Indonesian Journal of Physics
Vol 20 No. 4, October 2009

Preliminary design study of Long-life Gas Cooled Fast Reactor With Modified CANDLE Burnup Scheme

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Abstract

In this paper, preliminary design study of Gas Cooled Fas Reactors with Natural Uranium as Fuel Cycle Input has been performed. Gas Cooled Fast Reactor is slightly modified by employing modified CANDLE burnup scheme so that it can use Natural Uranium as fuel cycle input. The natural uranium is initially put in region 1, after one cycle of 10 years of burn-up it is shifted to region 2 and the region 1 is filled by fresh natural uranium fuel. This concept is basically applied to all regions. In this case the system has been applied to many power level which results relatively flexible discharge burn-up level up from about 20%HM to 30 %HM.

Keywords: *Gas Cooled Fast Reactor (GCFR), Natural uranium, Burnup-cycle*

1. Introduction

Gas cooled fast reactors are among fourth generation Nuclear Power Plants (NPPs) with hard neutron spectrum characteristics. Such hard spectrum can be utilized to create the reactors system with high breeding capability. In this study the gas cooled reactor system are combined with modified CANDLE burnup scheme[1-6] to create long life fast reactors with natural circulation as fuel cycle input. Therefore using this type of nuclear power plants optimum nuclear energy utilization including in developing countries can be easily conducted without the problem of nuclear proliferation. The optimization processes include adjustment of fuel region movement scheme, volume fraction adjustment, core dimension, etc.

As discussed in previous studies, the average burnup level of about 30% HM or more in general resulted in the optimal design from criticallity point of view. However such burnup level is significantly above current advanced fast reactor material specification. In this study, the long-life gas cooled fast reactors are optimized to reduce average burnup level by employing excellent neutronic characteristics of these reactors.

2. Calculation Method

The calculation is performed using SRAC code system (SRAC-CITATION system) and FI-ITBCH1 code, detail explanation can be found in references[6-9]. At the beginning we assume the power density level in each region and then we perform the burn-up calculation using the assumed data. The burn-up calculation is performed using cell burn-up in SRAC code which then give eight energy group macroscopic cross section data to be used in two dimensional R-Z geometry multi groups diffusion calculation. The average power density in each region resulted from the diffusion calculation is then brought back to SRAC code for cell burn-up calculation. This iteration is repeated until the convergence is reached. For the safety analysis we adopt the methods we have developed and upgraded.

The reactor cores are subdivided into several parts (regions) with the same volume in the axial directions (See Figure 1) The natural uranium is initially put in region 1, after one cycle of 10 years of burn-up it is shifted to region 2 and the region 1 is filled by fresh natural uranium fuel. This concept is basically applied to all regions.

3. Results and Discussion

Table 1 shows sample design parameters. The reactor power is 550 MWt, with axially subdivided into 10 regions. The period of each shuffling period is 10 years. The fuel is nitride type UN-PuN, with natural uranium as fuel cycle input.

Figure 2 shows effective multiplication change during burn-up. The value of effective multiplication constant is monotonously increases. Therefore the important condition for criticality is in the beginning of life (BOL). Figure 3 shows the burn-up history. It shows that at first half of the burn-up history the burn-up level is very slowly increases. It is caused by the relatively low flux level in regions 1-5. But after entering regions 6-10 the plutonium accumulation rate significantly increases. Figure 4 shows infinite multiplication change during burn-up history. Consistent with the Figure 3, the slow accumulation of plutonium at half period of burn-up history caused slow increase of infinite multiplication constant. However for the first 10 years the increase of infinite multiplication constant relatively higher than in the period of 10-50 years. It is caused by the shuffling scheme which put first region near the 10'th region.

Figure 5 shows conversion ratio change during burn-up history. At the BOL the conversion ratio is high due to very low enrichment (fresh fuel is natural uranium) but gradually decrease and becoming slightly higher than one at the end of life (EOL).

Figures 6 and 7 shows the U-238 and Pu-239 atomic density change during burn-up history. U-238 atomic density decrease slowly at the BOL and significantly accelerated after half of burn-up history. This is consistent with the results in Figs. 3-5. Pu-239 atomic density increases slowly at the BOL and its change rate significantly increases after half of burn-up history when the fuels enters the most active regions (Regions 6-10).

This results shows that gas cooled fast reactors can be designed as nuclear power plant with natural uranium as fuel cycle input. The results is roughly comparable as Pb-Bi cooled NPP.

Table 1. Sample Design Parameter

Parameter	Value/description
Power (MWth)	550
Number of equal volume region in core	10
Sub cycle length (years)	10
Fuel type	Natural Uranium, nitride
Fuel volume fraction	65%
Cladding volume fraction	10%
Coolant volume fraction	25%
Fuel diameter	1.2 cm
Coolant type	He
Axial width of each region	17.5 cm
Active core radial width	120 cm
Reflector radial width	50 cm
Reflector axial width	50 cm

Figure 1. Sub-region division and shuffling scheme

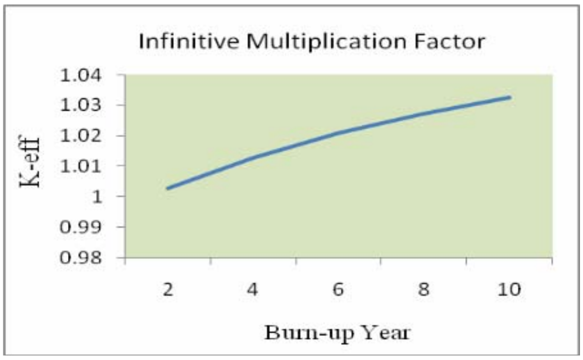

Figure 2 Effective multiplication change during burnup

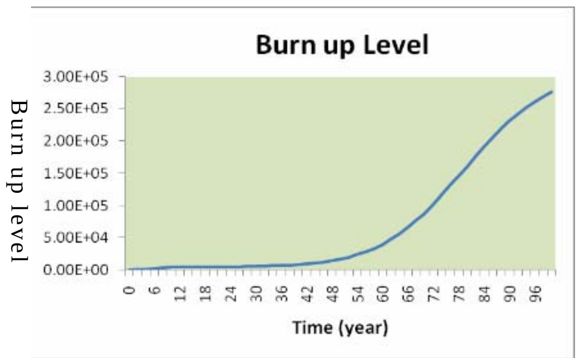

Figure 2. Effective multiplication change during burnup

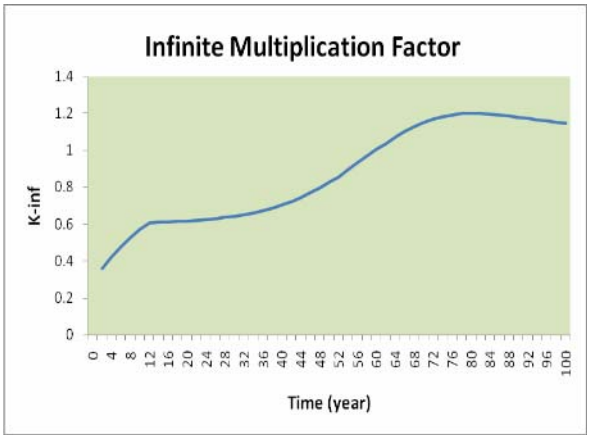

Figure 3. Burn-up level change during burn-up history

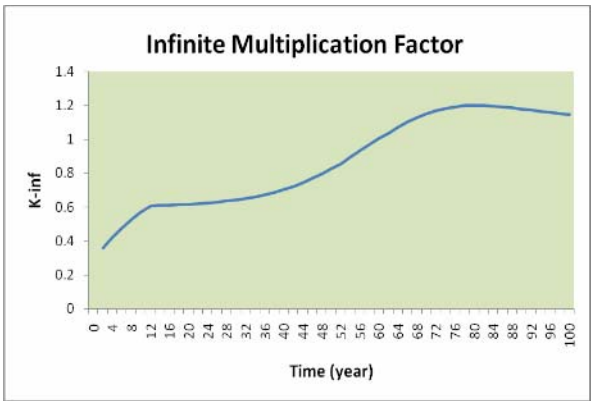

Figure 4. Effective multiplication change during burn-up history

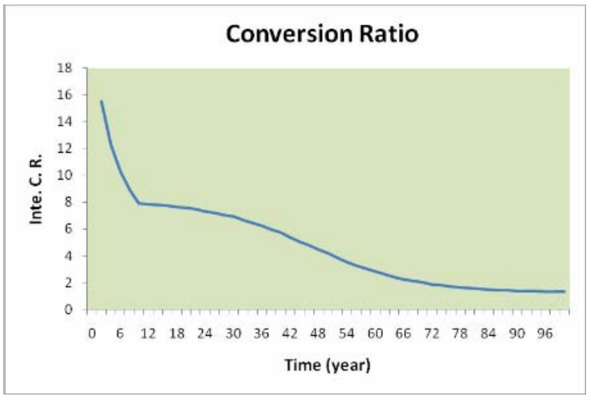

Figure 5. Conversion ratio change during burn-up history

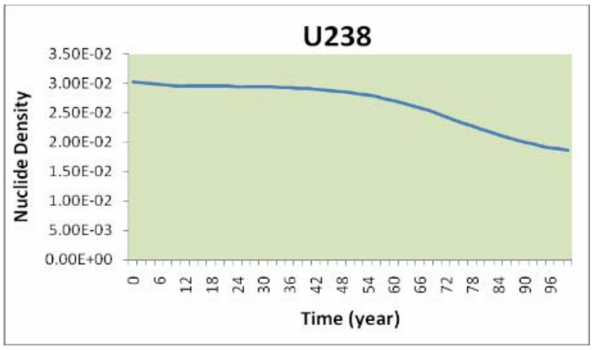

Figure 6. U-238 nuclide density change during burn-up history

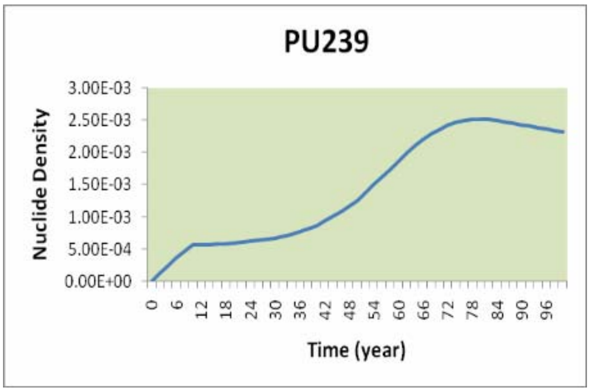

Figure 7. Pu-239 nuclide density change during burn-up history

Conclusion

Preliminary design study of Gas Cooled Fas Reactors with Natural Uranium as Fuel Cycle Input has been performed. Gas Cooled Fast Reactor is slightly modified by employing modified CANDLE burnup scheme so that it can use Natural Uranium as fuel cycle input . In this case the system has been applied to many power levels which give relatively flexible discharge burn-up level up from about 20%HM to 30 %HM.

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