Design Study of 600 MWt Long Life Modular Gas Cooled Fast Reactors

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Abstract. Design study of long life 600 MWt gas cooled fast reactors which can be operated for 25 years without refueling or fuel shuffling has been performed. A small Gas-cooled Fast Reactors (GFRs) core loaded with uranium nitride fuel (UN) and mixed nitride fuel (UN-PuN) have been calculated by SRAC code system and FI-ITB CH1 code. The results show that it has been obtained some designs which can be operated for 25 years with relatively excess reactivity. The maximum excess reactivity is 2% dk/k. The reactor core is divided into three regions, the first region is filled with highest content of plutonium and located in the most outer region. The second part of the core is filled with second highest plutonium content and located in the inner part of first region. The third region is filled with the lowest content of plutonium and located in the central part of the core. At the beginning of life the first reactor is the most dominant, but as time proceeds the second and the third regions of the core become more important. The average burn-up is around 10% HM

1. Introduction

As a lesson learned from the TMI II, Chernobyl, Fukushima Nuclear Accidents, inherent safety capability becomes necessary for next generation Nuclear Power Plants (NPPs) to avoid severe accidents causing core melting. Gas cooled fast reactors is one of the Generation IV NPP which has inherent safety capability based on optimal reactivity feedback. Small and medium long-life modular reactors are very prospective for remote area with small-medium power consumption level such as many small islands in Indonesia.

In this study small/medium sized (600 MWt) gas cooled fast reactor designs which can be operated more than 20 years without refueling or fuel shuffling has been investigated. Considering helium gas limitation in transporting heat from the reactor cores, we limit average power density to be less than 75 W/cc. Therefore relatively large core designs were taken and pancake type cores are chosen to reduce severe heat transport burden in axial direction. Such system need high breeding/conversion ratio fuel to produce enough plutonium during its operation. To obtain NPP design with inherent safety capability, reactivity swing minimization is important to limit unprotected rod-run-out transient over power (UTOP) accident.
2. Design Concept and Methodology

The reactor core configuration adopt 3 region active core model as shown in the Figure 1 as follows.\(^{10-13}\)

\[
\begin{array}{cccccccc}
S & S & S & S & S & S \\
R & R & R & R & R & S \\
C3 & C3 & C2 & C1 & R & S \\
C3 & C3 & C2 & C1 & R & S \\
C3 & C3 & C2 & C1 & R & S \\
C3 & C3 & C2 & C1 & R & S \\
\end{array}
\]

Figure 1  Reactor core configuration used in this study. C1, C2, and C3 is core region, R is reflector, and S is shielding.

The configuration is adopted from previous study shown in the references. The Core I (C1) region is given highest plutonium content, the core II (C2) is given lower Plutonium content than C1 and the Core III (C3) is given relatively low Plutonium content. Therefore at the Beginning of life (BOL) the core I plays most important role as the power peak is located in this region. However as burn-up proceeds, the role of C2 and C3 increases and the power peak gradually shifted toward central direction. The lower content of Plutonium in the regions C2 and C3 give higher conversion ratio to enhance life time of the core.

The calculation method adopts Multi groups diffusion model with 60-70 energy groups using two dimensional R-Z geometry diffusion and Burnup Calculations. The burnup Calculation include 30 nucleus Uranium, Plutonium, Americium, Curium, and other minor actinides. The group constant is calculated using SRAC code system especially PIJ module\(^{14-15}\). The multigroup diffusion and burn-up calculations are conducted using FI-ITB CH1 code\(^{16}\).

3. Results and Discussions

Table 1 shows the main parameters used in this study. The reactor power is 600 MWt of gas cooled fast reactor type. At the beginning we perform parametric survey calculations and then optimization process is conducted.
Table 1 Main parameters used in the study

| No | Parameter                                      | Value                        |
|----|-----------------------------------------------|------------------------------|
| 1  | Power (MWt)                                   | 600                          |
| 2  | Operation time (years)                        | 25                           |
| 3  | Fuel material                                 | UN/PuN                       |
| 4  | Number of main core regions                   | 3                            |
| 5  | Region radial width (cm) Reg 1/2/3            | 55/30/20                     |
| 6  | Axial height (cm)                             | 175 cm                       |
| 7  | Reflector width (cm)                          | 30                           |
| 8  | Pu content (%)                                | 14/12.5/7                    |
| 9  | Fuel, structural dan coolant volume fractions of Region 1 | 35%/20%/45%                 |
| 10 | Fuel, structural dan coolant volume fractions of Region 2 | 35%/20%/45%                 |
| 11 | Fuel, structural dan coolant volume fractions of Region 3 | 35%/20%/45%                 |

Figure 2 shows k-inf parametric survey results for various Plutonium percentations. The calculations were performed for plutonium percentations from 8% to 15%.

Figure 2  K-inf as a function of burnup time for various Plutonium percentations.

It is shown in figure 2 that for low plutonium content the k-inf initially less than 1.0 (sub critical) but the k-inf value tend to increase till 6 years and then decreases. On the other hands, fuel with the high
plutonium percentage tend to continuously decreases with initial value much higher than 1.0 in order to achieve 10 years life time.

Figure 3 shows k-eff as a function of burnup time for optimized design. It is shown that the reactor can be operated for 25 years without refuelling or fuel shuffling with excess reactivity less than 2% $\text{dk}/k$. The $K_{\text{eff}}$ pattern initially decreases, then around 6 years start to increase till about 23 years and then start to decrease. The k-eff pattern change is basically influenced by composition in each core regions in which the outer core has the highest content of Plutonium while the central core has the lowest content of Plutonium at the BOL. Therefore the conversion ratio of the central core is the highest. At the end of life (EOL) the central region becomes dominant.

![K-eff change with burn-up for optimized design](image)

Figure 4 shows the k-inf pattern change with burn-up for the most outer core (Core I). It is shown that the K-inf pattern is monotonously decreases due to relatively high plutonium content. Figure 5 shows conversion ratio change with burn-up for the Core I. During the operation conversion ratio is always above 1.0 but its value continuously decreases. At the BOL its value is about 1.1 and at the EOL its value decreases to about 1.01.
Figure 4  K-inf pattern change with burnup time for the Core I

Figure 5 Conversion ratio pattern change with burnup time for the Core I

Figure 6 shows Pu-239 atomic density change for the Core I region. It is shown that the BOL the Pu-239 atomic density increases with monotonously reduced rate of change. At the EOL its value is relatively flat. At the EOL the U-238 to Pu-239 atomic density ratio is much smaller compared to that of BOL due to reduction of U-238 atomic density, as shown in Figure 7, and the increase of Pu-239 atomic density.
Figure 6 Pu-239 atomic density pattern change with burnup time for the Core I

![Pu-239 atomic density pattern change](image)

Figure 7 U-238 atomic density pattern change with burnup time for the Core I

![U-238 atomic density pattern change](image)

Figure 8 shows K-inf pattern change with burn-up for the Core II. Its pattern is similar to that of the Core I but with lower value of K-inf due to lower Plutonium content. Figure 9 shows conversion ratio pattern of the Core II. It is shown that initially the conversion ratio increases till about medium of life (MOL) but then decreases. This pattern is different from that of The Core I. The Plutonium content in the core II is smaller than that of the Core I. The shift of the power peak from the outer part of the core (the Core I) to the center direction has also influence on the conversion ratio pattern.
Figure 8  K-inf pattern change with burnup time for the Core II

Figure 9  Conversion ratio pattern change with burnup time for the Core II

Figure 10 shows Pu-239 atomic density pattern change during burn-up. It is monotonously increases and even though the rate of increase decreases till the end of life there is still no reversal pattern.
4. Conclusion

Design study of long life 600 MWt gas cooled fast reactors which can be operated for 25 years without refueling or fuel shuffling has been performed. The results shows that it has been obtained some designs which can be operated for 25 years with relatively low excess reactivity. The maximum excess reactivity is smaller than 2% $\Delta k/k$. The reactor core is divided into three regions, the first region is filled with highest content of plutonium and located in the most outer region. The second part of the core is filled with second highest plutonium content and located in the inner part of first region. The third region is filled with the lowest content of plutonium and located in the central part of the core. At the beginning of life the first reactor is the most dominant, but as time proceeds the second and the third regions of the core become more important. The average burn-up is around 10% HM

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