Preliminary Study of Gas Cooled Fast Breeder Reactor with Heterogen Percentage of Uranium–Plutonium Carbide based fuel and 300 MWt Power

Sandro Clief Pattipawaej¹, Zaki Su’ud
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: sandro_clief@yahoo.com

Abstract. A preliminary design study of GFR with helium gas-cooled has been performed. In this study used natural uranium and plutonium results LWR waste as fuel. Fuel with a small percentage of plutonium are arranged on the inside of the core area, and the fuel with a greater percentage set on the outside of the core area. The configuration of such fuel is deliberately set to increase breeding in this part of the central core and reduce the leakage of neutrons on the outer side of the core, in order to get long-lived reactor with a small reactivity. Configuration of fuel as it is also useful to generate a peak power reactors with relatively low in both the direction of axial or radial. Optimization has been done to fuel fraction 45.0% was found that the reactor may be operating in more than 10 year time with excess reactivity less than 1%.

1. Introduction
One of the problem in nuclear reactor is fuel waste. This fuel waste was remainder of LWR (Light Water Reactor) which usually keep in the safe place or being processed to become the new fuel. Waste of LWR has been processed can be used as fuel in fast reactor (FBR). This is one of the advantage of fast reactor compared to thermal reactor.
In addition it can be used to burn LWR waste, FBR gas cooled (Gas Cooled Fast Reactor) also has another advantage that allows it to produce the output temperature is more than 800°C with a relatively long operating life and small excess reactivity [1].
Disadvantages of this type of reactor is safety factor. High conversion ratio value and large breeding rate of reactor impacts the reactor stability. Some neutronics parameters be related with reactor stability is reactivity and power distribution.

2. Design Concept and Calculation Methods
In this study, the reactor core is designed three-dimensional hexagonal compiled by hexagonal shaped assemblies with exactly the same size. Core reactor consists of three important parts of active cores located in the centre of core, then covered with reflectors and a blanket stand beside the outer core [2].
Active core in the radial direction is divided into three regions. Region I consist of 3 line assembly, region II and III consist of 2 line assembly. Region I is filled by twelve fuel assembly (A), one inner

¹ To whom any correspondence should be addressed.
shut down assembly (D) and six inner control rod assembly (F). Region II is filled by thirty six intermediate fuel assembly (B) and six outer shut down (E). Region III is filled by forty eight fuel assembly (C) and eighteen outer control assembly (G).

![Core design](image)

**Figure 1.** Core design (a) radial direction, (b) axial direction

In the axial direction of active core is divided into three regions (Top, middle and bottom). Central region has a size larger than the upper or bottom region which has the same size. A general description of the reactor core in radial and axial directions given in ‘figure 1 (a) and (b)’ [2]. Each fuel assembly in active core is filled by 127 cylindrical fuel pin [2], while the control and shutdown is filled by 108 cylindrical fuel pin plus one control or shut down rod with a much larger size.

| Parameter                        | Specification                      |
|----------------------------------|------------------------------------|
| Thermal Power                    | 300 MWth                           |
| Refueling period                 | 10 – 20 years                      |
| Core Geometry                    | Hexagonal 3D                       |
| Coolant                          | Helium gas                         |
| Number of fuel assembly:         | (12, 36, 48)                       |
| (Region I, II, III)              |                                    |
| Number of control Rod assembly   | 24                                 |
| Number of shut down assembly     | 7                                  |
| Pellet material                  | (U-Pu)C                            |
| Pellet diameter (mm)             | 7.5                                |
| Cladding thickness (mm)          | 0.94                               |
| Cladding material                | SiC                                |
| Uranium enrichment               | $^{235}\text{U}(0.72\%), ^{238}\text{U}(99.28\%)$ |
| Plutonium enrichment             | $^{238}\text{Pu}(1.7\%), ^{239}\text{Pu}(58.8\%), ^{240}\text{Pu}(22.8\%), ^{241}\text{Pu}(1.7\%), ^{242}\text{Pu}(5\%)$ [3] |

The fuel used in core reactor is uranium plutonium carbide. In core, the fuel each region division based on the high percentage of plutonium (Pu). The percentage of Pu in region III (radial direction) and region top/bottom (axial direction) is made higher to reduce leaking neutron. Low percentage of
Pu in region I (radial direction) and axial center region contributes to the high value of conversion ratio. General specification of reactors are given in ‘table 1’.

Neutronic analysis of reactor core analyzed used SRAC (Standard Reactor Analysis Code) code system. In SRAC calculation is divided into two parts, namely lattice calculation and core calculation. Macroscopic cross section is calculated at lattice calculation, based on some energy group utilizing reactor constant library JENDL-32 [5]. Furthermore macroscopic data, can be used in 3D diffusion equation. Solution of this equation generated in the core calculation. Diagram block of design calculation is given in ‘figure 2’.

3. Results and Discussion
Optimization is done for fuel fraction 45.0%. For this fuel fraction obtained maximum configuration of Pu in each region is given by Reg I: 9.2%, Reg II: 11.4%, Reg III: 15.9% for up/bottom region and Reg I: 7.2%, Reg II: 9.4%, Reg III: 13.9% for middle region in axial direction.

Figure 2. Block diagram of neutronic calculation with SRAC [4]

Figure 3. Effective multiplication factor ($k_{eff}$)
Figure 4. Reactivity
The value of the effective multiplication factor ($k_{\text{eff}}$) and excess reactivity of reactor is given by ‘figure 3’ and ‘figure 4’. While the power distribution in radial and axial direction is given by ‘figure 5’.

From ‘figure 3 and figure 4’, it appears that the reactor has operation time to 20 years with reactivity less than 0.8%. In the beginning of life (BOL) at burn up step 1 and 2, the reactor is dominated by burning process. From step 3 until step 13 is dominated by breeding process. In end of life (EOL), reactor had a positive reactivity that allows the reactor to operate more than 20 years.

![Figure 5. Power distribution of reactor (a) radial direction, (b) axial direction](image)

The large time of reactor operation is caused by the amount of fuel in this reactor. The other reason is the reactor have a large value conversion ratio and has low percentage of Pu (high fertile material number) at each fuel region. Conversion is high and the number of fertile material which much guarantee the process of breeding for a long time.

From ‘figure 5’, it appears that the reactor had minimum power at control and shut down assemblies due to the amount of fuel material is less. The minimum power is also found in Region III (radial direction) and top/bottom (axial direction) due to the number of neutrons leaking more than any other region.

The transition of power distribution in the reactor was also influenced by the high value conversion ratio. The rate of transition conversion ratio or in this case a high breeding rate especially in area with the number of neutrons and fertile material is abundant, have a direct impact on the rate of transmission in the region. Base on “figure 5”, shows that the power transition is a significant change from the first year (BOL) to tenth years (MOL). Furthermore, after MOL power transition and breeding rate is also declining.

4. Conclusion

Placement of fuel material with a low percentage of plutonium in the centre of the reactor and the high neutron population in this area impact on high internal conversion of reactor. High internal conversion and high fuel fraction (45.0%) guarantees a long life of the reactor. This reactor can operate more than 20 years with reactivity less than 0.8% but high transition of power distribution. The rate of transition power distribution from BOL to MOL is larger than from MOL to EOL caused by from BOL to MOL reactor is dominated by breeding process and from MOL to EOL is dominated by burning. The heterogeneous of fuel material in any directions able to cut peak power of reactor. Power peaking factor of reactor form BOL to EOL is less than 1.3.
References

[1] Elder R and Allen R 2009 Nuclear heat for hydrogen production: Coupling a very high/high temperature reactor to a hydrogen production production plant *Progress In Nuclear Energy* **51** pp 500-525

[2] Waltar A E, Todd D R and Tsvetkof P V 2012 *Fast Spectrum Reactors* (London: Springer) p 487, 28

[3] Expert group 1999 Actinide and Fission Product Partitioning and Transmutation, Nuclear Energy Agency (NEA)/ (OECD), --, p 303

[4] Oka Y, Madarame H and Uesaka M 2014 *An Advance Course in Nuclear Engineering* (Tokyo: Springer) p 61

[5] Okumura K 2002 *SRAC version 2002* (Japan Atomic Energy Research Institute) pp 1-28