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Design of Small Gas Cooled Fast Reactor with Two Region of Natural Uranium Fuel Fraction

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Abstract A design study of small Gas Cooled Fast Reactor with two region fuel has been performed. In this study, design GCFR with Helium coolant which can be continuously operated by supplying mixed Natural Uranium without fuel enrichment plant or fuel reprocessing plant. The active reactor cores are divided into two region fuel i.e. 60% fuel fraction of Natural Uranium as inner core and 65% fuel fraction of Natural Uranium as outer core. Each fuel core regions are subdivided into ten parts (region-1 until region-10) with the same volume in the axial direction. The fresh Natural Uranium initially put in region-1, after one cycle of 10 years of burn-up it is shifted to region-2 and the each region-1 filled by fresh Natural Uranium. This concept is basically applied to all regions in both cores area, i.e. shifted the core of i^{th} region into i+1 region after the end of 10 years burn-up cycle. For the next cycles, we will add only Natural Uranium on each region-1. The burn-up calculation is performed using collision probability method PIJ (cell burn-up calculation) in SRAC code which then given eight energy group macroscopic cross section data to be used in two dimensional R-Z geometry multi groups diffusion calculation in CITATION code. This reactor can results power thermal 600 MWth with average power density i.e. 80 watt/cc. After reactor start-up the operation, furthermore reactor only needs Natural Uranium supply for continue operation along 100 years. This calculation result then compared with one region fuel design i.e. 60% and 65% fuel fraction. This core design with two region fuel fraction can be an option for fuel optimization.

Keywords: two region, fuel fraction, Natural Uranium, Modified CANDLE
PACS: 28.20.Gd

INTRODUCTION

The Natural Uranium fuel cycle remains an attractive option for current and prospective reactors, for a variety of reasons. The fuel itself is simple, consisting of only seven basic components, and can be easily manufactured in many countries. The use of natural uranium avoids a requirement for Uranium-enrichment capability. It also avoids the creation of depleted-Uranium enrichment-plant.

In the present paper, a Modified CANDLE burn-up calculation for small and long life Gas Cooled Fast Reactor was described. Gas Cooled Fast Reactor included in the Generation-IV (GEN-IV) reactor systems are being developed to provide sustainable energy resources that meet future energy demand in a reliable, safe, and proliferation-resistant manner. These innovative reactor systems aim at the sustainability, safety and reliability, economics and proliferation resistance and physical protection of the future nuclear fuel cycle.

Conceptual design GCFR with Helium coolant which can be continuously operated by supplying Natural Uranium without fuel enrichment plant or fuel reprocessing plant. The CANDLE (Constant Axial shape of Neutron flux, nuclide densities and power shape During Life of Energy producing reactor) burn-up strategy can be applied to several reactors, when the infinite neutron multiplication factor of fuel element of the reactor changes along burn-up as the followings [1,2].

In this case CANDLE burn-up strategy is slightly modified by introducing discrete regions. The reactor cores are subdivided into several parts with the same volume in the axial directions. The previous study shows that Modified CANDLE concept was

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successfully applicable to long-life fast reactor with Natural Uranium as fuel cycle input [4]. This technology allows for the reactor which has been operating, furthermore it only need supply Natural Uranium as fuel cycle.

DESIGN CONCEPT

The reactor core is that part of the reactor where the nuclear fuel assemblies are located and the fission reaction takes place. Design was optimized by division of core into two regions with different fuel fraction. Inner core with 65% fuel fraction and outer core with 65% fuel fraction. Detail specification for the reactor design given by Table 1.

TABLE 1. Reactor Core Design Parameter

Parameter	Value/Description
Power	600 MWth
Fuel material	Nitride- Nat. Uranium
Cladding material	Stainless Steel
Coolant material	Helium
Inner core volume fraction	60% :10% : 30%
Outer core volume fraction	65% :10% : 25%
Fuel pin diameter	1.4 cm
Active core radial width	120 cm
Active core axial height	350 cm
Radial Reflector width	50 cm
Sub cycle length	10 years

In this design the active reactor core are divided into two region fuel, inner core was contains Natural Uranium with 60% fuel fraction and outer core with 65% fuel fraction (Fig. 1). Both cores area were subdivided into ten parts (region-1 until region-10) with the same volume in the axial direction. In Modified CANDLE burn-up scheme strategy (Fig. 2), the fresh 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 fuels [4]. This concept is basically applied to all regions in fuel cores area, i.e. shifted the core of i^{th} region into i+1 region after the end of 10 years burn-up cycle. Furthermore for the next cycles, we will add only Natural Uranium on region-1, so that this reactor will be able to operate until 100 years with only nitride Natural Uranium as fuel cycle input.

CALCULATION METHOD

The calculation is performed using SRAC code system (SRAC-CITATION system) with JENDL-3.2 nuclear data library [3]. 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 given 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.

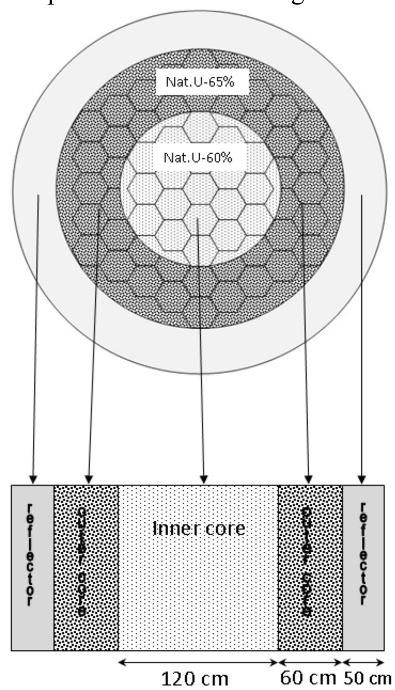

FIGURE 1. Reactor Core configuration.

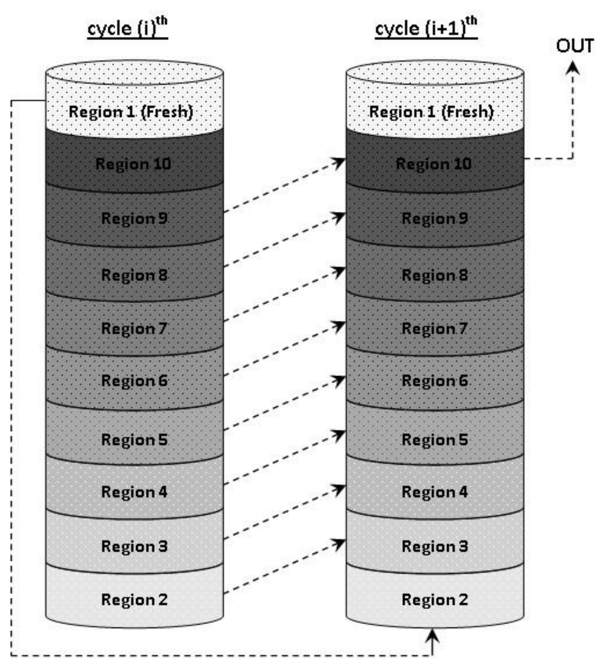

FIGURE 2. Modified CANDLE burn-up scheme.

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RESULT

The results of calculation with modified CANDLE strategy for 100 years burn-up are presented as follows. Fig. 3 shows effective multiplication in sub cycle. For the reactor with 60%, 65% and two region fuel (60/65)%, k_{eff} value always above 1.0. It can be indicates that the reactor can operate 10 years without refueling.

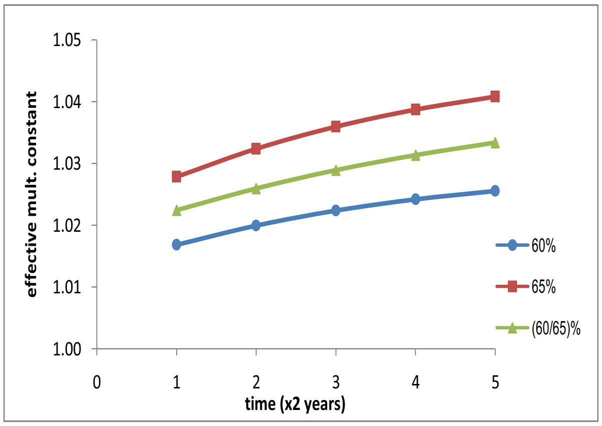

FIGURE 3. Effective multiplication factor in sub-cycle

Fig. 4 shows infinite multiplication factor change during burn-up history. It is shown that the infinite multiplication factor continuously increases. Inner core value increase more rapidly than others. The change of the slope is related to the position shift (see Fig.2).This condition is related to burn-up level change in Fig. 5.

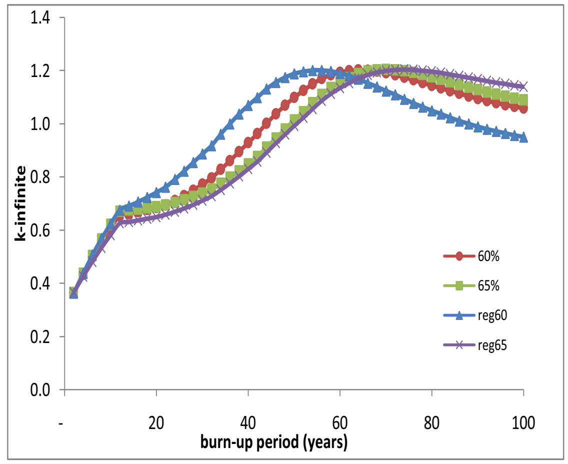

FIGURE 4. k-infinite Change during Burn-up.

TABLE 1. Initially fuel material composition in each region

Nat. U-60% (inner core)	% of Pu-239	Nat. U-65% (outer core)	% of Pu-239
Region-1	0	Region-1	0
Region-2	2.0	Region-2	1.6
Region-3	3.0	Region-3	2.2
Region-4	4.4	Region-4	2.7
Region-5	6.5	Region-5	3.8
Region-6	8.1	Region-6	5.6
Region-7	8.2	Region-7	7.3
Region-8	7.5	Region-8	8.2
Region-9	6.6	Region-9	8.3
Region-10	6.0	Region-10	7.9

Table 2 shows the initially composition material that is atomic percent of Plutonium-239 in core region (both inner core and outer core). After reactor start up the operation with this condition, furthermore reactor only needs Natural Uranium supply for continue operation until 100 years burn-up.

Figure 5 shows the burn-up level increases slowly up to 30 years of burn-up. But after that, along with significant accumulation of Plutonium, the burn- up level increases significantly. Change from fuel U-238 that have not able to generate power to become the main fuel containing enough Pu-239 that producing great power.

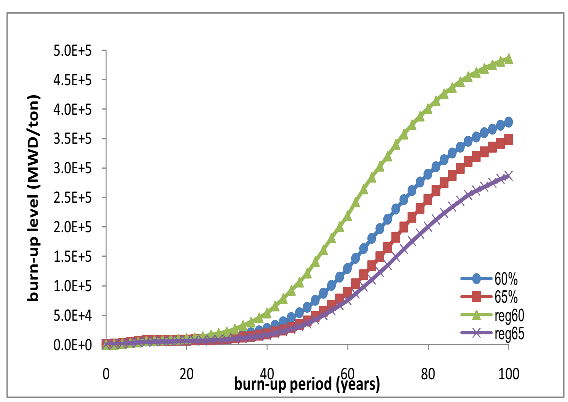

FIGURE 5. Burn-up Level change during Burn-up

Figure 6 shows the axial power distribution for all core configurations. Average power density for core with 60% fuel fraction is 75.7 watt/cc and core with 65% fuel fraction is 75.8 watt/cc. The value of average power density for core with two region fuel (60/65)% was higher i.e. 80.0 watt/cc.

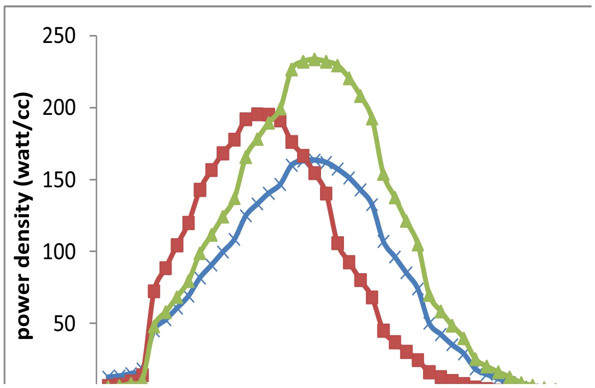

FIGURE 6. Axial Power Distribution for All Core Configuration

Figure 7 shows the power distribution in axial direction. It indicates that in 10 years operation there was some shift in the density resources toward more less of burn-up level.

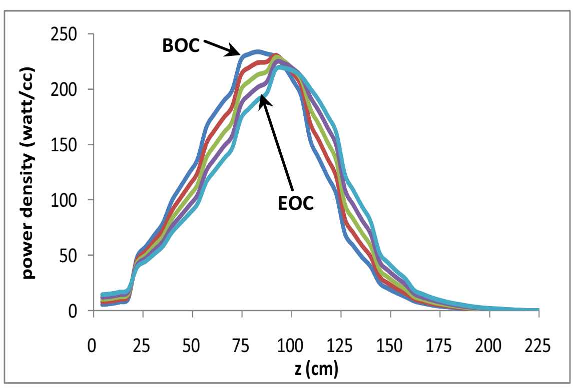

FIGURE 7. Axial Power Distribution in sub-cycle

CONCLUSION

Design of Small and Long-life Gas Cooled Fast Reactor with Helium coolant has been investigated. The reactor with thermal power 600 MWth was designed for 100 years long-life. Using Modified CANDLE burn-up strategy, a reactor start up the operation, furthermore this reactor only needs Natural Uranium supply for continue operation along 100 years without refueling in sub-cycle. optimizations performed by the division of fuel core i.e inner core (60% fuel fraction) and outer core (65% fuel fraction). This core configuration was result average power density value higher than single core without division. The average power density was 80.0 watt/cc.

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