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The Feasibility Study of Small Long-Life Gas Cooled Fast Reactor with Mixed Natural Uranium/Thorium as Fuel Cycle Input

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Abstract. A conceptual design study of Gas Cooled Fast Reactors with Modified CANDLE burn-up scheme has been performed. In this study, design GCFR with Helium coolant which can be continuously operated by supplying mixed Natural Uranium/Thorium without fuel enrichment plant or fuel reprocessing plant. The active reactor cores are divided into two region, Thorium fuel region and Uranium fuel region. 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 and Thorium is 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 is filled by fresh natural Uranium/Thorium fuel. 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 and Thorium on each region-1. The calculation results show the reactivity reached by mixed Natural Uranium/Thorium with volume ratio is 4.7:1. This reactor can results power thermal 550 MWth. After reactor start-up the operation, furthermore reactor only needs Natural Uranium/Thorium supply for continue operation along 100 years.

Keywords: mixed Natural Uranium/Thorium, burn-up, Modified CANDLE
PACS: 28.41.Vx

INTRODUCTION

Thorium is approximately three times as abundant as uranium in the earth's crust, reflecting the fact that thorium has a longer half-life. In addition, thorium generally is present in higher concentrations (2-10%) by weight than uranium (0.1-1%) in their respective ores, making thorium retrieval much less expensive and less environmentally damaging per unit of energy extracted. However, thorium is not fissile materials that can react spontaneously, is a fertile material whose use needs to be mixed with fissile materials such as U-235, U-233 or Pu-239. A mixed thorium/uranium (UN/ThN) fuel cycle offers several advantages over the conventional all-uranium fuel cycle. The fissile isotope U-233 produced from Th-232 has better

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fissile properties in thermal and epithermal energy ranges than U-235. The Th-232 also contributes to a smaller reactivity swing over the irradiation cycle, and reduces the requirements for control materials. It would be useful to combine these benefits with a long fuel cycle lifetime which has been investigated since long time ago[1-7].

In the present paper, a Modified CANDLE burn-up calculation for long life Gas Cooled Fast Reactor is described. In this study, conceptual design GCFR with Helium coolant which can be continuously operated by supplying mixed Natural Uranium/Thorium 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 [10-17].

In this case CANDLE burn-up strategy is slightly modified by introducing discrete regions. In this design 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 successfully applicable to long-life fast reactor with Natural Uranium as fuel cycle input [10-17]. This technology allows for the reactor which has been operating, furthermore we only need to supply Natural Uranium fuel.

DESIGN CONCEPT

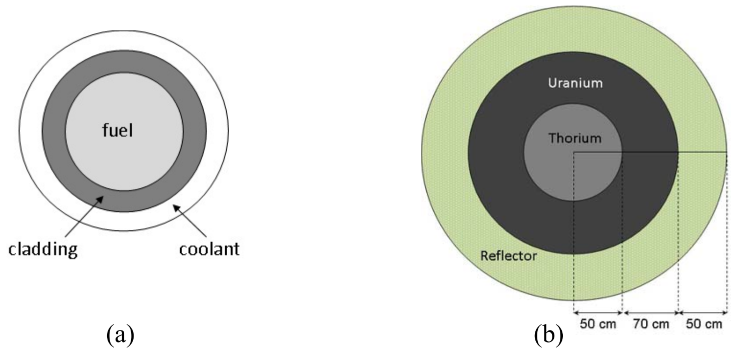
The reactor was designed to have long life. Reactor design optimization is evaluated to utilize mixed Natural Uranium/Thorium as reactor fuel. Detail specification for the reactor design given by Table 1.

TABLE 1. Reactor core design parameters.

Parameter	Value/Description
Power	550 MWth
Fuel material Cladding material	Nitride (Mixed Natural Uranium/Thorium) Stainless Steel
Coolant material	Helium
Core Volume fraction (Fuel:cladding:coolant)	65% :10% : 25% for inner core/Th 65% :10% : 25% for outer core/U
Fuel pin diameter	1.4 cm
Pin gap size	0.1 mm
Active core radial width	120 cm
Active core axial height	350 cm
Radial Reflector width	50 cm
Sub cycle length	10 years

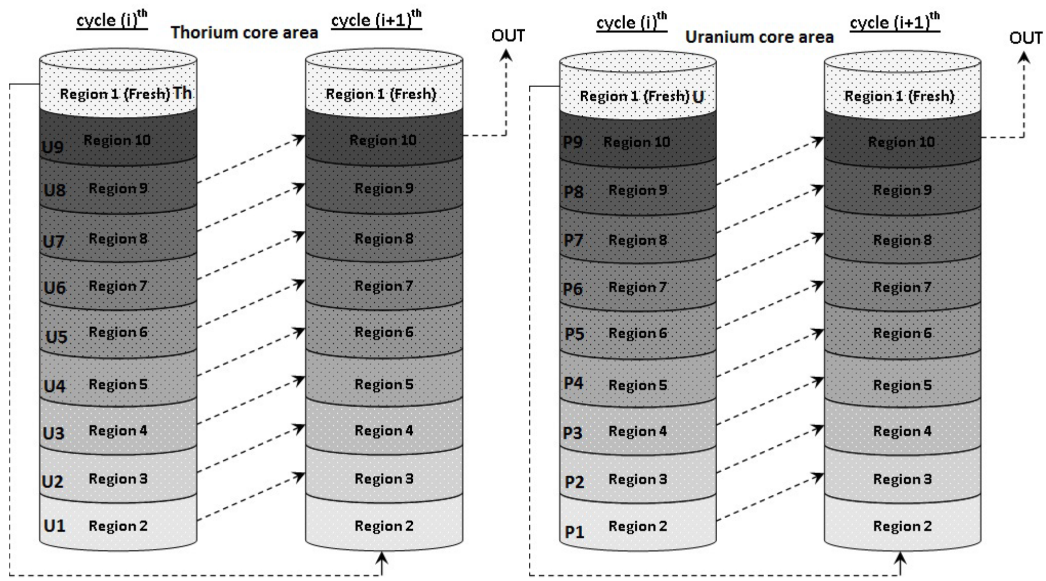
In this design the active reactor core are divided into two region, Thorium with 65% fuel fraction in Fig. 2(a) and Uranium with 65% fuel fraction in Fig. 2(b). This value was used in order to get the criticality. Both cores area (Thorium and Uranium area) is subdivided into ten parts (region-1 until region-10) with the same volume in the axial direction. In the Uranium core area, region-1 is filled with fresh Natural Uranium. Region-2 is filled with the fuel with Plutonium content P1; region-3 is filled with the fuel with plutonium content P2, and so on until region-10 is filled with the fuel with Plutonium content P9. Here P9>P8>…>P1. On the Thorium core area, region-1 is filled with fresh natural Thorium (Th-232). Region-2 is filled with the fuel with U-233 content U1; region-3 is filled with the fuel with U-233 content U2, and so on until region-10 is filled with the fuel with U-233 content U8. Here U9>U8>…>U1.

In Modified CANDLE burn-up scheme strategy, in both cores area, the fresh Natural Uranium and Thorium is 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 is filled by fresh natural Uranium/Thorium fuels. 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 (see Fig. 2). Furthermore for the next cycles, we will add only Natural Uranium and Thorium on each region-1, so that this reactor will be able to operate for 100 years with only UN/ThN as fuel cycle input.



(a) (b)

FIGURE 1. (a) fuel pin geometry; (b) cross section core



(a) (b)

FIGURE 2. Modified CANDLE burn-up scheme for: (a) Thorium fuel core area; (b) Uranium fuel core area

CALCULATION METHOD

The calculation is performed using SRAC code system (SRAC-CITATION system) with JENDL-3.2 nuclear data library [18]. 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.

RESULT AND DISCUSSION

The results of calculation with modified CANDLE strategy for 100 years burn-up are presented as follows. Table 2 shows the initially composition material in core region (both inner core and outer core). The second column shows the percentage of fissile material U-233 in inner core and the fourth column shows the percentage of the population of fissile material Pu-239 in outer core It was minimum value to get the criticality and must be accomplished in order to after reactor start up the operation with this condition then it can be continued by supply Natural Uranium and Thorium only on the next cycle (both Uranium/Thorium fuel area).

TABLE 2. Initially fuel material composition in each region

Thorium area	% of U-233	Uranium area	% of Pu-239
Region-1	0	Region-1	0
Region-2, U1	2.6	Region-2, P1	2.6
Region-3, U2	2.8	Region-3, P2	2.7
Region-4, U3	3.2	Region-4, P3	2.9
Region-5, U4	4.1	Region-5, P4	3.6
Region-6, U5	5.6	Region-6, P5	4.9
Region-7, U6	7.0	Region-7, P6	6.7
Region-8, U7	7.3	Region-8, P7	8.0
Region-9, U8	6.9	Region-9, P8	8.2
Region-10, U9	6.3	Region-10, P9	8.0

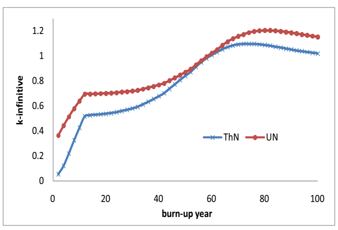


FIGURE 3. k-infinite change during burn-up

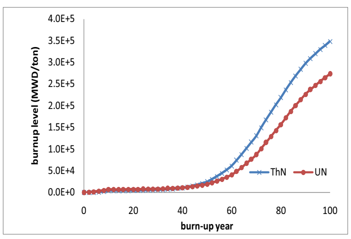


FIGURE 4. burn-up level change during burn-up

Fig. 3 shows infinite multiplication factor change during burn-up history. This condition is related to burn-up level change in Fig. 4. Change from fuel U-238/Th-232 that have not able to generate power to become the main fuel containing enough Pu-239/U-233 that producing great power. From cell calculation we get the value average burn-up Thorium is $9.51x10^4$ MWd/T. The total heavy metal weight for initial inner core (Thorium) for 550 MWth plant to operated 1 year is 2.111 HMT. In outer region we get the value average burn-up Uranium was $7.16x10^4$ MWd/T so the total heavy metal weight (Uranium) need for 1 year operation was 2.804 HMT

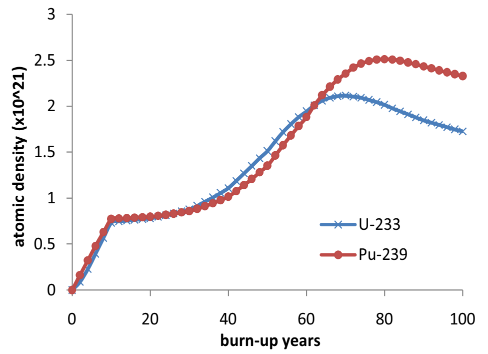


FIGURE 5. atomic density change during burn-up

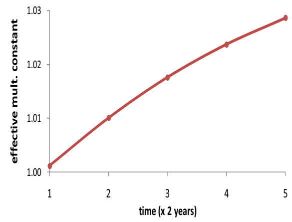


FIGURE 6. k-effective value in sub cycle

Fig.5 shows the atomic density of U-233 resulting from Th-232 and Pu-239 that resulting from U-238, change during burn-up history. Fig. 6 shows effective multiplication in sub cycle. It can be indicates that the reactor can operate 10 years without refueling because k_{eff} value always above 1.0.

CONCLUSION

The feasibility of design small and long-life Gas Cooled Fast Reactor with Modified CANDLE burn-up scheme has been investigated. It was supplied by mixed Natural Uranium/Thorium as fuel cycles. The results show the reactivity reached by mixed Natural Uranium/Thorium with volume ratio is 4.7:1. This reactor can results power thermal 550 MWth. After reactor start up the operation, furthermore reactor only needs Natural Uranium/Thorium supply for continue operation along 100 years.

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