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Conceptual Design Study on Very Small Long-Life Gas Cooled Fast Reactor using Metallic Natural Uranium-Zr as Fuel Cycle Input

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Abstract. A conceptual design study of very small 350 MWth Gas-cooled Fast Reactors with Helium coolant has been performed. In this study Modified CANDLE burn-up scheme was implemented to create small and long life fast reactors with natural Uranium as fuel cycle input. Such system can utilize natural Uranium resources efficiently without the necessity of enrichment plant or reprocessing plant. The core with metallic fuel based was subdivided into 10 regions with the same volume. 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 each region-1 is filled by fresh Natural Uranium fuel. This concept is basically applied to all axial regions. The reactor discharge burn-up is 31.8% HM. From the neutronic point of view, this design is in compliance with good performance.

Keywords: Metallic fuel, Natural Uranium, Modified CANDLE, Gas-cooled Fast Reactors, SRAC - CITATION code, burn-up, natural circulation
PACS: 28.41.-i

INTRODUCTION

Gas-cooled fast reactors (GFR) are among fourth generation Nuclear Power Plants (NPPs) with hard neutron spectrum characteristics which have excellent capability to utilize Uranium-238 during their operation. 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 this study small 350 MWth GFR designs which can utilize natural Uranium as fuel cycle input has been investigated. This reactor uses the metallic fuel with Uranium-Plutonium fuel cycle. The fuel alloy is stabilized using typically a 10% addition of zirconium to both. Alloy element of Zr (Zirconium) added to improve corrosion resistance, increase solidus temperature, and enhance dimensional stability. Zr was selected due to favorable irradiation testing results. As metal alloy fuels, U-10wt%Zr continued to be developed it was discovered that low smear density allowed the fuel to operate a much higher burn-up[1][2].

The CANDLE (Constant Axial shape of Neutron flux, nuclide densities and power shape During Life of Energy production) burn-up strategy is a unique and new burn-up concept. It 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[3][4][5]. 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.

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[6][7][8][9][10][11].

From the safety point of view removing decay heat in the severe accident in important, and in this case the air natural circulation in the outside of reactor vessel can be one of the alternative for this purpose.

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Therefore in case of severe accident such as in the Fukushima nuclear accident, the reactor is expected to remove the heat through radiation or convection to the wall and the wall will be cooled by natural circulation of air.

DESIGN CONCEPT

The reactor core of GFR usually gives hard neutron spectrum and similarly metallic fuel with its high density of fissile material can be expected to give hard neutron spectrum. Therefore the current design can be expected to give hard spectrum fast reactors which have high capability of converting fertile material into fissile material.

The modified CANDLE design where about half of the core will effectively becomes breeding zone while the rest become burning zone. Detail specification for the reactor design is given in Table 1. In this design the active reactor core is subdivided into ten parts (region-1 until region-10) with the same volume in the axial direction. In the Modified CANDLE burn-up scheme strategy (Figure 1), the fresh Natural Uranium is initially placed 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. This concept is basically applied to all regions in the fuel cores area, i.e. the core of i^{th} region is shifted into i+1 region after the end of 10 years burn-up cycle. Furthermore for the next cycles, we just add Natural Uranium on region-1, so that this reactor will be able to operate till 100 years with only metallic Natural Uranium (U-10%wt Zr) as fuel cycle input.

TABLE 1. Sample design parameters.

Parameter	Value/Description
Power	350 MWth
Fuel material	U-10wt%Zr (metallic)
Cladding material	Stainless Steel
Coolant material	Helium
Core Volume fraction (Fuel : cladding : coolant)	57% :10% : 33%
Smear density	85% TD
Pin pitch diameter	1.4 cm
Number of equal volume region in core	10
Active core diameter	220 cm
Axial width of each region	14 cm
Radial reflector width	100 cm
Sub cycle length	10 years
Reactor life	100 years

CALCULATION METHOD

Neutronic performance for analyzing the neutron aspect was calculated by using of SRAC-CITATION code system with JENDL-3.2 nuclear data library[12]. In 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 collision probability method PIJ (cell burn-up calculation) in SRAC code which gave eight energy group macroscopic cross section data to be used in two dimensional R-Z geometry multi groups diffusion calculation in CITATION code. The average power density in each region resulted from the diffusion calculation is then brought back to PIJ code for cell burn-up calculation. This iteration will be repeated until the average power density converged.

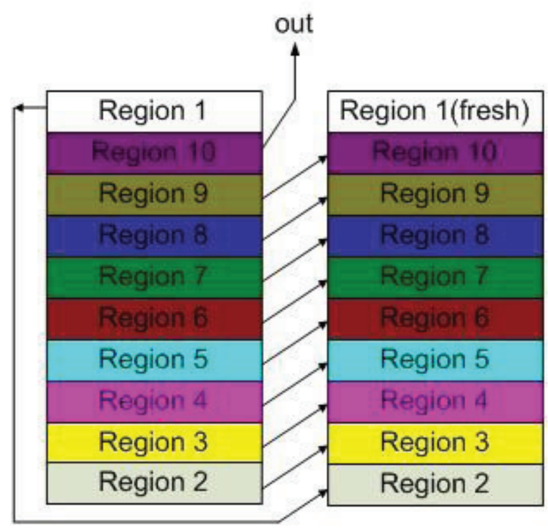

FIGURE 1. Modified CANDLE burn-up scheme and its shuffling

RESULTS AND DISCUSSIONS

The results of calculation with Modified CANDLE strategy for 100 years burn-up are presented as follows. Table 1 shows sample parameters design. The reactor power is 350 MWth with fuel volume fraction of about 57%. Such high fuel volume fraction is necessary to obtain modified CANDLE burn-up with relatively lower maximum discharge burn-up level.

The parametric survey results calculation during burn-up was described here; cell and core calculation result, effective and infinite multiplication constant, integral conversion ratio, burn-up level change history and distribution of atomic density U-238 and Pu-239.

Figure 2 shows that the infinite multiplication change during burn-up increased sharply at the first ten years of burn-up due to the location of the first region near the most active regions (see Figure 1). After that the infinite multiplication factor gradually increase and reach its maximum value near the end of burn-up history and then gradually decrease due to the significant decrease of U-238 atomic density.

Figure 3 shows conversion ratios change during burn-up. It is shown that during first 10 years, the conversion ratio decrease sharply due to accumulation of Plutonium-239 in the first region and to the decrease of Uranium-238. At a later time, the conversion ratios still decreases but rather slowly.

From Figure 4 and Figure 5, it is shown that the accumulation of Pu-239 increases sharply during the first 10 years and then increases rather slowly up to reach peaks near the end of their burn-up history. The Pu-239 atomic densities, then decreases slowly due to the significant reduction of U-238 atomic densities.

Figure 6 shows burn-up level history. It shown that the burn-up level at the beginning of life increased slowly until the midle of life. After that, the burn-up level increases rapidly until the end of life. This figure shows changes in the fresh fuel to become the main fuel that producing great power. The discharge burn-up for the 350 MWth core is 31.8% HM.

Figure 7 shows effective multiplication in one sub cycle. It shows that this reactor can operate for 1 cycle (10 years) without refueling because its value is always above 1.0. The criticality in the beginning of the cycle (BOC) was achieved and monotonously increased. Such situation occur due to the fact that the discharge burn-up is 31.8% HM which is far less than the maximum possible discharge burn-up for CANDLE or modified CANDLE burn-up scheme.

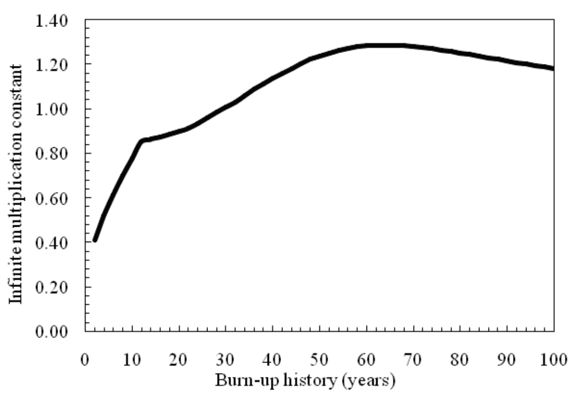

FIGURE 2. Infinite multiplication factor change during burn-up history.

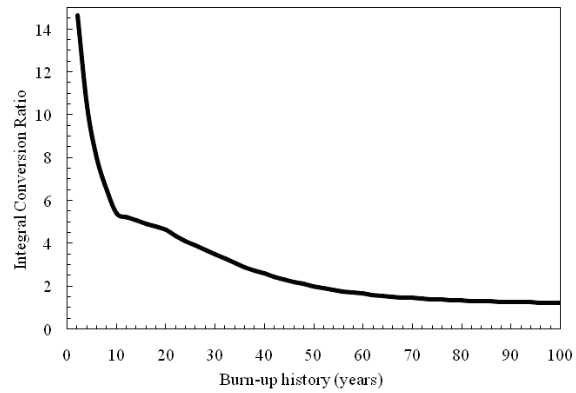

FIGURE 3. Integral conversion ratio during burn-up history

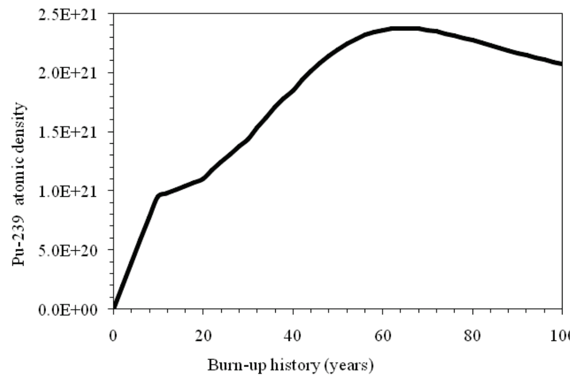

FIGURE 4. Pu-239 atomic density change during burn-up history.

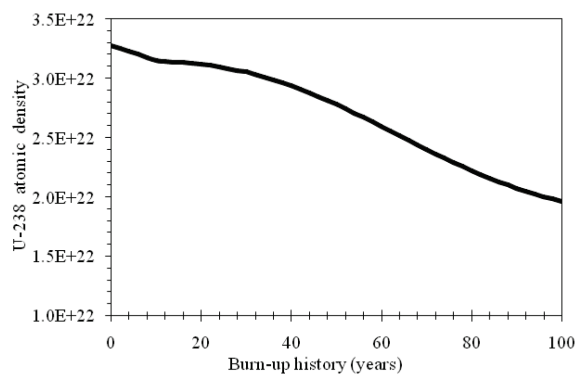

FIGURE 5. U-238 atomic density change during burn-up history.

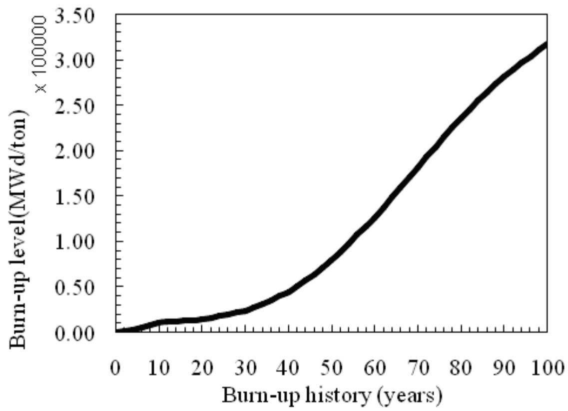

FIGURE 6. Burn-up level change during burn-up history

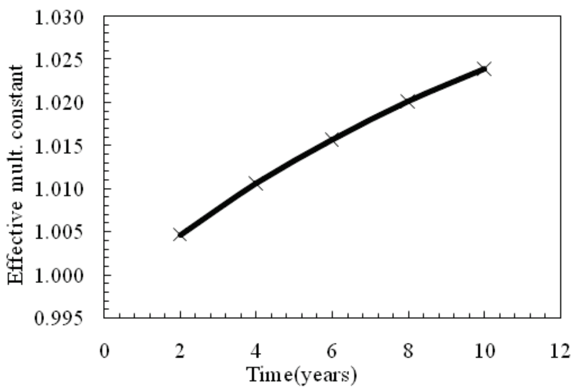

FIGURE 7. Effective multiplication factor change during burn-up time

In general the high breeding capability of this reactor resulted in monotonously increasing the effective multiplication factor during a 10 years of burn-up cycle and infinite multiplication factor which is still above 1.0 after 100 years of burn-up history. The sharp increase in infinite multiplication factor in the first 10 years of burn-up history is related to the position of the first region near the 10th region so that the breeding process is relatively accelerated compared to the situation when it is located far from the burning zone (regions 2-5). From Figure 2 it is clear that the infinite multiplication factor increases up to 60 years and then decreases. Therefore it can be thought that the breeding dominant region is from region 1 to region 6 while effectively burning zone is the region 7-10.

CONCLUSIONS

The conceptual design study of small and long life Gas Cooled Fast Reactor with Helium coolant and Modified CANDLE burn-up strategy has been investigated. The reactor with thermal power 350 MWth was designed for 10 years long life operation without refueling and fuel shuffling. The infinite multiplication factor change pattern increases up to 60 years and then decreases till the end of the reactor's life. Therefore the breeding dominant region is from region 1 to region 6 while the effective burning zone is the region 7-10. The reactor discharge burn-up is 31.8% HM. The present investigation confirmed that the reactor can be operated to 10 years without refueling and fuel shuffling and only require metallic natural Uranium as the fuel cycle input.

REFERENCES

1. W.J. Carmacka, et.al, *J. Nucl. Mater*. **392**, 139–150 (2009).
2. D.E. Burkes, et.al, *J. Nucl. Mater*. **392**, 158–163 (2009).
3. H. Sekimoto, et.al, *Nucl. Sci. Eng*. **139**, 306-317 (2001).
4. H. Sekimoto and M.Y. Yan, *Ann.f Nucl. Energy* **35**, 18-36 (2007).
5. A. Nagata, et.al, *Ann. Nucl. Energy* **36**, 562-566 (2009).
6. Z. Su'ud, and H. Sekimoto, "Modified CANDLE burnup scheme and its aplication for long life Pb-Bi cooled fast reactor with natural uranium as fuel cycle input". in *Proceeding of ICANCE 2007 conference*, November 13-14, 2007, Bandung, Indonesia.
7. Z. Su'ud and H. Sekimoto, *Int. J. Nucl. Energy Sci. Technol. (IJNEST)* **5**, 347–368 (2010).
8. M. Ariani, et.al, "Effect of Fuel Fraction on Small Modified CANDLE Burn-up Based Gas Cooled Fast Reactors" in *The 4th Asian Physics Symposium*, AIP Conf. Proceeding **1325**, 249-252 (2010).
9. Rida, S. and Z. Su'ud, *Int. J. Nucl. Energy Sci. Technol. (IJNEST)* **4**, 217–222 (2009).
10. Z. Su'ud and H. Sekimoto, *Annals of Nuclear Energy*, **54,** 58-66 (2013).
11. F. Monado, et.al, *Advanced Materials Research* **772,** 501-506 (2013).
12. K. Okumura, et.al, SRAC2006: A Comprehensive Neutronic Calculation Code System, *JAEA-Data/Code* 2007-004, Reactor Physics Group, Nuclear Science and Engineering Directorate, Japan Atomic Energy Agency (2007).