Fuel Assembly Design Study for Modular Gas Cooled Fast Reactor using Monte Carlo Parallelization Method

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Abstract. As one of the advanced reactors new generation concept, Gas-cooled Fast Reactors can achieve higher electricity efficiency compare to the previous generation. The modular design is perfectly matched with Indonesia region that has many small islands. In this paper will be discussed about the design study of the fuel assembly for modular nuclear power plants using helium as cooling (GFR). The design reactors with hexagonal assembly and square assembly as a comparison to see which assembly configuration in GFR to get optimum results. Calculation for neutronic used Monte Carlo method with parallelization to accelerate computing time. Using OpenMC program code to build full three-dimension core simulation and neutronic calculation with nuclear data ENDF/B-VIII.b5 as a library. The neutronics results show the optimum design can be achieved.

1. Introduction
The development of renewable energy source poses an essential factor to solve at this time, with the increasing of the world population and the needs of energy that safe for environmental to each country. Indonesia faces a crisis energy where many remote areas and small islands outside java island experience of a random blackout that significantly disrupt of regional productivity process, these region needs small electrical power up to a hundred MWe [1-3].

Gas-Cooled Fast Reactor (GCFR) is one of the fourth generation of nuclear power plant (NPP) design which operate in high spectrum neutron and in high temperature when operating using helium gas as a coolant that usually called reactor breeder or can produce its fuel and Hydrogen gas [4-6]. The small modular reactor such GCFR with small long life characteristic can operate up to 20 years without refueling. This NPPs uses natural uranium mixed with plutonium as fuel to reduce cost production of uranium enrichment and also for proliferation factor.

The previous research, neutronic analysis of small long-life gas-cooled fast reactor utilizing MOX fuel still uses a cylindrical pin cell in core [7]. In this study, we design an assembly for full core 3D modular GCFR and using several types of fuel. The neutronic calculation using the OpenMC code with parallelization method that can speed up computational process time as the problem that we face when using Monte Carlo method [8].

We conduct a comprehensive study to obtain an optimum assembly design for small modular gas-cooled fast reactors using Plutonium as fuel. This research conduct about neutronic calculation with survey parameters. Survey parameters about the total pin in square and hexagonal assembly, fuel volume fraction and types of fuel.
2. Calculation Method

In this research will be focused on the design and survey parameters of reactors assembly to obtain the results of neutronic analysis.

Hexagonal and square type assembly was used to determine the optimum value of K-inf. Figure 1 shows survey parameters design of assembly in core with different in total pin and fuel fraction pin. Using different type of fuel and its nuclide percentages to show critical value of assembly. The calculation neutronic analysis were performed using Monte Carlo parallel computing OpenMC code program with data nuclides by library ENDF/B-VII.1, run on cluster computer with 12 processor.

3. Result and Discussion

Table 1 shows design assembly and core reactor with survey parameter in fuels type using compose of natural uranium mixed with plutonium, variation in ratio between volume fuel and the volume pin cell, and variation in total pins in one assembly.

| Parameter                  | Value                                      |
|----------------------------|--------------------------------------------|
| Reactor Geometry           | Small Modular                              |
| Fuels Type                 | UO2, MOX, (U,Pu)N, (U,Pu)C, (U,Pu)Zr      |
| Assemblys Type             | Hexagonal, Square                          |
| Coolant/Cladding Type      | Helium Gas, SS HT9                         |
| Assembly height            | 120 cm                                     |
| Enrichment U235 in UO2     | 1-10%                                      |
| Plutonium percentages (%)  | 3-10%                                      |
| Fuel volume fraction (%)   | 35-50                                      |
| Total pin in Hexagonal     | 91 pin (6n) – 217 pin (9n)                 |
| Assembly                  |                                            |
| Total pin in square        | 81 pin – 169 pin                           |

Figure 1 Configuration of assemblys in reactor core
3.1. Variations of fuel fraction and total pin in assembly

Figure 2 and Figure 3 show the change in value of infinite multiplication factor (K-inf) with the increment of enrichment U-235 in case of 35-50% fuel volume fraction and 127 pins in one assembly and in case of six rings to nine ring in assembly (91 to 217 pins). Increasing the enrichment of fissile nuclide (U-235), will increase the value of K-inf of both cases. By increasing fuel fraction (left) and the total pin (right), the value of K-inf in these cases has a small difference (<1%).

Figure 4 and figure 5 with square assembly show the same results with case before, by increasing the total pin, the K-inf have small difference (<1%). Likewise, increasing fuel fraction have a same result.
3.2. Variation of fuels type in assembly

Figure 6 Shows the result of comparison between hexagonal and square assembly with similar parameters. Using the same fuel fraction at 40% and 127 pins for hexagonal assembly and 121 pins for square assembly, the K-inf of both assembly have a tiny difference and similar pattern with the increment of fissile nuclide.

Figure 7 and Figure 8 shows the changes in the value of infinite multiplication factor (K-inf) with an increment of fissile nuclide U-235 and percentages ratio of Plutonium in case of 40% fuel fraction and total pin 121 for square assembly and 127 for hexagonal. There is a different result for each fuel type. MOX fuel has a minimum k-inf, while (U,Pu)Zr is the highest. Both cases have similar results and pattern.
Figure 9 shows the results of comparison between hexagonal and square assembly with fuel type parameters and change in the value of infinite multiplication factor (K-inf) with an increment of enrichment U-235 and percentages ratio of Plutonium in case of 40% fuel fraction and total pin 121 for square assembly and 127 for hexagonal. The K-inf of both assemblies has slightly difference with the increment of fissile nuclide.

4. Conclusion

Fuel assembly design study of Modular Gas Cooled Fast Reactor using Monte Carlo Parallelization Method with OpenMC Program has been performed. The design of reactor are small, a modular type with helium gas cooled, with hexagonal and square assembly. The comparison in geometry assembly and it is fuel type to determine which design is better in use for full core reactors. In this research hexagonal and square assembly have resulted in the neutronic design for uranium and plutonium mixed fuel, variation of fuel fraction pin and total pin assembly has been discussed. Increasing total pin and the fuel fraction for each assembly shows it’s K-inf have a small difference (<1%). Using 40% fuel fraction and 121 and 127 pins assembly for square and hexagonal assembly and metallic fuel (U,Pu)Zr shows optimum K-inf.

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