

Comparative study of conceptual design of gas-cooled fast reactor core type tall versus pan cake based on MCANDLE-B burn up strategy

F Monado^{1*}, M Ariani¹, I Royani¹ and Z Su'ud²

¹Dept. of Physics, Faculty of Mathematics and Natural Sciences, Sriwijaya University, Palembang, Indonesia

²Nuclear Physics and Biophysics Research Group, Dept. of Physics, Faculty of Mathematics and Natural Sciences, Bandung Institute of Technology, Bandung, Indonesia

*fibermonado@unsri.ac.id

Abstract. Comparative study of the conceptual design of Gas-cooled Fast Reactor (GFR) core type tall versus pancake based on modified CANDLE-B (MCANDLE-B) burnup strategy has been done. MCANDLE-B is a burnup strategy that utilizes natural uranium or depleted fuel as its input cycle. The conceptual design of a reactor core that compared is the tall cylinder and the pancake cylinder. In this case, the fuel used is U-10%Zr, SS-316 as a cladding material and helium as a coolant. The total volume of the two reactor cores is the same, namely 15.4 m³. SRAC 2K6 software with PIJ and CITATION modules is used to carry out simulations. The PIJ module is used for fuel cell calculations and the CITATION module is used for reactor core calculations. The results of the comparison show that the pancake core allows the reactor core to use fuel with a volume fraction of 50%: 10%: 40%, for fuel, cladding and coolant respectively. The design obtained can be operated for 10 years without refueling.

1. Introduction

The Gas-cooled Fast Reactor (GFR) is one of the candidates for a new generation IV nuclear power reactor that will be used after 2030 [1]. Generation IV nuclear power reactors have advantages than previous generations, namely: reducing basic costs, higher nuclear safety, reduced nuclear waste, can burn its nuclear waste itself, and reduction in the risk of making nuclear weapons. Generation IV nuclear power reactors also offer new applications that are compatible with the more widespread use of nuclear energy, especially in the production of hydrogen and salinity of seawater [2].

The Modified CANDLE (MCANDLE) burnup concept was first introduced by Prof. Zaki Su'ud [3] from ITB Indonesia, which is a modification of the CANDLE method (Constant Axial shape of Neutron flux, nuclide densities, and power profile During Life of Energy production) proposed by Prof. Hiroshi Sekimoto from the Tokyo Institute of Technology, Japan [4]. In this method allows a Nuclear Power Plant (NPP) used natural uranium in its input cycle [5-7].

In this paper, presented a comparative study of two different core geometries of the MCANDLE-B reactor, but with the same volume. The simulation showed that the MCANDLE-B reactor with pancake cylinder geometry could be utilized fuel material less than others.



2. Methods

Natural metallic uranium (U-10% Zr) is used as fuel with a characteristic density of 16 g/cc and a melting point of 1160 °C [8-9]. The cladding material used is Stainless Steel 316, which is most widely applied for structural materials in the Fast Breeder Reactor (FBR). The cooling material used in this research is helium. The main parameters of the reactor core design are given in Table 1.

Table 1. Main parameter of design.

Parameter	Value/Description
Power	1200 MWt
Fuel material	U-10wt%Zr
Cladding material	Stainless Steel(SS-316)
Coolant material	Helium
Volume fraction	60% :10% : 30%
(Fuel : cladding : coolant)	50% :10% : 40%
Fuel Pin diameter (pin pitch)	1.4 cm
Number of equal volume region in core	10
Core Geometry	Cylinder: tall / pancake
Volume of the core	15.4 m ³
Radial reflector width	50 cm
Sub cycle length	10 years
Reactor life	100 years

The reactor core is divided into ten regions with the same volume. Each region is filled with fuel with different content (Figure 1). In the first cycle of burnup, region-1 and region-2 are placed near region-10, which contains the most active fuel. After the first cycle of burnup, fuel from region-1 is shifted to region-2, fuel from region-2 shifted to region-3, and soon, then region-1 is replenished with fresh fuel.

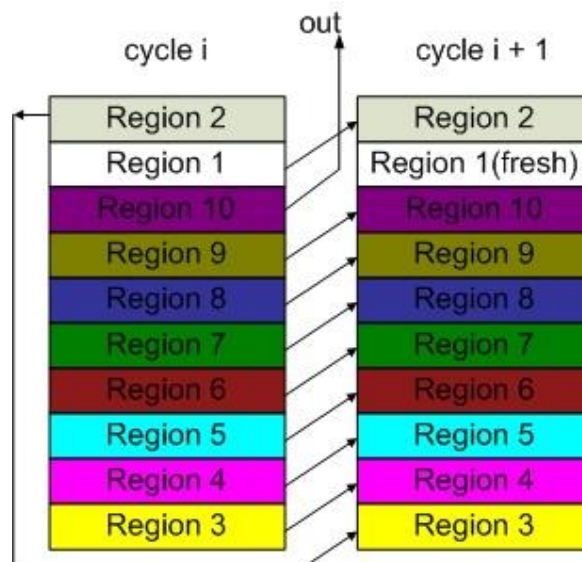


Figure 1. Burn up strategy: Modified CANDLE type B

The SRAC 2K6 software with PIJ and CITATION modules is used to carry out simulations [10]. The PIJ module is used for fuel cell calculations, and the CITATION module is used for reactor core calculations.

3. Results and Discussion

In this section, we show result of simulation of the core namely: the effective multiplication factor and relative power densities. The effective multiplication factor is a value that identifies the ratio of the number of neutron populations at time t to the number of neutron populations at time $t-1$ inside the reactor core. Figure 2 showed the effective multiplication factor of the core. The black and the red line indicated for tall geometry and the blue and the green line indicated for pancake geometry.

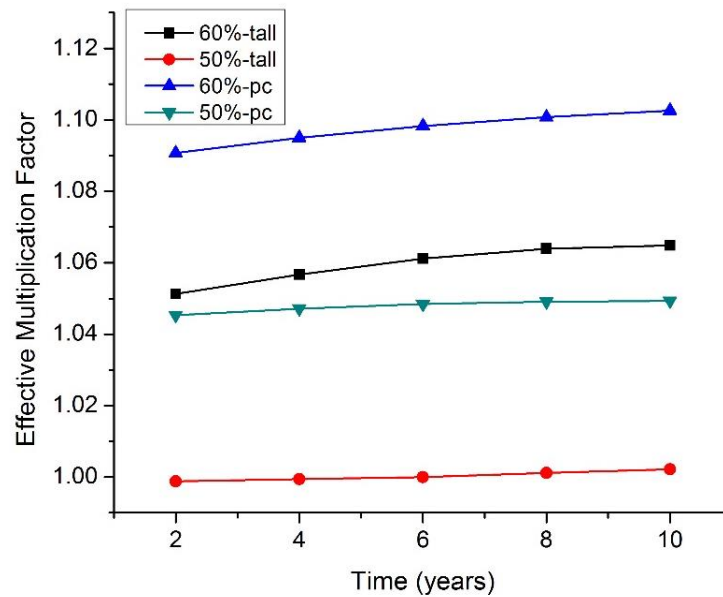


Figure 2. Effective multiplication factor

From Figure 2, it can be observed that the effective multiplication factor of pancake core are 50% and 60% and tall core 60% reached critical condition from BOC (beginning of cycle) until EOC (end of cycle). These values are meaningful; the cores can operate for ten years without refueling or fuel shuffling. The others not reached critical, which is have negative reactivity (see Table 2).

Table 2. Reactivity and effective multiplication factor of the core.

Parameter	Core type			
	Tall		Pancake	
Fuel fraction	60%	50%	60%	50%
k_{eff}	1.05130	0.99877	1.09074	1.04532
reactivity ($\% \Delta k/k$)	4.88	-0.12	8.32	4.34

Figure 3.a and 3.b showed the relative power densities of the core. In these figures, the relative power densities of the pancake geometry with 50% fuel fraction (blue line) and 60% fuel fraction (green line) compared with the tall geometry (black line, 50% fuel fraction, and red line, 60% fuel fraction).

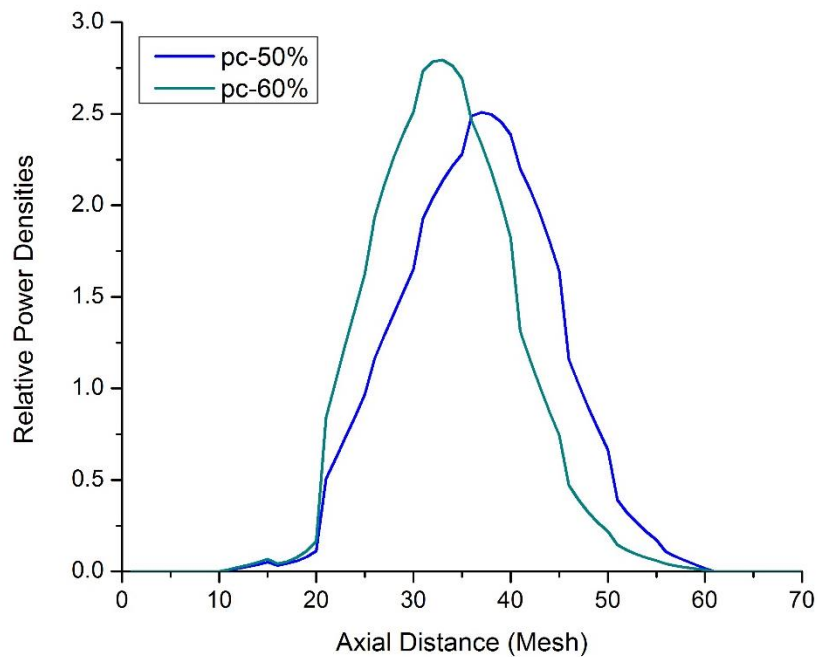


Figure 3. (a) Relative power densities of pancake model.

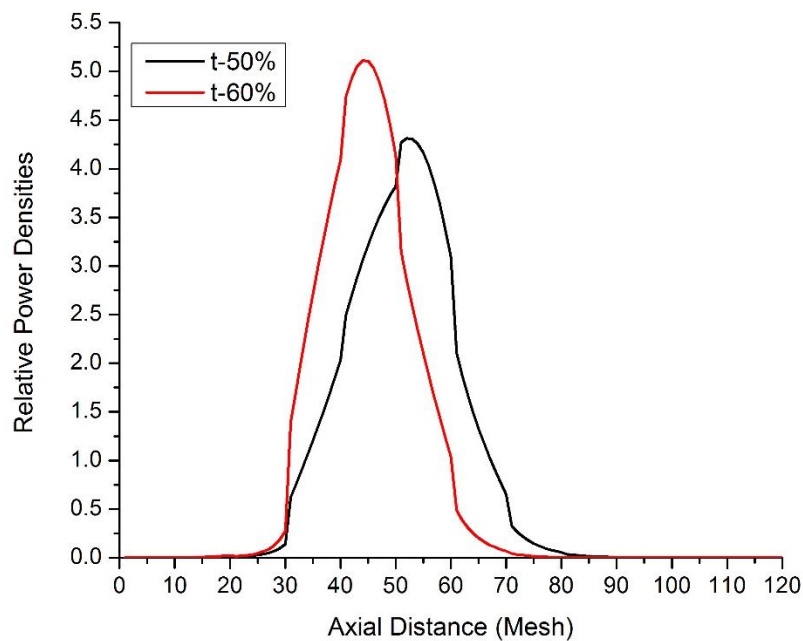


Figure 3. (b) Relative power densities of tall model

Figure 4 showed the relative power densities of the core of the pancake geometry. The black line, red line, and blue line are for the beginner of a cycle, middle of cycle, and end of cycle, respectively. The shape of power is relatively constant. That is the characteristic of the CANDLE reactor. The peak of the power was shifted in the right direction, which means the burning region shifted to the fresh fuel.

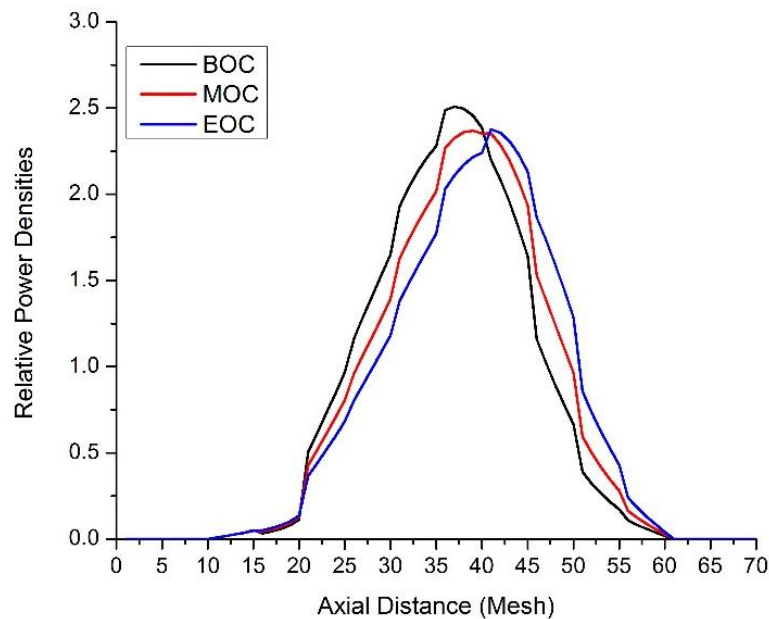


Figure 4. Relative power densities in axial direction of pancake model.

4. Conclusions

The conceptual GFR core with power 1200 MWt base on MCANDLE-B strategy of burnup has been simulated. The reactor core geometry: cylinder RZ-tall and cylinder RZ-pancake have compared. The core pancake geometry showed better performance, this core can be operated along ten years without refueling; with fraction, 50%, 10% and 40% for fuel, cladding, and coolant respectively.

Acknowledgment

Thank you to Sriwijaya University Research Institute for funding this research through “Hibah Unggulan Kompetitif” Number: 0015 / UN9 / SK.LP2M.PT / 2019.

References

- [1] Board of Governors International Atomic Energy Agency 2012 *International Status and Prospects for Nuclear Power 2012* (IAEA Report: GOV/INF/2012/12-GC(56)/INF/6)
- [2] Gauché F 2017 *GIF Annual Report 2016* (Gen IV International Forum)
- [3] Su'ud Z, Sekimoto H 2007 *Proc. Int. Conf. on Advances in Nuclear Science and Engineering* (Bandung: Indonesia) p 13
- [4] Sekimoto H, Ryu K, Yoshimura Y 2001 *Nuclear Science Engineering* **139** 306
- [5] Su'ud Z, Sekimoto H 2013 *Annals of Nuclear Energy* **54** 58
- [6] Monado F, Su'ud Z, Waris A, Basar K, Ariani M, Sekimoto H 2013 *Advanced Materials Research* **772** 501
- [7] Su'ud Z, Miftasani F, Ilham, Sarah A, Ariani M, Sekimoto H, Waris A, Permana S 2017 *Energy Procedia* **131** 6
- [8] Hofman G L 1996 *A Short Note on High Density Dispersion Fuel* (Argonne National Laboratory Report 9700 South Cass Avenue Argonne, IL 60439 USA)
- [9] Simunovic S, Ott L J, Gorti S B, Nukala P K, Radhakrishnan B, Turner J A 2009 *Modeling of Gap Closure in Uranium-Zirconium Alloy Metal Fuel – a Test Problem* (OAK Ridge National Laboratory Report, Oak Ridge Tennessee 37831-6283)
- [10] Okumura K, Teruhiko K 2007 *SRAC 2006: A comprehensive neutronic calculation code system* (Japan Atomic Energy Agency: Japan)