AIP Conference Proceedings

The study of capability natural uranium as fuel cycle input for long life gas cooled fast reactors with helium as coolant

Menik Ariani, Octavianus Cakra Satya, Fiber Monado, Zaki Su'ud, and Hiroshi Sekimoto

Citation: AIP Conference Proceedings **1719**, 030038 (2016); doi: 10.1063/1.4943733
View online: http://dx.doi.org/10.1063/1.4943733
View Table of Contents: http://scitation.aip.org/content/aip/proceeding/aipcp/1719?ver=pdfcov
Published by the AIP Publishing

The Study of Capability Natural Uranium as Fuel Cycle Input for Long Life Gas Cooled Fast Reactors with Helium as Coolant

Menik Ariani[1a], Octavianus Cakra Satya[1], Fiber Monado[1], Zaki Su'ud[2], Hiroshi Sekimoto[3]

[1]Department of Physics, Faculty of Mathematics and Natural Sciences, Sriwijaya University, jl Palembang-Prabumulih km 32 Indralaya OganIlir, South of Sumatera, Indonesia
[2]Nuclear and Biophysics Research Division, Faculty of Mathematics and Natural Sciences, Bandung Institute of Technology, jlGanesha 10, Bandung, Indonesia
[3] CRINES, Tokyo Institute of Technology, 2-12-11N1-17 Ookayama, Meguro-Ku, Tokyo, Japan

[a)]Corresponding author: menikariani@gmail.com

Abstract. The objective of the present research is to assess the feasibility design of small long-life Gas Cooled Fast Reactor with helium as coolant. GCFR included in the Generation-IV reactor systems are being developed to provide sustainable energy resources that meet future energy demand in a reliable, safe, and proliferation-resistant manner. This reactor can be operated without enrichment and reprocessing forever, once it starts. To obtain the capability of consuming natural uranium as fuel cycle input modified CANDLE burn-up scheme was adopted in this system with different core design. This study has compared the core with three designs of core reactors with the same thermal power 600 MWth. The fuel composition each design was arranged by divided core into several parts of equal volume axially i.e. 6, 8 and 10 parts related to material burn-up history. 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 fuel. This concept is basically applied to all regions, i.e. shifted the core of the region (i) into region (i+1) region after the end of 10 years burn-up cycle. The calculation results shows that for the burn-up strategy on "Region-8" and "Region-10" core designs, after the reactors start-up the operation furthermore they only needs natural uranium supply to the next life operation until one period of refueling (10 years).

Keywords: Gas cooled fast reactors, fuel cycle, modified CANDLE, natural uranium.
PACS: 28.50.Hw

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 enrichment and reprocessing are the most important key technologies for bomb-making. The using 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 long life Gas Cooled Fast Reactor is 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.

In this study, conceptual design GCFR with Helium coolant can be continuously operated by supplying natural uranium without fuel enrichment plant or fuel reprocessing plant. The CANDLE (Constant Axial shape of Neutron

The 4th International Conference on Theoretical and Applied Physics (ICTAP) 2014
AIP Conf. Proc. 1719, 030038-1–030038-4; doi: 10.1063/1.4943733

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 [3,4]. 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 successfully applicable to long-life fast reactor with natural uranium as fuel cycle input [1,5,6]. This technology allows for the reactor which has been operating, furthermore it only need supply natural uranium as fuel cycle.

DESIGN CONCEPT

Three reactors were designed to produce small power and have long life operation. Reactor design optimization is evaluated to utilize natural uranium as reactor fuel. Detail specification for the reactor design given by Table 1.

TABLE 1. Reactor designs parameters.

Parameter	Value/Description
Thermal power	600 MWth
Cladding material	Stainless Steel
Coolant material	Helium
Fraction of fuel : cladding : coolant	65% :10% : 25%
Fuel pin diameter	1.4 cm
Core geometry	Cylinder 2-D
Active core radial width	240 cm
Active core axial height	350 cm
Radial reflector width	100 cm
Sub cycle length	10 years

In this design the active reactor core are divided into several parts with the same volume in the axial directions. On REG-6 core design in Fig. 1(a), the active core was divided into 6 parts axially; REG-8 core design in Fig. 1(b) was divided into 8 parts axially and REG-10 core design in Fig.1(c) was divided into 10 parts axially. For all of designs at the beginning life region-1 is filled with fresh natural uranium. 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, region-2 shift to region-3 and so on until the material content of region-10 removed from the core. This concept is basically applied to all regions in fuel cores area, i.e. shifted the core of region (i) into region (i+1) 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.

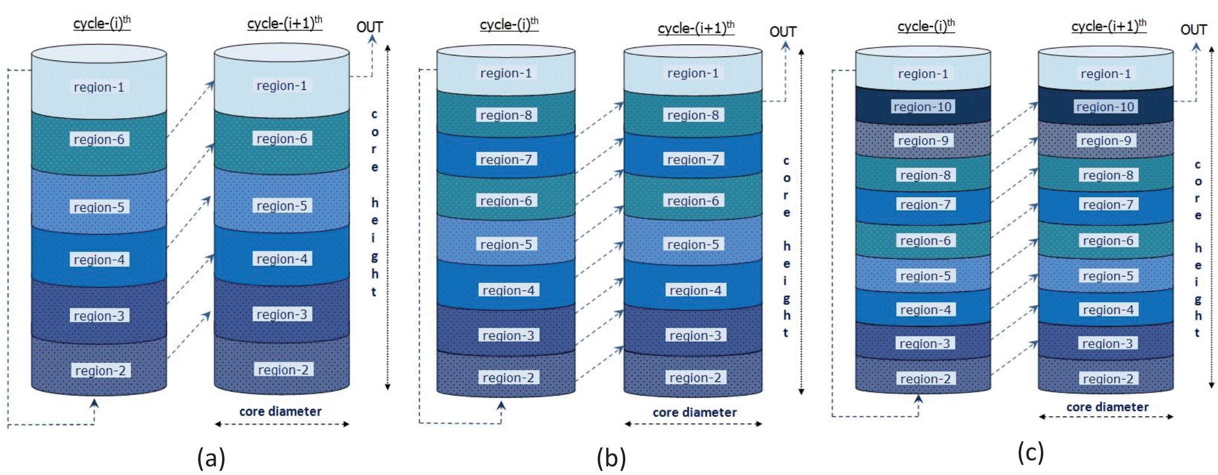


FIGURE 1. Burn-up scheme for the REG-6 core (a), REG-8 core (b) and REG-10 core design (c)

CALCULATION METHOD

Neutronic performance for analyze the neutron aspect of this reactor core was calculated by using of SRAC-CITATION code system with JENDL-3.2 nuclear data library [2]. 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 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. 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 repeat until the average power density was convergence. The parameters survey used for analyze results of the design include: burn-up level, integral conversion ratio, effective multiplication factor for 1 cycle, the power distribution on axial direction and nuclide density distribution for Pu-239 and U-238 during the burn-up of material history.

RESULT AND DISCUSSION

The results of calculation with Modified CANDLE strategy for REG-6, REG-8 and REG-10 along material burn-up history presented as follows. Table 2 shows the initially composition material in each core region. The second, third and fourth column shows the percentage of fissile material Pu-239 compared with U238.

TABLE 2. Initially percentage of plutonium-239 to uranium-238 density

Fuel region	REG-6 (%)	REG-8(%)	REG-10 (%)
Region-1	2.8	2.8	2.4
Region-2	3.2	3.0	2.6
Region-3	4.6	3.7	3.2
Region-4	7.1	5.3	4.4
Region-5	8.3	7.3	6.2
Region-6	8.2	8.3	7.8
Region-7		8.1	8.3
Region-8		7.7	7.9
Region-9			7.4
Region-10			7.1

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 fresh natural uranium only on the next cycle until the reactor life.

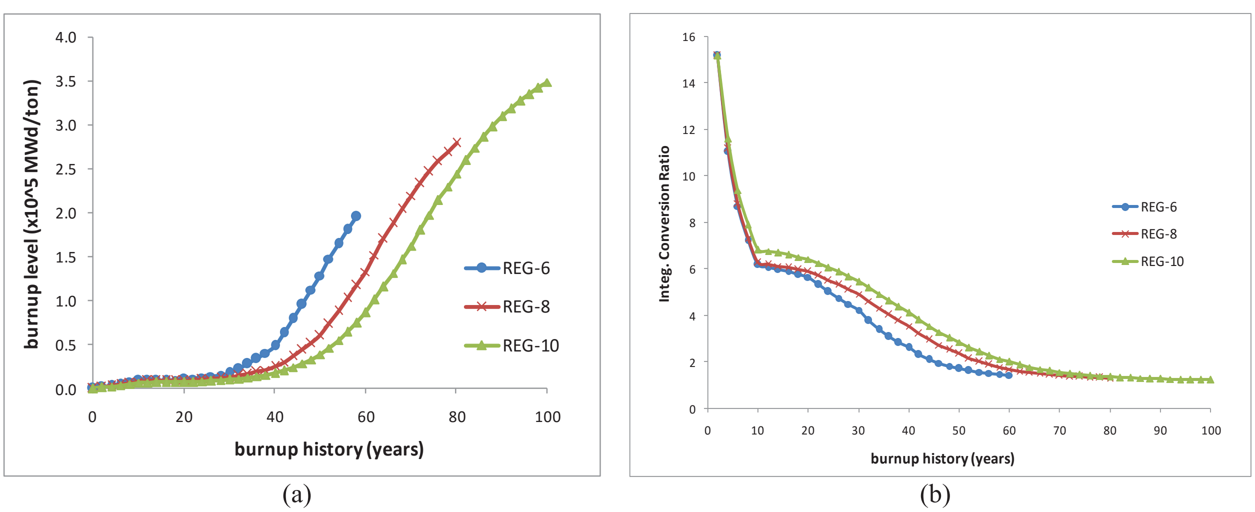
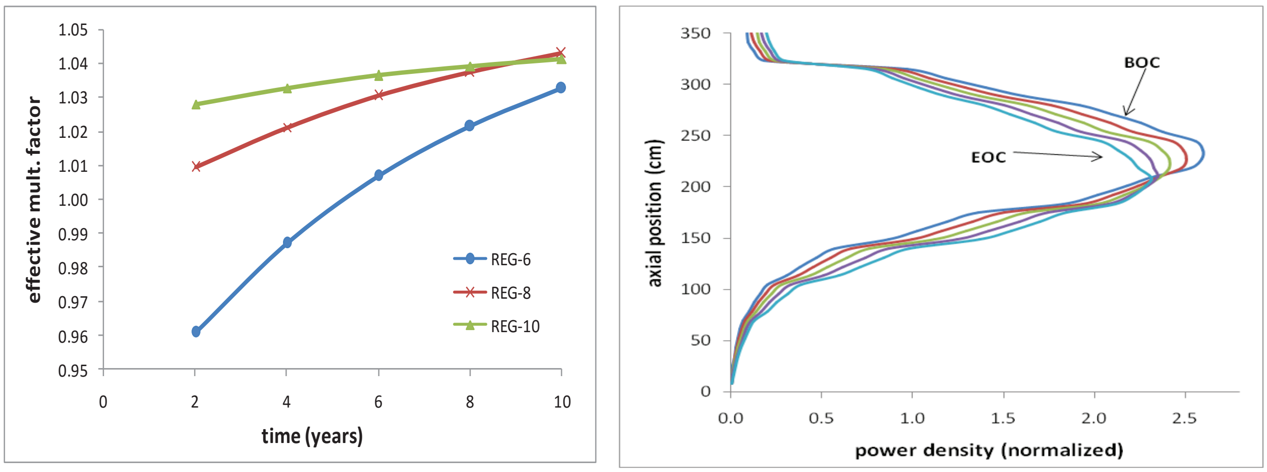


FIGURE 2. (a) Burn-up level change during burn-up history and (b) Integral conversion ratio during burn-up

Fig. 2(a) shows burn-up level history. 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. Maximum discharge burn-up for REG-8 is about 35% (349 GWd/tHM). This value is competitive to the value of the presently expected fast reactor system with reprocessing plant. Fig. 2(b) shows integrated conversion ratio change during burn-up. It is shown that the ratio of production rate to depletion rate of fissile nuclides. The value was decrease along with the increase of burn-up due to the reduction of uranium-238 to plutonium-239 atomic density.



(a) (b)

FIGURE 3. Effective multiplication factors for one cycle refueling (a) and power density profile in axial direction (b)

Two dimensional full core calculations by using 8 group cross-sections provided the effective multiplication factor of one cycle in Fig. 3(a). It can be indicates that both of REG-8 and REG-10 core design can operate10 years (1 cycle) without refueling because the value always above1.0. But for REG-6 core design the criticality value start from 6^{th} year, so this reactor can operates after 6 years fuel burn-up. Fig. 3(b) indicates that in 10 years operation there was some shift in the power density resources toward more less of burn-up level. Near the boundary between fresh fuel (region-1) and burning region (region-2) U-238 absorbs a neutron leaking from the burning region and becomes Pu-239. Therefore the burning regions shift to the fresh fuel region.

CONCLUSION

The feasibility design of small and long life GCFR with Helium coolant has been investigated. The fuel composition was arranged by divided core into several parts of equal volume axially i.e. 6, 8 and 10 parts related to material burn-up history. The calculation results show that for the burn-up strategy on "REG-8" and "REG-10" designs, after the reactors start-up the operation furthermore they only needs natural uranium supply to the next life operation until one cycle (10 years). For "REG-6" designs the criticality value do not reach in begin of cycle but start from 6^{th} year.

REFERENCES

1. Ariani, M., et al, Applied Mechanics and Materials **260-261**, 307-311 (2013).
2. Okumura, K., et. al., SRAC2006: A Comprehensive Neutronic Calculation Code System, JAEA (2007).
3. Sekimoto, H., Ryu, K. and Yoshimura, Y., Nuclear Science Engineering**139**, 306-311(2001).
4. Sekimoto, H. and Yan, M.Y., Annals of Nuclear Energy **35**, 18-36(2007).
5. Su'ud, Z. and Sekimoto, H., IJNEST **5** No.4, 347-368(2010).
6. Su'ud, Z. and Sekimoto, H. Annals of Nuclear Energy **54**, 58-61(2013).