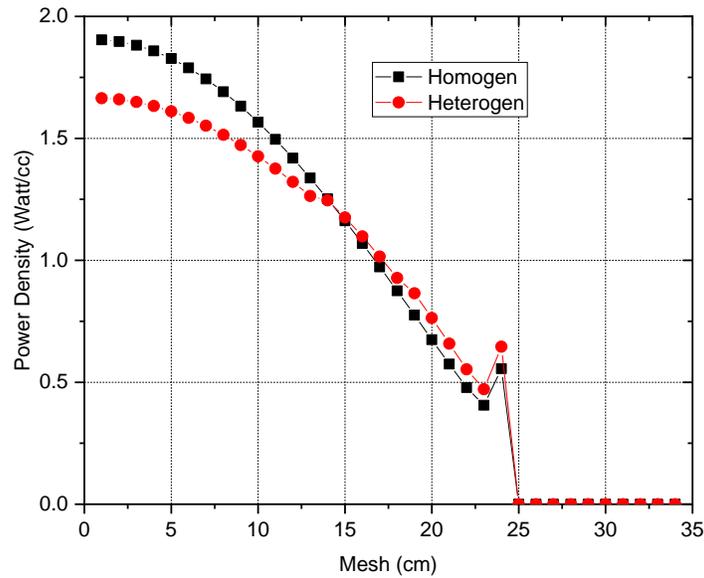


Figure 4. The power distribution to the radial direction of the mesh in the homogeneous and heterogeneous core configurations

Figure 5. describes the effect of the addition of protactinium (Pa-231) on the k-eff value. The addition of 0% to 5% protactinium causes a decrease in the k-eff value during combustion. The variation of protactinium addition of 4% showed the most effective results, with a delta k-eff value of 0.00931 (k-eff ~ 1%).

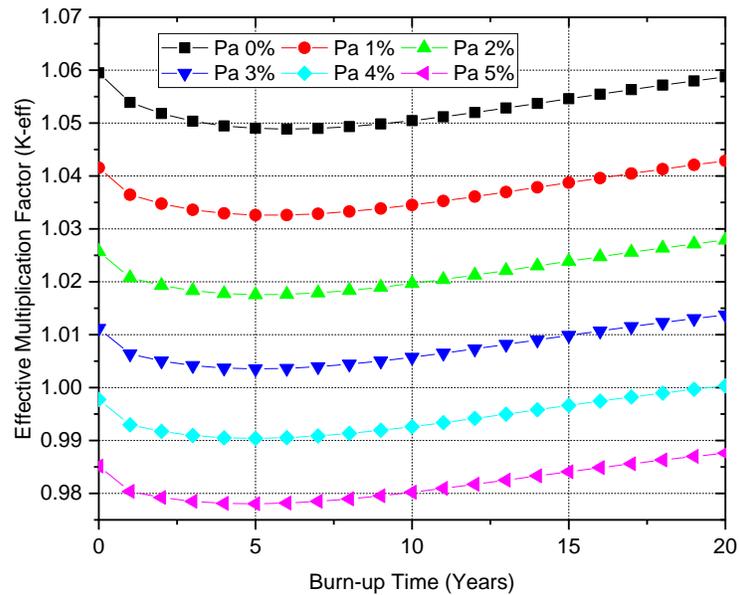


Figure 5. The k-eff value with the addition of Pa (0%-5%)

Figure 6 explains the effect of variations in the fuel fraction from 60% to 65%, where the variation in the fuel fraction of 63% shows the k-eff increased significantly with an average value of k-eff ~ 1 and the maximum excess reactivity value obtained is 1, 02%. The final result in Figure 7 shows that the calculation of the k-eff value at the variation of the 63% fuel fraction with the addition of Pa-231 4%, results in the reactor with the most critical condition with a maximum excess reactivity value of 1.02%.

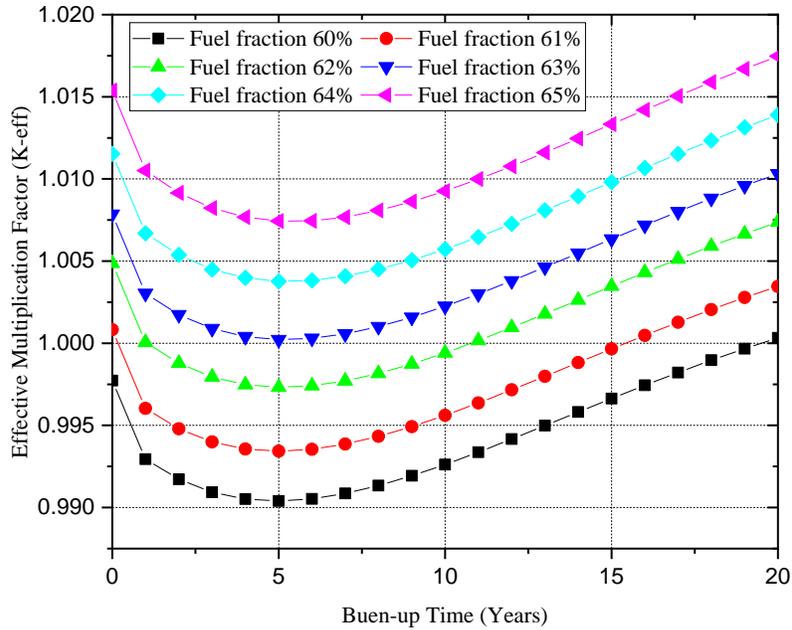


Figure 6. The k-eff value (Pa 4%) with variations fuel fractions (60%-65%)

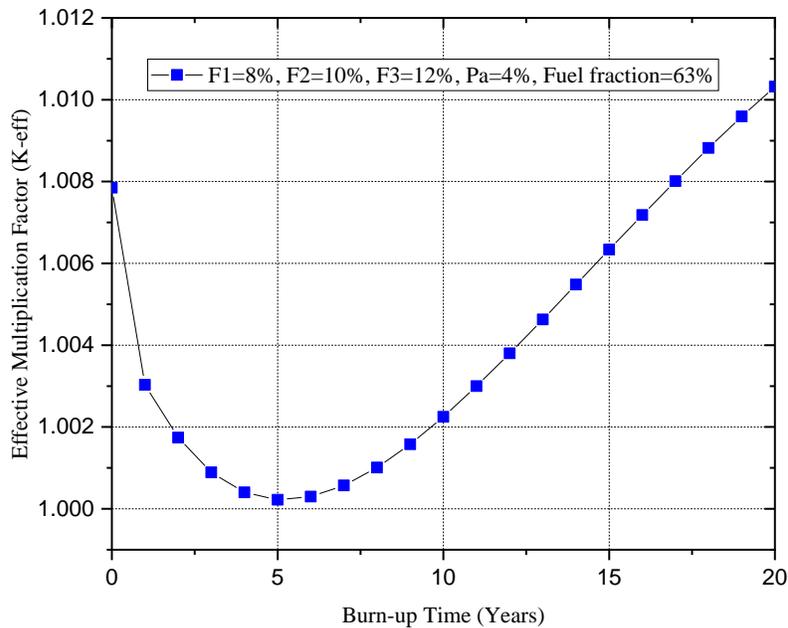


Figure 7. Optimization results design k-eff value



Conclusions

Analysis performance of uranium plutonium carbide (UC-PuC) as fuel in gas cooled fast reactor (GFR) with addition of protactinium as a burnable poisons has been done. The k-eff value which indicates the criticality level of the reactor, can be reduced during the combustion period to reach a critical state in the reactor by adding Pa-231 0% to 5% and varying the fuel fraction from 60% to 65% to produce the k-eff value. which indicates the reactor is in a critical state (k-eff ~ 1). The results obtained show that, the addition of protactinium 4% with a fuel fraction of 63% results in a k-eff ~ 1 value and produces a maximum excess reactivity of 1.02%.

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